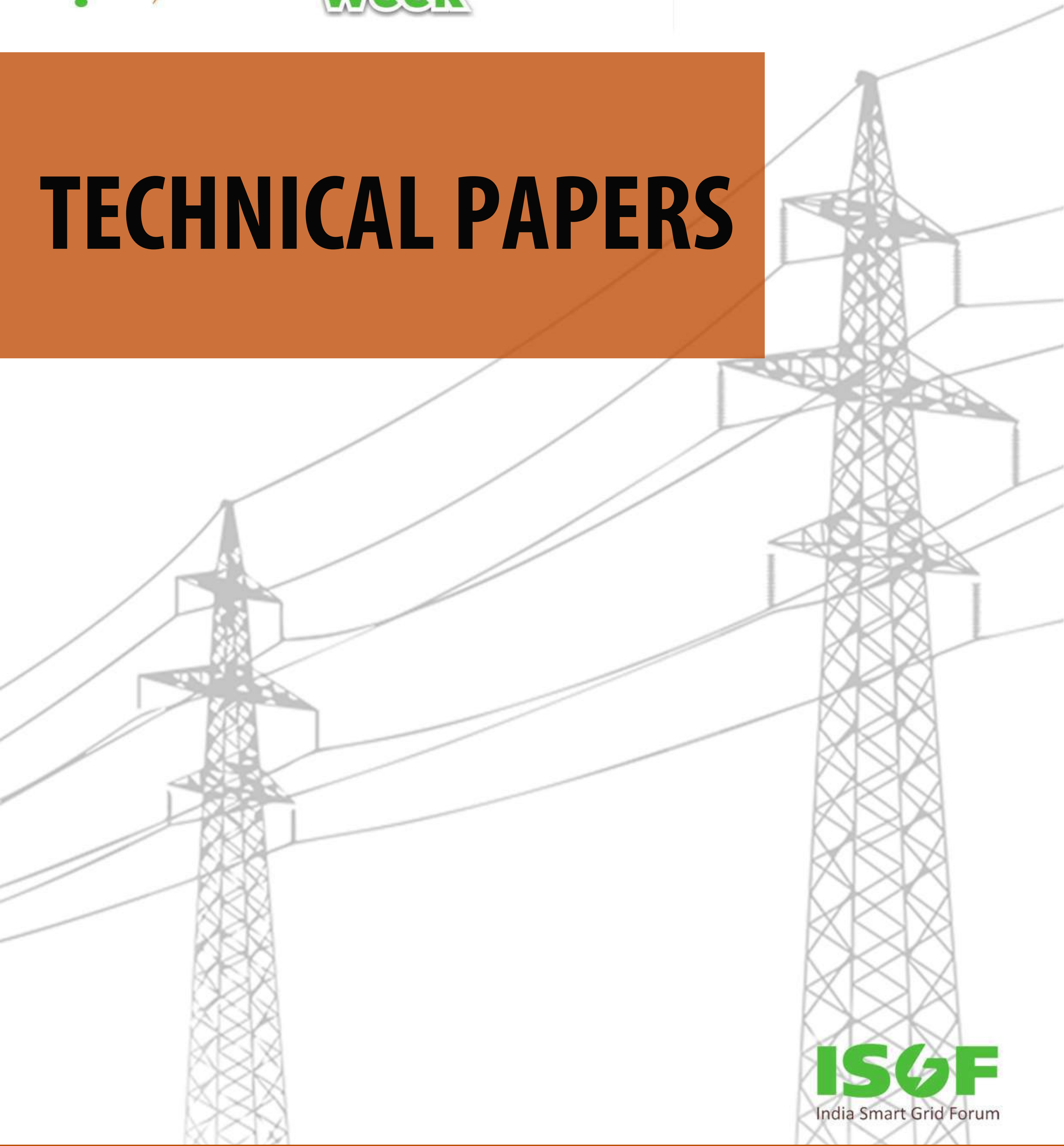
India SMART GRID Week

TECHNICAL PAPERS



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A Valuation-based Framework for Considering Distributed Generation Photovoltaic Tariff Design

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***Abstract*— Distributed generation photovoltaic (DGPV) cost-benefit analyses (CBAs) can provide substantive insights into understanding the potential flows of value among stakeholders that grid-connected DGPV programs might induce. Tariff design has a significant impact on the level and accrual of such value – thus, a cost-benefit analysis is a robust starting point for stakeholder engagement and discussion on DGPV tariff design. To that end this paper outlines a holistic, high-level approach to the complex undertaking of DGPV tariff design, the crux of which is an iterative cost-benefit analysis process. We propose a multi-step progression that aims to promote transparent, focused, and informed dialogue on CBA study methodologies and assumptions. When studies are completed, the long-run marginal avoided cost of the DGPV program should be compared against the costs imposed on utilities and non-participating customers, recognizing that these can be defined differently depending on program objectives. The results of this comparison can then be weighed against other program objectives to formulate tariff options. Potential changes to tariff structures can be iteratively fed back into established analytical tools to inform further discussions.**

Keywords—tariff design, ratemaking, distributed generation, photovoltaic, solar valuation, value of solar, cost-benefit analysis

I. Introduction

Stakeholders contributing to ongoing discussions over distributed generation photovoltaic (DGPV) tariff design will often have different perspectives on how export tariffs should be structured. This divergence of perspectives may at some level stem from disparate stakeholder interests and assessments of the net costs and benefits (C&B) of DGPV programs, as well as the distribution of how and to whom those C&B accrue. As Indian regulators look to emulate recent progress in certain states in India and quickly accelerate DGPV growth, a common analytical framework, which hinges on a transparent cost-benefit analysis process, might be employed to encourage more open, informed, forward-looking discussion over tariff design. A number of Indian states, including Gujurat, Tamil Nadu, Uttarakhand, Andhra Pradesh, West Bengal, Kerala, Karnataka, among others, have set up forms of net energy metering for DGPV, and many more are in the process of designing regulatory structures to compensate DGPV. It is by applying frameworks such as the one proposed in this paper that Indian policymakers can gain a system-wide understanding of the C&B of DGPV programs given their objectives, ensuring a sustainable solar market as DGPV penetration grows in India. This framework can make use of existing evaluations of the technical issues that will need to be addressed in Indian states (such as those found in Magal et al., 2014 [1]) to quantify the C&B of DGPV.

This paper offers a high-level approach to the complex undertaking of a DGPV tariff design process, the crux of which is a program cost-benefit analysis (CBA) study.

In the context of a larger regulatory framework, we choose to focus on tariff design because of the significant impact this DGPV program design component has on the various flows of value (benefits, costs, and risks) among power sector stakeholders. In that context, this paper is organized into a series of steps that can be taken during the design of a DGPV tariff. These steps are intended to serve as a roadmap of iterative or cyclical activities rather than an explicit, linear schedule.

II. Step 1: Declare the Objectives of the Program

The energy regulator and other relevant government bodies should consider publicly declare their objectives with respect to the DGPV program, as informed by public policy mandates and other goals. Objectives typically take the form of either desired aspects or desire outcomes of the program – they range not only in importance but in tangibility and measurability. Establishing such objectives ex-ante enables tariff design discussions and options to be appropriately assessed for alignment with a transparent set of values. Table I lists examples of potential objectives of a DGPV program.

TABLE I. POTENTIAL OBJECTIVES OF A DGPV PROGRAM

Focus Areas	**Taxonomy of Potential Objectives**
	Example Objectives
Utility	preserve financial health of utility; ensure fair recovery of administrative and network infrastructure costs; establish new utility investment opportunities; efficient rate-making to ensure proper price signals to customers
PV Owner	simplicity and attractiveness of DGPV value proposition; ease of application process; incentivize deployment; responsiveness to consumer demand and financibility
Ratepayer	protection from unjust rate increases or allocation of risk; mitigation of cross-subsidization impacts among participants and non-participants; protection of low-income customers
Grid / Technical	deployment goals and timeframes; alleviation of supply shortfalls, network congestion reduction, inducing of

Focus Areas	Taxonomy of Potential Objectives
	Example Objectives
	load-shifting behavior; implementation feasibility; discourage illegal interconnections
Society	economic development and job creation; empowerment of small- or medium-size enterprises; energy security; address environmental justice concerns
Environment	global and local emissions reductions; water use and quality impact reduction

a. Some of the listed example objectives could be classified under more than one focus area

III. STEP 2: CONSIDER PROGRAM COSTS AND BENEFITS TO BE ANALYZED

DGPV exhibits a range of C&B to various stakeholders. Table II lists a summary of those C&B, as synthesized from [2] [3] [4]. The costs and benefits of DGPV are highly dynamic quantities, changing with time and location of energy production, local (i.e. feeder) and global (i.e. system) penetration levels, as well as the performance attributes of the system (e.g. reactive power support). The methodologies employed to valuate these C&B (see Step 3) range in the granularity and accuracy for which they characterize this dynamism [5]. Furthermore, they accrue in a distinct manner to a diverse set of stakeholders.

TABLE II. COSTS AND BENEFITS OF A DGPV PROGRAM

Aspect	Range of DGPV Costs and Benefits
	Example C&B
Benefits	avoided utility energy costs; reduced consumer electricity bills; avoided ancillary service costs; reduced line losses; deferred/reduced utility generation, transmission, and distribution capacity investments; fuel price hedging; emissions reductions and air quality improvements; water use reductions; water quality improvements; grid security and reliability; economic development; regulatory compliance benefits
Costs	cost of DGPV system; cost of metering infrastructure; program administration; reduced utility fixed cost recovery; interconnection cost; lost margin on power re-sale; changes to conventional generator operations; distribution system upgrades; cost of enabling information and communication technology systems

In Step 2, the presence of the various DGPV costs and benefits in a prospective CBA study (see Step 4) can be publicly deliberated among relevant stakeholders and evaluated against the backdrop of the program objectives established in Step 1. Furthermore, such deliberation should be informed by the relative difficulty to robustly assess various metrics (see Step 3).

IV. STEP 3: CHOOSE STUDY ASSUMPTIONS AND METHODOLOGIES TO ASSESS COSTS AND BENEFITS

Upon selecting which set of C&B will be included in a valuation exercise, a multi-stakeholder dialogue can then be focused on *how* selected costs and benefits are assessed, and what underlying assumptions will be used to serve as a foundation for that assessment. *C&B quantification and cost-effectiveness analyses can vary significantly based on the methodologies and input assumptions employed* – thus, careful consideration of these aspects is key to producing credible valuation estimates. For example, when quantifying the economic value of DGPV, should it displace the costs of a marginal or average generator? Will DGPV be incorporated in integrated resource planning, or will it be layered on top of already-planned systems? At what level of spatial and temporal granularity will DGPV be valuated? What stakeholder perspectives will be considered? If included, how will societal benefits such as the health impacts of reduced particulate emissions from conventional generation or improved water quality be quantified?

Denholm et. al [6] discusses the range of methodologies and tools that can be employed to generate estimates of various DGPV costs and benefits from the system perspective. For each C&B covered, approaches are described in increasing order of difficulty, with discussion focused on the relative accuracy of the approach and tools required.

Keyes and Rábago [7] outlines key study assumptions where initial discussions might be focused, such as discount rates, demand and fuel price projections, stakeholder perspectives considered, and geographic and system boundaries. They emphasize that developing a robust set of base assumptions is critical to any study, and that transparency in both methodology and assumptions is key for fostering stakeholder buy-in and program success. Non-disclosure agreements may be a necessary tool to circumvent sensitivities with utilities.

Overall, stakeholders must balance a desire for theoretical accuracy against practical considerations. Table III outlines key questions for stakeholders to consider while evaluating a particular methodology as part of the CBA process. These considerations may change as they are revisited in more mature DGPV markets. For example, the value of accuracy may not be paramount when cumulative DGPV levels are still low, but may gain importance as with increased DGPV capacity.

TABLE III. KEY CONSIDERATIONS FOR VALUATION

Aspect	Key Considerations for C&B Valuation Methodology Selection
	Questions
Accuracy of Estimate	How accurate will the methodology be, relative to more simple or more complex approaches?
Value of Accuracy	How much value will additional accuracy yield for the process?
Cost of Estimate	How much will it cost (in time and money) to execute the methodology in question, relative to other approaches?
Execution Feasability	Is there technical capacity available to implement this methodology? Are adequate models and data sets publicly available in acceptable timeframes?
Implementation Feasability	How equipped and willing are relevant government bodies to implement complex study results?

Facilitating a focused, transparent, and pragmatically grounded multi-stakeholder discourse will help to establish methodological transparency when CBA studies are conducted. While consensus may never be reached among stakeholders, allowing for periods of public comment, addressing concerns, and encouraging focused discussions on study assumptions and methodologies will help to articulate areas of disagreement, leaving room for consensus-building in other areas.

V. Step 4: Conduct Cost-Benefit Analysis Study

The crux of the proposed framework is the DGPV CBA study – the results of which will be used to inform not only tariff design discussions (Step 5), but continued stakeholder dialogue over CBA methodologies and input assumptions (Step 3) as study results are assessed. An iterative process is envisioned where periodic updates to study assumptions, valuation methodologies and tariff design are conducted, as informed by continued stakeholder discussions.

Depending on the scale of the geographical and temporal resolution chosen for the analysis, a variety of approaches, spanning operations and planning models to power flow simulations to financial analysis tools, can be integrated to conduct a DGPV valuation study. No one tool is capable of accurately characterizing the range of potential technical and financial impacts of a DGPV program over various timeframes and system boundaries. Thus, utilizing a combination of tools and analytical techniques is likely key for conducting a robust valuation. As a matter of process, outputs from power sector simulation tools (e.g., bulk planning or operations models, transmission or distribution power flow simulations) are often used as inputs to financial analysis tools that assess utility rate and revenue impacts, as well as stakeholder cost-effectiveness metrics such as the Utility Cost Test, Ratepayer Impact Metric, or the Societal Cost Test.

In formulating a DGPV program, regulators may also consider whether subsidies for DGPV are appropriate, and if so, the levels, types, and sources of subsidization. To this end, CBA studies can be used to understand how potential incentives and subsidies induce different levels and patterns of deployment or mitigate inequities.

A key question to explore is who will be designated to conduct the CBA study. An appropriate balance can be struck between the desire for study transparency and practicalities around capabilities and data availability. In some contexts, it may be appropriate or desirable to enroll a third party consultant, or to install an independent monitor with the utility modelling teams. Utilities typically hold the grid data necessary to perform system-perspective valuation studies but may be perceived as biased towards promoting a lower value for DGPV.

VI. Step 5: Propose Tariff Structure

Understanding various flows of value among stakeholders will enable regulators to allocate costs during a tariff design process in a manner that is aligned with their stated objectives (see Step 1). Table IV lists key components of a DGPV tariff that can be considered.

TABLE IV. Key Tariff Components

Components	**Key Tariff Components**
	Examples
Compensation Structure	NEM; avoided cost compensation; FIT[a] [8]; net FIT [9]; value-of-solar [9]
Import/Export Tariff Building Blocks	variable energy charges; fixed/variable network and administrative charges; time-varying rates [11]; demand-based rates; standby charges; bi-directional distribution charges [3]; minimum bills [12]
Export Tariff Level	fixed rate; degression rate; inclining block rates
Export Tariff Contract Terms	term length; credit reconciliation terms and limits; generation limits; exit clauses
Purchasing Arrangements	utility offtaker; independent buyer office

[a] Many FIT structures exist, including fixed rate FITs, degression rate FITs, and FIT premiums.

For any proposed tariff structure, the long-run marginal avoided cost of the DGPV program can be compared against the costs imposed on non-participating customers. This will yield insight into the amount of cross-subsidization, if any, that would be expected to occur between non-participants, the utility and DGPV system owners. In the event that cross-subsidization is occurring, the terms of the tariff or program might be adjusted, via e.g., increases to fixed charges, minimum bills, limits on system size, or program caps. Potential changes to tariff structures can be fed back into established analytical tools to inform decisions and stakeholder discussions. On the other hand, some level of cross-subsidization may be tolerable if it results in a simple and easy-to-implement program (e.g., NEM), or even desirable if incentivizing deployment using ratepayer funding is an objective. CBA studies will likely show a diverse range of value flow and accrual among customer classes which change with grid location and time of energy production. Table V lists potential incentives and pricing mechanisms that can be explored during ratemaking which may help tariffs better reflect the various value dimensions of DGPV.

TABLE V. Pricing Mechanism for Capturing DGPV Value

Dimension	**Pricing Mechanisms for Reflecting DGPV Value Dimensions**
Time of production	time-of-use pricing [11], panel orientation incentives [13], hourly or dynamic pricing [11]
Location of production	locational incentives [14], distribution locational marginal pricing [5]
Local- and Grid- Level Penetration	penetration-scaling tariff pricing, system capacity caps
System Performance Attributes	Incentives for allowing system curtailment or encouraging specific inverter functionalities

While these mechanisms can be useful to some extent, it may not be pragmatic to design highly-customized tariff rates to ensure solar C&B are disbursed at a theoretical financial optimum (i.e. one which attempts to reflect all value dimensions fully). Furthermore, if simplicity and feasibility of implementation are identified as key program objectives (as is often the case for early-stage programs), using a single tariff (i.e., NEM or FIT) might be desirable.

While the tariff structure is key in influencing the flow of value among stakeholders, tariffs must be formulated in the context of a larger regulatory framework. For instance, if a CBA study shows that fixed network and administrative costs may not be fully recovered from program participants for a given tariff structure, system or program size limits might be desirable. Frameworks must also select and allocate costs for the required meter technology, considering the metering needs of the proposed tariff and future needs with respect to data collection and advanced distribution system management. Smart meter and smart grid targets might be tied to DGPV deployment to help create new investment opportunity for the utility and promote longer-term DGPV integration. Sanctioned business models should also be identified (e.g., virtual NEM, community NEM, third party leasing, shared utility-consumer ownership, utility ownership), as aligned with objectives.

VII. Discussion

As formal decisions are issued, regulators might bear in mind that regulatory frameworks are not set in stone. While honoring existing contracts helps to preserve investment certainty, new terms can be proposed to steer the market toward desired levels and spatial distributions of deployment, as aligned with established and emerging policy objectives. To begin, and one may design and implement a pilot DGPV program in order to assess effects of distributed solar on the electricity grid (potentially calibrating valuation models), while evaluating and demonstrating new technologies or billing methods, increasing public acceptance, and gaining stakeholder buy-in.

CBAs which holistically consider planning, operational and financial implications of DGPV programs are being explored in various contexts, typically under the purview of a value-of-solar (VoS) tariff formulation process. VoS tariffs are intended to reflect the principle that DGPV owners can feasibly be paid for the costs they incur and be paid for the benefits they contribute to the system, with the understanding that these benefits can change over time with wholesale electricity market conditions. Formulating a tariff to reflect this principal fundamentally necessitates a detailed CBA methodology.

The U.S. State of Minnesota established a VoS tariff formulation process where stakeholders were able to review all aspects of the methodology before a final rate was set [15]. While no true consensus was ever reached on the methodology employed (or the final tariff level, for that matter), the process nonetheless successfully garnered open dialogue and methodological transparency. As well, it will have enabled stakeholders to continue to meaningfully contribute to VoS proceedings as the tariff is periodically reevaluated.

While a VoS tariff formulation process is a sound impetus for conducting a CBA study, we argue that there is nevertheless strong practical utility to conducting such a study even if VoS tariffs are not being actively considered. Provided that time and resources (both financial and technical) are available, establishing the analytical framework to understand the costs, benefits and expected impacts of a program will lead to informed decisions that are aligned with the objectives of the power sector regulator and other relevant government bodies. It also establishes the models, financial analysis tools and other technical capabilities which could eventually inform shifts toward more systematically fair apportionments of DGPV costs and benefits (i.e. a VoS tariff). State Energy Regulatory Commissions in India might consider investing in building such capabilities, either internally, within their regulated utilities, or with a third-party consultant.

VIII. Conclusion

A multitude of objectives and stakeholder perspectives are prioritized and harmonized during a DGPV tariff design process. CBA studies can provide substantive insights toward understanding the various flows of value that a program may create, and can be used directly or indirectly to inform public consultation processes and formal proposals and decisions. The framework presented in this paper strives to promote methodological transparency and active stakeholder participation in the often iterative CBA study process. The extent to which independent decisions must be made by empowered stakeholders (i.e. regulators, utilities) depends on the specifics of the consultation process, the DGPV program objectives, and surrounding institutional and governance arrangements. However, ensuring that stakeholders understand the full range of issues considered will help to enable focused and productive engagement.

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Beyond AMI: From Smartmeters to Advanced Distribution Automation

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I. Abstract

Smartmetering / Smartgrid infrastructures are essentially a consequence of regulatory mandates or operational efficiency programs in utilities. But once this technology is deployed, it can offer much higher value beyond its intended purpose. Bidirectional communication deployed up to the Smart meters offers accurate information of the elements scattered in the LV domain. Note that the deployed meters in the LV line offer information for grid operation in addition to billing information so the available measurements can be really useful in several supervision and control systems. This means that on top of advanced metering infrastructure (AMI), other applications can be integrated to obtain more returns from the investment.

Intelligence in the LV network opens the door to several operational improvements in the utility grid. The "LV network supervision" concept comprises aspects such as LV feeder automation, commercial losses (fraud) detection, detection and correction of unbalances, faults detection in LV feeders, and topology verification of the distributed elements regarding phase and LV feeder. Existing operations (processes and others) are improved in the electric company due to the new technology integrated into the grid. Utilities will also be able to manage the lifecycle of their assets and implement preventive maintenance operations-

This paper describes and analyzes LV network supervision solutions available today, based on Smartmeters/AMI plus other technologies, and focus on the advantages and applications derived from the addition of intelligence into the LV into the Indian grid, based on some pilot experiences already in place in India and abroad.

This analysis points out the amount of data produced by these systems, and therefore the need of corporative information systems to be adapted in order to manage the new information available. Finally the expected evolution and the main challenges (technical and non-technical) faced by LV supervision solutions are described.

Keywords: Smartgrid, intelligence, distribution, operation, LV, supervision, automation, asset management, communications, metering.

II. Introduction

Distribution companies continue the "Smartization" process of their power distribution grids started years ago with the introduction of electronics, telecommunications and information systems in the grid operation.

Smartgrid and Smartmetering infrastructures were first a consequence of regulatory mandates, but once they are in operation, they can offer much higher value beyond their intended purpose. Bidirectional communication deployed up to the Smart meters offers accurate information of the elements scattered in the LV domain. Note that deployed meters in the LV line offer information for grid operation in addition to billing information [1] so these available measurements may be useful in several supervision and control tasks. This means that on top of advanced metering infrastructure (AMI), several other applications can be integrated.

Intelligence in LV network will bring several advantages and applications in terms of "LV network supervision" [2] [3]. The concept of "LV network supervision" comprises aspects such as LV feeder automation, commercial losses (fraud) detection, detection and correction of unbalances, faults detection in LV lines, and topology verification of the distributed elements regarding phase and line. This implies numerous benefits for the utility, but also for the users, as service availability and reliability can be improved. Utilities will also be able to manage the lifecycle of their assets, integrating each point into the Smart grid, in order to implement asset management in LV grid. These capabilities in LV Smartgrids offer the required support for the correct integration of small scale renewable distributed generation sources.

III. THE NEED FOR LV SUPERVISION

As stated in the introduction, LV grids are typically passive networks where real time information is not available. Issues that may arise are identified through end customer complaints (call centres), and thus identifying the problem source by the location of received complaints.

Policy and regulatory mandate evolution during the last years in India [5] [6] and elsewhere has been the starting point for LV grid operation. Within the most important aspects of this shift we can highlight:

- Increasing number of "micro" sources of distributed generation, connected to the LV grid.
- Massive deployment of Smartmeters, which combine precise measurement technologies with telecommunication in a cost effective solution due to scale economies.
- Increasing introduction of smart loads which can be controlled.
- Energy efficiency policies that are starting to be taken into account by consumers.

These aspects made main stakeholders work together towards the LV grid evolution, so that it can be operated according to the business needs of the different electricity distribution companies. In this context there is a need of LV distribution grid monitoring and supervision so demand management can be optimized. Upgrading the whole distribution network by adding new elements that meet the new requirements may not be a cost-effective solution due to the size of the LV grid. Therefore updating the existing infrastructure seems the most suitable alternative.

In the next sections we will define the system architecture for LV distribution grid supervision. First it is important to identify which are the useful LV elements that need to be monitored. Thinking on how to do this monitoring, we would define the requirements for supervision elements within the system. Finally, a system architecture that is able to cover these functionalities is proposed.

IV. LV GRID MONITORING

This section analyses the LV elements to be monitored. This proposal combines supervision both at the Secondary Substation and at intermediate LV grid points.

A. LV supervision at the Secondary Substation

Secondary Substations are the first elements to be monitored inside the MV-LV grid. Both the secondary of the power transformer and the LV feeders can be supervised.

This list summarizes the supervision needs identified within a Secondary Substation:

- Instantaneous measurements of V, I, P, Q and power factor per phase in the secondary of the transformer.
- Register of the main electric parameters, creating the following profiles:
- Energy profiles – hourly.
- Profile with the medium values of current and voltage.
- Profile with the maximum values of current and voltage.
- Quality of service measurements, such as THD, flicker or network harmonics.
- Detection of several network issues. For instance, overcurrent, overvoltage, fuse blown out detection. Even high impedance faults in Medium Voltage network can be detected based on measurements taken form the LV grid (secondary of the power transformer). Three phase system unbalances could also be detected.
- Phase and feeder identification for the different clients connected to the LV grid.

This information allows distribution companies to improve their LV network operation, enabling:

- Energy balances with the aim of identifying losses (both technical and non-technical).
- Load level control per phases and feeders, so load unbalances can be detected.
- Preventive supervision of the network. This way status information can be obtained before clients call making complaints.
- Asset management could be implemented integrating each point into the Smartgrid. Utilities could manage the lifecycle of their assets.

B. Supervision at intermediate LV grid points

In addition to monitoring inside the Secondary Substations, in some countries there are ongoing experiences of supervising also intermediate points within the LV grid. Note that new generation Smartmeters that are being deployed already monitor the LV grid at the boundary between the distribution operator and the end customer infrastructure. Supervision at other intermediate points is focused on controlling the voltage levels in LV lines with high penetration of Distributed Energy Resources (DER), to monitor voltage levels.

Sensors scattered over LV grid will allow voltage control operation. These sensors can send the voltage measurements taken at the installation point periodically through radio or powerline communication. The controller in the Secondary Substation collects the voltage measurements of the elements scattered in the LV domain. This information can be used in order to act upon the tap changer of the power transformer and therefore dynamically adjust the voltage level.

V. SYSTEM ARCHITECTURE

In this section a system architecture needed to cover the functionalities described above is proposed. Additionally, the evolution needed at the corporate IT information systems of the distribution companies will be analyzed.

A. LV supervision architecture example

This control system is based on measurements from the Secondary Substation, note that other architectures could also integrate measurements of intermediate points in the LV network. Elements to be monitored inside the Secondary Substation are highlighted in Figure 1 below; the picture was taken from a real field setup.

Figure 1 - LV elements to be monitored inside the Secondary Substation

We will focus on the solution to be installed at the Secondary Substation. It can be based on a modular device – evolution of the Smartmetering Data Concentrator or Field Remote Terminal Unit (FRTU) - that manages the three phase LV feeder supervision elements through a fieldbus (RS485). The same device could integrate the supervision of the secondary of the power transformer. LV feeder supervision elements are installed into a kit connected to the output of the three-pole basis of the LV panel, containing three current sensors and a connector for transmitting signals (Voltage and currents) to the feeder supervisor. Note that due to the size of the LV grids, easy to install solutions are a must.

All the available information is transmitted through IP communications to the centralized information systems of the distribution company. This LV supervision system example is based on cellular communications – GPRS – as these are the mainly adopted systems for distribution grids supervision solutions.

There is plenty of information to be sent with different types of events and measurements. Electronic equipment related to LV supervision is able to produce an enormous amount of data.

This has a direct impact on the corporate IT information systems of the utility, which need to be adapted so they can manage and process all this new information available. This evolution needed at the information systems level is an important requirement for LV supervision integration. Information systems architectures will be detailed in the following section, understanding some of the options available depending on the operation structure of each distribution company.

B. Evolution needed at the information systems

There are different IT information systems approaches regarding where to send the LV supervision information. There are mainly two approaches related to the operation structure of each distribution company:

1. Support LV supervision as an extension of the Smartmeter (AMI) remote management systems.

Distribution companies taking this option manage LV grid monitoring elements in a similar way as they do with the deployed Smartmeters. Nevertheless some changes are required in the existing system architecture.

Data Concentrators that manage LV customer per Secondary Substation should be adapted to include the new network elements to be monitored. Also, new interfaces need to be defined to support LV supervision events and alarms. These events are, for example, fuse blowout detection, or high impedance fault detection in Medium Voltage based on measurements taken form the LV grid.

2. Support LV network operation with an independent DMS/SCADA system.

Other distribution companies associate LV network supervision with remote control elements. As a result, functionality evolution is done at the Field Remote Terminal Units (FRTUs) already available in Secondary Substations. These devices deployed for Medium Voltage supervision and control would be evolved to integrate measurements from the LV grid supervision points to be monitored.

In this option, operation systems are kept separated from the existing information systems deployed for Smartmeters.

No matter the approach selected, information systems need to be adapted for this new LV grid operation. The resulting system must be able to manage real time measurements taken from different points of the LV network.

C. Proposal for the system evolution: Modular approach

In this section a modular approach for the information systems evolution needed is described. This approach ensures flexibility and scalability, making integration and future evolution feasible.

This proposal is based on a "message oriented" system; see Figure 2 with the architecture example below. LV network has several information sources to be processed in parallel for different applications. Therefore distinct modules are defined, one independent module per functionality (quality of service, fraud, billing or network operation). These modules are subscribed only to the information types they need. Depending on the application and timing availability required the data processing could be deferred or in real time (event correlation), although typically a combination of both is needed. This proposal covers a scalable and modular architecture, based on the exchange of messages between modules.

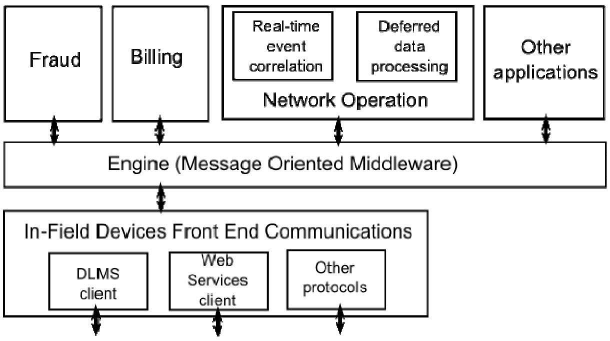

Figure 2 - Modular architecture for the information system

Specific modules can be added/removed when needed, adapting the system to the requirements of each distribution company. Integration between the different modules is also ensured by the stability of the interfaces and the messaging model, so those modules may even be developed and maintained by different companies.

As an example, different communication protocols can be supported for the in-field devices front end. Protocols for data exchange between the Head End System and the devices scattered in the field may be different depending on the application, for example each module can offer:

- Communication based on Web Services.
- Communication based on DLMS.

Know-how of specific communications protocols and devices in the field is important to optimize the success rate of data readings. This is even more important for communications over LV grid, where data bandwidth is usually limited. Certain modules, such as DLMS client, could be developed and integrated by specific companies with knowledge of these protocols and devices.

Along the same feeder, advanced LV supervision functionality analysed in this paper could be integrated as an independent module as shown in Figure 3.

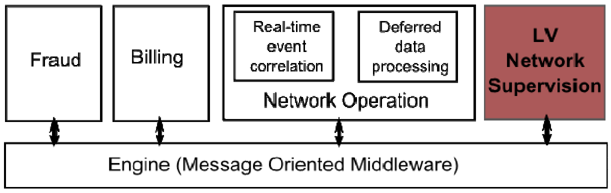

Figure 3 - LV network supervision module integration

VI. MAIN CHALLENGES FOR IT GRID INFORMATION SYSTEMS

Massive adoption of these systems will depend on multiple factors.

Firstly, the regulator and policy maker's task should be highlighted. It has a direct influence on the economic justification of these systems, for the electricity distribution companies, the end users and the development of the society as a whole. There are some factors that would support the supervision systems deployment. The activation of "micro" sources of distributed generation, quality of service and distribution grid operation improvement.

Furthermore, the adoption depends on the availability of solutions that combine technology, right cost and integration in the existing LV grid. Technology is a key element. At this moment LV supervision systems can benefit from the progress made during the development and deployment of the latest generation of Smartmeters. This makes embracing these systems much easier, as there is electronic equipment available that brings telecommunication systems, advanced signal processing, metering, control and information storage together, at a right cost taken into account the volumes involved. Additionally, it is important to keep on researching new protection algorithms optimized for low power generation systems being deployed along the LV grid. Adaptive algorithms are required, so they can adjust to the different load and network generation levels and therefore improve the fault detection mechanisms.

An essential aspect will be how the sensors are integrated in the LV panels. The availability of solutions that are easy to install in the existing Secondary Substations will ensure the feasibility of these LV supervision systems. Figure 4 shows a LV panel with the installation of sensors per feeder that these systems require.

Finally, distribution grid system evolution takes us to open interoperable standard based systems. In India distribution companies are every minute more interested in LV grid supervision, so they can monitor different network points with the aim of predicting their status. A key issue here is that Smartmeters are standardized, but other elements required for LV supervision are not. This is an important challenge that will be detailed in the section below.

Figure 4 LV supervision sensors installed in a LV panel

A. *Standardization required for interoperability*

Standardization frameworks for LV supervision elements are required in order to ensure interoperability. Note that standard based systems can end up being proprietary if the data model is not well defined, therefore protocols need to cover not only syntactic but also semantic interoperability.

This is applicable to DLMS, where we should define a proper data model so it can really be open. In order to be interoperable, the following LV supervision elements should share the data model.

- Elements at the Secondary Substation (feeder supervision).

- Supervision elements at intermediate points of the LV grid.

Other elements may be photovoltaic inverters, sensors with integrated communication, smart breakers at the Secondary Substation... The integration of these elements in the existing infrastructure would enable an important evolution in network planning. The combination of the information taken from LV supervision and the interaction with a mesh network of smart elements in the grid would make automatized operation at LV possible.

VII. Installation and Commissioning: Interacting with the Secondary Substation

When starting the deployment phase of a distribution Smartgrid project in the LV grid, when the grid is up and running, most of the times the focus is placed in the technological aspects of the project, but these projects are usually much more challenging from the logistical point of view. An analysis follows.

The electricity distribution grid has not received a significant level of investment in many cases, when compared with the transport network (as its criticality is lower). Additionally, most of the facilities and assets do not implement automation or remote monitoring. Moreover utility maintenance crews may not visit some of these facilities for years, as long as they keep on working. Note the explicit difference with primary substations.

On the other hand, all over the world the electricity utilities are either vertical companies (integrating from generation to retailing), or have grown out of mergers and acquisitions of local/regional players. As a result of this, the resulting distribution grid is quite heterogeneous in philosophy, physical topology and equipment used. Sometimes also the strategies have shifted over time within the same company, as facilities are coming from different periods.

Figure 5. Secondary Substation in distribution grid

The consequence of all this is that the variability faced in a LV distribution Smartgrid project is enormous, and to some extent unpredictable. A first phase on any project consists on making a preliminary categorization of the facilities to determine which ones are subject to upgrading, and which ones are simply too old or outdated and are due to complete refurbishment, and which ones simply are left aside.

The primary conclusion is that in many cases, when a Smartgrid deployment or pilot is planned in LV distribution, the information obtained from the company asset management and inventory databases may differ from what actually is in the field. Errors and misalignments occur since the infrastructure can be much older than the information systems and countless repairs and field operations may have taken place. These deviations are quite annoying at the time of launching the project and specially at ramping up, since countless incidences seem to slow down the standardization of processes. The Smartgrid project team must live with these issues, they will surely happen. It is very common for instance that air insulated switchgear in a secondary substation becomes a Gas Insulated Switchgear (GIS) after an on-site inspection. As a preliminary conclusion, the on-site inspection of all the facilities definitely pays off.

Another important point is the tag (service interruption) required while the secondary substation is upgraded with the new equipment. Usually the focus is in the cost of the equipment, but the service interruption time may account for a significant part of total cost, so the duration of the tag is a magnitude to be carefully scrutinized. As a result of this, the

Smartgrid solution (equipment, cabinets, sensors…) should be as integrated as possible, so installation time and processes can be optimized. Additionally, all the aspects of the deployment shall be planned in order to have a fast commissioning and validation of the secondary substation after upgradation. Some utilities decide to reduce the functionality and implement systems as devices which do not require a tag, so there is no service disruption to customers.

Often during commissioning remarkable difficulties arise, as the secondary substations in the existing grid were not designed with future upgrades in mind. As a result of this, the existing spaces to accommodate new equipment are usually minimal and specific equipment and sensors have to be developed to cope with the diversity of switchgear and secondary substations in the distribution grid.

Last, but not least, we have to take into account that the distribution grid is very different from a primary substation, where the entire infrastructure is in perfect working condition. In a secondary substation, we may find a switch that has not been operated in years, and we do not have any diagnostic tool to assess its status prior to performing a switch open operation. This may lead to switch fail at the time of restoring service after the supply interruption. These situations happen and must be covered. We do not have to forget that the facilities may have tens of years of service already.

VIII. Conclusion

LV network supervision solutions are a cost-effective alternative to increase the distribution grid capacity due to better control and monitoring of the LV grid. Smartmeters being deployed in the LV domain offer information for grid operation in addition to billing information. Therefore several other applications such as LV network supervision can be integrated on top of advanced metering infrastructure (AMI).

This evolution forces a redefinition of the operation structure and evolution of the information systems. It is important to highlight the importance of adapting the IT information systems to the enormous amount of data that can be obtained from LV distribution grids. Being able of combining this information with data coming from other sources (such as geographical information, meteorological predictions or distributed energy generation predictions) will provide the distribution companies the knowledge needed to successfully operate the network, provide a better service to their customers, and at the same time reduce their operation costs.

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ENVISIONING A SMARTER GRID
POLICY, REGULATORY AND TECHNICAL FRAMEWORK

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Abstract—Bhutan today with 1480 MW installed generation capacity poised for about 10,000 MW addition in near future and with about 0.15 million customers and with a peak load of about 320 MW is strongly connected to the Indian Grid which is one the largest electrical grids of the world. Operation, maintenance, and development of such have its own advantages as well as challenges. To efficiently manage this grid with such dynamics of present as well as of the future require that relevant technology is adopted to help in visioning and operating the grid. Leveraging the smart grid technology to address the sheer grid challenges is vital. This paper provides a smart grid policy and regulatory framework as well as a technical framework which are important requirements towards making the grid operation efficient and relevant for present challenges and near future technical and market evolvement.

Expectation for want of data and information is no less than in real time largely due to the communication infrastructure connecting countries and continents around the world as well as the extensive social media and application usage. It is no different with the customers or any stakeholders in the power or energy business. Smart Grid is the response with the ever evolving information communication, rising challenges of the electrical network systems, operational needs of the utilities, energy market and customers as well as to be near future ready for renewable energy integration to the grid.

Key Words: smart grid, master plan, policy.

INTRODUCTION

Electricity. Is it only an energy form, a commodity, a value added service, a strategic resource or is it a sustenance source for humanity? Equally important question at this point in time is on "how to more efficiently" produce and consume electrical energy, for it will have immense benefits to humanity not only for its importance but for its volume of use and requirements in every aspect of living. Efficiency in generating, transporting and utilizing electrical energy has direct impact on global sustainability of resources especially on "Energy Security" and "Carbon Footprint". A well defined "Smart Grid Vision and Policy Framework" for a utility and country at large gives one of the major dimensions for energy security and carbon footprint reduction in the way this energy is produced and consumed.

A definition of Smart Grid says: "a smart grid is the electricity delivery system (from point of generation to point of consumption) integrated with communications and information technology" [1]. Smart Grid has its own various definitions but it is felt that every utility and country at large should define its own based on what is important and relevant for the present as well as looking into the future.

As societies develop and advance, energy has and will be one of the fundamental requirements towards sustainable development. The immense infrastructure for transmission of electrical power form the generation stage to the consumption and the way the same is operated and maintained is changing not only due to technological advancements but also with the changing demands and requirements of the customers and the market itself. We are looking into a future where the present customers of electrical utilities would become prosumer where they would be a potential supplier of energy to the grid involved not only in consuming energy but determining how it is generated, transmitted and eventually consumed. These challenges of the future coupled with the challenges of increased demand on the electrical infrastructure, the challenges of efficiently operating the grid with increased and interconnected network, the challenges of integrating and dispatchability of renewable energy and new technologies onto the grid (viz. wind, solar, electric cars etc.,) and also the requirements of the market on how the energy is traded requires the advent of smart grid concepts. These are some of the challenges that our power system in Bhutan is currently facing and is only going to be more prominent with the fast change and development the society goes through both politically as well as naturally.

Hence, towards a sustainable development of smart grid and to get maximum tangible and intangible benefits on the investments and resources (social, technical and well as financial), a comprehensive approach for a smart grid vision, policy, regulatory and a technical framework, leading to a deployable smart grid master plan and a road map is required.

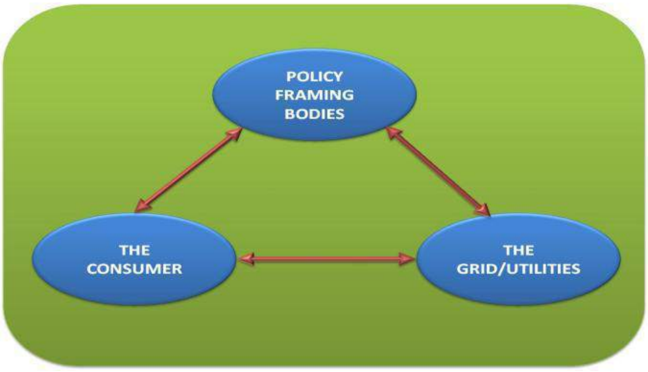
A SMART GRID FRAMEWORK FOR SUSTANIABLE DEVELOPMENT

For sustainable development of smart grid, a strategic development plan is proposed as given in figure 1 below:

Figure 1: Strategic Smart Grid Development Plan

The three important partners in developing, implementing and sustaining a smart grid as described in figure 1 above are the policy framing bodies, the consumer and the grid/utility itself. All the three partners have a symbiotic relationship (figure 2) and each have to be positively participative to leverage the investment in smart technology leading towards a smarter grid.

Figure 2: The Three Partners in Smart Grid Development



The grid operated by the utilities, especially in a regulated environment requires policy guidelines for a realistic and practical investment plans not only for securing its investments but also to encourage towards developing a technical master plan and vision on how the systems evolve and develop. The grid by itself has to evolve technically before smart grid investments can provide the benefits and the operational efficiency. Hence, it is important that a coordinated investments in grid up gradation and enhancements vis-à-vis smart grid technologies are planned. Also, from the consumer perspective, regulations and policies provide the confidence, awareness and protection from utilities which are generally monopolistic in its business more so because of the nature of the business itself.

Towards a positive collaboration amongst the three partners and its requirements and interests, two important frameworks viz. "A Policy and Regulatory Framework" and "A Technical Framework" need to be studied and established for a sustainable smart grid deployment, investment and sustenance. The subsequent sections in this paper describe a way ahead for a policy, regulatory and a technical framework establishment for Bhutan smart grid.

POLICY AND REGULATORY FRAMEWORK

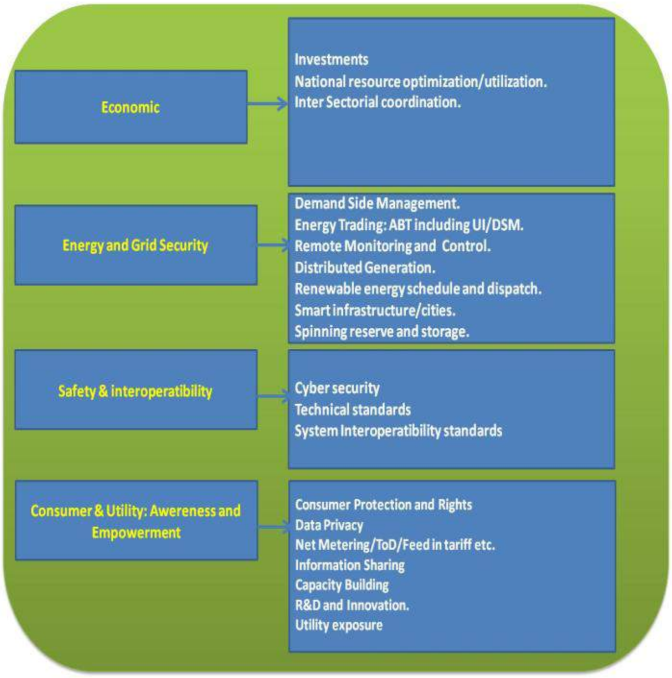
It is expected that the smart grid policy apart from creating more pro smart grid regulations, standards, service rules etc, gives a way ahead to utilities for developing and deploying smart grid master plans towards making the grid efficient and relevant for future apart from inculcating Research and Development (R&D) and innovation. It also provides investor's confidence investing in product development as well as to the consumers the acceptance, eventually leading towards improved systems and services. A collaborative effort from all the stakeholders (viz. the policy making bodies, regulators, utilities, businesses and customers) would be required to have a modern, efficient and secure grid leveraging the power of smart grid technology for meeting the service expectation and market requirements on how the power is traded and consumed.

The four broad aspects that may need to be addressed in a smart grid policy framework which also become the very objectives of smart grid policy requirements are;

(i) Economic;
(ii) Energy and Grid Security;
(iii) Safety and Interoperatibility;
(iv) Consumer and Utility Awareness & Empowerment;

The figure 3 below provides the smart grid policy framework which needs development into an operational policy document.

Figure 3: Policy Framework



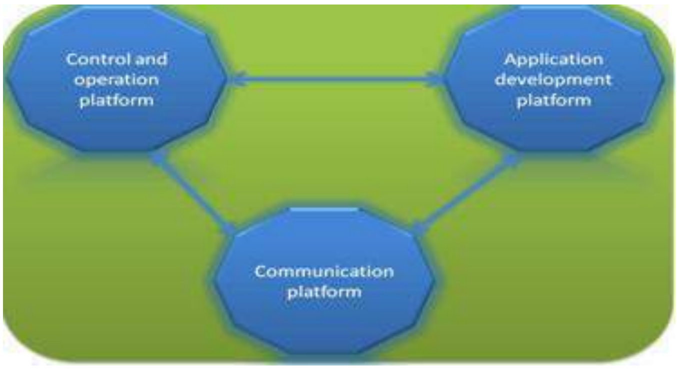
Towards making the grid smarter, policies and regulations should also be made smarter. It is recommended that a smart grid policy is conceived as well as a paradigm shift in modifying the existing grid regulations, supply rules, standards are required. Some of the grid operation regulatory requirements, incentives and operation framework provided in the existing grid regulation for the utilities and consumers may need a relook. Additional mechanisms in the regulations towards meeting the policy objectives of smart grid and ultimately the service and market requirements are felt necessary.

TECHNICAL FRAMEWORK

A national technical framework supported by a policy leading towards a smart grid master plan is proposed. The technical framework discusses the potential of leveraging the presently available technologies and systems for development of utility smart grid master plan helping the grid to be smarter.

Technically three broad platforms are defined in figure 4 which need planning and study in implementing the technical framework leading to smart grid master plan and projects. Study, optimization and standardization considering the technology advancements and possibilities on 3 platforms viz. (i) Communication platform layer (ii) Control & Operations platform (the PLC/Sensors level) and (iii) Application platform, need to be done. Once a base survey of the present technology and planning on the above three platforms are done, prioritizing the smart grid projects forms the basis for the smart grid master plan formulation.

Figure 4: The Three Platforms for Smart Grid Implementation



The communication platform: The backbone communication has already been established to and from all the generating stations and high voltage substations on the optical ground wire network (OPGW). Also, ADSS optical cables have been laid to all the 202 sub districts. With the ADSS termination and fiber lighting and ADSS network integration with the OPGW, communication on fiber would be available to a central location in each of the sub-districts. The demand of smart grid for the requirement of a communication medium, the challenge would then be to reach each of the distribution transformers (DT) on the distribution network and beyond to the house hold level. This mile of communication from the sub-district center to the DT and house hold is proposed to be studies on PLC, fibers or any wireless communication technologies (viz. Zig-bee, GPRS/GSM networks, Wi-Max etc). A techno commercial study on this medium selection and integration to the fiber backbone for an end to end communication network will need to be proposed in the national smart grid technical framework. It is felt that there would not be one communication medium fit all situations and the study will need to take various parameters including population density, alternate application on the network, reliability apart from others to aptly select the communication technology from the sub district center. This would ensure optimized utilization of the national asset as well as provide an end to end communication backbone for development of smart grid.

Control Operation platform: Any system and most importantly development of smart grid require data acquisition systems. This in electrical utilities are in the forms of programmable logic controllers (PLC), Remote Terminal Units (RTU), protective relays, Phasor Measurement Units (PMU) and any intelligent electronic devices in the generating stations to the grid to the consumer premises. Technology selection and communication protocol standardization becomes important especially considering interoperatibility. The technical framework would need this aspect to be addressed again considering optimized and intelligent investment plans.

Application platform: The data acquired from the control operation platform and transmitted vide the communication platform need to be received, analyzed, stored and application developed to make useful interpretations for efficient grid, system and market operation. This platform require that appropriate standard open systems of database servers are standardized such that the data could be reused by any system and re-sensing , transmission and especially manual updation of data for varied application is avoided. The technical framework should address standardization of this sufficiently such that automatic data update for usage by applications from different vendors or self developed applications are possible. The ultimate aim is that a central server repository database for access by any HMI (application) at any level (technical, network or business) for a utility is available with data from PLC/RTU, Enterprise Resource Planning (ERP), GIS, consumer data etc.

Smart grid master plan developed with the guidelines of the above technical platform standardization (supported by an intelligent policy) would ensure inter-operatibility, system integration, technology migration and most importantly leading towards efficiency in business and energy market operations and services as well as optimized national resource usage/investment on smart grid technologies.

SMART GRID MASTER PLAN

An optimized smart grid master plan inline and supported by the smart grid policy and the national technical framework should be formulated by each utility. Considering the power system from the point of generation to the point of consumption, objectives and pillars of smart grid master plan for utilities (generation, transmission, and distribution) need to be addressed. The smart grid pillars and objectives for utilities (generation, transmission and distribution) and the vision of the smart grid master plan for policy and regulatory bodies could be different. Expectation of all parties involved need to be addressed while developing, constituting and finalizing the smart grid master plan towards effective grid operation and service delivery ultimately to the customers.

The smart grid master plan for Bhutan Power Corporation (BPC), the only transmission and distribution utility in Bhutan considers the following as its pillars and objectives. The rational of the smart grid projects in the roadmap are formulated for:

(i) Grid security;
(ii) System reliability;
(iii) Energy efficiency;
(iv) Energy markets enabling;
(v) Customer service; and
(vi) Carbon reduction.

The BPC smart grid master plan conceptualizes a long term (2035), a medium term (2025) and a short term (2017) plans. The road map addresses the projects under various implementation terms considering meeting the objectives and pillars. The short term plans should cover the pilot projects for technology understanding; design testing, benefit quantification and confidence building before venturing into implementing the smart grid projects of the medium and long terms. The figure 5 below provides the road map for BPC smart grid master plan:

Figure 5: BPC Smart Grid Roadmap

CONCLUSION AND RECOMMENDATION

Considering that Grid smartness is not a choice but a requirement, a policy framework on Smart Grid is necessary and this paper discussed the framework and objectives on which it could be built. Also, the Grid regulation may need a rethinking apart from the other existing rules, regulations and standards for the energy sector considering the requirements of the 21st century grid of Bhutan. Also, a national smart grid technical framework supported by a policy guideline for Bhutan Smart Grid was discussed in this paper. Subsequently a Smart Grid Master Plan and Roadmap for BPC was discussed for coordinated implementation of activities. It is recommended that a calendar for smart grid milestones will need to be developed where Bhutan smart grid vision, policy, regulatory framework and deployable master plan and roadmap form a part of the same.

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Role of Microgrids in India's Smart Grid Framework

(ISGW Theme: Regulatory Support for Smart Grid Projects)

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***Abstract*—This article addresses the role of microgrids within India's "Smart Grid Vision and Roadmap," and its "Model Smart Grid Regulations for States. These frameworks reflect dramatic changes that are unfolding in India's generation, transmission and distribution landscape, especially the rapid proliferation economy-wide of distributed and renewable generation that are creating numerous points of power injection. This article evaluates the role that microgrids could play to build a new "smart integrated grid" within these frameworks. The article examines the types of policy, regulatory and institutional changes needed to support advanced microgrid investments that could serve as a "connecting building block" for the Government of India's (GOI) Smart Grid, between the bulk power system and distributed assets, managing and optimizing distributed resources with smart technologies for the benefit of local facilities, customers, communities, the grid and the marketplace. The GOI's "Smart Grid Vision and Roadmap" expands the boundaries of the electricity value chain to include decentralized elements and distributed energy technologies; opens the door to new entities to participate in the electricity market; and creates the need for new regulatory structures to realize the full potential of smart grid technologies. This paper draws upon lessons being learned in United States and European pilots/initiatives to discuss regulatory innovations for enabling "smart microgrids" to become an "integrative agent" that fuses power and information to integrate decentralized with centralized energy, harmonize on-grid with off-grid rural electrification efforts, and attract private capital to increase the supply and delivery capacity through market-based approaches.**

Keywords—Smart Grid, Microgrid, Integrated Grid, Electricity Regulatory Reform, Distribution System Planning and Operations, Intelligent Energy Management, Distributed Networked Electricity Delivery Systems

I. INTRODUCTION

India's "Smart Grid Vision and Roadmap" (Roadmap) is intended to transform the Indian power sector into a secure, adaptive, sustainable and digitally enabled ecosystem by 2027 that provides reliable and quality energy for all with the active participation of stakeholders. Recognizing that the electricity generation, transmission and distribution landscape has been undergoing dramatic changes over the past decade, the Roadmap represents a marked departure from the traditional highly centralized and target-driven, supply-push electricity sector strategy. Over the span of three five-year plans, the Roadmap sets significant targets at the distribution systems level to spur the development of distributed resources and to stimulate a customer/demand driven approach using smart technologies. The Roadmap seeks to achieve these targets by evolving a "Smart Grid," an electrical grid with automation, communication and information technology (ICT) systems that can provide the capability for two-way power and information flows, monitor power flows from points of generation to points of consumption and control power flow or curtail the load to match generation in real time. Increased visibility, predictability and event control of generation and demand would bring flexibility to both generation and consumption and enable utilities to better integrate intermittent renewables, reduce the cost of peak demand, reduce outages and increase system efficiencies. [1]

In light of rapid proliferation of distributed and renewable generation, the Roadmap recognizes that it will be imperative to incorporate smarter automation and IT systems into the grid in order to manage onsite solar PV, electric vehicles, and other distributed energy and intermittent renewable sources. Moreover, in the face of growing peak demand in India, the Roadmap makes peak load management through load control, such as demand response and intelligent energy management, a high priority in efforts to close the supply gap that exists in India. [1]

Through the development of the National Smart Grid Mission, the GOI intends for the Roadmap to spur new operating grid parameters, empower new market players and galvanize new regulatory structures to incent both public and private support for grid modernization. The Roadmap expands the boundaries of the electricity value chain to include decentralized energy elements/distributed energy technologies (onsite renewable energy, distributed generation, demand-side management, electric vehicles, energy storage, demand response, etc.); opens the door for new entities/third parties to participate in the electricity market such as, microgrid operators, energy service companies (ESCOs), virtual power plants, aggregators, prosumers; and creates the need for regulatory innovations to change utility incentives, tariff structures and roles to achieve India's policy objectives of universal energy access, electricity reliability and resiliency, greenhouse gas emissions reduction and environmental quality, and sustainable economic growth and development.

Towards realizing the full potential of smart grid technologies, the Roadmap sets significant microgrid targets, including: Developing microgrids, storage options, virtual power plants, solar PV to grid (PV2Grid) and building to grid (B2G) technologies to manage peak demand, optimally use installed capacity and eliminate load shedding and black-outs; Developing microgrids in 1,000 villages, industrial parks, commercial hubs by 2017, 10,000 by 2022 and 20,000 by 2027, which can island from the main grid during peak hours or grid disturbances. [1] While microgrids have not been defined in the Roadmap, consensus is growing internationally on the salient elements of microgrid systems, as embodied in the following two definitions: (1) The U.S. Department of Energy defines a "microgrid" as a group of interconnected loads and distributed energy resources within clearly defined electrical boundaries that acts as a single controllable entity with respect to the grid and that can connect and disconnect from the grid to operate in grid-connected or island-mode; (2) CIGRE C6.22 Working Group defines a microgrid as an electricity distribution system containing loads and distributed energy resources (distributed generators, storage devices or controllable loads) that can be operated in a controlled, coordinated way, either while connected to the main power network or while islanded.

The GOI has been developing Model Smart Grid Regulations to provide a regulatory framework than can spur smart grid implementation. These regulations, which are intended for adoption by the States, relate to such decision-making matters as the approval of smart grid investments (including pilot projects), recovery of investments, tariff design, incentives and penalties to motivate the adoption of smart grid solutions by utilities, cyber security, technical and interoperability standards and protocols, and end-user/customer deployment, especially protecting customers' interests and ensuring the value of service delivery. The value of investments in smart grid solutions will need to be balanced against the risks, especially the risk of obsolescence due to technology advancements, market changes, etc. Smart grid-related investments may involve longer lead times than conventional investments, requiring upfront capital investments, while realization of the full benefits of the technology may occur in phases over a longer period of time.

II. Advanced Microgrids in a Smart Grid

The U.S. Department of Energy (USDOE) and Sandia National Laboratories envision the "advanced microgrid" as playing an integral role in a modern electrical grid. [2] Equipped with new functionalities enabled by advancements in information, communications and control technologies (ICT, power electronics, modelling and simulation, distribution automation, data analytics, etc.), the advanced microgrid could serve as a "building block" for transforming a nation's electricity value chain, both upstream and downstream. The USDOE and Sandia are evaluating the changing capabilities of microgrids and envision systems that could contain multiple customers and noncontiguous properties, multiple resources, resource interconnection on both sides of the meter, islanding capabilities, functionalities to provide grid services and use existing distribution networks, as well as to create dedicated distribution infrastructure, including distributed networked electricity systems. [2] These systems could be utility-owned, privately owned or have hybrid ownership/operating structures. Such "smart" microgrid systems incorporate intelligent energy management software and hardware for balancing energy supply (including storage) and demand to maintain stable and reliable operations; a "smart" system contains ICT that enhances energy management and the optimization of the system's operations and components, including sensors, communications and automatic control technologies used to generate, manage, distribute and use electricity more intelligently and effectively. Advanced microgrids employ smart controllers and advanced, automatic control technologies, and incorporate information and communications infrastructure for intelligent and efficient load and energy resource management.

These microgrids operate on an "intelligent distributed energy management" service model. Advanced microgrids provide coordination and control to integrate multiple distributed energy, energy storage and demand-side assets within the system, using specialized hardware and software to control such integration. Within integrated smart microgrid systems, varying load is intelligently and effectively managed and shaped through managing and optimizing multiple distributed energy and demand-side assets. Key features include: Integration of multiple distributed energy resources (DER), ensuring maximum utilization of renewable energy sources; resource and load profiling, controlling and forecasting; centralized control (intelligent, dispatch controller) for resource optimization and demand management; load prioritization; integrated digital communications infrastructure; real-time data acquisition and monitoring of electrical and physical signals; and minimized outages and fast response to network disturbances through automatic connect/disconnect of system components. [2]

If developed as part of India's evolving Smart Grid, advanced, "dynamic" microgrids could benefit the macrogrid, communities and the market by contributing to better matching of supply and demand; improving asset utilization; integrating and optimizing clean, efficient and intelligent technologies into India's power system; and building a new flexible, resilient and transactive electricity value chain. Strategically deployed, advanced microgrids could enhance the power value chain from "source to sink" by harnessing cost-effectively the benefits of distributed resources and load management; supporting markets for new resources; and deploying information, communications and control applications to foster distributed networked electricity systems. Smart microgrids also have a broad range of applications across all market segments.

III. 21st Century Operating Grid and Power Delivery

India's Roadmap embodies a "dispersed vision" of a 21st century operating grid because it aspires, through a range of targets, to provide distributed control and heterogeneous service in addition to providing universal homogeneous service quality. This is not a vision, therefore, that seeks just to overlay India's legacy grid with information and communications infrastructure to build a super-centralized grid. As a result, such a dispersed operating grid vision would not operate under the same linear constraints of a super-grid centralized power structure that faces such limitations as: Centralized generation heat loss and transmission line losses; load growth stress; limitations in meeting environmental objectives; infrastructure interdependencies; vulnerabilities to energy disruption, natural and man-made disaster, with increased reliability costs; high costs to expand through the development of new central plants and transmission lines to meet growing demand. [3]

Influenced by public policy mandates and market changes, smart grid technology investments could substantially alter the current configuration of India's electricity generation, transmission and distribution system. Under a dispersed vision of distributed resource control, smart grid technologies could potentially expand the legacy utility grid by connecting smart microgrids or smart microgrids nested within distributed networked electricity systems (containing distributed renewable generating assets) to the existing bulk power system. Potential system complexities of managing wide and dynamic sets of distributed and intermittent resources and control points may necessitate exploring such capabilities, which would go beyond what two-way command and control systems could provide with smart meters, fast sensors and complex controls within utility distribution systems [3]

Advanced microgrids would have the ability to cluster loads and DER units as an integrated system, which would operate in islanded or parallel-grid modes (microgrids are generally connected to the larger utility grid through a point of common coupling), and which could contribute to smarter distribution through faster control of hundreds of individual DER units. Managing clusters of DER and loads within an autonomous system that is designed to island during system disturbances, these dynamic microgrids could not only provide necessary levels of power quality, availability and reliability to meet customer requirements, but also serve as a grid resource to provide a "systems" approach to realizing the potential of DER. Such a systems approach could avoid problems that DER could create for the utility distribution system if these resources proliferate as standalone or dispersed resources, in random and uncoordinated ways. [3], [4]

If such smart microgrids became a connecting building block within a distributed networked electricity system (DER units placed under the control of dispatching microgrids that are linked) to manage and optimize distributed resources, the potential benefits could be more cost-effective compared to alternative super-grid utility distribution system capital investment options. Benefits could include reducing the cost of energy and managing price volatility, improving reliability and power quality, increasing resiliency and the security of power delivery, shaping load profiles, and helping to manage high penetration and the intermittency of renewables. Moreover, the number and types of DER units within each microgrid would not be relevant to the dispatch of their resources, just the attributes of the power to be dispatched. An alternative, therefore, to a smart grid concept that governs many DER units with an elaborate and sophisticated utility command and control system, is to build upon advanced microgrid concepts to dispatch microgrids in a distribution system to achieve India's smart grid objectives. If the advanced microgrids are compatible with operating protocols, with the macrogrid and neighboring microgrids, these systems could complement and participate as a functional unit in a modernized grid. This combination could minimize stranded assets and assure that resources are used to their design capacity. Advanced microgrids could, therefore, provide a cost-effective means of integrating large amounts of DER into the macrogrid, offering significant system efficiency and reliability improvements. [2], [3], [4]

IV. Regulatory Innovations for an Integrated Smart Grid

A new policy eco-system would need to be evolved to help manage a transition to such smart power system architecture and operations that include both centralized and decentralized components. To support advanced microgrid investments, this policy eco-system would need to be designed to support the development of highly flexible, configurable and interactive networks of intelligent utility, customer and third-party applications, technologies and devices; market data, price signals and transactions; and "system of systems" operations to enable distributed energy resource integration and load-side management. [4] A new intelligent energy management type of regulatory model would need to evolve as part of developing India's Smart Grid to support the role of advanced microgrids in shaping scalable systems than can use smart controls and communications to monitor, manage and optimize distributed assets in real time, as well as to use layers of intelligence to link customers with energy using infrastructure and facilities within communities – all with a view to advancing resource integration, overall efficiencies and optimal energy investments. Such a policy eco-system is fundamentally different in nature than the centralized regulatory model that has governed electricity generation, transmission and delivery worldwide to date. This policy eco-system would not only need to overcome barriers and risks embedded in the traditional electricity regulatory system, but also to support investment in interoperability and integration on a power system-wide scale (source to sink) to help standardize the use of distributed and demand-side energy resources as part of overall power system planning, grid operations and power market trading. This would entail developing a new regulatory and social compact for a 21st century smart operating grid. [4]

A. Electricity Act of 2003 and Smart Grid Regulation

To support such changes to India's operating grid and electricity regulatory regime, the Electricity Act of 2003 (EA2003) would need to be amended to authorize smart grid investments. If the smart grid ecosystem described above were authorized, smart microgrids and distributed networked electricity systems could contribute to developing interoperability and integration approaches that could be used to standardize the use of demand-side and DER as part of utility planning, grid operations and control and power market trading.

Reforms enacted by the EA2003 are supportive of this smart grid vision, but would need to be re-examined under a new smart grid regulatory regime, especially reforms relating to the distribution systems level (as for example, open access/third party access; distributed companies that can be in the business of generation and distribution). Other reforms (allowance for multiple licensees or competing companies in distribution and the encouragement of parallel networks) would need further clarification within the context of developing an integrated smart grid (for example, the roles and responsibilities of utility distribution companies and new actors (i.e., microgrid developers and operators, system integrators, aggregators, prosumers) and the rules to govern the creation and operation of distributed networked systems in which energy sharing could take place, as well as the interconnection and integration of such systems with other localized energy systems and the utility distribution company or companies. EA2003 amendments and the Model Smart Grid Regulations would need to define such terms as advanced microgrids, intelligent energy management and distributed networked power delivery systems.

In developing Model Smart Grid Regulations for States to adopt, the GOI should consider provisions that would lay an appropriate foundation for pursuing a dispersed smart grid vision, regulations that: (1) Further a vision of an "integrated grid" in which all electricity resources, including distributed energy resources and demand-side resources) can be integrated on a basis in parity with current bulk supplies, including integration into utility planning, grid operations and the power markets; (2) Promote technology innovation to realize the full potential of smart grid capabilities, including the demonstrating, testing and validating of new forms of smart energy architecture and delivery infrastructure, especially at the distribution systems level; (3) Support the use of smart grid technologies to expand the legacy power system to include cost-effective decentralized elements (smart microgrids, intelligent distributed energy management and distributed networked electricity system pilots) and a "system of systems" approach in implementing the vision, targets and outcomes of the Smart Grid Roadmap; (4) Value and fully take into account the benefits, attributes and costs of advanced microgrids, distributed resources and energy efficiency; (5) Define microgrids and advanced microgrids for purposes of implementing the microgrid targets set out in the Roadmap and evaluate smart microgrids as a third element of the Smart Grid, together with macrogrid operations and grid-load interaction, in transforming India's electricity system; (6) Require the development of new cost-benefit analytical frameworks, standards and protocols, and performance metrics in connection with standardizing the deployment and valuation of microgrid systems and distributed resources, and also in connection with advancing the interoperability of systems, applications and devices from "source to sink" within the electricity value chain; (7) Require the development of appropriate performance and output-based cost recovery criteria, tariff structures and incentives for utilities to help shape a new utility business and service delivery model, one that is consistent with and in furtherance of the objectives of the Roadmap and a dispersed smart grid vision; and (8) Promote the development of more robust interstate and intrastate power markets to help support a shift to a customer-driven, "dispersed" smart grid.

Putting these types of measures into effect would help to frame a legal, policy and institutional environment within which (i) an holistic and integrated policy eco-system could evolve to support the development of advanced microgrids as integrative agents between the bulk power system and distributed assets; and (ii) on-grid and off-grid programs and activities could be aligned and harmonized in a manner to accelerate energy access and poverty reduction consistent with grid modernization. This smart grid and advanced microgrid regulatory platform would integrate India's policy objectives (clean energy, energy access, energy efficiency, climate change, environmental quality, energy surety and resiliency, smart cities, electric vehicles, etc.) and change utility incentives, tariff structures and roles to achieve such objectives, while maintaining the reliability and affordability of the utility power system.

Such measures would enable the development of an integrated smart grid designed to increase the independence, flexibility and intelligence for optimization of energy use and energy management within localized energy networks, whether at building, system, district/community or distribution system levels, as well as to integrate locally developed resources into the smart grid. These measures would support the development of smart utility distribution systems that could: (1) Optimize energy availability across a larger variety of energy sources, improving economics; (2) Create an infrastructure for more optimum management of overall energy requirements (heating, cooling and power); and (3) Increase control and management of reliability at the local level. [4]

B. Reforming the Traditional Regulatory Paradigm

The measures described above would be directed at changing the traditional regulatory paradigm to support a distributed grid as part of evolving a smart grid. The measures would reform current regulatory, tariff, market design and incentive structures to better align utility interests with achieving India's policy objectives; to engage new players to increase the competitiveness of the electricity sector; and to expand the parameters of information, power and transactional flows from source to sink. Such reforms will challenge two basic assumptions of the traditional paradigm: (1) There is little role for customers to play in addressing system needs, except in times of emergency; and (2) The centralized generation and bulk transmission model, relying on “grow and build out” strategies, yields cost-effective results based on economies of scale. [5] In this regard, reform efforts would address the limitations of traditional cost of service and rate of return regulation that uses an annual rate case cycle, which encourages overinvestment in capital spending because earnings are directly tied to the rate base. Under the traditional model, utilities are rewarded for the inefficiencies in the bulk and distribution systems that require capital spending to build for unmanaged peak loads. This model does not incent utilities to improve performance because the benefits of efficiency gains are reflected in the next year’ rate case and the model operates upon historical utility performance where utilities are measured against their own past performance. Regulatory reform would seek to induce utilities to optimize system efficiency to reduce capital needs and to manage resources effectively towards achieving policy objectives, while maintaining the reliability and affordability of the grid for customers. [5]

To achieve a more efficient allocation between capital and operating expenses for achieving regulatory objectives, the U.S. and other countries are evaluating the need to shift to a results-based model, such as the United Kingdom’s new regulatory regime, “RIIO” (Revenue set to deliver strong Incentives, Innovation and Outputs) to shift the focus of regulation from the reasonableness of historically incurred costs to the pursuit of long-term customer value – placing emphasis more on outputs than inputs and using longer term rate plans. Rate design measures that provide dynamic price signals to customers would allow them to align their investments in DER more efficiently and economically; such rate design should reflect the value of grid service to customers with DER, the value of grid service to customers without DER, and the value that DER can provide to the grid. Payment structures should also reflect value based on timing, location, flexibility, predictability and controllability of the resource. Measures also will need to be taken to assure that the burden of meeting utility revenue requirements does not fall disproportionately on customers who cannot afford or are unable to install DER or participate in retail markets. [5]

To address legacy system structural biases against DER and microgrids, consideration should also be given to the following types of changes that are being evaluated in the U.S. and other countries: (1) Transmission planning that treats DER as a cost-effective resource option to manage distribution system flows, shape system load and enable customers to choose cleaner, efficient and more resilient power options; (2) Utility mapping to site DER and microgrids where these resources could contribute the most value to the grid and the development of distribution resources plans to delineate optimal DER portfolios to meet cost-effectively State and National goals and address customer needs and interests; and (3) Reforming the role of utility distribution companies into distribution system operators with responsibility for the operation of the distribution networks to achieve targeted levels of reliability and resilience, make more efficient demands upon the bulk power system, and build retail markets that are designed and operated to value system-based investments and operation protocols that can drive distribution utility innovation and efficiency. [6] [5]

V. Conclusion

This article recommends consideration of the foregoing types of electricity reforms to structure an effective policy eco-system in India for achieving its Smart Grid Vision and Roadmap and for developing advanced microgrids as integrative agents for fusing power and information to integrate decentralized with centralized energy; harmonize on-grid with off-grid rural electrification efforts; and attract private capital to increase supply and demand capacity through market-based approaches.

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Characterization and Effectiveness of Technologies for India's Electric Grid Reliability and Energy Security

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***Abstract*— India's electricity grid is aging, and the transmission and distribution (T&D) losses amount to 25%, with $5.7 billion financial losses to the utilities. In 2013-14, India had an average peak power deficit of 9% and an average energy deficit of 8.7% due to insufficient generation and transmission capacity, resulting in rolling blackouts. Technologies and interoperability standard have enabled utilities and systems operators in the United States (U.S.) to engage customers for electricity reliability. The Indian Government's Restructured Accelerated Power Development and Reforms Program established the need for automated systems to collect baseline data and information technology adoption for grid reliability. Tata Power Delhi Distribution Limited's (TPDDL) advanced Smart Grid project plans to increase reliability and readiness of customers for automated demand response (AutoDR). The project includes smart meters and interoperable communications for data analytics and automated dispatch for load reduction during power deficiency. This study characterizes TPDDL's integrated AutoDR system, including advanced metering infrastructure, data analytics, smart meters, and interoperability standards. We evaluate the technology effectiveness where the analyses show a 75th percentile load reduction of 10% for 144 commercial and industrial facilities with an aggregated coincident total peak load of 25 megawatts (MW). AutoDR can improve customers' responsiveness and a utility's arbitrage for electricity shortfall and high cost of peak power. A well-designed program can accelerate technology use and encourage customer participation. Innovative technology solutions can enhance the grid reliability by minimizing the instances of outages in India, and improve energy security by enabling integration of renewable generation to scale.**

***Keywords*—** *Smart Grid Transactions; Automated Demand Response; Open Standards; Communication Technologies*

I. Introduction And Background

Technology impacts on electricity reliability, energy security, and carbon reduction can be significant. In 2012–13, India had an average peak power deficit of 9% and an average energy deficit of 8.7% [1]. In 2014, India had the world's fourth largest installed generation capacity—255 gigawatts (GW)—of which about 70% is from fossil-based fuels, with coal being the dominant power source [2]. While India has plans to improve electricity reliability by increasing generation with abundant coal, it is also pursuing aggressive renewable energy generation to improve energy security.

Enabling technologies, as well as policies that engage customers and efficiently manage the electricity system and its use, will play a key role in achieving these goals. India lacks sound policies and a technology roadmap for customer participation in electricity grid programs. One utility in India, Tata Power Delhi Distribution Limited (TPDDL), recently concluded a demand response (DR) automation project using Smart Grid technologies. The U.S. Department of Energy's (DOE) report to the Congress defines DR as short-term changes in electricity usage by end-use customers, from their normal consumption patterns. Demand response may be in response to: (a) changes in the price of electricity, and (b) participation in programs or services designed to modify electricity use in response to wholesale market prices or when system reliability is jeopardized [3]. While DR can be manual, a fully automated DR (AutoDR) does not involve human intervention, but is initiated at a building through the receipt of an external communication signals [4]. Automation technologies that allow customers to transact with the electric grid at different time scales are successfully deployed in the U.S. and other countries [5]. Technology applications in India can support low-carbon growth and cost-effective roadmap to reduce peak power and improve resiliency by better integration of variable generation (e.g., solar) [6].

This study evaluates TPDDL's project from the context of an AutoDR system, which includes advanced metering infrastructure, smart meters, data analytics, and interoperability standards. We characterize the technology effectiveness where the analyses have shown a 75th percentile load reduction of about 10% for 144 commercial and industrial facilities with an aggregated coincident total peak loads of 25 MW. With Delhi's total generation capacity of 8.2 GW and its consideration as one of the 100 Smart Cities in India, there is an opportunity to leverage technologies and flexibility in energy use. Two other symbiotic studies provide insights on: (1) Customer characteristics and DR performance, and (2) potential for scaling and valuation [7, 8]. Earlier studies have reviewed India's Smart Grid initiatives and have proposed a technology framework for the integrated energy efficiency and DR action plans [9], and identified grid integration technologies, knowledge transfer, and their market potential for the U.S.-India collaboration in the broader context for efficient, responsive, and resilient buildings [10].

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The U.S. federal and state initiatives are promoting grid-integrated technologies and standards that enable electricity demand to transact with supply as a cost-effective and carbon friendly solution to ever-increasing demand. The U.S. Federal Energy Regulatory Commission (FERC) estimated the 2019 U.S. potential for reduction in peak demand with full participation as 138 GW, or 14%, relative to a scenario with no DR programs [11]. These FERC estimates assume universal deployment of advanced metering and default dynamic pricing tariffs with advanced technologies for grid transactions. In a recent study, the contribution of DR for ancillary services or fast dispatch markets by the independent system operators was 28.3 GW, or 6% of peak load [12]. These technologies for automation are deployed in commercial DR programs for over 1,200 customers with a total enrolled DR capacity of over 250 MW [13]. Select constituents in the U.S. are also aggressively pursuing using energy efficiency building codes and communication standards as a mechanism to increase DR participation and cost-effectiveness [14].

In India, the following key initiatives offer significant opportunity for technology applications: (1) the National Smart Grid Mission (NSGM) in the power sector, (2) the Ministry of Power's (MoP) Restructured Accelerated Power Development and Reforms Program (R-APDRP), (3) 100 Smart Cities, and (4) aggressive renewable generation. The recent initiative, NSGM, highlights the challenges with increasing distributed and variable generation and an electric vehicle (EV) rollout, and the need for dynamic management of load and generation. In addition to automation, the NSGM recommends communication and information technology (IT) systems to monitor the power flows, real-time demand management to match generation, and allowing customers who produce and consume electricity (prosumers) to safely connect to the electric grid. The NSGM builds upon the R-APDRP implementation, which uses advanced technologies within the distribution systems and in cities. India has ambitious plans to generate 100 GW of solar power by 2020. This is significant considering that nearly 30% of this capacity will be achieved through customer-side rooftop solar panels. Studies suggest that wind and solar integration require enabling technologies, frequency regulation markets, and utility cooperation for reliable grid operations, especially during peak demand [15].

II. Advanced Technologies for Grid Transactions

This section describes advanced technologies that are deployed in the U.S. to enable customers to transact with the electricity grid. In particular, it describes three key technology areas that enable customers, distributed energy resources (DER), and electric vehicles (EV) to participate in the electricity markets and support India's electricity reliability goals. Smart Grid standards, essential for communications interoperability and cyber-security, are also reviewed.

The technologies used by the customers to transact with the electric grid must be based on the paradigm of interoperability standards. Such standards when integrated with information and communication technologies can accelerate and leapfrog deployments, reduce integration costs, and improve adaptation to new programs and market structures. These technologies can also be used to facilitate the integration of the DER into the grid and allow two-way communications and cyber-security. The following technology applications are characterized for the Indian context:

a. Customer transactions with the electric grid and markets
b. Customer-side distributed energy resources integration
c. Electric vehicle integration in a distribution system
d. Smart Grid Interoperability Standards

A. *Customer Transactions with the Electric Grid and Markets*

Research and data from commercial deployment suggests that customers with automation technologies provide higher average load reduction compared to those customers who did not have automation [16]. AutoDR customers have a higher participation rate, and their enrollment "improves operational efficiency and reduces operational costs," which are primarily driven by avoiding the non-performance penalties and higher energy costs for peak power [17].

The U.S. electricity markets for transmission and distribution (T&D) systems are diverse. The independent system operators (ISO) and regional transmission operators (RTO) oversee the bulk electric power systems and wholesale electricity markets. In most cases, the member utilities manage the distribution systems and DR programs at the customer-level or retail markets. Grid-integrated technologies must allow both loads and customer-side distributed generation to participate in either of the electricity markets to maximize their effectiveness.

Figure 1 shows two-way AutoDR technologies to automate prosumer control systems with both ISO and utility markets. A "client" with a controller in a building energy management and control system (EMCS) interacts with either the utility or ISO market signals for DR transactions. A DR automation "server" in the grid enables the utility or ISO to dispatch grid reliability (including emergency) and price signals to the client, which initiates pre-programmed DR strategies that are chosen by the customers. Examples of two-way signals include prices, operation modes, and telemetry for load data, among others.

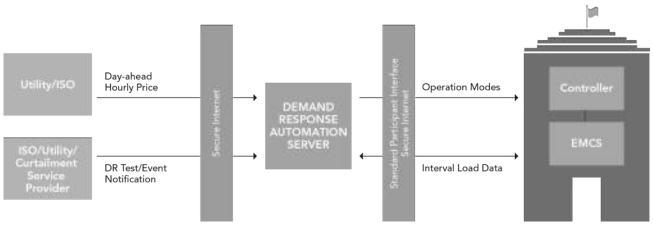

Fig. 1. Customer-side Transactions with Utilities and System Operators (*Source: Lawrence Berkeley National Laboratory, DRRC Annual Report*)

Table I shows that California utilities, which have the highest number of AutoDR customers in the U.S., offer different incentive levels to their customers [18]. The three major utilities—Pacific Gas & Electric Company (PG&E), Southern California Edison (SCE), and San Diego Gas & Electric (SDG&E)—provide incentives ranging from $200 to $400 per kilowatt (kW) of estimated load reductions. PG&E offers greater incentives for advanced AutoDR technologies (e.g., dimmable lighting controls) to encourage their adoption.

TABLE I. UTILITIES' 2012–14 INCENTIVES FOR DEMAND RESPONSE ($/KW)

Technology Category	PG&E	SCE	SDG&E
Automated Demand Response	$200	$300	$300
Emerging & Advanced Technology HVAC/R	$350	NA	NA
Emerging & Advanced Technology Lighting	$400	NA	NA

B. Customer-Side Distributed Energy Resources Integration

Historically, DR technologies were used to reduce peak power, and in the case of ISOs, to balance the centralized generation and demand changes using ancillary services [5]. With the increase in distributed and customer-side DER, technologies that dynamically manage customer's electricity reliability, distribution grid safety, and two-way power flows are gaining momentum. To optimize customer resource capabilities and operation schedules, simulation and modeling tools, shown in Figure 2, are used for optimization using external and internal data parameters such as electricity costs and prices, weather, and load forecast using distributed energy resources customer adoption model [19]. Integration of market-based signals empowers the customer decisions for local reliability (e.g., microgrids) and provisioning grid transactions.

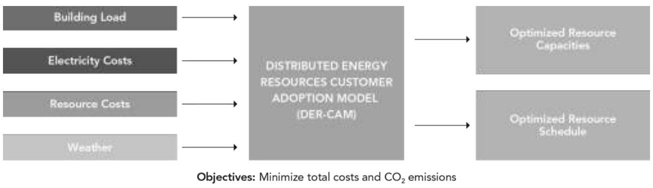

Fig. 2. Dynamic Optimization of Customer's Distributed Energy Resources (*Source: Lawrence Berkeley National Laboratory, DRRC Annual Report*)

C. Electric Vehicle Integration in a Distribution System

The U.S. has aggressive goals to deploy 1 million electric vehicles (EV) by 2015 to lower emissions from the transportation sector [20]. While large-scale deployment and charging of EVs can put more strain on the grid, they offer unique opportunities to improve grid reliability. Using the technologies and tools mentioned above, Figure 3 shows forecasting and schedule optimization for real-time control, EV fleet charge management, and vehicle-to-grid resources [21]. The technologies have allowed the ISOs and distribution utilities to use EVs as a grid resource while maintaining the EV customer's benefits and mobility needs in mind.

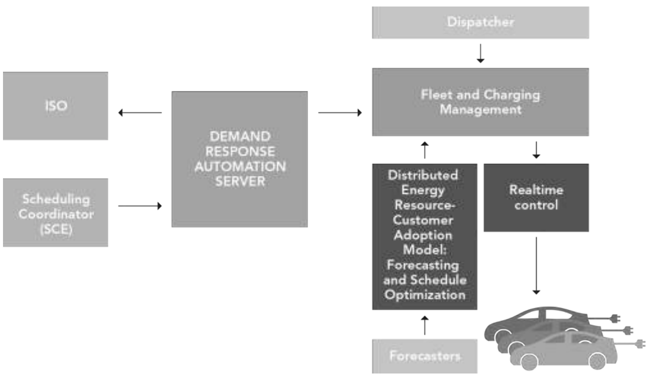

Fig. 3. Electric Vehicle Integaration for Smart Charging and Grid Services (*Source: Lawrence Berkeley National Laboratory, DRRC Annual Report*)

D. U.S. Smart Grid Interoperability Standards

Demand response provides multivariate benefits or values for utilities or ISOs and different vendors to develop and sell products for customer sectors and the grid. Technologies based interoperability standards allow different vendors to easily participate in grid transactions [22]. A Smart Grid can be viewed from different domains that are operated by disparate entities, and can provide benefits such as efficiency in electricity delivery, consumption and de-carbonizing the grid using renewable generation. While this study focuses on interfaces between the distribution and customer-side systems, there is an underlying and critical need to develop standards for a secure and interoperable Smart Grid, and to improve cyber-security of the critical infrastructure [23]. The U.S. efforts also provide cyber-security guidelines [24] and have led to acceptance and use of DR technologies to harmonize Smart Grid standards and a global architectural framework.

Summary: Technologies can improve electricity reliability and energy security by managing the demand to reduce peak power without additional capacity, and better integration of variable generation. The priorities of both U.S. and India are well aligned in the areas of distributed and renewable generation, demand-side transactions, and development of technologies and power systems for the next-generation electric grid. These priorities represent key market opportunities for grid-integration technologies and energy efficiency in India.

III. TECHNOLOGY CHARACTERIZATION IN INDIAN MARKETS

This section characterizes technologies to increase reliability and readiness of customers for an AutoDR project by a distribution utility in India, TATA Power Delhi Distribution Limited (TPDDL). This first-of-its-kind project includes smart meters and a DR system for automated dispatch and load reduction during power deficit periods. Major U.S. vendors in this market provided the advanced technologies and services to modernize the distribution system and improve electricity reliability. These technologies are similar to those deployed in the U.S. for customer transactions with the electric grid and markets, and for interoperability standards.

A. Advanced Technologies for Distribution System Reliabilty

TPDDL technology solutions include an AutoDR system and DR controller, provided by a U.S. vendor. The automated metering infrastructure and Smart Meters provide 15-minute interval energy use data. Figure 4 shows the interconnection between TPDDL and the customer. While the meter data management systems use energy data for billing and to provide customers access to energy data, the AutoDR system uses the data for measurement and verification (M&V) or DR settlement. The AutoDR system uses interoperable communication standards to send the operation modes to the DR controller. Customers use the online portal to commission the DR controller, view DR event status, and configure operation modes. DR controller "polls" for these operations modes from TPDDL and the direct digital control (DDC) outputs, as opposed the analog controls, activate the customer's pre-programmed DR strategies.

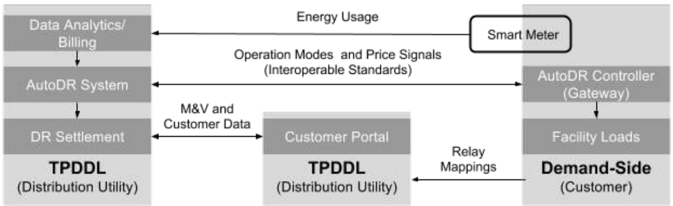

Fig. 4. Automated Demand Response System Architecture by TPDDL

B. Technical Specifications

The U.S. vendors worked with TPDDL for technology transfer and for the applications of AutoDR technologies in the Indian markets. The deployments identified new requirements to lower technology costs and to harmonize Smart Grid interoperability standards. For example, using the development lessons, the AutoDR controller solution costs 45% less than the traditional controller used in the U.S. Providing a minimum necessary number of DDC inputs/outputs, memory, processor units, control system protocol interfaces, pulse inputs, and Ethernet and cellular communications reduced the cost. Use of open and industry-supported standards reduced the deployment and installation costs. Since most of the facility controls did not have connectivity (e.g., Internet) to the external network, GSM cellular modems provided DR communications.

All 173 customers who participated used simple DR strategies to turn the equipment ON/OFF, which involves the curtailment of non-critical loads with customer's consent. TPDDL programs defined the signals, which included operation modes such as NORMAL, MODERATE, HIGH, etc. These modes are used to indicate load- or price-change levels. The AutoDR system also provides other DR programs such as electricity/energy prices, and load changes (e.g., kilowatts/kilowatt-hours, percent). The participating loads from the customers included 3-phase pumps, motors, compressors, cooling systems, etc. where the AutoDR controller monitored the status (ON/OFF) and changed the status of loads in ON state upon the receipt of DR signals.

Summary: The TPDDL project characterizes technology for field tests. While technology costs were lower, vendors are considering improvements to further reduce the costs. The lack of network connectivity required the use of cellular data networks, which increased the operation costs. Solutions such as mesh networks; low-data transfer, etc. can be considered in future. The lack of intelligent controls in facilities led to the use of simple DR strategies. The use of advanced strategies and dynamic optimization may be necessary to temporarily reduce the service levels as opposed to complete lack of service (e.g., dimming lights) without impacting the building operations.

IV. Technology Effectiveness In Indian Markets

This section describes the customer sectors and their performance results. The reliability of DR performance can be a proxy to assess the effectiveness of automation technologies. Considering there were no preset load-reduction estimates, *reliability* refers to the automated execution of DR strategies.

A. Analysis of Customer Performance Results

The customers included offices, educational institutions, retail stores, industrial facilities, water and sewage pumping, flour mills, and cold storage. Of the 173 customers, meter data were provided for 144 customers, which was used in our analyses. The resulting total coincident peak was 25 MW.

The baseline models are key for measurement and verification (M&V) of DR performance. The baselines provide an estimate of what the facility load would have been on the day of the DR event without any DR actions. While TPDDL used the 5/10 (pronounced *5-in-10*) baseline for M&V, our study also used the 5/10 with a Morning Adjustment (MA) factor. Earlier studies have reviewed different baseline models used in the U.S. and concluded that the MA factor significantly reduces the bias and improves the accuracy [25]. Table II shows the taxonomy for each of the nine customer sectors, total peak demand, and total demand reduction percentage when measured against the whole-building power (WBP) and 5/10 baseline. Our analyses show a total coincident peak demand of 25 MW with average reduction of 10%, or 2.3 MW. According to the TPPDL, the total connected customer load is 67 MW, the maximum DR from all the customers was 7 MW, and the total DR achieved from 17 events was 0.063 million units (or million kWh). Customers defined the control strategies and end use types for AutoDR. These control strategies were based on day-ahead notifications.

TABLE II. CUSTOMER SECTOR PEAK DEMAND REDUCTION (KW AND %)

Sectors	Peak Demand kW (# cust.)	% WBP (75_{th} percentile)
Cold Storage	1,131 (6)	34
Commercial	4,646 (11)	8
Education	1,936 (3)	3
Flour Mill	7,265 (25)	19
Hospital	1,434 (2)	18
Industrial	10,044 (77)	10
Others	1,889 (14)	26
Pumping	556 (3)	62
Retail	62 (3)	50
Total	**25,259 (144)**	**10**

To evaluate the grid impacts of these results, we have to understand the electricity supply and demand conditions in the DR region. Figure 5 shows the allocation and actual energy drawl imbalance in TPDDL territory. The imbalance is calculated from the scheduled drawl (allocation) versus actual demand data, which can be a proxy for drawl (*Imbalance = Allocation – Drawl*). Of the 4,000+ imbalance hours from April to September 2013 shown in Figure 5, 25% of the hours represent over-drawl conditions for TPDDL. The over-drawl can be potentially reduced from 324 megawatt-hours (MWh) to 147 MWh if TPDDL had dispatchable demand for the top 40 hours of the highest over-drawl power (~1% of the total).

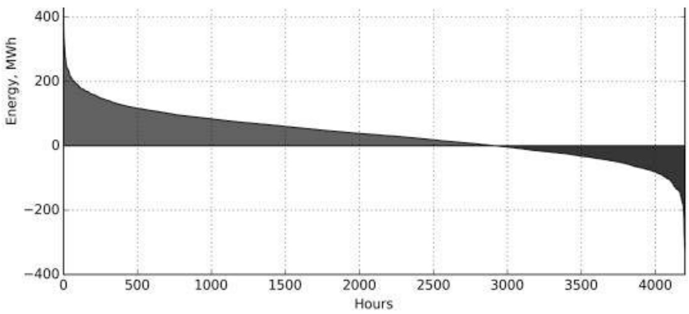

Fig. 5. Over- and Under-Drawl Imbalance Conditions for TPDDL (Apr. to Sep. 2013); Top: Under-drawal, Bottom: Over-drawal

Figure 6 shows an aggregated DR performance, and for each of the sectors for all 17 events using a 5/10 baseline. The industrial and flour mill sectors were the majority customers with a 75th percentile DR of 10% and 19% respectively. The aggregated DR from all customers is 10%, and the cumulative coincident peak demand is 25 MW. The 75th percentile is considered because it represents a conservative estimate, reflecting the lack of financial incentives offered to customers that encourage persistent DR performance. The financial incentives have the potential to improve the performance.

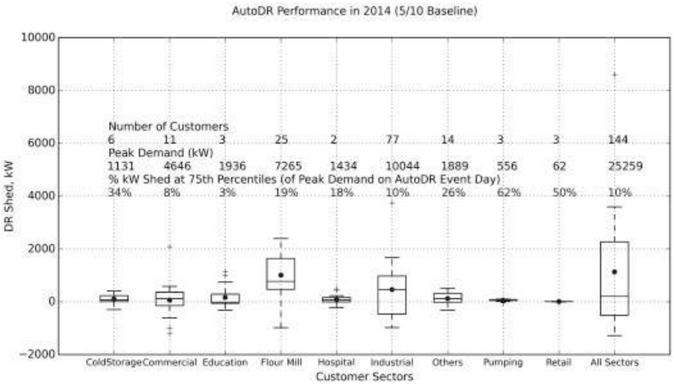

Fig. 6. Individual and Aggregated Customer Sectors' AutoDR Performance

Note that these results indicate the reliability of technology performance and automated execution of DR strategies. The minority of customer sectors, other than flour mills and industrial that did not perform well, need further investigation for performance of load effectiveness. However, this must not be interpreted as lack of technology effectiveness. The detailed customer analysis, baseline models, and load effectiveness are described in our complementary study [7].

B. *Technology Costs and Market Potential in India*

One of the key metrics to evaluate AutoDR cost-effectiveness is to look at the customer technology enablement costs and how much DR they can provide. For example, if it cost $10,000 to enable a DR of 100 kW, then the customer technology enablement cost is $100/kW. These costs typically include hardware and software, controls programming for DR strategies, and integration of AutoDR signals with these pre-programmed strategies for end-to-end automation. Similar to energy savings, these DR savings accumulate every year, which leads to larger technology adoption benefits over time. From the U.S. experiences, the average AutoDR technology enablement costs in existing buildings are about $215/kW [13]. While this cost is high, it still costs 10% to 15% of current grid-scale battery storage costs [6]. Deployment and operational costs of AutoDR and grid-scale batteries continue to decrease as a result of technology improvements and scaling. According to TPDDL, the DR technology enablement costs per customer are expected to be less than INR 80,000 (~$1,300). Based on thus preliminary data, the estimated technology enablement costs for 2.3 MW of DR from 144 customers is $80/kW. This cost is about 63% lower than similar technology deployments in the U.S. This study did not review all the reasons for these lower costs due to insufficient information.

For TPDDL and similar Indian utilities, peak load reduction can result in savings, either through reduction in unscheduled interchange over-drawl penalties, reducing the need for short-term power purchase through the day-ahead market, or by avoiding generation from expensive marginal generation units. For customers, potential benefits come from avoiding higher prices during peak hours and through improved grid reliability. Cost savings can vary, based on whether the reduction in peak demand is a shed or a shift to non-peak hours. Customers can also receive financial incentives, a compensation for costs incurred to enable DR automation, and their "opportunity costs" from DR. The incentives that the utility will need to provide will depend on the costs and savings of both consumers and the utility. These incentives, in turn, will dictate the participation and response rates of the customers. The detailed valuation of DR through the TPDDL pilot study and the market potential for DR in the state of Delhi are described in our complementary study [8]. Previous studies describe the technology market potential in the context for efficient, responsive, and resilient buildings [10].

Summary: AutoDR has the potential to lower utility's over- and under-drawl imbalance band significantly by providing slow and fast dispatchable demand. The customers were not paid any incentives or performance-based credits to participate in the demonstration. The TPDDL-paid AutoDR technologies and Smart Meter were key motivations for customer recruitment and participation in the field tests. Customers also benefited from online access to energy use data, which can be used for energy efficiency improvements. Customers responded to the day-ahead signals, which can be scaled to shorter notification times as needed. The technologies used by TPDDL provide additional benefits. Customers can be better aware of their load profiles and facility operations, which can drive to energy efficiency goals. According to TPDDL, the key technologies benefits include: customers' empowerment, better feeder management and customer loading, optimization of grid investments, and peak power purchase savings. TPDDL anticipates expanding AutoDR project to 800 more customers resulting in a three-fold increase in DR potential of 20 MW.

V. DISCUSSIONS, CONCLUSIONS, AND FUTURE WORK

In this paper we reviewed and characterized the grid integration technologies necessary to enable customer-side loads and DER to participate in utility's electricity markets. The study has engaged public and private sector stakeholders from the two countries, as well as regulators, utilities, and customers in India. The preliminary findings and results reported here suggest that DR is a promising area for continued support from the U.S. and India, and public and private sectors. India's Smart Grid initiatives are at a nascent stage. The U.S. knowledge and technology transfer in this area through bilateral collaboration can leapfrog India's quest for technology and accelerate their adoption. Initiatives such as NSGM and R-APDRP provide an excellent platform for technology development and adoption in the Indian markets. We reviewed an advanced demonstration project by India's TPDDL to verify the effectiveness of AutoDR technologies. The TPDDL project provides insights on customers, demand, and DR benefits. The lessons will help TPDDL, other utilities, and regulatory agencies develop market mechanisms to improve the distribution system. The project is a testament to India's accelerated technology adoption, which drives improved reliability of the U.S. electric grid.

A. Discussions

The TPDDL project provides early insights for demand flexibility. The small dataset show the need for more empirical studies to identify benefits at various levels (e.g., customers, utility, system) and evaluate the role of technologies and regulations for electricity reliability and security imperatives.

AutoDR and Demand-Side Flexibility Benefits: Customer's load flexibility and AutoDR can improve electricity reliability and mange peak loads within the distribution system. Utilities can use AutoDR as a resource to adjust corresponding over- or under-drawl conditions to reduce price risks, unscheduled interchange penalty, and to improve reliability. To scale technologies within larger areas, India must consider the value stream at different Smart Grid domains, and also the impacts of AutoDR notifications of shorter duration (hour, minutes).

Electricity Reliability and Energy Security Imperative: India's grid reliability and energy security objectives are drivers to review the TPDDL project for scalable applications of technologies. These objectives and ever-increasing demand charge the public bodies, government, commissions, and utilities to develop grid codes and dynamic-pricing electricity markets to encourage AutoDR programs and technologies.

B. Conclusions

From the characterization and performance analyses, the technologies were effective in average load reduction of 10%, or 2.3 MW. Two major customer sectors, flour mills and industrial, had a load reduction of 10% and 19%, respectively. Albeit a minority, other customer sectors, cold storage, commercial, education, pumping, and retail show promising results. These results are indicative of technology potential for large impacts where T&D losses amount to 25% and average peak power deficit is 9%. Technologies can lower utility's over- and under-drawl imbalance band by providing slow and fast dispatchable demand. The technologies used by TPDDL can also be used in large commercial and industrial facilities for resilient and responsive cities. The following factors can affect the success of DR automation technologies in India.

- Electricity market design to establish technology value.
- Financial incentives for persistency in DR performance.

Flexible and responsive demand will help India mitigate investment costs for expensive generation, improve system efficiency, and help integrate renewable energy into the grid. By the same token, the U.S. will gain critical technical and market knowledge by adapting their technology to the Indian environment. The implementation of DR systems and technologies is highly dependent on the local context; market conditions, policy and consumer behavior, and the international collaborative nature of this project will help accelerate knowledge transfer with tangible results.

Through the NSGM, R-APDRP, Smart Cities, and relevant initiatives, India should conduct technology research and development while deploying mature and tested technologies to support both energy efficiency and grid integration. National policies, model projects, and education and training must encourage customer participation, harmonize standards, and facilitate system- and component-level interoperability for grid connectivity. We believe that cost reductions from hardware and software development and plug-and-play features will advance Smart Grid objectives in India, which also benefits the U.S. by lowering the deployment costs. Initial results show that AutoDR can improve customer responsiveness and utility arbitrage for electricity shortfalls and the high cost of peak power. Without a formal DR program and financial motivation, the performance may not be persistent. A well-designed program accelerates technology use and customer participation and potential new value streams. Innovative technology solutions can enhance the grid reliability by minimizing the instances of outages, and improve energy security by enabling integration of renewable generation to scale.

C. Future Work

Future technology development in India must focus on two key aspects: cost reduction and performance scaling. The technology enablement costs considered simple DR strategies such as switching equipment ON/OFF. Advanced strategies involve controls programming and integration of DR signals, which costs more. The key questions to focus are: **What are the technical considerations to reduce the technology costs by additional 50%? How to develop scalable demand-responsive controls systems for persistent AutoDR load reduction of 10% or greater? What market-based incentive type and levels are appropriate for DR to be reliable?**

ACKNOWLEDGMENT

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BIOGRAPHY

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Intelligent Connectivity as a Fabric of Smart Cities

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***Abstract*— According to the McKinsey Global Institute, India's urban population is expected to soar from 340 million in 2008 to 590 million in 2030, with cities expected to house 40% of India's population. The migration will put pressure on cities critical infrastructure including energy, water, transportation, public health and safety. India's smart cities must be equipped with information, technologies, tools and capabilities to anticipate, manage, respond and quickly scale up to the growing needs of its citizens.**

Intelligent connectivity is an essential component of the city's infrastructure and smart grid for unifying data, analytics and decision-making across vertical domains. Connectivity involves upfront planning and must be rapidly deployable and scalable on new, retrofit and legacy assets. At the edge, machine to machine (M2M) embedded sensors must provide high computer power, performance at low battery usage. Coverage must be ubiquitous, with a need for hybrid implementation of cellular 3G, LTE, Small Cells and Wi-Fi radio technologies, yet secure and reliable. The deployment must be interoperable across vendor products and minimize both Capex and ongoing TCO for the city.

In this paper, we discuss how Qualcomm Technologies, Inc. (QTI) and its subsidiaries are addressing these requirements by: a) driving the evolution of intelligent connectivity standards globally (e.g. 3GPP LTE and Wi-Fi), b) designing robust M2M products for specific verticals, and c) building relationships for interoperable ecosystem enablement. We also share lessons from water, smart grid and city connectivity trials currently underway.

***Keywords*— Cellular, connectivity, industry solutions, intelligent connectivity, moible, smart cities, wireless**

I. INTRODUCTION

By 2050, two thirds of the world's population will reside in cities, up from more than 50 percent today. This urbanization is a worldwide trend: The United Nations forecasts that by 2050, urban dwellers will account for 85 percent of the population in developed countries and 63 percent of the population in emerging regions. In India alone, 32% of the population is currently urban and expected to hit 50% in the same period [1]. This dramatic demographic shift puts stress on every aspect of a city's infrastructure, be it water, energy, roadways, waste management, hospitals, etc. Cities and urban areas necessitated by economic growth, high quality of life and sustainability, must be adequately equipped with information, technologies, tools, and capabilities to anticipate, manage, respond, and quickly scale up to the growing needs of their citizens. A significant component of this daunting task is accomplished through digitization, particularly as more people and places, machines, sensors and things are increasingly connected.

The Internet of Everything (IoE) provides an open, and scalable framework to envision the underlying connectivity architecture for the digitization of smart cities. At its core, the IoE is connectedness, communications, and intelligence, through increasingly and interconnected ecosystems that benefit people's lives. It requires different types of wireless and wireline connectivity to support a wide range of use cases with varying performance, cost, & energy requirements. The IoE benefits from standards (e.g., Wi-Fi, 4G LTE) that provide seamless usability, interoperability across multiple vendors and the scale of a global ecosystem. Without seamless integration or interoperability of such diverse and heterogeneous ecosystems, the needs of smart cities (ubiquitous coverage, high reliability, robust security, analytics and performance) cannot be realized.

Section II of this paper reviews the technologies that enable connectivity and lays out the need and requirements for intelligence at the edge of the smart cities IoE architecture. Section III discusses use cases in specific verticals such as energy, water, infrastructure and buildings with specific implementation examples in Section IV. We finally conclude with some key takeaways for the India context.

II. INTELLIGENT CONNECTIVITY

Connectivity, as the fabric of smart cities, covers a broad spectrum of enabling technologies that can deliver amazing user experiences, reliability and value. From wireline and fiber, to mobile, cellular and wireless, these technologies can be configured as high performing, low latency personal area, micro or macro wide area broadband networks, delivering short, medium and long range real-time communication and 1000x data traffic. See Figure 1. Mobile, in particular, has grown by leaps and bounds, and matured rather quickly as a global standard that can now deliver with, for example, multimode 3G and 4G LTE [2], higher throughputs faster, with heterogeneous spectrum configurations and a more simplified core network. Smart cities can begin with existing infrastructure but future proof the architectures to exploit the latest innovations of LTE-Advanced features including

- LTE MTC (Machine Type Communication) which optimizes LTE for IoE applications offering to significantly increase battery-life, reduce cost/complexity and enhance coverage [3],

- Heterogeneous Networks (HetNets) made up of macro, small cells (pico, femto) and relay base stations to address the 1000x densification needs in urban areas through advanced interference management techniques [4].
- LTE Direct which is a proximity based device-to-device platform that can enable range of enhanced applications across devices, apps and operators such as for public safety and disaster management [5].
- LTE Broadcast can most efficiently handle the same/identical content being consumed by a large number of users at the same time – Virtually unlimited users can access the same content. This is especially useful for cities during disaster management and major public events [6].
- LTE Unlicensed extends the benefits of LTE Advanced to unlicensed spectrum. Smart city users will benefit from common unified LTE network for all spectrum types [7].

	Wireline / Fiber	3G/4G/LTE	LTE-U	LTE-D	Wi-Fi (802.11 n)	Bluetooth	RF Mesh
Typical Coverage	Not appliable	~122m radius	~100m radius	~500m radius	~55m radius	~10m radius	~100m radius
Spectrum	Not applicable	Licenced	Unlicensed 5GHz	Licensed	Unlicensed 5GHz	Unlicensed 2.4GHz	900 MHz
Typical Capacity	Trans capacity of 1Tbps/sec	~200 / cell	~200 / cell	~200 / cell	~8-10/ node	~5-10 / AP	~30 / Gateway
Characteristics	Vast higher bandwidth. High Installation costs, Susceptible to physical damages	Reliable Network sustainability Seamless interworking. Infrastructure and Spectrum Costs	Unified 4G core Fewer Nodes Co-existence with Wi-fi. Longer path to wider adoption	High device density, Continous awareness Privacy sensitive. Decentralized control	Good market penetration and wide availability Inexpensive Infrastructure. Requires a gateway w/ backhaul.	Open standard, Suitable for short range, small data. Slow data rate and limited range	Stable Topology, High bandwidth. Network optimization is proprietary

Fig. 1. High level comparison of connectivity technologies

Work is already underway in the industry to explore and innovate on how the next generation 5G mobile technologies can further benefit mission critical applications for IoE and smart cities [8]. As these technologies evolve, city planners must consider future proofing current designs for forward compatibility.

Another ripe area to provide wireless connectivity in smart cities is Wi-Fi, both as an access layer to collect sensing data, and as aggregation/backhaul layer technology. Urban environments are proliferated with plug and play type 802.11 a/b/g/n access points. While these provide basic connectivity solutions, the Wi-Fi standards are evolving to address smart cities use cases as many cities are starting to rethink the business model and use the existing infrastructure to connect not only people, but also objects and sensors. For example, 802.11ac supports higher capacity and higher data rates for mobile and computing devices [9].

The mesh topology of Wi-Fi, which could include up to 10 routers per square mile in dense urban areas, provides an adaptive, secure, and low-latency network that could be useful in low cost smart city deployments. Many utilities, however, remain concerned about interference and poor propagation for solutions based on legacy Wi-Fi standards, and a more robust, wide area, sub-1 GHz standard (802.11ah) is still a few years away [10]. RF mesh networks are traditionally deployed to take advantage of unlicensed bands, stable topology and ability to customize for specific deployments. RF mesh networks are evolving to support long range, low-power, sub-Ghz connectivity to the devices, sometimes using ultra-narrow band (UNB) technology.

With advances in beamforming, 802.11ad [11] utilizes bandwidth rich 60 GHz spectrum for multi-gigabit short range connectivity, and is ideally suited for high performance applications like wireless display/audio and instantaneous docking/synching. Features in the 802.11ah standard will enable multi-year year battery life that is ideal for home/ building automation. While Wi-Fi is becoming ubiquitous in smart cities, seamless interworking with cellular based 3G/ 4G/ LTE systems is needed for best access to heterogeneous networks in mission critical scenarios. Seamless 3G/ 4G/ Wi-Fi roaming will enable automatic discovery and access for mobility applications: For example SIM/USIM based authentication could enable a single set of credentials for access to all hotspots.

Bluetooth also plays a key role in providing connectivity solutions for smart cities as a wire-replacement communications protocol primarily designed for low-power consumption, with a short range based on low-cost transceiver microchips. Bluetooth protocols simplify the discovery and setup of services between devices and the technology is useful when transferring information between two or more devices that are near each other in low-bandwidth situations. For smart city applications, Bluetooth v4 (aka Bluetooth Smart) is the intelligent, power-friendly version of Bluetooth wireless technology.

Another short range personal area networking technology (PAN) is 802.15.4 [12]. The focus of which is low cost, low-speed ubiquitous communication between devices. These systems exploit the low duty cycles of the protocol, for gains in low power consumption.

Integrating these heterogeneous connectivity technologies (4G, Wi-Fi, Bluetooth, etc.) in a seamless, distributed and secure manner without impacts to latency and throughput will be absolutely essential to the performance, quality of service and functioning of the smart city fabric. For example, LTE and Wi-Fi are now converging in access point products that deliver high capacity, high density, and coverage and enable multi-carrier 3G/4G services support. Multi-carrier, multi-mode technologies will be essential components for a smart city deployment, as a city must provide reliable coverage across its entire geographical footprint.

Intelligence at the Edge

Another critical requirement will be to effectively address the sheer volume, velocity and veracity of the data from millions of devices, sensors, machines and citizens sent over the network connections to the cloud for real time decision making. Transferring entire amounts of data streams to one or few data centers or back end IT systems will not be adequate. Proactively anticipating and scaling up the cloud operations may work in the short term but won't be sustainable, particularly as the vertical systems must be interconnected for holistic decision making within a smart city. A more viable long term approach therefore would be to expand the capabilities at the edge of the network, pushing back some of the basic analytics, processing, data interpretation and event driven decision making closer to the source. An "intelligent" edge system (edge = end-devices + access nodes) can be delegated to make localized decisions for its nodes and sensors based on the information it receives from these elements, as well as programmable "rules" from the cloud. See Figure 2 for an example architecture. In this architecture, the cloud will continue playing a major role (synchronizing data access/functions across devices), but enhancements at the edge will also be key to the growth and performance of the Internet.

A geographically, virtually or logically distributed edge computing architecture provides the necessary scale and latency for handling millions of nodes, while offloading the data traffic over the network in a secure manner. A classic example of intelligent connectivity is aggregating different air links and / or spectrum (licensed, unlicensed, shared access) at the edge to increase capacity and availability (e.g. LTE + Wi-Fi convergence). Another example is using behavioral patterns and machine learning models in an edge node to detect anomalies in readings, performance or behaviors, taking some safety measures when thresholds are exceeded or anomalies detected, and communicating only these anomalies and status to the cloud for more broader system wide decision making.

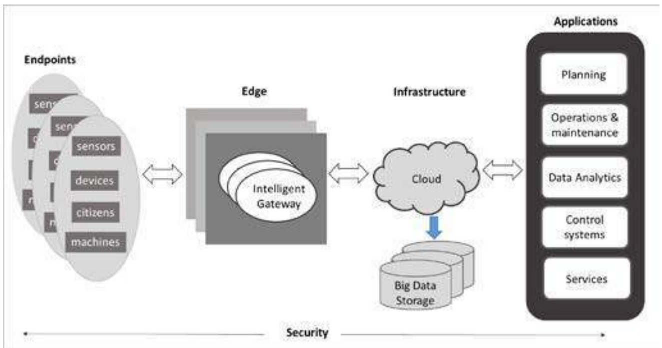

Fig. 2. End to End architecture for a smart city. A multiplicity of end points and edge systems across various verticals such as energy and grid, water, traffic and transportation, will connect to the cloud.

Transformation of the edge brings benefits to the entire ecosystem:

- OEMs: Expands the reach of the Internet, growing addressable market; provides new opportunities to offer differentiated products and features
- Operators: Increases network capacity to support the continued growth of connected devices and data consumption; enables new, differentiated service offerings
- Developers and value added service providers: New and expanded capabilities foster the creation and discovery of innovative applications, systems and service offerings
- Regulators and government: Supports socio-economic development, greater accessibility and affordability of devices and services help bridge digital divide

There is a great need for all the fragmented heterogeneous systems to move away from silo-ed monitoring, operations and control and instead, work seamlessly to share intelligence for holistic monitoring and decision making at a city level. Horizontal interoperability with open standards are critical to such collaboration and foster cooperation among all the services within a city. Establishing an open data platform enables powerful opportunities for cities to connect with citizens in meaningful ways. By making data platforms open, public information is easy to access, allowing city employees, utilities, citizens and third-party developers to create new applications and services for the benefit of the city and its residents. There are also clear advantages to leveraging trusted, standards-based technologies and resilient open-data architectures to address current and future security and privacy requirements for these data platforms. Joint efforts in both the private and public sector will ensure that attack vectors are minimized and sound data privacy policies that incorporate current and anticipated legal requires as well as expectations of the public are broadly adopted and enforced. Work is currently underway in a number of standards bodies to define end-to-end security strategies that address the unique challenges of smart cities and the industrial Internet of Everything to:

- protect edge node and hub devices throughout their lifecycle as well as data in motion as it is collected and routed through the network;
- offer strong authentication and authorization schemes that offer interoperability and resiliency;
- implement system and application level self-diagnosis and self-healing capabilities in response to attack;
- implement hardened network architectures that minimize possible attack vectors through proper configuration and design; and
- optimize the performance of security software running OS, firewall, and deep packet inspection services at all levels of a vertical IoE solution stack.

III. USE CASES FOR SMART CITIES

A smart city may implement a wide range of IoE based digitization solutions of assets and decision making in one or more of the following areas (see Figure 3):

- Infrastructure
- Energy
- Parking and Transportation
- Buildings
- Government

- Health care
- Education

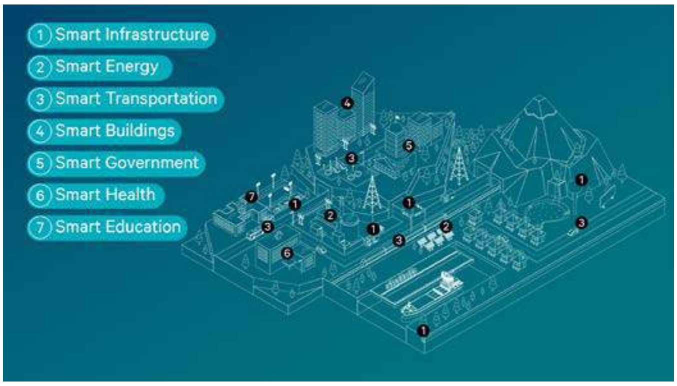

Fig. 3. Typical Smart City verticals

We highlight some of the key use cases in this paper.

A. *Smart Energy*

Smart grids and load management utilize advanced grid devices and sensors that make it easy to monitor and manage energy consumption in real time.

Solar Energy Meter

Solar installations continue to boom and become more affordable than ever. There are more than half a million solar energy installations in the US today, with Y-Y growth of 21% (in MW performance). Cumulative solar installations in India have crossed the 3000-megawatt (MW) mark with 734 MW installed so far in 2014 [13]. Meters (especially solar installations) are often remote or may have suboptimal connectivity capabilities, making remote monitoring and access to critical information such as power generation and usage difficult. In such cases interconnect solutions with cellular metering and data transfer on smart meters can provide reliable connectivity to the backhaul. Remote management and monitoring of energy usage and consumption data can then be reliably collected in real or near real time. The solution is scalable, more cost effective and aids asset managers to grow inventory.

B. *Smart Parking and Transportation*

Through smart mobility, traffic and charging we're using short-range communications to relay information about traffic congestion and road hazards, while also reducing overall CO_2 emissions through better traffic management, more accessible parking and electric vehicle charging.

Smart Parking:

In urban environment, with a rapid increase in motor vehicles on the roads, parking availability has not met this demand. Motorists waste up to 40% of idle time searching for spaces [14]. In addition, city councils are potentially missing valuable revenue through the inability to automatically reset recently vacated meters. Using suitable interconnect and cellular 3G modems, a connected network of smart parking meters and vehicle detection devices can provide real time parking space inventory information to consumers, city councils and business owners. This can lead to an optimization of city parking revenue while also enhancing the citizens' end user experience using smart phones. Added environmental benefits include less CO_2 emissions with motorists spending less time searching for parking in their vehicles.

Telematics:

Advanced telematics platforms play an important role in maintaining vehicle fleets, optimizing transit routes and managing traffic flow in modern cities. Not only does the underlying cellular technology and associated cloud-based platforms help to ease traffic congestion and facilitate more efficient transport of goods and services; these systems also help first responders safely navigate to the scene and coordinate with one another in emergency scenarios.

C. *Smart Infrastructure*

With smart water, recycling and lighting, we are able not only to increase public safety through smart (connected) LED lighting retrofits that inform cities of outages, but we are also able to drive up efficiencies by reducing hazards, complications, and costs associated with water and recycling management.

Smart Water management:

Excess rain results in billions of gallons of sewer overflow each year. Undetected leaks & bursts mean the cities may be losing fresh water at unprecedented rates. Embedded M2M enabled devices, capable of continuous level and pressure sensing and water management solutions integrated with intelligent connectivity capabilities can identify rising water levels, pressure changes and overflow conditions early and communicate real time data and/or alarms to the control center in the cloud [15]. This allows the utilities department or the city to quickly identify possible resolution and mitigation strategies, and act immediately. Furthermore, using advanced edge processing, connected intelligent water level detection sensors can generate greater efficiency in management of fresh water resources, reduce overflow rates, coupled with early and more accurate leak detection and can in return result in substantial cost savings to the government and improved pipeline infrastructure. Pinpointing the source of such leakage removes guess work for maintenance crews thus saving valuable time and increases efficiency.

Waste Disposal:

Trash management and sanitation is an issue with several city officials trying to keep the cities clean and green. Open litter containers can attract pests, and are unsanitary and unsightly. Without digitization of waste disposal assets, there is currently no way for city maintenance crews to schedule pickup and or check if the lots are full. An M2M enabled interconnect solution embedded in a solar powered trash compactor, can enable access to real time data from any computer or smartphone for a just-in-time trash collection. Such a solar powered compostable and recycling program can not only support enclosure designs that keep critters out and odors in, but can also provide visibility into status of trash levels, and historical data and real time analytics that is essential for capacity planning, optimizing trash routes, improving servicing and ultimately reducing the carbon footprint.

D. Smart Buildings

Smart buildings are a classic use case involving integration of ubiquitous connectivity across disparate devices, systems and services to give citizens, building management and businesses more comprehensive control and access of their buildings. Here too, there are opportunities for energy savings and increased operational efficiencies, hitherto unexploited.

Smart campus:

In traditional campuses, building subsystems generally do not communicate with each other, rather they operate independently. Thus far, buildings have rarely used occupancy data or information 'outside the four walls' to drive operations inside. However, in a smart cities context, connected (Wi-Fi/ BT/ small cells) subsystems can exchange information within building or interconnect disparate subsystems via cellular connectivity to a smart grid. Smart sensors enabled with a technology such as the AllJoyn™ framework, a collaborative open source project of the AllSeen Alliance, can enable disparate subsystems to communicate with each other [16]. Using AllJoyn, different subsystems can be developed independently and be assured of interoperability with each other software platform & tools can further support remote monitoring and control of subsystems. For example, occupancy loads can be determined using badge in/out, traffic and parking data can drive campus subsystem operations. Modern buildings and campuses can take advantage of communications from energy grids to raise and lower energy usage – in some cases even selling loads back if equipped with renewable energy source such as solar!

IV. LESSONS FROM TRIALS AND DEPLOYMENTS

Qualcomm Technologies, Inc. (QTI) is the world leader in next-generation mobile and digital communication technologies. For more than 29 years, QTI's ideas and inventions have driven the evolution of wireless communications, connecting people more closely to information, machines, entertainment and one another. Today, Qualcomm® technologies are powering the convergence of mobile communications and consumer electronics, making wireless devices and services more personal, affordable and accessible to people everywhere [17].

Now we are doing even more to bring efficiency, safety, and sustainability to the future of urban living at every level. Our technologies and products provide the foundational connectivity capabilities for multiple smart city applications in the energy, transportation, buildings, and vertical infrastructure. More specifically, QTI is working with ecosystem participants globally to:

- Serve as a technical advisor to help determine the optimal connectivity solutions
- Serve in a technology planning role, helping municipalities and townships maximize their physical assets while providing enhanced services to their citizens and communities
- Provide intelligent connectivity solutions via cellular, 3G, 4G, small cells, and related technology
- Provide machine-to-machine capability for city infrastructure
- Connect producers with service providers within cities

An expansive portfolio of wide-area and local-area connectivity technologies can provide end-to-end solutions with minimal upfront capital expenditures, nominal operational expenses, extensive multi-use and lower total cost of ownership for many users, cities, municipalities and governments. Leveraging these solutions also positions cities with an eye to the future, providing more sustainable solutions that do not require new network build-out. Here are some specific examples.

A. LinkNYC:

New York City has an aging network of public payphones and its fiber networks are not currently being utilized to provide public internet access. QTI, as technology advisors in multi partner consortium (CityBridge) is looking to change this with LinkNYC. LinkNYC is a first-of-its-kind communications network that will bring the fastest available municipal Wi-Fi to millions of New Yorkers and visitors. The five-borough LinkNYC network, which will be funded through advertising revenues, will be built at no cost to taxpayers and will generate more than $500 million in revenue for the City over the next 12 years. QTI connectivity and interconnect solutions will help to enable this transformation of public payphone network [18]. An analogous concept can be leveraged for digitizing thousands of Gram Panchayats with e-government services in India.

B. Smart Water management, The City of Cincinnati and Island of Saipan

A smart water network can pinpoint leaks and theft, gaining a quick payback in regions where water is scarce and costly. The U.S. EPA estimates that wastewater plants and drinking water systems account for up to one-third of the municipalities total energy bill. In 2014, QTI in collaboration with partners, developed, tested and deployed a smart assets solution that enables water utilities to improve water quality, reduce water loss and better manage water resources through real-time data transfer across their infrastructure. Several cities including the City of Cincinnati have already adopted this solution [19]. On the island of Saipan, where 70 percent of potable water is lost to leaks and theft, cellular-based smart water meters and pressure sensors across the water system enable officials to reduce annual water loss by 10 percent, provide more people with 24/7 water service and save water maintenance costs substantially [20].

C. *Transforming Public Waste Management, Philadelphia:*

In 2008 the city of Philadelphia began a program to replace open trash bins with BigBelly connected waste stations in an effort to curb litter, reduce CO2 emissions and save the city money. Their existing trash bins needed to be emptied as often as 4 times a day which required extra city staff and clogged city streets with trash trucks that were burning lots of fuel. The BigBelly solar units automatically compress trash when the unit gets full, holding up to five times as much as a regular trash can. Utilizing 3G modems from QTI, each bin is connected wirelessly and shares real-time information with the BigBelly CLEAN (Collection, Logistics, Efficiency, and Notifications) system to notify waste workers when the units are full. This alone has helped to reduce collection trips by over 50%. Since 2008 the city has installed over 1,000 units, saving them over $1 million annually and reduced greenhouse gases and other pollutants related to collecting waste by 80% [21].

V. CONCLUSIONS

Local and central government in most countries are currently looking to upgrade and tailor their complex infrastructure to meet the anticipated demands of urbanization over the next few decades. The nine pillars of the Digital India Initiative are avenues for enabling Smart Cities in India, both in the greenfield (100 new smart cities) or brownfield/ heritage cities to achieve the goals of increased sustainability and livability for the citizens in a cost effective and resourceful manner.

QTI recommends that cities and municipalities adopt a three pronged approach to smart cities enablement:

- Reimagine legacy infrastructure, exploring new ways of deriving value add from existing capabilities. That may mean, for example, integrating back-end currently silo-ed IT systems used by various city departments into a common data layer for city level decision making. Alternately, it could be equipping every roof top with renewable solar energy and contributing such energy back to the grid.
- Reuse existing systems, infrastructure such as mobile broadband networks and smart phones to reduce Capex and ongoing Opex versus overlaying expensive fiber for the last mile in remote areas.
- Convert single use infrastructure into multi-purpose use. For example, equip existing electricity poles or street lights with additional environment sensors, Wi-Fi access points (to bridge the digital divide) or small cells.

Aside from policies and regulations, additional considerations must be given to India specific technology and deployment needs and requirements including:

- Scalability: As new sensors, devices, citizens, applications and services are brought online, the infrastructure must be able to support these IoE devices, without recurring network planning. Self-organizing systems can be developed to meet this demand elasticity.
- Cost effective: The total cost of ownership is a critical gauge for cities as they consider these massive infrastructure projects without overhauling existing infrastructure. Opportunities include a) leveraging existing infrastructure, and b) sourcing equipment and labor locally. QTI has reference designs for smart cities use cases which can be licensed to be further developed and manufactured for differentiation by a local partner in India.
- Innovation: Innovation and co-creation of new e-government services, new e-citizen applications and new approaches to maximizing efficiencies are key ingredients and can only be fostered by cultivating and sustaining a thriving ecosystem via an active and healthy cross-industry collaboration.

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UNLOCKING THE VALUE OF SMART METERS WITH BEHAVIORAL SCIENCE

An Insight Paper from Opower

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Senior Director for Regulatory Affairs & Market Development
Opower Asia-Pacific

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Synopsis:

The traditional utility business model is changing rapidly. Major drivers include the transition to Smart Grid, market restructuring, and increased adoption of distributed energy resources. During this period of change, engaged consumers can be a significant asset and can maximize the return on AMI investment. Consumers today typically interact during periods of discontentment, such as an outage or receipt of an unexpectedly high bill. Engaged consumers, on the other hand, actively participate in utility innovations. They hear what utilities have to say and act accordingly. Utilities are empowering consumers by investing in Customer Engagement platforms that borrow from the success seen in other industries that have employed similar techniques, such as retail, personal banking and even social media — which create a personalized and highly tailored engagement approach for each consumer. Based on dozens of surveys conducted globally with utilities, Opower's customer research team has confirmed that engagement indeed leads to higher customer sentiment and satisfaction. Proactive customer engagement also affects how consumers perceive Smart Meters. Opower has found that households with AMI that receive integrated communication solutions express 15% higher satisfaction rates. Sentiment improvements are significant, but more meaningful are measurable impacts to the utility's bottom line. In this white paper we show how more engaged and more satisfied consumers deliver value, not just to end consumers but to utilities as well - lowering cost to serve, increasing ease of customer acquisition and cross-marketing potential, while at the same time yielding cost effective demand response and energy efficiency solutions.

The statistics for smart meter installations are staggering – 313 million smart meters were installed worldwide in 2013, with an expectation that this will hit 1.1 billion meters by 2022[1]. However, utilities face an uphill battle in terms of both delivering and realizing value for smart meters. Projected efficiency and demand reduction savings from large-scale installations have in many cases failed to materialize. To ensure continued viability of AMI investments, utilities are now focusing their efforts on improving customer satisfaction and trust.

This paper will focus on how instituting a customer engagement platform pre-AMI deployment engages customers prior to rollout, eases the initial acceptance of smart meters, and helps the utility to derive value from this engagement in order to enhance the business case for AMI investment.

Why invest in a customer engagement platform?

Utilities around the world are activating customers by investing in Customer Engagement platforms that allow them to deliver the right message to the right customer, through the right channel, and at the right time. This approach — which borrows from the success seen in other industries that have employed similar techniques — creates a personalized and highly tailored engagement approach for each customer.

Based on dozens of surveys conducted globally with utilities, Opower's customer research team has confirmed that tailor-made engagement indeed leads to higher customer favorability metrics. Empowered with personalized insights and consistent feedback, engaged customers perceive their

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[1] "Smart Meters: Smart Electric Meters, AMI and Meter Communications – Global Market Analysis and Forecasts", Navigant Research 2014. http://www.navigantresearch.com/research/smart-meters

utilities as providers of trustworthy information interested in helping customers save money (see Figure 1 below).

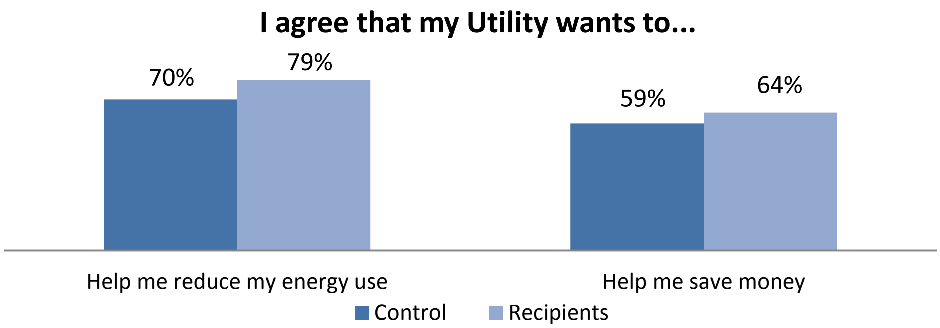

Figure 1: Opower study – Measuring customer sentiment in a large utility that delivers Customer Engagement

Proactive customer engagement also affects how customers perceive Smart Meters. Opower has found that AMI customers, provided with integrated communication solutions, express 15% higher satisfaction with Smart Meters (see Figure 2 below).

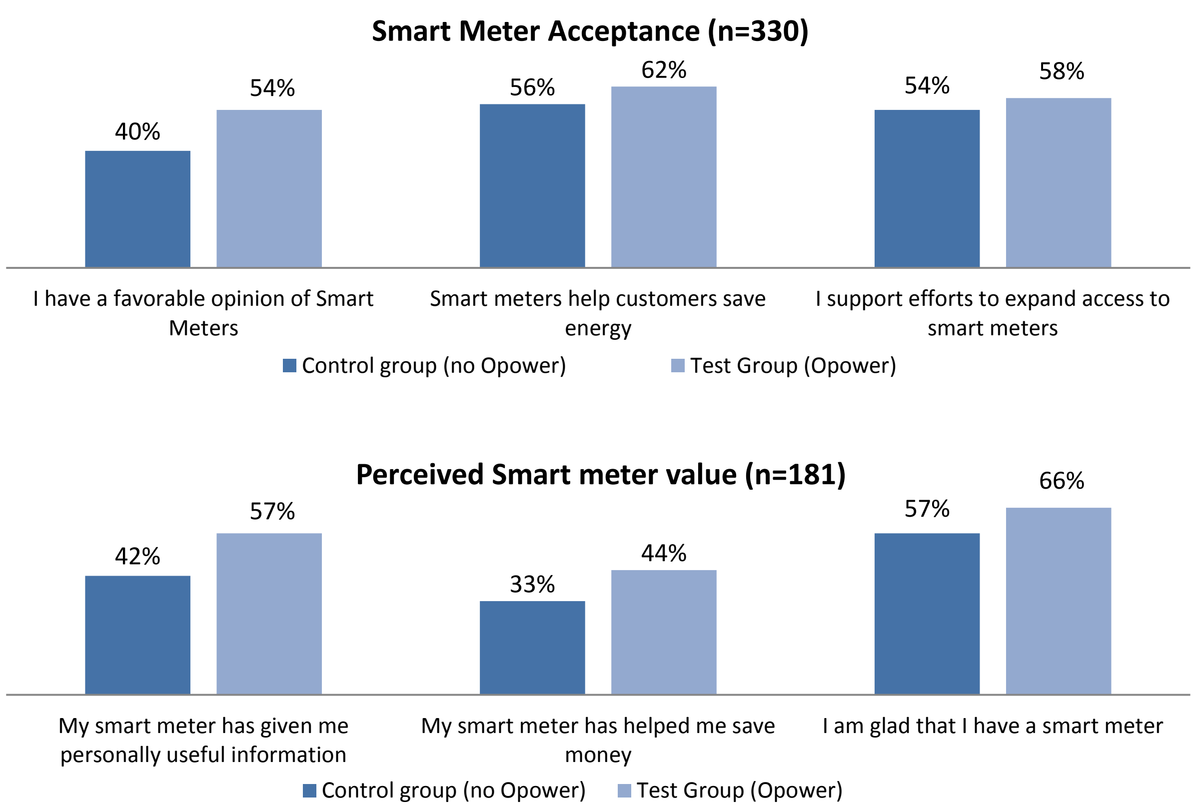

Figure 2: Opower Survey – Customer attitudes towards Smart Meters before and after Customer Engagement

Sentiment improvements are significant, but more meaningful are measurable impacts to the utility's bottom line. In the next four sections we show how more engaged and more satisfied customers deliver value to the utility business.

Qualifying the value of customer engagement for utilities

VALUE SOURCE #1: Lower customer acquisition costs through effective marketing

As utilities continue to expand their program offerings, they need to educate customers on a wide variety of efforts, including new self-service options, online energy insights, demand response programs and other services such as appliance rebates. Traditionally, utilities have used standardized, one-size-fits-all mass mailing to drive education, and have struggled with low open and recall rates. With modern technology, utilities can now offer highly personalized outreach through both mail and digital channels. Utilities can also boost their marketing effectiveness by segmenting customers based on a variety of customer information (demographic, psychographic, behavioral) and tailoring messaging and channel choice to meet the needs of each individual customer.

AMI data allows for even finer segmentation by enabling a utility to look at individual household load curves and targeting programs that cater for each specific usage type (see Figure 3).

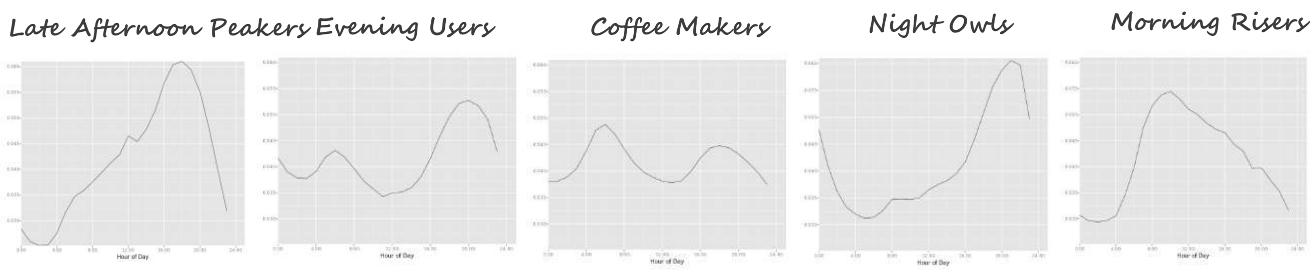

Figure 3: Examples of household load curve archetypes

By saving on per-customer fixed costs in recruiting customers into programs, utilities can either increase participation using the same marketing budget or reduce the budget while still realizing the same participation levels. Either approach translates into cost savings per household.

VALUE SOURCE #2: Reduced cost-to-serve via proactive engagement

Utility cost structures are under growing pressure; utilities are always looking for opportunities to reduce cost to serve. Increased customer engagement can be a key tool to reducing cost to serve because engaged customers are more likely to use self-service tools and be more reliable ratepayers. Specifically, proactive customer engagement leads customers to shift to lower-cost interaction channels (like digital channels), increasing the adoption of paperless billing and on-time payments.

One example is increased call center efficiencies. Customers call their utility providers, on average, between three and five times a year[2]. Some of these calls (high bill calls in particular) result in expensive call escalations and truck rolls. But when customers receive personalized energy insights, they are more likely to accept higher bills and take advantage of self-service tools, leading to less frequent calls.

With AMI data it is possible to foresee high bills and alert consumers well in advance of the impending bill. Customers are then able to plan their usage in advance of the bill and be better prepared to handle the bill when it arrives. Figure 4 shows an example of an unusual usage alert provided by Mercury

[2] "The Value of Utility Customer Engagement: Engaged customers deliver cost savings across the utility business", p5. Opower 2014.

Energy to its consumers, together with three key metrics – Customer Satisfaction, Brand Value and Call Center Volume – measured by Opower in order to determine value:

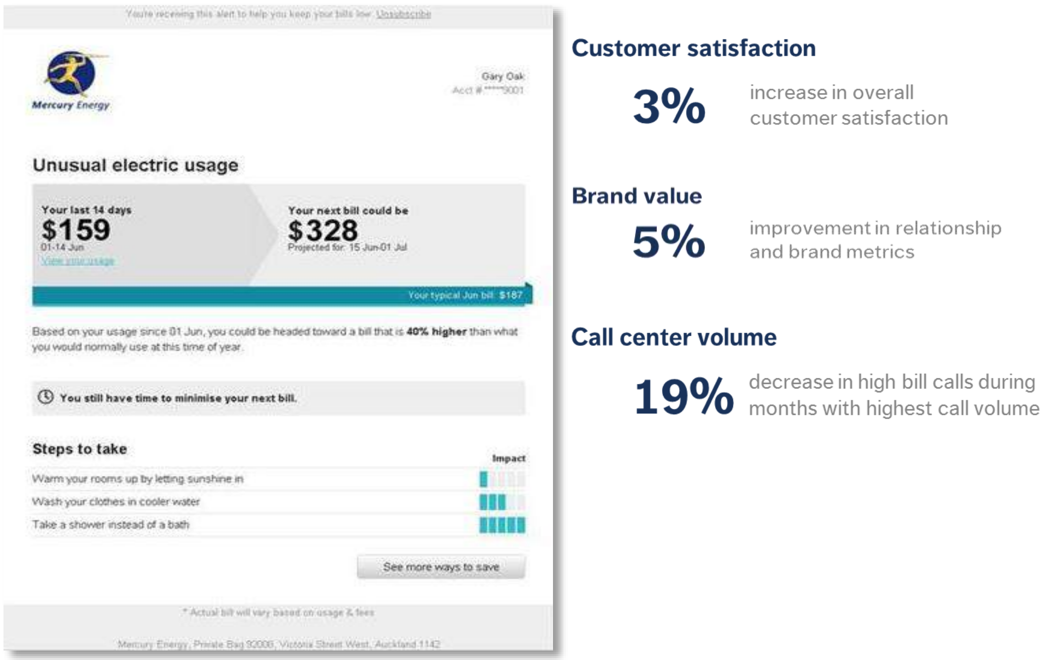

Figure 4: Unusual Usage Alerts from Mercury Energy – reports provided and key metrics measured by Opower

VALUE SOURCE #3: More cost-effective, scalable programs that promote energy efficiency

Over the past decade, efficiency marketing programs in the US have experienced significant growth driven in large part by state regulation, mandates, and self-imposed targets. However, customers are either not aware of utility efficiency program offerings (in fact, even the most promoted programs have an awareness rate of only 28%[3]) or they do not see any value in participating.

As a result, many utilities are trying a new approach, delivering highly engaging, personalized insights to drive interest in energy efficiency programs. These insights can work using information alone or can work in conjunction with installed devices, creating value for utilities by driving interest in corresponding marketing programs to provide a highly scalable energy savings that can create additional utility revenue. From a consumer perspective, Behavioral Energy Efficiency (BEE) programs are some of the most cost-effective efficiency programs at scale. It is estimated that BEE, if implemented across the United States, has the potential to save residential consumers more than 18,000 GWh and $2 billion each year[4]. In some states, the difference between the costs of more expensive programs and behavioral EE is as large as $0.06/kWh[5], with the average cost-effectiveness of behavioral energy efficiency programs being $0.03 per kWh[6]. AMI can further enhance customer experience and insights provided as part of a BEE program, as seen in Figure 5 which shows a household's usage disaggregation once AMI data is available.

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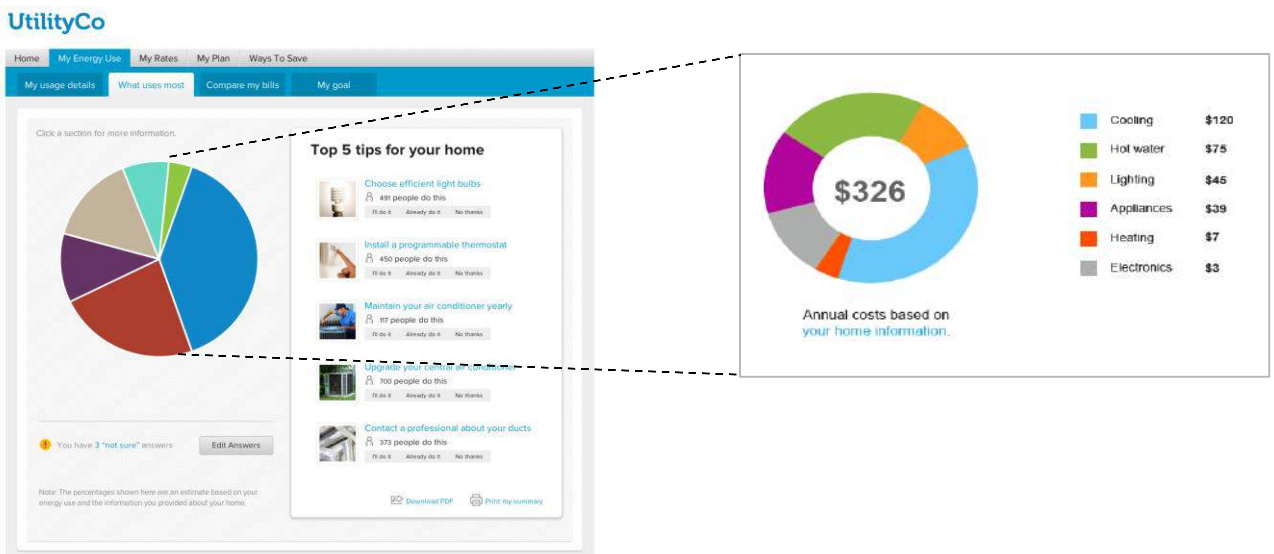

Figure 5: Household Usage Disaggregation as illustrated by a personalized pie chart (using AMI data)

VALUE SOURCE #4: Increased adoption of Demand Response

Typically, demand response (DR) initiatives are constrained by very low customer engagement. In fact, it is estimated that only 5%[7] of retail customers participated in DR programs in 2012. As a result, there is currently a huge (70%[8]) gap between actual peak reduction achieved and potential peak reduction.

The gap persists largely because existing options for demand response programs have been limited and, customers are largely unaware of program benefits. Utilities have begun to offer customers an array of options which puts them in control of their reductions.

One of these, empowered by AMI data, is Behavioral Demand Response (BDR) and is a new type of a two-way communication platform designed to drive customer awareness and peak energy savings at scale without in-home devices. Through personalized communication and feedback delivered across email, text, and voice channels (see Figure 6), BDR can drive behavioral change at peak times. These programs can drive between 5-15% decreases in usage during peak times can save US utilities $7-$20 in avoided capacity costs per household over the course of a year[9].

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[7] 2012 Assessment of Demand Response and Advanced Metering, Federal Energy Regulatory Commission; based on reported number of customers enrolled in direct load control and TOU DR programs.

[8] Ibid; Calculated difference between reported potential and actual savings across eight U.S. regions (Figure 3-7).

[9] Assuming 10 peak events, excluding the program cost.

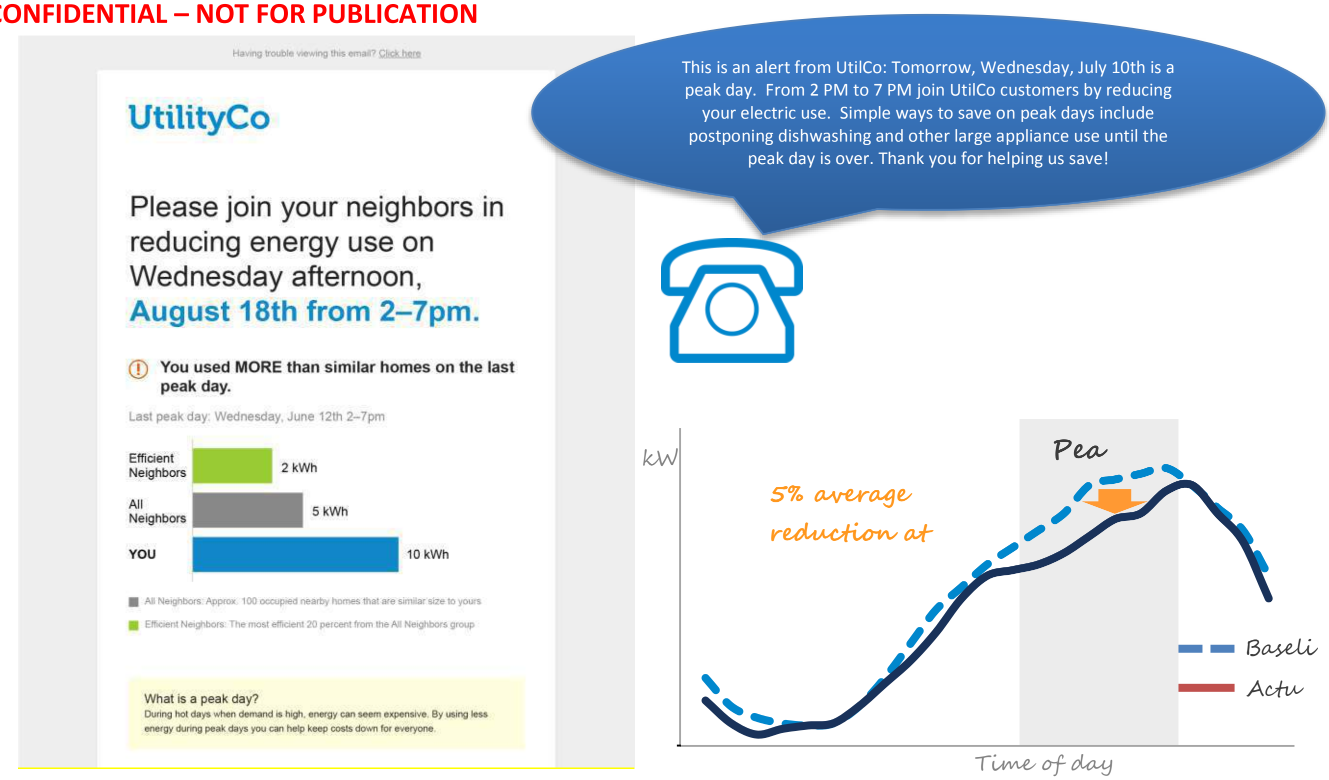

Figure 6 : Peak time rebate communication with peak savings results as measured by Opower

Next Steps

With a better understanding of the value of each engaged customer, utilities must answer three key questions in order to efficiently capture this value.

1. How many customers within a utility's base can be successfully engaged?

2. How should engagement approaches vary, based on customer type?

3. How should a utility coordinate its customer engagement investment to minimize cost and maximize impact?

Leading utilities have been able to successfully address these questions head-on. At a time when the entire energy landscape is constantly changing, utilities need to lead the innovation charge. Failure to do so will ultimately cost them more than just customer sentiment.

Distribution System - Automation Technologies and its Cyber Security

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Abstract

The recognition of the contributions and challenges of the distribution system for delivering the generated power to the end consumer with high availability, reliability and efficiency has increased the responsibility of the distribution system owners and operators. Accordingly, this segment of the entire delivery chain is now seeing increased focus on developing and strengthening the network both in terms of equipment installation and implementing automation solutions.

This technical paper will discuss the various Distribution Automation technologies/functions like:

- SCADA/DMS
- Outage Management System (OMS)
- Advanced Metering Infrastructure (AMI) (or) Smart Metering.

and advanced applications like

- Demand Response

These new system concepts will enable more efficient operation, voltage optimization and maximization of energy throughput. They also contribute to outage identification, outage recovery and optimal system performance under changing conditions. The Distribution Automation also paves the way for a "Self-Healing Grid".

The urgent need of making the grid "SMART" has made the Operational Technology (OT) systems which were otherwise in a secure network to hand-shake with the external systems for data and information exchange. This induces a sense of insecurity to the operational assets of the utilities. Thus, when a utility is implementing various solutions and integrating these systems for data exchanges, the systems need not only be inter-operable but also need to be secure.

Hence, this paper will also discuss the various cyber security vulnerabilities and mitigation techniques.

Keywords—Keywords from your abstract

Distribution Management, Demand Response/Demand Side Management, Cyber Security, Smart Grid

INTRODUCTION

The Distribution utilities today face challenges not only from the grid connectivity point of view but also in delivering power with increased efficiency and reliability. With the distributed generation, the grid connectivity and the power flow is changing and changing fast from a radial, uni-directional flow network to an inter-connected and multi-directional flow network. Besides these there is also an ever increasing energy demand and sustainability requirements of the environment we live in.

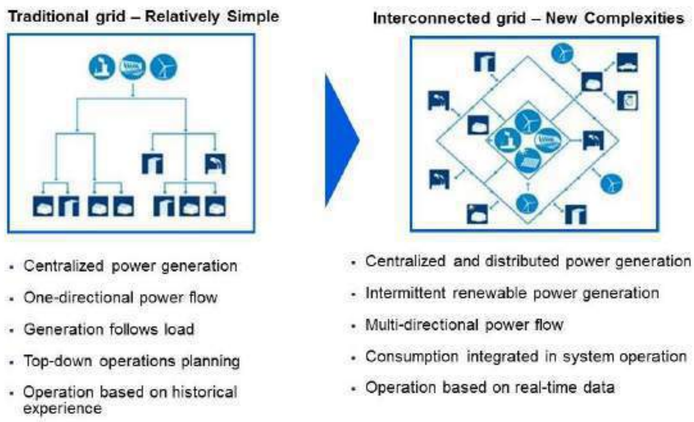

Figure 1 - Traditional v/s Inter-connected grid

Under these circumstances of operating a distribution system, automation solutions becomes an effective tool not only for the operators to monitor and control the network, but also for the management to take decisions. The grid automation provides a greater and wider visibility of the network thereby enabling remote and faster controllability. Implementation of automation brings in enormous data from the field and there is a growing importance of managing these data and using them as information by implementing Information Technology (IT) solutions. The traditional control systems which are called the Operational Technology (OT) need to be bridged with the IT systems. While a smart grid converges the OT and IT systems within a utility, the important aspect of its implementation is to efficiently integrate them as per the utilities requirements.

There are different traits that a Smart Grid is expected to improve in the power system operations, like -

- Optimize asset utilization and operating efficiency.
- Provide power quality
- Anticipate and respond to system disturbances in a self-healing manner.
- Operate resiliently against physical and cyber-attacks
- Enable active participation by consumers.
- Address Distributed Generation and energy storage options

In the following sections, we will look into the key functionalities that form a part of Distribution Automation solution.

SCADA/DMS

A Supervisory Control And Data Acquisition (SCADA) system is the base for any automation system. It enables to acquire data from the field process devices to a central remote location. As there are possibilities for different types of devices available at the process, interoperability of these devices is very important. To achieve this, there are communication protocol standards. The different protocol standards are applicable at various levels of application. A snapshot of the most popular protocol standards used in modern day grid automation are listed below:

Data interface between	Protocol Standard
Sub-Station and Remote control center	IEC 60870-5-101
	IEC 60870-5-104
	DNP3
Sub-Station Gateway/Data Concentrator and sub-devices	IEC 61850
	MODBUS

These protocol support bi-directional communication for both monitoring and control purposes. A general network configuration of a SCADA system between a substation and the remote control center is as depicted in Figure [2] below:

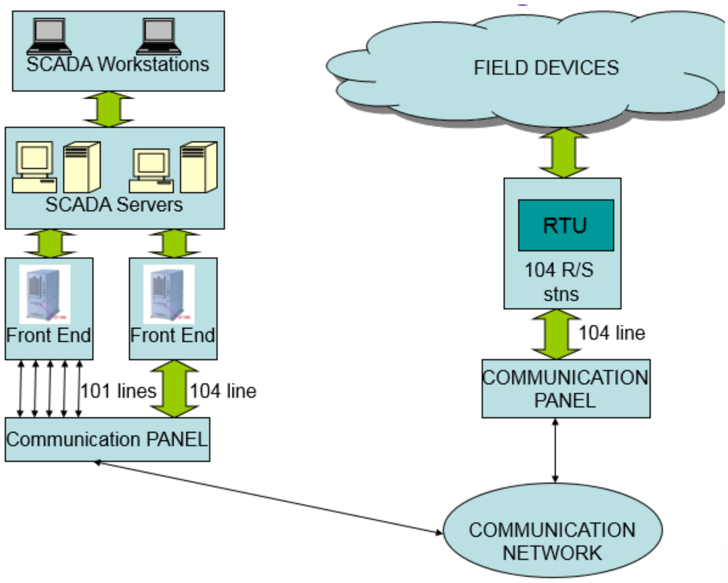

Figure 2 - General Network Configuration

The SCADA system itself has set of functions which support the system operator and can be categorized as under:

- Process Data Handling
- Alarm and Event processing
- Supervisory Control
- Device Monitoring
- Operator Functions
- Historical Data Storage, Reports and Trends

DISTRIBUTION MANAGEMENT SYSTEM (DMS)

While SCADA is the basic platform of an automation system, the applications for the distribution network widely known as Distribution Management System (DMS) is a key component of smart grid (or) distribution automation. The DMS provides functionalities to improve the operations and the efficiency of the sub-transmission, medium and low voltage distribution networks. The DMS interfaces with the SCADA system and facilitates the network analysis and network optimization of the distribution system. Typical system architecture of a SCADA/DMS system is shown in Figure [3] below:

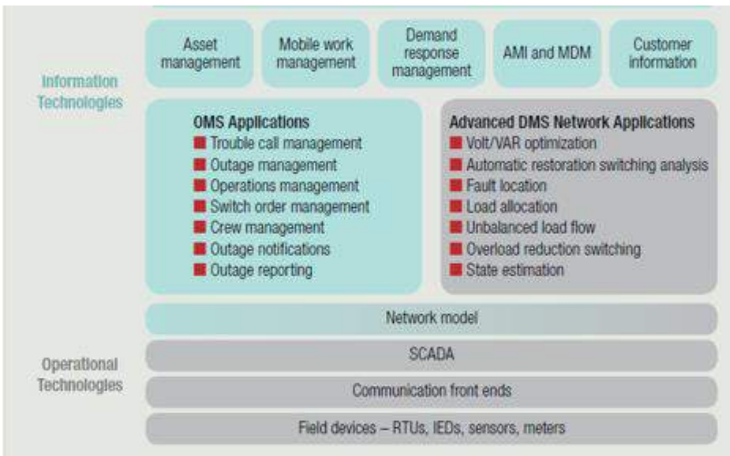

Figure 3 – SCADA/DMS/OMS system architecture

The reliability of a distribution system is measured by two main indices – Customer Average Interruption Duration Index (CAIDI) and System Average Interruption Duration Index (SAIDI). The efficiency of a distribution system is measured by the distribution losses and the voltage quality. Accordingly, the two main applications of the DMS are

- Fault Location, Isolation and Restoration (FLISR)
- Volt-Var Optimization (VVO)

In FLISR, the fault location deals with detecting the permanent fault in a feeder. The faults are detected through the relays whose values are telemetered through the SCADA system. The fault parameters are read and analyzed by the DMS applications and based on the network topology built in the system at the time of system engineering, faulty sections are identified. Once, the fault and the faulty section is identified/located, the Isolation function, isolates the faults by producing operation sequences (also called as switching sequences) of the network devices which can be remotely controlled. The Restoration function, attempts to restore the power to as many customers as possible, thereby reducing the number of customers affected and improving the reliability indices. The restoration function also produces switching sequences of the network devices which can be remotely controlled for supply restoration. These switching sequences can be executed either automatically or manually. In automatic switching, the switching operations are executed automatically with/without operator approval depending on the system configuration. In case of manual switching, each operation in the switching sequence for Isolation/Restoration has to be done by the operator. The Automatic/Manual operation depends on the utilities needs and possibilities.

The Volt-Var Optimization (VVO) function improves the efficient operation of the network by:

- Keeping voltages in limits
- Reducing losses by minimizing reactive power flows
- Reducing peak power by voltage reduction

The capacitor banks and the transformer tap changers are controlled to achieve the required voltage and reactive power operating range. This application is also interfaced with the SCADA system and uses the real-time network information, thereby using the "as-is" status of the network in the optimization calculations.

OUTAGE MANAGEMENT SYSTEM (OMS)

While a SCADA/DMS system improves the overall operational reliability and efficiency of the network, there is always possibility of outages. These outages can be either planned or unplanned. The OMS system provides a platform to intelligently manage the outages and provides support in decision making process to support daily grid operations and minimize outages.

ADVANCED METERING INFRASTRUCTURE (AMI)

AMI is a complete infrastructure which includes smart meters, communications, meter data management system (MDMS). In the implementation of AMI, the communication is bidirectional, which means that this facility enables monitoring the consumption of the customer connected as well as controlling of the meter/appliances. In fact, the bi-directional communication is the major difference between the traditional Automated Meter Reading (AMR) system and the AMI. The smart meter component of an AMI system also has a display unit either within the meter or separately mountable unit, which displays information about the energy usage. With this information customer can make choices of running the home appliances selectively and efficiently based on the consumption pattern and the price at the time of use. The communication network which binds the distribution system with the customer and "inside" customer premises are called Home Area Network (HAN) and Neighborhood Area Network (NAN).

AMI, while enabling bi-directional communication between the utility and the customer, can also be extended to a full fledge Demand Response program.

DEMAND RESPONSE

Demand Response is a program to control and change the end customer energy consumption pattern depending on the factors like time of use price, peak shave-off incentives. Peak shave off is reducing the consumption to reduce and bring down the peak levels, so that the electrical network can deliver without any disturbances arising due to overloads. As peak shave off is more important from the utilities perspective to maintain the operating conditions of the grid, incentive payments are normally included to encourage end customers to volunteer and subscribe to the program. The time-of-use consumption will trigger self-interest in the end customer to use the appliances based on the tariffs fixed at different time of the day. DR opens up a disciplined usage of energy by intentionally altering the time of usage of home appliances. Demand Response is a voluntary program where the end customer "participates" in helping the utilities to manage the energy distribution.

The implementations of smart meters and other AMI systems are widely viewed as enabling technologies for demand response that will permit greater and more effective use of demand response strategies. These technologies will allow for demand response programs to be more extensive and more efficient. Demand response programs built on AMI will not only promote increased participation by commercial and industrial customers, but will foster the integration of residential customers into demand response programs.

CYBER SECURITY

As we move forward with implementing intelligent solutions and making the grid smart to deliver quality power with improved efficiency, reliability and in a sustainable way, there is also a major concern. Building intelligence means inter-connecting various devices and systems to exchange information to bring in more situational awareness about the status of the network and decision making support to operate and maintain the grid. With implementing solutions like Demand Response, the devices getting connected are no more limited to the utility premises, but include devices and appliances in the customer premises.

As the IT and OT systems are getting integrated, the OT systems which were otherwise in a secure perimeter (physical and electronic) to hand-shake with the external world, there by inducing a sense of insecurity to the operational assets of the utilities. Also using the Ethernet based technology in the Automation Systems, is gaining wide popularity and acceptability, as it gives tremendous benefits in terms of solution implementation and maintenance. They also bring in the threat of viruses, internet based attacks etc. Thus, when a utility is implementing various solutions and integrating these systems for data exchanges, the systems need not only be interoperable but also need to be secure. Hence, the cyber security for automation in electric utilities has gained a lot of importance and attention in the recent years. Cyber Security has transformed from a nice-to- have to a must- have for the utilities world over.

Recognizing the need of building the security into the deployments, the utilities have started implementing solutions and execute operational practices towards addressing the Cyber Security aspect. It will be worthwhile to note that, addressing the Cyber Security is not limited to building different technical solutions but it is also as much important to have strong operational (or) IT policies within the utility organization.

There are different mitigation techniques that can be implemented towards making a system more secure. Some of them are:

System Hardening: Insure all hosts run at a minimum level. Only mission critical software, services, ports and devices are allowed.

Access Control: Strong authentication and Role Based Access Control (RBAC) is a natural requirement in any security architecture, but is never stronger than the implementation.

Network Partitioning: Insure cyber assets are isolated, categorized by criticality, external interfaces and physical location. In Network partitioning, the electronic perimeters are clearly defined and fenced to restrict the network access.

Intrusion Detection and Prevention Systems: Deploy sensors or agents on all hosts, perform log management of all devices, and use security information and event management (SIEM) to detect and possibly respond to anomalies in the system.

Patch Management: Processes and technology to insure that all available security updates that are verified not to interfere with system operation are installed in all hosts.

Anti-Virus: Employs blacklist, heuristic, and behavioral detection and prevention of malware.

Application and Traffic White Listing: Only allows preapproved software and traffic in the system.

While the need and the importance of this critical aspect of automation are felt across the utilities, the drivers and the level of implementation may differ. However, the demand for cyber security solutions will increase and become mandatory requirements as part of solutions and products. Accordingly, the standards organizations are also taking up the standard's development activities on priority. The table below summarizes the various standards around the cyber security.

Standard	Main Focus
NIST SGIP-CSWG	Smart Grid Interoperability Panel – Cyber Security Working Group
NERC CIP	NERC CIP Cyber Security regulation for North American power utilities
IEC 62351	Data and Communications Security
IEEE PSRC/H13 & SUB/C10	Cyber Security Requirements for Substation Automation, Protection and Control Systems
IEEE 1686	IEEE Standard for Substation Intelligent Electronic Devices (IEDs) Cyber Security Capabilities
ISA S99	Industrial Automation and Control System Security

In-spite of having different methods to protect the systems against the cyber threats and vulnerabilities, implementing solutions to address cyber security needs to be a continuous one. The system protection can only be enhanced from one level to the next and the utility organizations cannot be complacent w.r.t cyber security.

Also, it is not sufficient to implement technical solutions to address this issue, the organizational policies also needs to be in place and reviewed time-to-time to have an effective protection of the utilities assets.

CONCLUSIONS

The smart grid is more than any one technology, and the benefits of making it a reality extend far beyond the power system itself. While the transition in the grid connectivity is already happening and the utilities are facing the reality, the transition in the way this new gird is operated is the need of the hour.

However, this transition will not be easy. The integration of smart technologies of many different kinds will be essential to a functioning of a smart grid, and the path to integration is supported with interoperability standards.

Technology is the key, but it is only a means to an end—the smart grid can and should be defined by broader characteristics. In the end, though, a fully realized smart grid will benefit all stakeholders. These new technologies, supported by appropriate standards encourage the industry as a whole to march forward with a positive thought of making the grid "Smart" by implementing such systems and solutions. The utilities should therefore, be very prudent in choosing and designing a solution according to the specific requirement of a project.

While the SCADA, DMS and OMS applications are discussed separately in the above sections, the approach should be to have a good tightly integrated SCADA/DMS/OMS system.

From the cyber security perspective, technology is insufficient on its own to provide robust protection. Cyber security policies and processes must be implemented in the organization to best be able to assess and mitigate the risks and respond to incidents. There is no such thing as 100% security or a 100% secured system. Hence, implementing solutions around the cyber security has to be a continuous one. Therefore, it's not only important to protect a system from the current vulnerabilities, but is also equally important to have mechanisms (technical and process) in place to quickly detect and effectively react to any incidents and isolate security breaches.

Spotlight on
Smart and Strong Electric Power Infrastructure

Best practice shared from the ISGAN Annex 6 case book

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***Abstract* — This paper summarize a number of smart-grid cases from the case book within ISGAN Annex 6: Power T&D Systems. The case book spotlights a number of projects sharing best practice in how to meet the challenge to develop the electricity network to become stronger and smarter using different approaches. For example how:**

- **Existing and new AC power transmission lines can carry more power by the use of smart technologies such as WAMS and Synchrophasors.**
- **HVDC lines with Voltage Source Converters can be used for interconnectors that also support the existing grid e.g. by avoiding voltage collapse.**
- **The use of smart voltage control concepts can increase the hosting capacity for distributed energy resources**

Keywords— smart grids, power transmission and distribution, ISGAN; synchrophasors; HVDC; WAMS; hosting capacity

I. INTRODUCTION

To reach a more sustainable future and to support the long-term CO_2-reduction goals, the full potential of renewable energy sources - a clean energy transition - is needed. At the same time stability, security of supply and quality of service for the electric power system must be secured.

The introduction in the generation mix of a continuously increasing share of generation from renewable energy sources (RES), the geographical spread of generation when increasing the amount of distributed production, as well as changing patterns of demand from new types of load such as electric vehicles, will create new challenges for the electric power transmission and distribution (T&D) systems. The on-going evolution of the power system, to cope with these challenges, is illustrated in Fig. 1.

To provide the real-time flexibility needed to efficiently handle the new operating conditions of the power grid, the T&D system has to become smarter and stronger. This requires increased knowledge and supervision of system behavior and wide area implementation of information and communication technology (ICT) for monitoring, protection, control, automation and visualization. There is further a need for additional controllable devices based on power electronics such as flexible AC transmission systems (FACTS) and high voltage direct current (HVDC).

The new energy landscape opens for solutions that can be made on different levels in the electricity system and increased interaction between different parts of the T&D system is required. This calls for new technical solutions, sharing of data, and at the same time new business models.

Next to the developments in the grid, there is also a new role for customers when time-dependent electricity prices, local generation, and customer as well as grid-side energy storage, all become increasingly feasible.

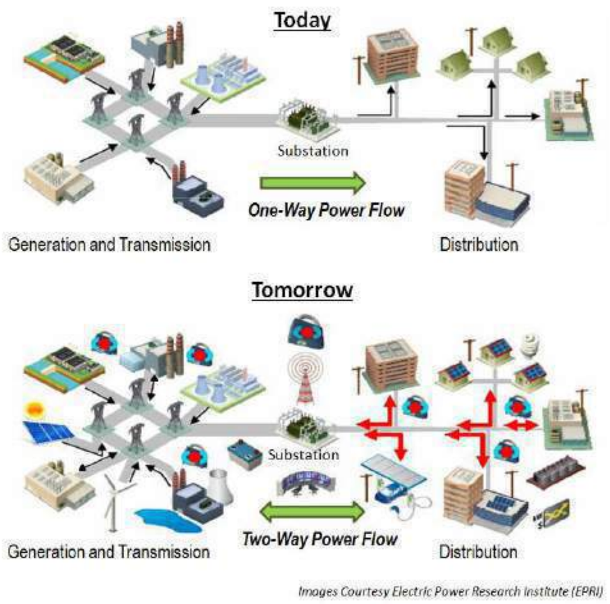

Fig. 1. Illustration of how the power systems are evolving towards including more RES and storage both at transmission and distribution level, more information and possibility to control, and more flexible loads.

This paper is based on the ongoing work with a case book within ISGAN Annex 6: Power T&D Systems. The case book spotlights a number of projects sharing best practice and different approaches on how to meet the challenge to develop the T&D network to become smarter and stronger.

II. ISGAN

ISGAN, International Smart Grid Action Network, is a mechanism for international cooperation with a vision to *"accelerate progress on key aspects of smart grid policy, technology, and investment through voluntary participation by governments and their designees in specific projects and programs."*

ISGAN is an initiative within the Clean Energy Ministerial (CEM) and an Implementing Agreement within the International Energy Agency (IEA).

The focus of ISGAN is a government-to-government cooperation in which 24 countries and the European Union are working together to support informed decision making on smart grid projects and systems. [1]

III. THE ISGAN ANNEX 6 CASE BOOK

There is no generic solution or size that fits all for the solution towards the smart and strong grid. Different countries have different challenges, will use different solutions to those challenges, and have reached different maturity in the implementation of those solutions. At the same time there are generic solutions and findings from experiences that can be adapted by other countries to make local implementation faster and more efficient. Smart grid solutions are also found across the entire electrical system, from the high voltage transmission grid, through the distribution grid and finally on consumer level.

ISGAN Annex 6 will be publishing a case book where the member community has contributed with specific projects to illustrate applications, solutions and technology from different countries and from different levels in the electrical system. The cases are selected to cover the following key drivers for building a smart electrical grid: To integrate renewables (R); To improve the market (M); To activate customers (C) and To increase security of supply (S).

Version 1.0 of the case book covers a range of examples, as listed in Table I:

TABLE I. CASES INCLUDED IN THE ISGAN ANNEX 6 CASE BOOK VER. 1.0

Country	**Case**	**Level**	**Driver**
France	Smart Substation	TSO/DSO	R, S
Ireland	East-West HVDC Interconnector	TSO	R, M, S
Sweden	Embeded HVDC link	TSO	R, M, S
U.S.	Wide Area Reliability	TSO	R, M, S
Italy	WAMS Experience in Italy	TSO	S
South Africa	Situational Awareness	TSO	R, S
Austria	Active Distribution Network	DSO	R
Italy	Customers´respons under time-dependent electricity prices	DSO	C

Of course there are many more good examples of smart grid projects all over the world, beyond those covered in the ISGAN Annex 6 case book. Further information is for example found in [2], [3], [4], [5].

The ISGAN Annex 6 case book will be an evolving document that is periodically updated with new projects, both regarding transmission and distribution.

Fig. 2. The ISGAN Annex 6 case book will be officially published during spring 2015.

The ISGAN Annex 6 case book will be published on the ISGAN webpage: http://www.iea-isgan.org/, see Fig. 2.

IV. THE SMART TRANSMISSION SYSTEM

The new challenges to which the electrical network is exposed require a smart and strong infrastructure where the need for flexibility is an important requirement. The main mechanism to make the power system more flexible is to allow for faster changes in power flow. During the last 20 to 30 years the digital technology has spread to almost every aspect of our life and this digital evolution is providing the power system with new and better solutions. Solutions are available for power system management and automation with faster communication of more data. Solutions are also available for high voltage technology with the development of power electronics for FACTS, such as static Var compensators (SVCs) or thyristor controlled series compensators (TCSCs), and HVDC.

A large majority of existing and new transmission lines are based on AC technology. Controllability of AC lines is traditionally low and the usable capacity of lines is normally not determined by thermal rating but rather by stability criteria. To allow better utilization of existing and new lines, two main elements are required: more information and more control of the power flows.

More control of the power flows in the transmission system is possible with power electronics for AC and DC. The need for more information is fulfilled by faster and more accurate ICT. Together, ICT and power electronics form the core technology to design and operate a smarter and stronger grid, which is illustrated by several cases presented in the forthcoming sections.

A. East-West HVDC Interconnector

The Irish transmission system operator (TSO), Eirgrid, shares a case in the case book where they have improved the security of supply in their network by providing additional capacity.

This was done by building the East-West Interconnector (EWIC), a voltage source converter (VSC)-HVDC based link, which connects the electricity transmission grids of Ireland and Great Britain. The interconnector has a capacity of 500 MW (equivalent to approximately 10% of the Irish peak demand) and also provides a range of ancillary services, such as frequency response; reactive power provision; and includes 'black start' capability for both Ireland and Great Britain.

The project is instrumental for Ireland to reach its renewable electricity targets but also greatly contributes to lowering the electricity price for consumers, as shown in Fig. 3.

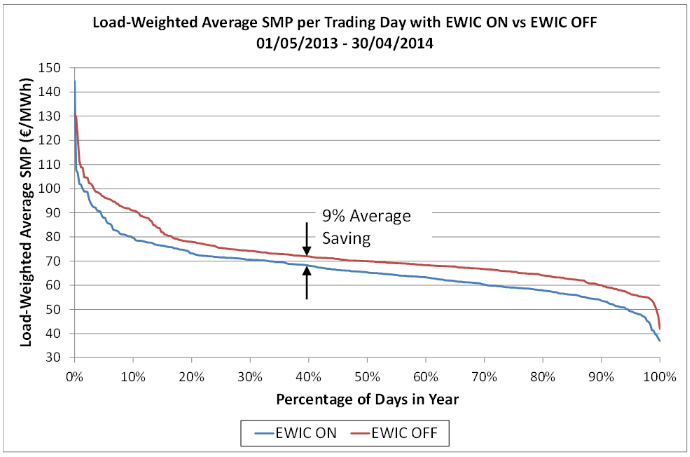

Fig. 3. Indications since the beginning of commercial operation suggest that EWIC is facilitating competition and exerting downward pressure (9%) on system marginal price (SMP) in Ireland due to better utilization of common resources rather than relying on local solutions.

The EWIC project had three key objectives.

- To improve the security of supply by providing additional capacity.
- To exert downward pressure on wholesale electricity prices in Ireland by providing direct access to the larger Great British electricity market.
- To allow the export of excess power from Ireland at times of oversupply to the Irish network.

B. Embeded HVDC link

Also the Swedish TSO Svenska Kraftnät has used VSC-HVDC technology to make their network smarter and stronger by building the South West Link (SWL), as shown in Fig. 4.

This link combines different types of technologies: overhead AC and DC, as well as underground DC. Using overhead techniques helped keeping the cost down. Combining DC overhead line with a cable prevented a large delay as no new right-of-way was required. The DC technology makes it possible to control the power flows and increase the transfer capabilities.

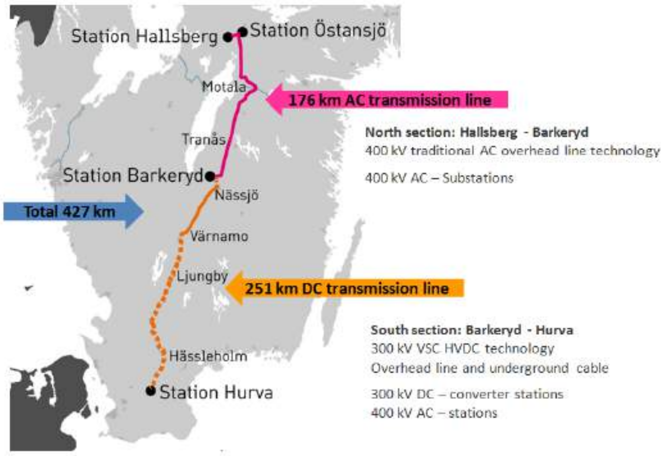

Fig. 4. Map presenting the location of the different techniques used in the SWL, from north to south: 176 km AC overhead line followed by 61 km DC overhead line and 190 DC cable.

The main driver behind SWL is to increase the reliability and improve security of supply to the south of Sweden. Increasing the capacity to the southern part of Sweden became especially important after the decommissioning of a nuclear power plant which led to increased capacity limitations related to voltage instability.

The South West link is also an important part in the necessary development of the national grid, required to enable the introduction of renewable energy as planned in accordance with Swedish and EU energy policy objectives.

C. Wide Area Reliability

Important technologies for getting more information are wide area management systems (WAMS) and phase measurement units (PMUs).

The United States share in a case for the case book their experience from The Bonneville Power Administration (BPA) synchrophasor project.

BPA is receiving data from 126 PMUs at 50 key substations and large wind-generation sites throughout the Northwest of the United States. In addition, BPA has also developed an application capable of assessing the dynamic performance of its generating fleet within minutes of a power grid disturbance.

The project provides grid operators and reliability coordinators with more frequent and time-synchronized system information. Better system visibility will help system operators avoid large-scale regional outages, better utilize existing system capacity, and enable greater utilization of intermittent renewable generation resources. The synchrophasor-based controls will use wide-area synchronized measurements to determine voltage stability risks and will initiate corrective actions in less than one second. Also four real-time analytical applications are in use in the control centre together with operational displays.

Another important benefit of the project is that the collected data is used to validate the system models leading to more accurate models, which is essential for reliable and economical grid planning and operation.

Improved understanding of power grid performance leads to possibilities to optimize the capital investment. It is also expected that the synchrophasor data will lead to large-scale outage avoidance and early detection of equipment problems.

D. WAMS experience in Italy

Also a second case is related to WAMS and PMUs, where TERNA, the Italian TSO, shares their operational experiences of the WAMS for the synchronised monitoring of the Italian power grid interconnected with the Continental European system. Currently, 55 substations in Italy are monitored by PMUs, mainly on 400 kV level.

Functions have been developed for oscillatory stability analysis, network separation detection, load shedding intervention evaluation and line thermal estimation. The development of real-time functions is still ongoing, also in view of implementing Wide Area Control/Protection System (WACS/WAPS) solutions.

Fig. 5 A typical geographic display of the WAMS platform. The background colors of the map depend on the voltage magnitude

The WAMS platform, available to operators in the control room, provides a valuable support to operation. Real-time plots and charts of system quantities such as phase angle differences, and the output of monitoring functions such as oscillation identification, allow operators to better track system stress and dynamic phenomena, and evaluate the possible impact of switching actions. An example of a typical geographic display is given in Fig. 5. Cooperation with other countries of the same synchronous area, in the form of real time PMU data exchange, has proven being particularly useful.

E. Situational Awareness

Another possibility to improve the network operation based on increased information is the “Situational Awareness System” that is being implemented in South Africa.

The idea with situational awarenesss is to combine the electrical interconnected power system with environmental conditions and by doing so being able to more accurately anticipate future problems to enable effective mitigation actions.

Grid situational awareness provides real time support for decision making based on real-time event management, forecasting, power stability and management through dynamic system sources.

The South African utility, Eskom, describes a Proof of Concept which aims at investigating the feasibility, requirements and development of a visualization server stack for the grid situational awareness concept. The Proof of Concept focuses on integrating various data sources. This data enables Eskom to be able to make better decisions. Experience is essential for implementing and applying the data.

The majority of the time in this project was focused on collaborating with different providers of data, possible users of the data throughout the business as well as system architects in order to establish a road map for future implementations regarding the integration and visualisation of data from disparate sources.

Information is needed from all parts in the system and advanced, accurate and fast applications are required. Within a sound business management system (BMS), supervisory control and data acquisition (SCADA) and other Network Information Systems (NIS) will enable better, automated management of energy, assets, distribution and demand-side activities as well as substation automation. This complex interdependence, which is illustrated in Fig. 6, raises the urgent need for interoperability among different components and “systems of systems” from diverse vendors that need to “talk” to each other.

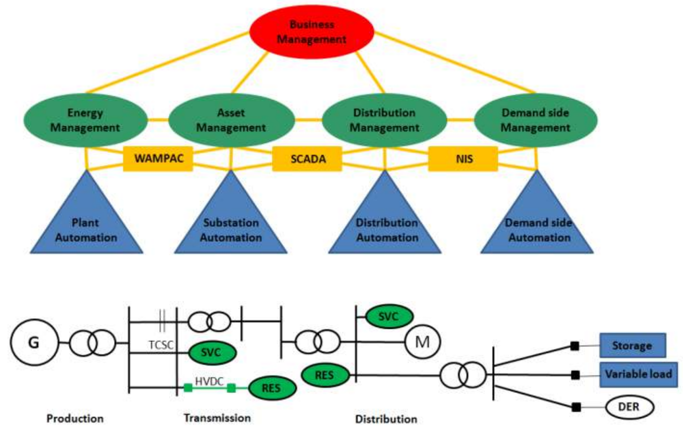

Fig. 6 Illustration of the information interdependencies of the power system including for example wide are monitoring, protection and control (WAMPAC), supervisory control and data acquisition (SCADA) and network information systems (NIS).

Also the evolution in the grid operation sector will require an even closer cooperation between transmission system operators and distribution system operators. Further discussions regarding this topic can be found in [5].

F. *Smart Substation*

France has in the Smart Substation project an industrial pilot project with experimentation of a new technological package including new advanced control functionalities. The project is executed by a consortium led by the French TSO, RTE.

The project aims to design, build, test and operate two fully digital smart substations by 2015: one transmission substation; and one distribution substation. The distribution substation represents the interface between the transmission and distribution systems. The digitalized architecture will be deployed on existing substations.

The project will assess the benefits provided by solutions such as a lower environmental impact, better integration of the renewable energy sources, improved transmission capacities, and optimal use of the existing assets.

The intention with the project is to enable the electrical power equipment to work closer to their physical limits. At a national scale, a transmission system using smart substations is able to transport more energy than a traditional grid. The development of digital substations enables, not only locally but also at a national scale, an optimization of the development and reinforcement of the transmission grid. The introduction of digital technology in all transmission substations is also a technological solution that will contribute to reaching the European commitments in terms of renewable integration.

V. Distribution Grids and Customer Activation

A. *Distribution Grids*

The distribution grid has often been built with very traditional technologies offering low cost and high reliability. But with the described changes in the energy system, new solutions must be found to allow an efficient way to meet the new challenges, without endangering the reliability or resulting in high costs. Increased controllability as well as new market models will provide the opportunities to meet these challenges. Tests and implementation of smart functionality in the distribution grid has demonstrated increased capability to operate the grid safely closer to physical capability limits and increased the hosting capacity for renewable electricity production, without the need for investments in new primary infrastructure.

B. *Active Distribution Network*

An example of projects aiming at increasing the hosting capacity for renewable electricity production in low and medium voltage networks is given in the Austrian case in the case book.

The main goal of the Austrian project is to find an efficient way for the integration of renewable electricity production with regard to optimized investment by maximizing the utilization of the existing asset base.

The main challenge of integrating distributed energy resources (DER) in rural distribution networks, as pointed out in the case book, is to keep the voltage within the specified limits, which the project aims at doing through the use of smart planning, smart monitoring and smart control.

For medium voltage networks with high share of distributed generation, two different control possibilities have been investigated for maintaining the voltage within its permitted band: a stand-alone solution integrated at substation level based on measurements; and a solution in a distributed management system based on state estimation. Both solutions are controlling setpoints of the on-load tap changer transformer and generators.

In the project led by Austrian Institute of Technology, AIT, it has been demonstrated that the implementation of voltage control concepts in medium and low voltage networks can increase the hosting capacity significantly.

C. *Customer activation*

One of the drivers pointed out to build smart grids is the activation of customers. Activation of customers includes activating customers with own production, which increases the amount of renewables, but it also includes different ways to change the customer load profile. A smoother load profile increases the efficiency of the system. Activation of customers is a very wide area, but this could be achieved among others by getting more consumers participating, directly or indirectly, in the electricity market and through new tariff structures such as time-of-use tariffs.

D. Customers´ respons under time-of-use tariffs

The second Italian case describes their experience of introducing time-of-use tariffs and the effects of such tariffs on electricity consumption by residential customers in Italy. The long-term goal is to induce the Italian customers to adjust their consumption according to the abundance or scarcity of electricity. This will for example lead to less need of reinforcements in the network due to a reduction of the load during peak hours.

The results show that, even if there was a limited shift of consumption from peak hours to off-peak hours in the period following the introduction of the mandatory ToU tariff, the change in the behaviour of the users is not negligible The role of the customers in shaping their energy consumptions as active users to face time-dependent electricity costs has been shown in the project. The research project was run by RSE (the Italian TSO) in collaboration with and under the patronage of AEEG (the Italian regulatory agency).

VI. CONCLUSIONS

The purpose of this article and of the casebook is to illustrate lessons learned and to highlight a wide range of applications related to power T&D systems or smart grids. The examples are intended to support the value smart grid solutions can bring in order to integrate renewable energy, improve the market, activate customers, and increase the security of the electricity supply.

The following examples, chosen from various countries and addressing several technologies, offer a variety of lessons learned:

- United States: Synchrophasors increase power transmission in existing transmission infrastructure, allowing the introduction of more renewable energy, and increasing the reliability of electricity supply.
- Sweden: HVDC advanced voltage source converter (VSC-HVDC) technology increases transmission capacity and helps avoiding voltage collapse in the grid. AC and DC overhead and underground cables are combined to upgrade the capacity in existing transmission corridors to minimize the environmental impacts.
- Ireland: VSC-HVDC technology is used to build a combined submarine and underground interconnector, linking two electricity markets and thereby decreasing electricity prices and increasing the security of supply. The project provides a good illustration of community involvement, simultaneously increasing the acceptance of the project and youth interest in engineering.
- Austria: Smart solutions in the distribution grid increase the hosting capacity for distributed energy resources, including renewable electricity production, other types of distributed generation, demand response, and electric vehicles. The case illustrates that capacity can be increased without adding primary infrastructure.
- France: Smart substations demonstrate how electrical equipment can operate closer to its limits, thereby minimizing investments. At the same time, functionality has increased with enhanced monitoring and diagnostics. New sensor technologies improve operation and maintenance of equipment.
- South Africa: A new visualization system reduces down time and improves operation, maintenance planning, and fault-location.
- Italy: Time-based tariff systems increase customer involvement and improve the efficiency of the system by balancing peak and off-peak consumption to better fit with the availability of power. Several proposed applications may further improve the systems.
  In addition, WAMS technology improved the operation of the transmission system by better tracking of system stress and dynamic phenomena that potentially could lead to system disturbances.

VII. ACKNOWLEDGMENT

This paper is based on the ISGAN Annex 6 case book and on the work done by the authors of the included cases: Séamus Power, EirGrid; Ulf Moberg, Svenska Kraftnät; Phil Overholt, Department of Energy; Diego Cirio, RSE S.p.A. - Ricerca sul Sistema Energetico and Giorgio Giannuzzi, TERNA; Oswald van Ginkel and Renier van Rooyen, ESKOM; Michel Bena, RTE; Helfried Brunner, AIT; Simone Maggiore, RSE S.p.A.

Others that have contributed to the paper are: Math Bollen, Carl Öhlén, Oscar Lennerhag, and Eero Heikkinen, STRI; Brian Marchionini, DoE.

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Secured Information Exchange In Smart Grid

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Keywords: Smart-grid, structure, integration of renewable energy resources, bidirectional data flow, spread-spectrum, direct sequence spread spectrum, PN sequence, frequency hopping spread spectrum.

Abstract:

Smart Grid is a cyber-physical system that integrates power infrastructure with information technologies. To facilitate efficient and secure information exchange wireless networks must to be widely used in smart grid. But the open nature of the wireless network has raised issues of confidentiality and security of transmitted information .Various attacks such as eavesdropping, information tampering, and jamming and malicious control command injection.In present we use conventional wireless methods for exchanging all kinds of information of demand, protection system, tariff rate, customer details, safety details along with power quality data and event management data. This information has to be transmitted securely else the system can be vulnerable to third party interference or even more. ‘Spread spectrum’ technique is an important ingredient that prevents such attacks in wireless communication as well as achieve the privacy of dynamic system state information during transmission. These low probability of intercept (LPI) and anti-jam (AJ) features are why the military has used spread spectrum for so many years. Spread spectrum signal are transmitted at a lower spectral power density, measured in watts per hertz. The use of Pseudo-Noise (PN) codes in spread spectrum makes signal appear wide band and noise-like.

The paper focuses on the different technology like Frequency Hopping Spread Spectrum (FHSS) and Direct Sequence Spread Spectrum (DSSS) for secured exchange of information to ensure better QOS (Quality of Service) and reliability as well as to prevent any distortion in data at the receiver.

1: Introduction:

1.**1what is a smart grid?**

In general smart grid is the modernization of electrical power delivering system that can integrate the actions of utility and consumers in order to deliver sustainable and secure electricity supply. It provides a power system capable of two way communication, real time monitoring and control. Thus improves overall efficiency and also includes integration of renewable energy into the existing system. The limitations of the existing grid, degradation in the quality of power with significant increase in demand can be settled with modernization of the grids or smart grids.

1.2. What are the limitations of the existing grids?

i. Less reliability
ii. Lower efficiency
iii. Inability to meet higher demands
iv. High cost
v. Poor power quality
vi. Environment pollution
vii. Unable to take care of customers' choices
viii. Vulnerability to natural calamity and third party interference

1.3 Main features of smart grid:

i. Intelligent
ii. Efficient
iii. Capable of accommodating energy from any source
iv. Real time monitoring and/or control to motivate consumers to control their energy consumption
v. Better power quality
vi. Resilient to interference and jamming
vii. Environment friendly
viii. Integrating renewable energy

1.4 Structure of smart grid

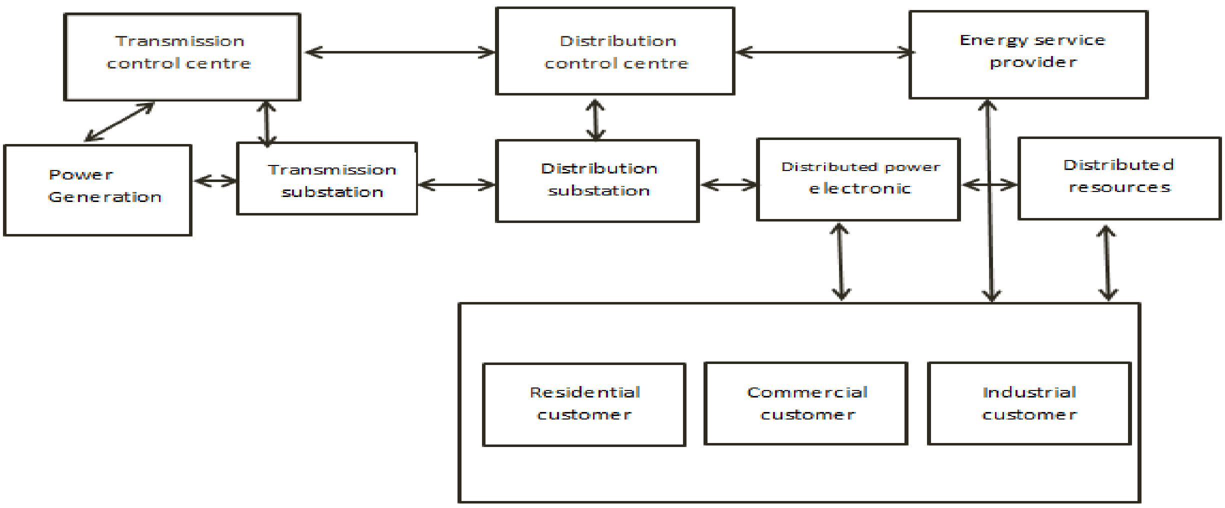

Fig:1: Structure of smart grid

1.5 Advantage of smart grid

a) Energy conservation and less environment pollution.
b) Bi-directional flow of power, Real time monitoring & information supply and demand balancing.
c) It provides Automatic Meter Reading(AMR) remote connection and load management.
d) Allow integration of Renewable energy resources to the system.
e) Better choices for consumer to monitor and control their energy use.
f) Reduces Harmonics of the system and thus improving power quality.
g) Enhances the level of reliability and security of supply.

h) Improves the economy of the system with efficient management of power supply.

Bidirectional data flow of information is required in smart grid to create an automated and widely distributed network which also requires real time information to manage the electric power efficiently. While transferring all this information from one grid to another if gets leaked to any other will make the power system vulnerable to jamming, third party interfering, even to terrorist attacks. Normally we use wireless communications for sharing the information which can be tampered easily. So extra security measures must be taken to ensure secure transmission of information throughout the grids.

4. **<u>Structural analysis:</u>**

4.1 **Information shared over smart-grids**

i. Smart metering data
ii. Operation event data
iii. Power quality details
iv. Protection system fault data
v. Asset management data
vi. Demand response data
vii. Station maintenance data
viii. Engineering data
ix. Load profile recording
x. Pre-payment details
xi. Tariff plan details
xii. Contact management details
xiii. Expense estimation
xiv. Safety details
xv. Load distribution data

4.2 **Using the information:**

This information is used in different utilities, generating stations, distribution stations in different systems like

i. SCADA (Supervisory Control And Data Acquisition)
ii. EMS (Emergency Management System)
iii. DMS (Distributed Management System)
iv. GIS (Geographical Information System)
v. SER (System event Recording)
vi. DFR (Digital Fault Recorder)

4.3 **Recent communication systems used in smart grids:**

4.3.1 PLCC (Power Line Carrier Communication)

This method is used for bidirectional data communication between customer and the utility. But it has a small bandwidth which is not applicable for widely distributed network as in smart grids

4.3.2 ZIG BEE

It includes home automation and control, industrial real time monitoring, use of wireless sensors etc.

4.4 **SECURITY LAYERS NEEDED IN SMART GRID**:

Smart grid communication system framework includes security layers such as

- Physical security
- Equipment security
- Network security
- Application security
- Information security

For secure transmission of the information for efficient use of the electrical energy, they must be encrypted. One of the various methods is spread Spectrum method.

This can be achieved by direct sequence spread spectrum and frequency hopping spread spectrum methods.

4.5 **Spread spectrum**

Spread-spectrum techniques are methods by which a signal (e.g. an electrical, electromagnetic, or acoustic signal) generated with a particular bandwidth is deliberately spread in the frequency domain, resulting in a signal with a wider bandwidth. These techniques are used for a variety of reasons, including the establishment of secure communications, increasing resistance to interference, noise and jamming, to prevent detection, and to limit power flux density (e.g. in satellite downlinks).

How spread spectrum (ss) work?

Spread spectrum uses wide band, noise like (pseudo-noise) signals. Since spread spectrum signals are noise like, they are hard to detect. Spread spectrum are also hard to intercept or demodulate making the secure. Further, spread spectrum transmissions are hard to jam (interfere with) then narrow band signals. Because of the above two properties, this form of telecommunications has been used by the military since its conception. Spread spectrum signals use fast codes that run many times the information bandwidth or data rate. These special codes are called pseudo random or pseudo noise codes, since it appears to be random noise, however there is nothing random about it.

Spread spectrum transmitters use similar transmit power levels to narrow band transmitters, but because spread spectrum signals are so wide ,they can be transmitted at much lower spectral power density (measured in Watts per Hertz) , then narrow band transmitters. Since spread spectrum (SS) is transmitted with low power, but wide bandwidth, a SS and narrow band signal can occupy the same band with little to no interference.

Most SS systems transmit a radio frequency signal bandwidth as wide as 20 to 254 times the bandwidth being sent. Some SS systems have employed radio frequency bandwidths 1000 times their information

The performance increase for very wide band systems is referred to as process gain. This term is used to describe the received signal fidelity gained at the cost of bandwidth.

The numerical advantage is obtained from the **Claude Shannon's equation** describing channel capacity:

$$C = Wlog\left(1 + \frac{S}{N}\right)$$

Where; C=channel capacity, S=signal power, W=band width, N=noise power

From this equation the result of increasing the bandwidth becomes apparent. By increasing W in the equation, the S/N may be decreased without decreased performance. The process gain (GP) is what actually provides increased system performance without requiring a high S/N. This describes mathematically as:

$$GP = \frac{BWRF}{RINFO}$$

Where; BWRF= Radio Frequency Bandwidth, RINFO= Information Rate

There are two types of the spread spectrum techniques **Direct-sequence spread spectrum** & **Frequency hopped spread spectrum.** Direct sequence spread spectrum is technique in which data sequence directly modulates the pseudo noise sequence known to only transmitter & receiver. Frequency hopping means to transmit data in different frequency slots.

4.5.1 **Advantage of spread spectrum**

a. Reduced Interference
b. Better quality of data integrity
c. Lower susceptibility to multiple fading.
d. Harder to detect, demodulate and jams
e. Inherent security
f. Co-existence (less interference with each other)

4.6 **Direct sequence spread spectrum**

Direct sequence spread spectrum systems are so called because they employ a high speed code sequence, to modulate their RF carrier. The high speed code sequence is used directly to modulate the carrier, thereby directly setting the transmitted RF bandwidth. In direct sequence spread spectrum (DSSS) the binary data is directly multiplied with the PN sequence at transmitter side. The direct sequence spread spectrum is like white noise. The amplitude & thus power in direct sequence spread spectrum signal is same as in original signal. Due to the increased bandwidth of direct sequence spread spectrum signal the power spectral density must be lower. After dispreading the received signal with the same PN sequence data is obtained. The properties of the direct sequence spread spectrum are efficient modulation, broad modulation bandwidth, continuous transmission, quick synchronization, low power spectral density, minimized interference.

PN codes utilised in a spread-spectrum system for:

- The processing gain increases the code length as well as bandwidth and signal likely transmit below the noise level that protect against interfering signal.
- Randomness
- Unpredictability.

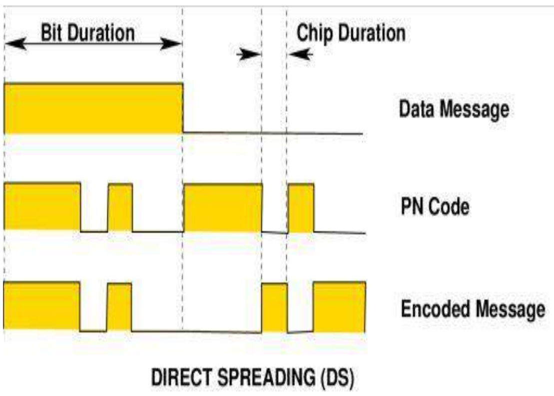

Fig:2: pn sequence code generation

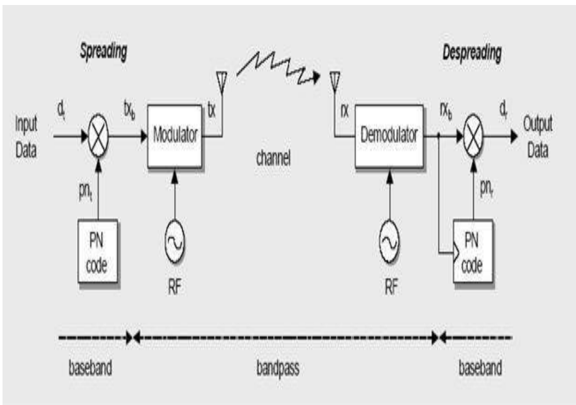

Fig:3: model of a direct-sequence spread bpsk system

5.2 **Spreading and modulation in dsss:**

In DSSS we need to spread the data over a higher bandwidth before modulating. So first of all the input data is multiplied by a noise like signal (Pseudo noise) i.e. a binary signal with higher value at +1 and lower value at -1. This PN code has a frequency which is approximately 1000 times that of the input signal. It produces the baseband signal as tx_b. Where $tx_b = d_t \times pn_t$

Now the baseband signal bandwidth = R_s

After spreading the signal is modulated using a suitable carrier signal (sinusoidal) and transmitted over the channel.

5.3 **Demodulation and de-spreading in dsss:**

The spread spectrum signal cannot be detected by convention narrowband receiver .In the receiver, the baseband signal rx_b is multiplied with the PN sequence pn_r to dispread the signal i.e. to decrease the bandwidth to its original value.

If $pn_r = pn_t$ and synchronized to the PN sequence in the received data, then the binary data is recover on d_r; otherwise dispreading is not possible.

Then the sent information can be extracted from the signal using coherent carrier demodulation. To simplify the description of modulation and demodulation, the spread spectrum is considered for BPSK Communication (without filtering) over a channel.

Simulation output:-

The input Bits : [1 0 1 0 1 1 0 0 1 1 0 1]

Length of each bit to be long 50

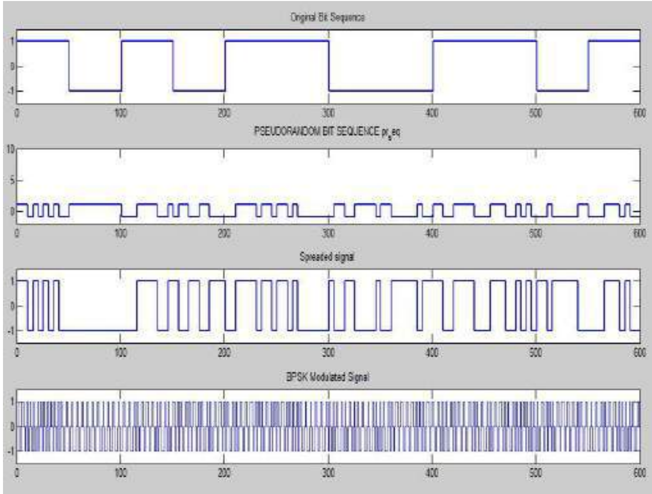

Fig:4: Simulation Output

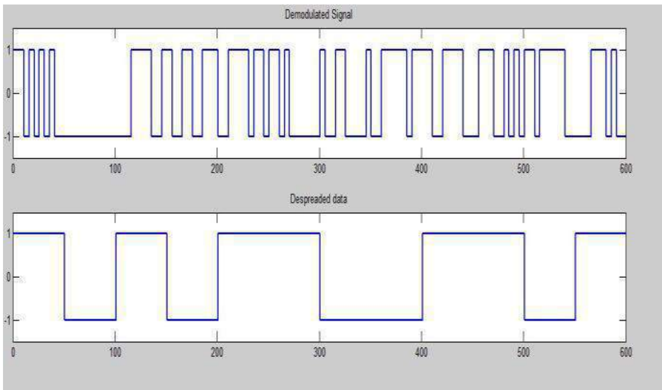

Fig:5: Demodulation & de-spreading

6. **Discussion**

In wireless communication serious security threat is eavesdropping attack, jamming and interference.

Ability to Selectively Address. By setting the transmitter's code, we can target a specific receiver in a group, or vice versa. This is termed “Code Division Multiple Access”.

Bandwidth Sharing. It is entirely feasible to have multiple pairs of receivers and transmitters occupying the same bandwidth. In a world where the radio spectrum is being busily carved up for commercial broadcast users, the ability to share bandwidth is a valuable capability.

Security from Eavesdropping. If an eavesdropper does not know the modulation code of a spread spectrum transmission, all the eavesdropper will see is random electrical noise rather than something to eavesdrop. If done properly, this can provide almost perfect immunity to interception.

.These characteristics endeared spread spectrum communication to military community, who are understandably paranoid about being eavesdropped and jammed.

Based on our discussion in this project, it is clear that implementing an integrated and fine-grained security solution that is able to address potential security and privacy issues in each sub-system of a smart grid is critical to guarantee its successful deployment. Moreover, the design of security solutions should take into account the salient features of the smart grid as well as the underlying power system. Looking to the future, the joint efforts from industry and academia will make the era of “smart energy” become reality at a staggering speed.

7. Conclusion:-

Smart-grid metering and control systems hold enormous promise for improving efficiency, convenience, and sustainability. However, the complicated and heterogeneous system architecture has made securing the smart grid particularly challenging. We introduced the spread spectrum architecture for smart-grid secure data transmission detailed the system's security requirements, summarized the recent efforts from industry and academia, and highlighted several areas and directions for further research.

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Analysis of Adaptive Over Current Protection Schemes for Active Distribution Network

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***Abstract*-With the integration of Distributed Generation units into the existing distribution system, the protection schemes get constrained. Specifically the existing over current relay fails as the fault current level is altered in every feeder due to the integration of DGs. Fault current seen by the relay may increase or decrease based on DG location. Further, due to the presence of DGs the power flow is not unidirectional rather it becomes bidirectional. Due to this the overcurrent relays lose the dependability and selectivity. In the process primary and backup overcurrent relays may lose the coordination. In this work, an adaptive negative sequence based over current relaying scheme is proposed to overcome the relay coordination problem. Typical IEEE 14 bus (18 kV) micro grid system is simulated using Real Time Digital Simulator (RTDS) to realize the effectiveness of the proposed technique.**

Keywords— Adaptive overcurrent protection schemes, microgrids, the mode of operation, protection issues.

I. INTRODUCTION

Microgrids are power systems that combine renewable energy sources, combined heat and power (CHP) plants. This combination of different kinds of generation or distributed generations (DG) is configured in a way to improve reliability [1]. Fig. 1 shows the construction of a microgrid that has numerous power sources and controllable loads. Microgrid experiences conditions like the grid-connected and islanded mode [2]. Under such conditions, the power flows are bidirectional which change passive distribution networks to active [3]. In the event of islanding, short circuit currents would be small. Therefore, protection schemes could not detect the faults. The existing protection scheme fails to work while switching between the two modes. Another protection issue is the overcurrent relays as they are having an inverse current time characteristic and the trip time would be very large or infinite in the case of islanded mode [5]. Other protection issues in distribution network equipped with DGs are recloser-fuse coordination [6], sympathetic tripping [7] and relay-relay coordination [8].

The protection scheme is largely influenced by the presence of DG units connected to the distribution network. To extenuate the DG's impact on the protection system, several methods have been proposed by the researchers, which are classified as

1. Disconnection of DG instantaneously after fault detection [9]
2. Reconfiguration of network using protective devices (extra breakers or recloser, or using distance relays or directional relays) [10]
3. Adaptive protection [11]-[12]
4. Deployment of fault current limiters (FCLs) [13]

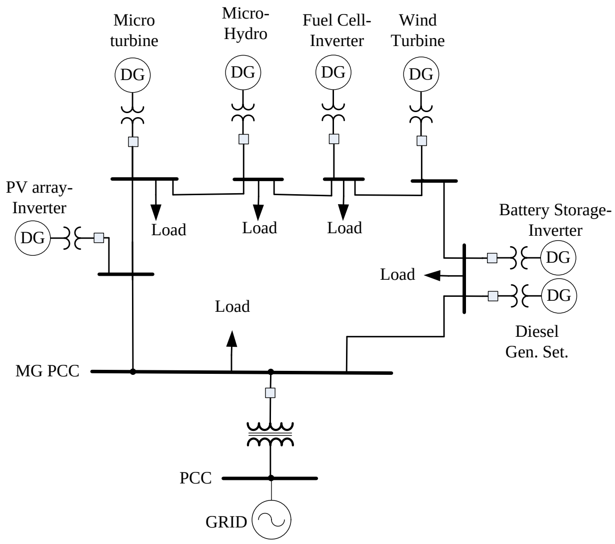

Fig. 1. Microgrid architecture

The high cost of the reconfiguration of a network or deployment of FCLs makes it difficult to protect microgrid. Therefore, integrating an adaptive protection system with the control system is a reliable solution. Microgrids need an adaptive protection scheme which can adapt when the system switches between two modes. In this work an adaptive, Negative sequence based over current relaying scheme is proposed to overcome the relay coordination problem in a system with DGs. The ratios of fault currents (fault currents with and without DGs) at the relay location are taken into account to update adaptively time multiplier settings (TMS) of the backup relay with respect to the primary relay. Typical 14 bus (18 kV) micro grid system is simulated using Real Time Digital Simulator (RTDS) to realize the effectiveness of the proposed technique. The current signals are stored at a sampling frequency of 1 kHz and one cycle DFT is used to estimate the phasor. Many test cases are considered and the proposed technique is found to be accurate.

II. Real Time Digital Simulator

The RSCAD software represents the state-of-the-art in the power system simulation environment, which consists of power systems and control components in a graphical user interface. More information regarding the RSCAD software is referred in [14]. The RSCAD software consists of individual modules. The draft module is to assemble a power system model using power and control system components, whereas the run time module can alter system parameters and operating scenarios in the system model during a simulation run. The user can also monitor power system parameters which are received from the RTDS.

RTDS (Real time digital simulator) [15] is a professional simulation tool with which the real-time power-system electromagnetic phenomena can be calculated. The RTDS simulator is used at the Department of Electrical Engineering, IIT-Roorkee is established with six racks. Each rack has been provided with different type of cards to perform multiple functions.

1. GPC (Giga Processor Card-PB5 version) card
2. GTNET (Giga Transceiver network) card
3. GTWIF (Giga transceiver workstation interface) card
4. GT input/output cards
5. GTSYNC (Giga transceiver synchronization) card

Each rack is equipped with three GPC (Giga Processor Card-PB5 version) cards and each of them has two processors. These processor cards are used to solve the equations represent the power system and control system components.One GTNET (Giga Transceiver network) card within a rack is assigned to communication between the personal computer/hardware and the GPC cards via network protocols. One GTWIF (Giga transceiver workstation interface) card is installed to communicate with other racks participating in a simulation case. Apart from the above cards, RTDS has been provided with GTSYNC (Giga transceiver synchronization) card and GT input/output cards to facilitate the user to interface various types of external devices and/or software.

RTDS hardware showed in Fig. 2 makes it possible also to import and export signals to external devices which is particularly important for closed-loop testing of external equipment with a power-system model. In this way, the RTDS user can analyze the external device itself as well as its impact on the rest of the power system. There are many such programs available – ATP (Alternative Transients Program), EMTP (Electromagnetic Transients Program) and PSCAD/EMTDC. In each of these programs, the power system that generates the transient data can be modelled in detail. The relay protection scheme must be tested with transient data generated from an electromagnetic transient simulation program.

In this paper, the proposed relay protection scheme is tested in a real time using areal time digital simulator (RTDS). Proportional secondary voltage and current signals which the overcurrentrelay would see are used through detailed models of instrument transformers. The overcurrent relay protection scheme responds to the corresponding fault and trips the circuit breaker. The power system is simulated in real time with a time step of 50.0 microseconds.The appropriate signals are sent from RTDS to the overcurrent relays in and also the output of the overcurrent relays fed back to the simulator (software-in-loop). The following sections deal with system modelling on RTDS platform, overcurrent relaying scheme, results analysis, and conclusions.

Fig. 2. Photograph of RTDS and different type of cards diagram

III. System under Study

The proposed adaptive overcurrent scheme is tested on the standard IEEE-14 bus system. The IEEE-14 bus microgrid considered for testing is shown in Fig. 3 with possible interfacing of four DG units. The microgrid is connected with loads at each bus. The system parameters are given in Appendix A. Phase over current relay, R2 is located at bus B2 whereas negative sequence over current relay, R1 is located at bus B2 and various faults are created at F and results are tabulated.

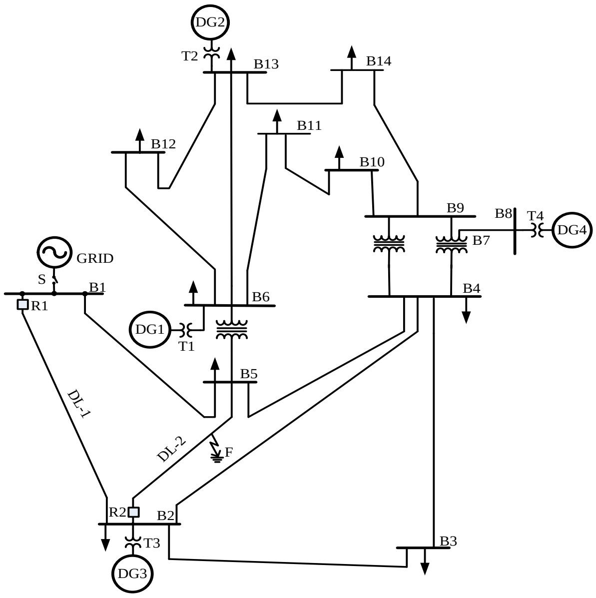

Fig. 3. System studied

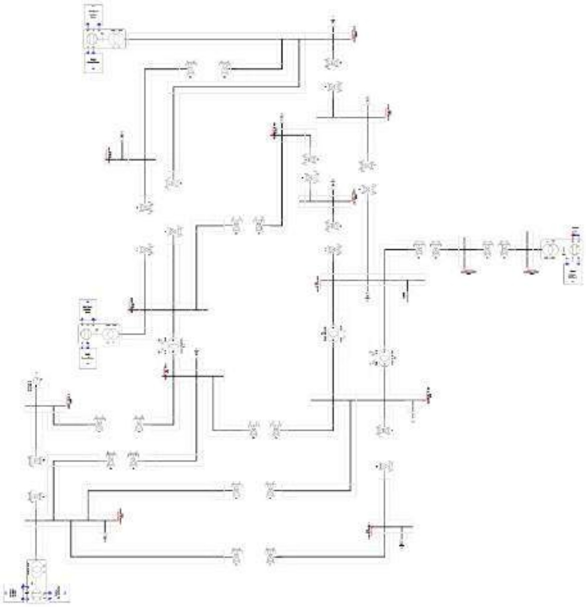

Fig. 4. RSCAD model of DG connected distribution network

18kV, 50 Hz IEEE-14 bus microgrid as showed in Fig. 4 is simulated in Real Time Digital Simulator. The power network consists of two lines (DL-1 and DL2) and loads of constant impedance type distributed on each bus. Overcurrent relays with inverse definite minimum time characteristics are

TABLE I
SETTINGS OF OVERCURRENT RELAYS

Relay	CT Ratio	Pickup current, A	TDS
R1	450/1	0.92	0.1
R2	250/1	0.82	0.07

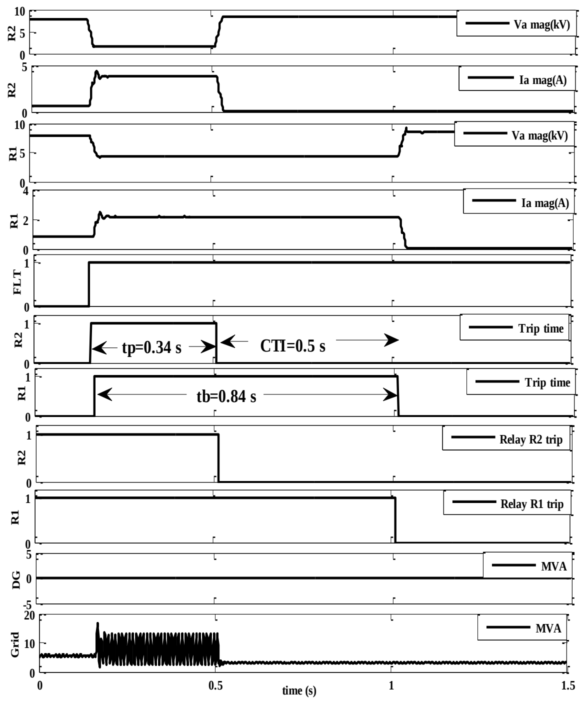

Fig. 5. Primary and back up overcurrent relay response when DG is OFF

TABLE II
SETTINGS OF OVERCURRENT RELAYS INCLUDING NEGATIVE SEQUENCE

Relay	DG	CT Ratio	Pickup current, A		TDS
			Phase	NS	
R1	NO	450/1	0.92	0.53	0.1
R2	NO	250/1	0.82	-	0.07
R1	5 MVA	450/1	0.82	0.46	0.1
R2	5 MVA	250/1	0.95	-	0.07

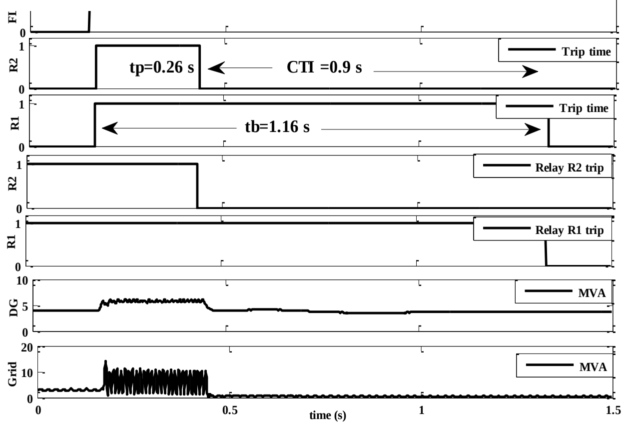

Fig. 6. Primary and back up overcurrent relay response when DG capacity is 5MVA

modelled to produce a trip signal. Table I presents current transformer (CT) ratio and overcurrent relay settings (TDS and Ip). Time dial setting (TDS) is evaluated for primary and backup overcurrent relays which satisfy the protection coordination by maintaining minimum Coordination time of interval (CTI) of 0.2 s. Pickup current is obtained from the maximum load current. Fig. 5 demonstrates the operation time of primary and backup overcurrent relays.

The same system simulated by connecting DG-3 at bus B2. The effect of connected DG on primary and backup overcurrent relays has been evaluated. The results in Fig. 6 indicate that there is a large increase in CTI as compared to the previous case.

IV. PROPOSED SCHEME

Most commonly overcurrent protection function use inverse definite minimum time characteristics which is given by

$$t = \frac{0.14}{\left(\frac{I_f}{I_p}\right)^{0.02} - 1} TDS \qquad (1)$$

Where t is operating time, TDS is time dial setting and I_p is the relay pickup current setting. The overcurrent relay may have phase over current element, negative sequence over current element. The phase over current relay is intended to isolate the faults section as soon as possible. Negative sequence over current relay [17] is an important depiction of power systems for fast and sensitive backup protection. Hence it is prospective to incorporate negative sequence into the protection scheme. Fig. 7 shows an operational diagram of the proposed scheme. Three phase current at the relay terminal stepped down using a current transformer with a CT ratio mentioned in Table II. These signals are processed to compute phasor through one-cycle DFT with 1-kHz sampling frequency. Negative sequence current calculated from phasor information which is denoted as I_2. Pickup value of phase over current relay is based on the maximum load current. Whereas the pickup value of negative sequence overcurrent relay is times load current. If the fault current is higher than the pickup current setting for t (1) seconds, a trip signal is produced.

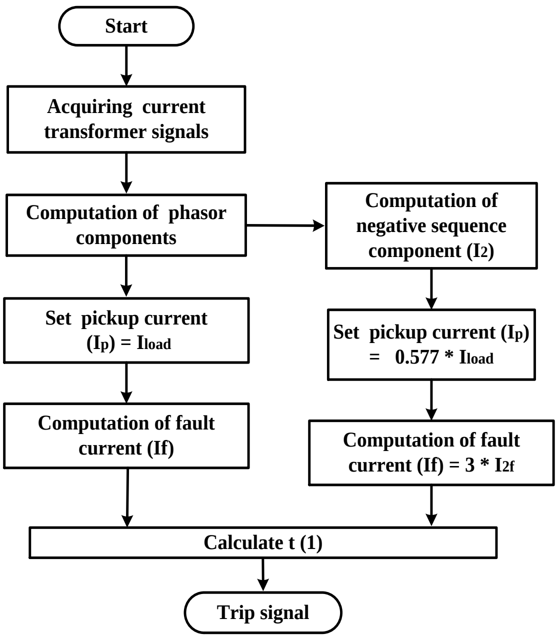

Fig. 7. Algorithm for over current relaying

Simulations are carried out to validate the proposed approach during connection of DG-3. Numerous cases were simulated and it was found that negative sequence over current relay provides a correct decision for backup operation but not phase over current relay. This is due to the fact that significant change in magnitude of the phase current from pre fault to fault condition when the DG-3 is connected. Whereas it is

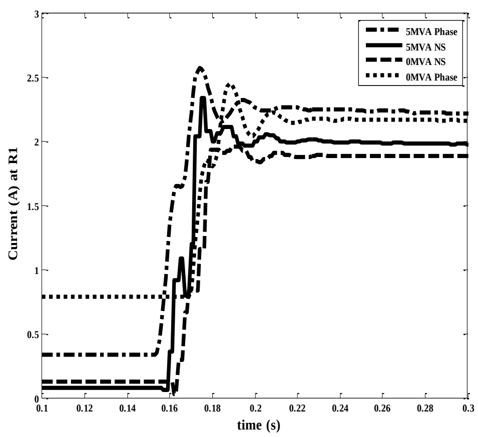

Fig. 8: Comparison of line to ground fault currents at backup overcurrent relay R1

observed that there is a small change in a negative sequence current from pre fault to fault condition as showed in Fig. 8. Using proposed approach, backup over current relay, takes less time to clear fault when distributed generators are connected to the distribution network. The results of the distribution network for the line to ground fault in the line are shown in Fig. 9. It is clear from the figure that with a negative sequence overcurrent relay to relay R1 CTI is reduced from 0.5 s to 0.3 s.

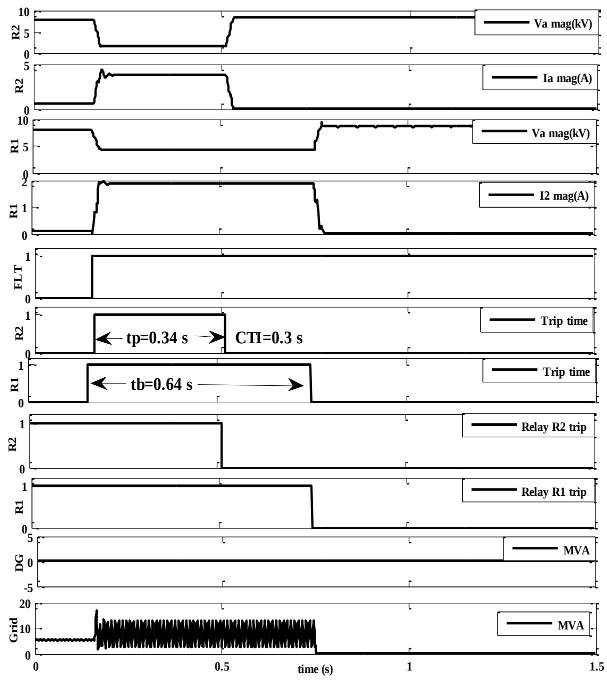

Fig. 9. Primary and back up (including negative sequence) over current relay response when DG is OFF

While the DG capacity of 5MVA is connected, the phase overcurrent relay pickup current is reduced due to decrease in load current. However, when the load current falls to a low value, the negative sequence overcurrent relay pickup value also decreases substantially which are provided in Table II. To demonstrate the performance of the proposed scheme, the same system is simulated by including DG at bus B-2. The effect of connected DG on primary and backup overcurrent relays has been evaluated where overcurrent relay settings are modified as per table II. The simulation results in Fig. 10 confirm that with the backup operation of negative sequence overcurrent relay provides very good performance in a distribution network consisting of DG, and thus infer the CTI from 0.9 s to 0.28 s.

The results clearly demonstrate that the negative sequence overcurrent relay significantly influences the tripping operation that is required for a distribution generation environment. A phase overcurrent relay will malfunction or slow in operation at many situations in such an environment. The negative sequence overcurrent relay should be provided where pickup values are updated with DG capacity.

Performance of negative sequence overcurrent relay as backup operation is verified for line to ground, line to line

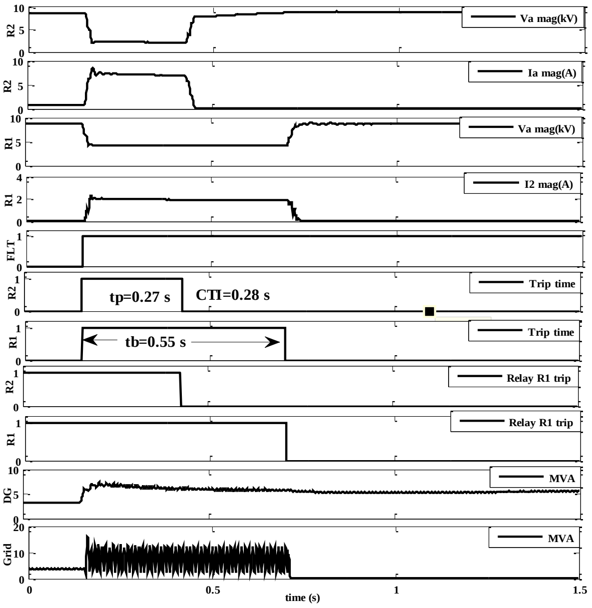

Fig. 10. Primary and back up (including negative sequence) overcurrent relay response when DG capacity is 5 MVA

fault and double line to ground faults which is shown in table III. Over current relay settings (TDS, Ip) are obtained at different levels of DG capacity. Time of operation indicates that the negative sequence overcurrent relay substantially reduces CTI. Whereas phase overcurrent relays have slow operation, which leads to large CTI between the primary and backup relays.

The results clearly demonstrate that the negative sequence overcurrent relay significantly influences the tripping operation that is required for a distribution generation environment. A phase overcurrent relay will malfunction or slow in operation at many situations in such an environment. The negative sequence overcurrent relay should be provided where pickup values are updated with DG capacity.

Performance of negative sequence overcurrent relay as backup operation is verified line to ground, line to line fault and double line to ground faults which is shown in table III. Over current relay settings (TDS, Ip) are obtained at different level of DG capacity. Time of operation indicates that the negative sequence overcurrent relay substantially reduces CTI. Whereas phase overcurrent relay leads to conclusion that slow in operation time, which leads to large CTI between the primary and backup relays.

V. CONCLUSION

The problem of protection coordination in distributed generation environment is addressed. The proposed approach is combining the use of negative sequence and phase over current relays. The simulations performed in the studied system show the reliable coordination between overcurrent relays for distributed generation. Results indicate that negative sequence overcurrent relay substantially reduces CTI. Unbalanced faults, various DG capacities are considered to test the proposed scheme. This paper concludes that the use of negative sequence overcurrent protection scheme as a feasible alternative to phase overcurrent relays for backup protection.

APPENDIX A

System data:
Parameters of the source are
Rated RMS line-to-line voltage=18 kV
Base voltage= 18kV
Rated short-circuit MVA= 100 MVA
Frequency= 50 Hz
Synchronous generator parameters are
Rated MVA: 5-9 MVA
Rated RMS line-to-line voltage= 2.4 kV
Base angular frequency (ω) = 50 Hz
Inertia constant (H) = 2 MWs/MVA
Machine Zero sequence impedances:
M_{rz}= 0.002 pu, M_{xz} = 0.130 pu, R_s =1.0 × 10^5 pu, X_s =0 pu
R_m = 0.5 pu.
Machine electrical data:
X_a=0.01pu, X_d=1.56 pu, X_d'=0.296 pu, X_d''=0.177 pu, G_{fld}=100 pu, B_{fld}=100 pu, X_q=1.06 pu, X_q'=0.177 pu, X_q''=0.052 pu, R_a=0.0036 pu, T_{do}'=3.7 s, T_{do}''=0.005 s, T_{qo}'=3.5 s, T_{qo}''=0.05 s
Exciter parameters are
Rectifier smoothing time constant (T_a): 0.02 s
Rectifier regulation factor (K_c): 0.2
Maximum field voltage control (V_{MAX}): 14.5 pu
Minimum field voltage control (V_{MIN}): −14.5pu
Integrator time constant (T_e): 0.8 s
Rate feedback time constant (T_f): 1.0 s
Exciter field current controller gain (K_b): 25 pu
Maximum exciter field current (kA, RMS): 8.0 pu

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TABLE III
PERFORMANCE OF BACKUP OVERCURRENT RELAY, R1

Fault Type	DG Capacity, MVA	CT Ratio	Fault current, A		Operation time, s		Pickup current (Ip), A		TDS
			Phase	Negative sequence	Phase	Negative sequence	Phase	Negative sequence	
LG	2	450/1	1.94	1.76	**1.03**	**0.63**	1	0.577	0.1
	2.5	450/1	1.82	1.58	**0.90**	**0.59**	0.85	0.49	0.1
	5	450/1	1.94	1.63	**0.75**	**0.55**	0.82	0.46	0.1
LL	2	450/1	2.27	2.79	**0.86**	**0.45**	1	0.577	0.1
	2.5	450/1	2.28	2.43	**0.72**	**0.44**	0.85	0.49	0.1
	5	450/1	1.65	2.55	**0.99**	**0.42**	0.82	0.46	0.1
LLG	2	450/1	2.38	1.84	**0.80**	**0.60**	1	0.577	0.1
	2.5	450/1	2.33	1.72	**0.69**	**0.56**	0.85	0.49	0.1
	5	450/1	2.2	1.98	**0.74**	**0.55**	0.82	0.46	0.1

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Innovative Business Models for Smart Grid Deployments

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***Abstract*— The objective of this paper is to demonstrate the various business models available with utilities to undertake smart grid deployment. "Smart" projects are capital intensive with investments in smart meters, customer interface units, head-end and MDMS system and software. In addition, there is considerable operating expenditure consisting of communication costs, licensing cost, etc.**

Utilities can self-fund/ consumer-fund (tariff) these projects or can partner with a private player. Self-funding is a big challenge for utilities which are in any case struggling with their financial health. Thus, there is a need for innovative business models, which do not burden the utilities. Private participation can be encouraged though various models like fixed fee based, revenue improvement sharing based, cost reduction sharing based or power quality improvement linked fee based. The decision on which business model to adopt depends on a number of factors like availability of funding with utility, utility's willingness to fund the project on its own balance sheet, legal and regulatory framework, and presence of such service providers in the industry.

In the quest for going "Smart" the utilities first need to shortlist the business model that would work best for them. Then a comprehensive business case is essential for achieving funding for smart grid projects. The business case must clearly capture the costs and benefits and risks of the project. It should originate from the business need of the project, defining the functionalities required from the system to achieve this need. The next steps are seeking regulatory approvals before initiating a process to appoint the service provider. The paper will discuss one such success story from the developing world where the utility and the community are benefitting from adoption of an innovative business model.

***Keywords*— business models for smart grid, smart metering, utilities, innovative business models, cost benefit analysis**

I. Introduction

Deployment of information and communication technology (ICT) is transforming utilities. This metamorphosis is made possible by use of real-time information to manage supply and demand efficiently, sustainably and economically. There are a number of benefits utilities can draw from this transformational change – operational and financial. ICT interventions can also help improve the relationship that utilities have with their customers, which has largely been restricted to billing until now [1].

Embracing technology however comes with its own costs. Smart grid programs are known to be capital intensive along with requirement for significant opex. There are a number of components that go in to create a smart grid project. These are determined by the functionalities that the utility is looking for from the smart grid rollout. Thus, the starting point for utilities is to understand how smart technologies can help them in achieving their business objectives better.

The next and more challenging step is to finalize the business model for the project. Already pressured by tighter revenue, many utilities are struggling to attract the investment needed to upgrade existing assets and fund the development of the more complex infrastructure as demanded by smart. Current estimates show that a US$17t investment is needed in global power infrastructure through 2035 [1]. Utilities may explore various business models like self-funding, governmental grants, viability gap funding, revenue-share or benefit-sharing models. However, each model comes with their pros and cons and the utility along with consultation with the appropriate Regulator needs to finalize the business model for the project.

In the Indian context, most Indian power utilities are suffering from huge financial losses, estimated to be around INR 2 Lakh Cr. (2010) [2]. In such a scenario, projects supporting utilities business get priority over transformational projects. In such a scenario, there is merit for the utilities to explore innovative business models which in some cases may be a hybrid of two or more models.

This paper first provides an overview of typical project sizes with specific examples from across the globe and goes on to discuss the typical challenges faced by utilities in raising funds. Next, it discusses a variety of innovative funding options available with the utility to meet the capex and opex requirements for smart projects. Lastly, it lists the steps various stakeholders (including utilities, regulators, policy makers etc) can take for embracing smart transformation. Successful deployment of smarter grid will strengthen "Access, Availability and Affordability of Power for All" agenda as well.

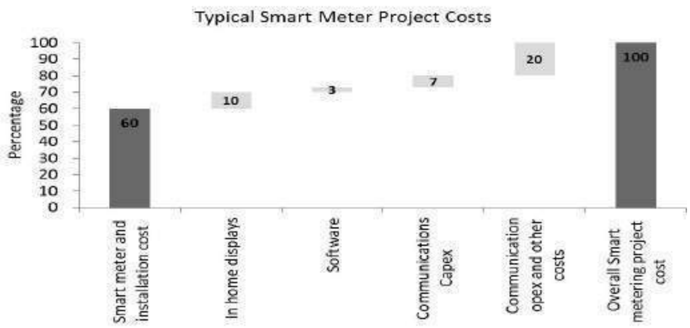
II. COST INGREDIENTS OF "SMART" RECIPE

There are a number of components which go into making a smart grid. These depend on the functionalities required from the project. Smart projects are a combination of hardware – electrical and computing, software and communication modules. A seamless integration of these components can provide new capabilities to the utilities and can go a long way in improving the customer experience.

For instance, a basic smart metering project comprises of smart meters, data concentrators, head-end servers, MDMS servers and in-house display. These form part of the hardware requirements for the project [3]. There can be additional components based on the functionalities required from the project. In addition, smart metering projects require the back-end software solution to validate process and manage the large amounts of data flowing at regular intervals from the meters. Some of the systems that may be included are MDMS, prepayment engine (if required), analytics solution, and integration with billing, customer-care and outage management. In addition, activities of survey, meter installation and de-commissioning, and customer engagement also involve expenditure.

Operational expenses are also a considerable component of smart grid projects. Since communication is pivotal to smart grid projects, depending on the technology, it can form a substantial part of the opex. In addition, license fee, annual support and maintenance form part of the opex.

For a typical smart metering project, the percentage break-up of costs is shown below:



Source: EY research

On the benefits side, there are several benefits which utilities can achieve from smart transformation. Key benefits a utility can get out of smart rollout are illustrated below [4]:

Improve Customer Operations	Costs of manual meter-reading	⇩
	Cost of special meter visits	⇩
	Cost of Disconnection and Reconnection	⇩
	Customer complaints	⇩
	Customer contact volume	⇩
	Faulty meters	⇩
	Cost of billing operations	⇩
Improve Distribution Network Operational Efficiency	Field force cost efficiency of asset maintenance	⇧
	Field force cost efficiency of outage response	⇧
	Prioritization of outage restoration by lost revenue impact	⇧
	Operational costs of network planning	⇩
	Grid Stability	⇧
Defer Distribution Capital Expenditures	Asset failure	⇩
	Deferred Distribution capacity investments	
Revenue Protection	Non-Technical Losses	⇩
	Technical Losses	⇩
	Cost of client compensations from outages	⇩
Improved Market Efficiency	Cost of energy peak generation / purchase	⇩
	Improved settlement process in the energy market	
Deferred Generation Capital Expenditures	Deferred investment generation capacity	
	Spinning reserves extending the lifetime of current generation assets	⇩
Retail	Provision of new services through upselling and tariff bolt-ons	⇧
	Extended and enhanced advertising opportunities	⇧
	Enhanced Data Broker Opportunities	⇧
	Improved Marketing Efficiency	⇧
	Supplier switching process rationalisation	⇧
	Improved customer engagement and trust in order to reduce churn	⇧
Regulatory	Reduced risk of rate case failure	
	Streamline the rate case process	
	Enhance the new rate design process and the consolidation of existing rates	

	Demand Response Verification	
	Outage Minutes Validation	
	Improved Reliability of Supply (e.g. CAIDI/SAIDI) and thereby increased recovered revenue	
	Facilitation of DER integration	
Environmental Benefits	C02 emission	⇩
	SOx, NOx, and PM emissions	⇩
Improve Generation Operational Efficiency	Operational costs of generation planning	⇩
	Spinning reserves improving the operating efficiency of current generation assets	⇩

III. CHALLENGES FACED BY UTILITIES IN FUNDING SMART PROJECTS

Utilities globally are facing significant capital demands at a time when capital is hard to come by. Revenue is flat, conservation is taking hold, and cash flows are weak, which means borrowing stresses the balance sheet and challenges credit ratings. And issuing equity dilutes shares, creates more dividends and saps the corporation of its earnings power. Given this situation utilities are finding it hard to support existing infrastructure and growth. Thus, using own funds for investing in smart grid is becoming an insurmountable task for the utilities.

The Indian utilities are facing similar challenges in making funds available to invest in infrastructure. The financial losses of utilities have reached to such levels, that they are now hindering the ability of discoms to pay power purchase dues and interest payments to lending agencies. Moreover, such dilapidated condition of discoms has resulted in under-investment in the distribution network leading to poor upkeep and maintenance. Consequently, the quality of supply gets hampered leading to customer dissatisfaction and poor recovery. This is in turn leads to further deterioration of financial health. This vicious cycle is depicted below [5]:

Vicious cycle of financial health of discoms

These financial losses which have accumulated over a period of time can primarily be attributed to High AT&C losses, widening gap between Average Cost of Supply (ACS) and Average Revenue Requirement (ARR), increasing dependence on coal etc. [5].

Central schemes have been initiated by the Government of India to improve the situation of the state power distribution companies. These have had differing funding models to fund the improvement in the state of technology and infrastructure in these utilities. One such scheme was the R-APDRP scheme which targeted sustained AT&C loss reduction. The funding mechanism of the scheme was part loan and part grant from the central government linked to the achievement of targets by the utilities [6].

Recently, another scheme Integrated Power Development Scheme (IPDS) has been launched by the Ministry of Power. The scheme has a similar funding mechanism wherein the center will provide 60-75% (except special category states) of the loan as grant to the power distribution companies. The ambit of the scheme also includes smart metering to consumers in areas where SCADA has been implemented [7].

Specific to smart grid, there are 14 pilot projects which are being funded by the central government. The grant part of the funding is limited to 50% of the overall funding in these projects [8]. The remaining portion is to be arranged by the state utilities. One such smart grid project is in the city of Mysore. However, the utility in this case has an innovative financing model. The Third Party appointed by the utility to implement the project has brought in a percentage share of the equity, thus sharing the state utility's burden of the funding portion.

IV. FUNDING OPTIONS AND FACTORS AFFECTING UTILITY'S CHOICE

There have been multiple routes which have been taken by utilities to fund their expenditures. These have traditionally been funded either through loans/grants from central / state schemes, loans from funding agencies and multilateral agencies or through internal accruals. As described earlier, given the financial pressures on utilities, they may have to explore new ways of raising funds. The table below lists the options that utilities can look at with pros and cons of each of the funding option:

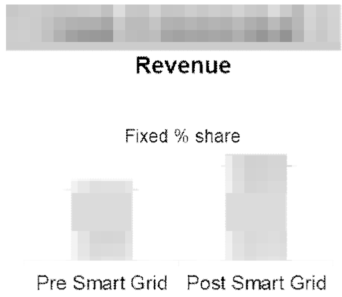
Funding Option	Advantages	Disadvantages
Central Government	► No cost of financing ► Discom retains asset control	► Govt. may put stringent conditions ► May require to comply with defined timelines ► Regular reporting involving multiple

Funding Option	Advantages	Disadvantages
		stakeholders
Financial Institutions	► Relationship is clear and well-documented ► Multiple solutions available also covering working capital requirements	► Non-attractive interest rates ► Unfavourable market environment
System integrators / Equipment Suppliers / OEMs / Third Party (Revenue sharing model possible)	► Possible to make single party responsible ► Turn-key contracts ensuring end-to-end implementation ► Costs treated as opex	► Risk and reward sharing model can be complex ► Less control over assets & solution ► Utility bound to suppliers for the future ► Correct base-lining is a major hindrance for reward-sharing model
Shareholders	► Clear relationship ► Ability to cover most types of expenses ► Ongoing costs treated as opex	► Difficult for govt. owned entities ► Require high return on investment ► Utility needs to carve-out the business

While Indian utilities till now have mostly resorted to loans/grants from government / funding institutions / multi-lateral agencies, they can explore the route of involving a third party. There could be different business models that the utility can adopt while involving a third party. The business model can be designed to bring in some to all the funding required for the project. Also, the third party's role can vary from merely a supplier to a supplier-cum-operator [9] [10].

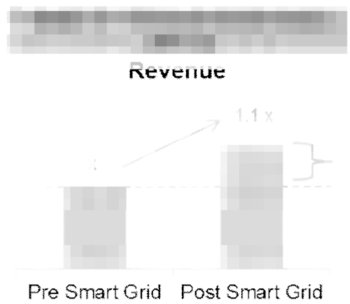
There are many other considerations while structuring such projects. Some of the other considerations are the amount of control to be given to the third party, concession period, Third party's remuneration model, monitoring mechanism, regulatory provisions, stakeholder & customer interest.

One of the business models to structure this alliance is through a revenue share mechanism. Here the utility can give a percentage share of the revenues getting generated through smart system installed and operated by the third party. The share can be in some proportion to the amount of investment being brought in by the service provider. The business case here will be primarily based on the benefits from billing & collection improvement, theft reduction, remote disconnection/ connection, and meter reading cost reduction, renewable integration especially Solar rooftops/ other DDG options.



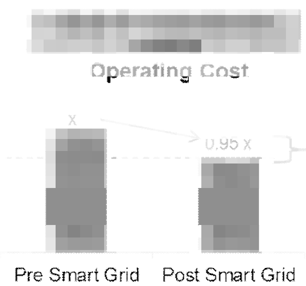
Such a model may result in a slight dip in utility's revenue position in the short term. Also, such a model does not motivate the service provider to improve revenues, consumer experience or power quality as there is little impact on his earnings.

Other models which link performance with returns can be useful. For example, service provider can be given a share of the revenue improvement which is because of the smart system implemented by the third party. Here, there is an incentive for the third party to increase the revenue and thus will motivate the service provider to first locate and then plug the gaps in metering, billing and collection.

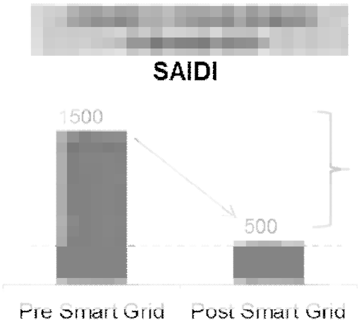


Smart grid projects can help utilities reduce costs on multiple fronts. Some of the key areas of cost savings are in terms of reduction in meter reading costs, maintenance costs, power purchase cost with use of peak-load management, and reduction in Unscheduled Interchange (UI) charges. In order to motivate the third party help utility reduce costs further the utility may enter into a savings sharing model. The remuneration mechanism and KPIs for the third party will be required to be set upfront while appointing the service provider.

The dynamics of such a model are showcased below:



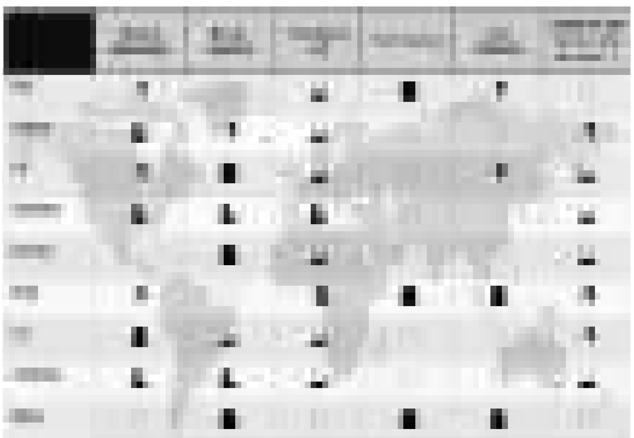
Indian utilities fare poorly when compared to their global counterparts on technical performance parameters like SAIFI, SAIDI, CAIFI, CAIDI, etc. One of the main benefits of smart grids is improvement in power quality through grid stability. The utility may tie third party's remuneration to the improvement in these parameters post smart grid implementation. An illustration of the same is shown below:



One of the biggest challenge that performance linked models could face is attributing improvement to smart grid projects. There are usually multiple initiatives being taken at a distribution company level to improve performance. In a utility one of these initiatives would be the smart grid project. It would thus be a challenge to attribute any change in performance to the smart initiative. Another challenge with performance-linked model is base-lining of performance parameters prior to smart grid implementation.

V. FIRST STEPS TO THE "SMART" JOURNEY

The drivers for smart grid adoption vary across geographies. While utilities in developed countries are focusing on reducing operational costs, the developing countries are aiming theft reduction and collection improvement. The figure below compares the importance of some of the key drivers across some of the geographies:



The utility needs to first understand its key drivers for going smart [1]. This is pivotal because that then defines the functionalities required from the project. These functionalities would dictate the hardware and software requirements for smart grid and would have a direct implication on the cost of the project. The utility also needs to bear in mind the regulatory and social impacts of such a project. As can be seen from global examples, the customer is at the heart of such projects. Thus, the utility must design the projects keeping a strong focus on customer needs.

After identifying the functionalities and project area and with a high level estimate of the project cost, the utility needs to ascertain the business model it wants to adopt to fund the project. Considering the pros and cons of each of the business models, the utility may go with one of the models or a hybrid model. The impact of any such model should be discussed with the regulators and the country / state specific procurement guidelines should be kept in mind before going ahead with appointing the third party. Once the funding model is finalized the utility should prepare a detailed cost-benefit analysis for the project and discuss the same with the important stakeholders.

VI. RECOMMENDED ACTIONS FOR OTHER STAKEHOLDERS

While we have talked about the steps that utilities require to undertake to initiate smart transformation, there are actions which other key stakeholders can commence to make the smart journey easier for the utilities.

Regulatory interventions can accelerate the pace of smart adoption in India. Standardization of cost-benefit analysis methodology of smart projects, "Time of Use" tariff design, creation of remote connect/ disconnect regulations, net-metering regulations, and standardization of specifications of hardware and software are some of the initiatives that the central and the state regulators can focus on.

The citizens will be at the centre of smart initiatives, and consumer support is critical success factor. Consumer engagement and education on various smart aspects should be initiated to make the citizens aware of how they would ultimately benefit from these smart interventions. Efforts would be required at both the central and the state level. While the centre can be involved in helping design the programs and strategy at a high-level, it will be the state which will have to customize the programs accordingly and ultimately engage the customers. At the same time, the capacity building of utility personnel through structured programs for skill development on various aspects of smart grid is essential.

As funding is an immediate road-block facing this journey, investors and utilities need to start engaging on an ongoing basis to understand each other's expectations. Banks, private equity players, NBFCs, OEMs, system integrators, corporates, utilities, policy makers and regulators should come together and explore the way forward.

VII. A SUCCESS STORY IN THE MAKING

One success story in the making is that of City of Tshwane (Pretoria), South Africa [11]. The municipality of the City of Tshwane was struggling with poor collections and huge arrears on account of non-payment of electricity bills. In addition, there was pilferage of electricity, and power theft was quite rampant in the city. So, it initiated the roll-out of smart meters to all as a part of its smart city roadmap “Smart 2055” [12].

Like most other utilities, the City was also struggling with funding the project. Thus, they adopted an innovative business model for the project. The project was structured on a Build-Own-Operate-Transfer model as a 100% off-balance sheet project for the City. The City appointed a service provider which would bring in the entire capital for the project. The service provider was required to fund both the capex and opex of the project. In return the service provider can charge a percentage fee of electricity charges paid by the customers [11].

The City also decided to move to pre-paid metering for 100% of its customers over a period of time. Thus the challenge for the service provider was to install smart meters, operate them in pre-paid mode and also provide and manage the vending system for pre-paid electricity. Stringent SLAs were signed between the City and the service provider in order to ensure service quality. The service provider was also entrusted with the responsibility of providing a 24x7 call center to support the customers which have moved to smart metering.

This rollout now provides various functionalities such as prepaid metering, remote connect and disconnect remote maintenance, SMS alerts and web-based portal for consumers to monitor their consumption and balance. In the future, the City may request the service provider to implement demand response with the system and thus the system has been carefully designed to incorporate that functionality with minimum intervention at a later date.

An important component of this project has been customer engagement. Right from when the project was envisioned, the City began to engage the customers through various means. The City organized various stakeholder sessions, roadshows and contests to keep the customers involved in the initiative. The City not only used the offline media but also used radio, TV and social media to reach out to the customers.

As of now the project has been a success and a large percentage of the total electricity charges now flow to the utility through the new smart system. The success of the project was achieved through immaculate planning, design and implementation of the program. The service provider created the right partnerships with funders, communication provider, OEMs and system integrator. The service provider for further supported by technical, financial and legal advisors.

VIII. CONCLUSION

Smart grid projects come at considerable price-tag. Most utilities globally are cash-strapped. However, this should not stop utilities from taking benefit of smart transformation. Thus, while utilities must explore the traditional funding opportunities, they must not overlook any innovative funding options. These innovative funding options can share the burden of funding the smart grid projects. The utility should go ahead with the relevant funding option which is beneficial and acceptable to the various stakeholders.

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Optimal Energy Scheduling for a Smart Home Integrated with Solar PV and Battery Energy Storage

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***Abstract*—Residential demand response plays a key role in electricity management in the smart grid framework with increasing intermittent distributed generations (DGs) and load demand. Battery energy storage system (BESS) in conjunction with rooftop PV/ wind energy system can be recognized as a way to efficiently integrate to grid. In this paper, an optimization algorithm that schedules home appliance usages and DGs is proposed for optimal power consumption. Energy cost minimization, user comfort maximization and peak load minimization are considered as objectives. As the objectives increases, tradeoffs are likely to become complex, hence the problem is formulated as multi-objective mixed integer linear programing problem and solved using multi-objective genetic algorithm (MOGA). The simulation study of a single home shows that while the algorithm developed is successful from a technical standpoint, the high cost of energy storage at this time limit its widespread deployment.**

***Keywords*—battery energy strorage; energy management system; multi-objective mixed integer linear programing; solar PV**

NOMENCLATURE

$x_{a,h}$	Power consumption of particular appliance '*a*' in hour '*h*'
α_a and β_a	the minimum and maximum operating power for power of shiftable appliances
P^T	Power consumption pattern of a time-shiftable appliance
L	Peak load
A	Total appliances set
T, A-T	Time shiftable appliances and Power shiftable appliances set
p_s^h	Hourly selling price
p_b^h	Hourly buyback price
g^h	Hourly renewable generation
x^h	Hourly total load
e_{ch}	Charging efficiency of battery bank
$E_{ch\_\max}$	Maximum hourly charge
$E_{dis\_\max}$	Maximum hourly discharge
$E_{b\_\max}$	Maximum storage capacity
h	Time period (here hour of the day)
H	Total number of periods in the schedule (typically an entire day)
l_1^h	Energy transfer from gird to battery in period h
l_2^h	Energy transfer from gird to home in period h
l_3^h	Energy transfer DG to grid in period h
l_4^h	Energy transfer from battery to grid in period h
l_5^h	Energy transfer from DG to home in period h
l_6^h	Energy transfer from battery to home in period h
l_7^h	Energy transfer from DG to battery in period h
R_b	Battery utilization cost per unit energy per cycle

I. INTRODUCTION

With the recent developments in cost effective battery storage system technologies, successful development and demonstration of smart hybrid inverters [1] of few kW ratings for customer level, demand response inverters [2] of few hundreds of kW ratings for distribution level and installation of smart meters on one side. And on the other side increased usage of comfort based and smart appliances, electric vehicle etc., and massive integration of distributed renewable energy resources accounts for increased building energy consumption and disproportionate amount of peak energy usage. Energy consumption from residential buildings is increasing around the world. In India it is predicted to rise by more than eight times by 2050 under the business as usual scenario, it is of vital importance to develop energy-efficiency strategies focused on the residential sector to limit the current trend of unsustainable escalating energy demand.

Hence, residential renewable plus storage based electric systems are emerging as an cost effective [3] [4] and important demand response resources with the introduction of localized renewable infeed, Time-of-Use (TOU) tariffs and the option to optimize load schedules to reduce the cost of electricity imported from the grid. The consumer level benefits of this system include lower energy bills, lower peak demand, serves as backup power and provides an efficient way to integrate renewable energy resources. At electricity distribution level maintaining system voltages within acceptable limits, as a power factor correction device at the station level (VAR support) and provides ancillary services through further aggregation at the grid level.

However, without careful coordination, these potential benefits might not be realized at multiple home level. Depending upon the scenario whether in-feed tariff scheme available or not, size of the system and an either individual home level control or aggregated control of multiple homes various dispatching schemes are proposed in literature. The possible techniques are: 1. Self-use of renewable 2. Buy/Sell electricity to the grid with help of hybrid inverter.

Residential energy management is an two-stage optimization strategy with receding time interval [5] namely day-ahead scheduling and short-time scheduling cum real-time controlling. A day-ahead optimization problems involves, calculation of economical operation schedule of domestic electric appliances (deferrable type and elastic load types as per their energy demand requirements and preferences), battery and optimal dispatch scheduling of PV/Wind generation using forecasted data and electricity prices sent from utility supply/ aggregator in case of collaborative control of a group of customers. Whereas, a short-time scheduling is carried out over a time horizon of an hour to few minutes, which tries to maintain the constant power schedules obtained in day-ahead optimization and real-time demand response activities considering the uncertainties in the data.

Penetration of DER's of multiple customers' needs to be coordinated to avoid creating new peaks. At community level, where an aggregator coordinates the battery storage decisions of multiple homes. Using a Stochastic optimization problem [6]. A majority of the developed techniques depends on the minimization of resulting energy costs, including receding horizon strategies based on model predictive control (MPC) [3, 4], multi-agent systems [9], mixed integer linear programming (MILP) [10] , heuristic techniques like particle swarm optimization (PSO) [11], Genetic algorithm [12], [13] and game theory [14]. Different variations of load models (thermostatic and non-thermostatic appliances), PV, wind and battery storage models [15] and user comfort models are also presented [12]. As highlighted in [16] most of the proposed techniques didn't considered the importance of balance between energy cost minimization and user comfort maximization and their competitiveness.

This paper investigates a genetic algorithm based multi-objective optimization strategy for optimal dispatch scheduling of renewable energy and battery storage resources, and optimal time-shiftable and power shiftable load scheduling in a residential home with grid connected photovoltaic (PV) generation plus battery storage component and a TOU tariff or real-time pricing for grid in-feed. The optimization strategy uses a mathematical model of the energy balance of the major components comprising the electrical system, namely the grid in-feed, PV system, storage system, deferrable loads. The physical constraints of the components also considered. The objective functions considered are minimization function representing the cost of the energy imported from the grid, savings by selling energy to grid and utilization cost. Maximization function represents the average-to-peak ratio. The key contribution of this paper is an algorithm which can provide best strategy considering the tradeoff between energy cost, user comfort and peak load. There exists a solution which can reduce peak load to great extent with a slight increase in energy cost, because of non-linear relation between cost and peak load which was shown in [17] too with a simulation study.

The paper is organized as follows: Section 2 provides a brief description about the local energy management problem, different components and related issues. Section 3 presents the proposed building energy management. The definition and implementation of a case study, a smart home with photovoltaic panels and battery system, is given in Section 4. Some of the obtained simulation results are presented in Section 5. Finally, in Section 6 the most important conclusions are drawn.

II. OPTIMAL DISPATCH PROBLEM

A. *Single home optimization model*

In this case we consider an optimal day-ahead scheduling of a simplified PV + battery system, is connected to grid via a smart demand response inverter in a smart home. The inverter is assumed to have programmable charge and discharge rate and time control, maximum and minimum charge limits via a home energy management system. The battery can store the electric energy from the grid when the price is low, and discharge the energy when the price is high.

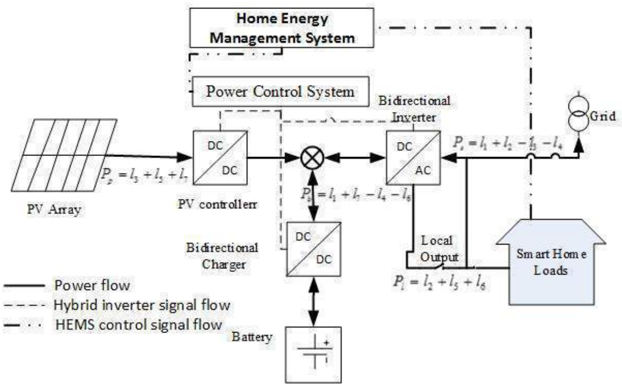

Fig. 1. PV+Battery System model showing retailer buying and selling energy through a smart grid to smart home with DER's

Fig. 1 shows the block diagram of major smart home system components and net power flows among them i.e., a Battery storage, roof top PV, hybrid inverter and smart appliances which are controlled by a Home energy management system.

III. MATHEMAICAL MODEL OF THE PROBLEM

Finally, complete content and organizational editing before formatting. Please take note of the following items when proofreading spelling and grammar:

A. *Objective functions*

The goal of the problem single user is customer oriented rather than utility oriented i.e., to find an optimal tradeoff between the minimization of net energy cost (i.e., buying cost + utilization cost - selling cost) and maximum peak to average load ratio. The amount of tradeoff between demand response, customer comfort level and peak load. Minimization of energy cost and peak load demand. [15] The objective function can be modelled as,

1) Minimization of Energy cost: The net cost of energy is obtained adding total cost of buying the electricity plus utilization cost of the storage system and subtracting the profit obtained by selling the electricity to grid.

$$\text{Min } (\sum_{h=1}^{H} p_s^h \times \left(l_1^h + l_2^h\right) - p_b^h \times \left(l_3^h + l_4^h\right))$$

2) Minimization of battery utilization cost: Depending upon the technology the life of a battery will be few thousand of cycles. Hence its depreciation needs to be considerd by calculating Net present value per charging cycle is calucated from the total cost of the battery bank [4].

$$\text{hourly cost of cycling / watt-hour i.e., } R_B = \left(\frac{\text{cost of the storage system}}{\text{cycle life}}\right) \times \frac{1}{E_{B\_\max}}$$

3) Maximization of Average to Average-to-peak Ratio: To make the schedule grid firendly and quality of the solution we consider peak-to-average ratio as a metric.

$$A.\,P.\,R = \frac{L_{avg}}{L_{\max}}$$

B. Constraint conditions

The goal of the problem single user is customer oriented rather than

1) Appliance constraints: Time shiftable applinces model as in [10] is given by,

$$0 \le s_t \le 1,\ 1^T s_t = l,\ \forall t \in T$$
$$X_t = P^T s_t, \forall t \in T$$

Similalry, the power shiftable appliance model is written as,

$$1^T X_a = l_a,\ \forall a \in A - T$$
$$x_{a,h} \ge 0,$$
$$x_{a,h} \ge \delta_a,\ \forall h \in [h_{a,s} \ldots h_{a,f}],$$
$$\alpha_a \le x_{a,h} \le \beta_a,\ \forall h \in [h_{a,s} \ldots h_{a,f}],$$

2) Battery Physical constraints: The capacity limits and charge and discharge rate limits needs to adhered for efficient operation of batteries.

$$l_4^h + l_6^h \le E_{b\ dis\_\max}$$
$$l_1^h + l_7^h \le E_{b\ ch\_\max}$$
$$\sum_{h=1}^{24} l_4^h + l_6^h \le \sum_{h=1}^{24} e_{char} \times (l_1^h + l_7^h)$$
$$E_{b\_\max} \le \sum_{h=1}^{24} e_{char} \times (l_1^h + l_7^h) - l_4^h - l_6^h \le E_{b\_\max}$$

3) Load Constaints: The total hourly energy supplied to home from grid, battery and PV must be equal to total demand and they must be non-negative and within limits.

$$\sum_{a \subset A} x_a^h = l_2^h + l_5^h + l_6^h$$
$$l_i^h \ge 0$$
$$l_i^h \le E_i^{\max}$$

4) Minimization of physical transferlimits:

$$l_1^h + l_2^h - l_3^h - l_4^h \le L$$

The overall optimization problem considering the objectives and constraints will be of the form given below, which is a multi-objective constrained mixed integer linear problem.

$$\min\ F(x,l) \text{ and } \max F(l)$$
$$\text{s.t. } g(x) \le 0,\ g(l) \le 0$$
$$h(x) = 0, h(l,x) = 0,$$

The solution to the problem contains the optimal scheduling for the deferrable loads, storage, the dispatchable generation and grid connection.

IV. Simulation Study

In this section, we will evaluate the load scheduling algorithm described in section III with the following data and then results and analysis are presented.

1) Appliances and jobs: We considered a set a typical residential home with a daily requirement of 20kwh and deferrable home appliances and their preferred simulate appliances with jobs of different types as in [10] is shown in Table I. The thermostatically controlled appliances and instant loads will be scheduled in short-term opitimization problem.

TABLE I. Loads and their consumption profiles

S. No.	Name	Load Type	User preference and power Requirement
1.	Hob and Oven	Non-Shiftable	Operating Period: 7pm-8pm (Hob/oven) Hourly consumption: 1kWh
2.	Heater	Non-Shiftable	Operating Period: 9pm-10pm, 3am-5am (Heater) Hourly consumption: 1kWh
3.	Fridge & freezer	Non-Shiftable	Operating 24 hours Hourly consumption:0.12kWh
4.	Water boiler	Power-Shiftable	Hourly Consumption 0-1.5kWh Daily requirement :3kWh
5.	Electric Vehicle (15 milesdaily driving)	Power-Shiftable	Preferred charging period: 8pm-8am Charging power:0.1kW-3kW Daily requirement: 5kwh
6.	Washing Machine	Time-Shiftable	Operating 2hrs, once per day 1kWh for the 1st hour 0.5 kWh for the 2nd hour
7.	Dish Washer	Time-Shiftable	Power: 0.8kWh for 1 hour Daily requirement:0.8kWh

B. Pricing

A day-ahead real-time pricing model is considered from a retail electricity market [18]. The pricing model is varied hourly. However, the price information is available for the whole day. A time-of-use tariff is also obtained by averaging the real time pricing. Buying price is considered as 1.1 times selling price, which is almost equal.

C. *Renewable Energy*

Figure 2. shows the typical hourly forecasted generation profile using a simple mathematical expression as in [19] on a winter day of a 2kWp PV system situated near Ahmedabad. The average renewable energy production is 600 Wh.

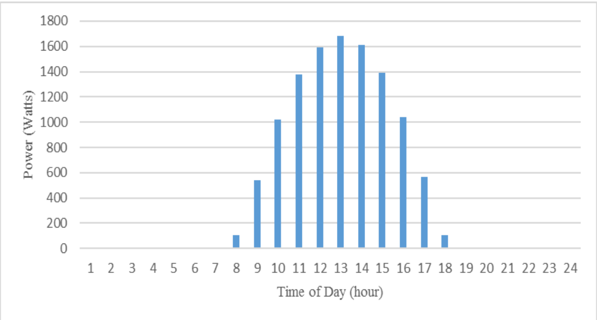

Fig. 2. Solar PV Roof top system day-ahead predicted power generation

D. *Storage*

For batteries, we set the maximum capacity is 5kWh, which is reasonable for an average battery bank [18]. The charging efficiency is 90%. In addition, the maximum charging rate is 500 Wh at 230V.

TABLE II. BATTERY BANK SYSTEM CONSTRAINTS

Parameter	Value
Maximum Battery capacity (kWh)	5
Maximum and minimum discharge rate (kWh)	0.5
Charging efficiency (%)	90
Minimum storage level	0
Charge and Discharge cycles	2000
Maximum Battery capacity (kWh)	5
Maximum and minimum discharge rate (kWh)	0.5

E. *Solution Methodology*

We simulate this optimal dispatch scheduling algorithm using multi-objective Genetic algorithm [20] in MATLAB.

F. *Results and Analysis*

The algorithm takes into account forecasted renewable energy generation information, appliances power consumption patterns, user preferences and day-ahead hourly real time buying and selling price of electricity or TOU which are simulated from India Energy exchange (IEX), a retail electricity market. As the objectives increases, tradeoffs are likely to become complex and less quantified. Hence the problem is treated as multi-objective mixed integer linear programing problem and solved using Multi objective genetic algorithm in MATLAB. Three case studies are done namely 1) Minimization of electricity cost and user discomfort with PV and no BESS, 2) minimization of cost and user discomfort with PV and BESS 3) minimization of cost, user discomfort and peak load for both RTP pricing and TOU pricing mechanisms.

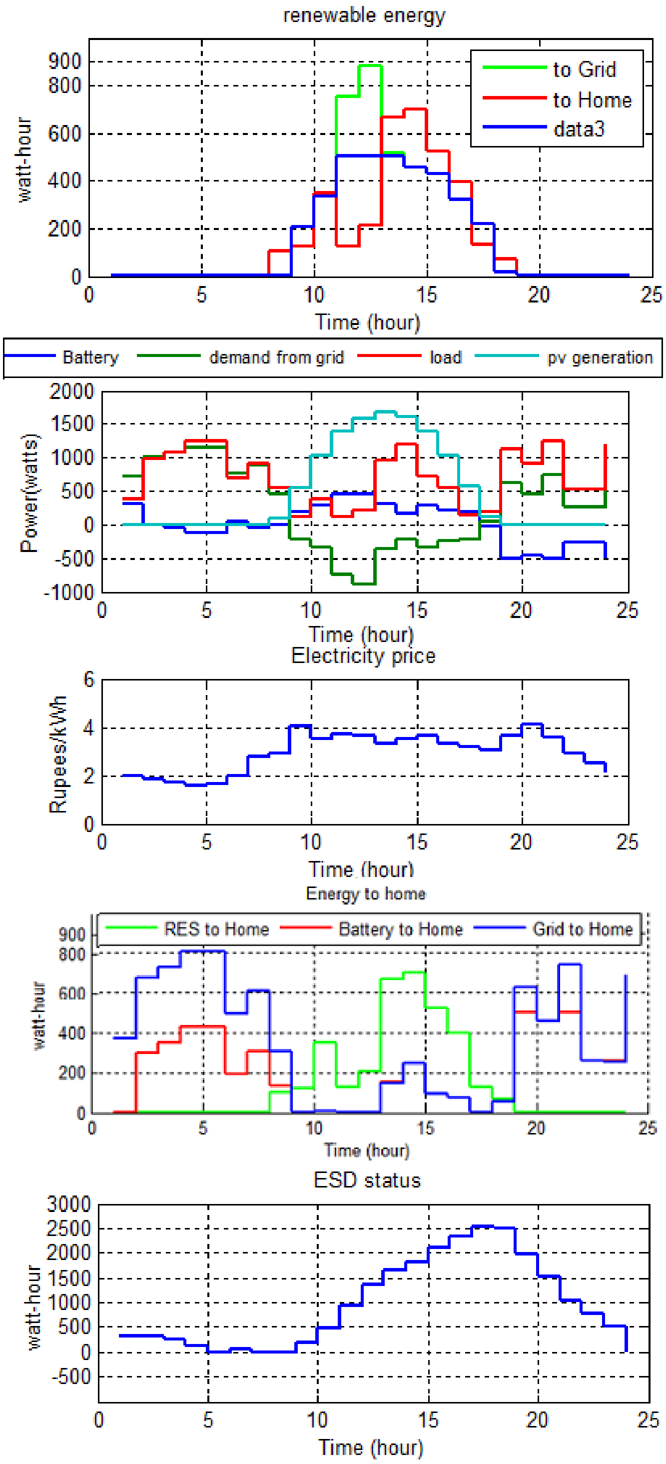

Fig. 3. Optimal dispatch Scheduling results with real-time pricing (a) distribution of PV energy among grid, home and battery (b) load demand, battery charge/discharge , demand from grid and PV generation, (c) TOU pricing, (d) Energy flow to the home load from all the three sources (e) Battery state of charge

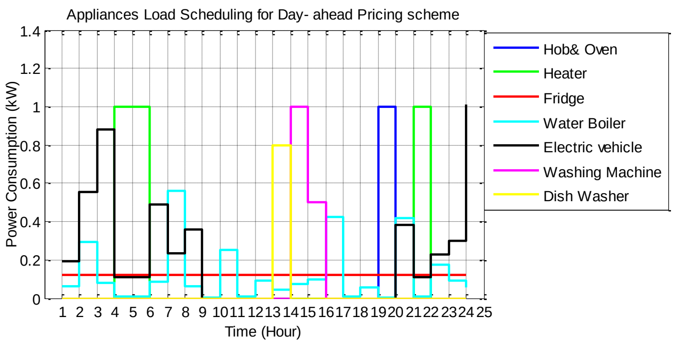

Fig. 4. Optimal load Scheduling results obtained using the proposed approach for the considerd realtime time pricing

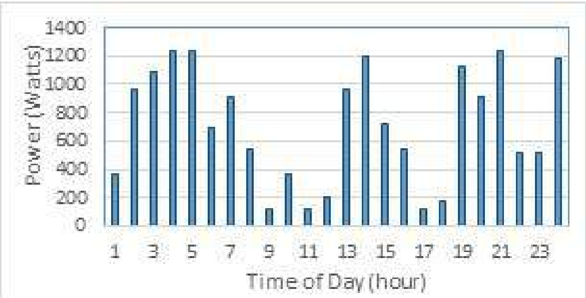

Fig. 5. Overall load demand profile of the home for the considerd realtime time pricing scenario

TABLE III. COMPARISION OF RESULTS

Objective	**Day-ahead Real time pricing**		**TOU pricing**	
	Peak Load (kW)	*Electricity Cost /day (Rupees)*	*Peak Load (kW)*	*Electricity Cost /day (Rupees)*
*Base Case * (without PV and battery)*	1.225	46.3	1.225	48.1
Case 1:Minimize Cost	1.72	4.4	1.74	15.78
Case II: Minimize Cost + maximize of P.A. R	1.145	9.6	1.72	17.72
Case III: Minimize cost + storage utilization cost + maximize of A.P.R	1.145	11.2	1.145	21.08

From the case studies with a typical residential load profile with 20kwh of daily requirement, 2kWp PV system and 5kWh battery and simulation results it is observed that peak load is increased by 40% approximately and energy cost is decreased by 67% considering PV+ battery system. From case-1 to case-2. There is reduction in peak load by 15% with a slight increase in total cost. Similarly, from case 2 to case 3 by assuming battery utilization cost of small value, the economic benefit of PV+ battery system has been reduced, depending upon the considered depreciation cost. Here we considered a small value of .10 rupee/kWh/cycle.

From Fig. 4 and 5. It can be seen that depending on the energy price and loads, energy can be bought and sold dynamically and battery system can be charged and discharged to accomplish jobs while minimizing total cost. The demand from the grid can be negative, meaning the energy flows from home to grid (e.g., selling renewable energy or battery energy).

By considering the actual depreciation cost it is observed that, It may not be commercially viable considering todays BESS cost and technology along with present tariff system. But in soon will be a viable option under widely distributed real time pricing and cheaper Energy storage Devices.

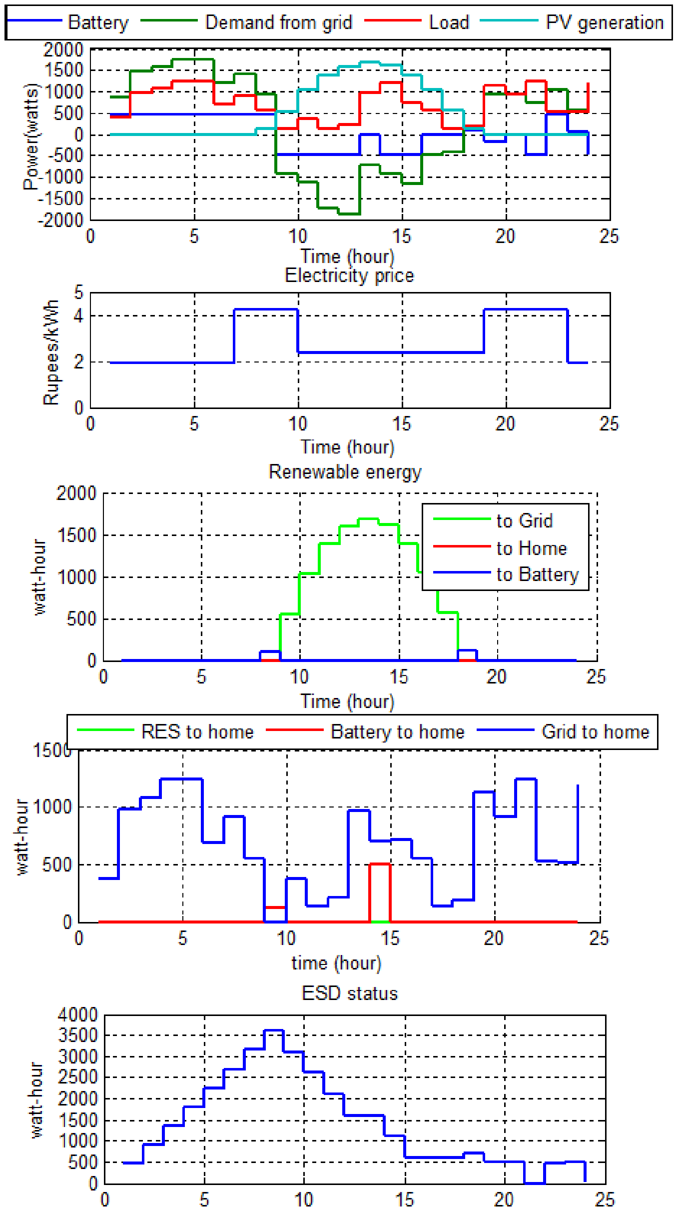

Fig. 6. Optimal Scheduling results with TOU pricing (a) load demand, battery charge/discharge , demand from grid and PV generation (b) TOU

pricing, (c) distribution of PV energy among grid, home and battery (d) Energy flow to the home load from all the three sources (e) Battery state of charge

V. CONCLUSIONS

In this paper a multi-objective based scheduling model to determine the most economic operation schedules of various time-shiftable and power-shiftable appliances and dispatch schedules of energy resources depending on the forecasted demand, generation and day-ahead real-time electricity prices. First, we applied this model to one house with the objective functions of only reducing net energy cost. In this case, though the energy cost is reduced from base case, but a new peak load occurs at low price time periods which is more than base case scenario.

In second case, it was solved using presented multi-objective solution methodology to the same house with objective the functions of reducing peak to average load, net energy cost. It was found that reduction in the peak load obtained by increase in the energy cost. In third case, instead of assuming the utilization cost of battery system is negligible we considered a small value to test the algorithm (although the practical value is higher).

Real-time pricing is more effective than TOU with inclining block rate in reducing energy cost and peak load. Further the optimization schedule provided this model is ideal one, based on predicted values. The uncertainty in predicted values needs to be considered in time receding energy management implementation.

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Get smart with Smart Grids

The smart way of implementing smart grids – a business model led approach

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***Abstract*—Smart grids are one of the biggest developments in the power utilities industry worldwide in modern times. They offer the potential to significantly reduce grid inefficiency, enable more interactive demand management, better integrate distributed power sources into the grid, change customer experience and facilitate new uses for electric power.**

However, the realization of these benefits is not a given. Like any major project, there are the challenges of delivering on time, on budget and operating successfully. But it is not just a matter of rising to those challenges. Success also relies on a complex interplay of technological, cross-sectoral, behavioral and regulatory factors in addition to effective project implementation. Last, but not the least, the involvement of the customers in the success of the whole programme cannot be over emphasized.

This is where, PwC believes that the business model for deployment of smart grids comes into significance. Utilities need to give more weight to the transformational changes when thinking about their smart grid strategy and not just focus on technological and business case led initiatives.

Keywords—smart grid,demand management,intelligent network, changing customer experience

I. Introduction

Smart grid is the latest buzz word to take over the Indian power utilities space. A lot of utilities are planning to implement a smart grid; the government has launched a national level forum – the India Smart Grid Forum – to enable policy makers, technocrats, utilities, consultants and consumers to work together towards advancement of the smart grid concept in India. Smart grid consultants and smart grid associated infrastructure and equipments vendors are scouting opportunities to sell their products / services to the utilities. Discussion seminars / workshops are taking place where various stakeholders are sharing their views and putting up suggestions towards a smart grid roadmap for India.

In the recent past, we have heard a number of smart grid pilot projects taking off or making steady progress. It is probably not correct to term these as “full-scale smart grid deployment”, for the simple reason that in all of these cases, there was no end-to-end deployment of smart grid, but deployment of a few components e.g. smart meters, distribution management systems etc. To name a few, we have heard of Bangalore Electricity Supply Company (BESCOM), North Delhi Power Limited (NDPL), Ahmedabad Electricity Company (AEC) being on the forefront of deployment of smart meters. Further, a number of state-owned utilities in Andhra Pradesh, West Bengal, Madhya Pradesh, Maharashtra, Tamil Nadu, Uttar Pradesh, Himachal Pradesh and Punjab are also making headway towards a smart grid era through the Restructured APDRP of the Government of India.

So, given this context , it is worthwhile to step back and ask ourselves a question – are we following the right approach to the deployment and replication of smart grids? While it is not PwC’s intention to pre-judge the outcome of all such initiatives, our question is more targeted to emphasize the need for being smart with respect to the approach for deploying smart grids and achieving the desired end goals.

II. Changing Utility Value Chain

The traditional utility value chain has always been linear and stable, with:

- The generators focusing on building large and centralized power plants
- The transmitters focusing on dispatching and carrying the dispatchable generation from the generation plant to the load centres
- The distributors focusing on building a network to accommodate maximum demand
- The retailers focusing on delivering the energy and billing the end consumers
- The consumers demanding that they can consume what they want and when they want, and,
- The Regulators monitoring the whole value chain, while allowing reasonable rates of return to the utilities for meeting customer services standards

However, this model is under threat due to a number of reasons:

- Changing demand patterns – increased and new uses of electricity, and especially, increased levels of electrification and economic growth in the developing countries, have resulted in changing demand patterns

- Substitution – there has been a good amount of increase in the number of independently operated micro-grids, off-grid communities / campuses and distributed generation, offering instances of substitution to the main-stream grid

- Technology – lower costs of photo-voltaic cells, storage options, communication network and sensors, and digitization of grid equipment, have made alternate ways of access to electricity, more than feasible

- New entrants – electricity aggregators, traders, power exchanges, energy service companies and energy information providers have established themselves as relevant players in the value chain

- Customer expectations – increased demands for reliable and high-quality power, digital experience, social media, are influencing the customer expectations

- Fuel supply challenges – geo-political risk, competition for scarce resources and growing global demand for energy, are posing fuel supply challenges for the utilities

- Decarbonization – increases in the adoption of renewable energy sources and preference of electricity from renewable sources as a low carbon alternative, are putting the utilities under pressure to provide necessary means of carriage

What all these together are giving rise to is a new business model for the utility operations.

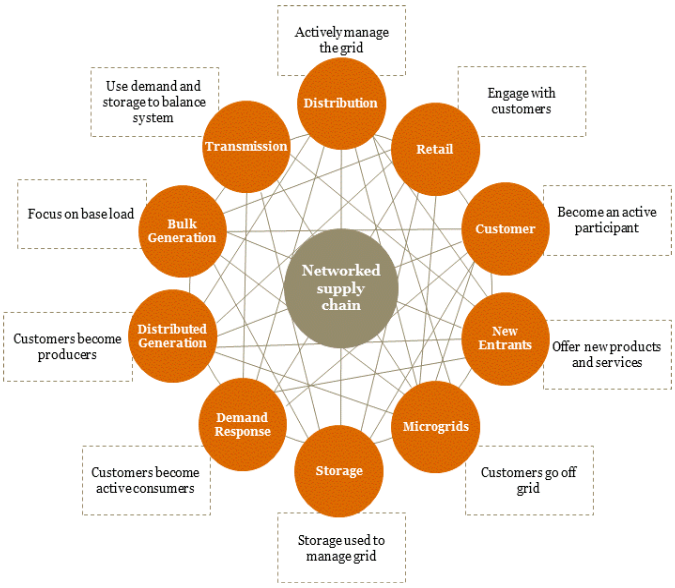

Fig. 1. A new networked model

III. DIFFERING DEPLOYMENT OF SMART GRID TECHNOLOGIES

In the legacy model, the grid was subjected to active management in case of bulk generation and transmission and passive management in case of distribution, whereas in the new model, the grid is actively managed for all sections of the value chain, including new elements such as renewable generation, storage and controlled demand.

In this new business model, several grid architectures could emerge to manage the evolving "smart grid model" of utilities:

- Traditional architecture – despite increased focus on renewables, traditional fossil fuel based grid with limited renewable and distributed generation shall remain in operation

- Distributed architecture – this will include distributed generation working in tandem with existing large scale generation and transmission grid

- Localized architecture – will feature localized micro-grids and markets meshed together; distribution and transmission networks will no longer be required

- Super-grid architecture – this will be characterized by long distance transmission moving renewable energy over continental distances from sources to points of use.

Grids of future will utilize a blend of these architectures, dependent on local conditions and policy objectives. At present, the grid architectures evolving and the smart grid technologies being adopted around the world are dependent on these two characteristic sets.

TABLE I. WHAT GRID ARCHITECTURES ARE EVOLVING?

Geography / Nation	**Local conditions / Policy objectives**	**Type of grid architecture**
North America	• Managing peak demand • SAIDI/SAIFI exclusions • Distributed generation	Traditional Distributed Localized
South America	• Theft • Load growth • Power quality	Traditional
Europe	• Network congenstion • Aging infrastructure • Renewable generation • Distributed generation	Distributed Super-grid
Africa	• Growing demand • Theft • Need for reliable power	Traditional Localized
China	• Long distance transmission • Rising energy demand • Economic development	Traditional Super-grid
South-east Asia	• Growing demand • Need for reliable power • Theft	Traditional Localized
Australasia	• Distributed generation • Growing demand	Traditional Distributed

Of the different smart grid technologies, smart metering has been the first one to find acceptance and see mass deployment, to various degrees of success. In the North America, initial stimulus funding created an initial surge in activity, which has now abated. In the South America, pilots are being considered mainly in response to high levels of theft. In case of Europe, except for Sweden, Italy and Finland, who were the early adopters, the rest of the Europe is pursuing an "80% by 2020" goal.

In Africa, there has been increasing activities on smart metering, but no national deployments. Further, pre-paid meters have been the main driver here. In China, large scale smart meter deployments are happening, but these are mostly to ease the activity of meter reading than for grid control. The smart metering programs in most of the south-east Asian countries, including India, have not been supported by government / regulatory mandates, to the extent it should have been, and hence, the progress is quite slow. In the Australasia region, New Zealand and few states of Australia are undertaking full-scale roll-out of smart metering programs.

Irrespective of the geography where smart grid technologies are being deployed, basically, there are three approaches being considered for developing the smart grid strategy, as shown in the figure below.

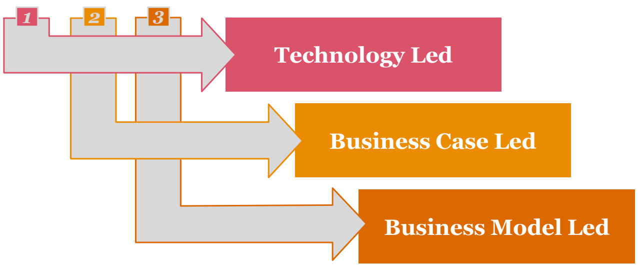

Fig. 2. Approaches to deployment of smart grid strategies

In our opinion, most utilities' approaches have been technology and business case led and few utilities have given appropriate weight to business model change as a driver for their smart grid strategies. Further, the utilities' approaches across these three drivers are not always fully integrated.

The technology-led approaches have often been R&D based, with little or no consideration given to the business case and the broader business changes the technology will require to prove successful. These changes have also been devoid of any strategic view, aimed at resolving short-term technical and engineering problems with new technology. Examples of such implementation are trialing of smart metering communication technologies or new feeder automation technologies.

The business case led approaches have been targeted at solving critical problems, where process and technology changes have been effected, involving integrated solution across the departments of the utilities and backed with a business case. Examples of this are non-technical loss reduction through smart metering data analytics.

The business model led approach is characterized by identification of the new business paradigm that the utility will be operating in and the potential business models that will be required. Further, it involves identification of the capabilities required for the utility to deliver those new business models, and delivery of technology and organizational capabilities. Examples of this are implementation of systems and processes to enable the utility to become a back-up power provider to the micro grids or implementation of systems and processes to operate a multi-owner solar park.

In order to adopt a business model led approach, utilities need to first understand the future market paradigms and then develop a coherent view of (1) the business model, (2) the required products and services, and, (3) the required capabilities. Examples of the future market paradigms could be:

- Green command and control – this will involve regulatory and policy-led adoption of new green technologies, e.g. government mandate that all new houses must have options for solar energy connectivity
- Ultra Distributed Generation – involves market-led adoption of distributed generation with the utility becoming a supplier of back-up power
- Local energy systems – involves fragmentation of the grid into self-sustaining units and/or development of interconnected micro-grids
- Trans-national market – involves introduction of trans-national energy markets providing options to source (or supply energy) over long distances

IV. The Consumer

It is an accepted fact that it is indeed difficult to understand the perception of the Indian consumer, whether he / she is buying a jewellery or a car or even a hair-clip. A lot of organizations engage specialised market research agencies and advertising agencies to understand the buyer perceptions before and after they launch a product to decide about product features, product variants, product launch timings, product pricing etc. However, when it comes to electricity, as you all would be aware, it a different ball game.

An electrical consumer in India may or may not have an address, may or may not be getting a bill for what he consumers and may or may not be paying for what he is consuming; however, when it comes to demanding an electricity connection or raising voice against power outages, he is on the forefront! If he is a rural consumer and is categorized under the BPL beneficiary, do not be surprised to find a television set or an electrical heater for cooking, though he is entitled to only a 100 watts CFL!! In a city, you may find the consumer having an air-conditioner, a geyser, hot plates etc. in his residence while his official connection would be a 1 kW load!!!

The simple reason for discussing all the above is this: unless they agree to the smart grid technique managing their consumption behavior through switching off and switching on their electricity supply or their appliances, the program will not succeed. Therefore, a "change management" program targeted towards changing the mindset of the Indian consumer with regard to his / her attitude towards consumption of electricity and usage of appliances, and increasing his / her appreciation for the benefits of the smart grid, is absolutely essential for successful and sustained adoption of this new movement.

V. Investment

Creating the smart grid means adopting technologies to transform the existing electricity grid — which is fitted largely with 20th-century infrastructure — to 21st-century standards to create greater efficiencies, reliability and the integration of renewable energy sources. This will leave its mark on the entire grid ecosystem — from electricity generation to transmission and distribution to consumers. The backbone of the smart grid is the integration of two-way communications between utilities and consumers through advanced metering infrastructure (AMI), or “smart meters”, and sensors that discern where and how much electricity is being consumed. The AMI is designed to provide customers and utilities alike with the knowledge of energy information — pricing, demand, power and quality, for example — in real time or near real time.

Therefore, building a smart grid entails initiatives going well beyond smart meters. These include laying new, advanced high-voltage transmission lines, modernizing substations and gathering and managing the prodigious amounts of data the smart grid will produce.

In the context of the above discussion, it is important to ask whether the current state of India’s transmission and distribution network permits us to perform smart grid operations or not? If not (which will be a definite answer to the previous question), then how much of the same should be upgraded? What would be the associated investment and what should be the targeted return on investment? Who will bear the cost – should there be special government support or should it be on a PPP model or should it be complete pass-through, thereby increasing the tariff for the end consumer? And, most importantly, what are the new business models that smart grid must enable?

According to us, while in the present day scenario, we spend a lot of time on debating on the right quantum of investment to be allowed in the electricity sector, its source and its implication of electricity price for the end consumer, debating on the investment requirements for the smart grid and arriving at an amicable decision, will be far from easier. Additionally, it will be challenging for utilities, governments and regulators to consider the investments required and their implications on the end consumers.

VI. Conclusion

The utility industry is set to see a transformation driven by a number of disruptive forces. While the forces are common, their magnitude will vary across jurisdictions as will the starting point. As a result, different jurisdictions will see different changes. Utilities need to give more weight to these transformational changes when thinking about their smart grid strategy and not just focus on technological and business case led initiatives.

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Communication Backbone for the Smart Grid Infrastructure:

A fresh approach for improving the QoS

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*Abstract***— In India, in all the discussions and deliberations, two things are most conspicuous by their absence: "Standards for Communication Network Architecture" and "Business Model" for deploying & running the Communication Infrastructure for any Critical Infrastructure, be it Smart Grid, Smart Water, Smart Health, Smart Transportation or Even Smart City. The Critical Information Infrastructure is the backbone and foundation of any modern society/community today. They all need highly reliable Communication Backbone.**

This Paper deliberates this crucial aspect, which may alter the future of Smart Grid deployments as well as, any Smart Infrastructure Deployments at the National Level thus defining the future of "Digital India".

Keywords—Standards, Communication, Architecture, Security, Protocols, Interfaces, Smart Grid, Smart City, Smart Building, Smart Home, Critical Infrastructure, Critical Information Infrastructure, QoS, MNO, MVNO, Embedded SIM, eUICC.

INTRODUCTION:

The success & failure of the new Electricity Infrastructure shall highly depend on the Electronics, IT & Telecommunication Technologies used & deployed. A single mistake in choosing the wrong technology might result in a set-back that shall take many years to rectify the problems and move forward in the right direction, and thus, jeopardizing the progress of the nation itself… Different Communication Technologies & Protocols are being discussed or even advocated as the most suitable or most cost effective communication technologies for the upcoming Smart Grid Deployments.

Broad discussions at various Smart Grid conferences and the 'India Smart Grid Forum' as well as 'Indian Smart grid Task Force' have highlighted the keystone role of COMMUNICATIONS for Smart Grids, in addition to the bottleneck it currently poses. ISGF in its "India Smart Grid Vision and Roadmap" [1], as well as, in the White Paper on "Post R-APDRP Strategy" [2] have made a well-defined roadmap with precise Milestones to address this daunting task.

While the roadmaps and even Pilots have focused on functionality, there is limited clarity on Technology Solutions, Architectures and Protocols that may best meet the goals of open standards, modularity, inter-operability, and price-performance. The claim of "following standards" is insufficient because it doesn't answer the question of *which standard* and *why*. In fact, it is unlikely to be which standard but rather which standards since most Architectures (e.g., NIST's, ETSI's and/or oneM2M frameworks) do not pick one standard but have a layered approach capable of using multiple standards in the portfolio [3].

GLOBAL SMART GRID & STANDARDIZATION INITIATIVES:

Governments worldwide are driving Smart Grids in order to achieve their policies on energy efficiency, energy independence and reliable & cost-effective energy supply for the whole community. Billions of Dollars and Euros are provided for research, development and deployment of Smart Grid solutions. For a wide spread cost - effective deployment, interoperability and 'open interfaces for future extensions' standardized solutions are a necessity. Governments therefore also drive smart grid standardization, worldwide.

Standards-development organizations (SDOs) are busy mapping the Imperatives for standardization, including IEEE. In September 2011, the organization approved and published IEEE 2030, "IEEE Guide for Smart Grid Interoperability of Energy Technology and Information Technology Operation with the Electric Power System (EPS), End-Use Applications, and Loads". More than 400 people from across the power, communications and information technology industries worked on this collaboration longer than two years, creating an integrated knowledge base and reference model. Their effort has yielded the world's first system-level, interface-by-interface guide to the paths and turns to be considered on the smart grid journey.

Furthermore many standardization bodies and industry forums from the ICT and energy industry consider Smart Grid as a priority issue.

Standardization for the Energy and ICT Industry, especially the telecommunication industry, has been done historically in different standardization organizations. ITU, ETSI, 3GPP, IETF are major standardization organizations for the telecommunication industry. IEC, CENELEC and various national mirror bodies are the major standardization organizations for the Electro-technical including but not limited to the energy industry. With the strong integration of ICT in the Smart Grid these two worlds are coming together and extensive interactions between the relevant bodies (i.e. liaisons, joint activities) have to be established. SGIP is pushing this by bringing the different organizations together in the PAPs. The European Smart Meter and Smart Grid Coordination Groups are established as joint activities of the European ICT and energy domain standardization organizations [4].

It has to be recognized that ICT technologies have already been standardized for the electrical energy market by the energy standardization bodies. Prominent examples are the Common Information Model, substation communication and automation and security standards defined by IEC and recognized as foundational standards for the Smart Grid by NIST. IEC also plays an important role in Smart Meter standardization and together with ISO in the Electrical Vehicle standardization. Replication of this work in telecommunication standardization bodies is being avoided, but integration with new ICT developments like M2M communications is being considered.

For the widespread and cost-effective implementation of Smart Grids, the use of widely accepted and implemented telecommunication standards is a pre-requisite. For the network and application layers, the use of IP technologies as defined by IETF is state of the art. As 3GPP LTE standardization shows, following the all-IP paradigm enables cost-efficiency, easy deployment and lowering of operational costs. Work on the necessary extensions for cost-effective support of constraint devices like sensors and actuators is already under way in IETF. For WAN, MAN and LAN communication widespread wire line and wireless technologies like Ethernet, UMTS, LTE, DSL, Wi-Fi, ZigBee, Power line, SDH/SONET and Optical Networks provide a wide choice. Smart Grid specific solutions and extensions are being avoided, as far as possible,. An important issue is the efficient support of Machine-to-Machine communication by these communication technologies. This however covers not only Smart Grid applications, but also various other usage areas like Home Automation, Building Automation & Management, Vehicle Telematics and e-Health. A common approach for all these usage areas will result in cost-effective solutions and stimulated cross usage area applications. Standardization activities for common M2M service enablers are currently going in various bodies and with the announcement of the M2M partnership project by major regional SDOs a global standard is approaching.

For the back-end integration interfaces for pricing and billing, CRM, Identity Management, work force management, weather data and other applications have to be defined. OASIS is producing first results based on established web service solutions.

In the home area we have a wide range of automation, control and communication protocols. Co-existence (e.g. for power line and wireless solutions) and interworking are the major issues in this area. The ZigBee Smart Energy Profile 2.0 has some chances to be widely accepted as it will include support for various Smart Grid applications, but 6LoWPAN is a very interesting contender for the same space.

SGIP in the U.S. does a good job in bringing together all the relevant standardization bodies and major stakeholders and in identifying areas for urgent need for standards or alignment between standards. Even though it is U.S. focused, it impacts international standardization also. At the European level, similar activities have been initiated with the Smart Meter and Smart Grid Co-ordination Groups. They have also the goal to bring their results in international standards (i.e. IEC). Only limited information on standardization activities in China are available, however they also are now getting active in international standardization at IEC and interact with the US and European activities. Incidentally, over a period of time Indian representation in the International Standards Organizations and Committees had declined sharply, which is now being reversed with a renewed vigor.

Also, the Indian Industry bodies like ISGF & IEEMA; Standardization bodies like BIS & TSDSI, and Government Departments like DeITy, DoT and MoP are playing a pro-active role in coming up with globally harmonized interoperable open standards for the Eco-system.

COMMUNICATION AND ITS IMPORTANCE:

A major disconnect which has recently become apparent is: the technological trends in ‘smart Homes’, ‘Smart Buildings’, ‘Smart Cities’ and ‘Smart Grid’ are being considered and pursued in isolation from each other with ‘silo’ approach, by the respective stake holders. In fact, they form a very tightly interwoven and homogenous confluence of similar technologies being applied in different domains for a common cause of making our planet earth ‘smart and green’.

The relationship between Smart Grids and Smart Cities needs to be understood in this context: "In a smart city, energy, water, transportation, public health & safety, and other key services are managed in concert to support smooth operation of critical infrastructure while providing for a clean, economic and safe environment in which to live, work and play”. Hence, the perspective in Infrastructure Design for any city has undergone a paradigm shift with advent of Convergence & Networking Technologies, Solutions for Information, Communication, Entertainment, Security & Surveillance; which are beginning to have a profound impact on the way we look at the Buildings’ Design (be it residential or commercial) and Town Planning.

Such a systems level approach in design and standardization is likely to not only enable newer and better services, but also allow far greater synergies and cost-effective deployments, reducing the lifecycle (total) cost of ownership of any Infrastructure, be it the smart grid, a home, a building or even a city, with attendant environmental benefits, including carbon reductions.

SMART CITIES, SMART BUILDINGS & SMART HOMES:

With the evolution of the converged & networked society, further fueled by the ‘Internet of Things’ era, a multitude of new applications of the Information & Communication Technologies have changed the way we live, work, play, interact and even think…

But, true convergence is still eluding the evolved citizens of Today’s Global Village because of a lack of harmonized standards in the respective ecosystems of the Smart Homes, Smart Buildings and Smart Cities. The smart nodes of one network cannot talk to smart nodes of the other networks. A wide array of proprietary systems/solutions, or systems/solutions with very limited interoperability are being deployed in each application areas for the todays' Home Automation, Building Automation, Industrial Automation or even the Infrastructure Automation needs of the society. This is definitely going to ensure that we shall not be able to derive the maximum benefits of these Technologies, whatsoever…

Smart projects are often connected to other aspects of infrastructure, and should be thought of as large systems of systems, the success of which relies on the optimization of all the sub-systems that support it. Some of the earliest deployments of smart infrastructure have proven to be not so smart. For example, by failing to identify the requirements of their customers, some utilities have deployed metering systems that do not support any of the customer-focused functionality that delivers much of the benefit from deployment. Other deployments have failed to identify dependencies or interactions with adjacent systems, impacting overall performance and restricting functionality.

Smart infrastructure projects are large systems of systems. The hugely complex nature of a smart infrastructure project creates a very real risk that oversights in the planning phase can cause the sub-optimization of sub-systems, which can severely impair the overall success of the project. Organizations can mitigate this risk by taking a far-reaching, structured, and detailed approach to project planning. By encapsulating the requirements of all stakeholders (both within and outside an organization), modeling the impacts of change, and tracing requirements throughout the project, it is possible to quantify the impact of different decisions in the planning stages, rather than realize mistakes once the project has been completed [5].

Looking at how the market is at an inflection point between talking about what 'smart city' means and understanding how to implement it, the evidence of the shift is in the increasing maturity of the demand side, implementing an Integrated Infrastructure to enable collaborative citizen's services with open data and innovative apps and develop standards and protocols for future city development.

M2M TO IoT:

"M2M" because of its pervasive nature is now very aptly known by the name "IoT". A concept that originally sounded like something out of sci-fi movie -- the "Internet of Things" -- is, in fact, a reality, and one that is bound to become even more widespread. Promising to be the most disruptive technology since the World Wide Web, the Internet of Things is predicted to result in up to 100 billion Internet-connected objects by 2020. Relying on embedded computing and sensors, and driven by smartphone and tablet adoption, IoT shall witness an explosion of new uses by consumers and enterprises alike. I believe that the Internet of Things, or the ability for consumer devices and appliances to communicate with one another via Web access and a complex system of embedded sensors, will "enable a wide range of new applications and services while raising many new challenges".

M2M essentially was, and, in the industrial parlance *is,* still "application specific" 'Machine to Machine' communication with "very definite functionality and expectations" with 'controlled mode' of communication; while IoT could be termed as its next avatar, yet it is going to see a whole set of new avatars in next few years n decades, because IoT is about the "Connected Intelligence", a sort of "universal global neural network" in the cloud. The developments in the last few decades in the pervasive embedded processing and revolutions in communication and sensors technologies have catapulted the homogenous M2M networks into heterogeneous global neural networks of "aware" and interconnected devices with unique IDs, interacting with other machines/objects, infrastructure, and the physical environment. The IoT comprises of smart machines interacting and communicating with other machines, objects, environments and infrastructures. As a result, huge volumes of data are being generated, and that data is being processed into useful actions that can "command and control" things to make our lives much easier and safer—and to reduce our impact on the environment. The creativity of this new era is boundless, with amazing potential to improve our lives.

Some define it as a vague n generalized glossy scenario of Smart Buildings, Smart City, Smart Lighting, Smart Grid, Smart Health and Industrial Automation Systems & Solutions. Some others define IoT as telemetry-like services over cellular network. Another group defines at as a One Box Solution for each Home.. **Internet of Things is all about "heterogeneous" and "aware" devices interacting to simplify people's life in some way or the other.**

Yet many technological hurdles must be passed before this vision becomes a reality. New types of sensors, new ways of connecting devices, and new strategies for embedded computing and securing the complete signal path must be rolled out to bring IoT's vision to the forefront.

Hurdles & Challenges in fast growth of IoT: The IoT value chain is perhaps the most diverse and complicated value chain of any industry or consortium that exists in the world. In fact, the gold rush to IoT is so pervasive that if you combine much of the value chain of most industry trade associations, standards bodies, the ecosystem partners of trade associations and standards bodies, and then add in the different technology providers feeding those industries, you get close to understanding the scope of the task.

In this absolutely heterogeneous scenario, coming up with common harmonized standards is a major hurdle. The other hurdle is – viable and acceptable business models of services based on the IoT. Convergence of the multitude of stakeholders of the IoT ecosystem to common business models and standards is a major imperative for the wide acceptance of the IoT wave by the masses. We need to see acceleration and a maturing of common standards, more cross-sector collaboration and creative approaches to business models.

Current methods for managing IT & Communication Infrastructure will not scale to meet the demands of IoT's "systems of systems".

CRITICAL INFORMATION INFRASTRUCTURES:

The critical Information Infrastructure is the backbone and foundation of any modern society/community today. Those ICT infrastructures upon which, the core functionality of

Critical Infrastructure is dependent. The critical information infrastructure (CII) is any physical or virtual information system that controls, processes, transmits, receives or stores electronic information in any form including data, voice, or video that is So vital to the functioning of the Critical Infrastructure that the incapacity or destruction of such systems would have a debilitating impact on national security, national economic security, or national public health and safety. A few essential components of the Critical Information infrastructure are: **Smart City, Smart Health, Smart Water, Smart Surveillance, Smart Grid and Smart Street Lighting etc.** They all need highly reliable Communication Backbone. Because of ubiquitous availability and comprehensive Network coverage, Cellular Communication has become the most preferred Communication Technology.

The contrast between IT and critical infrastructure networks is the fact that humans are the central feature for IT networks, but are only a side focus of critical infrastructure. In fact, the more effective and capable a critical infrastructure network becomes the less a human will be involved in any way.

The Protection of the Critical Information Infrastructure comprises of: Preventing cyber attacks against critical infrastructures, Minimizing vulnerabilities to cyber attacks; Minimize damage and recovery time from successful cyber attacks.

Challenges in Protecting CII: Lack of **“**visibility over, and classification of, critical information infrastructure**”,** Lack of **“**a standardized framework or metrics to identify and classify critical information infrastructure**”,** Lack of **“**standard, nation-wide practices, for defining the baseline metrics” for identification of critical information infrastructure, Lack of **“**knowledge and awareness about factors**”** impacting critical information infrastructure, Inadequacy of “relevant and workable information to take decision at the national level**”,** Inability in **“**Activating, driving, ensuring desired actions and seeking conformance from the entities on the specific terms**”**.

THE CRUCIAL IMPERATIVE:

A case in point: The Smart Grid being the convergence of IT, Communication & Power Technologies designed to cater to a nation’s Integrated Energy Infrastructure requirements comprehensively is a mission critical deployment needing the highest possible grade of security. This is because, once these Smart Grid Deployments are complete, you shall not need to possess nuclear weapons to bring a Nation Down, but would simply need a bunch of good Hackers who could penetrate thru the Smart Grid network of a nation and shut down the power to the nation.

CELLULAR COMMUNICATION:

Mobile networks are being used to connect all sorts of devices; automated reading of utility meters, intelligent connectivity of cars and commercial vehicles to enable drivers to access navigation, infotainment or breakdown services, traffic lights, home security and assisted living. The number of mobile connected devices is expected to be 10.5 billion by 2020, resulting in a huge new market opportunity, predominantly in the machine-to-machine (M2M) and consumer electronics sectors.

Because of ubiquitous availability and relatively comprehensive Network coverage, Cellular Communication has become the most preferred Communication Technology. The ease of connecting anytime, from anywhere to anywhere, has made it the default choice for WAN/Backhaul Communication requirements in the m2m solutions deployments. But, Under R-APDRP we saw the limitations of a cellular (mobile) based communications system. This was even before extending services to rural areas or adding smart functionalities, with stronger requirements. The limitations are because of the Over-optimization in Network Planning by the Service Providers. This approach in Network planning affects the QoS in any Voice or Data Communication, which varies & fluctuates from time to time, as well as, from location to location. Thus, No Single Service Provider of Cellular Communication can guarantee a reliable, resilient and ubiquitous communication uniformly in any geographical territory. Such unreliable Communication Networks must NOT be used as the communication Backbone for any Critical Information Infrastructure or Critical m2m Applications..

All parties in the M2M ecosystem will struggle if we remain solely dependent upon the traditional SIM card, which is predicated on only associating with one network operator.

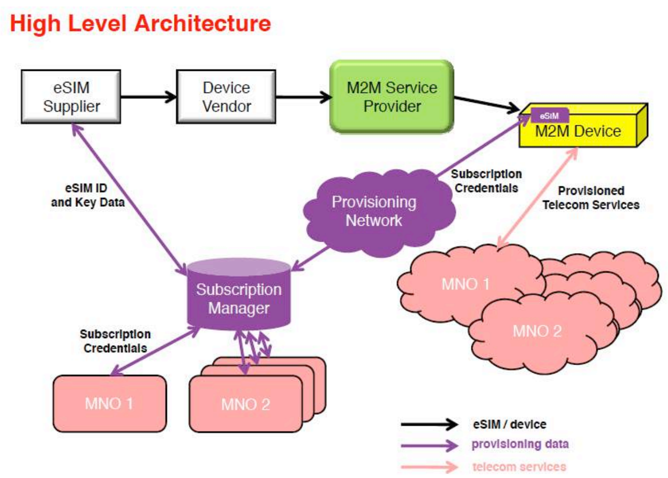
This is because changing SIM cards is problematical for many business-to-business (B2B) customers. For the industry, optimizing manufacturing process is a key challenge that “Embedded SIM” solves by providing a global product for a global manufacturing process with local provisioning when the product is deployed in the field. It also solves the challenge of managing those devices in the field when many M2M devices are remotely located, often hermetically sealed, their after sale location is not known during production and furthermore their product life cycles are lengthy. Many of the interfaces and processes needed to make the remote provisioning of SIMs work are virtually identical to current SIM personalization processes and interfaces used by mobile network operators today.

EMBEDDED SIM:

An ‘embedded’ SIM has the same functionality as a removable SIM, but in a different form factor –a chip, designed to be permanently soldered into an M2M device. It has 8 electrical pins, which are exactly the same as the 8 gold contacts on a normal SIM. These SIMs have many benefits for the M2M industry: cheaper to produce, withstands vibration, and it’s small size lends itself well to the growing IoT market. But there’s a problem: If **you can’t easily change SIM, how can you change from one mobile operator to another?** The Embedded SIM Specification solves this by allowing new operator profiles to be downloaded when required. - This makes it possible to change from one operator to another at the end of contract. - All of this carried out securely Over The Air. The Embedded SIM Specification also applies to removable M2M SIMs too. - There are millions of M2M devices already deployed using removable SIMs -retrofitting them with Embedded SIMs allows them the same benefits going forward.

Advantages over current removable SIM Cards: Removable SIM cards are often inaccessible within M2M wireless modules making it difficult if not impossible to change the SIM once deployed. Embedded SIMs never need to be removed –new operator profiles are simply downloaded to the SIM when required. The Embedded SIM Specification simplifies logistical processes: Installation of a single SIM Stock Keeping Unit (SKU) into an M2M device at the point of manufacture, download of an appropriate operator profile in the destination country for that device, removes the need for stock control and shipping of physical pre-provisioned SIM cards and all this operational flexibility is delivered with no compromise on security.

The Elements Involved: Embedded SIM is functionally identical to a traditional SIM**.** At manufacture, the embedded SIM will have a ‘provisioning profile’ assigned with secret keys that allows the associated subscription manager to download and manage ‘operational profiles’ on the eUICC. The technical specification can accommodate both an initial declaration of the MNO in the eUICC, as well as the selection of a new MNO later. The implementation will depend upon the commercial agreement between the operators and their customers. **Subscription Manager manages the embedded SIM by:** Generating SIM profiles in real-time, Management and execution of MNO policy, secure routing profiles to the embedded SIM. **MNO:** Uses subscription manager to manage profiles, Maximum re-use of existing provisioning interfaces and processes.



Embedded SIM is NOT Soft or Virtual SIM. Embedded SIM technology is an extension of today’s SIM technology: It uses the same SIM hardware in devices, but now subscription credentials can also be downloaded remotely at any time during the lifetime of the SIM. All of the existing standardized SIM form factors can be used, including embedded (MFF1, MFF2) and removable (2FF, 3FF)

Soft or Virtual SIM is a very different concept: It does not use existing SIM form factors, instead using hardware and software within the M2M device itself to perform the role of the SIM. This approach may benefit from removal of traditional SIM costs, but mobile operators are very concerned about the reduction in security of their credentials. Any SIM approach not based on a certified hardware secure element will be subject to continual attack by the hacking community and if compromised result in a serious loss of customer confidence in the security of Operator systems. Additionally, Multiple Soft SIM platforms carrying credentials in differing physical platforms, all requiring security certification and accreditation would become an unmanageable overhead –both in terms of resource, and proving their security in a non-standardized virtual environment.

eUICC offers the Value we Need for the M2M applications: Complete and cost-efficient life-cycle management of SIM and device, including “everything” from activation to deactivation on a SIM and device management level; Open, complete SIM management to Manage everything around SIM; Open device management and device knowledge with use of extensive device DB; open service delivery platform (SDP) environment for application support to allow use of any SDP - internal or external; and, both SIM and network subscription management (SM).

GSMA Embedded SIM Specification: Remote SIM Provisioning for M2M: The GSMA created a specification that enables the remote ‘over the air’ provisioning of machine-to-machine (M2M) devices that are hermetically sealed or installed in hazardous or remote locations. Backed by global operators and SIM suppliers, the specification promotes a common, global, remote provisioning architecture that will help to ensure interoperable technical solutions that reduce costs, boost security and accelerate the rapidly growing M2M market. The GSMA’s vision is to unite all stakeholders behind a single, common and global specification to help accelerate the growing machine-to-machine (M2M) market. The GSMA’s remote provisioning specification allows mobile network operators to provide scalable, reliable and secure connectivity for M2M connected devices, removing the need for each operator to develop their own technical solution.

GSMA Embedded SIM Test Specification: The purpose of the Test Specification for GSMA Embedded SIM is to ensure that products made by vendors, including eUICC, SM-DP and SM-SR entities are functionally compliant to the GSMA Embedded SIM Technical Specification. The Certificate Issuer (CI) process within the GSMA Embedded SIM architecture ensures the various system entities (SM-DP, SM-SR, EUM, and eUICC) can all be trusted by each other.

The Embedded UICC Protection Profile: It is imperative that the SIMs used in GSMA Embedded SIM solutions are ***as secure as*** today’s SIMs. To ensure this, a Common Criteria security evaluation process is used. The starting point for this process is what is known as a **Protection Profile.** A Protection Profile is actually a document that states rigorously states a security problem for the Target of Evaluation (TOE) –in our case the GSMA Embedded UICC itself. The problem includes the environment, security threats, objectives and assumptions. The document then goes on to specify the security requirements to address that problem without dictating how these requirements will be implemented. In order for a vendor to get their embedded UICC (eUICC) product evaluated they must supply to the evaluator their actual product. And they must also supply what is known as a Security Target (ST) – another document, which is created directly from the

Protection Profile document and used in the evaluation process. The vendor's eUICC Product is evaluated and certified according to Common Criteria (EAL4+) using GSMA Protection Profile as a template for the vendor product's ST. If successful, a certificate is issued validating the product's evaluation. The product is placed on the Validated Products List, and the report is made publicly available. Periodic reassessment is required.

Unique MVNO Model for Critical Communication Backbone:

Consider a case where, for any & every critical m2m service to be deployed, there is one common Govt. designated MVNO (Mobile Virtual Network Operator), who alone is authorized to offer the cellular communication backbone to the m2m Service Providers & Critical Communication/Information Infrastructure.

Further, the SIMs are not the contemporary type, but the SMD SIMs, which are soldered on the PCB, during assembly of the m2m communication device/module. These SIMs have all the features enumerated in the preceding slides viz.: Device/SIM Management, Subscription Management, Application Management, Security, Roaming Steering, Throttling/ Scheduling & QoS Monitoring etc..

The MVNO has 'back-to-back' Subscription & Service Level Agreements with all the Service Providers in the Nation on Uniform & Regulated Revenue Sharing arrangements. The MVNO has a comprehensive NOC equipped with all the required capabilities to enable, monitor & control, and thus, effectively manage all the m2m services imperatives for maintaining the required QoS dynamically.

The m2m device manufacturer has 'n' No. of Roving Test Subscriptions from the MVNO. The m2m communication devices/modules are tested with the test subscriptions and shipped to the solution deployer. The solution deployer commissions the complete Solution/Network and Tests it with his respective Test Subscriptions. The Solution Deployer Hands over the commissioned solution to the Utility or the respective Service Provider.

The Utility/Service Provider now buys the required regular Subscriptions from the MVNO as per the use case & business case along with signing the SLA based on QoS needs of the Service being rendered. The respective m2m Service Provider does not need to go to individual regional Service Providers to negotiate and buy subscriptions and/or sign the QoS SLAs.

Now, it's the responsibility of the MVNO to meet all the QoS needs and SLAs with each m2m Service Provider, irrespective of the multiple regional or geographical diverse locations of m2m nodes belonging to each respective m2m service rendered by the respective service providers. The MVNO NOC has a comprehensive suite of Tools to manage the m2m communication backbone in a MNO Agnostic manner. It continuously monitors the QoS on each m2m node, and if at any given moment, the QoS falls below the negotiated/committed QoS, it dynamically switches the connectivity to an MNO whose Signal Strength or QoS at that moment is better than the current MNO, whose network the particular m2m node was using..

Even, in case of Mobile m2m nodes, this Architecture & Business model is highly advantageous, as all the roaming steering from one geographical location to another is seamlessly handled without compromise on the QoS…

CONCLUSION:

To establish a resilient, reliable & efficient communication backbone for the various critical information infrastructures and other critical m2m applications, there is clearly a **dichotomy** between: on the one hand, the situation **"Cellular Communication Networks are widespread but unreliable"**. And, on the other hand, the situation, **"Laying a widespread and comprehensive Wire-line Communication backbone is neither feasible nor economically viable"**.

To resolve this impasse, we need to have a fresh approach in developing a use cases based Communication Architecture followed by enumerating the changes needed in the Regulatory Framework to enable evolution and deployment of a robust, yet cost effective and ubiquitous communication backbone using the prevalent cellular communication infrastructure. However, this approach shall need a fresh re-think in the Regulatory regime around the aspects that shall be impacted, if this approach is considered for improving the QoS in the ***"Critical Communication Infrastructure"*** which works as the backbone for the Smart Grid Communication Infrastructure, as well as the **"National Critical Information Infrastructure"**.

The need for proven, scalable, and standards based solutions for Indian deployment scenario, with inherent complexity and tradeoffs, requires specialized, skilled, and multi-stakeholder engagement.

Strong, clearly understood, tangible benefits to be gained from the adoption of the "Unified & Secure Communication Architecture, Protocols, Interfaces and Standards" along with correct "Business Models governed by a mature & rational "Regulatory Framework" for the "Smart, Green and Secure Community" will be needed in order for both questions to be answered.

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Considerations in Standardization for Demand Response Ready Air Conditioners in India

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Abstract— The following overlapping and converging trends require a careful consideration of what ought to constitute demand response (DR) ready capability for air conditoners (ACs) in India: a) Increasing peak load from air conditioners (ACs) b) Plans for increased intermittent renewable generation capacity and c) increased numbers of appliances with "smart" functionality. In India, given the likely estimated future growth in ACs will add load of ~60-100 GW, DR ready ACs can provide an opportunity to mitigate this peak demand. However, DR implementation in India will require considerations that are different from those in the United States (US) and Australia. For example, cell-phone penetration in India is higher than broadband Internet penetration. In this paper, we present a draft specification for DR-ready appliances in India, building from international experiences and from existing IEC standards. We present this specification in order to begin the debate about what such a specification ought to consider, including issues such as the need for automation, bi-directional communications and low latency requirements (or fast response from loads).

Keywords— demand response, smart appliance, air conditioners, renewable energy integration, standards

INTRODUCTION

India is poised for a rapid increase in peak electricity demand from air-conditioners due to rising incomes and large population centers in hot climates. (Figure 1). Since 2004, room air conditioner (AC) sales in India have been growing at more than 15% per year, with more than 3 million units sold in 2012 (Phadke, Abhyankar and Shah, 2013). Although India currently has very low room AC penetration, large growth in AC sales is expected to result in a peak demand addition of 60 GW to 100 GW by 2030 (Phadke, Abhyankar, and Shah 2013; Planning Commission 2014).

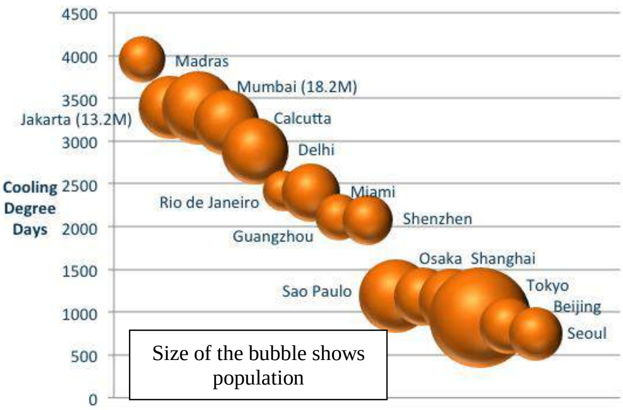

Figure 1. Many of India's large urban centers have among the hottest climates Source: (Sivak 2009)

Meeting this additional demand would require a massive increase in electricity generation supply, especially during the peak summer periods, and have implications for energy security and the national balance of trade. This potential rise in electricity demand can be managed through a combination of policies to enhance the efficiency of ACs being sold in the Indian market, and through the adoption of demand response technologies (DR) and policies, as we will discuss later. Furthermore the recent announcements by the Government of India of a targeted 100 GW of solar generation capacity also necessitate increased penetration of energy storage and demand response technologies in order to integrate this intermittent renewables generation capacity. Finally, there is a global convergence toward the "Internet of Things" (IoT), with appliances, smartphones, etc. all increasingly connected to each other. Each of these trends, namely: a) increased AC sales, b) increased intermittent renewable energy generation and c) increased penetration of smart appliances (including ACs) creates an opportunity for the Indian economy to deploy “demand-response ready” or “smart” ACs in order to ensure peak load management and grid stability. In the US, about 60,000 MW of DR capacity exists in various DR programs, and the combination of demand response and energy efficiency programs has the potential to reduce non-coincident summer peak demand in the US by 157 GW by 2030, or 14–20% below projected levels (Siddiqui 2009). Demand Response (DR) can, therefore, be considered a valuable resource for managing the electricity grid. It can effectively mitigate peak demand and also reduce the costs associated with integrating intermittent renewable energy generation (Klobasa 2010).

- ***Demand Response*** refers to changes in the operating mode of appliances or equipment in response to changes in electricity prices, the state of the electricity network, or external requests for load modification. The user may respond manually, or may willingly permit automated changes to lower energy costs and/or financial incentives.
- ***Smart Appliance*** has been variously defined as: 1) “a product that uses electricity for its main power source which has the capability to receive, interpret and act on a signal received from a utility, third party energy service provider or home energy management device, and automatically adjust its operation depending on both the signal’s contents and settings from the consumer” (AHAM/ACEEE, 2011), alternatively, 2) “the automated alteration of an electrical product’s normal mode of operation in response to an initiating signal originating from or defined by a remote agent”

SCOPE

In this paper we discuss current developments in the International Electrotechnical Commission’s (IEC) standards process and issues needing consideration in standards for DR-ready or smart ACs in India, based on the draft IEC standard being developed by IEC TC59 WG15, which sets out a reference framework for defining appliances as “smart” or “demand-response ready”. We do not discuss communications specifications, which are being developed separately under the IEC Project Committee 118 (PC118) on “Smart Grid User Interface” which focuses on the cross-domain interfaces that support secure communications and information between the electricity service provider, and the controls, electrical load, storage, devices, etc. within the consumer (user) domain. (IEC PC118, “IEC 62939 TR: Smart Grid User Interface,” Draft Technical Report, 118/40/TR, 2014)

RELEVANT STANDARDS

Standards for Demand Response and “smart” appliances have been in development since 1997 in Japan, since 2003 in Australia and are still being revised internationally under IEC TC59 and in the US under the ENERGY STAR program. As can be seen from Figure 2, standards development is a lengthy process requiring consultations with many stakeholders in order to arrive at an acceptable consensus framework. The field of smart appliances is currently at an early stage of development with IEC TC59 WG 15 expected to publish a draft technical specification in mid-2015.

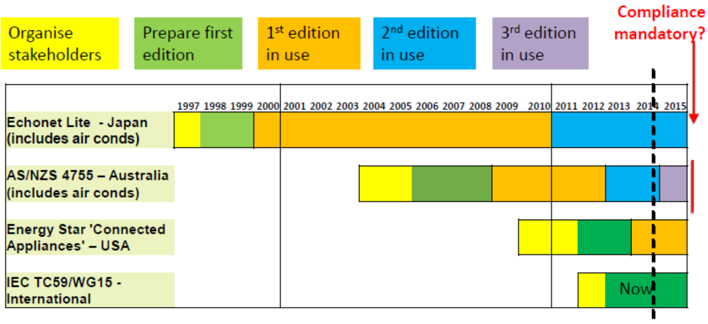

Figure 2 Typical Timeline for standards development (Source: Wilkenfeld, 2014).

We will now discuss various use cases that have a bearing on requirements for a specification for demand-response ready appliances.

LATENCY (OR RESPONSE TIME)

As shown in Table 1 below, space-cooling equipment such as ACs and chillers can be used in many different types of demand response programs.

Customer Type	Equipment/ Building Component	Control Strategy	DR programs: Emergency or Energy Resource	DR programs: Capacity Resource	DR programs: Regulation Service or Reserves
Residential	Air conditioners	Cycling/forced demand shedding	√	√	√
Commercial	Chillers	Demand limiting during on-peak period	√	√	
		Pre-cool building over night-storage		√	
		Forced demand scheduling	√	√	
Industrial	Chillers	Demand limiting on time schedule		√	

Table 1: Cooling equipment use in Demand Response programs [adapted from (Walawalkar et al. 2010)]

For example:

- as an "emergency" or "energy" resource during a time of high demand
- as pre-scheduled "capacity" that can reduce load according to a pre-planned schedule
- as a means of providing regulation services and reserves in real time or on short notice.

In order to accommodate these different types of demand response functionality, response times from seconds (for regulation services or emergency energy resources) to minutes to hours (for pre-scheduled capacity) may be required. A clear and flexible definition of "DR-ready" or "smart" space cooling equipment is needed in order to accommodate the various types of DR programs, technologies and frameworks. Integration of intermittent renewable energy resources may also require response times of the order of minutes or seconds if demand response is used for regulation services.

Hence any specification for DR-ready appliances should account for such widely varying timescales for different DR program (i.e. response time) requirements.

AUTOMATION AND BIDIRECTIONAL COMMUNICATION

Automated DR, which enables energy service providers to control the usage of end use equipment remotely and automatically, is one of the key DR strategies/programs that have been found to improve load response and peak load reduction (PowerCents DC 2010). For example, during

Technology	Communication Medium	Capabilities	Pros	Cons
Radio controlled chip that communicates with the appliance microprocessor	Radio signal	Modulate energy consumption (uni-directional communication only)	Lower cost than cell or WiFi	Easier to bypass; actual participation in the program cannot be confirmed and could raise issues for compensation
Frequency controlled chip that communicates with the appliance microprocessor	Grid frequency	Modulate energy consumption (uni-directional communication only)	Lower cost than cell or WiFi	Unidirectional communication capability; easier to bypass;
Wi-Fi chip that communicates with the appliance microprocessor	Wi-Fi network	Modulate energy consumption + report back the status of the device (bi- directional communication)	Hard to bypass; reports back if bypassed/overridden; compensation to consumers can be based on actual participation	Higher cost compared to radio/frequency based switches; Costly for retrofit; Requires WiFi network
Cellular chip that communicates with the appliance microprocessor	Cellular network	Modulate energy consumption + report back the status of the device (bi-directional communication)	Hard to bypass; reports back if bypassed/overridden; compensation to consumers can be based on actual participation; ubiquitous availability of cellular network (in cities)	Higher costs compared to all options discussed above
Smart plug that can be remotely turned off/on	Wi-Fi network (or cellular network)	Switch on/off the power to the device + report back the status of the plug (bi-directional communication)	Can enable auto DR capabilities in existing stock of appliances; reports back if bypassed/overridden; compensation to consumers can be based on actual participation;	Higher costs; can be easily bypassed

Table 2 Auto DR technology options

evening peak periods, with consumer's consent, AC temperature set points could be automatically changed, resulting in load changes (including peak load reduction) without major discomfort to consumers. [1] Alternatively, the AC can be switched off remotely for a certain interval, or instructed to reduce load by a set percentage. ACs can be equipped to automatically respond to remote signals to alter their demand (Bode 2013).

If most room ACs sold in India starting in 2016 had this capability, by the end of 2020, about 20 million ACs with a connected load of 30 GW (1.5kW of connected load on average for a Room AC) and peak load contribution of more than 20 GW (assuming 70% of ACs are on during peak load), would have the potential to reduce 8 GW of demand if signaled to reduce their loads by 30% (for example by increasing their temperature set point by a few degrees). Realistically, actual load reduction would likely be on the order of 10-15% (i.e. ~3GW) similar to recent findings in the US. (EPRI, 2009). Actual load reduction that could be achieved will depend on the level of consumer participation in demand response programs.

Various auto DR communication technology options are shown in Table 2, above. The simplest and the least expensive technology for automated DR is radio signal based automated load control technology which has been used for more than two decades for automated DR.[2] However, this technology is unidirectional (i.e. one-way) and cannot report back any status from the device it controls which makes it easier to bypass particularly on smaller units with easily accessible electronics and also making it difficult for the utilities to know if the device has received the signal and can respond.

Wi-Fi or cellular Internet Protocol (IP) based technologies allow bidirectional or two-way communication between the device and the utility, including exchange of various parameters related to the status of the ACs and other information that can be reported back. For example, if the signal was used to remotely change the temperature setting on a room AC, whether and when that temperature setting was changed again can be reported back. Such bidirectional systems are likely to provide the most reliable information on DR program compliance, but can have higher costs. Providers of DR programs need to assess the trade-off between reliability of DR participation and cost of equipment and evaluation, monitoring and verification when designing financial compensation schemes. A specification for a DR-ready appliance ought to allow these various types of auto DR technology solutions to be deployed in order for the market and DR-program developers to have the flexibility to implement the appropriate kind of DR technology.

DRAFT IEC TC59 WG15 SPECIFICATION

The current specification being drafted by the IEC TC59 WG 15 defines a "Customer Energy Manager" (CEM) as "a component or set of functions which has the capability to receive and process Grid Information, Appliance Information and User Instructions and which manages one or more Smart Devices". The CEM could be analogous to the radio, frequency, Wi-Fi or cellular controlled chips shown in Table 2. The current draft specification requires the CEM to:

- be able to receive and pass on Grid Information to at least one device,
- be able to receive Appliance Information(e.g. its state or energy consumption level etc.)
- be able to transmit information to the grid (i.e. bi-directional communications).
- be able to receive/pass or act on emergency and other types of load control signals
- be able to be programmed with preferences (by user, remote agent or both) and act on them.

CONCLUSIONS

There is a significant potential for future peak load reduction (~3-8GW) by implementing demand response programs for ACs. In addition DR can also provide benefits in integrating intermittent renewable energy. However, implementation of DR programs will require ACs with some sort of "DR-ready" or "smart" functionality. The IEC TC59 WG15 specification framework for "smart" or "Demand-response ready" appliances is still in draft stage and being developed further. However, Indian stakeholders including manufacturers, utilities, and government agencies such as the Bureau of Indian Standards (BIS) and the Bureau of Energy Efficiency (BEE) could participate actively in its development, and ensure that the requirements of the Indian consumer, electricity grid and manufacturers are considered in its development, for example by ensuring:

- bi-directional or two-way communication
- ability to deploy technologies with low latency (or fast response time) e.g. Wi-Fi or cellular and
- ability to deploy auto Demand Response
- flexibility in order to implement cost-effective solutions.

Involvement in the international development of the standards for DR and price communications and also possible adoption of such a specification for smart appliances in India may be increasingly necessary in order to manage the increasing peak load due to increasing demand for space cooling and increasing penetration of intermittent renewable energy resources on the Indian grid.

[1] See example of set point adjustment- http://www.herterenergy.com/pdfs/Publications/2013_Herter-SMUD_ResSummerSolutions2011-2012.pdf

[2] See http://repository.tamu.edu/bitstream/handle/1969.1/6651/ESL-HH-94-05-31.pdf for summary of the experience of the direct load control programs in the US

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Smart Metering and Demand Response

Case Study- TATA Power Delhi Distribution Ltd

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Abstract: The paper explains the first utility initiated large scale Auto Demand Response program integrated with Smart Metering. The project covers C&I consumers spread over the entire TPDDL geography. The paper covers in detail the project objectives, the technology components and architecture, salient features of the project, the challenges faced during implementation, benefits derived out of the project and the road ahead for scaling the project.

Keywords—Auto Demand Response (ADR), Smart Meter, Radio Frequency (RF), Advanced Metering Infrastructure (AMI), Commercial &Industrial (C&I) Customers, Software as a Service (SaaS), Tata Power Delhi Distribution Limited (TPDDL)

INTRODUCTION:

TATA Power Delhi Distribution Ltd has always been on the forefront of implementing new technology to improve its operations and increase customer satisfaction. It has to its credit many firsts in implementation of technologies like Grid Sub Station Automation, Automated Meter Reading, Distribution Management System, Outage Management System and ERP etc. After completing the first phase of technology roadmap, TPDDL has now embarked upon its journey towards becoming a smarter utility of the future by launching its pilot project on Automated Demand Response and Advanced Metering Infrastructure which will result into reduction in peak demand at the time of critical grid stress.

PROJECT OBJECTIVES:

The pilot project intended to cover high end consumers having sanctioned load of 100 KW and above and envisaged a peak demand reduction through Automated Demand Response (ADR) which demonstrate Technological capability of project components like:

RF based smart metering, Head End System,

Meter Data Management System and its integration with IT-OT system, ADR system

Understand customer behavior for adoption of new technology and participation in ADR

Develop Case study for regulator to work on differential tariffs and financial incentives

TECHNOLOGY COMPONENTS & ARCHITECTURE:

This was the first time a large scale utility initiated integrated AMI & ADR program was being implemented. Since the project involved evolving technologies and high degree of product and solution development along with newer system integration challenges, the process of vendor selection and finalization was critical part of the project implementation. The finalized architecture and technology components were as follows **(Ref Fig 1.1):**

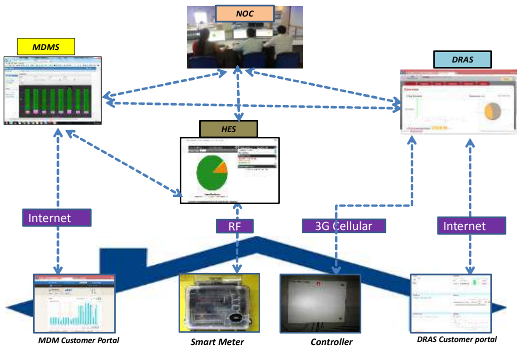


Fig 1.1 Design Architecture and Data Flow

HT CT operated Smart Meters which transmit data in 15 minutes granularity.

RF Mesh based communication network for Smart meter which operated in unlicensed frequency band on 865-867 MHz.

Head End System for real time data acquisition of smart meters through RF mesh.

Meter Data Management system for maintaining a repository of all the granular meter data.

Site Controller for controlling the non-critical loads during the DR events at the consumer end on cellular communication.

Demand Response Automation Server on cloud as SaaS model for initiating and verification of DR events.

Customer portals for MDMS as well as DRAS.

Integration of MDMS with different IT-OT applications through Enterprise Service Bus based on Service Oriented Architecture.

SALIENT FEATURES OF THE PROJECT:

As on date we have enrolled 167 consumers engaging them in Automated Demand Response (ADR) through auto controller along with smart meter based on RF Mesh communication with shed potential of 12 MW under this project. The consumers who are participating in the project are spread over 25 zones of TPDDL and are being fed from 39 different grids covering 108 feeders. With these deployments we have successfully been able to demonstrate the technical capabilities of Smart meter with RF based communication as well as the technical capabilities of the ADR infrastructure after successful testing and commissioning. Some of the salient features of the deployments which are unique in nature for a distribution utility:

RF Mesh network spread over an area of approx. 250 Sq km covering scattered HT consumers in the TPDDL license area.

4 hour Advance intimation to the consumers in case of a scheduled DR event with opt out option through return SMS/Email **(Ref Fig 1.2).**

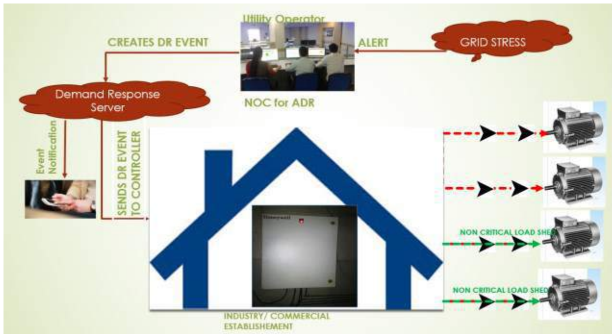


Fig 1.2 DR Event Pictorial representations

Near Real time 15 min granular data transmission of 15 min load interval data to TPDDL data acquisition system.

Real time intimation to consumers in case of violation of set thresholds with regards to Low PF and Load **(Ref Fig 1.3).**

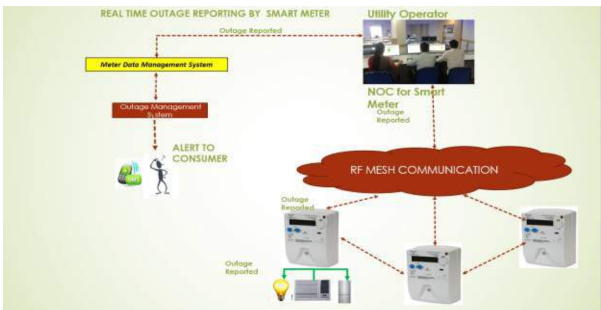


Fig 1.3 Smart Metering Pictorial Representation of real time outage reporting

Advanced customer portal for providing granular 15 min interval data to customers for monitoring consumption pattern on daily/hourly basis **(Ref Fig 1.4).**

Fig 1.4 Smart Metering Pictorial Representation of granular information availability & real time load alert

Integration of MDMS and DRAS system, enabling elimination of role of aggregator and use of shadow meters for the purpose of calculation of baselines and actual shed calculation.

Integration of MDMS system with the existing SAP system for creation of automatic service order and billing system.

CHALLENGES:

The project is covering geographical area of more than 250 Sq km in Lawrence Road, Narela, Bawana, Alipur, Jahangirpuri, Delhi University, Civil Lines, Naraina, Pitampura, Rohini, Badli area of TPDDL with select Industrial and Commercial Consumers having loads greater than 100 KW and engaging sectors like Flour Mills, Food Processing Industry, Cold Storages, Commercial establishments, Educational Institutes, Hospital, Plastic & Footwear Industry etc.

During the project execution a number of challenges were faced by the execution team which is listed below. The team worked in closed association with the technology solution providers to overcome the issues listed below and demonstrate a successful solution deployment.

DESIGNING ADR WITH SMART METER ARCHITECTURE:

Conceptualization of ADR with Smart meter architecture in this unique project where ADR, AMI, ESB and ERP systems are conceptualized under Smart Grid scenario as no use case available.

Designing of solution while considering integration with existing IT-OT infrastructure.

SELECTION OF TECHNOLOGY SOLUTIONS:

Willingness of potential technology partners to invest in this complex project in order to keep the project cost within approved budget.

Selection of best technology to fit in proposed architecture.

Capability of integration with existing IT-OT systems.

Capability for scale-up.

Existing IT-OT systems need to be upgraded to meet interfacing requirements of selected technologies.

CONSUMER RELATED ISSUES:

Conducting multiple interactions at different hierarchical level for convincing consumer to participate in DR program.

No direct incentive for participating consumers.

Technical feasibility for enrollment which included manual starters / MCB operated loads, continuous automated process.

Long process for enrolling Govt. consumers.

Low occupancy of commercial establishment.

Large no. of Govt. /Institutional complexes as well as shopping complexes are without central air-conditioning system.

Consumer readiness to give control to 3rd party like utility.

SETTING-UP COMMUNICATION NETWORK:

Design of RF network for wide spread consumers on digital elevated maps based on GIS data of TPDDL and with RF noise analysis tool **(Ref Fig 1.5)**.

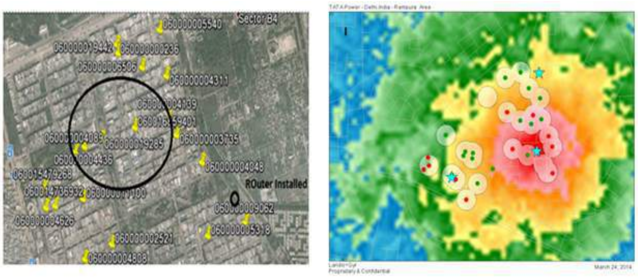


Fig 1.5 Consumers mapped in GIS to capture their geo-spatial co-ordinates and analysed RF signal coverage with RF noise analysis tool

Change in original network design due to consumer back-out or to accommodate new consumers in new geographical cluster and RF radiation pattern which define location of communication network elements (Collector, routers and repeaters were placed at TPDDL grid sub stations as well as at roof top of consumer premises) as shown in **Fig 1.6**.

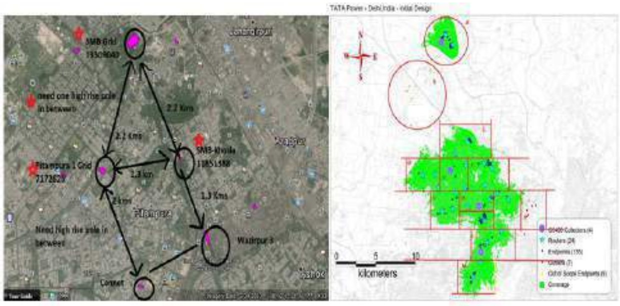


Fig 1.6 Location of communication network element after analyzing RF signal pattern

Difficulties to create RF mesh or hopping as meters are in metallic enclosure, in basement or in interior of premises.

Merging of two different communication technology for Neighborhood Area Network (NAN) between meter & DCU and for WAN between DCU & HES at access of fiber in WAN).

Reliable power supply for communication network elements like DCU (Data Concentrator unit) and bridges.

INTEGRATION ISSUES:

Integration between different systems through enterprise service bus.

Co-ordination between different vendors in different time zones.

Capturing and finalization of use cases for interface requirements.

Integration of applications which communicate on different protocols.

Integration of cloud based application (DRAS) in SaaS model with TPDDL SMS server.

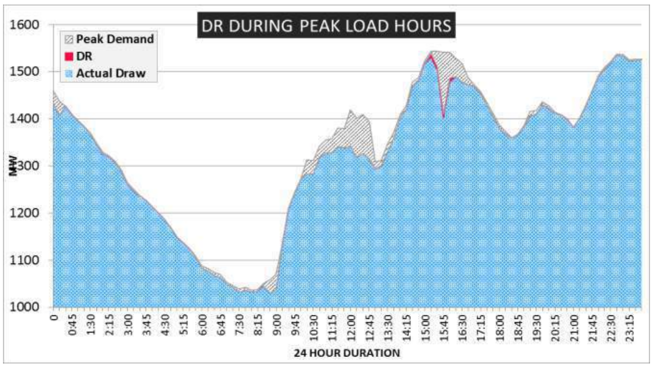
Capturing consumer response for OPT-OUT through SMS.

LEARNINGS & BENEFITS:

FINANCIAL:

In addition to the above technical capabilities, TPDDL has conducted 17 DR Events starting the month of May 2014 and have achieved a max shed potential of 7.2 MVA with a cumulative saving of 0.063 MUs in 14 hrs and 45 mns. These events were scheduled during the peak demand timings as observed by TPDDL.

Considering as an example a DR event was conducted on 26th August from 1500hrs to1600 hrs. which resulted in achieving a DR shed potential of 7.2 MVA on system peak load condition **(Ref Fig 1.7).**



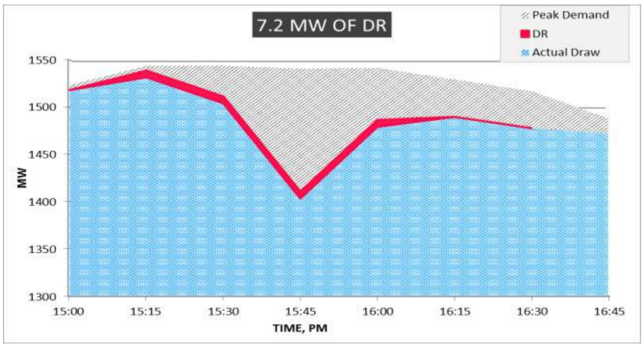


Fig 1.7 System load conditions during DR Event on 26th August

The conditions prevailing during the duration of event are summarized below in **Table 1.1.** During the above conditions, the shortage of power was due to the reasons mentioned below:

our application of Short Term Open Access (Banking) from MP for 280 MW from 1300 hrs to1700 hrs was rejected. The rejection came at around 2200 hrs on 25th August; hence, there was no option to buy from the exchange. In order to meet the shortages the only option was to arrange for costly power generated from spot gas at rate Rs. 9 per unit. But shedding of 7.2 MW noncritical load at consumer end avoided costly power purchase during DR event on 26thAugust as shown in **Table 1.2.**

S. No	Description	Unit	Amount
1	Per Unit cost of power through spot gas	Rs	9
2	Shed Achieved during DR event	MW	7
3	Units Saved due to DR Event	KVAh	7000
4	Avoided Power purchase from costly generation	Rs	63000
5	Avoided Power Purchase Cost/MW	Rs	9000

Table 1.2 Cost benefit analysis for DR event

Start Time - End Time	Interval	Power Available	Spot Gas Power Arranged	Load Sanctioned by DTL	Frequency (Hz) for the day	Actual Drawl of NDPL (MW)	Shortage (MW)	Shortage after SPOT Gas (taken through UI)	Load Shed (MW)	DR Shed Achieved MVA
1500 hrs	15:15	1323.33	208	1531.33	49.85	1581.49	258.16	50.16	0.00	7.159
	15:30	1351.33	180	1531.33	49.82	1591.76	240.43	60.43	0.00	
	15:45	1351.33	180	1531.33	49.84	1593.39	242.06	62.06	0.00	
1600 hrs	16:00	1354.78	180	1534.78	49.81	1582.42	227.64	47.64	0.00	

Table 1.1 Power condition prevailing at the time of DR Event on 26th August

Due to coal shortage, multiple generation units were offline and this had resulted in general shortage across the entire Northern Region. This also resulted in pushing up power rates at the exchange. In addition to the above, there was a corridor constraint in the NR-WR region and

An analysis of the aggregate peak demand of the consumers who enrolled in the DR shows a peak demand of 31.76 MVA on 26th August 2014 and out of that a DR shed potential of 7.2 MVA reveals that 22.5% of the peak load was shaved.

Similar situation also occurred on 22nd August also and due to the shortage which existed, there was a situation which necessitated over drawl / load shedding. We were able to reduce the effect of over drawl/shedding by a quantum of 4.9 MVA through DR event conducted which is 12.76% of aggregated peak load i.e 33.1 MVA on same day.

The detailed cost benefits analysis for illustrating the per unit DR cost and per unit savings on account of avoided power purchase and network augmentation cost is described in **Table 1.3 & Fig 1.8.**

INCREASED RELIABILITY THROUGH PEAK LOAD SHAVING:

During grid stress situations when the grid frequency is low, the utility generally needs to resort to load shedding. In such a scenario, DR event facilitates the utility to curtail the requirement of load shedding to the extent of non-critical load shed. In this way, the participating consumers get the benefit of increased reliability as only non-critical load which does not hamper their production cycles or comfort is only shed and balance supply continues as usual.

Demand Response - Cost Benefit Analysis Summary										
(Rs/ kWh Unit)	**Year1**	**Year 2**	**Year 3**	**Year 4**	**Year 5**	**Year 6**	**Year 7**	**Year 8**	**Year 9**	**Year 10**
Net Power Purchase cost at TPDDL periphery	5.61	5.75	5.91	6.1	6.34	6.5	6.47	6.45	6.43	6.42
Deferred Cost for additional sub transmission network to meet peak demand	18.04	18.04	18.04	18.04	18.04	18.04	18.04	18.04	18.04	18.04
Total Avoided Cost	23.65	23.79	23.95	24.14	24.38	24.54	24.51	24.49	24.47	24.46
Lebelized DR Costs	5.68	5.68	5.68	5.68	5.68	5.68	5.68	5.68	5.68	5.68
Net Cost	-17.97	-18.11	-18.27	-18.46	-18.7	-18.86	-18.83	-18.81	-18.79	-18.78

Table 1.3 Cost Benefit Analysis Summary

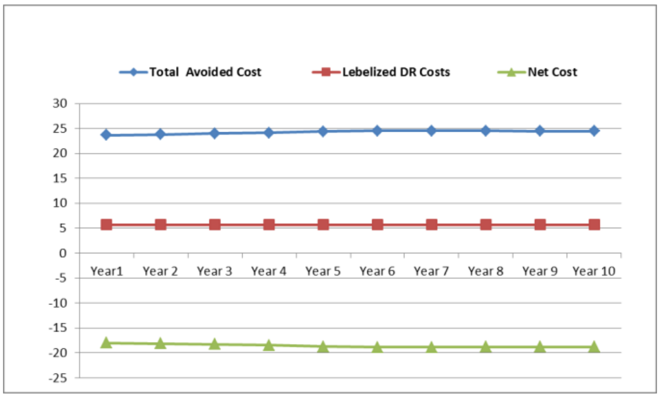


Fig 1.8 Graphical Representation of Cost Benefit Analysis Summary

The summary shows that the solution is beneficial as the net cost is negative, thus savings on account of solution far outweigh the costs. Some percentage of these savings can be used to pass on financial incentives to the participating consumers without impacting the tariffs.

UNDERSTANDING CONSUMER BEHAVIOR:

The 167 consumers which have been enrolled in the program are voluntary participants in the program. Their participation in the program can be attributed to factors like effective and transparent consumer interactions & audits, their trust on TPDDL based on their past relationship with us and also the fact that most of them are early adopters of technology.

From **Table 1.4 & Fig 1.9, it** can be seen that

Fig 1.9 Facility Wise Shed Potential V/s Sanctioned Load

Industry	Cold Storage	Flour & Dal Mill	Footwear & Plastic	Printing	steel	Hospital	Others
No of Consumers	8	39	39	7	10	3	61
Shed Potential (KW)	1364	3292	1718	423	629	375	3300
Sanctioned Load (KW)	10248	16891	6660	1528	2221	1970	24000
Percentage	13%	19%	26%	28%	28%	19%	14%

Table 1.4 Facility Wise Shed Potential V/s Sanctioned Load

out of the participating industrial & commercial establishments maximum enroll ability was found in flour & Dal Mills (39 Nos) and Footwear & plastic Industry (39 Nos). The shed potential contribution when compared to sanctioned load was found to be high amongst Flour & Dal Mills, Footwear & plastic, Printing and steel industries.

Further, due to consumer education and enablement through granular usage pattern made available through smart meters data, we have also seen a trend towards for some select consumers shifting their consumption from peak/normal to off peak hours. This trend is particularly seen in the industrial consumers. Through successful demonstration of this project, we are also able to understand consumer behavior and methodology of incentive required for scaling up of DR.

WAY FORWARD:

The learning through the project has helped us gain deep insights into the technology deployment & implementation challenge and this experience shall guide us to scale up these deployments. We have put forward schemes for scale up ADR which shall enable a peak reduction up to 40 MW and AMI scale up which shall cover high revenue base consumers nearing 2.5 lakhs. Analysis of the TPDDL's restricted and unrestricted system load data and power procurement data from May to Nov 2014 reveals that the actual load demand exceeded the permitted overdrawl limit of 38 MW in 92 hourly incidents. Thus, DR can be effectively used to manage the peak power in such scenarios.

In addition to this, we have already made suggestions to the regulator to introduce financial incentives for the participating consumers and also to make participation in DR mandatory for consumer having sanctioned load greater than 300 KW and for big government organizations like Delhi Jal Board, Delhi Metro Rail Corporation etc.

TABLES AND FIGURES:

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1. TPDDL's Roadmap for Smart Grid Technologies by Quanta Technology, USA
2. TPDDL's Power System Control Daily Flash Report
3. Delhi Electricity Regulatory Commission's Tariff Order for TPDDL

Smart Metering Technology: The Evolving Economy of Smart Distribution

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Abstract-*Indian distribution sector needs complete overhauling due to its poor financial and operational performances. Bankrupt state power distribution utilities in many states were unable to run their business and also not paying their bills or their debts. There is an urgent need of smart metering to maintain commercial viability of the Indian distribution sector. This is especially relevant presently as the new smart technology and poor financial health of distribution utilities signifies the development of new business model entrusted for much needed investment for capacity addition, and efficiency of operation with the help of private participation. The paper proposes need and introduction of smart metering and relevance with to India.*

Keywords- **Smart Meters, Smart Metering Technology, Smart Metering Economics.**

I. INTRODUCTION

Despite impressing performance in generation and transmission sector, and implementation of electricity act 2003, distribution sector still a weak link and continue to contribute losses in the system. Power sector after-tax losses, excluding state government support (subsidies) to the sector, were Rs 618 billion ($14 billion) in 2011, equivalent to nearly 17 % of India's gross fiscal deficit and around 0.7 % of GDP[1][1].

Distribution sector in India is characterized by inefficiency, low productivity, frequent interruption in supply and poor voltage, despite APDRP and R-APDRP funding[2] So far India's reform policies are not be sufficient to achieve reliable, efficient power because distribution reform hasnot been done [2]. Various repotted analyses of the failure of power sector reforms in India have identified similar symptoms related to institutional shortcomings such as political interference, setting of unscientific tariffs,populists policies of government like subsidies, especially in SEBs, as the main hurdles to reforms based on the standard textbook prescriptions of unbundling, corporatization, wholesale market deregulation, independent regulation and private sector participation (PSP). To overcome the difficulties leading totechnical as well as governance challenges, basic and radical restructuring of the power sector hadbecome imperative [3&4]. As a result, ministry of power (MoP) has been taken various reform initiatives like unbundling[3], corporatization, privatization and outsourcing of various services of the distribution sector. Four different models to carry out the function of power distribution have been evolved; government owned DISCOMs, privately owned DISCOMs, public private partnership (PPP) model, distribution franchisee model (DF).Up gradation of schemes and developing accurate energy accounting system by proper& accurate will be one of the most important way metering can only fill gap betweenthe revenue generated through metering and the cost of power paid by the utilities.Adoption of smart technology is the first step towards the efficient operation and proper and accurate metering.

II. INDIAN SCNERIO

The main issue of Indian distribution sector is highAggregate Technical and Commercial losses (AT&C).All state electricity boards and utilities in the country are facing financial crisis due to these losses.Estimation to total AT&C losses in India is

[1]These losses are overwhelmingly concentrated among distribution companies (discoms) in the unbundled states and among SEBs and power departments in the states that have not unbundled.

[2]The Restructured Accelerated Power Development and Reforms Programme (R-APDRP) started in 2008 is a revised version of the Accelerated Power Development Reforms Programme (APDRP). The APDRP scheme was initiated in 2002-03 as additional central assistance to states for reducing the AT&C losses in the power sector and improving the quality and reliability of power supply. This was to be achieved by strengthening and upgrading the sub-transmission and distribution system of high-density load centers like towns and industrial centers.R-APDRP is for urban areas- towns and cities with population of more than 30,000 (10,000 in case of special category states).The focus of R-APDRP is on actual, demonstrable performance in terms of sustained loss reduction.

[3]Presently, barring a few states, all the others have unbundled their erstwhile state electricity boards (SEB) and have corporatized their successor entities having one generationand transmission company and many distribution companies according to the requirement of states. Some Indian states like Tamilnadu and Punjab unbundled their SEBs into two entities- one dedicated to transmission called and another entity dedicated to both generation and distribution.

about 25.30%[5].Losses are mainly due to improper metering, billing, mistakes in record keeping, manual errors and loose connections.

Modern electronic Static Energy meters are capable of sensing, measuring and computing various electrical parameters and store the same for a set period. Along with instantaneous values of electrical parameters, meters are also able to detect tampering attempts with date and time so that utility can easily know such kind of illegal activities and take appropriate action without any delay. Replacement of traditional electromechanical meters with modern electronic meters has made tremendous decrement in electricity theft but at the same time in Indiapeople are finding new ways to tamper energy. Strict implementation of rules and regulations and use of latest technology in distribution sector, educating people towards efficient use of electricity and coordination of renewable sources with conventional energy sources can only improve the energy scenario in India.

III. SMART METERING

Smart meters are basically static energy meters with digital display and bidirectional communication facility in addition to having connect/disconnect load switch to physically connect/disconnect the consumer as per the decision taken by the utility. Smart meters allow two way communication between the meter and the central system along with the measurement and computation of electrical parameters. It stores and communicates requested data as per programmed intervals. Like modern electronic energy meters smart meters also detect, resolve abnormal & tamper events, and communicate any tamper attempt with the utility and store the same. They have inbuilt memory to store all relevant meter data, events for a required period. Smart meters are available with the options of prepaid and postpaid metering. They are able to record bidirectional measurement of power. Smart meters may be a better solution to reduce meter tampering and electricity theft by using its bidirectional communication features and decision making ability.

Commonly used smart metering technologies are Automatic Meter Reading (AMR) and Advanced Metering Infrastructure(AMI). AMI extends AMR technology by providing two way meter communications, allowing commands to be sent towards the consumer for multiple purposes, including "time-of-use" pricing information, demand-response actions, remote service disconnect/ connect, remote programming. Communication technologies are critical element for connecting thousands of meters from the field to the utility's metering data management center. Introduction of AMI has started replacement of old fashioned mechanical meters with "smart meters."Smart metering is the backbone of smart grid vision. Smart meters are configurable remotely. Bidirectional communication of information via some communication network back to the utility for monitoring and billing purposes is one of the main features of smart meters.

Through Home Area Network (HAN) smart meters are connected with all important home appliances and can operate them individually as per demand. In this way it can control the uses of energy and reduce the peak demand. Smart meter unit is made up with two separate units. One is the metering unit and the other is its communication module. This whole arrangement is connected under the supervision of the utility and the meter display device is connected at consumer premises which only can be readable. This arrangement reduces the chances of electricity theft. Accurate billing of used energy will also keep consumers happy and satisfactory.

Communication technologies are critical element for connecting thousands of meters from the field to the utility's metering data management centre. Introduction of AMI has started replacement of old fashioned mechanical meters with "smart meters." Smart metering is the backbone of smart grid vision.

IV. COMMUNICATION ARCHITECHURE OF SMART METER

Smart meters are configurable remotely. Bidirectional communication of information via some communication network back to the utility for monitoring and billing purposes is one of the main features of smart meters.Fig.1 is showing the smart meter communication architecture as proposed in India.

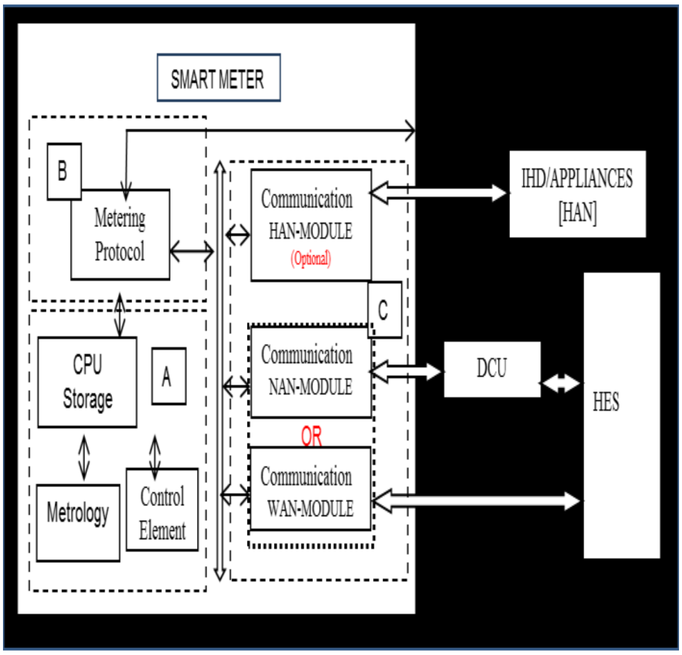

Fig 1 Proposed Smart metering Communication Architecture in India [6]

A : Metering and Control block,B : Metering Protocol
C : Communication Modules
Optical port as per IS 15959.
Port for connectivity to Data Concentrator Unit(DCU) or Head End System(HES).
Port for In Home Display Device(IHD) or HAN.

Main components of smart metering communication architecture are discussed in short:

A. Metering and Control Block[6]

This block consists of smart meter and its load switch control circuit. Smart meter and load switch should fulfill following requirements:

1*) Metering Requirements*

Smart meter metering and metrological requirements should be as per the requirements of latest version of IS 13779.

2*) Control requirements*

Performance of load switch is checked by “Load switching capability”,” Performance requirements for load switching”, “Specified rating” tests. The test conditions and test parameters are taken as per latest version of Indian standard for prepayment meters IS15884:2010.

B. Metering Protocol[6]

Meter data / commands are exchanged as per IS 15959. The standard titled “Indian Companion Specification” for IEC 62056 series of standards has defined the minimum requirement for the meter to support for data communication between meter and data collecting units.

C. Communication Modules[6]

Proposed Smart meter communication module should be provided with inbuilt transceiver module for two way communication with DCU or HES. Meters should have an optical port for local communication, an inbuilt communication module NAN (Neighborhood Area Network) for meter to data concentrator or directly for WAN (Wide Area Network), one more port for IHD or HAN. The maximum number of ports available should be three.

D. Remote Communication Requirements[6]

Different kinds of the communication transceiver are given in Table 1.

TABLE 1

Proposed Communication Technologies Profile for Smart Meters in India[6]

Network / Layer	HAN (wireless option)	HAN (plc option)	NAN / FAN (wireless option)	NAN / FAN (plc option)	Direct-WAN-connected meter
PHY MAC	IEEE 802.15.4 (g/e) MAC/PHY (2.4GHz/865MHz)	IEEE 1901, ITU-T G.9901, G.9902 (G.hnem), G.9903 (G3-PLC), G.9904 (Prime-PLC)	IEEE 802.15.4 (g/e) MAC/PHY (865MHz)	IEEE 1901, ITU-T G.9901, G.9902 (G.hnem), G.9903 (G3-PLC), G.9904 (Prime-PLC)	Ethernet, 2G, 3G, LTE, Wimax
Convergence (Adaptation)	6LoWPAN (RFC4944)	6LoWPAN (RFC4944)	6LoWPAN (RFC 4944)	6LoWPAN (RFC4944)	IETF RFC 2464, 5072 and 5121, PPP (IETF RFC 1661)
Network	IPV6,RPL	IPV6	IPV6, RPL	IPV6	IPV4/IPV6
Application	DLMS/COSEM-TCP (ICS)	DLMS/COSEM-TCP (ICS)	DLMS/COSEM-TCP (ICS)	DLMS/COSEM-TCP (ICS)	DLMS/COSEM-TCP (ICS)

V.NEW POWER SYSTEM BUSINESS MODEL WITH SMART GRID/ SMART METERING TECHNOLOGY

Vertical integration business model is having unidirectional power flow. With the introduction of smart grid technologythe flow of information and power has started in many directions and the involvement of small customer has become important. Now customers are becoming more and more demanding and empowering the grid by feeding back the extra power ,and want to know each step of their energy uses and the cost they are paying for.

This modernization in technology has introduced more complex business models. Fig 2 is showing vertical and new emerging business model of power system business chain.

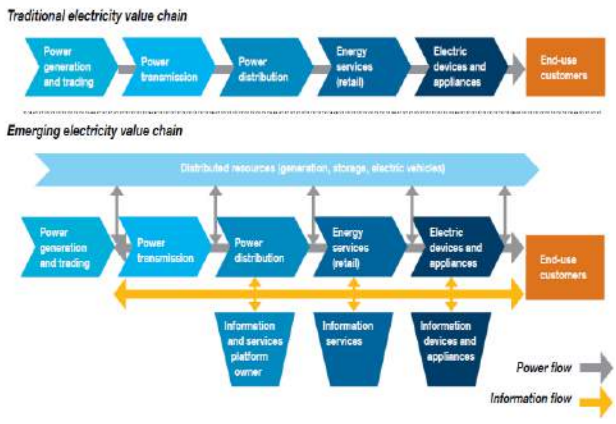

Fig 2 Power System Business Models[7]

New business models called "platform models"[7] are introduced to adjust with today's requirement and to efficiently use modern technologies.
The term platform,refers to a common architecture(essentially, a design for products, services and infrastructure facilitating users' interactions) and set of rules (protocols,rights and pricing terms) that provide a standard foundationgoverning transactions among two or more parties of electricity value chain.

The platform provides an energy marketing portal through which the customer can buy/sale electricity with best deals.All the information and money are exchange via this portal .The platform owner also provides information to customer about energy management to efficiently usethe available energy and minimize the bill.

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VI. INDIAN SMART METERING PROJECTS[8]

India Smart Grid Task Force(ISGTF) under the aegis of Ministry of Power has approved 14 pilot projects for implementation across the country.The functionalities covered in these projects include -AMI, Peak Load Management, Outage Management System, Power Quality Management, Distributed Generation and Micro grid.

A. Pudducherry Smart Grid pilot project[9]

The town area of Pudducherry is the first smart grid trial which is being implemented by Puducherry Electricity Department and the Power Grid Corporation of India.It has covered with, 87031 smart meters of different makes using different communication technologies implementation in collaboration with 60 service providers. It has been based on narrow and broadband power line communication at 865MHz and 2.4GHz.This project includes Distribution Transformer Monitoring Solution (DTMS), Fault Passage Indicators, Smart Street Lighting system, Integration of Renewable through Net Metering, Smart Home, Solar Charging based Electric Vehicle & Microgrid.
Pudducherry electricity board has started billing of consumers on the basis of online metering data from smart meters. Tamper cases are being detected, DT wise Energy accounting, auditing, unbalancing in transformer loading identified, direct sms have been sent to concerned engineer in case of any fault in line. Upto 57% Saving in consumption is achieved by automation of street lighting, improvement in voltage profile, reduction in losses, improved supply quality ,integration of roof top Solar PV with net metering, reduction of power bills and Electric vehicle with solar charging are the main achievements of this project.

VII. CONCLUSION

Smart metering technology is beneficial for consumers and for utilities. With the real time data display smart metering is making consumers more aware for optimum use of energy. With the help of load connect; disconnect features utilities are finding new ways to shift peak load and it is becoming easier to find out the culprits of energy tampering. Real time data communicated by smart meters is also useful for distribution automation to provide uninterrupted power supply to the consumers by reconfiguring the load distribution and clearing the fault as soon as possible In this way utility can supply reliable and quality power to customers.

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Study of DC Microgrid Accompanying with Renewable Energy Sources for Rural Application

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***Abstract*— Distributed generation (DG) of renewable energy sources is now gaining importance in the field of power business due to its high power quality and being environment friendly in contrast to conventional electric grids. A DG network shows high system efficiency due to its modularity and cost effectiveness. A better way to realize the emerging potential of DG is to take a systemized approach which views generation and associated loads as a subsystem or a "microgrid". Problems encountered in an ac microgrid are synchronizing of several DGs, inrush currents due to large number of inductive loads, and phase unbalancing while connecting rural networks. The shortfalls of ac microgrid have lead the focus to shift in the line of dc microgrid mainly for rural application.**

This paper establishes the advantages of dc microgrid over ac microgrid in stand of efficiency of the conversion process in the system and power transfer capability. The study also shows that the power transfer capacity can be increased in dc network system due to minimum number of conversion stages. Various challenges in DC microgrid like bus voltage imbalance, effect of voltage instability due to fluctuation of weather parameters are also studied.

Keywords—Microgrid, Renewable Energy Sources, Distributed Generation, Synchronization, Efficiency.

I. Introduction

In microgrid topology, two basic structures can be adopted; dc and ac. A dc microgrid consists of renewable energy sources, dc-dc converters, dc loads and dc bus whereas in ac microgrid the main components are renewable energy sources, dc-ac and ac-dc converters, ac loads and ac bus.

In our case a microgrid architecture has been considered for village electrification purpose consisting of renewable energy sources e.g. solar PV and wind generator along with battery bank as a compensating device, transmission & distribution (T&D) network and loads.

When the power generated by the renewable energy sources transmitted and distributed in the form of dc, the network is called dc microgrid and otherwise called ac microgrid.

The main disadvantages of ac microgrid are, synchronization problem of distributed generators, inrush current due to inductive loads which again complicate the battery energy management in the system, three phase unbalance for single phase load etc.

Sometimes ac micro-grid system has a benefit to utilize existing ac grid technologies, protections and standards. But its application involves some problem of low efficiency due to the number of power conversions required within the crucial current path from the source to the load.

Solar PV generates purely dc output where wind generator as it comprises of ac generator, outputs variable voltage & variable frequency. By putting a rectifier to the output of the wind generator, the power can be converted in dc. Similarly the battery bank which is treated as a compensating device also delivers dc output.

According to the dc microgrid architecture these power sources can easily be connected to a common bus by putting a dc-dc converter in between them where in ac microgrid architecture in addition to the dc-dc converter a dc-ac inverter needs to be connected as the bus transfer the power in the form of ac.

In conventional power generation, the main idea is to generate the power centrally and transfer it to the loads located hundreds of kilometers away. To minimize to transmission & distribution losses, voltage is stepped up (e.g. 415V to 33KV) at generator side and again stepped down in a same ratio at load side.

On the other hand the electronic loads are designed to operate in dc. As the available power is ac, one or more conversion processes are required.

Both steps explained above are not energy efficient. In distributed generation with renewable energy sources, these

constrains can be avoided by using low voltage dc transmission.
The capacity of the individual renewable energy sources and the battery bank are designed based on the load profile which are delivering limited amount of power.
From this perspective, the loads used in rural electrification have been designed as energy efficient. Presently the rural loads e.g. light, fan, pump, computers, televisions, mobile chargers etc. are dc operated which eventually rejects the multilevel conversion processes between dc and ac. It is noticed that the overall efficiency of LED in different illumination conditions is 50% more than CFL. A dc ceiling fan uses 70% less energy for the same airflow as a conventional ac ceiling fan. They have better controls of different speeds and are smaller size for a given output of air movement. Being "brushless" it should also be quieter and less prone to the buzzes. DC motors with pumps are an attractive option because of their compatibility with the power source and because their efficiency is noticeably higher (~ 25%) than that of ac motors.
Firstly the conversion losses of different components of different converters used in microgrid are analyzed. Then, converter efficiency has been calculated for both microgrid systems. Simulations have been done to show the overall efficiency and the power loss against distance of the ac and dc microgrid system.

II. Analysis of Conversion Losses of Different Components

A detailed loss study has been done on the different types of converters used in the system e.g. dc/ac inverter, ac/dc rectifier & dc/dc converter. Here the loss occurs mainly within four components; MOSFETS, DIODES, INDUCTORS & TRANSFORMERS [1]. These losses directly affect the efficiency of the system.

A. MOSFET Loss

MOSFET LOSS can be identified as high side & low side.
The high side MOSFET losses include,

Conduction loss, $P_{con\_HS} = I^2{}_{out} \times R_{DS(ON)} \times \frac{V_{out}}{V_{in}}$

Switching loss, $P_{sw\_HS} = \left(\frac{V_{in} \times I_{out}}{2}\right) \times (t_{rise} + t_{fall}) \times f_{sw}$

The low side MOSFET losses include,
Conduction loss,

$$P_{con\_LS} = \left[I_{out} \times R_{DS(ON)} \times \left(1 - \frac{V_{out}}{V_{in}}\right)\right] + \left[(t_{DT(R)} +) \times V_{BF\_F} \times I_{out} \times f_{sw}\right]$$

Switching loss = negligible

B. Diode Loss

The DIODE losses include,

Conduction loss, $P_{con\_D} = V_F \times I_{out} \times \left(1 - \frac{V_{out}}{V_{in}}\right)$

Switching loss = negligible

C. Inductor Loss

The INDUCTOR losses include,

DC loss, $P_{dc\_L} = I^2 out \times DCR$ (DC resistance of the inductor).

D. Transformer Loss

Similarly the TRANSFORMER losses include,

Magnetization losses, $L_m = A_L N_1^2$

where A_L is the inductance factor and can be found in datasheets for specific cores.
To calculate the resistive losses in the transformer the total length of wire needs to be determined.

$$L_1 = coreleg_{perim} \times N_1 turns$$

$$L_2 = coreleg_{perim} \times N_2 turns$$

where $coreleg_{perim}$ is the perimeter of each core leg and can be seen in datasheet.
The total resistance on the primary and secondary side is

$$R_1 = \frac{\rho_{cu} L_1}{A_{c1,bundle}}$$

$$R_2 = \frac{\rho_{cu} L_2}{A_{c2,bundle}}$$

Where ρ_{cu} is the resistivity of copper and is equal to 1.68×10^{-8}.
The total resistive losses can then be calculated as

$$P_{cu} = R_1 I_{1,RMS}^2 + R_2 I_{2,RMS}^2$$

Core losses, $P_{core} = C_m f^x B^x (C_{t0} - C_{t1}T + C_{t2}T^2)$

Where,
$C_m, x, y, C_{t0}, C_{t1}, C_{t2}$ are parameters which have been found by curve fitting of the measured power loss data and T is the temperature.
The total maximum power loss for the transformer is

$$P_{total} = P_{core} + P_{cu}$$

The meaning of the symbols used in the equations are explained below.
V_{in} = Input voltage of the converter, V_{out} =Output voltage of the converter, I_{out} =DC output current, $R_{DS(ON)}$ =MOSFET drain-source on state resistance
t_{rise} = Duration of the turn-on transition, t_{fall} = Duration of the turn-off transition, f_{sw} = PWM switching frequency, $t_{DT(R)}$ = Dead time when Low Side MOSFET turns off and High Side MOSFET turns on, $t_{DT(F)}$ = Dead time when High Side MOSFET turns off and Low Side MOSFET turns on, V_{BD_F} = Body diode forward voltage of Low Side MOSFET, V_F = Power Diode Forward Voltage.

According to the market survey it is found that the inverter without transformer shows an efficiency of 98% [2], full bridge rectifier shows an efficiency of 97% [3] and dc/dc converter shows an efficiency of 90% [4].

III. Calculation of Converter Losses

A micro-grid can be built using ac or dc current net work.
Here the distribution is designed as a radial network and the loads are selected according to the village requirement.
In Fig.1 the architecture of ac microgrid has been described.
Here Solar PV array is connected to the ac bus through dc-dc converter and dc-ac converter (inverter). Similarly the wind generator is connected to the ac bus through ac-dc converter (rectifier) and dc-ac inverter. The battery bank is also connected to the bus through dc-dc converter & ac-dc converter rectifier and inverter). As the load is selected as dc type it also requires two steps of power conversion as depicted in Fig1.
The efficiency at every conversion point has been identified and the power at different point in the bus has been calculated.
The power output stages from PV at point A, wind at point B & battery at point C are calculated as

$$P_{3PV} = e_{1PV} e_{2PV} P_{1PV} \ldots\ldots\ldots\ldots\ldots(1)$$

$$P_{3W} = e_{1W} e_{2W} P_{1W} \ldots\ldots\ldots\ldots\ldots\ldots(2)$$

$$P_{3B} = e_{1B} e_{2B} P_{1B} \ldots\ldots\ldots\ldots\ldots\ldots(3)$$

The power consumed by the load from point D is calculated as enumerated by the functional block as shown in fig.1.

$$P_{1L} = e_{1L} e_{2L} P_{3L} \ \ldots\ldots\ldots\ldots\ldots\ldots(4)$$

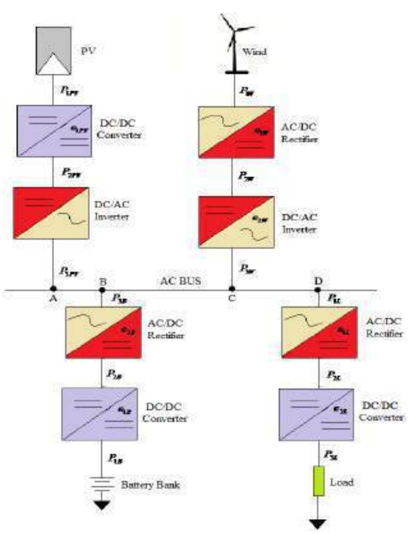

Fig.1. Schematic diagram of ac microgrid

In Fig.2 the architecture of dc microgrid has been described. The solar PV array is connected to the dc bus through a dc-dc converter, the wind generator is connected through ac-dc converter (rectifier) and dc-dc converter, the battery bank is connected through a dc-dc converter and as the loads are selected as dc type these requires only single step conversion and connected through a dc-dc converter as depicted in Fig.2.
The power output from PV at point A, wind at point B & battery at point C are calculated as,

$$P_{2PV} = e_{1PV} P_{1PV} \ldots\ldots\ldots\ldots\ldots\ldots(5)$$

$$P_{3W} = e_{1W} e_{2W} P_{1W} \ldots\ldots\ldots\ldots\ldots\ldots(6)$$

$$P_{2B} = e_{1B} P_{1B} \ldots\ldots\ldots\ldots\ldots\ldots\ldots(7)$$

The power consumed by the load from point D is calculated as enumerated by the functional block as shown in fig.2.

$$P_{2L} = e_{1L} P_{1L} \ldots\ldots\ldots\ldots\ldots\ldots\ldots(8)$$

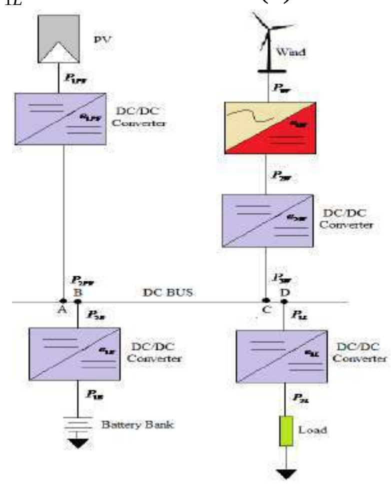

Fig.2. Schematic diagram of dc microgrid

Where the symbols denoted in the equations explained as below,
P_{3PV} = Power generated by solar PV array before conversion, P_{1PV} =Power feeding by solar PV at point A in the bus after two stages of conversion, e_{1PV} = Efficiency of dc/dc converter, e_{2PV} = Efficiency of dc/ac inverter, P_{3W} = Power generated by wind generator before conversion, P_{1W} = Power generated by wind at point C in the bus after two stages of conversion, e_{1W} = Efficiency of ac/dc rectifier, e_{2W} = Efficiency of dc/dc converter, P_{3B} = Power generated or consumed by battery bank before conversion, P_{1B} = Power generated or consumed by battery at point B in the bus after two stages of conversion, e_{1B} = Efficiency of ac/dc rectifier
e_{2B} = Efficiency of dc/dc bidirectional converter, P_{3L} = Power available at point D in the bus before two stages of conversion, P_{1L} = Power consumed by load after two stages of conversion, e_{1L} = Efficiency of ac/dc rectifier, e_{2L} = Efficiency of dc/dc converter.
From the two different architectures of microgrid, the equation for power balance between sources & loads can be written as,

$$P_{PV} + P_W + P_B = P_L \; where \; (P_L \rangle P_G) \ldots\ldots(9) \; and$$

$$P_{PV} + P_W - P_B = P_L \, where(P_L \langle P_G)..........(10)$$

where,

P_{PV} = Power generated by solar PV in the bus,

P_W = Power generated by wind in the bus,

P_B = Power generated or consumed by battery to or from the bus,

P_L = Power consumed by the load from the bus,

P_G = Total generated power ($P_{PV} + P_W$)

Putting the values of power in equation (9) calculated from equation (1) to (8) we get another set of equations which described a comparative study of efficiency in ac & dc microgrid system.

For ac microgrid,

$$(e_{1PV}e_{2PV})P_{1PV} + (e_{1W}e_{2W})P_{1W} + (e_{1B}e_{2B})P_{1B} = (e_{1L}e_{2L})P_{1L} \ldots(11)$$

For dc microgrid,

$$(e_{1PV})P_{1PV} + (e_{1W}e_{2W})P_{1W} + (e_{1B})P_{1B} = (e_{1L})P_{1L} \ldots(12)$$

From equation (11) and (12) it is seen that as efficiency is always less than 1, so cascading of more than one converter always gives poor efficiency than if one converter is being used.

A simulation has been done to calculate the generation from 10KW solar PV array and 6KW wind generator taking the irradiance and wind speed of IIEST, Shibpur campus. The real time data of irradiance and wind speed has been collected from the weather monitoring station located in side IIEST, Shibpur campus.

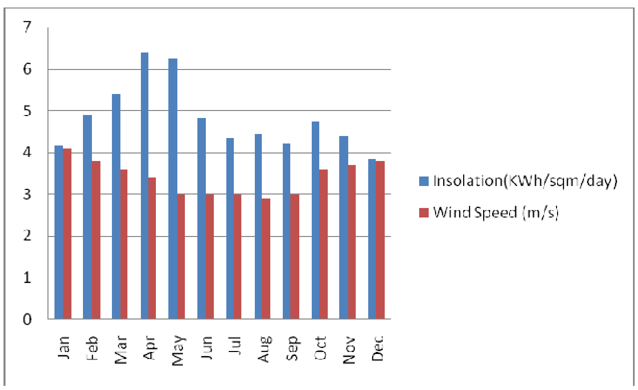

Fig.3. Month wise average insolation and wind speed

Fig.3 shows that the yearly average insolation is 4.8KWh/sqm/day and yearly average wind speed is 3.41m/s. Considering this weather parameter and conversion losses in dc microgrid according to fig.2, the month wise total energy generation from wind and solar PV has been simulated at point A and B of dc bus. Similarly the total energy generation in ac bus of ac microgrid has been simulated. Both the results are depicted in fig.4. It is clearly understood from the graph that the overall efficiency of dc system is about 20% more than ac and also noticed that the power loss varies throughout the years. As the energy generation in the month of June, July, August & September is much lower than the other months, it is also significant that the extra energy generated from dc microgrid will fulfill the load demand significantly.

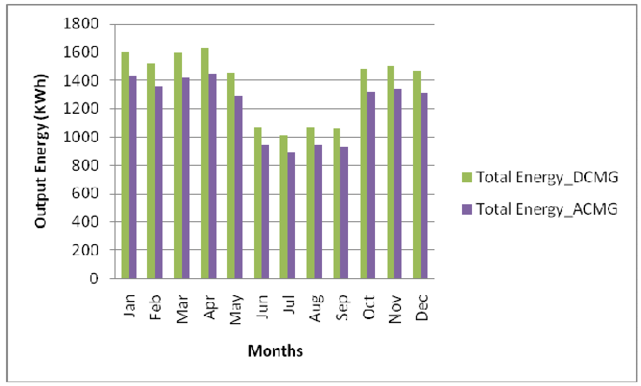

Fig.4. Month wise comparative study on energy generation of dc and ac microgrid

IV. POWERTRANSFER CAPACITY

A calculation on power transfer capacity is derived based on line voltage drop. According to the electricity regulation the line voltage drop should be < 3% in transmission and distribution system. As the dc microgrid system is radial in nature, the voltage drop plays a significant role for the stability of the converters and also to minimize the power loss. In dc microgrid voltage drop depends on the dc resistance of the transmission line and the current through it. The generated power from the reneable energy sources can be calculated as,

$$P_G = V_S * I_S \ldots\ldots\ldots\ldots\ldots\ldots\ldots..(13)$$

This generated power is transferred to the loads located in different locations within the system. Due to the resistance present in the transmission line, the voltage drop can be calculated as,

$$V_{d\_wire} = I_{dc\_wire} * R_{dc\_wire} \ldots\ldots\ldots\ldots\ldots\ldots(14)$$

Now, in manufacturer data sheet the unit resistance r_{dc_wire} (Ω/m) of transmission line is given. If the length of the wire is l, the total resistance of the wire is

$$R_{dc\_wire} = r_{dc\_wire} * l \ldots\ldots\ldots\ldots\ldots\ldots..(15)$$

From equation (14) & (15) the total length of the transmission line can be written as a function of voltage drop.

$$l = \frac{V_{d\_wire}}{r_{dc\_wire} * I_{dc\_wire}} \ldots\ldots\ldots\ldots\ldots\ldots(16)$$

For transferring the power at maximum distance but in economic way, the voltage drop will be maintained maximum within the maximum allowable limit. Therefore the equation (16) can be written as,

$$l_{\max\_dc} = \frac{V_{d\_wire\_\max}}{r_{dc\_wire} * I_{dc\_wire}} \ldots\ldots\ldots\ldots\ldots\ldots(17)$$

The power transfer can be calculated as a function of distance between source & load. The power at load can be defined with the help of current as the voltage is constant.

$$I_{dc\_wire} = \frac{P_{dc\_load}}{V_{dc\_load}} \quad \text{.................................(18)}$$

If the voltage drop remains maximum, the voltage at load will be minimum but above the minimum allowable limit and equation (18) can be written as

$$I_{dc\_wire} = \frac{P_{dc\_load}}{V_{dc\_load\_\min}} \quad \text{........................(19)}$$

Where,

$V_{dc\_load\_\min} = V_S - V_{d\_wire\_\max}$ ....(20)

Now from equation (17) & (19) the maximum distance to transfer power can be written maintaining the voltage drop maximum but within the allowable limit,

$$l_{\max\_dc} = \frac{V_{d\_wire\_\max}}{r_{dc\_wire} * \frac{P_{dc\_load}}{V_{dc\_load\_\min}}} \quad \text{........(21)}$$

$$= \frac{V_{d\_wire\_\max} * V_{dc\_load\_\min}}{r_{dc\_wire} * P_{dc\_load}}$$

$$= \frac{V_{d\_wire\_\max} * (V_S - V_{d\_wire\_\max})}{r_{dc\_wire} * P_{dc\_load}} \quad \text{.......(22)}$$

From equation (22) it is clear that a particular amount of dc power can be transferred to a maximum distance keeping the voltage drop within maximum allowable value. If the amount of power requires to be increased within the same transmission line the maintaining the same voltage drop the transfer distance has to be decreased.

In ac network the power at load can be defined as,

$$I_{ac\_wire} = \frac{P_{ac\_load}}{V_{ac\_load} * \cos\phi} \quad \text{..................(23)}$$

As the voltage is constant, the power is mainly determined by the current and cosφ or power factor. In ac system the apparent power has two parts; active or real power and reactive power as shown in fig.5. As the rural load is selected as dc type, it requires only active power for operation where the reactive part should be avoided. Therefore in low voltage microgrid, to carry the same amount of active power up to a certain distance, dc transmission shows less power loss than ac as extra active power has to be generated in ac to compensate the reactive part. Moreover, the voltage drop regulation can be done accurately in dc system.

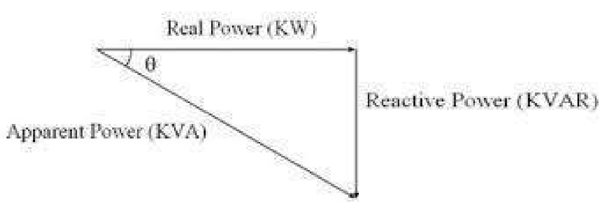

Fig.5. Power triangle for ac network system

The symbols used in the equations are explained as below.

V_S = dc source voltage

$V_{d\_wire\_\max}$ = Maximum allowable voltage drop

$l_{\max\_dc}$ =Maximum distance covered in dc microgrid.

r_{dc_wire} = unit resistance of dc wire (Ω/m)

P_{dc_load} = dc power at load point

I_{dc_wire} = dc current flowing in the wire

V_{dc_load} = dc Voltage at load point

P_{ac_load} = ac power at load point

V_{ac_load} = ac voltage at load point

I_{ac_wire} = ac current flowing in the wire

cosφ = power factor

DCMG = dc microgrid

ACMG = ac microgrid

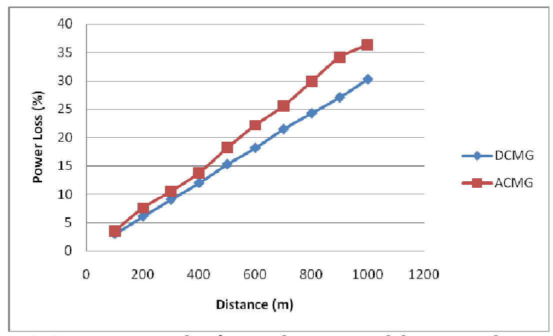

Fig.6. Comparative study of power loss in ac and dc microgrid against distance traveled

Fig.6 describes the percentage power loss against distance traveled in transmission line for ac & dc microgrid. It clearly shows that the power loss is about 20% more in ac system than dc.

V. CHALLENGES

A. Bus Voltage Imbalance

Due to the voltage drop characteristics of the T&D line in a microgrid, there is a voltage imbalance occurs throughout the bus. In a typical DC microgrid with a radial topology, power flows from its point of common coupling (PCC) to the end bus in one direction. Therefore, a voltage drop problem can occur with a line voltage drop and the lowest bus voltage is formed at the receiving end in the system. The value of the line voltage drop increases in proportion to the load current magnitude and the line length in the microgrid. However, voltage control with only a bi-directional inverter might not cover all the system voltages as a DC distribution system becomes larger. This is because the systems can have a large voltage difference between the point of common coupling and the end bus. Therefore, a local voltage control with proper DG allocation method is needed for a medium/long distance system [5].

B. *System Instability Due to Fluctuation of Weather Parameters*

The variability of solar irradiance and wind speed with a high ramp-rate can create fluctuation in the PV-wind output. In a weak microgrid with a high PV-wind penetration can create significant voltage fluctuations. Energy storage devices are used to smooth out the fluctuation. Different strategies have been developed where the ramp-rate of PV panel output is used to control the PV inverter ramp-rate to a desired level by deploying energy storage (which can be available for other purposes, such as storing surplus power, countering voltage rise, etc). During the ramping event, the desired ramp-rate is governed by controlling the energy storage based on an inverse relationship with the PV panel output ramp-rate to improve the fluctuation mitigation performance.

Another strategy called moving average method has been developed where the ramp rate cannot be controlled directly; rather the ramp rate depends on previous value of PV-wind output [6].

VI. CONCLUSION

A basic study on dc as well as ac microgrid has been carried out in this paper. It is understood that the utilization of renewable sources with rural load pattern is suitable with dc microgrid. The overall efficiency is about 20% more than ac microgrid and the power transfer capacity is also about 20% more in dc microgrid. The study also reveals that there are some challenges which are voltage drop control for stability of the bus, system instability due to fluctuation of weather parameters in dc microgrid. The future study will include the solutions for above mentioned challenges to design a stable dc microgrid for rural loads.

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The Grid+ project: connecting smart grid initiatives in the future European electricity grid

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***Abstract*—The Grid+ project is a Coordination and Support action which has the objective of supporting the European Electricity Grid Initiative (EEGI). This is a European Industrial Initiative which includes a 9-year plan for research, development and demonstration to accelerate the innovation of the European Electricity grids. This paper discusses the main results of the Grid+ project which include mapping of storage activities in Europe, Gap Analysis and labelling of demonstration projects, scalability & replicability studies and a knowledge sharing database.**

***Keywords*—Smart Grid, storage, scalability, replicability, knowledge sharing**

INTRODUCTION

In the European electricity system of 20 years ago, electricity was centrally generated by large power plants, and transported via transmission and distribution grid to the consumer, which passively paid his electricity bill. Nowadays, the European electricity network is facing multiple challenges, the most important of which the increasing electricity demand, integration of renewable energies and the ageing grid infrastructure. In a liberalized energy market, the consumer is no longer passive but has become a 'prosumer', injecting renewable energy into the grid and causing bidirectional energy flows. Storage systems and demand response are used as a solution to the unpredictable wind and solar generation, triggering a multitude of research and demonstration projects in various member states. Aside from these challenges, new opportunities arise, like the exponentially increasing information exchange and connectivity of devices to the internet. Meanwhile, European regulation continues to incentivize these innovative concepts and technologies. In 2008, the European Counsil and Parliament agreed to the 'climate and energy package', committing to reduce greenhouse gas emissions, increase the share of renewable energy generation and improve energy efficiency by 20% compared to 1990 levels [1]. In the same year, the European Commission launched the Strategic Energy Technology plan (SET), which contained eight industrial initiatives: Wind, Solar, Carbon Capture & Storage, Fuel cells and Hydrogen, Nuclear Fission, Nuclear Fusion, Bio-energy and Smart cities and Electricity grids. The latter initiative is called the European Electricity Grid Initiative (EEGI), which has the objective to provide a vision and framework for the necessary innovations and investments in the European electricity sector in order to reach the ambitious 2020 energy targets. Therefore, in February 2013 the EEGI Roadmap 2013-2022 was presented, setting out the R&I priorities to prepare the transmission and distribution system for the necessary technological evolutions [2]. Since its launch, the EEGI roadmap received several updates. Besides the EEGI roadmap, the implementation plan 2014-2016 and later for 2015-2017 were created to focus on the practical implementation of the innovative technologies. The latter document is fully compliant with the Integrated Roadmap (IR), which unites visions from different sectors to provide an overarching strategic document.

The Grid+ project supports the EEGI and translates the roadmap vision into concrete actions in the field [3]. Naturally, a strong interaction exists between the Grid+ projects and the European network operator associations EDSO4SG [4] and ENTSO-E [5]. Besides keeping the roadmap up-to-date, one of the objectives is to map the ongoing research and demonstration projects in Europe and analyze possible gaps and opportunities. In particular, special attention in the Grid+ project is given to the storage mapping, where an overview of innovative investments on different storage technologies in European member states is presented. These mapping exercises are described in chapter 1and 2 of this paper. The Grid+ project aims not only to map out the existing projects, but to monitor their objectives and scope. Essentially, the technological development of new and existing research and demonstration projects should at all times be scalable and replicable, and at the same time be compliant with the strategic objectives put forward by the EEGI roadmap. Therefore, the EEGI labelling procedure was created, indicating which projects were fulfilling these requirements. For new projects starting up, ensuring the scalability and replicability of the developed technologies is not straightforward. Therefore, based on a questionnaire of demonstration projects, a tool was developed to assess scalability & replicability. This is discussed in chapter 3. Another very important point is knowledge sharing. In this way projects can exchange information and best practices, and new projects get an overview of the already available information from other projects. Finally, conclusions and outlook for the coming years are presented.

I. MAPPING: GAP ANALYSIS

In Europe, many smart grid projects are carried out, often having different objectives, methods and funding sources. However, projects starting up are usually driven by a bottom-up motivation, where a local innovative idea is pursued. However, the solutions developed in the project are often researched in other member states as well. In addition, some topics might be of interest and are overlooked by existing projects or more technological development than currently performed is required. Therefore, the Grid+ consortium set out to investigate ongoing Smart Grid demonstration projects, assessing the main objective and methods of the projects and identifying possible overlaps and gaps ([6], [7]). The methodology of this work was as follows.

As input, several sources were used to collect a list of recent or ongoing demonstration projects. For the transmission sector, the ENTSO-E monitoring report provided an overview of Smart Grid projects within the ENTSO-E member countries [5]. For the distribution side, the JRC project database was used [8] and an ERA-net report that contains information of ongoing demonstration projects [9]. To categorize the content of the demonstrators, the same structure as the EEGI roadmap was used. This divides all R&I in 11 clusters, each with several Functional Objectives. A cluster should be interpreted as a set of projects with common objectives and methodologies which carry large overlaps and should be considered together. Functional Objectives are a further subdivision which specify concrete actions or research objective which are tackled by the projects in the coming years [2]. The clusters and associated functional objectives are given in Table 1, 2 and 3.

Table 1: TSO related clusters of the EEGI roadmap [4]

Cluster	Name	Functional Objective	Full names of Functional Objectives
C1	Grid architecture	T1	Definition of scenarios for pan-European network expansion
		T2	Planning methodology for future pan-European transmission system
		T14	Towards increasing public acceptance of transmission infrastructure
C2	Power technologies	T3	Demonstration of power technology to increase network flexibility and operation means
		T4	Demonstration of novel network architectures
		T5	Interfaces for large-scale demonstration of renewable integration
C3	Network operation	T6	Innovative tools and methods to observe and control the pan-European network
		T7	Innovative tools and methods for coordinated operation with stability margin evaluation
		T8	Improved training tools and methods to ensure better coordination at the regional and pan-European levels
		T9	Innovative tools and approaches for pan-European network reliability assessment
C4	Market designs	T10	Advanced pan-European market tools for ancillary services and balancing, including active demand management
		T11	Advanced tools for capacity allocation and congestion management
		T12	Tools and market mechanisms for ensuring system adequacy and efficiency in electric systems integrating very large amounts of RES generation
C5	Asset management	T15	Developing approaches to determine and to maximize the lifetime of critical power components for existing and future networks
		T16	Development and validation of tools which optimize asset maintenance at the system level, based on quantitative cost/benefit analysis
		T17	Demonstrations of new asset management approaches at EU level

Table 2: Common TSO/DSO related clusters and objectives of the EEGI roadmap [4]

Cluster	Name	Functional Objective	Full names of Functional Objectives
TD	Joint TSO/DSO Activities	TD1	Increased observability of the distribution system for transmission network management and control
		TD2	The integration of demand side management at DSO level into TSO operations
		TD3	Ancillary services provided through DSOs
		TD4	Improved defense and restoration plan
		TD5	Methodologies for scaling-up and replicating

Table 3: DSO related clusters at the EEGI roadmap [4]

C1	Integration of smart customers	D1	Active demand for increased flexibility
		D2	Energy Efficiency from integration with Smart Homes
C2	Integration of DER and new uses	D3	DSO integration of small DER
		D4	System integration of medium DER
		D5	Integration of storage in network management
		D6	Infrastructure to host EV/PHEV
C3	Network operations	D7	Monitoring and control of LV network
		D8	Automation and control of MV network
		D9	Network management tools
		D10	Smart metering data processing
C4	Network Planning and asset management	D11	New planning approaches for distribution networks
		D12	Asset management
C5	Market design	D13	Novel approaches for market design analysis

The methodology of the Grid+ gap analysis is as follows. First the objectives of all available projects in the abovementioned sources were investigated and classified in one or several of the clusters and functional objectives. In a second step, a limited number of domains was identified that were orthogonal to the vertical structure proposed by the EEGI. The list is given in Table 4.

Table 4: (source [6]) Identification of domains for EEGI roadmap clusters and functional objectives

Domains	TSO	DSO
Hardware	x	x
Software tools	x	x
Integration into the system - technology integration/ interoperability & standardization	x	x
Market designs	x	x
Cost benefit analysis (CBA) - business models	x	x
System reliability	x	
Grid services regulation	x	
Stakeholder involvement	x	
Customer involvement		x
Privacy issues		x
Better planning of future network		x

Comparing the list of the domains with the functional objectives, one obtains a matrix like the one given in Table 5 and Table 6. In the abscissa of the table, the functional objectives from the EEGI roadmap are given, with the domains in the ordinate identified by the Grid+ gap analysis team.

Table 5: (source [7]) Maturity level of transmission projects

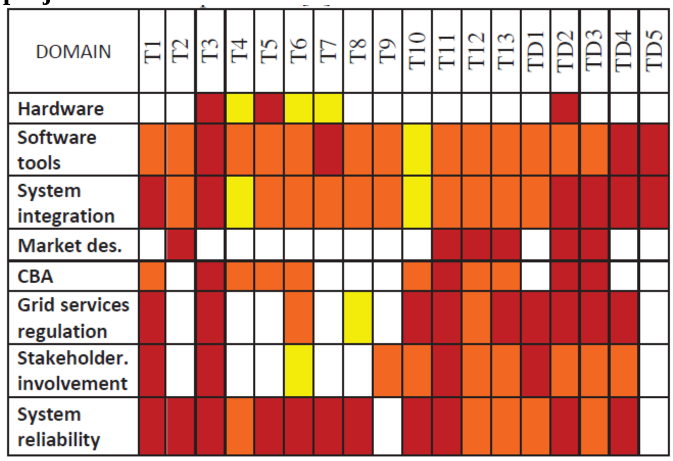
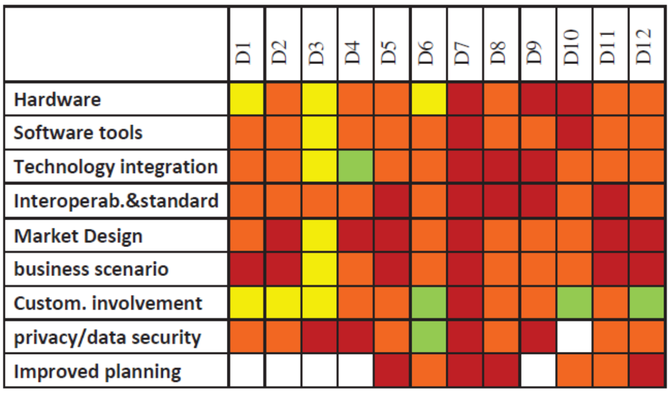


Table 6: (source [7]) Maturity level of distribution projects



A green color means that the topics in the respective functional objective of the EEGI roadmap are well addressed by the current generation of demonstration projects and there is no barrier in this area for large-scale development. Yellow means that exchange of info is needed and the demos need to validate the maturity. Fields with the orange color are partly addressed by the existing demonstrators; however moderate development is still required. And dark red indicates that more research is needed on this topic. On the transmission side, demonstration of innovative power technologies to increase the network flexibility is clearly needed. Also on the common topics between the DSO and TSO level, much remains to be done (e.g., appropriate and harmonized regulation for ancillary services provided by (prosumers connected to) the distribution network). On the distribution side, monitoring and control of the low-voltage network still requires a lot of effort, as well as interoperability and standardization.

II. Storage Mapping

Due to the unpredictable nature of the renewable energy injection, the network operators face the challenge of balancing injection and offtake and keep the frequency and voltage within limits at all times. Flexible consumption and demand response are more and more used as an alternative to gas-fired power plants to provide short term balancing. In addition to demand response, storage technologies are excellent to support the grid. Many different technologies are being researched and demonstrated, however until recently no overview was given for the European member states. Within Grid+, the storage demonstration efforts in 14 member states of the EU were gathered. Only storage projects with a direct relation or integration into the grid were analyzed, while pure material science was not considered. To collect the large amount of data, the Grid+ team involved national experts. In total, almost 400 projects were included in the mapping analysis, with a total value of 985.85million euro. This unique information was for the first time available at European level.

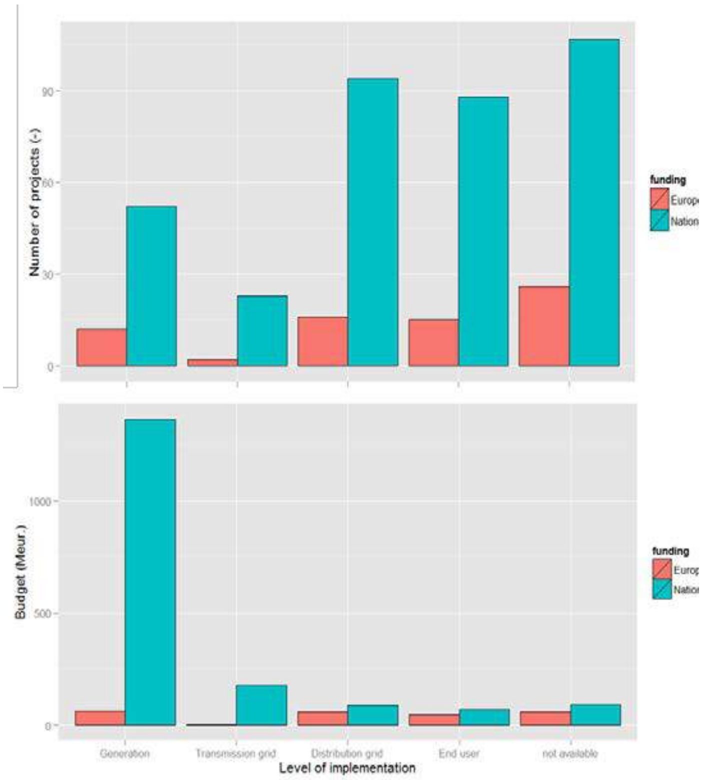


Figure 1: [10] Total amount (top) and total budget (bottom) of storage research and demonstration projects per implementation level

The results of the storage mapping per implementation level are given in Figure 1. 'Generation' on the left of the figure means that the storage project is close to a large central generation unit, 'Transmission' and 'Distribution' are storage projects to support the stability of the transmission and distribution grid, respectively, and 'End user' is related to the most dispersed form of storage e.g. batteries installed at the consumer. Note that only investments in research, development and demonstration were considered in the analysis. Commercially available solutions like pumped hydro plants, which account for 99% of the storage capacity in Europe, were not taken into account.

As can be seen in Figure 1, the national project funding is higher than the European, however compared to other investment areas, storage development is quite strongly supported by European funding. Another striking result from this analysis is that the amount of storage projects is of the same order of magnitude than the generation projects; however the total project funding is much more focused on the large-scale storage close to generation units. This has to do with an enormous investment in Belgium for an 'Energy island' in the North Sea. At transmission level, two large-scale demonstrators in UK and Norway add to the total budget.

The results per technology are given in Figure 2.

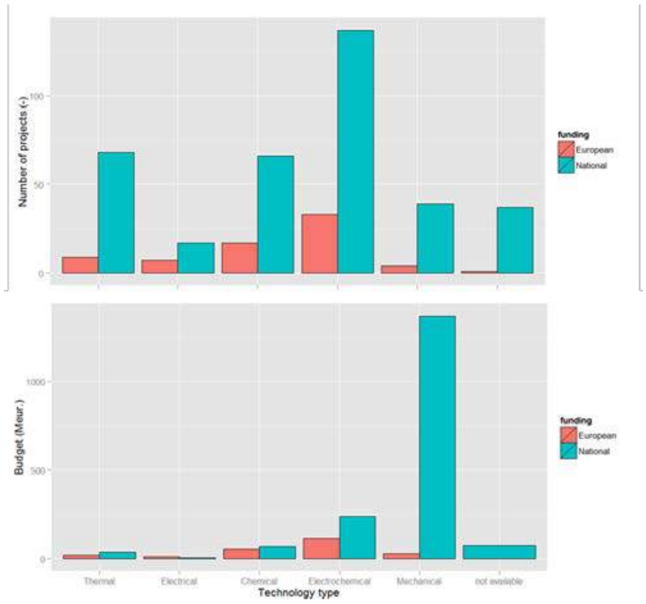


Figure 2: Total amount (top) and budget (bottom) of storage projects per technology

The national funding for mechanical storage vastly outweighs the investments in other technologies, but again this is due to a few very large projects. The electrochemical investments however, are due to a large number of projects, almost exclusively on battery related technologies. Chemical storage receives considerable European and national funding, where for instance power-to-gas demonstration projects are active in Germany.

III. SCALABILITY & REPLICABILITY INTERACTION

Often demonstration projects test prototypes of innovative technologies that should be rolled out in a large-scale demonstration project at a later stage of development. If such projects are successful, the technologies can be rolled out on an even larger scale and possibly also in another region than the one of the initial tests. Therefore, it is of utmost important that the smart grid solution developed in R&D or demonstration projects has a certain degree of scalability and replicability.

The former is related to the scale of a certain solution. For instance, a control algorithm might suffer from increasing calculation time when the data have to be processed centrally. In order to increase the scale of a technology, modularity is also essential. And to function well in slightly different circumstances, the solution should be easily adaptable.

Replicability is related to rolling out the solution on a large scale in a different region. Not only geographically there may be differences, also in the development costs, network infrastructure or market design may be different. These factors are often not sufficiently taken into account by demonstration projects. Overall, three main categories of barriers for scaling up & replication were identified : Technical, economic and regulatory. In [11], all the factors in these three categories that were identified by the GRID+ project to be relevant are discussed in detail. At this point, one should also mention the GRID4EU and TWENTIES projects, which studiy scaling up and replication of large-scale DSO and TSO projects in six EU member states, respectively [3].

In order to assess the current level of scalability and replicability, a large – scale questionnaire was performed. An example of the result is given in Figure 3.

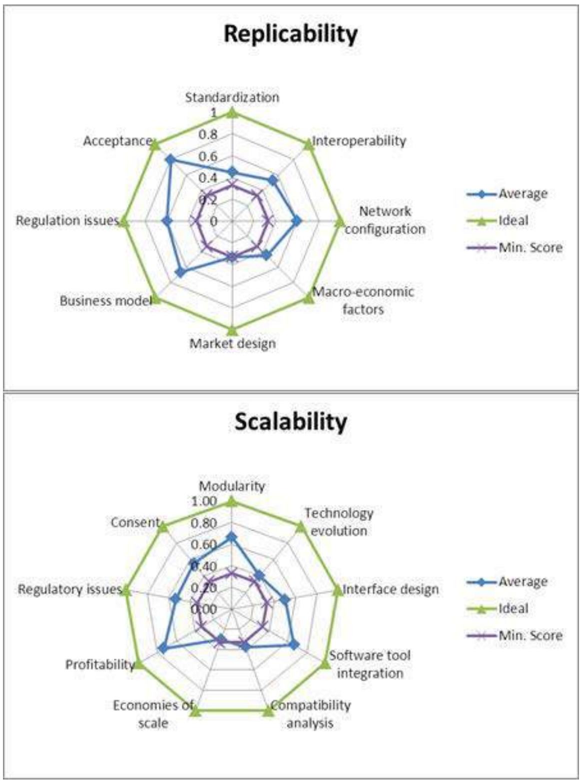


Figure 3: (source [11]) Replicability and Scalability of DSO related projects in Europe

The most important factors that were considered are given in Figure 3 along with the average scores of the projects. For scalability, the economies of scale, which is related to the cost evolution with the size of the project, and a compatibility study clearly require more attention. For replicability, standardization of the developed technical solutions and market integration are crucial.

In addition to the questionnaire, a tool was created that allows newly started projects to test the scalability and replicability of their setup.

In addition to monitoring the existing smart grid projects, Grid+ created a label for smart grids projects. Projects that receive this EEGI label are considered to be highly scalable and replicable and therefore compliant with the targets set out by the EEGI roadmap. The list of qualified projects can be found at [12].

IV. Knowledge Sharing

Finally, in order to promote knowledge exchange between demonstration projects, a knowledge sharing platform was created by the Grid+ team. Access is free and available online [12]. The database is structured according to the EEGI roadmap. You can either submit or access articles about project results. In this way, valuable knowledge about best practices (and less successful outcomes) are shared among Europes demonstration projects.

Conclusion

In conclusion, the Grid+ project achieved several high-level objectives. First, a large-scale mapping exercise was performed to assess possible gaps and topics that were not sufficiently addressed by the current generation demonstration projects. The studies revealed several topics that should receive R&D/demonstration focus in the coming years.

For the field of storage, an assessment was made on innovative investments for fourteen European member states. Results revealed not only the balance between national and European funding, the amount of projects and related funding provided a clear picture which individual country is investing in which type of technology.

In order to help spreading the results of ongoing or recently finished demonstration projects, and make start-up projects compliant with the EEGI roadmap, several actions were taken. First, a questionnaire was performed with ongoing demonstration projects to assess their scalability and replicability potential. Results revealed that certain areas like standardization and taking into account the market design could receive more attention for start-up projects. Secondly, an EEGI label was created for projects that are considered to be highly scalable/replicable and at the same time compliant with the EEGI roadmap. And finally, a knowledge sharing platform and community was set up to support dissemination of scientific knowledge and best practices for demonstration projects.

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Monitoring and analysis of Oscillations in Southern Regional grid of India using Synchrophasor Data

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***Abstract*—Worldwide the Synchrophasor technology is being deployed for providing access to time- synchronized phasors at the control centre. Synchrophasors have enhanced wide-area visualization and situational awareness of power system behaviour under steady state as well in transient/dynamic conditions. This paper illustrates the utility of synchrophasors in monitoring and analysis of oscillation occurring in grid. Few case studies will be discussed where low frequency oscillation were observed in grid were analysed in offline using synchrophasor data. This paper also discusses about the way forward with respect to the analysis of oscillations. Offline tools like Matlab is being used for carrying out multiple signal prony analysis and eigen value analysis to find the dominant modes present, their amplitude and damping factor.**

Keywords—Low Frequency Oscillation, Synchrophasor, Prony Analysis, Eigen Value

I. Introduction

Indian power grid is expanding at a fast pace to achieve its goal of Electricity for all by 2012. In order to achieve this, regional grids of Indian power system are being connected synchronously to help in seamless transfer of power from one region to another [5]. As on date all of five regional grids in India Vis Northern, Eastern, Western, Southern and North-Eastern grids are operating synchronously and being operated as a single grid. This however has also increased the complexity towards the monitoring and control of such large grid. Such widely spread grid requires wide area monitoring which may only be possible by emerging technologies like Synchrophasors/PMU's.

Synchroph**a**sor pilot projects have been taken up in all five regional grids since May 2012 to explore the application of Synchrophasor and currently sixty synchrophasors are installed under pilot project in India. Synchrophasor**s** have been installed at important generation complex, load centre and locations considered important from point of view of operation. Synchrophasors have enhanced wide-area visualization and situational awareness of power system behavior under steady state as well in transient/dynamic conditions. The availability of synchrophasor data at every 40 millisecond interval from few locations has made it possible to visualize the magnitude and angle of all the three voltage/current Phasor; sequence components of voltage/current phasors; frequency and frequency difference, rate of change of frequency and angular separation between pair of nodes in real-time at the Load Despatch Centre. The dynamical behavior of power system can be observed in almost near real-time at the control center which hitherto was possible only in offline mode in the form of substation Disturbance Records (DR) or through offline dynamic simulations performed on network model. With this multi-dimensional high resolution data, even minute changes in the grid can be visualized by the grid operators like never before [6].

II. Low Frequency Oscillations

Small signal instability is due to insufficient damping torque leading to low frequency electromechanical oscillations in system which is oscillatory in nature. If there are N generators in a system, then total number of such LFO modes would be N-1. During Low Frequency oscillations, mechanical kinetic energy is exchanged between synchronous generators of the inter-connected system through tie lines. Most of these oscillatory modes in normal power system state are well damped. However, they get excited during any small disturbance in the system and lead to oscillation in power system parameters like rotor velocity, rotor angle, voltage, currents power flow etc. Due to oscillation in parameters, protection equipment may undesirably operate leading to cascade tripping in power system. Therefore, it is necessary to detect such modes and initiate corrective actions to ensure system reliability and security. Among these parameters the rotor velocity of the generators and the power flow in the network are most important. The rotor velocity variation causes fatigue to the mechanical parts of turbine-generator system. The power flow oscillations may amount to the entire rating of a power line, when they are superimposed on the stationary line flow and would limit the transfer capability by requiring increased safety margins.

Low frequency oscillations can be classified as four major types as indicated below:

a. Inter-Area Mode (0.1-1Hz): Inter-area modes are associated with swinging of a group of generators in one part of the system with group of generators in other parts due to weak interconnecting lines between two power systems.

b. Intra-Plant Mode (1 Hz -2.5 Hz): It is due to the swinging of units in a generating station with respect to each other.

c. Control Mode: These are in system due to poor design of controllers of AVR, HVDC, SVC, AGC etc.

d. Torsional Mode (10-40 Hz): These modes are associated with the turbine-generator shaft system and associated rotational components.

III. DETECTION OF LOW FREQUENCY OSCILLATIONS USING SYNCHRPHASORS

With the current SCADA system, power system operators are unable to identify LFOs in the system due to inherent slow updating rates i.e. once in every 4 -15 Seconds (analog values). The oscillation at generator level i.e. intra-plant or local mode was assumed as it appeared as hunting in the generators while the inter-area modes were not visible to system operators by any means apart from simulation studies. The SCADA data reporting rate is comparatively slow which are not useful in detecting the oscillation or the changes going in the system in sub-seconds.

With advent in the technology, faster data processing and time synchronized phasor measurements availability at a reporting rate of 25-50 frames/second from Phasor measurement unit (PMU), now operator is able to visualize such oscillations in the system. Tools and techniques are also in development to detect the source of such oscillation and to analyze them in real time and take corrective action before they create further complexities in the system. The detection of LFOs and their history is of great help in planning and implementation of damping controllers of HVDC, TCSC etc. At present PMUs have enabled the operator to visualize such LFOs whose source can be tracked with placement of optimum number of PMUs giving complete observability of system.

Low frequency oscillation have been observed in grid following a disturbance, during a sudden load/ generation loss, Improper tuning of PSS, malfunction of governor/ control system and during increased power flow in transmission lines. Apart from this spontaneous inter area oscillations have been observed in grid. Few case studies of oscillations that had occurred in grid are discussed in this paper.

IV. CASE STUDY 1

A. *Antecedent conditions*

On 20th April 2014 at 02:00 hrs Unit # 1 and 2 of Generating Station Vallur were in service with a total generation of 865 MW with all six outgoing feeders in-service.

B. *Sequence of Events*

The sequence of events prior to the tripping of units and the subsequent oscillations is given in TABLE I.

TABLE I: Sequence of Events

Line	Trip Time	Reason
400 kV Vallur-NCTPS-1	02:43	R-ph Zone 1 diff. protection
400 kV Vallur-NCTPS-2	03:24	Y-ph Zone 1 diff. protection
400 kV Vallur-Alamathy-1	03:58	R-ph Zone 1 diff. protection
400 kV Vallur-Alamathy-2	03:58	B-ph Zone 1
400 kV Vallur-KVPT-2	03:58	B-ph Zone 1 gen. protection

At 03:53 AM Units 1 and 2 of NCTPS generating about 1200 MW tripped on turbine overspeed protection. Vallur Units 1 and 2 tripped at 04:50 as all the evacuating lines tripped. The connectivity diagram around Vallur is shown in Fig. 1 and Fig. 2.

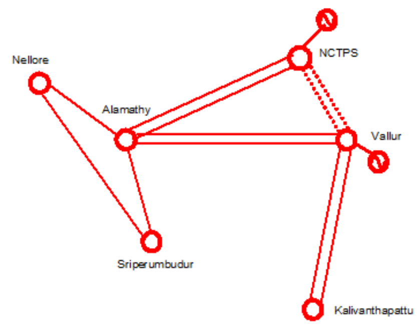

Fig. 1: Connectivity around Vallur at 03:52

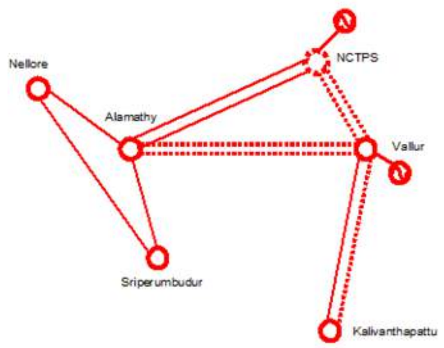

Fig. 2: Connectivity around Vallur at 03:59

C. *Post Tripping Events*

Following the tripping of one line of a double circuit line between Vallur and Kalivanthapattu, Vallur unit was connected to the grid by a single long line. Immediately following the line tripping oscillations were observed throughout the southern grid. These oscillations were prominently observed from a PMU placed at Kolar which is connected by a 400 kV line to Sriperumbudur. The oscillations lasted for around 2 minutes as shown in Fig 3.

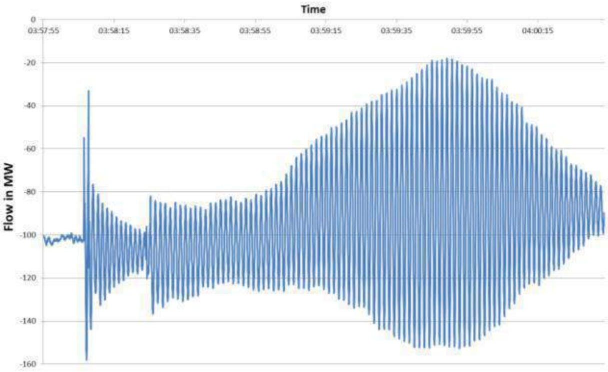

Fig. 3: PMU plot of active power in the 400 kV Kolar-Sriperumbudur line

On inquiry it was found that hunting was observed in Vallur following the line tripping at 3:58. The station recorder snapshot is shown in Fig 4.

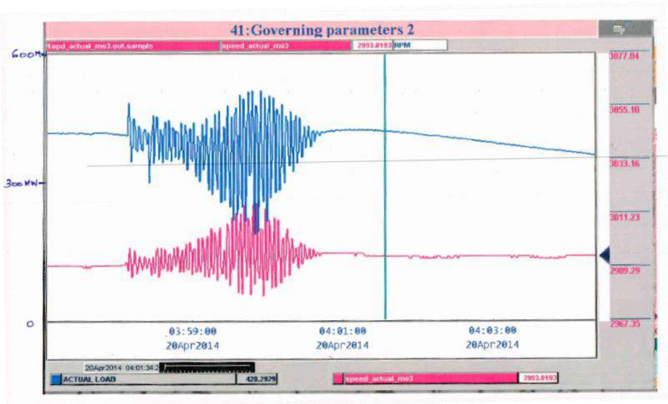

Fig. 4: Station recorder plot from Vallur

D. *OMS Analysis*

The Oscillation Monitoring System (OMS) developed in-house in SRLDC was used to analyze the oscillations and to identify the dominant modes. The program was developed on MATLAB and the snapshot of the result is shown in Fig 5.

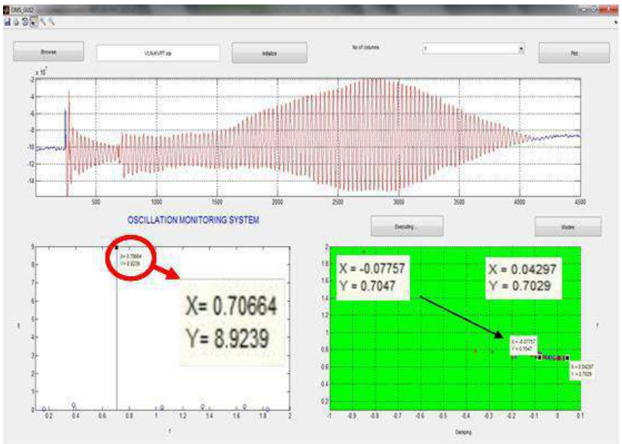

Fig. 5: Snapshot of OMS engine in SRLDC for Case I

Analysis was performed on the PMU data from **Kolar** and the frequency of the dominant mode of oscillation was **0.7 Hz**. The damping ratio changed from -1 % to +1.7 % over the period.

E. *Studies conducted in PSSE*

Post tripping the event was recreated using PSSE where the system and network conditions was given as in the real case and the post event flow at **Kolar** was recorded to compare with the OMS analysis. The plot is shown in Fig 6.

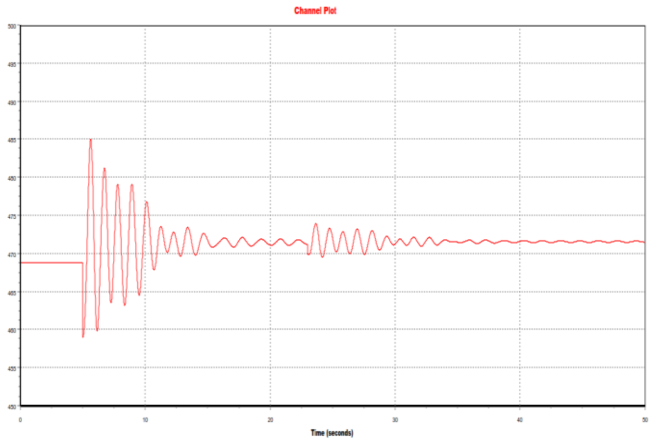

Fig. 6: PSSE study result: Kolar station waveform

The frequency of most dominant mode observed was **0.8 Hz**. Since the model parameters are not accurate enough the mode shape and damping nature are not quite the same as observed in real time.

F. *Conclusion*

Oscillations were observed at SRLDC and on enquiry the station too confirmed hunting in generators. Hence generation reduction at Vallur was started at 04:00 AM and was maintained at 550 MW with oil support in both the units. Further Station load was brought down to 400MW at

04:30 hrs. Since the oscillation decayed only after the generation and hence the flow was reduced, it was necessary to know if the PSS was active. It was found that the function was activated but might have been improperly tuned.

V. CASE STUDY II

A. Antecedent conditions:

On 06-05-2015 at 05:22 AM Unit 2 of Madras Atomic Power Station (MAPS) at Kalpakkam Tripped which was generating about 200 MW. Prior to the tripping the frequency of the grid was 50 Hz and the inter-regional flow in Raichur-Sholapur was 120 MW.

B. Event Details:

At 05:23 AM oscillation were observed in Raichur-Sholapur line flow from the real time PMU data obtained at SRLDC. Oscillation in frequency were predominant and of higher magnitude in the PMU data from Tirunelveli. The utilities in the region of Tirunelveli were enquired for any abnormal operation. On inquiry it was informed that hunting was observed in unit 2 of Kalpakkam. The hunting was a result of spurious activation of overspeed limiting gear which resulted in the pressure varying between the extremes in the S.V. Valve of the turbine governing oil system causing load hunting and subsequent oscillations. The plots from PMU data is given in Fig. 7 and 8.

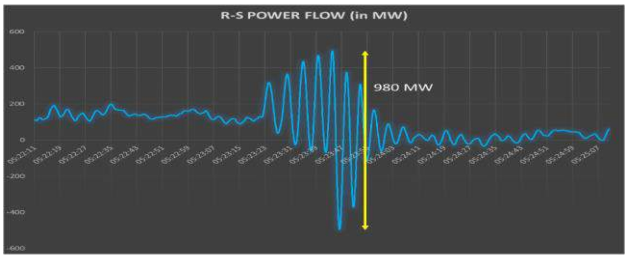

Fig. 7: PMU plot of active power flow in the Rchr-Shlpr link

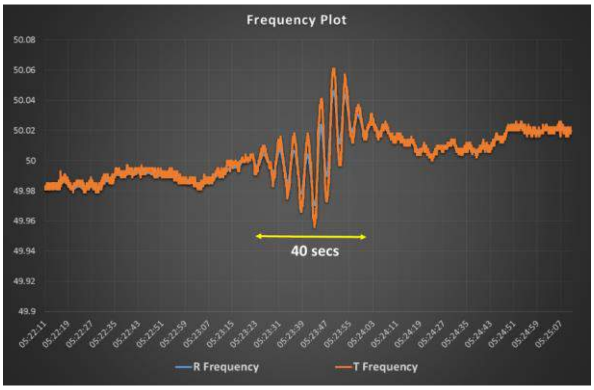

Fig. 8: PMU plot of frequency at Raichur (R) and Tirunelveli (T)

C. Post event conditions:

During the hunting the MW output from the unit fluctuated between 20 and 120 MW for about 29 secs following which the unit was tripped. The flow in the inter-regional AC link kept growing up as a result of the swing and when the rate of change of flow (dP/dt = 980 MW/s) crossed the setting of the Special Protection Scheme (SPS setting = 400 MW/s) the signal for SPS was sent and SPS acted resulting in reduction in line flow and also the oscillations. The snapshot of the modal analysis in real time for the inter-regional flow is shown in Fig 9. As can be seen there was one mode with negative damping during the period of oscillations.

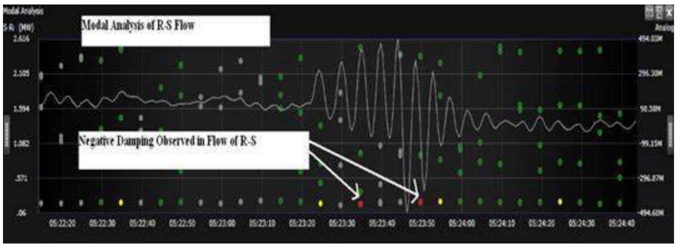

Fig. 9: Real time modal analysis snapshot of station Raichur

D. OMS Analysis:

The PMU data from both Tirunelveli and Raichur was analyzed using the OMS Engine in SRLDC. The dominant mode observed was **0.23 Hz** with the damping ratio changing from -5 % (negative damping) to 13 % after the SPS operation. The snapshot of the results of OMS analysis on frequency and active power flow is shown in Fig. 10 and 11 respectively.

Fig. 10: Snapshot of OMS engine in SRLDC for Case II – Frequency data

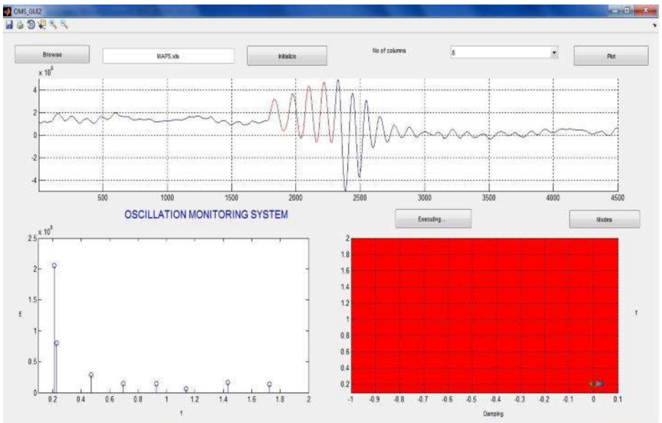

Fig. 11: Snapshot of OMS engine in SRLDC for Case II – MW data

E. Action Taken and Conclusion:

It was found that a power sensing relay for the overspeed limiting gear was faulty at MAPS mainly due to continuous energisation. It was suggested that some form of redundancy be brought to the relay coil and regular maintenance and replacement of the coil as recommended by manufacturer and relevant standards be carried out.

VI. CASE STUDY III

During the early morning hours on 9-12 August 2014, Low frequency oscillations have been observed in the Indian Grid. These oscillations have resulted in hunting in several of the generating plant in Eastern, Western and Northeastern region. In addition, the oscillations were observed in HVDC power order and several transmission lines. The magnitudes of oscillation were quite high as observed from the SCADA as well as synchrophasor data and the damping observed was less than 2 %.

A. Antecedent Conditions:

At around 04:30 AM on 9th Aug 2014, Calcutta Electric Supply Corporation (CESC) reported to Eastern Regional Load Despatch Centre (ERLDC) about hunting being observed in the transmission line connecting the CESC system with the West Bengal system in Eastern Region. With this ERLDC started looking into the Phasor Measurement Units Data for the oscillation. This was then reported to the National Load Despatch Centre (NLDC), who also verified that the oscillations were occurring in the Grid. The oscillation were found to be observed in Eastern, Western and North eastern regional grid with higher magnitude compared to Northern and Southern grid.

B. Event Analysis

It was necessary to find out the mode shapes and the dominant mode of oscillation in each of these days. The OMS Engine in SRLDC was also used for analyzing all the PMU data collected from over various regions. From the analysis it was found that on 9-11th Aug the dominant mode frequency was **0.75 Hz** while on 12th Aug it was **0.6 Hz.** Mode Energy Classification was performed on the results obtained and the same is shown in Fig. 12-15.

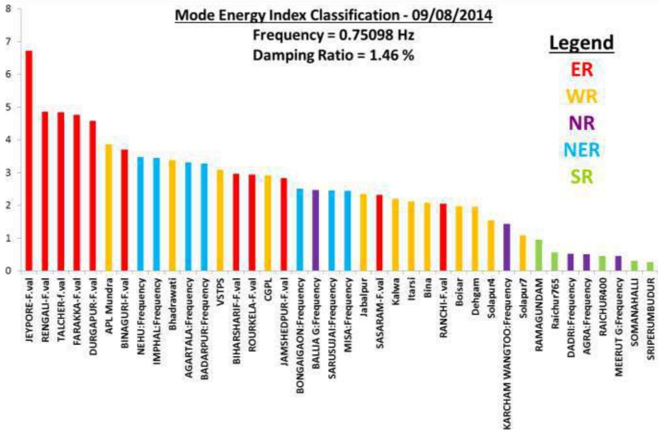

Fig. 12: Mode Energy Classification – 9th Aug 2014

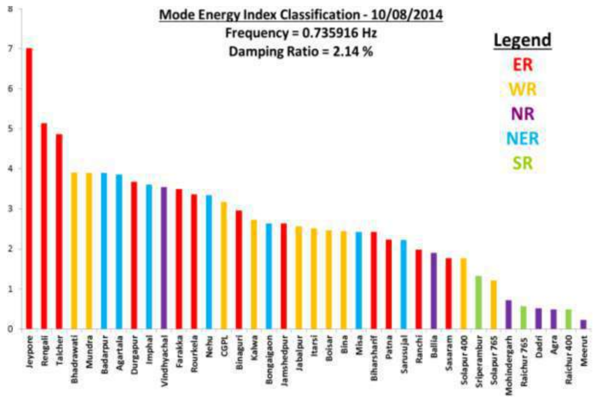

Fig. 13: Mode Energy Classification – 10th Aug 2014

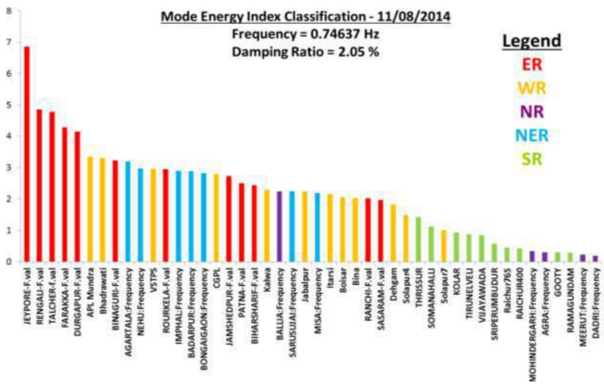

Fig. 14: Mode Energy Classification – 11th Aug 2014

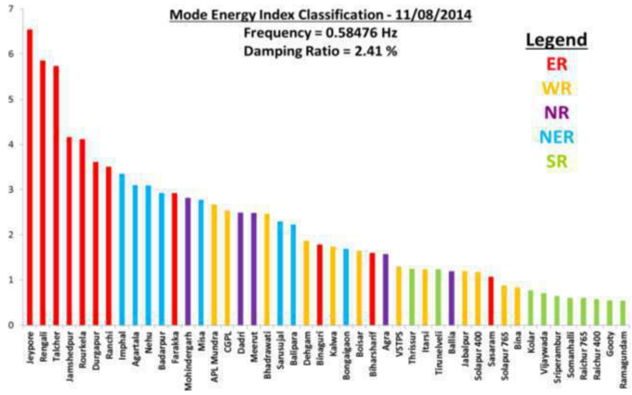

Fig. 15: Mode Energy Classification – 12th Aug 2014

Coherent groups were obtained from the OMS Analysis. It was observed that the PMUs in ER and WR were in phase with phase shift of -30^0 to 30^0. Southern Region was almost in phase opposition with that of ER region (around -140^0 to -160^0). The mode shape is shown for 11th Aug 2014 in Fig 16.

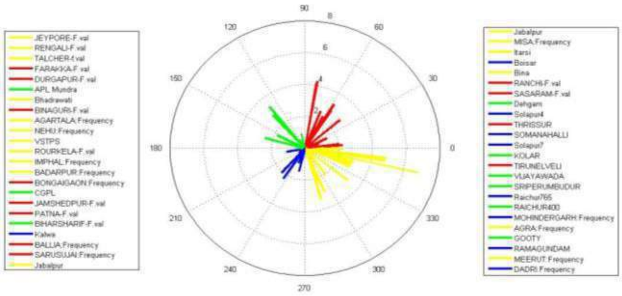

Fig. 16: Mode Shape – 11th Aug 2014

The All India distribution of the mode for oscillations observed on Aug 9-11 is shown in Fig 17. From the figure it is clear that the mode travelled from areas in Eastern Region (i.e. Jeypore, Rengali and Talcher) to Western Region and then spread gradually to the Northern and Southern Regions.

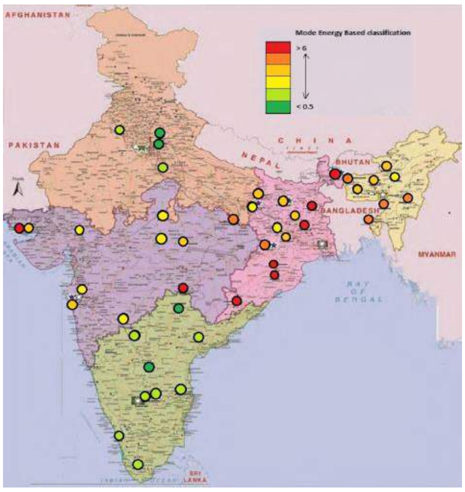

Fig. 16: Mode Spread – 9th- 11th Aug 2014

Conclusion

The paper has illustrated few case studies where oscillation monitored in grid where analyzed using Matlab. Synchrophasors have particularly been very useful in post-dispatch event analysis. Customized applications of synchrophasors in the operation and well as planning domain are being developed for further exploitation of the technology. The present OMS Engine in SRLDC runs offline i.e. after extraction of PMU data in csv form this data is utilized to analyze the oscillations and obtain the mode shape and mode values. In future it is envisaged to make the engine online through some open source PDC. The online OMS Engine would not only determine the mode frequency and damping but also determine the highest participation in that mode among various PMU data available. It is also planned to make the engine recognize patterns either automatically or through manual intervention. On re-occurrence of the event/pattern it could easily alert or inform the operator about what kind of event it is and its likely occurrence.

Acknowledgement

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A Practical Approach to Predictive Analytics using IoT/Big Data – Asset Fitness Center

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Abstract—We are living in an increasingly connected world and the Internet of Things (IoT) has emerged to be the technology for integrating devices and sensing/measuring parameters that have hitherto been not thought of as possible or useful. But now, with the emergence of integration capabilities and smarter technologies, today's utilities are faced with a major challenge to handle, manage and process huge volumes of data that are created from their Smart Grids, Smart Meters, devices and sensors. Big Data Analytics are the way forward to meet these challenges and help utilities derive highly useful and actionable intelligence & information from the piles of data created. This paper investigates how utilities can do real time performance monitoring of their assets, analyze their utilization patterns and reduce their operations & maintenance costs through our predictive analytics platform – Cuecent Real Time Decision Support System that combines IoT, Big Data and AI enabled analytical capabilities. This paper also discusses how challenges faced by T & D companies in maintaining ageing assets can be addressed by deploying asset 'fitness center'.

Keywords—SmartGrid, Hadoop, IoT, Predictive Analytics, Neural Networks, Sqoop, Mahout, Asset Condition Monitoring

I. Introduction

Power Transmission & Distribution (T&D) companies are asset intensive and are mostly devoid of any harmonious, advanced and state-of-the-art mechanism to keep their assets in the network to perform at their best to deliver a highly reliable power delivery mechanism. Globally T&D networks are plagued by several issues [1] such as:

a. Poor Asset utilization: Current utilization levels are anywhere between 40 to 50%.
b. Aging Assets: Some assets are close to end of their lifespan.
c. System losses: Close to 10% of the losses are attributed due to transformer and line related losses.
d. Lack of tools to proactively sense, alert any impending breakdowns and guide the operations and maintenance team to take measures to improve grid efficiency.

II. Asset Condition Monitoring

The significance of asset condition monitoring stems from the fact that the risk of asset failure that is unanticipated can be really impacting on several factors:

a. Cost of failure can be in several multiples of the cost of the asset that failed
b. More frequent outages
c. Overall reliability and safety of the network

On the other hand, a paradigm shift in the operations can be brought about when the maintenance management concepts move from traditional reactive maintenance to a highly mature state of asset optimization and maintenance. This may include improvement to asset utilization as well as decisions on inventory optimization. Fig. 1 shows how the real time asset condition monitoring is indeed become a necessity to get better Return on Investment (ROI) from assets.

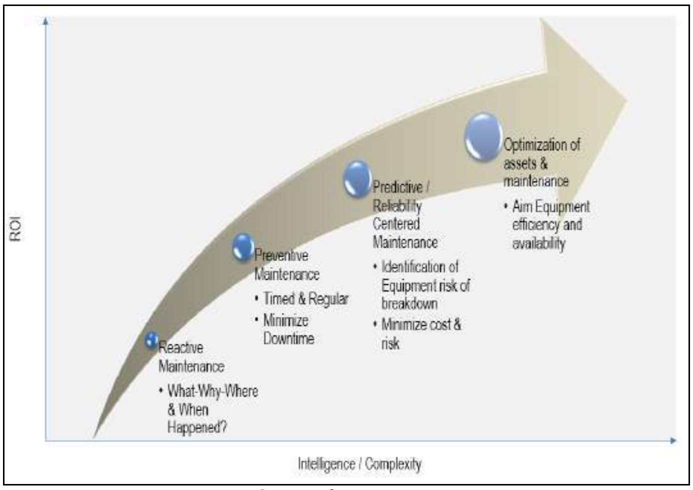

Fig.1 Evolution of Asset Maintenance

III. SmartGrid Initiative – Technology Convergence

Existing grids are required to deliver the growing demand for power, as well as provide a stable and sustainable supply of electricity and integrate renewable sources of energy into the network, while taking care of the aging infrastructure.

The smart grid is transforming the entire supply chain including generation, transmission, distribution, and consumer end-use of electricity using entirely new technologies, infrastructure, and computational systems. A smart grid will be able to analyze, protect, and optimize the operation of its interconnected components, from electricity generation systems to high-voltage transmission and distribution networks to collaborating with consumer end-use systems.

The major drivers for smart grid are capacity, reliability, efficiency and sustainability. Smart grid solutions increasingly blend utility operating technology (OT) and utility information technology (IT). The smart grid initiatives [2] would generate volumes of data associated with its assets with the smart grid initiatives like Advanced Metering Infrastructure (AMI), Meter Data Management System (MDM), Outage Management Systems (OMS), Distribution Management Systems (DMS) & Enterprise Asset Management (EAM). The implementations of smart grid technologies can lead to an estimated cost savings of up to $2 trillion by 2030 [3].

The smart grid information technology has expanded to include systems outside the grid and integrating enterprise applications for better decision making. Hence robust security must be in place to ensure data security, privacy and grid safety. The SEI, in support of the U.S. Department of Energy (DoE), fosters the adoption of the Smart Grid Maturity Model (SGMM) by electric utilities and service providers and works to advance smart grid software engineering. The benefits analysis framework [4] for Smart Grid projects are as follows:

TABLE I. BENEFIT ANALYSIS FRAMEWORK

Benefit Category	Benefit Sub-category	Benefit
Economic	Improvised Asset Utilization	Optimized Generator Operation
		Deferred Generation Capacity Investments
		Reduced Ancillary Service Cost
		Reduced Congestion Cost
	T&D Capital Savings	Deferred Transmission Capacity Investments
		Deferred Distribution Capacity investments
		Reduced Equipment Failures
	T&D O&M Savings	Reduced Distribution Equipment Maintenance Cost
		Reduced Distribution Operations cost
		Reduced Meter Reading Cost
	Theft Reduction	Reduced Electricity Theft
	Energy Efficiency	Reduced Electricity Losses
	Electricity Cost Savings	Reduced Electricity cost
Reliability	Power Interruptions	Reduced Sustained Outages
		Reduced Major Outages
		Reduced Restoration Cost
	Power Quality	Reduced Momentary Outages
		Reduced Sags and Swells
Environmental	Air Emissions	Reduced Carbon Dioxide
		Reduced SO_x, NO_x and PM-10 emissions
Security	Energy Security	Reduced Oil Wastage
		Reduced Wide-scale blackouts

IV. PREDICTIVE ANALYTICS IN 'CONNECTED' GRIDS

Predictive analytics [5] is forward-looking science using history data/past events coupled with real time data to anticipate the future. Predictive analytics is a combination statistics, advanced mathematics and set of artificial intelligence techniques such as decision trees, neural networks, genetic algorithms and other mathematical algorithms. Predictive analytics unearths the patterns and relationships within large volumes of data to predict behavior and events. Internet of things is gaining momentum and these sensors/IOT devices would generate huge amounts of data. These techniques require processing power to perform complex calculations that often require multiple passes through the data.

The practical challenges faced by organizations trying to adopt Predictive analytics are complexity involved in developing models, data gathering, processing needs (CPU and storage) and costs involved in hardware and software for optimal performance and better Return on Investment (ROI). Last but not the least is the selection of tools and techniques.

Predictive analytics in Smart grid and utility industry can help improving the reliability of operations by preventing faults, reducing outages and improving KPIs like System Average Interruption Frequency Index (SAIFI) and System Average Interruption Duration Index (SAIDI). Predictive analytics are utilized for the maintenance and modernization of an aging infrastructure and for improved visibility across automated systems and leverage real time data for smart control to enable situational awareness in Operations. It can also identify gaps in asset health parameters and establish best asset management practices.

The impact of equipment failures, capacity limitations, and natural accidents and catastrophe, which cause power disturbances and outages, can be largely avoided by online power system condition monitoring, diagnostics, and protection using IoT and Predictive Analytics.

V. ASSET FITNESS CENTER

A. How it works

A real time asset monitoring center also known as 'Asset fitness center' can be deployed to sense and acquire data from in real time from the various sensors and devices in the smart grid network & analyze the data using statistical models to predict the failures and proactively manage the situations. The large volumes of data generated from various sources and formats can be managed using big data storage like Hadoop Distributed File System (HDFS) and in-memory data store.

An asset fitness center can enhance the reliability and visibility providing real time access to data, pro-active alarm management, forecasting and advanced analysis that translate data into actions to fully realize smart grid capabilities. The equipment's real time performance data would be compared with historical data to arrive patterns in behavior and predict the possible failure and seamlessly generate a work order or inspection request into asset management application for the maintenance engineers can attend to the issue proactively. Depending on the asset health index, the maintenance schedules can be adjusted. Smart Grid maturity model (level 4) recommends the asset models to be based on real performance and monitoring data & Asset life to be managed through condition based predictive maintenance [6]. Fig.2 defines a typical asset fitness center.

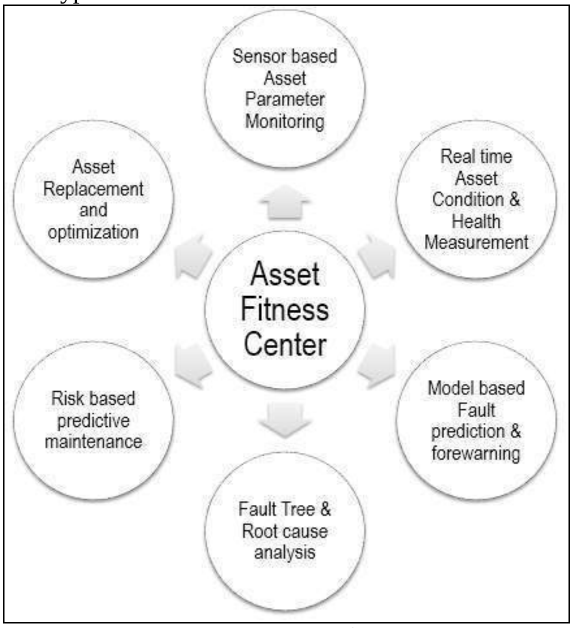

Fig.2 Asset Fitness Center functionality

B. Reference Architecture

The Smart grid and asset fitness center would require ability to exchange, parse and act on many forms of data and respond to unforeseen conditions and provide alerts in real time. This would require real time integration between operational systems, information systems and asset management systems. Deployment of billions of devices and sensors would generate huge amounts of data and information life cycle management has new set of challenges in storing, analyzing data for grid optimization, load balancing and monitoring asset health for pro-active maintenance.

The following are building blocks and functional aspects of big data/IOT based predictive analytics with a specific focus on Smartgrid [3] Asset fitness are as shown in Fig.3

- Ability to communicate with devices, sensors and automation/control systems
- Data Store to store and analyze the huge volumes of data that is being generated by the sensors and smart grid
- Visualization Tools
- Performance models - Grid reliability and stability under dynamic conditions.
- Grid visibility and analytical decision tools with situational awareness.
- Probabilistic models for load forecasting for dynamic pricing
- Optimized power flows
- Integration to Historian and Enterprise Asset Management Applications (EAM)
- Integration to Finance systems/ERP.
- Asset Optimization Tools / Dashboards - An Asset Fitness Center

1) *Visualization and analysis tools*

- Smart grid visualization tools - Algorithms for analytics
- Actionable outputs from operational data, as well as automatic detection and mitigation of cascading events.

2) *Forecasting and probabilistic tools*

- Advance forecasts of events that impact load.
- Advanced decision support – Improve operator visibility, improve dispatch decisions and optimize resource choices (renewable or flexible source)
- Automatic activation of remedial action schemes or other control schemes
- To improve operator visibility & Advanced decision support

Data volume can be addressed by vertical / horizontal scaling of servers by adding terabytes of storage. However this is not a cost effective solution to run analytics. To address this challenge Hadoop based big data solution would address the volume, variety and velocity in most economical way. Apache Hadoop software is a cost-effective, massively-scalable platform runs on clusters of commodity servers and storage drives and can scale up to thousands of servers for performance and capacity at a cost-per-terabyte that is much less than a conventional data store.

Not only SQL (NoSQL) databases relax the constraints of a traditional data store to deliver higher performance and scalability. In memory databases provide multi-fold performance eliminating most of data access latencies associated with storage and processors. In-memory database solutions tend to be are appropriate for complex event processing (CEP) that require the performance. Hadoop is fast and massively scalable, data processing is performed in batch mode, Hadoop software includes a module, Apache Hive, designed to enable queries on big data. Hive facilitates querying large datasets in distributed storage by projecting structure onto the data and using an SQL-like language called HiveQL. HBase is used to perform complex queries, including ad hoc queries, in your Hadoop environment. The Apache Mahout Machine learning library, to create predictive algorithms that can run directly on Hadoop. 'R' programming language can be used for statistical computing and data mining.

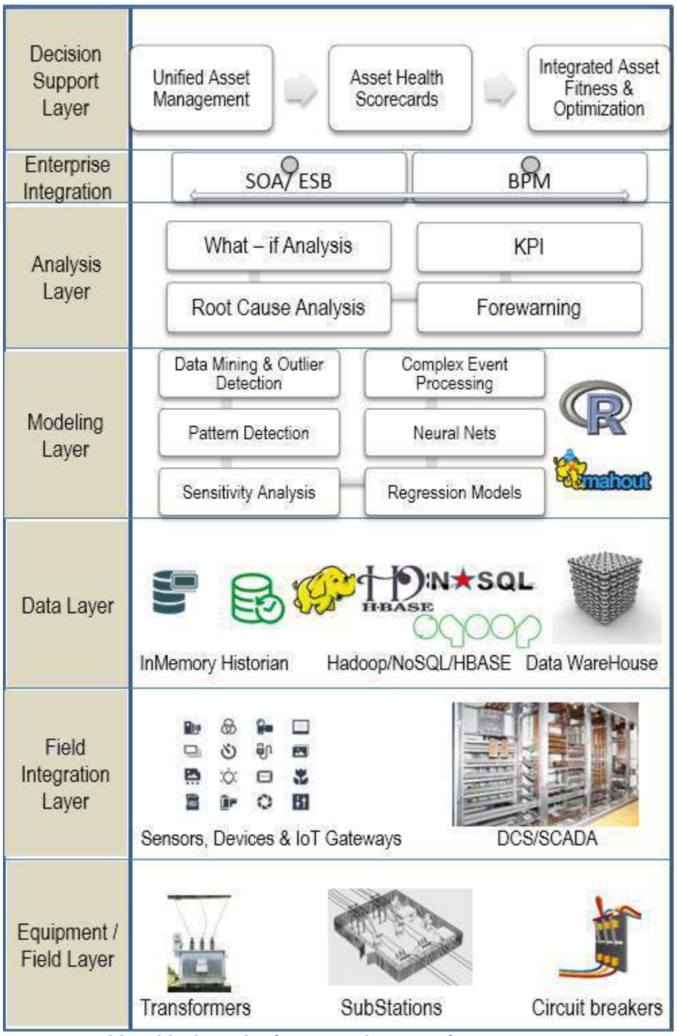

Fig.3 Building blocks and reference architecture for Asset Fitness Center

However, since Hadoop processes data in batch mode, additional components are needed to integrate predictive analytics into real-time business processes like Flume etc. There are number of other NoSQL databases are available in the market like Cassandra, Mongo DB etc. that run on commodity servers and storage drives to provide high performance and massive scalability at relatively low cost.

Asset fitness center visualization layer and dashboards can be built using BI Tools. Predictive analytics libraries to be built to analyze the data or one need to buy commercially available analytics software. This solution would require customization and integration efforts into IT landscape.

Asset fitness center would provide unified dashboard of asset health, operational efficiency, energy usage and emissions for operations, maintenance, quality and corporate teams of organization. It provides integrated asset management and key performance indicator (KPI) visualizations to help users make more informed decisions by integrating operations systems and Information systems including EAM and ERP applications. It will identify conditions that lead to high failure in advance their by proactive maintenance can be done to extend the component life.

The asset fitness center to consider best practices to arrive at asset health index by including all characteristics, history of equipment patterns, operating conditions, sensitivities, common failures, past history of failures based on type/severity. In addition to the physical factors, the financial impact of a failure also to be taken into account. This would include operating costs, loss of opportunity in terms of revenue/profits, regulatory compliance costs and reputation management costs.

Based on all these factors the asset fitness center would help monitoring the assets in real time for condition based maintenance and predictive maintenance and enable organizations to plan for pro-active maintenance and Just in time Asset retirement.

C. Asset Analytics example

Example of the Asset health index computation for a circuit breaker and transformer are as depicted in Fig.4 and Fig.5. Set of real time parameters from SCADA/DCS systems and sensor data are collected in real time from the asset. The connectivity mode is dependent on the instrumentation involved. The data from lab and/or maintenance data would be used while determining the Health index.

Typically, the data coming from these sources would be analyzed using statistical tools, followed by a neural network modeling. The output of this would be consumed by a fuzzy logic heuristic modeler to compute the degree of belief for asset availability which can be used as asset availability index or asset risk index. Asset health index (AHI) is typically a computation similar to this:

AHI = Sum(*weightage * Condition assessment by category)*

such that

0 <= weightage <= 1 and

0 <= Condition assessment by category <= 1

Condition assessment by category can be O&M History or Lab analysis history or live parameter fluctuation trends and weightages are individual categories.

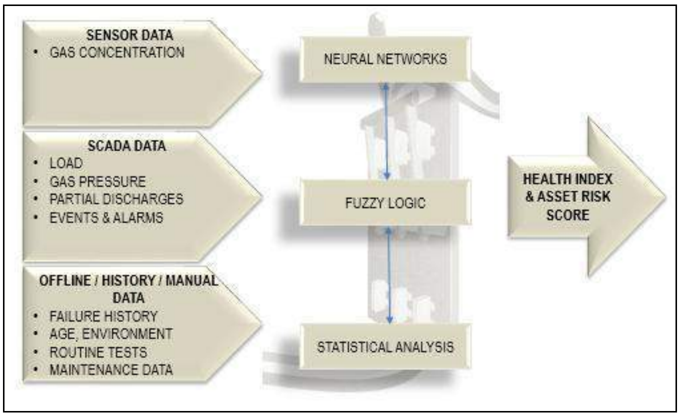

Fig.4 Asset Health index and Risk Score example for Circuit breakers

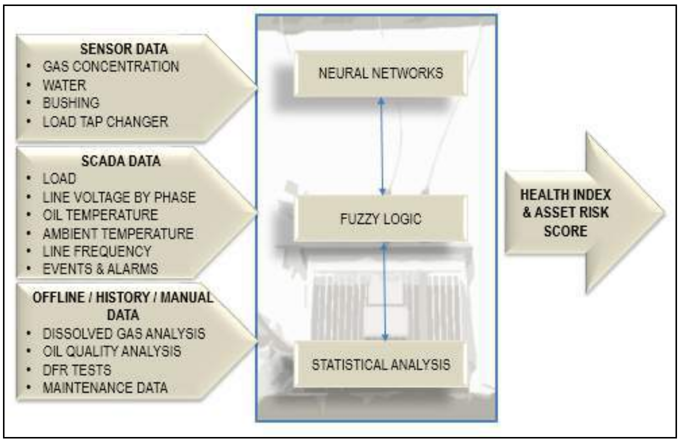

Fig.5 Asset Health index and Risk Score example for Transformers

Individual asset health indices of all assets can be computed in real time or in periodic intervals of time. These indices for all assets can be rolled into asset categories, areas, vendors etc and analyzed for faults, failures, patterns in comparison with vendor specifications and / or the baseline figures. Informed decisions can be taken through the decision support system automatically which suggests risk of utilizing the assets and if it would be make sense of holding the asset or replacing this by taking into account the maintenance history, performance and costs.

VI. CONCLUSIONS

Advanced technologies such as IoT and Big Data have enabled greater and deeper insights into the way assets perform and the manner they impact the businesses. The benefits can be far reaching when these technologies are integrated with maintenance management systems to provide robust optimization of assets. Potential benefits could be:

1. Higher Reliability: With better insights, better decisions are taken for asset utilization and availability.
2. Better efficiency : The assets in the Smart Grid would perform with better efficiency at higher utilization levels
3. Lower costs: Reduced costs of maintenance and asset holding costs.

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APPLICATION OF PHEVs FOR SMART GRID IN INDIAN POWER SECTOR

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***Abstract*- The ever-increasing rate at which global energy reserves are depleting has alarmed economic, environmental, industrial, and societal levels worldwide. These problems together with the Kyoto Protocol measurements push manufactures to increase the number of PHEVs in market. Electric bikes come under middle segment and India is seen as future hub for electric vehicles business. Market is expected to rise by 100% this year and then 200% in the consequent years. Plug-in-Hybrid Electrical Vehicles (PHEVs) can be charged by Renewable Energy Systems (RESs) and Inductive power transfer (IPT). IPT technology that has been widely accepted for numerous industry and charging applications. Coordinated Charging is essential to minimize the impact on the electricity production system and could be implemented using smart meter technology. The V2G Concept and the issue of power quality management for smart grids is given importance in this paper and also it proposes a load management strategy based on transformer derating for minimizing harmonic distortion in distribution feeders and transformers. In this paper better Distribution strategy is suggested with the help of PHEVs. Also we are concentrating more on two-wheeler EVs, as scope of two wheeler electrical vehicles is more as compared to four wheelers PHEVs in developing countries like India.**

***Keywords*-Smart Grid, V2G, Charging System, AMI, IPT, Harmonic Distortion, Transformer losses.**

I. INTRODUCTION

The V2G approach considers BEVs/PHEVs as a generation resource for the buildings at certain periods of time via bidirectional power transfers, which could increase the flexibility of the electrical distribution system operation [1]. EVs are expected to participate in most energy markets, to improve the sections of bulk energy, spinning reserves and frequency regulation. The plug-in EV will be always close to the energy demand, and potentially the efficiency of stored energy in EV´s batteries is significantly higher than the energy stored in hydrogen and in fuel cells hydrogen cars. Moreover the hydrogen cars have just limited capacity to provide ancillary services to the grid in comparison to EVs [2] .The EVs can be used as loads, energy sources (small portable power plants), and energy storages in a smart grid integrated with renewable energy sources (RESs). BEVs/PHEVs have large-capacity batteries and an intelligent converter to connect to electric power grid. High speed bi-directional communications networks will provide the framework for real time monitoring and control of transmission, distribution and end-user consumer assets for effective coordination and usage of available energy resources [3]. A maximum power transfer of about 10 kW is given by current technology of bidirectional converters and practical limits of residential service could support. Efforts are being made to modernize this concept in terms of Wireless charging i.e. IPT and implementation technologies such as AMI and RESs and also in reducing the problems related to harmonics [3]. Along with Non Linear Pricing, another potential use of PHEVs is the supply of reactive power to the grid. The PHEV power inverters could also adjust the power factor coming from the vehicle to allow reactive power support to the grid [4]. Electric vehicles are capable of providing a set of interesting ancillary services to the grid, in that they may contribute to provide the required storage capacity, that enable use of renewable energy. In addition the individual perspective benefits from the possible revenues from providing these services and constitutes a significant motivation to the EVs owners [5]. Two wheelers, dominate the market with 97-98% of sales occurring for electric bikes, scooters and motorbikes. The impacts of typical smart grid operations such as PHEV charging with charging stations must be assessed for transformer health and performance considerations. Charging stations are expected to be located in residential and light commercial areas [6].

II. METERING STRATEGIES FOR V2G

The AMI(Advance Metering Infrastructure) includes supporting Hardware and Software ensuring the measurement, storage and processing of consumption data of end user integrating electricity, gas, water and heat meters. It is interaction with the consumer using different types of interfaces as well as interaction with service provider, using communication system. The AMI concept is often associated to other terms like smart metering. Smart metering will lead to opportunities to make PHEVs a controllable load, to apply vehicle-to-grid (V2G) and to combine PHEVs and renewable energy in the network [6]. The first, a basic version of the smart meter, will include all the necessary functionalities to cope with the less demanding charging approaches, i.e. the DC and the MPT, in domestic\ environment. The second, an advanced version of the smart meter for home charging, will incorporate enhanced functionalities in order to deal with the more elaborated charging strategies, i.e. Smart Charging (SC) and V2G. The third, an advanced smart meter for public charging points, has the same vehicle management functionalities, but with less complexity as it does not have to control household related appliances or micro generation units [7].

III. SMART CHARGING AND DISTRIBUTION NETWORK SYSTEMS

Most existing systems use a 'hard-wired' power interface to couple the EV to the grid but such systems pose many disadvantages. For this reason, the technique of inductive power transfer (IPT) technology has been widely accepted for numerous industry applications [7]. IPT system under various operating conditions indicate that the proposed bidirectional contactless power transfer concept is viable and can be used in applications such as V2G systems to charge and discharge electric or hybrid vehicles, which are connected to the power grid [14]. The electric vehicles in the V2G service are not only mobile distributed loads but also mobile distributed generations for Indian market. The effective operation of V2G depends on the grid scheduling and control system. The tradition distribution network is radial structure and a single power supply, and the protection of distribution network is designed on this basis. The structure of distribution network will be changed when the distributed powers access to distribution network. The distributed power will provide fault current in addition and change the node short-circuits value when the distribution network failure, which will affect the correct operation of the protection unit. The other problems include power quality; reliability influence and islanding detection are also need a further study [13].

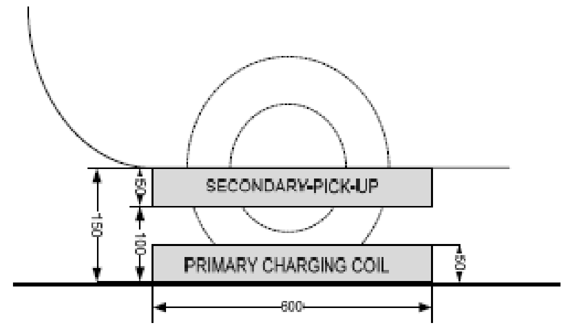

Fig.1. IPT System Physical Layout [7]

IV. EFFECT OF RENEWABLE ENERGY SOURCES FOR CHARGING

The Cost and emisssion reductions in a smart grid are worked out by maximizing utilization of EVs and RESs(Wind and Solar energies can turn out to be beneficial in the ratio of 2:1 for urban places) [8]. The load levelling model as follow :

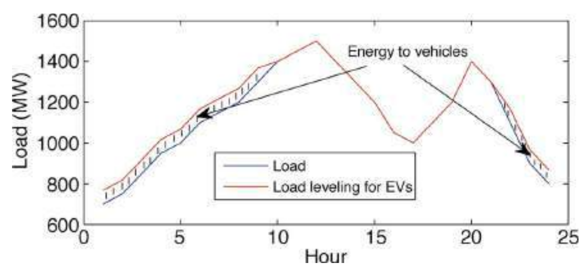

Fig.2. Load leveling for EVs [8].

1) Line 1 (load-leveling model): EVs are charged through conventional generation using load-leveling optimization

2) Line 2 (smart grid model): EVs are charged from RES**s** as loads and discharged to the grid as sources.

The charging of PHEVs has an impact on the distribution grid because these vehicles consume a large amount of electrical energy and this demand of electrical power can lead to extra large and undesirable peaks in the electrical consumption. The improvements in power quality are possible by using coordinated charging. Un-coordinating the charging of PHEVs will require expensive grid improvements and more peak power plants. Demand side management can minimize the impact of charging and may curtail some of the costs of UC. The coordinated charging method offers the PHEV user many advantages: low electricity cost under the constraint of maximum electrical driving share; while at the same time offering electricity producers, transmitters and distributers advantages too: no extra peak demand, more base load and less variable load. Smart meter technology can be used for implementing coordinated charging [8] .

Parameters	Without PHEVs	Uncoordinated Charging	Coordinate Charging
Load(kVA)	40	56	40
Line Current(A)	182	266	183
Node Voltage(V)	213	207	213
Power Losses(%)	3.1	4.4	3.8

Table 1. Coordinate and Uncoordinate charging

In the case of uncoordinated charging, this limit has been reached and action must be taken to reduce the voltage drop. The problem of the voltage drop can be tackled by placing a capacitor bank or an on-load tap changing transformer although the latter is not common at low voltages, but may be necessary in the future [10] .

V.DEMAND SIDE MANAGEMENT

Demand side management describes the planning and implementation of activities designed to influence Indian customers in such a way that the load shape curve of the utility company can modified to produce power in an optimal way. The selling of power is different from the selling of other items because power cannot be stored. Power has to be generated at the time it is needed or demanded by the consumer. Power curves or load curves are used to help power companies to determine power demands at certain times of day. These power curves are accurate, but there exists a certain margin of error, which is referred to as the margin of operation. Power companies strive to keep this margin as low as possible because this energy produced is never utilized. The following demand-side management techniques are popular at the present time all over the world [12].

- Modifying the Power Curves
- Reducing the Lighting loads
- Replacing the Motors
- Improving HV AC
- Smart Home Automation System

VI. IMPACT ON TRANSFORMER LOSSES

PEV charging stations are sizeable nonlinear loads because of their large rating ac-dc power conversion electronics. The resulting current harmonics can cause abnormal operation in transformers such as additional losses, reduced efficiency, temperature rise as well as premature insulation and windings failure. This could significantly impact the reliability, security, efficiency and economy of newly developing smart grids due to possible transformer outages and loss of transformer life. In order to accurately investigate these problems, a highly detailed nonlinear three-phase three-leg transformer model is implemented for this study [9] .In the following fig.3 it is assumed that the charging station is supplied from a step-down 25 kV/575 V mains distribution transformer rated at 2 MVA (Fig. 3). A large power diode rectification unit with the same rating is assumed to convert ac power into dc power necessary for battery charging. A common dc bus is assumed to supply up to 8 rapid charger units. Therefore, the maximum number of PHEVs arriving at the charging station is limited to 8 PHEVs, or in to a conventional fuel station. Furthermore, in reality, the rapid charger units will be of similar dimensions to conventional fuel pumps. In the modelling, the rapid charger units are lumped together as a single variable resistive load connected to a three-phase rectifier circuit applied by the nonlinear transformer. An active rectifier may replace the diode rectifier to draw sinusoidal unity power factor line current or a power quality compensation device (e.g., active filters) may need to be installed in parallel to the charging station to cancel the harmonics from the diode rectifier.

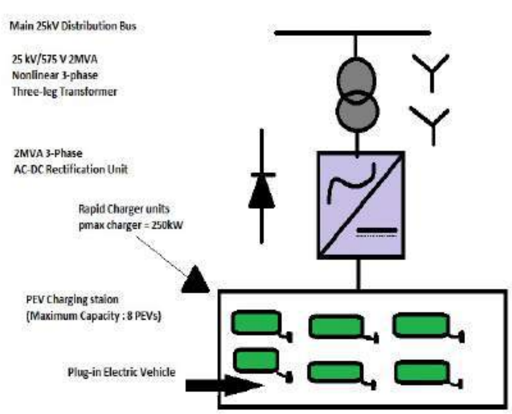

Fig.3. Nonlinear Three-phase three-leg Transformer model.

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VII. IMPACT OF HARMONICS ON TRANSFORMERS

The battery chargers for PEVs have high ratings and employ nonlinear switching devices which may result in significant harmonic currents injected into the distribution system [9] . Derating is defined as the intentional reduction in load capacity of a transformer operating under non-sinusoidal conditions. Derating of transformers is necessary because of additional fundamental and harmonic losses generated by nonsinusoidal load currents which cause abnormal increases in transformer temperature beyond rated operation. Transformers can suffer age reduction and premature failure due to resulting thermal stresses in the windings and core structure. The main methods for estimating transformer derating are: K-Factor , Harmonic Loss Factor , online harmonic loss measurement and computed harmonic losses. **K-Factor** derating is applied to determine the amount of load that must be curtailed or reconfigured to minimize harmonic losses at the transformer. K-Factor derating is proposed as an effective smart grid control parameter to control harmonic rich loads (Curtailment/penalties/incentives), which ultimately reduces distribution system harmonics losses, and prolong transformer lifetime.

VIII. DISTRIBUTION MANAGEMENT STRATERGY

When the number of vehicles participating in V2G reached a large-scale, it will cause certain influence to the safe operation of the distributed network if completely relying on the response of the vehicle on the load side. At the same time, it is obvious difficult for the regional dispatch centre to dispatch each vehicle [10]. Dividing the dispatch strategy into two parts: the dispatch strategy of regional dispatch centre--V2G station, and the dispatch strategy of V2G station—vehicle, shown as fig.4. The PHEVs has a higher capacity battery that is initially charged through an electric outlet, maximum use of this battery should be done to reduce the Fuel Consumption. So in this strategy the maximum power is drawn from battery via motor to drive the vehicle and the Engine for sustainity of V2G provides the rest of power.

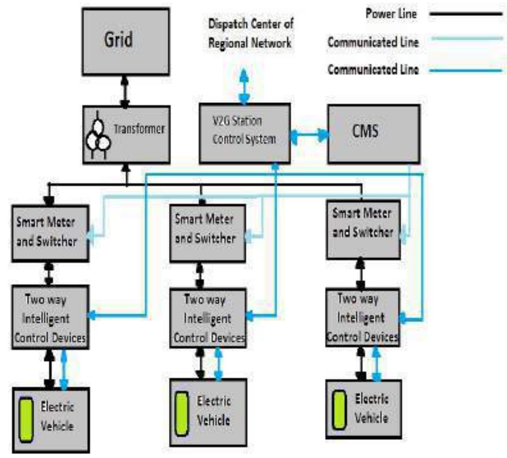

Fig.4. The topology t in V2G station

IX. ROLE OF GRIDABLE VEHICLES FOR INDIAN POWER SECTOR

The cost of batteries is comparatively high and limited driving range is a concern. However, battery technologies and capacities are rapidly improving and costs are expected to fall as the technology gains acceptance. Several car manufacturers such as Nissan, Mitsubishi, General Motors and Chevrolet have recently begun to roll out Plug-in Hybrid Electric Vehicles (PHEVs) from their production lines all over the World [10]. But according to the Indian scenario, the insertion of 4 wheelers in Transportation market needs much more advancement in terms of acceptance tendency of people. According to the economic levels of residents of India, the insertion can be implemented in 3 steps,

Step1- 4 wheelers GVs for higher class.

Step2- 2 wheelers GVs for higher middle class.

Step3- electric bicycles for lower middle class.

Almost 60% of Indian Population can afford this type of 2 wheeler (EVs). For normal people, if the distance to be travelled is in nearby vicinity or the area of transportation or working is less, rather than using GVs 4 wheelers, it is more economical to use 2 wheelers. For launching of GVs in India, first of all GVs and charging stations should be introduced in metropolitan cities like Delhi, Mumbai, Bengaluru, Chennai, Ahmadabad. Then according to the response of costumers, it should be introduced in other cities also. But 2 wheelers can be introduced in every part of India at this point of time. These vehicles are easily adoptable since size and capacities of them are comparatively lesser. Introduction of 4 wheelers will need new charging stations and modification in discharging system in the grid. Every bike will contribute 1-2 kW in the grid. This will help in Demand Side Management by reducing the overall demand by homes from the grid

X. CONCLUSION

The operational consumption could be sufficiently covered by the revenues that are associated to provide energy stored in off peak periods to the grid in peak power demand periods. PEVs have great potential when simply parked in the home garage or at work plugged into an outlet providing grid support. This technology has the potential to reduce and even eliminate our dependence on foreign oil, greatly reduce greenhouse gas emissions, and save large amounts of money for transportation. This issue needs to stay at the top of the list and is critical to our future energy independence. Furthermore, real-time pricing, and purchase and sales rates have to be considered in the scheduling, control, and optimization of GVs in a smart grid. The need for derating of the transformer is used to overcome the detrimental effects of temperature rise and additional losses from current harmonics injected by charging stations. Active rectifier may replace the diode rectifier to draw sinusoidal unity power factor line current or a power quality compensation device (e.g., active filters) may need to be installed in parallel to the charging station to cancel the harmonics from the diode rectifier. Smart meter AMI technology can be used for implementing coordinated charging. The impact of smart grid load management of high penetration of PEVs operating during peak load time is shown to have significant benefits in reducing transformer loading and minimizing harmonic losses Charging PEVs off-peak showed a reduction in *K-Factor*, however, there were still significant current harmonics generated to warrant further load curtailment action.

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Best Practices in Smart Metering Policy and Implementation

An international experience and learning for India

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Many countries throughout the world have embarked on a journey of mandating or encouraging the roll out of advanced and smart meters. Smart and advanced metering provides an opportunity to transform supply and consumption of electricity on a pan-country level. The paper strives to present the best practices derived from experiences of various countries for improvements in smart metering policies and smart meter roll-out. India being a nascent entrant can gain immensely from this experience to formulate an effective smart metering policy.

The study draws out learning from these international experiences from South Korea, the USA, the EU, and India on peak demand reduction, load management, advancements in transmission systems improvements, supply security billing improvements, reduction of theft and fraud and data management and security issues. These findings are correlated to the Indian conditions and for the specific requirements of the Indian power market. The paper can also be used as a ready reference by Bureau of Energy Efficiency and Ministry of Power to roll-out policies pertaining to smart and advanced metering, energy efficiency, and demand side management.

Keywords—Smart metering policy and implementation, international experience for smart metering, smart metering- risk, barriers, and benefits

INTRODUCTION TO SMART METERS

What are Smart Meters? It is no single technology or design, but an all encompassing term used to describe upgraded versions of the traditional meters. Similarly, Smart Metering is the technological upgrade of conventional metering systems deploying communication of real-time data from the consumer to the utility and in some cases vice versa. This enables both the parties to manage consumption and demand, reduce non-technical losses (cases of theft), demand side management (DSM) resulting in overall increased efficiency, progressive billing, cost savings, etc. In simple terms, smart meters can be considered as mainstream meters with electrical infrastructure retrofitted with information infrastructure (data communication abilities). Smart metering can be done for any utility e.g. gas or water, however, the paper restricts itself on power metering. (Refer Figure-1)

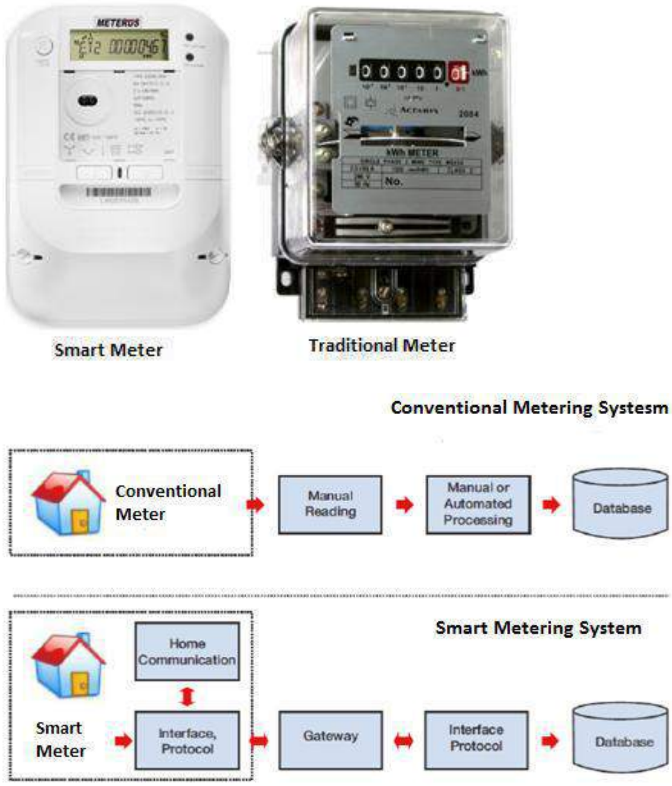

Figure 1: Smart metering vs. Traditional Metering

Nations across the world have set ambitious targets of installation smart meters. Smart meter roll-out in every country depends upon its own long term and imminent problems, national goals, techno-economical needs and development strategy. In line with these targets, each country has its own policy framework. The paper draws out experiences from the success and extent of roll-out of smart metering in South Korea, the USA, the EU, and India. This paper maps the key drivers, enablers and challenges of smart metering in each of these countries to draw out learning and potential solutions for the Indian power sector.

KEY DRIVERS FOR SMART METERING IN INDIA AND INTERNATIONAL EXPERIENCE

The following section lists down the key enablers for deployment of smart metering solutions in the Indian market. Each of these enablers is mapped with a nation/region and lessons are derived from the corresponding country experience.

Rising demand for power and Load Management

India experiences hasty changes in peak demand which varies steeply with changing industrial landscapes, geography or time of the day. The demand- supply gap of electricity can be as high as 12159 MW (8.98%, 2012-13) (CEA). In this scenario supply management not only becomes difficult but costly too. An opportunity is provided by smart metering to introduce solutions to modify or influence at the least consumption patterns. This is done by introducing measures such as time varying tariff or offering incentives for low usage which in turn help hedge the electricity supply. Managing the peak power supply helps in lower the investment in the grid due to a corresponding decrease in standby peak generation requirements.

California, USA has been a pioneer in time based tariff and other forms of demand response management. Power utilities in USA (California) use smart metering as a means to introduce varying price based tariffs to provide information to encourage customers to alter their demand pattern during different periods of the year and day to reduce peak power demand and for better load management. California is investing $2.8 billion through its power utilities to roll out smart metering solutions to manage their load efficiently. The figure below presents the impact of Price on hourly load (central valley area of California, summer 2003/04) is presented in Figure-2. The corresponding effects are demonstrated in the Figure-3.

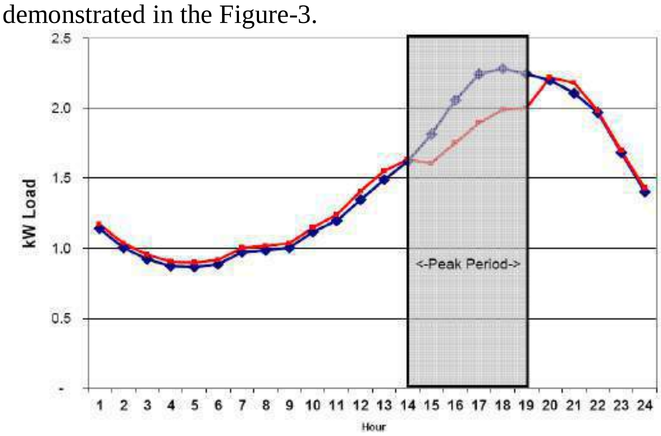

Figure 2: Impact of price on hourly load summer, California, 2003/04

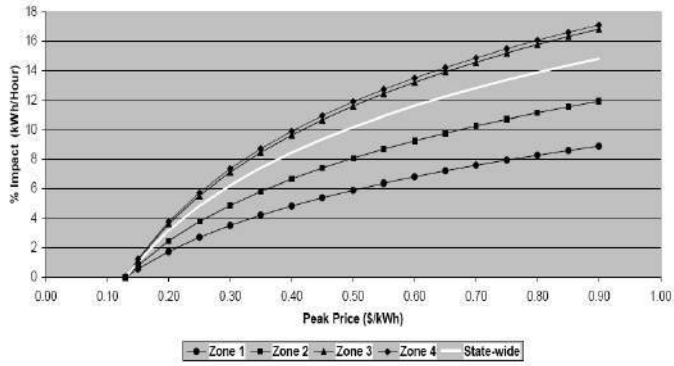

Figure 3: Percent Reduction in Peak-Period Energy Use on Critical Days Average Summer, California, 2003/04

Similarly, in Australia, high use of air conditioning systems has lead to significant peaks in electricity consumption and the peak is increasing at 3% a year. This has led to high supply costs on hot days and risks that the supply infrastructure cannot serve demand requirements. Currently 20% of available capacity is only used 10% of the time and with a flat tariff rate for residential customers this means that those without air-conditioning are subsidizing those that have it do by up to $205pa (Stromback 2010).

Pilot Trials on Demand Side Management demonstrated Reductions of 4%-8% with potential for further reduction up to 16% if time of use (TOU) tariffs and critical peak pricing (CPP) is introduced.

ETSA Utilities is an electricity distributor in the State of South Australia. ETSA developed a trial of residential air conditioner cycling in 2006-07 to assist with the summer supply/demand imbalance coupled with an extremely peaks in load profile of South Australia (Crossley 2008). The utility deployed direct load control device which was attached the compressors of 750 air conditioners across a selected consumer base. Pre-defined switching period were set. The results are demonstrated in the Figure 4

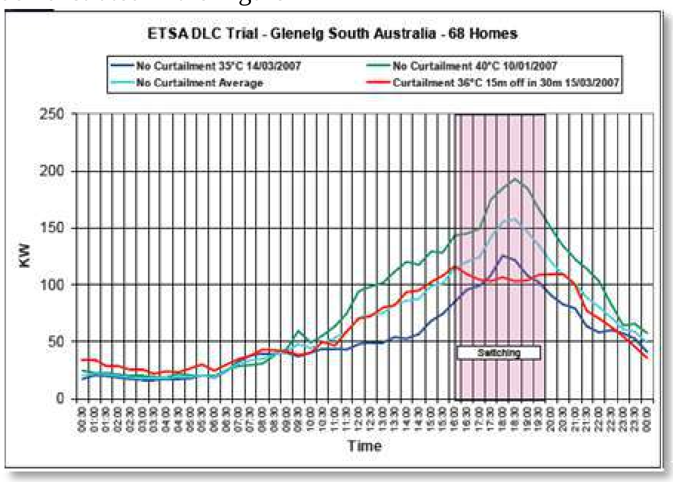

Figure 4: Impact of Load Control on Peak Demand. From Crossley (2008)

Cost effectiveness

Smart metering offers a choice to the consumer to save on power bills by the virtue of the ability to modify their power consumption with respect to the time based tariff. E.g. in case the tariff is highest in morning, the consumer can modify his electricity consumption such as washing, vehicle charging etc. to afternoon, where say, the tariff is low.

Cost Benefit Analysis

Deployment of nation-wide smart metering requires a proper quantification and deep understanding of the costs that the exchequer will bear. It is prudent to carry out a detailed cost-benefit analysis. South Korea has set up extremely high targets for smart grid roll-out. The country has formulated Smart Grid Law which aims to set up a nationwide smart meter electricity network by 2020. It has been estimated that development of the smart grid by 2020 would generate a new market worth approximately $54.5 billion annually and creating 500,000 jobs resulting in almost 1 job for every 50 new meters. The smart grid also been estimated to reduce the county's power consumption by 3% (Stromback 2010) with a saving of $10 billion a year in energy imports.

The Government of Australia (State of Victoria) in 2007 regulated a smart meter roll-out for customers in the next two years. A cost benefit analysis assessment was undertaken before the roll-out program which estimated savings of $2.7 billion to $4.3 billion in NPV terms over a 20 year period. A 26% drop in peak demand was expected as a result of compulsory time based utilization (TOU) (Stromback 2010).

Non technical losses

Non-technical loss is an umbrella term used for losses incurred due to theft, non-payment of bills, other unbilled consumption and, illegal connections. Some African countries incur losses to the tune of 50% of supply (Smith 2010). In India annual losses are estimated in the billions of dollars (World Bank 2009). The ultimate looser in this case is not only the utility but also the consumer (and non-consumers) who pays more in lieu of these losses. Smart metering and communication infrastructure can improve the accuracy of billing and the identification of where consumption is being used and lost.

Italy was one of the first countries in Europe to roll out smart meters on a large scale with energy supply company ENEL taking the lead in 2001. By the end of the decade, ENEL implemented more than 36 million smart meters (Renner 2011). ENEL collected its customer data and managed the energy network remotely, identifying the cases of theft and resolving them. The consumer data on power consumption allowed Italy to successfully combat power theft. ENEL reports that they have seen a total annual savings of $750 million from the installation of their smart meters (DNV Kema). Brazil is another such country which has been facing power losses as high as 20% due to theft resulting costing suppliers approximately $2-3 billion annually (Stromback 2010). Brazil is in the process of roll-out of 63 million smart meters by 2021 to fight off non technical losses.

Similar to Brazil, India has vastly varying geography; the implementation of smart metering in Brazil will give a fair idea of how the Indian market will respond.

Power efficiency and technical losses

The high degree of power management and increased power efficiency provided by smart electricity metering is expected to positively impact the industry. The ability of smart meters to record interval based power data over any timescale results into better power management. This information when relayed to the consumers enables them to align their power consumption accordingly. Smart metering can result in energy savings to the tune of 5 to 12% (ESMA 2008, ACEEE 2010). Similarly, energy savings for small business can range from 5% to 12% (Carbon Trust 2007). Optimal use of energy also results in low carbon release.

Environmental benefits

Power production and generation in India has a huge impact on climate change as 70% of the country's power comes from CO_2 intensive coal based power plants. Moreover, the country is on the path of investing into new power plants to meet its rising power demand and to upset the 30% AT&C losses and power peak deficits soaring as high as 12%. Moreover, the total demand gap from April 2011 till Nov 2011 will result into 69,000 Million Units (CEA 2012). If this deficit is met using additional coal based power plants will result into 59 million tonnes of CO_2 annually which is about 2.8% of India's overall GHG emissions (DNA India). Smart metering can result in T&D loss reduction, increased demand side efficiencies and optimal generation. Under these circumstances the onus to float climate change friendly policies lies with the government.

The United Kingdom has in its bid to combat climate change has formulated the UK Climate Change Act which sets out to reduce UK's GHG emission to at least 80% below 1990 levels by 2050, with the underlying assumption that overall demand for electricity may double by 2050. UK has mandated the roll out 50 million electricity and gas meters by 2019 to residential and small businesses. The UK Government undertook a detailed CBA on small consumers (small business and residential) which shows the Present Value total costs of $17.7 billion, total benefits of $29.1 billion with a total positive net present value of $11.4 billion*(DECC 2011a)

Favorable policy and regulatory framework

Smart meter deployment varies greatly from region to region, some countries have adopted mart metering as early as 2001, while countries like India are in a nascent stage. The vast gap between smart meter roll-out is contributed by vastly different policy and regulatory landscape across the world. North

America and EU had witnessed a boom in smart metering in the last decade; the same is projected for the Indian economy.

EU's Electricity Directive in 2009 requires all member states to have 80% of consumers fitted with smart meters by 2020 and full deployment by 2022. (Robinson). Sweden passed a legislation which required hourly metering for customers over 63 Ampere before 200 Ampere and monthly meter reading of household customers from July 2009

CONCLUSIONS

The key enablers and barriers for smart metering varies widely with the nation/regions' national interests, policies or targets. These can vary from increasing power efficiency, technological improvements, macro level instrumentation, and introduction of interoperability or inter-connectivity. Smart metering has been in commercial practice since the early 2000s, starting from EU to most of the developed countries. This presents a unique opportunity for India to learn from international experience. A snapshot of the key learning from the international experience is presented below. (Refer Table-1)

- Favorable regulatory and policy landscape
  - The onus for wide scale smart meter deployment should lie with the government which should be supplemented with political and regulatory support from all the concerned stakeholders.
- National standard for smart metering
  - A national standard should be prepared for large scale roll-out of smart meters in India. If necessary a separate standard shall be prepared for different geographies across the country.
  - Favorable policies should be rolled-out for successful implementation of smart metering benefitting both the government/utilities and end-user
- Developing market for smart metering
  - Smart Metering Pilots: As of now, smart meters have not been extensively tested in emerging economies; Brazil offers an insight into this. Despite its smart metering program is new, it has provided valuable insight as to how the Indian market will behave. The country also proves that smart metering have a place in emerging economies across the globe.
  - National level smart gird deployment should only be undertaken after the results from CBA are favorable
  - The smart metering is a new entrant to the energy market which means huge business development potential. The market can be expanded internationally after achieving domestic success.
- Essential Management practices
  - Customer Feedback Mechanism: A customer feedback mechanism and demand response system should be integrated with smart meters.
  - Central Data Base Management: The central data base management should be able to cope up with large amount of data.
  - Time Of Use tariffs: It is prudent to educate the customers along with the roll-out of TOU tariffs. Australia witnessed wide-spread criticism when consumers were exposed to the highest electricity tariffs due to them utilizing power during the peak hours.

Table 1: Smart meter drivers and results across various regions **Error! Bookmark not defined.**

Nation/ Region	**Key Drivers**	**Meters installed/ targets**	**Cost sharing pattern**
Italy	Electricity theft	36 mill by end of 2011 Almost completed	Consumer
Sweden	Monthly meter billing Easier change of supplier	1 mill meters Completed in July 2009	Consumer
Spain	Compliance with EU Directives Liberalise market-join with Portugal	Over 15 mill by 2018 15-20% completed	Consumer
UK	Energy savings Carbon reduction Security of supply Rising energy prices	53 mill by 2019 Limited installation at present	Consumer
Brazil	Theft reduction	63 mill meters by 2021	Utility – in discussion
South Korea	Expand export market Smart grid development security of supply	24 million by 2020 Currently 1 million meters	Utility
USA (California)	Peak demand reduction	Roll out to 11.2 mill customers by 2012	Consumer
Australia (Victoria)	Peak demand reduction	2.4 mill by 2012 Extended to 2013 due to implementation issues	Consumer
Canada (Ontario)	Reduce energy costs Reduce peak demand	4.3 mill by 2010 Completed	Consumer

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Carefully designed Smart Grid / Metering programs can resolve developing world's unique challenges

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Abstract— **The objective is to showcase how carefully designed Smart Grid / Metering (Smart) projects can resolve some of the challenges faced by the utilities in developing economies. Such projects are already being rolled out in America and more recently in Europe. Their drivers for "Smart" are network optimization, reduction in energy consumption and operational costs, enablement of EVs and micro-grid, in many cases policy thrust has been a strong driver despite weak business case.**

In contrast to the developed countries, the challenges in developing economies are around effective billing, load management, theft reduction, cash collection, customer satisfaction etc. If properly designed, a smart program can help the utility face many of these challenges. For example, smart meters can be configured to send alerts upon unauthorized access to meter and tampering. Analytics can be used to monitor household consumption, score consumers and based on certain logics on consumption patterns can highlight meter by-passing. They can also be used to remotely disconnect customers upon non-payment of dues. The information provided by smart meters can be processed and displayed to the customer though an interface unit or through a web-portal. Thus consumers can have more visibility and control over their electricity consumption.

EY has experience of over 40 global projects (across the world), but at this event we wish to showcase few examples where Smart is used as a Service which includes innovative models for funding, implementation, operation & transfer. One such implementation that EY is leading in South Africa which is helping utility to substantially reduce losses.

The paper also discusses the factors impacting the ease of adoption of smart. Policy framework robustness, supplier eco-system completeness, role of "prosumer" are all pivotal for a successful smart implementation.

Keywords— smart grid, smart metering, smart grid design, global smart grid projects, policy framework, customer engagement, societal impact, developing economies

I. INTRODUCTION

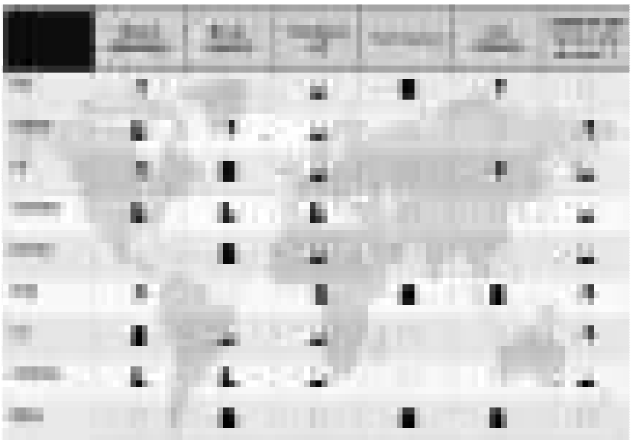
The electricity grid has traditionally been static – transporting electricity from centralized power plants along transmission and distribution lines to consumers. Modernization through a series of technological advances has created a smart grid that uses digital technology to provide information to both customers and utilities in real time to help manage and optimize the efficient use of power [1]. Smart technologies are modernizing energy systems and bringing massive change to the industry, consumers and competition.

Smart meter deployments have slowed down in the US as the central funding for the projects has now been nearly exhausted. The focus has now moved to projects in Europe and Asia Pacific. Smart metering activity is increasing in Western Europe – primarily Spain, France, and UK have projects underway or about to begin that will account for close to 93 million new meters by the end of 2020. In Asia-Pacific China is installing large number of smart meters as part of plan to upgrade electricity infrastructure and Japan is expected to account for almost 80 million smart meters [2].

While utilities in the developed world understand what value smart grid can unlock for them, developing countries are trying to understand how this technology transformation can help them fight some of challenges they face. How effective are smart interventions in environments which are different from mature economies? Can we simply copy the design of the smart grid projects from the other countries? These are some of the questions which bother utilities in developing economies before committing themselves to smart grid projects. This paper will try to answer some of these questions by sharing global experiences. The paper will also discuss the challenges experienced by Indian utilities and what can accelerate the pace of smart adoption in India.

II. DRIVERS OF SMART GRID ADOPTION

There can be several drivers which can lead to utilities considering smart grid as a solution. However, each of the drivers can have a different importance to a utility depending on which geography it operates in. The illustration below depicts the relative importance of key drivers for smart adoption across geographies:



Network optimization and Energy reduction are much more important drivers for the developed economies than theft reduction and cash collection. Also, one of the key drivers for them is reduction in operating costs and enablement of Electric Vehicles and Microgrids.

There are a number of benefits smart grid projects can bring to utilities. The major benefits are listed below [3]:

Improve Customer Operations	Costs of manual meter-reading	⇩
	Cost of special meter visits	⇩
	Cost of Disconnection and Reconnection	⇩
	Customer complaints	⇩
	Customer contact volume	⇩
	Faulty meters	⇩
	Cost of billing operations	⇩
Improve Distribution Network Operational Efficiency	Field force cost efficiency of asset maintenance	⇧
	Field force cost efficiency of outage response	⇧
	Prioritization of outage restoration by lost revenue impact	⇧
	Operational costs of network planning	⇩
	Grid Stability	⇧
Defer Distribution Capital Expenditures	Asset failure	⇩
	Deferred Distribution capacity investments	
Revenue Protection	Non-Technical Losses	⇩
	Technical Losses	⇩
	Cost of client compensations from outages	⇩
Improved Market Efficiency	Cost of energy peak generation / purchase	⇩
	Improved settlement process in the energy market	
Deferred Generation	Deferred investment generation capacity	
Capital Expenditures	Spinning reserves extending the lifetime of current generation assets	⇩
Retail	Provision of new services through upselling and tariff bolt-ons	⇧
	Extended and enhanced advertising opportunities	⇧
	Enhanced Data Broker Opportunities	⇧
	Improved Marketing Efficiency	⇧
	Supplier switching process rationalisation	⇧
	Improved customer engagement and trust in order to reduce churn	⇧
Regulatory	Reduced risk of rate case failure	
	Streamline the rate case process	
	Enhance the new rate design process and the consolidation of existing rates	
	Demand Response Verification	
	Outage Minutes Validation	
	Improved Reliability of Supply (e.g. CAIDI/SAIDI) and thereby increased recovered revenue	
	Facilitation of DER integration	
Environment al Benefits	C02 emission	⇩
	SOx, NOx, and PM emissions	⇩
Improve Generation Operational Efficiency	Operational costs of generation planning	⇩
	Spinning reserves improving the operating efficiency of current generation assets	⇩

III. HOW SMART CAN HELP UTILITIES IN THE DEVELOPING WORLD

The challenges faced by developing countries are different. Typically, the key issues faced are both commercial and technical in nature. They face high amounts of commercial losses attributable to theft, meter tampering and non-payment of bills. On the technical side most utilities are plagued with archaic infrastructure, over-loaded network and low dependence on IT [4] [5].

Most examples of smart grid projects are from the developed economies. However, some developing countries have also commenced their smart journey. One such success story in the making is that of City of Tshwane (Pretoria), South Africa. The municipality of the City of Tshwane was struggling with poor collections and huge arrears on account of non-payment of electricity bills. In addition, there was pilferage of electricity, and power theft was quite rampant in the city. So, it initiated the roll-out of smart meters to all as a part of its smart city roadmap “Smart 2055” [6].

The issue in Tshwane was large amount of debt owing to non-payment of bills by the customers. Thus, it was essential to understand how smart meters can be leveraged to help the

City in ensuring that future revenues are assured. Thus, the project was conceived to be a prepaid smart metering project. This would ensure customers paying the electricity charges upfront. The smart aspect brings in multiple other features like theft and tamper detection, remote connect/ disconnect, real-time remote recharge, SMS and email alerts, online portal to view consumption and the power of analytics. While go ahead with such an ambitious project, it was also required to design the vending system. It had to be ensured that multiple vending options were made available to the customers. The system is designed to have multiple vending options to top-up the customer's balance [4].

Like most other utilities, the City was also struggling with funding the project. Thus, they adopted an innovative business model for the project. The project was structured on a Build-Own-Operate-Transfer model as a 100% off-balance sheet project for the City. The City appointed a service provider which would bring in the entire capital for the project. The service provider was required to fund both the capex and opex of the project. In return the service provider can charge a percentage fee of electricity charges paid by the customers.

The design also included integration with City's existing billing system. The service provider was also required to provide a 24x7 call center to support the customers. In the future, the City may request the service provider to implement demand response with the system and thus the system has been carefully designed to incorporate that functionality with minimum intervention at a later date.

An important component of this project has been customer engagement. Right from when the project was envisioned, the City began to engage the customers through various means. The City organized various stakeholder sessions, roadshows and contests to keep the customers involved in the initiative. The City not only used the offline media but also used radio, TV and social media to reach out to the customers.

While customer is pivotal to the project, another important aspect is the society. While designing such a project, one needs to keep in mind how it can positively impact the society. The project was crafted to create jobs and promote local content. The key areas that project focused on are as follows:

- Livelihood enhancement
- Skill development
- Infrastructure development
- Business climate reforms
- Small business development

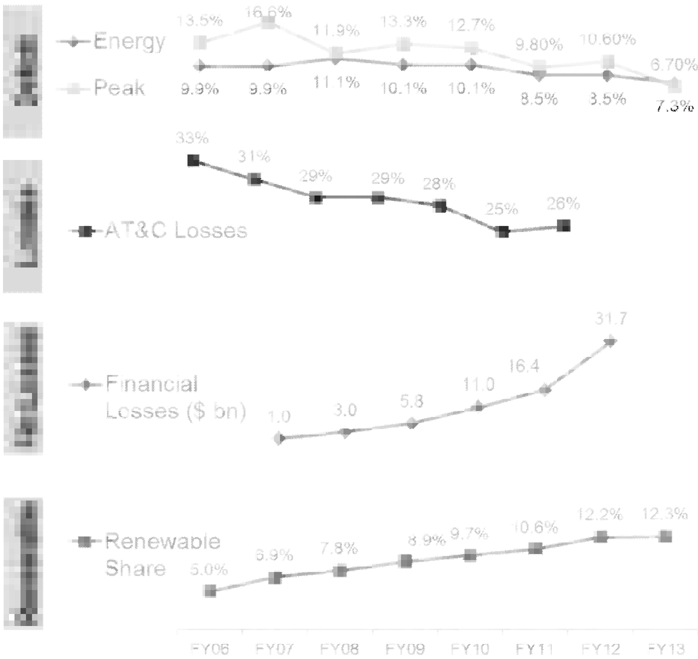
The project aims at developing City of Tshwane as a center of excellence within Africa to have knowledge, skill, manufacturing capabilities and trained man-power to execute the project in Tshwane and anywhere else in South Africa.

The careful design of the project is resulting in success and a considerable percentage of the total electricity charges now flow to the utility through the new smart system. The success of the project was achieved through immaculate planning, design and implementation of the program. The service provider created the right partnerships with funders, communication provider, OEMs and system integrator. The service provider was further supported by technical, financial and legal advisors.

IV. INDIA'S EXPECTATIONS FROM SMART GRIDS

The Indian power sector is facing its unique challenges. Despite generation capacity growing multi-fold there continues to be a demand deficit. There is substantial additional demand for electricity which remains latent due to the unavailability of sufficient power. The demand for power continues to grow and stood at 135 GW at the end of FY13. EY expects the demand for power to grow to 183GW by FY17 and 283GW by FY22[1].

The AT&C losses continue to be high [7] and last few years have not seen any major reduction in these losses. The financial losses of discoms have reached an alarmingly high level. Initiatives taken by the government and the private sector together have been able to increase the share of renewable energy in the overall power generation capacity in the country.



Source: CEA, PFC, MNRE

Increasing power demand, considerable demand-supply gap, high losses and rising share of intermittent renewable power are necessitating investment in Smart technologies in India. The benefits of smart metering which hold more relevance in the Indian context are:

[1] Source: CEA, EY research

Revenue Protection: The Indian utilities suffer from 26% (FY12) AT&C loss [6]. A significant portion of this is commercial loss which is mainly due to power theft, meter tampering, poor billing & collection efficiency. Smart metering can help track power theft in almost real-time and identify areas of leakage. Also, smart metering helps in accurate and timely billing. The technology also enables remote disconnection of defaulting customers.

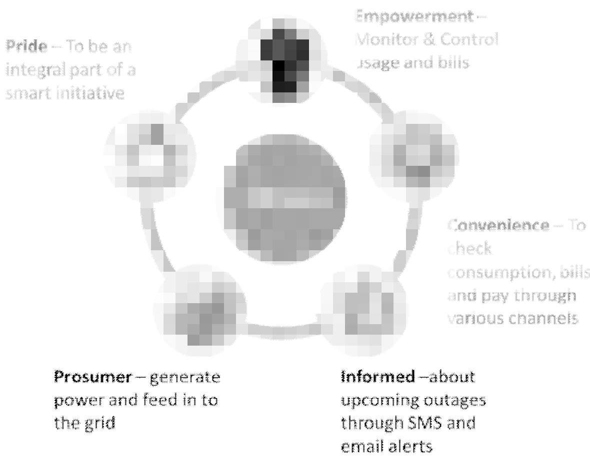
Improve distribution network efficiency: The India utilities rank much lower in power quality than their global counterparts. Smart grids through an outage management system can assist quick identification of outages and a quick resolution through field force. Additionally with increase in renewable energy coming on-stream on the grid, there is more intermittent power available in the grid. High dependence on renewable power can potentially disturb the grid. Thus, in order to integrate renewable power to the grid technologies are required to forecast renewable generation and balance the demand and supply on the grid.

Deferred generation capital expenditure: Smart technologies can help improve the overall balance of the grid and also reduce the losses on the grid. Thus more power can be made available to the end user. What that does is it reduces the requirement to invest in still additional capital expenditure in power generation.

Improved customer operations: Operations is a key area where smart technology can help achieve efficiency and cost reduction. With remote maintenance made available with smart grid this can lead to reduction in number of site visits and thus reduction in the related costs. Again, remote connection/ disconnection can obviate the need for site visits. Meter data and electricity charges can be made available to the customers online and thus some of the customer queries on billing get resolved without the need for them to reach out to contact center.

Other important benefits include peak load management/demand response, improved reliability of supply and reduction in the additional need for spinning reserves. In order to get these envisaged benefits from smart transformation, there are a number of elements which are required as part of the smart grid [6]. The interventions are at various levels of the power value chain and are shown below [8]:

The ultimate beneficiary of all the above interventions is the citizen. These initiatives will go a long way in ensuring good quality and affordable supply to the city's residents. These smart initiatives empower the citizen by providing him access to this electricity consumption and bills at the click of a button. Not only can he view his consumption but the technology will also enable him to view how other similar homes are consuming and ways to reduce his bills by becoming energy efficient. The customer can now be more informed about upcoming outages by the means of alerts on the mobile phone via SMS. Consumers at some point in time may also want to generate some electricity at home using technologies like roof-top solar panels. A smart system will totally enable them to do so and reap the benefits [8].



V. CRITICAL DESIGN ASPECTS OF SMART PROJECTS

It is essential to carefully design the smart project in order to realize the benefits expected from the project. The key drivers and envisaged benefits of the smart project require to be translated to the functional requirements of the project. Since smart projects come at a significant price-tag, the utility should try to make every Rupee of that investment count.

For instance, in Europe, the European Commission has recommended ten common minimum functionalities for smart metering projects in EU. These functional requirements are based on the key elements that are required for smart projects to provide benefits to all stakeholders of the smart project – customer, metering and system operator. The functionalities have also been recommended to enable, in a secure and safe environment, commercial aspects of supply/demand and the integration of distributed generation. The table below provides the functionalities as recommended by the Commission [9].

Consumer	a. Provide readings directly to the consumer and/or any 3rd Party b. Update readings frequently enough to use energy saving schemes
Metering operator	c. Allow remote metering by operator d. Provide 2-way communication for

	maintenance and control e. Allow frequent enough readings for networking planning
Commercial aspects of supply	f. Support advanced tariff system g. Remote ON/OFF control supply and/or flow or power limitation
Security – Data Protection	h. Provide secure data communications i. Fraud prevention and detection
Distributed Generation	j. Provide import/export and reactive metering

In case there are certain additional requirements of utilities, the member states may chose additional functionalities, but the list above is the minimum functionality for smart metering projects across EU.

Based on the functional requirements the technology architecture of the smart grid project is required to be prepared. Based on the coverage of the project the architecture can include the entire value chain from power generation to the meter at the customer's premises. In some cases the architecture can go on to include certain appliances at the customer sites as well. The architecture should be interoperable, scalable, re-usable and modular with appropriate redundancy built into the system to ensure business continuity. Also, cyber security is a very important feature of the technology architecture as information is very critical and cyber attacks can have severe impacts on the performance of the grid.

In addition to functionalities and technology architecture, there are other important design aspects which require the utility's attention. One of the most important design aspects is the business model that the utility wishes to adopt for funding the smart grid project. Utilities across the world are facing the pressure of limited funds, and while they understand the benefits of smart, they are finding it challenging to fund smart grid projects. There are a host of business models utilities can look at – government funded, self-funded, third-party/OEM funded or a hybrid of these. Each model comes with its own pros and cons, and a utility needs to evaluate these before going ahead with any business model.

Another important aspect is the design of customer engagement program. Customers are at the center of any smart project and customer acceptance is the cornerstone of success of any smart grid projects. However, several myths surround smart meter projects. Well-designed customer engagement programs including the use of media, social networking, focus group discussions, engagement sessions, etc. are important ingredients of an effective campaign. What is also essential for developing a successful proposition is a careful consideration of energy consumers' behaviours and needs. Understanding the customer and then acting on that knowledge, is a critical factor in the success or failure of the smart program.

Yet another design aspect is how the utility plans the rollout of the smart project. The utility may adopt a "PoC", "Big-bang" or a "Phased" approach. One interesting example is that of Germany, where EY assisted in determining how to roll-out smart meters to best meet EU requirements. Our analysis showed that a non-discriminate rollout of smart meters to 80% of consumers by 2022 would see the majority of German consumers at an economic disadvantage. Even under the most optimistic assumptions, most households would not recoup the costs of installing and operating smart meters by saving energy. Consumers who use the least power would be the most disadvantaged. Based on our study, we recommended that Germany's smart meter implementation be tailored to four different groups of consumers[2]:

Consumer group 1*: The 15% of consumers that use more than 6,000 kW of energy per year*
Recommendation: Roll out smart meters – if not already in place
Why?: These consumers use the most energy – about 75% of Germany's energy consumption **-** and so smart meters will see them save energy costs while helping the country meet its low carbon targets.

Consumer group 2: *Those consumers that produce combined heat and power (CHP), solar and wind renewable energy– about 5% of all consumers*
Recommendation: Roll out smart meters
Why?: Smart meters will play an important role in managing network congestion caused by over-production of renewable energy. We recommend using metering to limit renewable energy producers to 5% of their annual energy capacity during times of grid congestion. This is critical to mitigate the need for costly grid expansion and is the only way that any German roll-out of smart meters can be economically viable

Consumer group 3: *Consumers in new and renovated buildings – about 10% of all consumers.*
Recommendation: Roll out smart meters
Why?: It is far easier to install smart meters when these systems are considered during the planning and building process. Rolling out the approximately 500,000 smart meters per year required to this group adds security to investors and also ensures that these consumers will achieve energy savings.

Consumer group 4: *The majority of German consumers – about 70% of the market – including smaller businesses and households whose energy consumption is less than 6000KW per year*
Recommendation: Roll out intelligent meters.
Why?: These meters show consumers their actual energy usage via an in-home display (without communicating this to the utility company) and so encourage energy efficiency practices. Installation of these meters is vital if these low-usage consumers are to save energy, costs and enable load

[2] EY research

shifting. Intelligent meters are easily upgradeable to smart meters.

This mixed roll-out delivers tailor-made solutions for a diverse mix of consumers, allowing all end-consumers – rather than just heavy consumers – to save power and reduce energy bills. This roll-out also increases economies of scale and gives the market participants (including device manufacturers, meter operators etc.) the ability to plan ahead with more certainty and less investment risk.

VI. WHERE DOES INDIA STAND AND WAY FORWARD

India has commenced its smart journey. The start is fueled by an initial funding commitment from the center for smart pilot projects. Along with that the government has carved out the India Smart Grid Forum (ISGF) and the India Smart Grid Task Force (ISGTF). Both these bodies are constituted of work-groups to deliberate on various aspects of smart grid. In Aug 2013 the Ministry of Power released the Smart Grid Vision and Road map for India covering the initiatives covering the 12th, 13th and 14th Five Year plans. However, there are a number of interventions which are required in a short-term from funding, technology, supply chain and customer perspective. Below is a list of some of these key proposed interventions that are proposed in the short-term:

Business Case and Finance

Where we stand?	**Interventions**
• Standard DPR preparation by state discoms • 50% center grant for pilot	• Detailed business case (cost-benefit) preparation for commercial rollout

- Prepare standard funding model for commercial rollout: PPP, revenue sharing, benefit sharing, fixed fee, etc.
- Regulatory interventions to draw benefits of smart grids: time of use tariffs, remote connect/disconnect, etc.

Technology & Processes

Where we stand?	**Interventions**
• Smart players, OEMs, s/w providers, SIs piloting in Puducherry • ISGF & ISGTF formed and WGs tasked	• Process design for smart grid enabled environments – remote connect / disconnect, load control, demand response, remote maintenance, theft detection, analytics, etc.

- Technology interventions – load control, peak load management, renewable integration, electricity storage
- Cyber security is an important aspect

Supply Chain

Where we stand?	**Interventions**
• Standardization of meter specs • Appointment of PGCIL as consultant to pilots • PGCIL has initiated SI procurement	• Analysis of supplier eco-systems • Systems to manage field work

- Securing the right delivery partners across the value chain
- Securing meters availability and affordability
- Optimizing the number of installs per day

Customer Engagement

Where we stand?	**Interventions**
• Utilities to self-fund customer engagement • Govt. has identified it as a focus area, but not much initiative	• Design program for Customer engagement • Customer education on benefits of smart meters

- Interactive portals for customers with smart meters
- Change of mindset from “Consumer” to “Customer”
- Engagement of different customer segments
- Design with apt consideration to socio-political factors.

VII. KEY CHALLENGES FACED IN SMART TRANSFORMATION

Managing this transformational effort presents major strategic, operational and technological challenges. Smart grid programs are complex because of the sheer scale of change required and ongoing uncertainties, such as regulation and shifting supplier market offerings. In addition to major logistics issues, there are complex impacts on the energy supply chain, technology and data handling, and the whole customer experience. This presents utilities with multiple new challenges, for which they need to develop new expertise.

Below is a list of key challenges at various mile-stones during the smart journey.

Business Case	► Identification & Quantification of benefits ► Defining boundary conditions – Tenure, Time horizon, Schedule, Regulatory assumptions, macro factors, high level solution design, electricity demand ► Utility data – Level of confidence

	► Access to funding
Solution Design	► Finalize requirements ► Utility readiness ► Technology maturity ► System scalability
Regulations	► Alignment of regulations to achieve program goals ► Remove uncertainty in standards
Procurement	► Finalize technical specifications ► Adequate supplier eco-system
Rollout	► Socio-economic-political factors ► Geographical challenges ► Program Management challenges ► Immaturity of delivery partners
Customer Acceptance	► Customer rejection ► Customer education
Change Management	► Shift from consumer to customer mindset ► Monopolistic to Competitive ► Manual to IT enabled

VIII. CONCLUSION

Traditional power systems are moving towards digitally enabled smart grids which will enhance communications, improve efficiency, increase reliability, and reduce the costs of electricity services. The drivers for going smart vary from geography to geography and from utility to utility. The smart transformation of a utility is best designed keeping in mind the objectives of the utility to embrace smart technology. There are a number of aspects of a smart gird program right from inception to funding, and installation to customer engagement. Each aspect must be carefully designed to achieve the benefits for all the stakeholders for the project.

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Dynamic Energy Management on Smart Micro Grid

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Abstract— **Energy crisis pronounces the demand for the penetration of micro grids onto the legacy grid. Frequency control of the entire power system network will become a big challenge if renewable energy based micro grids penetrate the public power grid in a large scale. Yet, large penetration of such micro grids is the urgent need of the hour to meet the energy scarcity. This scenario demands the presence of a decentralized control in every Smart Micro Grid (SMG) capable of assisting a frequency control by performing Dynamic Energy Management (DEM) on the energy storage systems installed on SMG. DEM is the process of performing charge-discharge transactions on the storage modules to balance the supply-demand gap. This paper deals with the development of a Dynamic Energy Management System (DEMS) which enables SMG to be a complete package eligible to be connected to reduce the burden on the conventional grid. DEMS is capable of handling the supply-demand imbalance in both *Grid connected* and *Islanding* modes. The proposed DEMS employs Support Vector Machine (SVM) in grid connected mode and Fuzzy Logic in islanding mode to address the supply-demand imbalance. As frequency is very sensitive in the islanding mode, in addition to energy storage, Load Management is also performed. Demand Response Program (DRP) is enabled for some of the loads connected to the SMG. DEM Scheme is validated using appropriate computational models for both the modes of operation of SMG.**

Keywords—DEM, SMG, DRP, SVM, FPGA

INTRODUCTION

Penetration of microgrids onto the conventional grid is the present phase of evolution on electric power utility both nationally and globally [1]. Microgrid is the miniature of the legacy grid energized by Renewable Energy (RE) sources capable of meeting the local demands connected to it, partially or fully, in a synchronized manner [2]. Also, introduction of Demand Response Programs (DRPs) among the end-users is becoming an essential requirement to solve the global energy crisis from the demand side [3]. Integration of distributed RE based generation along with facilitation of DRPs on the demand side in a large power grid needs to happen at a micro scale and in a distributed manner as the legacy grid is a centralized complex network which cannot be bothered to a very large extent [4, 5]. The need for an Energy Management System (EMS) is to monitor and control energy production and consumption in generation, transmission and consumer facilities [5]. Performing energy management by introducing new schemes both on the generation and demand sides becomes a responsibility on the microgrid, as the governor control on the conventional grid is centralized and the former is distributed [6]. Whenever there is frequency variation on the grid, microgrid should be capable of taking necessary action to help the grid in balancing the total generation with the total demand. To facilitate this, Energy Storage System (ESS) is generally recommended to preserve power quality based on the frequency diagnosis [8]. The micro grid should have the ability to monitor its operating parameters viz., frequency, voltage, current etc. and then communicate these to a controller for necessary corrective action. The micro grid with real time measurement and communication facilities becomes a Smart Micro Grid (SMG). A SMG can be made to operate automatically through proper Energy Management System (EMS) besides interacting with the main grid as there is a requirement to sustain synchronized operation of all Distributed Generation (DG) schemes and various DRP schemes to maintain the system stability [9]. Several proposals of EMS for energy storage systems and microgrid have been made by researchers worldwide. EMS for energy storage takes decisions (a) to handle the rate of charging/discharging ESS based on the load and generation schedule [10], (b) to coordinate Hybrid Energy Storage Systems [11, 12] and (c) to regulate the storage system parameters [13].

Various wireless communication methods relevant for such applications are discussed in [14] and [15]. To check the operation of an EMS on a micro grid, a constrained/unconstrained optimization model is developed [16] and solved using techniques like integer programming [17] or Genetic Algorithm [18] which are verified either through simulation models [19] or on a physical microgrid system [20]. Multi-agent modeling is also used to realize the operation of the EMS sometimes [21]. Most of the optimization models use soft computing techniques based load forecasting [22, 23]. Micro Grid Central Controllers (MGCCs) developed in [24, 25, 26] are used to handle power flow variations to minimize energy cost and optimize power exchanges with conventional grid. Optimization techniques are used to tune parameters of MGCC which handles frequency excursions on the grid [27]. An agent based EMS is proposed to facilitate power trading among microgrids with DR and Distributed Storage. An index-based incentive mechanism is also proposed to encourage customers to participate in DR and the entire system is validated in a JAVA Agent Development Framework Environment (JADE) [28]. DRPs are beneficial in Home Energy Management (HEM) systems [29] and for power system security enhancement. Need for Automated Demand Response (ADR) and OpenADR protocol used to implement the various DRPs is discussed in [30]. In [31], DEMSi -- simulator for Demand Response is used with a validation in PSCAD and the solution is optimized using Particle Swarm Optimization (PSO).

The control actions performed by the EMS in all the cases cited above are localized with respect to specific problems on the respective SMG. In [32], an EMS control strategy proposed as “Dynamic Energy Management (DEM)” is developed using Support Vector Machine (SVM) to take necessary actions to handle supply-demand mismatch. DEM is stated as “the charge-discharge transactions in the energy storage systems to oppose frequency excursions on the grid in real time environment”. This control strategy is further revised in [33] with inclusion of more number of control actions to handle the frequency changes in all situations. The authors further proposed implementation of Dynamic Energy Management System (DEMS) realized using SVM on a Field Programmable Gate Array (FPGA) platform [34]; also concluded that SVM is better than neural networks in realizing DEM when implemented on FPGA. DEM control strategy is realized using digital logic and implemented on FPGA in [35].

This paper presents the development and testing of a DEMS capable of being fabricated into an IP Core or an Integrated Circuit and can be commercialized on a larger scale which in turn leads to a complete package of a DEM enabled SMG.

DEM SCHEME

DEM, an energy aware scheme shown in Fig.1, houses a DEMS capable of monitoring the status of the SMG at regular intervals and take necessary corrective measures that control the charge-discharge transactions of the energy storage systems in real time. The following energy storage schemes are added to the SMG to aid in the implementation of DEM Scheme – (i) a Pumped Hydro (PH) storage unit operated through Variable Speed Drive (VSD), and (ii) a battery bank interfaced through a Charge Discharge Controller (CDC). DEMS activates the VSD to increase or decrease the speed of the motor in the PH unit, or, it activates the CDC to perform the charge-discharge transactions on the battery based upon the decisions.

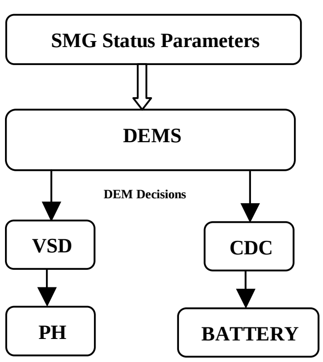

Fig.3. DEM Scheme

Qualitative analysis is carried out in deciding the status parameters of the SMG and these are listed in Table I. The status parameter values are independent of the size of the power system network. Based on the Status Parameters, DEMS takes a decision on charge/discharge transactions to help the grid maintain the energy balance. DEMS is so designed that it can handle the SMG in both grid connected and islanding modes of operation.

TABLE I. SMG PARAMETERS

Parameter	Definition	Conditions
S_{W1}	Status of power exchange between main grid and SMG	1: Power is imported from the grid; -1: Power is exported to the grid; 0: No power exchange;
S_{W2}	Status of power load demand on SMG	1 : Power is consumed; 0 : Power is not consumed;
S_{W3}	Status of power flow to PH	1 : Power is delivered; 0 : Power is not delivered;
S_{Ic}	Status of battery charging	1 : Charging; -1 : Discharging; 0 : Disconnected;
S_{SOC}	Status of State of Charge of the battery	1 – Fully charged; 0 – To be charged; -1 – No Charge;
$S_{\Delta f}$	Status of frequency error	1 : f < 50Hz -1 : f > 50 Hz 0 : f =50Hz;

The DEM decisions in Table II for the grid connected mode are based on all the six status parameters mentioned in Table I. These actions are decided based upon the control operations of the storage elements and the related charge-discharge transactions. On the contrary, in the islanding mode, the frequency of the SMG is very sensitive which makes its operation more critical and challenging. SMG should be capable of meeting the local demand fully with the help of storage modules in this mode. It is evident that the decisions in the islanding mode are pronounced by the critical status parameter – the frequency.

TABLE II. DEM DECISIONS IN GRID CONNECTED MODE

Class	DEM decisions
1	Maintain statusquo
2	Increase charging of PH
3	Decrease charging of PH
4	Charge the battery
5	Discharge the battery
6	Increase the speed of PH and charge the battery
7	Decrease the speed of PH and discharge the battery

TABLE III. DEM DECISIONS IN ISLANDING MODE

Class	DEM decisions
1	Maintain statusquo
2	Charge the battery
3	Discharge the battery
4	Adjust the speed of PH
5	Perform Load Management
6	Charge the battery and perform Load Management
7	Discharge the battery and adjust the speed of PH

As a result, the DEM decisions in the islanding mode are decided based on the present frequency and the frequency trend which are listed in Table III.

Apart from the charge discharge transactions related to storage elements, Load Management (LM) becomes essential in islanding mode to manage the frequency imbalance. At low frequencies, priority is given to decrease the speed of PH motor and upon persistence of low frequency, PH motor is switched OFF and LM is performed. On the contrary, at high frequencies, priority is given to LM module which ensures all consumers are connected to the SMG and once this is achieved, the speed of PH motor is varied to maintain the supply-demand balance.

SMART MICRO GRID SIMULATOR (SMGS) – A TEST BED FOR THE REALIZATION OF DEM SCHEME

DEM Scheme can be realized only on a SMG where the required real time operational data are continuously monitored and analyzed. Fig.2 shows the bus diagram of a SMGS employed to realize the DEM Scheme. The SMGS is energized by distributed generators: (i) Micro Hydroelectric Power Plant (MHPP) ii) Wind Power Plant (WPP) and (iii) Solar Power Plant (SPP). ESSs such as Battery storage with CDC and PH unit with VSD are connected to the SMG. Table IV shows the actual and downscaled specifications of all the components present in the SMGS. The RE sources together meet the power requirement of the consumer load centre, sometimes fully and otherwise partially owing to fluctuations in solar and wind power inputs.

TABLE IV. SPECIFICATIONS OF MICROGRID, DISTRIBUTED GENERATORS AND ENERGY STORAGE SYSTEMS ON SMGS

S.No.	Component	Field Size	Downscaled size
1.	MHPP	5MW	1kW
2.	SPP	$0.625MW_p$	$600W_p$
3.	WPP	6MW	1.5kW
4.	PH Unit	2.5MW	300W
5.	Battery	375kWh	24V,300Ah
6.	Local Load	10MW	2kW

The storage capacity of PH is larger than battery whereas the latter operates faster. The MHPP is assumed to have no governor control; it works on a predetermined schedule. Load forecasting and weather forecasting are performed using available intelligent techniques and made available to schedule the load dispatch of the MHPP. The PH unit lifts water from the lower reservoir at the tail race of MHPP to the upper reservoir. DEM helps frequency regulation by controlling the charge-discharge transactions of the connected ESSs in real time. The frequency parameter demands the presence of such different ESSs, in the power system for its fine and coarse tuning.

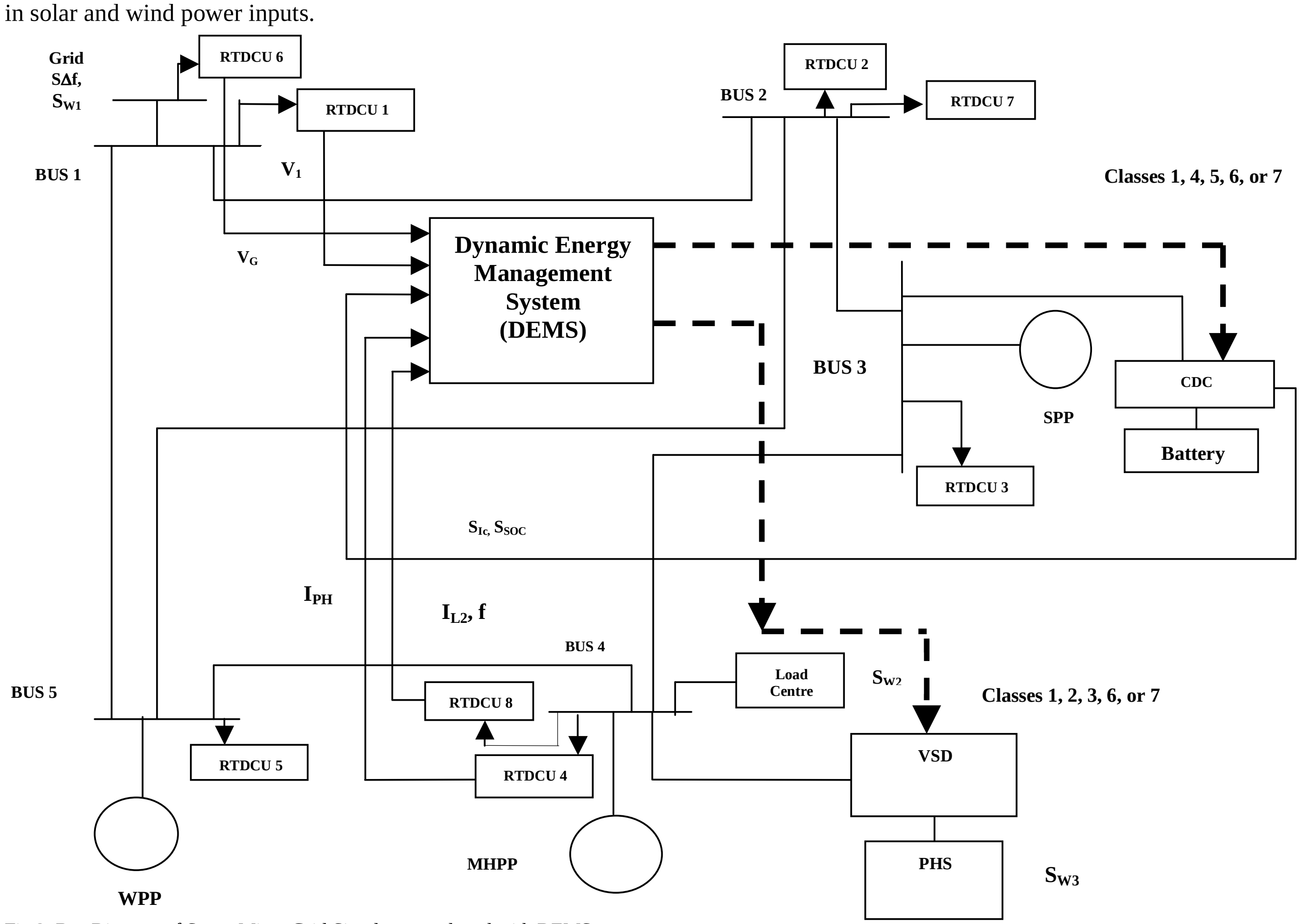

Fig.2. Bus Diagram of Smart Micro Grid Simulator employed with DEMS

A Real Time Data Collection Unit (RTDCU) is provided at every bus in the SMGS to measure the currents and voltages and transmit the data to a central computer through Zigbee Communication module installed in it. A remote RTDCU is also connected to the legacy grid to measure the voltage, current and the frequency of the grid. A specific data format is followed by all the RTDCUs.

MHPP present in the SMGS acts as a permanent source for generating the power in the islanding mode. One of the important control parameter in the islanding mode is the frequency and is dictated by the MHPP.

SIMULATION AND FPGA IMPLEMENTATION

Grid Connected Mode

The use of neural network algorithms could be a suitable option for designing EMS but the former suffers from various disadvantages such as longer training time, loss of generalization if the dimensionality of the input increases, local minima problem etc [36]. After an extensive analysis and comparison of the machine learning techniques with the digital logic, it is evident from [35] that SVM is the best machine learning technique that can be employed in realizing a DEMS for such a critical environment.

TABLE V. SIMULATION RESULTS OF SVM

Model	**γ (Gamma)**	**C (Cost)**	**Cross Validation Accuracy (%)**	**Testing Accuracy of unknown patterns (%)**	
ABCD	1	2	91.8239	80 (32/40)	8
BCDE	0.0625	64	95.625	94.8718 (37/39)	2
CDEA	1	8	86.1635	80 (32/40)	8
DEAB	1	16	89.3082	85 (34/40)	6
EABC	**0.0625**	**64**	**93.0818**	**100 (40/40)**	**0**

The simulation results shown in Table V differs from that shown in [32 – 35] in the accuracy being tuned to 100% in detecting a set of unknown patterns. This is because the kernel parameters are tuned based on Grid-Search algorithm [37].

Islanding Mode

Islanding mode of SMG is the result of intentional or unintentional grid disconnection to the SMG. Status parameter S_{W1} is considered to be zero in islanding mode as there is no grid exchange between the SMG and conventional grid. The loads connected to the SMG are enabled with DRPs which dictates the status parameter S_{W2}. A special case of Direct Load Control (DLC) DRP is used in this work.

Under normal conditions of frequency, the customer premise is energized by the SMG. In adverse conditions, a signal is transmitted to the Local Controller (LC) at the customer premises by DEMS either to switch ON or OFF the loads. In that case, the LC should perform any of the following two actions i) when the signal received is to switch OFF the loads, the customer is energized by the battery charged by a local solar PV system that includes battery storage installed at the premises ii) when the signal received is to switch ON the loads, the customer is energized by the SMG, disconnecting from PV. By this DLC Solar DRP, the customer can enjoy the benefits of uninterruptible power supply even when disconnected from the SMG.

A suitable implementation tool that can be used to realize the operation of DEMS in islanding mode is Fuzzy Logic [38] as DEMS has to perform critical thinking before taking any decision. The parameters involved in taking the decision are the present frequency of SMG (dictated by MHPP) and the change in frequency. Change in frequency is included to know the trend in frequency which enables the decisions to be human-like. Fig.3 and Fig.4 shows the membership functions for the input variables -- frequency and the change in frequency.

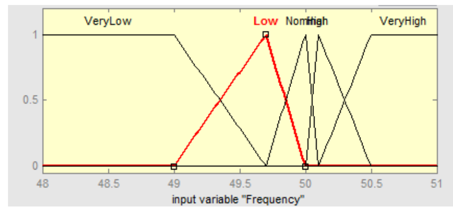

Fig.3 Membership Functions for the input variable Frequency

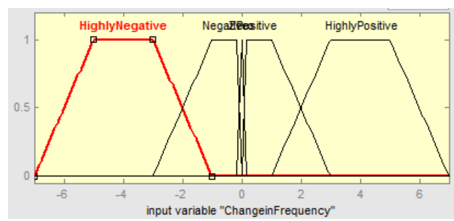

Fig.4 Membership Functions for the input variable Change in Frequency

Sugeno method of implementation is employed as the output is a discrete value. There are 5 membership functions for each of the input variable. A total of 25 rules are possible for which the DEM Decisions are assigned as shown in the surface view of the rules in Fig.5.

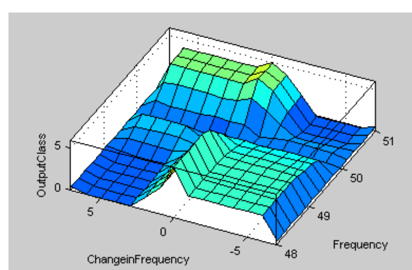

Fig.5 Surface View of the DEM Decisions for various combinations of the input variables - frequency and change in frequency.

SMGS shown in Fig.6 available in Energy Laboratory at Amrita Vishwa Vidyapeetham University, Coimbatore is used for the validation of DEM Scheme. DEMS implementation is chosen to be on Altium Nano Board 3000 which houses Xilinx Spartan 3AN FPGA as shown in Fig.7 programmed using the

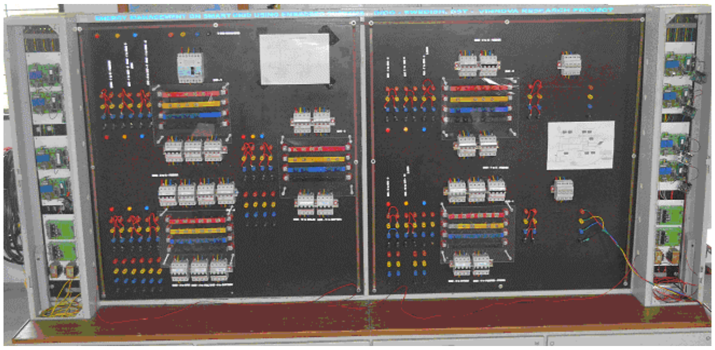

Fig.6. SMG Simulator in the Energy Laboratory of Amrita Vishwa Vidyapeetham University, Coimbatore.

Altium Designer IDE 10 as quick response of DEMS is crucial when compared with a conventional system [39]. The outputs are obtained as a result of processor logic implementation on the soft processor TSK3000 embedded in the Xilinx FPGA. The real time SMG data are available in the intranet and can be accessed from anywhere in the University Campus. The RTDCU data are analyzed and decoded to extract the required data to form the status parameters which depicts the status of SMG.

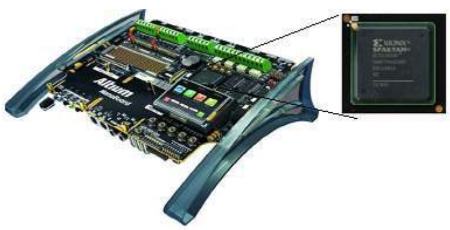

Fig.7. Altium NB3000 with Spartan FPGA

Appropriate decisions are displayed on the mini touch screen embedded on the Altium NB3000 board. The implementation report of DEMS as generated by the Altium Designer IDE is presented in Table VI.

TABLE VI. FPGA IMPLEMENTATION REPORT (GENERATED BY ALTIUM DESIGNER 10)

LOGIC UTILIZATION	**SVM**
Number of Slice FlipFlops	1651/22528(7%)
Number of 4 input LUTs	4037/22528(17%)
LOGIC DISTRIBUTION	
Number of occupied slices	2604/11264(23%)
Number used as logic	3781
Number used as route-thru	205
Total Number of 4 input LUTs	4242/22528 (18%)
Peak Memory Usage (MB)	239
Total REAL time to MAP (secs)	16

CONCLUSION

RE has penetrated to the tune of 12% in Indian power grid and the present power policy and planning of the power sector is to enhance the penetration further. It therefore is certain that an advanced power management technique like DEM is essential for the future power grid operation in the country. Presently the carbon foot print of Indian power grid is very high. The country has recently risen to a vulnerable position as the third largest nation in the world in GHG emission. The only remedial measure in this regard is adoption of more of RE and this is impossible in future without DEM which urges the need for a smart environment in the Microgrid level.

The feasibility of incorporating SVM based DEMS employing DEM control for stabilizing the frequency excursions on a SMG implemented on a FPGA platform is proved to be successful and is tested on a SMGS installed in the energy laboratory of Amrita Vishwa Vidyapeetham University. Quick response of an EMS is vital for a SMG as compared to the legacy grid which is accomplished with the FPGA implementation. The presence of DEMS in a SMG would be appreciated when many such RE energized SMGs penetrate the public power grid and operate in a synchronized manner which forms the urgent need for solving the global energy crisis.

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Leveraging **AMI** for Enhanced and Improved **OMS**

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ABSTRACT

Electrical grids are subject to failure that can cause planned and unplanned power interruptions for utility customers. Major faults and outages on power distribution system have a significant economic and social impact. Despite advances by utility industry to protect and harden electrical grid, unplanned outages and faults critically jeopardize the “Availability” & “Reliability” of power supply.

Over a last decade there has been significant improvement by Indian utilities in deploying Smartgrid solutions like GIS, AMI, OMS, SCADA-DMS, FPI, Customer Care, IVR and ERP to improve the operational efficiency of the utility.

This paper describes that how business processes like AMI GIS, CIS,FPI and DMS help in improving the performance of Outage Management System to efficiently manage the outage and thereby addressing both technical and organizational issues faced by the distribution utilities in the event of outages.

This not only improve the utility performance, to be measured in terms of SIFI / SAIDI, but also significantly improve the customer satisfaction and the attitude to wads utility.

Index Terms—Smart grid, GIS, AMI, OMS, SCADA-DMS, Customer Care, IVR, ERP,

INTRODUCTION & ISSUE

Economic growth and an increasing population translate to more energy demand in India. This situation, coupled with strict regulations on the quality and reliability of supply mounts increasing pressure on the Indian distribution utilities to keep the network at the best possible state.

While huge investments are already being made by Govt. of India through schemes like APDRP, RGGY & Smartgrid on replacing the aging infrastructure to prevent equipment failure, the chance of failure & outages however, cannot be completely eliminated. For the outages that can’t be prevented, it is therefore necessary to minimize the impact by keeping the outage time as short and the affected customers as few as possible and keeping customer informed during the outage management.

Power Distribution Utilities are challenged to improve their SAIDI for end customer benefits. The SAIDI, (System Average Interruption Duration Index) is the average outage duration for each customer served, includes both planned and unplanned minutes off supply. For Indian Distribution Utilities, average SAIDI is more than 55 minutes.

Under Govt. of India R-APDRP (Restructured Accelerated Power Development & Reform Program) program, the electrical infrastructure of the major Indian cities are being modernize and upgraded with Smart Solutions and devices like GIS, SCADA, DMS, RTU, FRTU, Auto Reclosure & RMUs to improve the efficiency, Performance and Financial strength of Indian distribution Utilities

This has significantly helped in creating a base line infrastructure, like AMI, GIS, CIS & DMS needed to successfully implement the OMS (Outage Management System).

Integrated AMI & OMS, described in this paper, is an intelligent solution for Efficient & Intelligent management of outages while keeping customer informed about the Outages.

OUTAGE CHALLENGES

Though, utilities have Traditional processes and systems to identify outages, dispatch crews and communicate with affected customers. However, utilities phase following three challenges

1. **Timely outage reporting & Reliability:** Utilities rely heavily on customer calls to learn about smaller outages. This dependence leads to delays and inaccuracies. Customers often assume a neighbor reported the outage, or wait to see if the power comes back on, or may not be home to notice. Lack of timely and reliable information can cause utilities to inadequately staff repair crews or to dispatch crews to the wrong area. It can also make it difficult to accurately predict restoration times
2. **Slow Restoration:** Utilities often have difficulty detecting smaller outages nested inside larger ones – for example, when a downed tree cuts service to several houses within an area affected by a feeder outage. Since most customers do not call to report power restoration, utilities have no way to verify whether service has been restored to all customers. As a result, the crew assigned to fix the large outage often leaves the area before nested outages are detected. Once the utility discovers a nested outage,

it must dispatch another crew to resolve the problem and restore service, which increases operational costs and results in longer outages

3. **Difficulty in Diagnosing single outages:** Usually 60-70% of outage calls are for single customer. In such cases, the problem is usually on the customer side. Unless utility service staff can determine over the phone on which side of the meter the problem lies, the utility must dispatch crew to the customer site to diagnose the problem

An AMI system can address these pressing outage-management challenges by providing a far more complete and real-time picture of outages and restoration.

AMI

The deployment of an Advanced Metering Infrastructure (AMI) is a prime example of smart grid infrastructure that can communicate with other smart grid information systems to deliver operational and business benefits across the utility. The major characteristic of AMI is the ability to share near-real-time data throughout the enterprise with true interoperability. As more AMI systems are being deployed, the utilities are looking for ways to leveraging AMI for the benefit and improvement of other business processes System. One such approach is the integration of AMI with the outage management system (OMS). Integrating the AMI and OMS can provide operational intelligence that allows more efficient and accurate outage detection and restoration verification. To realize tangible network performance benefits, these two systems must be interoperable and share near-real-time data.

OMS

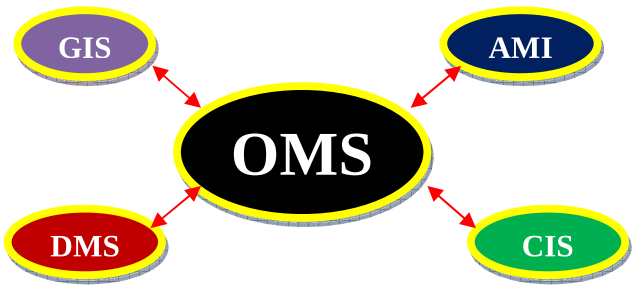
Outage management systems use customer outage reports, knowledge of distribution system infrastructure, and predictive algorithms to determine where a failure has occurred in the network. OMS process has two principal stages- outage detection/analysis and outage restoration. AMI systems can help significantly in both stages to reduce a utility's System Average Interruption Duration Index (SAIDI). Using the power of near-real time information has improved electrical utilities' SAIDI through faster and more accurate outage response

At the core of a modern outage management system is a detailed network model of the distribution system. The utilities Geographic Information System (GIS) is usually the source of this network model. By combining the locations of outage calls from customers, a rules engine is used to predict the locations of outages. For instance, since the distribution system is primarily tree-like or radial in design, all calls in particular area downstream of a fuse could be inferred to be caused by a single fuse or circuit breaker upstream of the calls.

The outage calls are usually taken by call takers in a call center utilizing a customer information system (CIS). Another common way for outage calls to enter into the CIS (and thus the OMS) is by integration with an Interactive Voice Response (IVR) system. The CIS is also the source for all the customer records which are linked to the network model. Customers are typically linked to the transformer serving their residence or business. It is important that every customer be linked to a device in the model so that accurate statistics are derived on each outage. Customers not linked to a device in the model are referred to as fuzzies.

More advanced Automatic Metering Infrastructure (AMI) systems can provide outage detection capability and thus serve as virtual calls indicating customers who are without power. However, unique characteristics of AMI systems such as the additional system loading and the potential for false positives requires that additional rules and filter logic must be added to the OMS to support this integration

Outage Management Systems are also commonly integrated with SCADA-DMS systems which can automatically report the operation of monitored circuit breakers.



Another system that is commonly integrated with an outage management system is a mobile data system. This integration provides the ability for outage predictions to automatically be sent to crews in the field and for the crews to be able to update the OMS with information such as estimated restoration times without requiring radio communication with the control center.

It is important that the outage management system electrical model be kept up to current so that it can accurately make outage predictions and also accurately keep track of which customers are out and which are restored. By using this model and by tracking which switches, breakers and fuses are open and which are closed, network tracing functions can be used to identify every customer who is out, when they were first out and when they were restored. Tracking this information is the key to accurately reporting outage statistics.

OMS BENEFITS

The biggest and utmost benefit of the outage management system is CUSTOMER SATISFACTION, however following, but not limited to, are other benefits of OMS.

- Reduced outage durations due to faster restoration based upon outage location predictions.

- Reduced outage duration averages due to prioritizing

- Improved customer satisfaction due to increase awareness of outage restoration progress and providing estimated restoration times.

- Improved media relations by providing accurate outage and restoration information.

- Fewer complaints to regulators due to ability to prioritize restoration of emergency facilities and other critical customers.

- Reduced outage frequency due to use of outage statistics for making targeted reliability improvements

IMPROVING OUTAGE DETECTION USING AMI

The ability of the AMI to communicate “no power” events to the OMS enhances the identification of probable incident locations, providing visualization and analysis of the affected area. While consumer-reported events must be tracked and managed, AMI event reporting is more immediate, reliable and available. An OMS can quickly leverage this information using the tracing and prediction analysis functions of a real-time operations distribution network model to determine the location of the affected protective device and faults

To be effective, an OMS needs as little as 15 percent of affected customers to call in but the rate of notifications received directly from customers can vary, depending on time of day, day of week and geographic location of events and hence OMS performance in not only become sluggish but its prediction maybe inaccurate. Where as in an AMI system affected meters directly report **“No Power”** to OMS, there is a higher number of notifications received, giving the OMS identification algorithms more complete information that results in more reliable incident location.

Most of the advanced meters used in AMI systems have a **“Last Gasp”** capability. This last gasp is a high-priority message transmitted by a meter when electrical service is out. The meter has a battery or capacitor which provides power to the meter for a few minutes. Providing this information to an OMS can dramatically improve outage notification times. In addition, the OMS interfaced with the AMI allows “**automatic or manual pinging of meters”**. While the response time of a ping request is variable, utilities using this functionality experience significant savings by validating events, eliminating unnecessary truck rolls and consequently making more efficient use of crews.

Moreover, “**pinging**” meters to validate restoration helps identify any residual or nested outages resulting from multiple faults downstream of a protective device. The OMS prediction engine performs the business logic required to create new incidents for the existing nested outages. Identifying nested outages while crews are on site eliminates the associated customer callbacks, customer service costs and duplicate trips to the field. There are some limitations as well:-

- A large outage can overwhelm an AMI system with last gasp messages
- “Last Gasp” or “Pinging” Message may got lost in Network Congestion
- Outage May affect the communication backhaul limiting message can get through
- There are unattended or unnoticed Nested or Single-Customer outages.

However, OMS systems can function well with, as little as 15% of outages reported and hence AMI “Last Gasp’ functionality is still an ideal input to the OMS outage detection process

Another benefit of AMI is to lessen the dependency on inaccurate trouble calls. As many as 60-70% of calls are single-customer outages. With AMI, an operator can perform an on-demand read to verify if the premise is energized. In the current generation of AMI systems with two-way communication capability, an operator can “ping” a meter as well. The verification speed depends on many variables but is usually near-real time. Even if the customer cannot be given instant verification of the outage, the system can respond before the time and expense of a crew dispatch

OMS & AMI INTEGRATION

Integrated Solution is the ability to share data between various software and systems. Utilities may have outage management, AMI, SCADA, DMS, CIS, IVR and other Smartgrid solutions like FPI systems available on the Network. Each system is capable of generating information that can be useful during outages. If these systems are linked to the OMS, you have the ability to manage outages, and the related data, from one location. The goal is to provide safe and efficient use of the utility workers’ time and company resources.

Technical integration links both internal and third party information together—to create a simplified process to better manage workflow. The key to this integration is having the ability to push or pull information to or from the OMS, AMI, GIS, SCADA, DMS, IVR, Call Centers

Interoperability is the main issue while integrating two different business processes. Complying with open-standards interoperability is the best way to integrate the applications with ease of deployment, maintenance and avoid the risk of obsolescence. International Electrotechnical Commission (IEC) 61968 Common Information Model (CIM) is the standard for message exchange within many utility business processes and which ensures the seamless integration and interoperability between processes like OMS and AMI. The synergy of integrated AMI and OMS enables robust functionality that supports faster response and restoration dispatch

RELIABILITY IMPROVEMENTS

An OMS supports distribution system planning activities related to improving reliability by providing important outage statistics. In this role, an OMS provides the data needed for the calculation of measurements of the system reliability. Reliability is commonly measured by performance indices defined by the IEEE P1366-2003 standard. The most frequently used performance indices are: SAIDI, CAIDI, SAIFI and MAIFI.

While deploying an OMS improves the accuracy of the measured reliability indices, it often results an apparent degradation of reliability due to improvements over manual methods that almost always underestimate the frequency of outages, the size of outage and the duration of outages.

An outage management system (OMS) provides the capability to efficiently identify and resolve outages and to generate and report valuable historical information. It also helps the utility inform the customer of the outage situation and restoration status (rather than the customer informing the utility first). An OMS typically works in conjunction with Automated Metering Infrastructure (AMI) geographic information systems (GIS), the utility's customer information system (CIS), and automated call handling systems, such as an interactive voice response (IVR) system.

Today, with the increasing requirements on utilities to track and report outages accurately, Integrated OMS, with AMI, GIS, DMS & CIS , is a critical analysis tool.

BENEFITS OF INTEGRATED OMS

Major benefits of an integrated OMS includes, but not limited to:

1. Increasing information expectations:
2. Reduction in un served electricity:
3. Accurate and speedy outage detection
4. Efficient Work force management.
5. Crew & Mobile Van Tracking
6. Customer Engagement & Call Back
7. Resolving Nested and Single customer outages
8. Prioritizing the restoration
9. Quick validation of outages
10. Information exchange for reporting
11. Accurate time stamping of outages & Restore
12. Analysis of utility performance
13. Optimization of resources and planning
14. Reduction in OPEX

CONCLUSIONS

The scale and variety of major outage events tend to overwhelm legacy outage-management tools, preventing utilities from meeting the expectations of external stakeholders and exposing the lack of accurate simulation capabilities and extensible tools. Heightened political pressure, coupled with the increasing outage frequency and severity of these events, is making utility management wondering improving operational efficiency and customer satisfaction.

OMS in tandem and with integrated GIS-SCADA-DMS & FPI solution provided all information to utility required to efficiently manage the outages

At present Indian distribution utilities are going through the transition of technical, organizational and culture reforms. Grid modernization should ultimately extend the benefits to the end user ie customer which evaluates the utility performance in terms of the frequency and duration of the outage.

The integrated AMI and OMS solution continues to serve the utility by automatically and precisely documenting restoration times. The utility improves the accuracy of outage location and the severity of outages, Performance indexes such as Customer Average Interruption Duration Index (CAIDI), System Average Interruption Duration Index (SAIDI) and Momentary Average Interruption Frequency Index (MAIFI); and other analyses shared with Management, Regulators, Customers and other stakeholders.

In summary, integrated AMI and OMS systems can clearly offers benefits that extend well beyond the expectations. The OMS provides the ability to consume AMI data and visualize, analyze, validate and report—all to facilitate outage events resolution. This functionality is critical in a utility's goal of improving customer service and decreasing operational costs—and getting more value from its AMI investment. Reduced outage time would certainly improve the customer satisfaction which is the ultimate goal.

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Energy Access in South Asia: Incubating Innovation in Rural Electrification through Off-grid Solutions

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Abstract

In the present context of South Asia, Off-grid customers rely on fuel (kerosene, diesel) to meet their energy needs with their fuel costs rising while solar panel costs have been falling – so a small amount of low-cost power supplied commercially can go a long way to improving the energy access picture. There is a need for rejig of the off-grid schematic for rural electrification. Familiarity with the customer base and increase in customer income and loads will allow for scaling up and sustainability of any off-grid solution. In this paper, I present an improvised A-B-C Model: I developed upon the nascent A-B-C Model of approach for rural electrification through off-grid solutions and incubated innovation – improvised A-B-C Model of approach seeks to **reduce risks for small private power producers in the off-grid space.**

I identify three sets of customers on the lines of A-B-C Model: Anchors – Businesses – Community members and develop upon the existing model framework and also identify and study their inter–dependencies: mapping affordability and utility duration indices will reduce market analysis costs and transaction costs for the private operators in the off-grid space.

In this paper I discuss few empirical evidence illustrating the improvised model and impact thereof; the importance of pursuing this model through necessary policy instruments and possible implications thereof in the context of South Asia – how the policy interventions should be structured and the impact on concept of sustainability of rural electrification through off-grid solutions.

Keywords

Innovation; Energy Access; Rural Electrification; Off-grid; South Asia; Energy Challenges in South Asia

INTRODUCTION

In developing countries around the world, nearly 1.3 billion people remain without access to electricity (World Energy Outlook 2012). Transmission and distribution line losses in developing countries often ran as high as 20 to 30 percent due largely to inadequate maintenance and investments in distribution systems. The financial viability of electric utilities in developing countries also remains constrained by improper billing, lack of payment, unauthorized connections and continued subsidies that often benefit customers who have the ability to pay.

As the International Energy Agency (IEA) *World Energy Outlook 2002* notes, over 1.64 billion people worldwide (99 percent of them in developing countries) lived without access to electricity. Four out of five of those are in rural areas and 80 percent are from South Asia and sub-Sahara Africa. With many developing countries struggling to make utilities economically sustainable and meet increased energy demand, the time was right for Governments to re-evaluate their energy strategies and begin to look into off-grid solutions for rural electrification. Over the past 10 years, though a large variety of technologies were made available in the market – there is a huge lacuna in terms of market penetration and market outreach.

In the present context of South Asia, Off-grid customers rely on fuel (kerosene, diesel) to meet their energy needs with their fuel costs rising while solar panel costs have been falling – so a small amount of low-cost power supplied commercially can go a long way to improving the energy access picture. There is a need for rejig of the off-grid schematic for rural electrification. Familiarity with the customer base and increase in customer income and loads will allow for scaling up and sustainability of any off-grid solution. In this paper, I present an improvised A-B-C Model: I developed upon the nascent A-B-C Model of approach for rural electrification through off-grid solutions and incubated innovation – my improvised A-B-C Model of approach seeks to **reduce risks for small private power producers in the off-grid space.**

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 # Also Mr. Abhijith Jayanthi serves as a Consultant with World Bank and as a member on the National Governing Council of Solar Energy Society of India (SESI) and Indian Association of Energy Management Professionals (IAEMP)

A-B-C MODEL

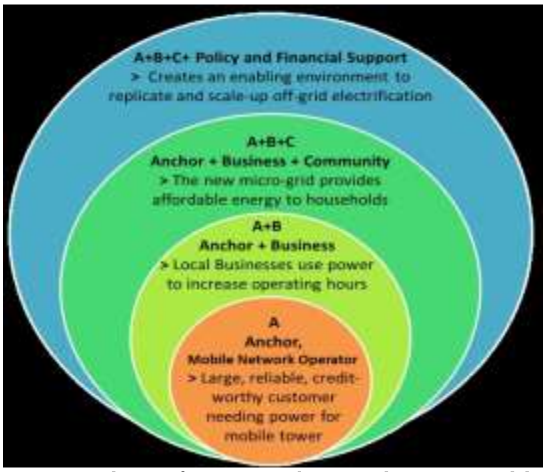


Fig. 1. Evolution of Power Distribution under A-B-C Model

Rural Electrification technologies / off-grid solutions can range from a few watts for solar lighting and phone charging stand-alone PV, to full grid connections or isolated mini-grid electrification that gives 24/7 access to a sufficient amount of power. Most small investors' initial focus will be at the lower wattage end of this scale, of getting 1-50W of electricity (micro-energy) to households, for 4-12 hours of power per day, rather than 50-500W of 24/7 access at first. Familiarity with the customer base and increase in customer income and loads will allow for scaling up at a particular location.

A-B-C Model has been developed as a structured approach to engage the private sector in providing off-grid energy solutions. The model builds on three sets of consumers: Anchors (A); Businesses (B); Community (C) which are arranged on cumulative coverage circles as indicated in the Figure 1. For private-sector led commercially viable off-grid energy solutions – it is imperative to begin with established and predictable load which forms the Anchor load; requiring continuous delivery of power and with time achieve traction, thus growing in size to cater to Businesses - for whom power is a critical input for expanding operations or improving productivity and after achieving certain size cater to Community Load – members represent uncertain load demand and affordability is a major issue considering they may have many other pressing needs in addition to power.

Though the A-B-C Model appears simple and intuitive, it largely remains a conceptual model with limited empirical evidence to collaborate with. Though, the model is not completely developed, in this paper I explore the linkages, study inter-dependencies and present an improvised A-B-C Model to reduce risks and improve profitability for small private power producers; thus ensuring sustainability of the Off-grid energy solution projects.

Key Challenges

Work on the A-B-C model is motivated by the recognition that many existing off-grid solution providers' efforts often proceed with insufficient attention to underlying on-the-ground realities/challenges. As presented in case studies by Barnes [1]; Failure to pay due attention to more formal principles has frequently led to attempts to express and model complex energy requirements without a clear exposition of the entities and relationships necessary for such requirements; as such a structured approach may be appropriate for simple pidgin metadata, but lacks precision for detailed linkages and inter-dependencies.

I argue that one essential test of a descriptive model should be the specificity of scenarios that it supports. If the intent is to support simple regular community structures on ground, such as "Existence of Definitive Anchor Loads" then it is reasonable to work with A-B-C model with Anchor Load being the first load serviced to begin with. I have found that, especially in my work in south Asian community, statistics compiled from metadata frequently fail on occurrence of a specific on-the-ground scenario and such occurrences are significant in number, A-B-C Model will not yield a profitable, more so sustainable working model to begin with.

In order to support such specific scenarios, A-B-C model must provide a logical foundation for including ground-level challenges including linkages and inter-dependencies between various energy consumer groups. As a parenthetical remark, I emphasize that including these factors almost certainly increases the human element and the working dynamics of the A-B-C model.

I studied the influence of factors such as market information and data collection; mapping of load locations and daily fluctuation in demand; Information on latest available technologies and energy resources available to reduce transactions costs e.g. ICT enabled pre-paid smart meters; Information and access to potential financing partners (equity, debt, R&D, grant) for investment and working capital; Information on Policy and Regulatory environment— new incentives, how to access government grants, required paperwork, reporting formats; Information on identifying local trained work force to support the business growth; and understand the importance of including these factors into the model – this explains the aberrations in the experience with A-B-C Model.

Barnes and Halpern [2] present various case studies illustrating that the forms of energy needed in off-grid areas are not limited to electricity. In the rural areas of developing countries, including already electrified areas, thermal energy from fuel-wood for household cooking and use in small industries is by far the most predominant form of energy. Other forestry related initiatives, are also addressing the fuel-wood supply-demand imbalance that many developing countries currently face – this influences the overall working model for a mini-grid solution.

Also, it is not possible to disaggregate the gross figures of unserved rural populations precisely according to these three classes (A-B-C) of unserved populations and thus correctly estimate the total size of the off-grid market. Whether an unserved community belongs to the off-grid or grid-extension group is a function not only of distance but also of load density along with growth of livelihood opportunity; thus, the size and growth projections of varied loads must first be determined. In addition, unserved rural communities may be undercounted. In some countries, a community is counted as electrified once the low-voltage (LV) line has been built through it and a minimum number of connections made (for example, in the India, LV line being made available categorize a community as "electrified," regardless of whether or not households are connected. Moreover, it has been argued that many unconnected consumers in areas already served by the grid could be classified as off-grid since the temporary solution to their "pre-electrification" status may be off-grid technologies, such as individual PV systems. A useful indicator is the national electrification rate: If this rate exceeds 80 percent, it is highly likely that only truly off-grid communities remain without electricity.

ABHIJITH'S IMPROVISED A-B-C MODEL

All countries—whether industrialized, middle income or low income—place a high priority on providing their citizens access to electricity. Despite this policy and the expenditure of billions of dollars, more than 1.5 billion people, mainly in Sub-Saharan Africa and South Asia, remain without access to electricity services today. To meet their lighting and other basic energy needs, many households continue to depend on expensive fossil fuel–based sources, such as kerosene, which are energy inefficient and polluting.

Twenty years ago, grid extension, diesel-powered mini-grids, and mini-hydropower generators were, for the most part, the only electrification options available to rural communities. With the commercial maturation of various small-scale, renewable energy–based technologies — from solar photovoltaic systems to small wind generators and micro hydropower—along with the evolution of innovative service delivery models, off-grid or stand-alone service provision has emerged as a viable alternative for increasing electricity access, especially in remote and dispersed communities. More recently, the dramatic rise in fuel prices has further increased the economic attractiveness of these technology options. But the long-term sustainability of off-grid electrification depends on more than technology.

Physical, technical and financial capacity constraints place a natural limit to the pace of achieving goals of expanding access to electricity solely through government action. Designing sound off-grid electrification projects is far from an exact science. The combination of high cost of service; poor customers; and newer, less familiar technology options often makes it a more complex task than preparing a conventional energy project. Nevertheless Barnes [1] presents clear evidence: remote communities provided any type of decentralized electricity supply have marked improvements in welfare. The benefits of rural grid electrification, which have been extensively studied and are well known, are similarly realized in off-grid situations, even though the amounts of power made available by decentralized systems are relatively smaller and the services provided more basic. For individual households, the main advantage is the shift from traditional/conventional to modern lighting systems, typically from kerosene lamps to the superior quality electric lighting. Poorer community members benefit indirectly from the power provided to schools, health centers, water-supply systems, and communication facilities. Where community conditions are favorable, off-grid electrification stimulates the creation of microenterprises that increase overall economic benefits and thus further increase the energy demand fuelling growth.

It requires to customize the usually proposed theoretical start-point of A-B-C Model to include these inter-dependencies into the model, to achieve effective prioritization and planning to enable economic choices of technology, appropriate infrastructure to ensure that services are provided over the long run, and sustainable financing to make these capital-intensive technologies affordable.

Linkages And Inter-Dependencies

Before we proceed further, it is important that we explore the influences on the three consumer segments i.e. Anchors – Businesses – Consumers. In practice, when an off-grid energy supply is provided; it not only caters to energy requirement but also builds an eco-system around itself. Consider Telecom Towers, which usually (if not otherwise) form a major component of anchor load to begin with (even in far-flung regions and remotest corners), bridging the tele-density gap and increasing access to other allied services. Today, with greater tele-density, and use of ICTs for administration (it is the telecom network's reach and usage that it depends on) – this led to innovative approaches to make multitude of services available at the grassroots level. This results in an eco-system of thriving business potential.

Businesses not only depend on power supply; but also on market access – with greater access to information, demand for varied products is seen and thus greater market penetration of various products (including new market creation) is possible. Barnes and Halpern [2] presents evidence for the expected welfare gains from off-grid interventions being higher than the long term costs – and that such gains are realized in the medium run. This will result in better community welfare and thus create more demand for electricity.

Institutional or community applications are another important market segment for off-grid electrification. For example, the operations of schools, clinics, and community centers can be significantly enhanced by electric lighting, refrigeration, educational television, computers, communication and simple entertainment systems that require small amounts of power. Community and other needed social structures are a result of trade-off between necessities and opportunities. With greater information access; there is a greater demand for welfare infrastructure, resulting in an increase in community engagement and thus raising the social equity – this not only indicates significant potential for use of electricity but also a high willingness to participate.

The relatively large unit size of the institutional installation and its assured nature (as opposed to individual households, who may not opt to sign up) greatly increase the Anchor Load's attractiveness to begin with. The paid-for requirement to service the institutional applications also creates the infrastructure to support retail sales in the same area i.e. there is a minimum infrastructure setup which is necessary to make any off-grid setup operational. A recent study by de Gouvello [3] has categorized these types of actions by service providers as systematic and pragmatic approaches. The systematic approach analyses the technologies used in the production processes of goods and services in a specific rural area. It identifies the bottlenecks, determines whether the use of electricity can contribute to diminishing or removing the limiting factors, evaluates the costs and gains, and provides guidelines to induce the proposed change in the processes. The pragmatic approach, on the other hand, follows an opportunistic tactic, taking advantage of pre-existing opportunities resulting from the ongoing or planned implementation of another project or program. This approach is usually observed when conditions are ripe for a quick-win project that would provide rapid revenue-enhancing gains, facilitated by access to electricity. No matter which approach is adopted, it is imperative to appreciate the linkages and interdependencies amongst energy access, business and community environments. The study argues that, to succeed, rural electrification programs shall generate new revenues and directly affect livelihoods.

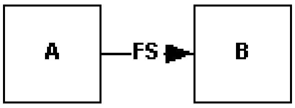
Critical Path And Critical Load Capsule: Abhijith's Improvised A-B-C Model

Extending the argument presented by de Gouvello [3] and drawing upon the inferences – with greater livelihood generation and additional revenue generation; the two approaches (systematic and pragmatic) present a *capsule* of crucial linkages and inter-dependencies which form a *critical load* of initial opportunity to be addressed. Using the two aforementioned approaches, I evaluated and arrived at the project design with a connected path of planned activities which are inter-dependent and are critical for error-less estimation of quantum of other activities on the path (for project initiation), and the earliest and latest consumer group that electrification will begin with, and the load thereof represent the *critical load capsule*. This process determines which loads are "critical" and which have "total float" (i.e., can be addressed later or delayed without having any detrimental effect on sustainability of the project).

For establishing the *critical path* and thus arrive at the *critical load,* I attempt to mathematically construct the dependency relation and incorporate it into the A-B-C Model. Dependency is a link amongst the three consumer groups, seen as terminal elements. Dependencies can be categorized into four types with respect to ordering terminal elements (in order of predictable nature of terminal load):

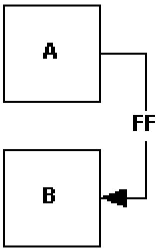
1. Finish to Start (FS)

A FS B = Terminal Load B can't happen before Terminal Load A is serviced



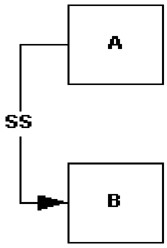
2. Finish to Finish (FF)

A FF B = Terminal Load B can't be serviced (i.e. Terminal Load B is created as a result of Terminal Load A being serviced) before Terminal Load A is serviced



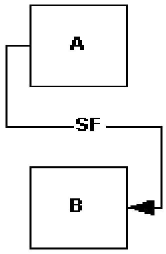
3. Start to Start (SS).

A SS B = Terminal Load B can't be serviced without servicing Terminal Load A



4. Start to Finish (SF)

A SF B = Terminal Load B can't be finished before servicing of Terminal Load A starts



Finish-to-Start is considered a "natural dependency", that which is usually observed whereas all the others are constraints to be imposed in the project design to reflect resource constraints or preferential dependencies which are specific to location/area. Start-to-Finish (SF) can rarely be seen, but is presented to achieve completeness in modelling the dependencies. Existence of a dependency can stem from Causal (logical) Relations; Resource Constraints or Discretionary (Preferential) Behavior of consumer groups.

Usual dependencies often reflected from causal (logical) relations or discretionary (preferential) behavior because the assumption was that resources would be available (which is the start point of technology adopted and project design) or could be made available. Nevertheless, ground-level realities necessitate taking into account resource constraint-derived dependencies as well. In addition, these dependencies can be modified by leads, and lags to better evaluate the critical load in bundles – each bundle plays the role of critical load for a short period while the overall critical load capsule is essential for the sustainability of the project.

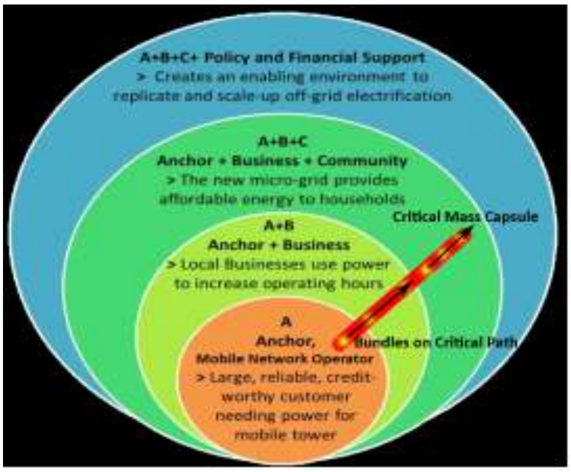


Fig. 2. Evolution of Power Distribution under Abhijith's Improvised A-B-C Model

Abhijith's Improvised A-B-C Model has been developed as a structured approach incorporating these dependencies through *critical load capsule* and *critical path* to engage the private sector in providing off-grid energy solutions. The model builds on three sets of consumers: Anchors (A); Businesses (B); Community (C) along with a *critical load capsule* which are arranged on cumulative coverage circles as indicated in the Figure 2. For private-sector led commercially viable off-grid energy solutions – it is imperative to begin with established and predictable load which forms the Anchor load along with the *critical load capsule*; requiring continuous delivery of power and with time achieve traction, thus growing in size to cater to Businesses – catering to energy requirements that become necessary with expanding operations or improving productivity and after achieving certain size cater to Community Load – members represent uncertain load demand and affordability is a major issue considering they may have many other pressing needs in addition to power. Addressing critical load capsule at the beginning is essential to attract the community and social fabric to have a sense of ownership about the off-grid project and thus ensure its sustainability

Empirical Evidence

Over the past decade, the Renewable Energy for Rural Economic Development (RERED) Project, launched in 2002, and its predecessor Energy Services Delivery (ESD) Project have helped thousands of poor rural households in Sri Lanka to switch from poor-quality kerosene lamps to more efficient electric lighting. The ESD Project, initiated in 1997, provided private-sector firms, non-governmental organizations, and cooperatives small, output-based grants and medium and long-term financing for SHSs and village micro hydropower in off-grid areas, as well as grid-connected mini-hydropower schemes. The US$45 million project resulted in electricity provision for over 22,000 off-grid households and private-sector investment in 30 MW of grid connected, renewable-energy power plants. Building on this success, the RERED Project, with $75 million in IDA credits and $8 million in GEF grants, has supported private-sector investment in an additional 85 MW of grid-connected, renewable-energy electricity generation, more than 100,000 SHSs, and independent micro-hydropower grids. In 2007, an additional US$40 million in IDA financing was provided to support another 50,000 off-grid connections and 50 MW of renewable energy, electricity-generation investments. Implementing the private sector–led renewable energy program has created a vibrant local industry of suppliers, developers, financiers, consultants, and trainers. By June 2008, some 120,000 households were using SHSs, with 750 new installations occurring monthly. Nearly 6,000 households are obtaining electricity from micro-hydro minigrids that communities own, operate, and manage. One hundred MW of mini-hydro and biomass based–powered grid-connected plants are in operation and contributing 4 percent of electricity to the national grid. Another 25 MW are under construction. This is as a result of taking the inter-dependencies between various potential consumer groups into consideration and the scale-up is planned taking into the cumulative growth in demand.

The Sustainable Solar Market Package (SSMP) contracting mechanism was adopted in Philippines to provide for the supply and installation of PV systems, along with a maintenance-and-repair contract (e.g., 5 years with an option to extend) in a defined rural area. Applications in schools, clinics, and other community facilities are bundled with requirements and incentives for commercial sale to households, businesses, and other nongovernmental customers. Funding for the public and community-services facilities is provided by the government or other donors, while a grant is used to help household consumers defray the cost of SHSs. They either obtain a loan from a partner microfinance institution or pay cash for the balance of the SHS payment. By bundling applications in a defined area, the SSMP approach addresses key affordability and sustainability issues of past PV projects: standardization, reduced transaction costs, larger business volume, and reduced risk. In the Philippines, 7 such contracts benefiting 76 villages are currently being implemented, with preparation of more packages under way to benefit 400 villages. This again shows the necessity to incorporate the interdependencies into the model along with the need for identifying and addressing the *critical load capsule*.

CONCLUSION

The challenge of provision of energy services in rural areas is not a new one. Over decades, governments have made tremendous efforts to bridge the energy access gap. With new technologies and new business solutions, private sector has an opportunity to complement government efforts in accelerating the pace of energy access. There is a need for collaboratively create approaches that are commercially viable and sustainable. The theoretical 'A-B-C' model is a contribution to help initiate this conversation, but fails to incorporate the linkages and interdependencies between the various classes of consumers. This paper attempts to mathematically structure the dependencies and thus incorporate them into the model – presenting an improvised A-B-C Model for roll-out of off-grid energy solutions factoring these dependencies to arrive at a more comprehensive working and growth model, and thus ensure over-all sustainability of the off-grid project.

Figures and Tables

Fig. 1. Evolution of Power Distribution under A-B-C Model
Fig. 2. Evolution of Power Distribution under Abhijith's Improvised A-B-C Model

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Fast Identification of Fault Location with Fault Passage Indicators under Network Reconfiguration

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***Abstract*—As the size and complexity of distribution networks is increasing, remote operated switches are being used to make the grid smarter. The distribution network is being continuously reconfigured to improve the voltage profile and reduce losses. Consequently, when an outage occurs on this dynamically changing grid, it is difficult and time consuming to pin-point the location of the outage. In order to overcome this problem, fault passage indicators (FPIs) are installed at the beginning of each feeder at the branching points on the grid. FPI is a device which provides a remote and local visual indication of the occurrence of fault even after the isolation of line. While the technology of FPI is established, in this paper we present algorithms, which keeps track of network reconfigurations and provide fast identification of fault location, based on the multiple FPI signals received at the utility control center.**

***Index Terms*—Distribution Automation, Fault Passage Indicator, Outage Management System, Smart Grid**

I. Introduction

Power companies are in immense pressure to reduce outage time for customers. Electricity customers are incresing day-by-day forcing the power companies to provide reliable power supply with less outages. Overhead lines are vulnerable to faults, because of the system equipment exposed to extreme weather conditions. Identification of fault on medium voltage distribution network is tedious and time consuming, because of the complexity of network and access to locations. Under these circumstances fast and exact location of fault plays a major role. Fault passage indicator (FPI) serves the purpose of identification and location of fault. A fault passage indicator is a device which provides visual and remote indication of a fault on the electric power system. FPI also called as faulted circuit indicator (FCI), is a device used in electric power distribution networks for automatic detection and identification of fault location in order to reduce the outage time [1], [2]. FPI operates in such a way to detect the change in magnetic field radiating from the overhead line conductors caused by a fault [3]. This change in status creates an alarm by communicating through remote terminal unit (RTU) to the distribution system operator. FPI is able to distinguish between fault current and the load current associated with the healthy feeder. [4].

The earliest types of fault circuit indicators (FCI) used to be simple over current devices that employs the magnetic flux field of a high magnitude to mechanically move or rotate a flag to indicate the passage of the fault current. These devices required resetting manually after every operation, and if reset properly after every incident, did reduce troubleshooting time significantly. Fault indicators continued to grow at a faster rate as the importance of reliability of the power supplied increased. Public Utility Commissions and customers began pressurizing the power companies to provide power with better quality. Indices such as "System Average Interruption Duration Index (SAIDI)," "Customer Average Interruption Index (CAIDI)," and other indices are mandate measures for power companies. Reducing outage times by faster identification of trouble location was one method to achieve a reduction in overall outage duration. Fault indicator application on a widespread basis was recognized as the most economical and expedient means to reduce outage times. This solution provided a proactive method to address the concerns of Regulating commissions. Estimates of outage reduction capability of fault indicators ranged from 25 % to 50%. Empirical public data is scarce, but a review of one utilities success is available as published in T&D magazine in August 1995. With the advent of microprocessor and communication technologies FCIs are added with storage feature. The addition of this feature to standard FCI products further enhances the ability of fault indicators to adapt to circuit load parameters wherever they may be installed. Further developments for the integration of fault indicators into smart automated distribution systems is progressing at a number of companies on a trial basis but is difficult to justify economically on a stand alone basis. The fact remains that troubleshooting personnel must still patrol the faulty circuits during outages. The instantaneous notification via communication systems of the fault progression on a circuit can be beneficial if remote reconfiguration is available. [3]

FPI helps in improving the reliability of the system as it will improve the system average interruption duration index (SAIDI) and customer average interruption duration index (CAIDI), also helps in reduction of the energy not supplied (ENS). [5]. Fault Indicators can be used as a preventive tool in order to reduce costs to utilities and their customers, also it had an advantage of using with and without distribution automation [6], [7]. This paper presents an algorithm to pinpoint the fault location using FPI status in a radial distribution network.

The rest of the paper is organized as follows: Section II describes the algorithm used in this work. An illustrative example is presented for explanation of the algorithm. Section III includes the implementation and results of a radial distribution network. This is followed by conclusions and future work in Section IV.

II. Algorithm and Flow Chart

A. Upstream Algorithm

The algorithm starts with radial network data which contains the status of circuit breakers and fault passage indicators. The algorithm takes the input as pairs of devices like (FPI, Upstream FPI) and when the fault is initiated the algorithm processes the status of FPI by following the steps as shown in Fig. 1. After all steps in the flow chart are executed, output of the algorithm is fault location in terms of the index of FPI. This algorithm is relatively fast, as the algorithm does not proceed sequentially in identifying the fault location. But, as the network configuration changes, the algorithm needs to be updated. To address this issue another algorithm is presented in the following section.

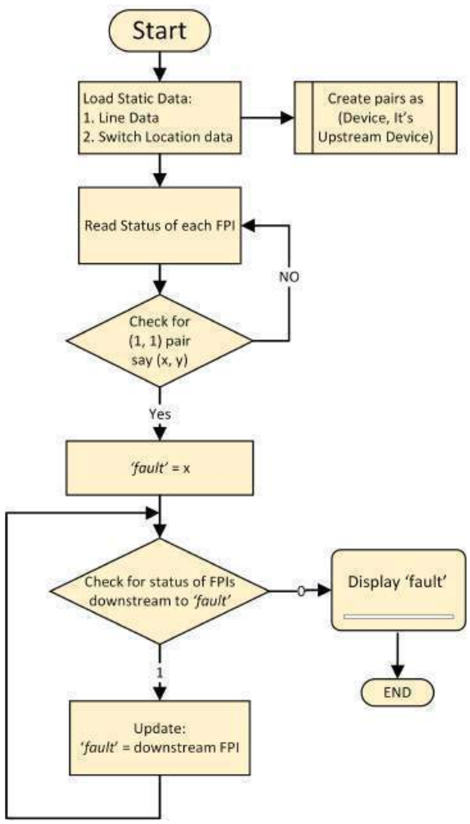

Fig. 1. Flowchart for fault location using upstream FPIs

B. Upstream and Downstream

The algorithm takes the input as sets of devices like (FPI, Upstream FPIs, Downstream FPIs) and when the fault is initiated, the algorithm processes the status of FPI by following the steps shown in Fig. 2. This algorithm initially checks for the circuit breaker status after the fault is initiated. Depending on the circuit breaker status it checks for the corresponding neighboring FPI status and processes according to flow chart. As this algorithm takes all neighboring FPIs into consideration, this algorithm not sensitive to network reconfigurations. However, as the program progresses sequentially it may relatively be slow in identifying faults far down stream.

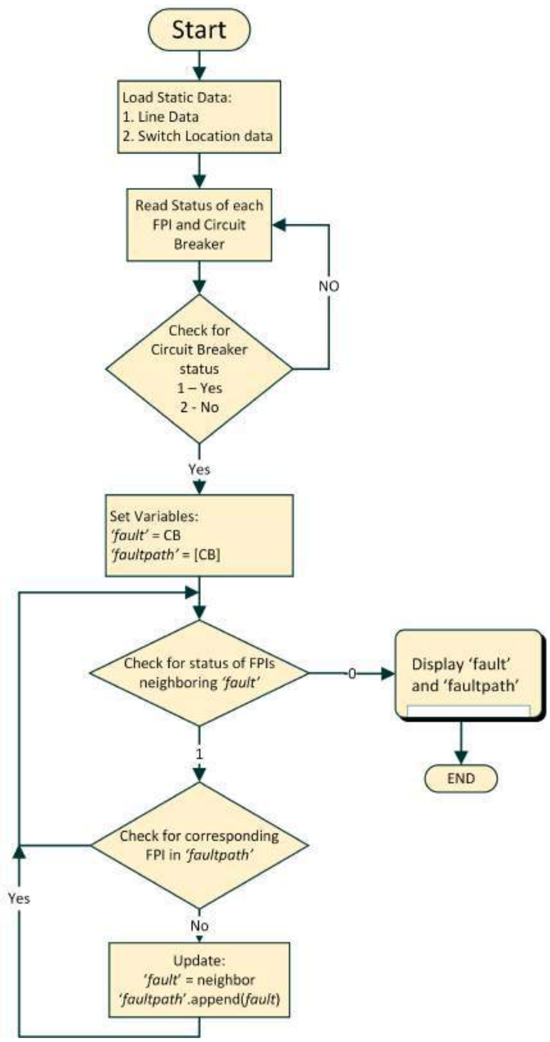

Fig. 2. Flowchart for Upstream and Downstream fault location

C. Illustrative example

Consider a radial network shown in Fig. 3. The feeder is connected through a circuit breaker and FPIs are connected at each branching point along the feeder. The example is used to explain the above mentioned algorithms.

1) Upstream Algorithm: Initially, a file is created with status of (Circuit Breaker, FPI) which is the input to the algorithm. A fault is created by connecting a fictitious ground between A7 and load point. Now, the algorithm check for all combinations of device pairs and if any device pair is (1,1)

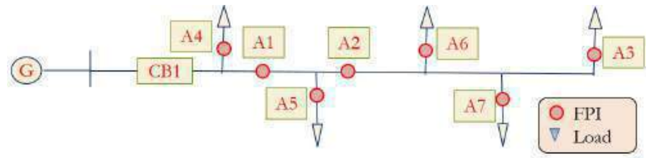

Fig. 3. Sample radial network

then fault = ‘first part of the pair’ like if we consider the pair as (x,y) then *fault* = ‘x’ and then it starts checking for the downstream FPIs. If any FPI status in the downstream is ON, then update the *fault* variable. This process repeats until all the downstream FPI’s status are checked. After completion of this process the output is *fault*=A7.

2) Upstream and Downstream Algorithm: Like in the previous algorithm, In this algorithm also a file is created with sets of FPI with its upstream and downstream FPIs. For the considered example, one of the sets is (A1, CB1, A4, A5, A2). Here, in this pair, A1 is the device and CB1 is the Upstream device and the remaining are the downstream FPIs before reconfiguration. Consider a fault is created by connecting a fictitious ground between A7 and load point. In the next step, check for the circuit breaker status and if the circuit breaker status is ’1’ then the *fault* variable is equal to CB and the first element of the *faultpath* array is set to CB. For the considered example *fault* = CB1 and *faultpath* = (CB1, A1). A1 is appended to the *faultpath* since the status of A1 is ON and it is not present in the *faultpath* before this step. Now *fault* = A1 and check for the neighboring devices. Repeat the process until all the neighboring FPIs are verified. Finally, the output is *fault*=A7. and *faultpath*=(CB1, A1, A2, A7).

III. Implementation and Results

The two algorithms are implemented for a radial network as shown in the figure. 4 [8]. The implementation is carried in a three layer process as shown in the figure. 5. The first layer is the input layer which contains the text files as switch data as the input to the second layer which is a processing layer. Switch data contains two columns, in which first column device id and the second column is the array of the neighboring devices corresponding to device id. The text file doesn’t change till the network is reconfigured. The second layer consists of FPIDemo python program which implements the above mentioned algorithm. And finally in the third layer the output is displayed. The results obtained by considering different faults are tabulated below.

The results obtained by implementation of the Upstream algorithm are shown in table. I. The first column indicates the fault created at load point by connecting a fictious ground and second column index or the FPI that is activated for the fault. Here a fault is created at a location near to A8 and A1 individually, and the program is executed for both the conditions and the result shows the index of the fault passage indicator (FPI). Similarly with the same fault location Upstream and Downstream algorithm is implemented then the result obtained is shown in the following table. II. Here in

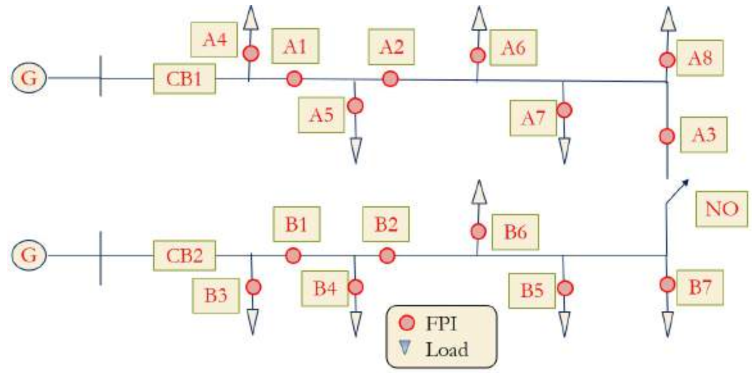

Fig. 4. Radial Distribution network

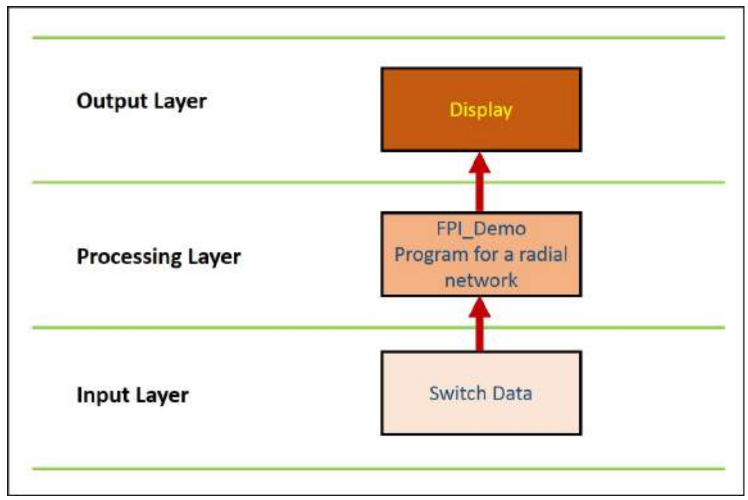

Fig. 5. Implementation

Fault created at	FPI index
At load point after A8	A8
Between A1 and A2	A1

TABLE I
Radial network result (Upstream Algorithm)

the table first colum indicates the fault created at load point by connecting a fictious ground, second column indicates the indexing of the fault passage indicator. Third column in the table presents the fault path i.e., the fault current path. This indicates the path to the power companies crew to check for the fault and isolate. If the FPI id contains the geographic location then it would become more easy to isolate the fault. This clearly indicates the reduction in the outage time for the fault.

Fault created at	FPI index	Fault path
At load point after A8	A8	CB1, A1, A2, A8
Between A1 and A2	A1	CB1, A1

TABLE II
Radial network result (Upstream and Downstream Algorithm)

The network is reconfigured by turning ON Normally Open

Fault created at	FPI index	Fault path
At load point after A8	A8	CB2, B1, B2, A3, A8
Between A1 and A2	A2	CB2, B1, B2, A3, A2

TABLE III
RE-CONFIGURED RADIAL NETWORK RESULT (UPSTREAM AND DOWNSTREAM ALGORITHM)

(NO) switch in the figure. 4 and CB1 is turned OFF. The Upstream and Downstream algorithm is implemented for the reconfigured algorithm and the results obtained, are shown in the table. III. The columns in this table are same as previous table. It is observed from the second row of the table, same fault is created by between A1 and A2, but the fault and fault path are changed when the circuit is reconfigured. This algorithm provides the added advantage of reconfiguration. If the circuit is reconfigured remotely by a distribution company through distribution management system (DMS) then FPI indication will work with the presented algorithm. FPI will automatically resets if the fault is isolated remotely.

IV. CONCLUSION AND FUTURE SCOPE

This paper presents an algorithm for fast identification of fault location using FPIs. From the above results it is observed that the algorithm works properly for radial network systems. Also it is observed that the Upstream algorithm executes faster, but the limitation is that it is sensitive to network reconfigurations. The issue is addressed and the Upstream algorithm is modified to Upstream and Downstream algorithm. It is observed from the results of table II and table III, it is conluded that even with the Circuit breaker CB1 in OFF status the algorithm finds the fault path. One of the observations is that the fault path shows the fault current that is flowing and the loads that are affected. With the faultpath identified, a message can be sent to the customers who are being affected because of the fault happened and estimated time can also be presented. With FPI's indication of LED glowing the time of outage is presented. From this it can be concluded that the FPI plays one of the major role in the distribution automation.

The possible future work is listed below:

- Improvement of algorithm for larger distribution network.
- Implementation of the algorithm for multiple faults.
- Visualization of output can be improved.

This paper presents the implementation of the fault passage indicator (FPI) in distribution network which has the capability of identification and location of fault in order to reduce the outage time.

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Open Automated Demand Response: Industry Value to Indian Utilities and Knowledge from the Deployment

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***Abstract* – India suffers from severe electricity shortages, particularly during peak demand hours, and often experiences shutdowns from several hours to days in certain locations. India faced an unprecedented blackout for two days in July 2012 that affected an estimated 680 million people, which is twice the population of the United States. This blackout highlights the increasing pressure on India's power system for infrastructure and market investments for peak load management and customer engagement. Certified Smart Grid products and technology solutions from the industry provide a robust Automated Demand Response (AutoDR) system to automatically manage demand when the grid is under stress. Using the AutoDR solutions by Honeywell, a key utility vendor in India, is testing the deployments of a cost effective AutoDR solution with its customers. The DR communications technology, developed by a U.S. national laboratory, is an open specification with a compliance-testing program for interoperable deployments.**

Tata Power Delhi Distribution Limited (TPDDL) is the first Indian utility to launch the AutoDR project with smart meters in the nation's capital. The project is implemented in partnership with Honeywell, IBM, and third-party MDMS (Meter data Management system) vendor, with participation from industrial and commercial electricity customers. A total of 173 consumers participated in this project. Utility customers having load greater than 100 kilowatts (kW) and a consolidated connected load of over 400 MW are included in the project. The project includes about one hundred 11-kilovolt feeders, fed from 40 substations spread across the utility's distribution territory. This paper reports the deployment lessons and technical challenges relevant to the Indian context.

Keywords— *Smart Grid Technologies; Automated Demand Response; Interoperability Standards; Peak Load Management;*

I. Introduction and Background

Certified Smart Grid products and technology solutions from the industry provide an Automated Demand Response (AutoDR) system to manage demand when the grid is under stress. AutoDR enables the utilities to send grid reliability and price signals to customers' controls and equipment, enabling the customer-chosen pre-programmed strategies to be activated with no human in the loop. .The DR communications technology, developed by the Lawrence Berkeley National Laboratory (LBNL), is an open specification with a compliance testing program for interoperable deployments.

Honeywell Smart Grid solutions provide the very reliable commercial and industrial AutoDR system, which is certified for interoperability. This solution includes the demand response automation server (DRAS) and automated demand response (AutoDR) Gateway. For the AutoDR, the facility controls are pre-programmed by the customers, and responses are fully automated to a receipt of an external signal from a utility. Customers are always notified of the DR event and have the option to opt out if they choose to. Honeywell's DRAS is a tool proven to achieve the goals of customer engagement and provide cost-effective and fully automated DR. The Honeywell DRAS was developed working with LBNL using an interoperable and standardized specification, supported by a testing and certification platform. It is the central point that manages utility DR programs, from participant registration through event management and monitoring. The AutoDR Gateway has been reused from the existing ComfortPoint™ hardware platform deployed at the customer site. It can integrate with site energy meters, collect energy data, and send the data to the DRAS.

Interoperability for DR communications was achieved through Open AutoDR specifications (OpenADR). OpenADR is U.S. national standard for standardized DR Price and reliability information. These standards were developed using the OpenADR 1.0 communications specifications, with the standards development organization, Organization for Advancement of Structured Information Standards (OASIS), developed the OpenADR 2.0 profiles under the Energy Interoperation committee [1]. These profile specifications, supported by the industry, were part of the OpenADR Alliance's testing and certification for the building controls and devices to receive and respond automatically to DR and price signals [2]. This specification helps the vendors to standardize, automate, and simplify the solution so that it provides the interoperability across the multivendor products. The International Electrotechnical Committee (IEC), under

Project Committee 118, is considering OpenADR 2.0 for international standardization, which would allow vendors to harmonize interoperable products globally [3].

TPDDL one of the most progressive utilities in India's capital became the first utility to launch the AutoDR project with smart meters. The project is implemented in partnership with Honeywell, IBM, the AMI for the project was from a US vendor, with participation from industrial and commercial electricity customers. A total of approximately 173 consumers participated in this project, with an aggregated peak demand of over 67 megawatts (MW). Utility customers having load greater than 100 kilowatts (kW) and consolidated connected load of over 400 MW are included in the project. The project includes about one hundred 11 kilovolt feeders, fed from 40 substations spread across the utility's distribution territory.

This paper reports the deployment lessons and technical challenges relevant to the Indian context. It is organized in two sections: the applications of technology solutions, and the major deployment challenges.

A. Background

At present, utilities and consumers in India are not very aware of DR technologies and their benefits. The current DR demonstration project provides an opportunity to instill confidence and trust of DR technologies on the part of government and private utilities, and also enable consumers to participate in demand response programs. Demand response programs enable consumers to play a significant role in the operation of the electric grid by reducing or shifting their electricity usage during peak periods, in response to time-based rates or other forms of financial incentives. Electric system planners and operators are using them as a demand-side resource options for balancing supply and demand. Such programs can lower the cost of electricity in wholesale markets, and in turn, lead to lower retail rates apart from providing opportunities to improve energy efficiency in their equipment and processes.

The aforementioned technology solutions have the potential to address the electric grid reliability and also alleviate the pressure on the power system by making the demand flexible through DR programs. The applications of such technologies can enable utilities and customers to leverage the existing infrastructure to address the shortage of peak power and improve reliability in the system.

II. Applications of Technology Solutions

The DRAS is managed by the utility to send AutoDR signals. The signals are based on programs defined by the utility. The OpenADR Gateway receives load shed events and communicates the shed events to the shed strategies configured in the site for reducing the current demand from that site. The commissioning tool allows users to quickly deploy the gateway in the site and reduces the commissioning time with an enhanced user interface.

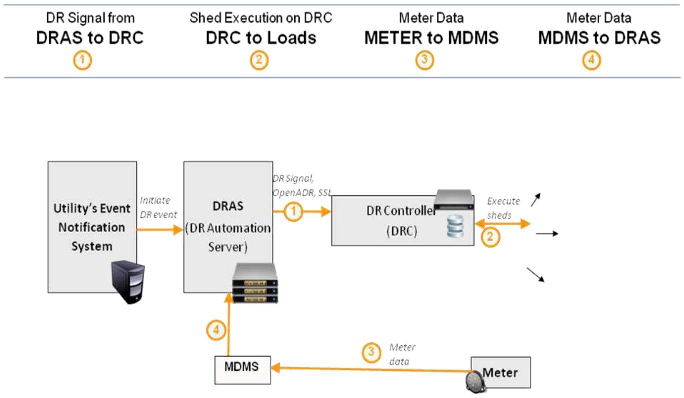


Fig. 1. AutoDR deployment topology between a utiltiy and a customer.

DRAS is integrated with the utility's event notification system, either by manual event notification by the operator or through an automated process. These events are converted in DR signals, and those are transmitted to the demand response controller/gateways in the site. The DR controller then shuts down or modulates the loads based on the shed strategies configured or commissioned in the site for each load. The meter data is integrated via the Meter Data Management System (MDMS) interface, where all the consumer's meter data are integrated with each site. The meter ID of each customer is used to associate the gateway with the meter data to calculate the telemetry, baseline, and calculated demand.

A. Honeywell Demand Response Automation Server

The Honeywell DRAS[4] is the central communication network used by the utility to efficiently manage DR program participants, understand device communication status, and initiate and manage AutoDR curtailment events. Upon the event initiation, OpenADR signals are communicated to each facility's Energy Management System (EMS) or control system, automatically initiating shed strategies predefined and implemented in collaboration with the customer.

With the Honeywell DRAS, the utility will be able to:

- Generate load shed via an end-to-end solution that allows a variety of flexible, automated load control events;
- Predict, monitor, and verify load shed;
- Adhere to standards and open protocols, thus lengthening asset lifecycles, allowing system interoperability and facilitating development of compatible software and hardware by a broad network of participating vendors; and
- Access the data and analytics required to quantify the benefits of demand response in real time, and initiate and monitor the effect of demand response events via a user-friendly utility dashboard.

B. Low-Cost Demand Response Gateway Solution

A low-cost demand rresponse gateway [5] is used to address key issues, such as:

- Complexity in deployment and configuration,

- Needed well-trained engineers for deployment, and
- High cost of hardware.

The AutoDR Gateway has been reused from the existing Building Solutions hardware platform deployed at the customer site. It has the capability to integrate with site energy meters, collect energy data, and send the data to the DRAS server, which is managed by the utility. Also, based on the programs defined by the utility, the Open AutoDR Gateway receives shed events and communicates them to the shed strategies configured in the site for reducing the current demand from that site. A commissioning tool allows the user to quickly deploy the gateway in the site and reduces the commissioning time with an enhanced user interface.

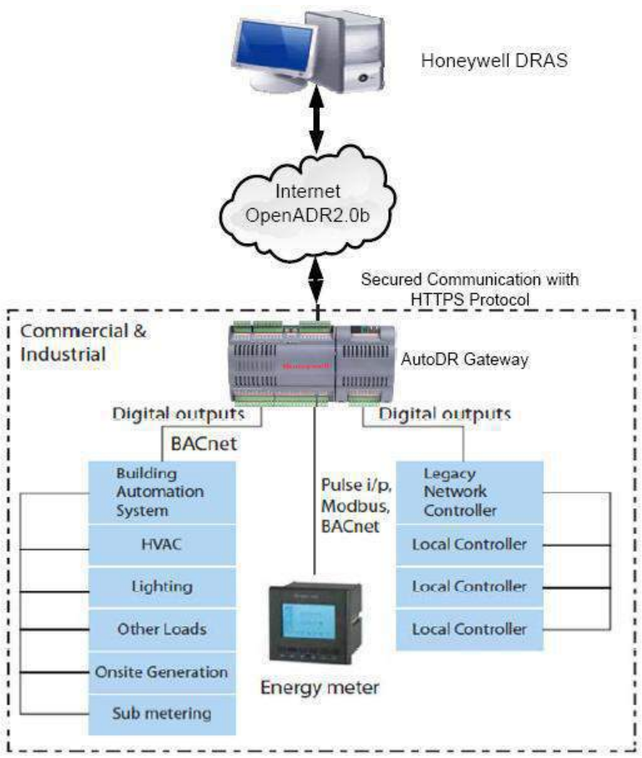


Fig. 2. AutoDR Gateway features and connectivity of the sub-systems.

The major features of this DR Controller are as follows:

1. Certified OpenADR 2.0b profile.
2. Meter Integration via industry standard protocols such as Modbus RS485, BACnet IP, BACnet MSTP, and Pulse interface.
3. Data storage up to five days, and the data can be recovered if communication failed between DRAS and AutoDR Gateway.
4. Configurable meter data push intervals.
5. Network Time Protocol (NTP) server communication to enable time synchronization.
6. Standard network configuration support, to secure the gateway communications.
7. Integration to building management system though a BACnet interface.
8. DR events triggered through onboard digital output terminals.

The DR and pricing standards used by the utility's DRAS and customer's DR controller provide the following benefits, in addition to interoperability:

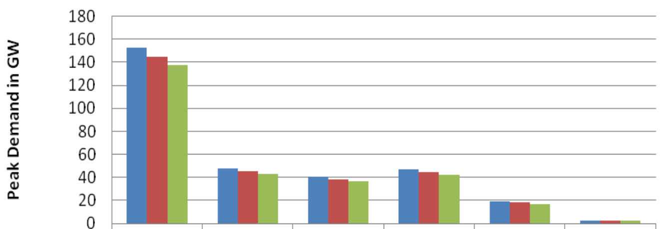
Low-Cost Deployments: This does not refer to hardware costs, which depend on the installation, commissioning, meter integration and integration of the AutoDR Gateway with the loads. Most of the older AutoDR Gateway solutions are using an OBIX(Open Building Information Exchange) interface to communicate meter data to the DRAS servers. Even though the protocol is interoperable and the configuration necessary to commission the system is time consuming and based on field inputs, it used to take an average of two days per site to deploy and commission the solution. Also if a user wants to integrate the system with third-party DRAS providers (or vice versa), then the systems will require much testing, modification, and customization.

With the new OpenADR 2.0 reporting service, it very easy to integrate the meter data from the field to the Gateway and then provide the data to the utility servers or DR management systems. Field technicians for the Honeywell new AutoDR Gateway with OpenADR 2.0 need very minimal training, and with minimum configurations the system can be deployed and commissioned in four to eight hours. Due to the above-mentioned savings, this will reduce the cost to serve to the customer, improve productivity, and quicken deployments.

Cyber Security: Security issues arose with previous AutoDR systems on the market. With OpenADR 2.0b, security considerations are embedded in the specifications; they are mandatory for OpenADR 2.0 compliance. This instills confidence in customers that the system is secure. As utilities and customers use the OpenADR2.0b solutions, the team has identified enhancements on the security considerations.

C. *India Auto DR Market Potential (Region-wise)*

Figure 3 shows the region wise AutoDR market potential in India. These assessments were done by smart grid operations team at Honeywell after conducting multiple workshops with the regional utilities and assuming the factors such as type of DR programs perused, market acceptance of the programs and overall cost effectiveness of the programs.



	All India	North	South	West	East	North East
BAU	152.746	48.136	40.367	47.108	19.088	2.536
Achievable	145.1087	45.7292	38.34865	44.7526	18.1336	2.4092
Maximum	137.4714	43.3224	36.3303	42.3972	17.1792	2.2824

Fig. 3. AutoDR market potential in India

The assessments indicate the following:

- Northern, Western, and Southern regions contribute for about 90% of India's peak demand.
- Assuming that the commercial and industrial (C&I) sector contributes 50% to peak demand, with the other 50% attributable to the residential and rural sectors.
- The C&I demand response market size throughout India is 3.81~7.63 gigawatts (GW).
- The C&I demand response market size in the Northern, Western, and Southern Region is 3.39~6.78 GW.

III. TECHNOLOGY DEPLOYMENT CHALLENGES

As this is one of the first AutoDR deployments for both Honeywell and the utility, the technical and management team has faced the following major challenges. These challenges lead to increase in deployment cost by 15% to 20%. That includes procurement of new devices such as modems and uninterruptible power supply (UPS) systems, integration of manually controlled loads, and other factors.

A. Interoperability challenges – Integrating the MDMS with DRAS Server.

The major challenges involve getting the meter data of all consumers from the MDMS system, mapping them to ggateways connected to the customer, and mapping them in a customer portal. Using the support of OpenADR 2.0b services, using Ei Report service, we achieved this interoperability and used the customers' meter IDs to map them to the gateway and in the customer portal. The MDMS acted as another OepnADR 2.0 client for the utility's OpenADR 2.0 server.

B. Handling Bulk data between DRAS and Gateways

To reduce the modem cost and the tariff rates, the system is designed to support GSM modems. Due to the lower network bandwidth, there were issues transferring the large amount of data from multiple sites to and fro from the DRAS to the gateway. And many of the gateways showed offline even though the gateways are online. The team configured the varying polling frequency in the gateways so that the gateways can poll the DRAS in different intervals to reduce the load on DRAS server.

C. Load Segregation Challenges

The segregation of critical and non-critical loads under the single site is always a challenge because of the inconsistent consumption patterns of the most of the consumer sites. Also in many cases customer did not have supporting technologies or equipment, which could support the integration into the controller.

D. Consumer Level Holiday, Customized Calendars

The DRAS server was supporting the common system-level calendar and holiday schedules. It was difficult to configure some of the customers' DR with this calendar who had different schedules. But most of the production industry consumer's operating calendars are different, and are not common. This new feature to standardize this information will be a new enhancement for upcoming releases.

The consumers' energy consumption patterns are not consistent and because of this representing the shed in the telemetry view is very difficult and even if we display the shed window it doesn't look like actual shed due varying consumption patterns. The technology team is currently working on this issue to find a solution.

E. Customer's Internet availability

Most of the customers did not have Internet access at the facility and because of that the team had to identify the low-cost Global System for Mobile communication (GSM) modems to enable the communication of AutoDR gateways with the DRAS server. Ensuring a secure installation of these modems at the sites was the major challenge.

F. Power Backup for the Gateways

The AutoDR controller is expected operate 24/7, so that it is receiving DR events from the DRAS server and sending the meter data to the DRAS server. Any interruption in the DR controller operating power supply may lead to improper operation of the DR system deployed in the consumer site. So a UPS power backup is necessary for a DR deployment if it does not have power backup facilities. In the current deployment, almost all the consumer sites do not have the power backup, so the deployment team needs to maintain a local power backup using UPS within the DR controller panel. This addition of the UPS led to the increase in deployment costs.

G. Integration of Manually Controlled Loads

In most consumer sites, such as flour mills and other production industries, the loads, such as pumps and motors, are not monitored through the automation system. These loads were controlled manually using electrical panels. When DR controller receives the shed events, it was not possible to detect the loads which are in ON status and for such loads trigger the appropriate shutdown commands. To overcome this integration issue, the team developed a small relay assembly, which can monitor the status of the load and drive the events received from the DR controller to respective loads which are in the ON state.

H. Regulatory Policies

The present project was done without offering any incentives to the customers. To encourage a larger participation, a incentive scheme for the customers to be introduced and regulator policies should encourage DR and energy efficiencies with specifics to support the technologies and solutions.

IV. CONCLUSIONS AND FUTURE WORK

This paper reviewed the technology solutions for addressing grid reliability and peak power in India. The findings from the application of these technologies were derived from an AutoDR project within a large utility in India's capital, New Delhi. Through the project's deployment, the team learned many lessons on the contextual applications of technologies with Indian customers and electricity markets.

The technologies successfully enabled an interoperable DR signaling infrastructure to the utilities. The controllers in the facilities used these signals to automate their responses. The results of these responses, conducted in another study, was over 10% of the peak load [6]. The technologies in each customer sector had its challenges. For example, the dust in the flour mills required an enclosure and heat dissipation methods. Even under these circumstances, the flour mill and industrial customer sector provided the most significant DR peak reduction, in the range of 10% to 20% [6].

The project has proved that AutoDR technologies provide value to both customers and utilities to leverage the load flexibility as a cost-effective and carbon-friendly solution to the increase in the generation capacity. Some specific technical findings from the deployments are as follows:

A. Automated Demand Response – Values Delivered

1) Scalable and Flexible Platform

With a single platform, DRAS allows customers to participate in multiple programs, depending on their business rules and the response nature of participating loads. As noted in Indian utility demonstration project requirements, flexibility and scalability is critical to successfully serving many different types of customer facilities, from office buildings and multi-use commercial buildings to college campuses and smaller factories.

2) Single Unified Head End

As a singular unified Auto DR head end platform, the DRAS can be deployed not only for these commercial sites, but also in future this can also be integrated to Non Honeywell commercial and industrial facilities, and residential buildings.

3) Customer Benefit, Relationships and Trust

The utility retains the customer relationship. It owns the curtailment portfolio and initiates the event from its command center. The utility is offering value to the customer, and therefore the program offers a great opportunity for it to provide a higher level of customer service. This is going to be of paramount importance in future, as the regulator approves retail supply of electricity in Delhi. The program will initially be implemented at 250 commercial customer sites, and will scale to thousands over time. The curtailed portfolio will be very reliable, as the solution is "co-authored" with the customer, taking into account the "business rules" applicable for the particular facility. The opportunity the solution provided for the customer to have detailed information of his consumption and load will help them to manage their load effectively and use the same to reduce their bill looking at their Time of the Day (ToD) tariff. The detailed audit also informs the customer how he can save electricity by becoming more efficient and using energy saving equipment and processes. The solution also gives customer a portal which provides his details of his consumption data including load profile which would help them in identify opportunity to improve energy efficiency and productivity, thus the solution also empowers the customer.

4) Event Management - Enhanced Analytics

The redesigned user interface includes features such as data/resource visualization, grouping of assets, and aggregation, which enable the utility to get the most out of every demand response event. More analytics continue to be implemented, and they will be available to the utility as they become available.

5) Customization Flexibility

Honeywell's DRAS is customizable based on the needs and requirements of utility. The DRAS is used to place pending call notices, calls, and post-call follow-up notices on the web, while other system components—such as the AutoADR Gateway poll the web interface, receive these notices, and act upon them. This polling process produces rapid responses to event calls. Commands can be delivered to the gateways in less than 10 seconds.

6) Dashboards and Baselines

DRAS generates baselines for the participating facilities, leveraging the meter data received from the site. DRAS follows the n/m baseline to calculate the baselines. The n/m baseline model is the average hourly load shape of the "n" highest consumption days within "m" selected like-days. DRAS adopts three common n/m weekday models: 3/10, 5/10, and 10/10[8]. In addition to using historical data from previous days, DRAS offers the capability to adjust baselines, based on measurements made in the morning of the same day, called *morning adjustments.*

7) Ease of Integration and the Software as a Service (SaaS) Deployment Model

DRAS offers application programming interfaces that can be used to integrate with any enterprise software used by the utility. In the current scenario, DRAS will integrate with the MDMS of utility's choice, thus reducing extra costs involved in installation of additional meters at the site, for baselining and reporting purposes. In a similar way DRAS can integrate with the Customer Relationship Management (CRM) system, payment systems, etc.

8) Open Standards-based Solution

The Honeywell AutoDR solution is based on open standards. The DRAS is OpenADR 2.0b certified. Utilities receive the following benefits from adopting the open standards-based solution:

- It ensures that utilities are not tied in to a singular or proprietary technology.
- There are no post-pilot stranded assets for the utility.
- OpenADR has already been adopted by 100+ vendors.
- It is scalable for generation-side activities

9) Cyber Security

Security is a central concern and an important element that must be addressed by any utility seeking to take advantage of the Smart Grid. Any "smart grid" system must be able to detect, prevent, and communicate and recover from system security threats, up to and including cyber security threats and terrorism. The Honeywell AutoDR solution was thoroughly evaluated to ensure that critical infrastructure cyber security standards were followed for all the elements in this project.

Honeywell addressed the functional requirements of cyber security at three levels: physical security, server security, and client security.

10) Easy Opt Out

Another feature DRAS provides to customers is an option to opt out of DR events and notify the utility. Cellular Short Message Service (SMS) functionality was used to opt-out of the DR events when customers chose. This opt-out functionality using SMS was unique, and the customers were using it without any additional documentation or training.

11) Better Asset Management

A good backing of DR potential from a network would give opportunity for utilities to optimize their assets and network. The changing customer behavior which is bringing in increased use of air conditioners and other electrical appliances would result into stress in the network, DR could be a better potential product to address to this need rather than increasing power procurement.

B. Future Work

The AutoDR technologies have a significant potential for deployments in the Indian markets. With the U.S. vendors such as Honeywell, IBM, and others that have competitive technology solutions for residential and commercial AutoDR services, additional field applications by the utilities are necessary to gain knowledge and support the scaling of technology transfer in new emerging markets in India. Technology vendors must work on the technology innovations to reduce the cost of the overall solution for the high-growth regions and demonstrate the solution to utilities across India. The bilateral collaborations between the U.S. and India must support the initiatives to promote AutoDR in the Indian market, as well in other high-growth regions. Both the public and private sector must work to develop the advanced shed strategies that are supported by the building management system for the standard loads. Such actions will provide the flexibility in integration of the AutoDR system with larger commercial and industrial buildings though their integrated building management system and a resource to the electric grid. The Smart Grid solutions team in Honeywell must provide any new feedback from deployment lessons to the standards organizations and policy makers with respect to interoperability and security for India-specific markets.

To make concept of Smart Grid succeed it is important for the government to come with policies, which essentially encourage energy efficiencies, reduce cost of power, and reduce our energy intensity.

ACKNOWLEDGMENT

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BIOGRAPHY

Rajesh V Poojary is a System Engineer in Honeywell System Engineering Group, working as a Solution consultant and Business Analyst, having 12 years of experience in IBMS domain, HVAC(Heating Ventilation Air Conditioning) design, consulting and commissioning, automated demand response, requirement engineering and analysis, and IBMS(Integrated Building Management System) training. He is having good hands-on experience with smart metering deployments, AutoDR deployments in C&I along with Honeywell and Non Honeywell BMS(Building Management System) systems. Prior to Honeywell he worked with Jonson Controls, India in HVAC design and commissioning. Rajesh holds Engineering degree Electronics and Communication, Master's of Science degree in Embedded and Control system design.

Girish (Rish) Ghatikar is a Deputy Lead for the Grid Integration Group, overseeing the U.S. and international demand response technologies and related clean energy technologies, services, and business. Ghatikar is also the project director of the U.S.–India Joint Center for Buildings Energy Research and Development (CBERD). Ghatikar holds Master's of Science degrees in Telecommunication Systems (Computer Technologies), and Infrastructure Planning/ Management, and a bachelor's degree in Architecture.

Ganesh Das heads the Strategy and Business Relations at TPDDL. His experiences are in the areas of strategy planning, business development, customer relationship management, process improvement, consulting and technology. His key interest areas are consumer behavior and effect of Technology on Consumers. He was the part of the global team involved in conceptualizing, development and enablement of “Smart Grid Maturity Model”(SGMM) whose rights now rests with Software Engineering Institute (SEI), Carnegie Mellon University (U.S). Dr. Das is holds a MBA, LLB and PhD in the area of Strategic Marketing and Consumer Behavior from Indian Institute of Technology, Delhi, India.

Sujoy Kumar Saha is an Electrical Engineer with specialization in Power Distribution. He has more than 24 years of rich experience in various organizations like HM, West Bengal State Electricity Board and Tata Power Delhi Distribution Limited. he is Deputy General Manager with Tata Power Delhi Distribution Limited (TPDDL, a Tata group company, he is responsible for major technology interventions including Smart Grid Initiatives.

Oracle Utilities Analytics

Transforming Complex Data into Business Value

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Abstract

Empowering Utilities With Data.

Despite expectations that smart meters will yield significant benefits for utilities, many distributors remain unprepared to realize the potential of these devices. A recent report by Oracle reveals more than two-thirds of utilities executives expect the advantage of the smart grid to exceed the industry's original expectations. Only 17% of utilities say they feel that have the tools and expertise required to make good use of the data they will collect from smart meters.

Data will be the driving force behind a successful smart meter roll-out. Insight from data analytics will help utilities boost engagement among today's energy-conscious public, better manage their networks and promote more intelligent energy use.

At the heart of smart meter technology lies the near instantaneous analysis of large amounts of metering data across the network. Energy providers will use this data to improve network conditions, automate network management and offer individualized services to their customers. Analytics will allow for exceptional levels of network and billing automation that will enable utilities to cut the time it takes to convert meter data into accurate customer invoices.

Even during periods of normal operation the analysis of smart meters can help utilities take advantage of these widespread data points to gain a better visibility into how electricity is being distributed throughout the network. With this information they can spot warnings signs and problems before things go wrong.

This presentation will explain the steps utility organizations need to take to revise their business models and boost IT in preparation for smart meter rollouts to ensure that best use is being made of the available data to better plan and manage the utility business.

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Transforming Complex Data into Business Value
India SMART GRID Week 2015
March 2015 | Bengaluru, India
Balu Ramasamy
Director – Utility Solutions
Utilities Global Business – Sales Consulting J-APAC
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Top Performing Companies use Analytics to Drive Business Performance

New Insights Shape Strategy and Execution

Imagine what analytics can do for your business

3x

Top performers are **3x** more likely to use analytics than low performers

53%

Use analytics to drive **strategy**

50%

Use analytics to transform **daily operations**

Sources: MIT, Gartner, Nucleus Research

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Top Performing Companies use Analytics to Drive Business Performance

Organizations Which Use Analytics Get

$10.66 For every **$1** they spend on **analytics**

...and The Potential for Utilities Is Huge

Only **17%** of utilities are completely prepared for the data influx. Up from **9%** in 2012.

Just **20%** of utilities give themselves an "**A+**" for getting information to the people who need it. Up from **8%** in 2012.

Sources: MIT, Gartner, Nucleus Research; Oracle Study 2013 – "Utilities and Big Data: Accelerating the Drive to Value"

Utility Industry Challenges are Driving the Need For New Analytic Paradigms

Deliver affordable electricity/gas/water to customers reliably, cleanly and safely

Analytics are Fundamental to Improving and Sustaining Utility Business Performance

Improve…

Customer Satisfaction
Targeted Interactions

- Segmentation-driven marketing offers
- Proactive alerting
- Personalized communication

Reliability
More Effective Monitoring and Proactive Maintenance

- Asset management
- Transformer load management

Operational Efficiency
Better Planning and Execution

- Employee utilization
- Revenue assurance
- Optimized field work

Safety
Understanding and Mitigating Hidden Risks

- Reducing public safety hazards
- Vegetation management
- Field work management

Oracle helps your utility transform into a data driven organization.

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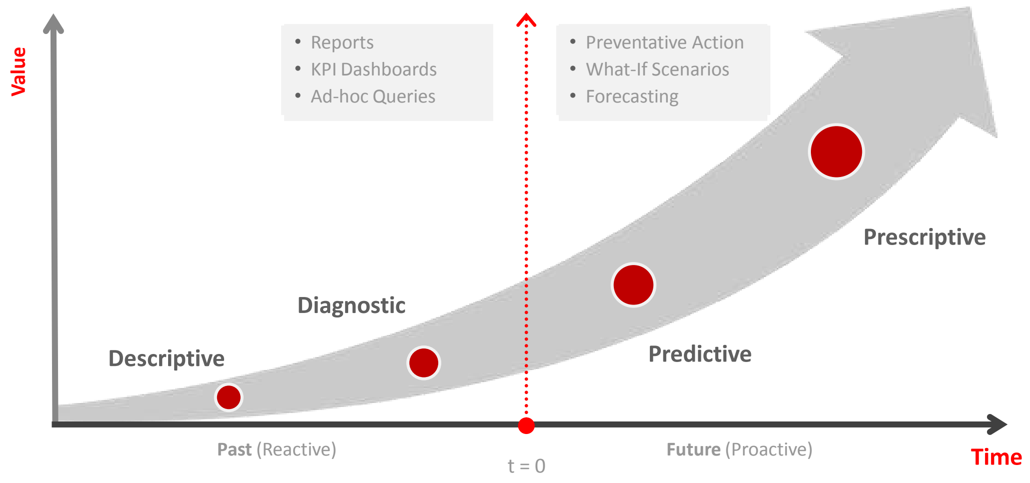
Leveraging Information to Act Fast & Efficiently



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Utilities Face Key Challenges in Realizing Full Value of Analytics

Information Silos	Static Business Processes	Skill Set Gaps

Collaborative Analytics Approach	Operational Integration of Analytics	Actionable Insights

Analytics Myths Lead to Failed Initiatives

- ✖ A single system can solve **all** analytical needs
- ✖ The “calculator” is the **most important** part of solving complex math problems
- ✖ Each utility’s needs are **totally** unique
- ✖ Build it and they shall come
- ✖ There is a **finish** line

A Closed Loop Approach is Required to Create Lasting Analytical Benefits

Important to consider the entire analytics process

ORACLE

A Complete Analytics Solution…

Collaborative Approach

Learns from expertise across industries, across utilities and across utility organizations

Shares data and results with all stakeholders

Capture

Integrated to source data from both operational systems and third party data

Supports both real-time and batch data feeds

Improve

Focused on results driven outcomes

Provides a feedback loop to improve outcomes

Integrated into operational systems

Organize

Broad functional area coverage

Easily extensible

High performance/scalable

Secure & sensitive to privacy

Analyze

Skilled analytics team

Process driven analytics approach

Robust data mining tools

Prebuilt analytics content

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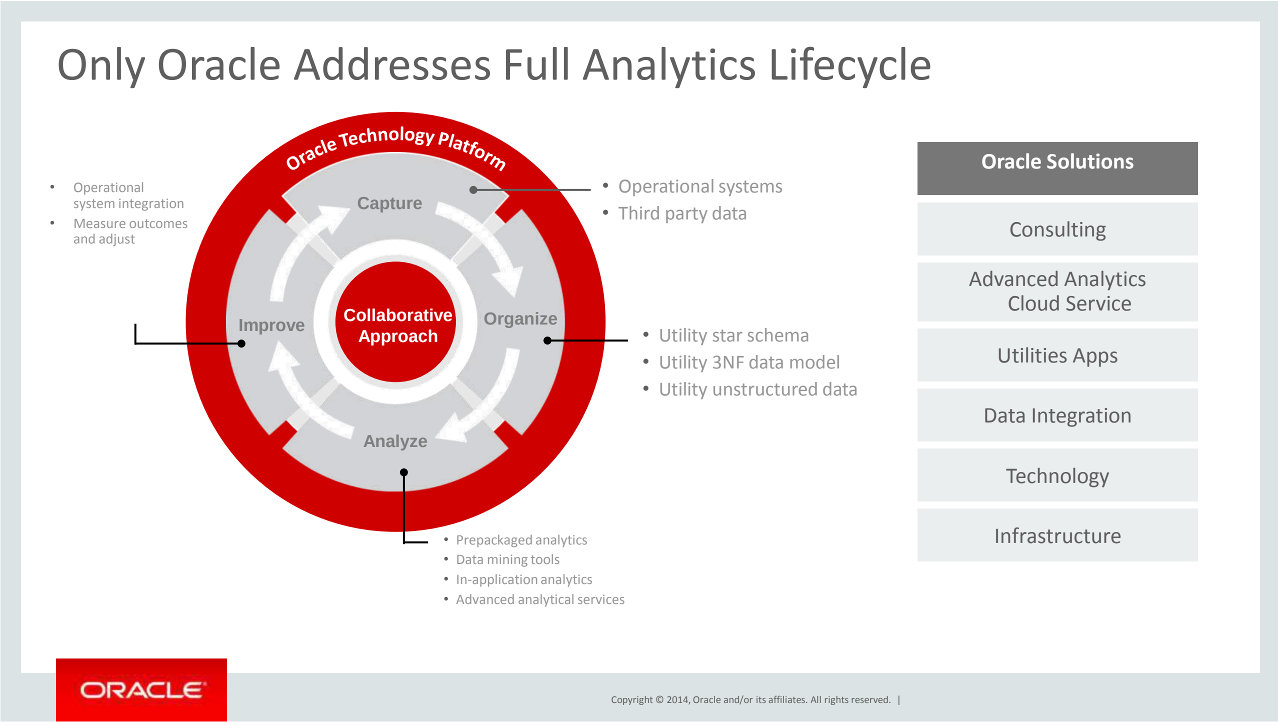
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Organize
Analyze
Improve
Collaborative Approach
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• Measure outcomes and adjust
• Operational systems
• Third party data
• Utility star schema
• Utility 3NF data model
• Utility unstructured data
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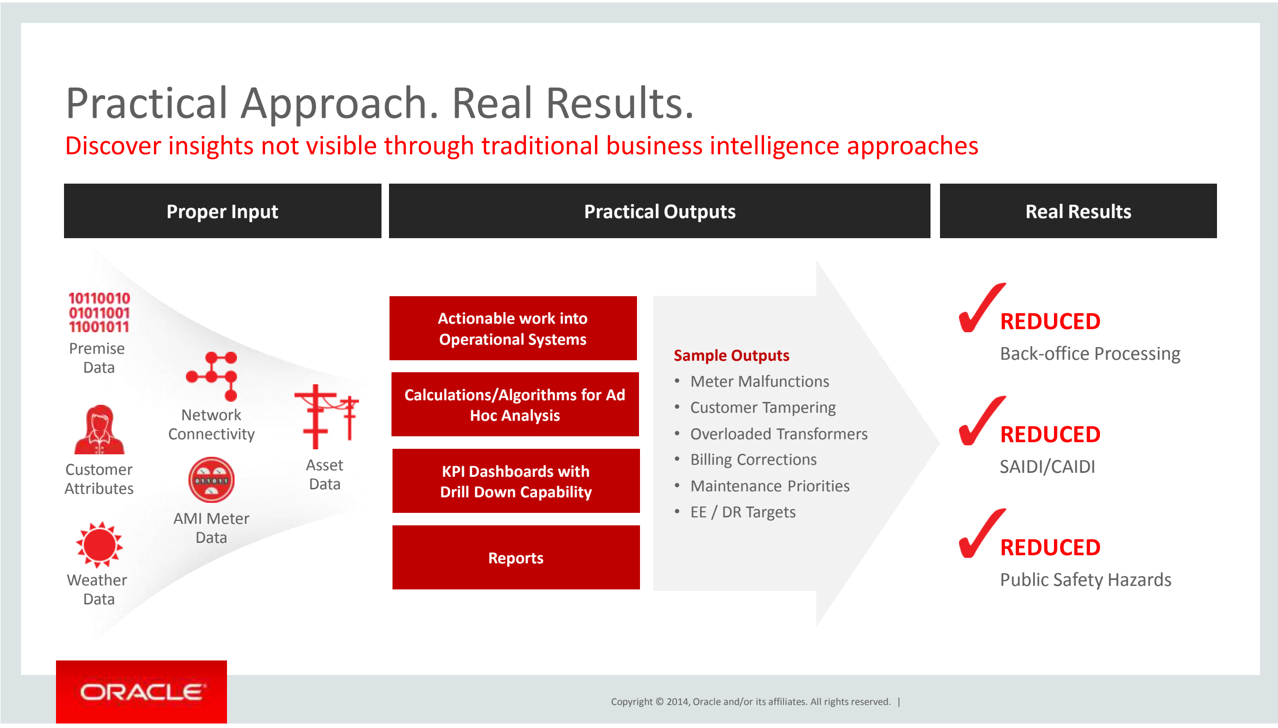
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Practical Outputs
Real Results
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01011001
11001011
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Network Connectivity
Asset Data
Customer Attributes
AMI Meter Data
Weather Data
Actionable work into Operational Systems
Calculations/Algorithms for Ad Hoc Analysis
KPI Dashboards with Drill Down Capability
Reports
Sample Outputs
• Meter Malfunctions
• Customer Tampering
• Overloaded Transformers
• Billing Corrections
• Maintenance Priorities
• EE / DR Targets
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REDUCED
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Achieve Success by Demonstrating Results and Quick Iterations

60-90 Days	Expand Use Cases. Maintain Value.	Exploit Data Platform. Maximize Value.
		
• AMI Performance • Revenue Protection	• AMI Performance • Revenue Protection • Transformer Load Mgmt **or** • Optimize Appointment Scheduling • Improve Crew Productivity • Optimize crew travel time	

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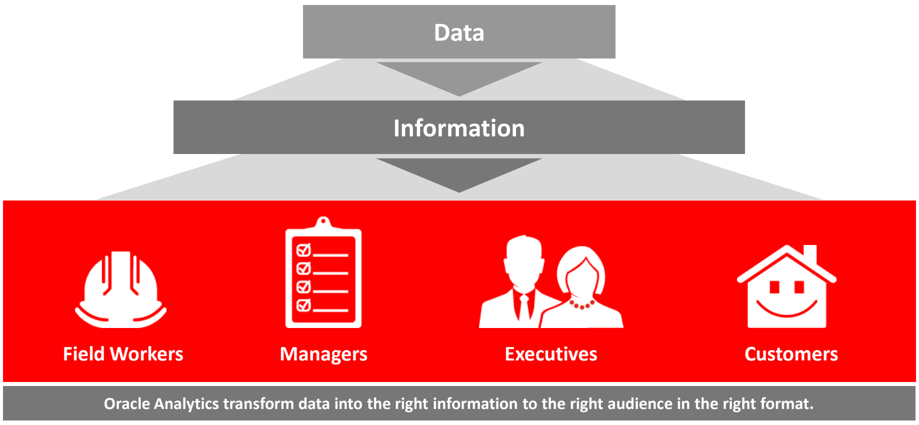
Deliver Actionable Insights to the Right People at the Right Time in the Right Format



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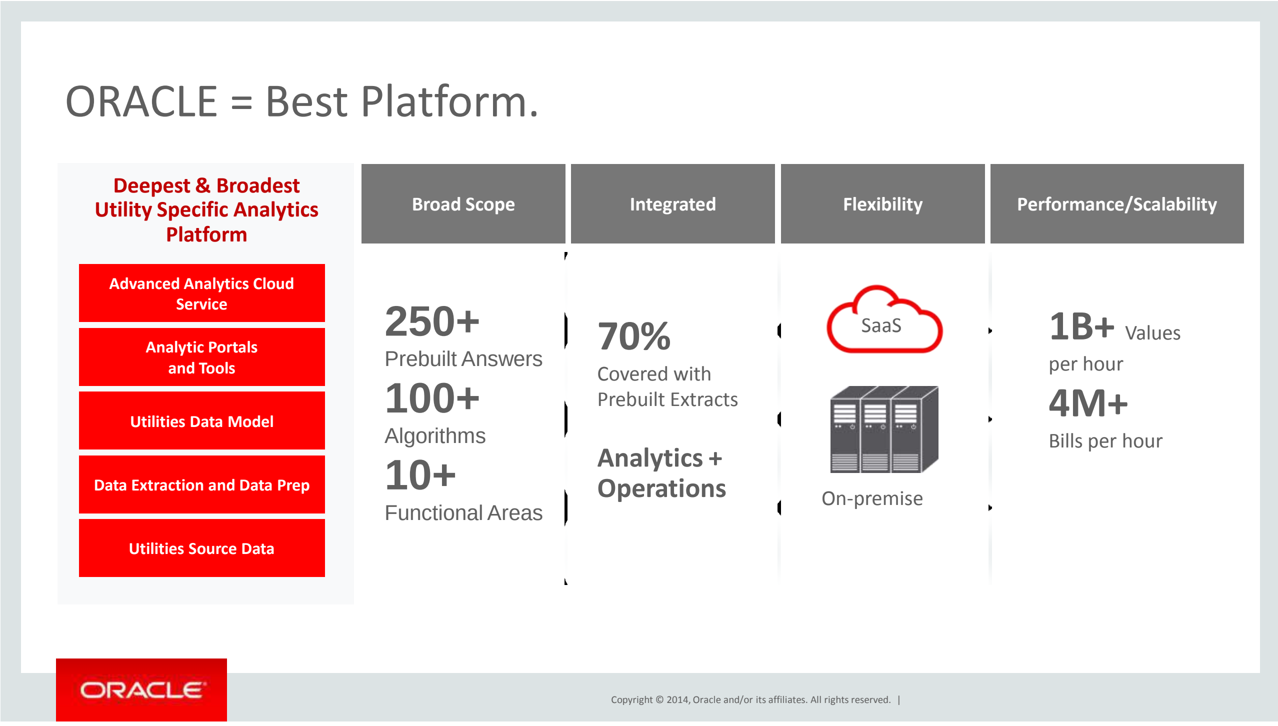
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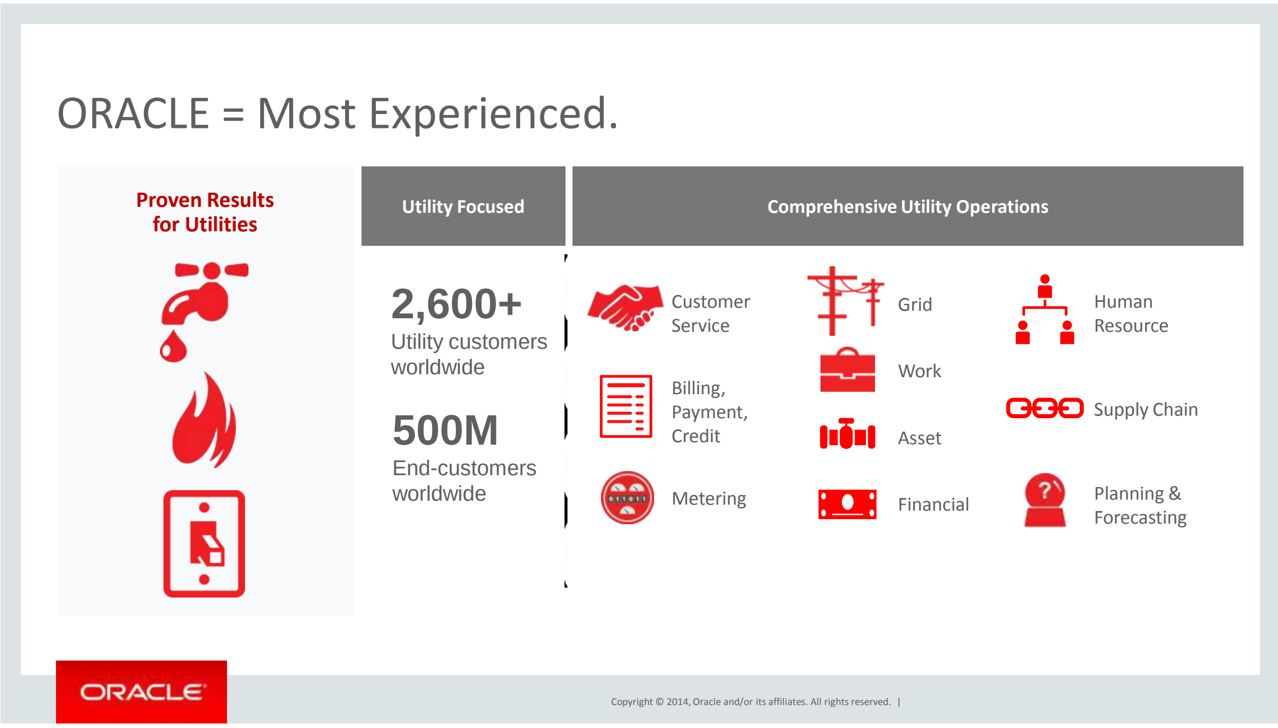
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Utility Focused
Comprehensive Utility Operations
2,600+ Utility customers worldwide
500M End-customers worldwide
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Metering
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ORACLE = Real Operational Results.

Focused on What Drives Utility Operations

Analytics & Operations

Operational Analytics – Results Driven

80% ↓ Back-office Processing Time	**300%** ROI	Public Safety Hazards ↓	**$1M+** ↑ Revenue

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ORACLE = Best Platform. Most Experienced. Real Operational Results.

Deepest & Broadest Utility Specific Analytics Platform	Proven Results for Utilities	Focused on What Drives Utility Operations
Advanced Analytics Cloud Service Analytic Portals and Tools Utilities Data Model Data Extraction and Data Prep Utilities Source Data		Analytics & Operations

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Utilities Results with Oracle Analytics

Oracle Analytics Proven Results

Operational Efficiency: Revolutionizing Revenue Protection

- Identified 4,400+ cases of theft for a **4.5M** customer account utility client
- Recognized $1M+ annual lost revenue through Oracle analytics services

Customer Service: Increasing Satisfaction

80% reduction in processing time, removal of mandatory overtime policy for billing group, increased **customer satisfaction** from faster response time

Safety: Analytics Prevent Gas Leaks

- Daily monitoring detects spikes in daily usage **preventing potential public safety hazards**
- Identify circumstances including copper theft of gas pipes in vacant homes resulting in unfettered gas leakage

Reliability: Oracle OMS shines during Superstorm Sandy

- Helped to restore power to 3M utility customers affected by outages
- Most accurate source for restoration progress responding to nearly **1M** utility customer calls

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Transform Your Complex Data into Business Value

✓ With Oracle as your strategic analytics partner, you extract insights from your data that ensure continuing operational improvements to address not only today's needs but also tomorrow's unknowns.

✓ Our unique combination of **Best Platform, Most Experienced, Real Operational Results** will help you transform into a data driven organization.

Let's discuss the next steps in your analytics journey…

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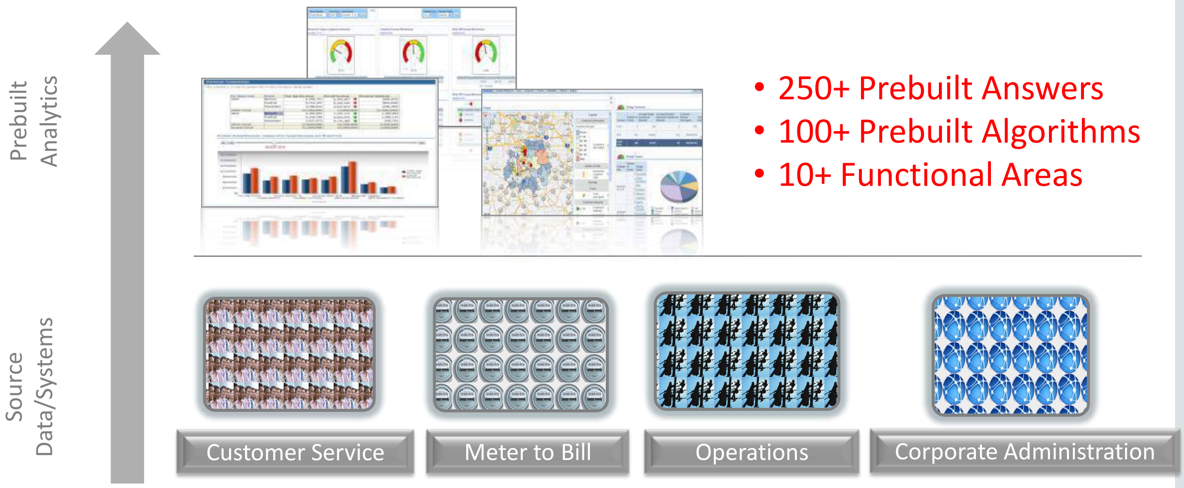
Proposed Next Steps

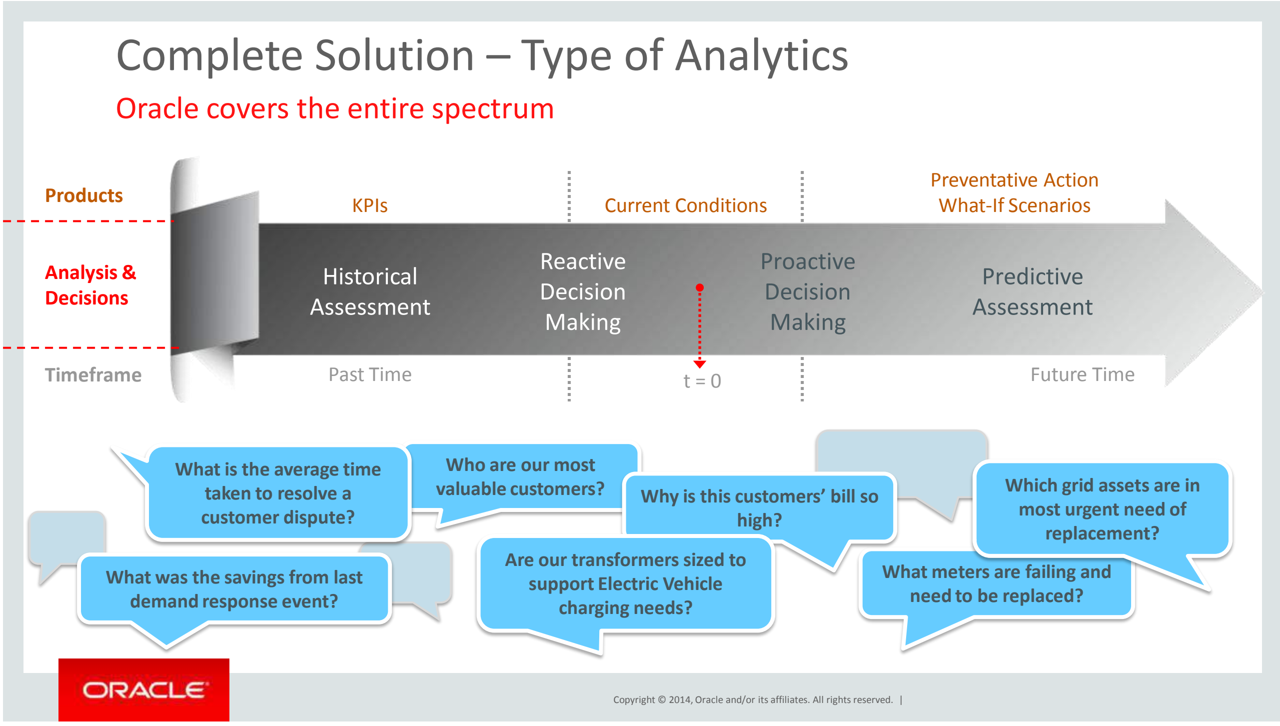
- Workshop to explore business use cases of analytics
  - Discussion on Operational Analytics
  - Discussion on Technology Blocking and Tackling for Big Data
  - Demonstrate value of Integrated Analytics
- Conduct a analytics value assessment
  - Leverage a new approach to uncovering operational efficiencies, risk management and innovative ideas
  - Start considering possibilities how an information management/analytics approach can provide "insight" that can reduce risk and improve safety and reliability

Complete Solution – Functional Areas

Utility expertise to deliver analytics across the entire enterprise



- 250+ Prebuilt Answers
- 100+ Prebuilt Algorithms
- 10+ Functional Areas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Future Time
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Who are our most valuable customers?
Why is this customers' bill so high?
Which grid assets are in most urgent need of replacement?
What was the savings from last demand response event?
Are our transformers sized to support Electric Vehicle charging needs?
What meters are failing and need to be replaced?
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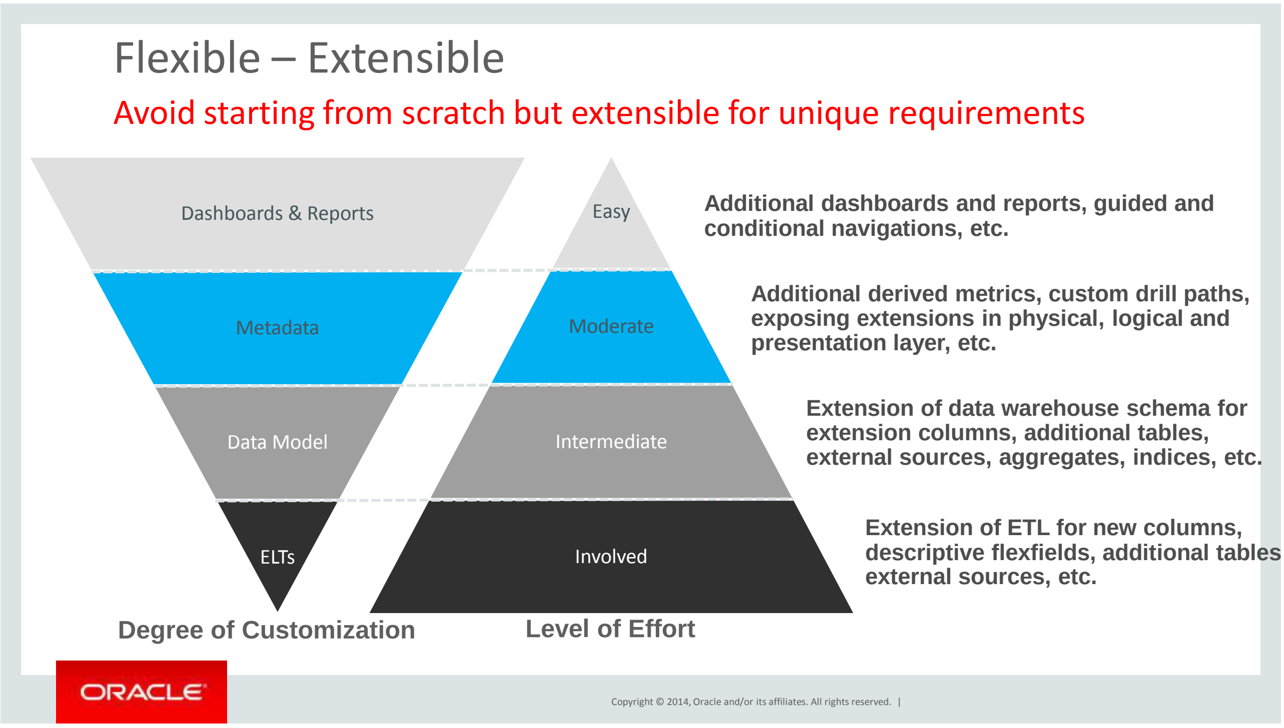
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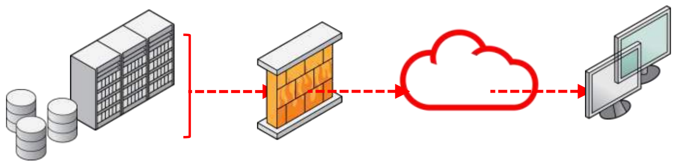

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Power Management of a Hybrid Microgrid

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***Abstract*—Hybrid microgrid management consisting of renewable energy sources like wind and small hydro along with AC/DC load network connected by bidirectional converter is proposed in this paper. A hybrid system consisting of wind, hydro, storage systems and grid is modeled and simulated using MATLAB/SIMULINK® for different scenarios of variable load demand profile and source variation. Control algorithm and energy management of distributed sources is proposed for achieving smooth transfer of power and stable operation of system. To stabilise the hybrid system, dump load, battery energy storage system are used as viable means. From simulation results it is found that proposed wind hydro system performs satisfactorily under different dynamic conditions to maintain voltage and frequency within the limits. Simulation results validates smooth operation of microgrid under isolated, grid connected and transition modes of operation.**

***Index Terms*— Distributed generation, Hybrid system, Energy management, micro grid, stability.**

I. INTRODUCTION

Promotion of power generation by locally available DG sources is one of the solutions to meet the growing demand for high quality and reliable power. Distributed generation provides advantages of security, reliability but presents challenges in terms of power management, integration and control. Wind-Hydro hybrid power system integration is less explored area in microgrid, integration of these sources can balance peak shortages and redundancies thus achieving more reliable supply to consumers. Hybrid system operating with renewable sources of power can be very effective in reducing greenhouse gas emissions, distribution losses, improvement in service quality, flexibility and reliability of power supply [1].Hybrid system is promising alternative to the traditional power distribution system as it offers consumers reliability of power, energy savings and economic benefits. Microgrid is a type of power system which consists of network of distributed generating sources (DGs), storage systems, and controllable loads which can operate in isolated/autonomous mode, grid connected mode or transition mode. Depending on the combination of different types of renewable energy sources and loads several AC and DC microgrids are proposed in the literature [2-13]. An energy management system is used in the case of a centralized system while each system operates autonomously in the case of a decentralized system.

Power generation using wind, solar thermal, small hydro, micro-turbine, biomass is ac in nature while power generated by PV, Fuel cell is DC in nature. With increase use of electronic loads (computers, servers, lighting systems) which require dc power for their operation, there is a possibility of Hybrid AC-DC microgrids can feed both ac and dc loads at their respective buses. Integration of power generated to the utility grid at distribution or low voltage network is predominantly through power electronic interfaces [14-15]. Power electronic interface receives power from DG sources and converts it to power at grid compatible voltage and frequency.

Power generation using wind and small hydro is intermittent in nature and hence it is essential to have a storage system especially in isolated mode of operation to maintain power balance. The storage device can be battery, super capacitor, or super conducting magnetic energy storage (SMES) system. In grid connected system, imbalance between supply and demand is mitigated by the grid and hence power management is not primary concern unlike bus voltages. In isolated mode of operation storage system plays key role in maintain power balance and voltage stability. In proposed work battery energy storage system is used as viable means.

The wind turbine coupled with PMSG is an attractive option, due to its low weight and volume, high performance, absence of gear box and low maintenance [16-18]. Power management in microgrid with inverter based distributed generators is done using droop control technique [19-21]. Hydropower is more reliable source of energy as compared to wind power because it has steady supply of power. Frequency is controlled by regulating the water flow and controlling speed of synchronous generator, voltage is controlled by regulating the excitation system [3-4].

It is necessary to extract maximum power from renewable energy resources like wind. Permanent magnet synchronous generator followed by an AC/DC converter is used to convert variable speed wind (variable frequency AC voltage) to constant DC, Hydro turbine generator AC output is converted to DC, bus voltage. Wind energy conversion system, battery energy storage system (BESS), and Hydro turbine generator output are coupled to a common dc bus link through dc/dc converters. AC loads and dump loads are connected to the utility grid at the point of common coupling (PCC) or ac bus. The converters at dc side are controlled to maintain a constant dc bus voltage while the converter at ac side (interface converter) is controlled to maintain constant voltage at ac bus. The dc-dc converters of wind, and battery storage systems are responsible for maintaining constant dc bus voltage whereas the ac bus voltage is maintained constant by the bidirectional interface converter using sine triangular pulse width modulation (SPWM) technique. For effective power management it is essential that there shall be seamless transfer of power flow from ac to dc and dc to ac side.

The organization of paper is as follows. The system description, modeling and operation are discussed in Section II. Section III presents the simulation results and Section IV concludes the paper.

II. SYSTEM DESCRIPTION, MODELING AND OPERATION

A. *Proposed System Description and Operation*

The proposed hybrid AC/DC micro grid is shown in Fig. 1. The system is modeled and simulation is performed in Simulink® environment of Matlab to test the system for varying operating conditions. It consists of Wind energy conversion system (40kW) coupled with PMSG and connected to DC bus through diode bridge rectifier and boost converter. Battery energy storage system is connected to DC bus through bidirectional converter. Hydro turbine coupled with Synchronous generator (60 KVA) is connected to dc bus via diode bridge rectifier. Variable ac and dc loads are connected to their respective buses, rated voltage of ac and dc buses are 400V and 500V respectively. The proposed system has an AC bus and DC bus to which loads are connected and hence it is very important to maintain the system parameters within power quality limits at these buses. As sources are intermittent in nature, there is always a possibility of shortage or excess of power compared to load. The main converter links AC and DC bus whose operation and control is critical for power management in present context. Control objectives for various converters are dispatched by energy management system.

Permanent magnet synchronous wind generator followed by an ac/dc converter is used in the present work to convert variable speed wind (variable frequency ac voltage) to a constant dc bus voltage. While power from BESS , Wind and hydro source is fed to DC bus, Interface converter is connected to AC bus along with utility grid which can feed the load on ac side. Details mathematical modeling of each power source is discussed in subsequent sub-sections.

DC bus voltage is maintained constant by the dc/dc converters of wind, hydro system, battery energy storage systems and also by the main AC/DC bidirectional converter. The controller of main converter shall allow power flow in either direction based on power mismatch on AC/DC side. When the total generation on dc side is more than load, the main converter acts as an inverter and injects power from dc to ac side. The main converter acts as a rectifier when the total generation on dc side is not enough substantial to meet loads on dc side.

The proposed hybrid microgrid shall be able to operate in three different modes viz., isolated, grid connected and transition mode. In the grid connected mode the supply demand mismatch is taken care by the grid while in isolated mode, battery plays a key role in managing the mismatch between supply and demand.

In grid connected mode, Battery energy storage system has no role to play in power management. A microgrid shall be able to island itself in case of fault in the grid and shall operate in islanded/isolated mode. The SOC of battery plays a key role during islanding depending on whether microgrid is importing or exporting power .

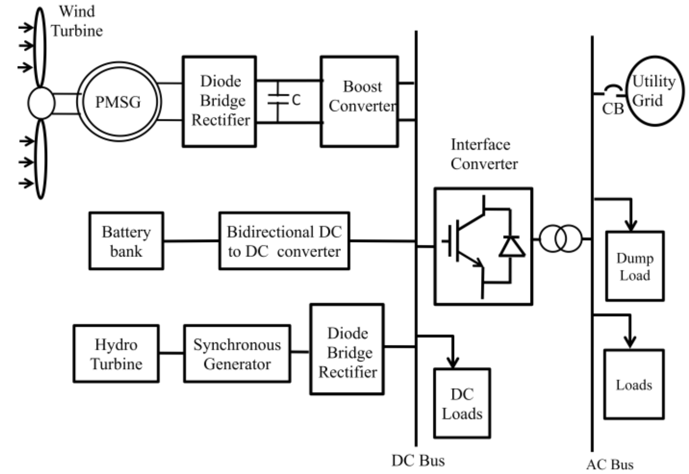

Fig. 1. Proposed hybrid AC/DC micro grid.

B. *Modeling of Wind Energy Conversion System (WECS)*

WECS consist of a variable speed wind turbine connected to a PMSG. The equations governing mechanical power output of a wind turbine is given by (1) and (2).

$$P_m = \frac{1}{2}\rho A C_p(\lambda,\beta)V_w^3 \tag{1}$$

$$\lambda = \frac{\omega R}{V_w} \tag{2}$$

Where, V_w is the wind speed, $C_p(\lambda,\beta)$ is the power coefficient which is a function of tip speed ratio, λ and blade pitch angle, β, ρ is the air density.

The dynamic equations for PMSG are expressed in the d-q reference frame. The voltage equations of a permanent magnet synchronous generator [22] in a rotating d-q coordinate are given as (3) and (4).

$$V_q = -(R + pL_q)i_q - \omega_r L_d i_d + \omega_r \lambda_m \tag{3}$$

$$V_d = -(R + pL_d)i_d + \omega_r L_q i_q \tag{4}$$

Where R and L are machine resistance and inductance per phase, V_d and V_q are the two-axis machine voltages, and i_d and i_q are the two axis machine currents. λ_m is the amplitude of the flux linkages established by permanent magnet, and p = d/dt.

The electromagnetic torque of the generator is given by (5)

$$T_e = \left(\frac{3}{2}\right)\left(\frac{P}{2}\right)\left[\left(L_d - L_q\right)i_q i_d - \lambda_m i_q\right] \tag{5}$$

Variable frequency output voltage of PMSG is converted into a constant dc voltage using an unregulated rectifier circuit. This output voltage is regulated using a boost converter circuit to maintain constant voltage at the DC bus (500V) as represented in Fig. 2 and the parameters of WECS are listed in Table I.

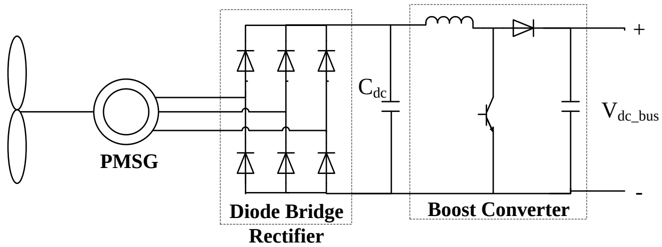

Fig. 2. Wind energy conversion system connected to dc bus.

TABLE I
PARAMETERS OF WIND ENERGY CONVERSION SYSTEM

Symbol	Description	Value
$P_{generated}$	Rated Generator Power	40 kW
ω_{rated}	Rated mechanical speed	314 rad/s
R_s	Stator Resistance	0.05 Ω
L_{ds}	Stator d-axis inductance	0.635 mH
L_{qs}	Stator q-axis inductance	0.635 mH
Ψ_f	Permanent magnet flux	0.192 Wb
P	Pole pairs	4
V_{w_rated}	Rated wind speed	14 m/s
R	Radius of wind turbine blade	5 m
N_b	Number of blades	3

C. Modeling of BESS

The power sources on dc side are intermittent in nature, a hence a storage device is required to maintain a constant dc bus voltage at set point and for smooth transfer of power especially in isolated mode of operation. The BESS comprises of a battery and a bi-directional dc/dc converter as shown in Fig. 3. The control scheme for battery comprises of two loops external voltage control and internal current control

The parameters represent states of a battery are terminal voltage (V_{batt}) and state of charge (SOC) and are determined [23] by using (6) and (7).

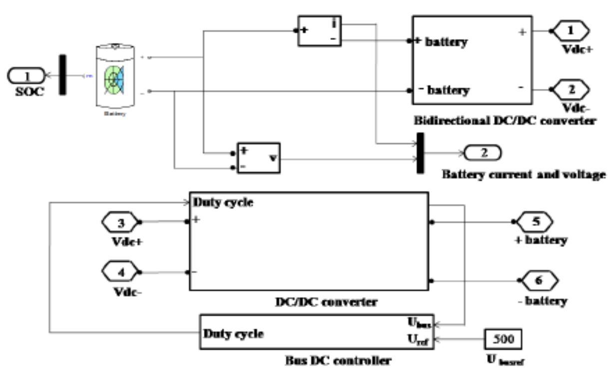

Fig.3. Battery with Bi-directional DC/DC converter

$$V_{batt} = V_0 + i_b R_b - K.\frac{Q}{Q - \int i_b dt} + A.\exp\left(-B\int i_b dt\right) \qquad (6)$$

$$SOC = 100\left(1 - \frac{\int i_b dt}{Q}\right) \qquad (7)$$

Where, V_0 is the open circuit voltage of the battery, R_b is internal resistance of the battery, Q is the battery capacity (Ah), i_b is the battery discharge current, K is the polarization constant (Ah^{-1}), A is the exponential voltage, and B is the exponential capacity ($(Ah)^{-1}$).

D. Modeling of Hydroturbine generator , Inverter and Grid

Hydro turbine blocks and synchronous generator is taken from simpower systems library, and are suitably modified as per analysis requirement in proposed work. Utility grid is modeled using a three phase variable ac source available in Simulink.

WECS, Hydro system and BESS are connected to AC bus via common DC/AC inverter. The controller for maintaining constant ac voltage at PCC point is shown in Fig 8. In the present context the system is assumed to be balance. The measured three phase voltages at PCC are converted in to dq axis components using park transformation. The d and q axis components are compared with the reference signals and the error obtained is given to a PI controller in order to generate required modulation index (m_a). The sine PWM technique is used in order to generate gating signals for the main converter to feed the load with required voltage and frequency as shown in Fig. 4.

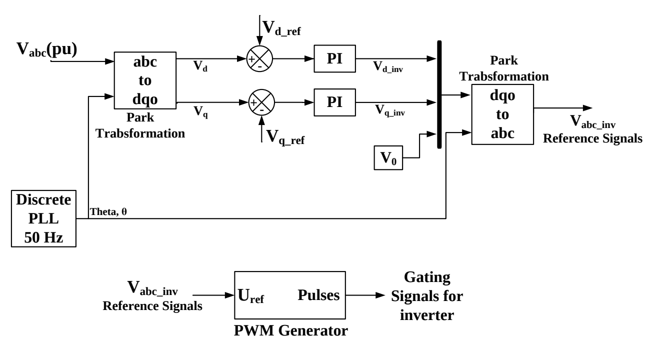

Fig. 4. Control circuit for main converter.

E. Dump Load Controller

Dump load is used to regulate the frequency if there is large mismatch between generation and demand [24]. The dump load controller is modeled using different blocks like frequency regulator block, phased locked loop, PI controller , set of resistors from Simulink library.

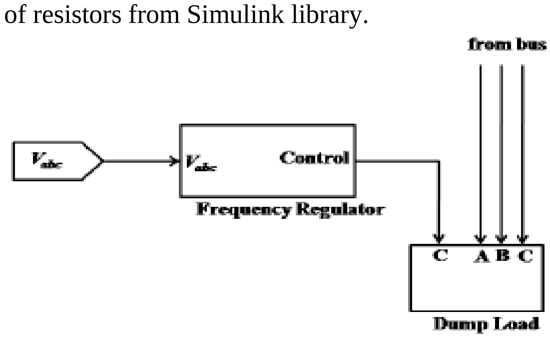

Fig. 5. Control circuit for dump load.

III. Simulation, Results and Discussion

The proposed hybrid AC/DC microgrid is modeled and tested using Simpower systems tool box of Matlab/Simulink®. The interfacing converter shall ensure seamless flow of power from ac to dc side and vice-versa based on the supply and demand gap on either side. The proposed microgrid is tested in all the three modes of operation (grid connected, isolated and transition) for variations in loads and generation. The parameters of system components for the proposed hybrid grid are given in Table III.

TABLE III
COMPONENT PARAMETERS FOR HYBRID MICROGRID

Symbol	Description	Value
C_{dc}	Capacitor across dc link	4700uF
L_{boost}	Inductor for boost converter of WECS	80uH
S	Rating of hydroturbine generator	60kVA
P	Rating of dump load	50 kW
C_f	Filtering capacitor for the inverter	70uF
f	Frequency of AC grid	50 Hz
AH	Battery AH rating	50 AH
L	Filtering inductor for Inverter	850uH
V_{dc}	Rated DC bus voltage	500 V
V_{ll_rms}	Rated AC bus line-to-line voltage (rms)	400 V

Based on combination of variation in AC/DC load and/or generation the simulation is classified in different cases for all the three modes of operation. Case A1 to A2 are for isolated mode of operation while Case B1 to B5 are for grid connected and transition mode. System parameters for these cases are listed in Table IV, V, and VI.

TABLE IV
ISOLATED MODE OF OPERATION

Case	A1	A2
Time (s)	0-0.5s	0.5-1.5s
Hydro Generation (kW)	50	50
Wind Generation (kW)	35	35
AC load (kW)	20	30
DC load (kW)	60	60
Battery Mode	Charging	Discharging
Power flow	AC to DC	DC to AC

TABLE V
GRID CONNECTED MODE OF OPERATION

Case	B1	B2	B3
Time (s)	0-0.5s	0.5-0.8s	0.8-1s
Hydro Generation (kW)	50	50	50
Wind Generation (kW)	35	35	35
AC load (kW)	20	15	50
DC load (kW)	40	40	40
Power flow	AC to DC	AC to DC	DC to AC
Operation Mode	Isolated	Grid-Tied	Grid-Tied

TABLE VI
GRID CONNECTED MODE OF OPERATION

Case	B4	B5
Time (s)	1-1.4s	1.4-2s
Hydro Generation (kW)	40	40
Wind Generation (kW)	35	35
AC load (kW)	20	20
DC load (kW)	90	90
Power flow	AC to DC	AC to DC
Operation Mode	Grid-Tied	Isolated

A. *Isolated Mode of Operation*

Case A1 (t=0-0.5s):

In this case system is simulated for 0.5 seconds. DC bus voltage is maintained constant by the dc/dc converters (Wind, Battery) on DC side of the system. The reference dc link is set to 500V while wind speed is set at 14m/s. For case A1, as can be seen from table the power generation is more than combined load. Net power of hybrid system is positive i.e total generation is more than load and hence battery charges during this time period. Battery current is negative it indicates charging as shown in Fig. 6.and SOC of battery is shown in Fig.7. Fig.8 shows the line to line voltage and current through the interfacing converter in isolated mode of operation.

Case A2: (t=0.5-1.5s)

To check the power transfer from AC to DC side and DC to AC side, the AC load in increased to 30kW at 0.5s. The total power generated is more than the load before 0.5s and is less than the total load after 0.5s (Case A2). During this period power generation is less than load and hence there is reversal of power flow. The power balance is maintained by battery and battery discharges. The state of charge of battery drops after 0.5s. The AC voltage at the output remains almost constant during this period. The control circuit of interfacing converter helps to maintain quality of output waveform. The line to line voltage and current through the interfacing converter during this stage is shown in figure 8. AC voltage at the output remains constant during an increase in load. The DC bus voltage waveform during this cases is shown in fig.9.

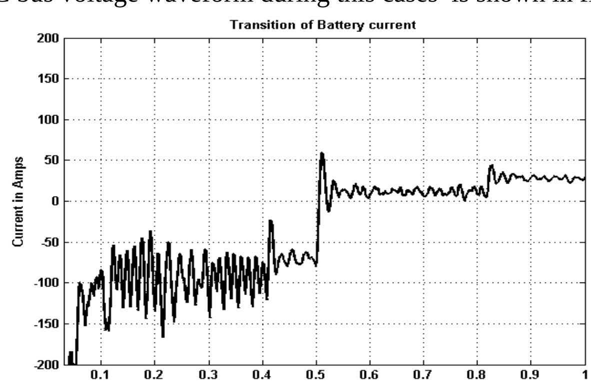

Fig. 6. Transition of battery current from charging to discharging mode during isolated mode of operation case A1-A2.

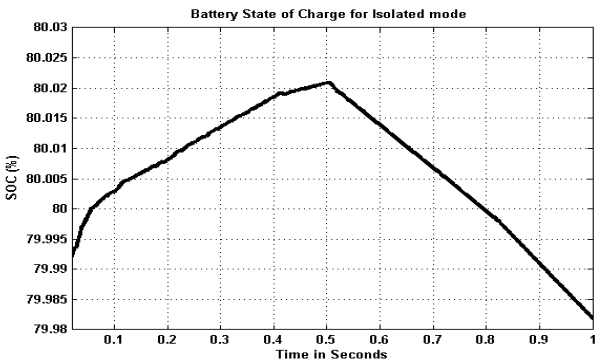

Fig. 7. State-of-charge (SOC in %) of Battery during isolated mode of operation case A1-A2

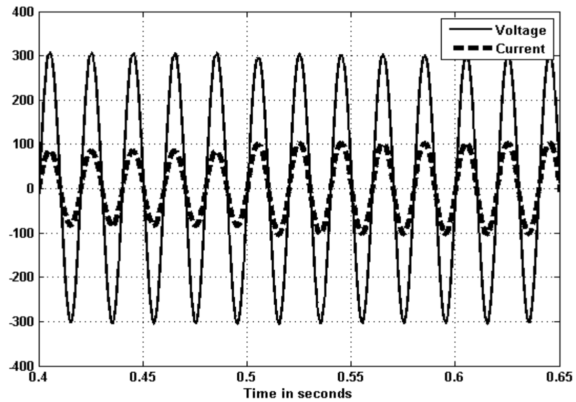

Fig.8. AC side phase voltage and current of the interfacing converter for Case A1-A2.

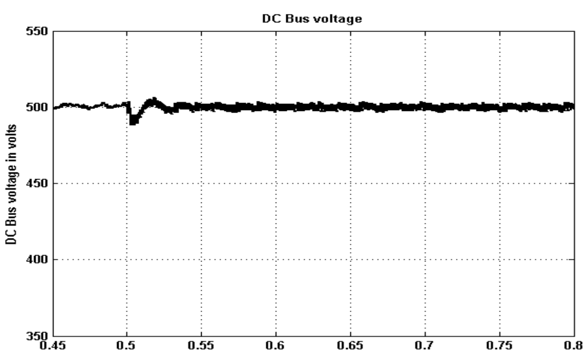

Fig. 9.DC bus voltage response during isolated mode of operation for step change in load

B. Transition Mode (t=0-0.5s and t=1.5-2.5s)

The cases are simulated separately for transition from isolated to grid connected mode and grid connected to isolated mode. At 0.5 seconds hybrid microgrid is connected to main grid at point of common coupling. Fig. 10 & 11 shows dc and ac bus voltages during this transition. From the figure it can be seen that system is able to have seamless power transfer from one mode to another. The total power generation before 0.5s (case B1) is more than the load and hence battery is charging. Once the system is connected to the grid (case B2), the battery is fully charged (SOC=100%) and any excess power is transferred to the grid. Once grid connected any supply demand mismatch is taken care by the grid.

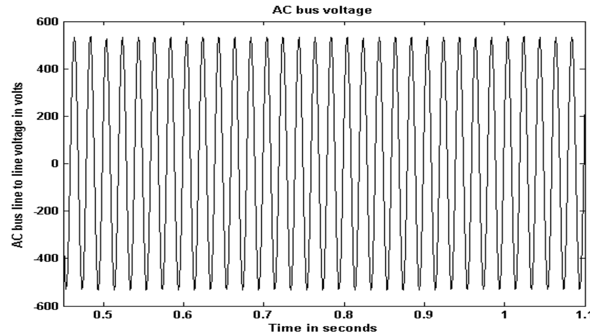

Fig. 10.AC bus (line to line)voltage when system is switched from islanding mode to grid connected mode

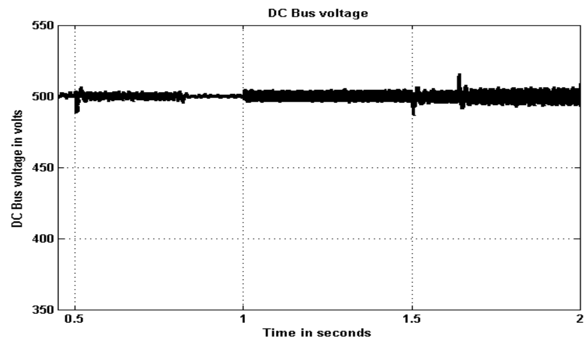

Fig. 11.DC bus voltage transient response when system is switched from islanding mode to grid connected mode.

C. Grid connected mode of operation (t=0.5s-1.4s)

For the cases B1 and B2, the AC generation is greater than AC load and hence power flows from AC to DC side. The interface converter shall be able to transfer power from dc to ac side and vice-versa based on the supply demand gap. To check this load on the AC side is increased to 50kW at 0.8s to ensure a power deficit on ac side which shall be supplied from dc side. The reversal of power flow in the interface converter can clearly be seen in Fig. 12.

At 1s, there is a sudden increase in load on DC side which cannot be supplied by DC side alone and hence net power flow is from AC side to DC side. The reversal of power from AC side to DC side due to a sudden increase in dc load and decrease in ac load is also investigated (Case B4). Fig. 13 clearly shows load current and voltage waveform .

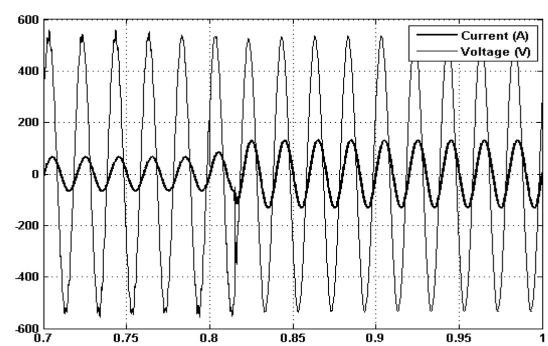

Fig. 12. AC side (line to line) and current of interfacing converter with varying ac load during grid connected mode.

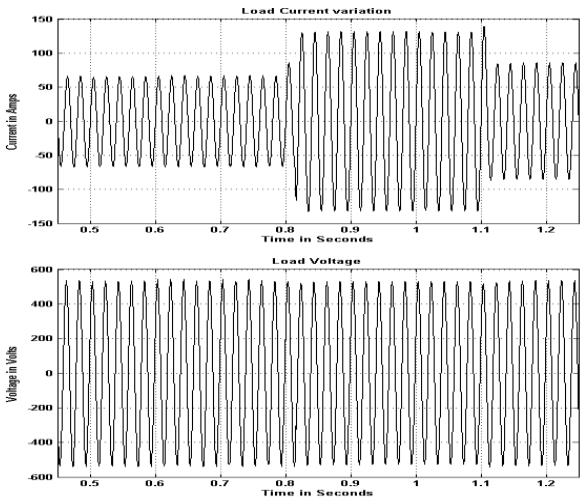

Fig. 13. AC load current and voltage for case B1 to B5

To analyze effect of sudden load reduction on hybid system performance, dump load with controller is utilized. Due to effect of dump load , initial rise in frequency due to sudden loss of load settles to normal value is shown in fig.14

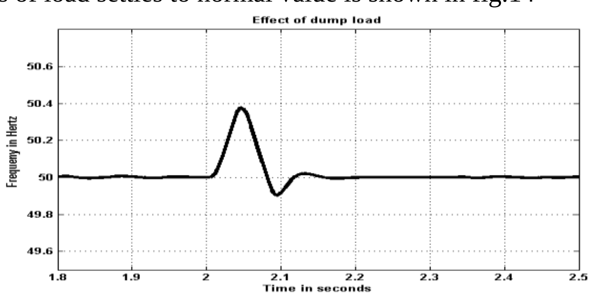

Fig. 14. Frequency response of system with dump load.

From the analysis It is clear that the control circuits on dc and ac side are effective in maintaining the dc link and ac voltage respectively while ensuring proper power management and seamless power transfer based on the supply demand gap.

IV. CONCLUSIONS

In this paper a hybrid ac/dc microgrid comprising of wind and hydro resource is proposed and analysed. Control strategies of individual converters and the interface converter to maintain stable system operation and reduce supply demand gap are analysed. The control strategies proposed are validated by simulation using Matlab/Simulink. The system is tested for varying load and generation conditions. From the simulation results, it is found that proposed wind –hydro system performs satisfactorily under different dynamic conditions maintain voltage and frequency within limits. The stable operation of hybrid system under isolated, grid connected and transition mode of operation is also validated by simulation results.

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High availability automation network in Digital Substation using PRP and HSR redundancy protocol

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Abstract—*In many application it is necessary to have a network with zero recovery time, when any error or fault is occur ,so full fill this requirement there is two redundancy protocol high availability seamless redundancy protocol (HSR) and parallel redundancy protocol (PRP) which recovered the communication if fault in the network.*

HSR and PRP are defined in the IEC62439-9 about high availability automation network and this protocol is implementing in network topology for substation communication. They give the assure keep of the communication when an error is occur in the network .These two protocols are compatible with Ethernet and they provide bump less redundancy, zero recovery time by sending duplicate frame two different path from source to destination so that in case of any information is lost from one path from other path the information is arrived at destination. This paper analyzes about these two protocols HSR and PRP and the recovery time.

Index Terms—PRP, HSR, DANP, DANH, SAN, IEC 62439.

I. INTRODUCTION

Recent advancements in power utility automation use Industrial Ethernet which provides stronger adaptability, high efficiency and more function. In many applications it is necessary to have network with zero recovery time, when any fault or an error is occur. To full fill the requirement of drop-out fault- tolerance in this application field so there are different method in which with some redundancy [1], the communication is recovered from fault in the network the recovery takes some time for this solution so there are different method in which with some redundancy, IEC 62439 series studied are several alternatives of redundancy but only two of them provide zero time recovery. These two Ethernet redundancy mechanisms are parallel redundancy protocol (PRP) and high availability seamless protocol (HSR) [2].These two redundancy protocol are compatible with Ethernet, and they provide bump less redundancy [5], high availability, zero recovery time, by introducing two independent path to send information duplicated from source to destination,so that in case of fault no information is lost, when duplicated frame that arrive to destination must be discarded

II. NETWORK REDUNDANCY PROTOCOLS IEC62439

Standard series specify two redundancy protocol designed to provide seamless recovery in case of single failure of bridge in the network. Which are based on the scheme- Duplication of LAN, duplication of transmitted information. These two different classes of network redundancy:-

- Parallel redundancy protocol is standardized as IEC 62439-3 Clause 4.
- High availability seamless redundancy protocol is standardized as IEC 62439-3 Clause 5.

These two standardization was started to fulfill the dependability and real time requirement of demanding application. such as substation automation and motion control. They provide zero recovery time in case of failure [3]. HSR and PRP are simply the implementation of double mode node in hardware.

A. PARLLEL REDUDANCY PROTOCOL

PRP is a method to provide redundancy in Ethernet network .the concept mainly introduce double LAN network, where source and destination connected to each other via independent two LANs. In case any fault happen in one of the network the communication is continue over the network or without loss of information.. As shown in figure1

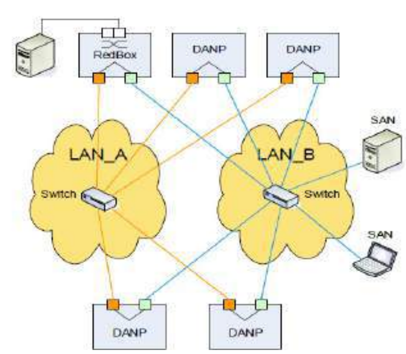

Figure 1: PRP Network

The main element are linked to the two network doubly attached node with (DANP), which duplicate information and send it through the two different LAN. All PRP nodes connected via two separate network LAN_A & LAN_B both constructed using non-aware PRP Ethernet switch. All messages are sent to both network and target device drops the duplicate frame that arrive later .in PRP network there can also be SAN (single attached node) that connect to only one of LANs. A redbox is a device that connects non-PRP nodes to the redundant PRP network. In the DANP node structure each node has two ports that operate in parallel and that are attached to the same upper layer of the communication stack through the LRE (link redundancy entity) as shown in figure 2[4].

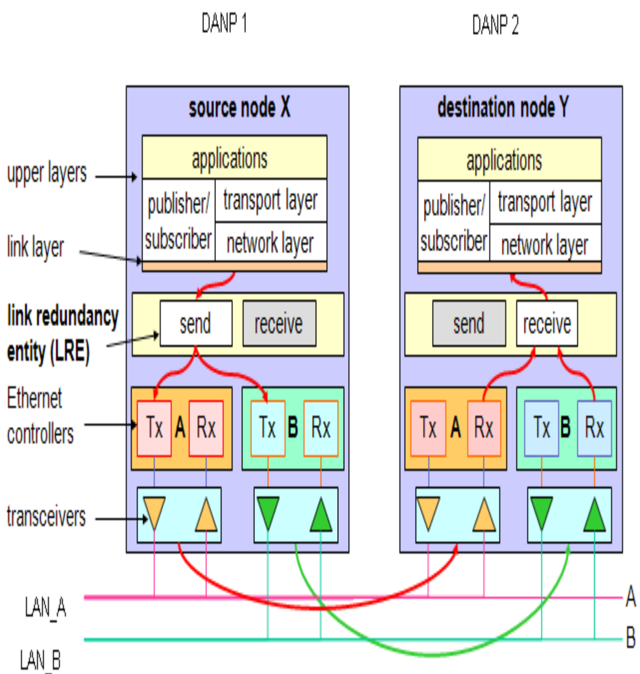

Figure 2: PRP with two DANPs communicating

Basic communication between two DANPs, the LRE present centre between upper layer and network adapter, so the upper layer network adapter ,so the upper layer are unaware of redundancy .The LRE mainly has two tasks one is handling of duplicate and management of redundancy. When receiving a frame from the node's upper layer. Then the LRE appends to the frame a RCT (Redundancy check trailer) which contain a sequence number and sends the frame through both its ports at the same time. These two duplicate frame transit through the two LAN with different delays but ideally they arrive at nearly same time at the destination node [4].
At the destination side when its receive frame from the network the LRE forward the first frame of a pair to its node's upper layer and discard the duplicate frame when its is arrive. It removes the RCT if required.
Checking and management of redundancy of the presence of other DANPs then the LRE periodically Sends PRP supervision frame and can evaluate the PRP supervision frame sent by other DANPs.

B. HIGH AVAILBILITY SEAMLESS REDUNDANCY

Clause 5 describe to implement a high availability seamless redundancy (HSR), retaining the PRP property of zero recovery time, this redundancy protocol can be applicable to any topology, in particular rings and rings if rings topology [6], HSR nodes have two ports too, double attached node with HSR. Each HSR nodes having two ring ports they are interconnected by full duplex links, as shown in figure 3[3].
The source DANH sends a frame passed from its upper layer, by add an HSR tag to indentify frame duplicate and then sends the frame over each port A-frame and B-frame .and then at destination DANH receive two identical frames from each port (A-frames and B-frame) within a certain interval, before passing the frame to its upper layer it remove the HSR tag of the first frame and discard duplicate frame [4],

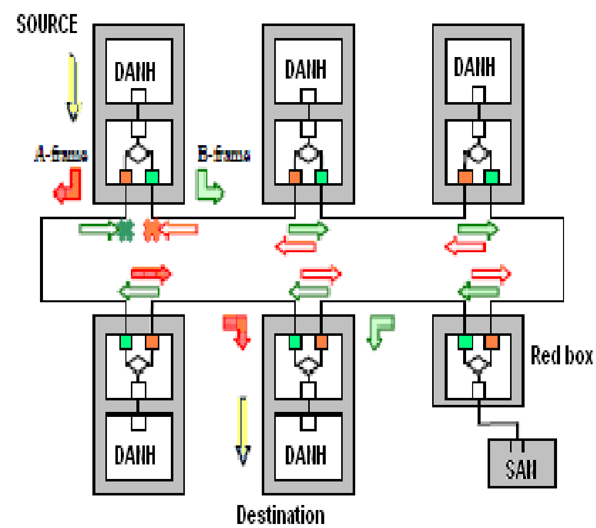

Figure 3: HSR Networks

These two frames (A-frame and B-frame) in the ring carry the HSR tag, inserted by the source, which contain a sequence number using this sequence number easily, indentify the duplicate frame. In figure 4 shows that HSR node operation .the upper layer send a frame to LRE which generate the duplicate frame and send each frame to simultaneously over port A and port B 1, 2. , and the switching logic forward frame one port to other port(3,4) but except (5,6) ,at the receiver side[2] the LRE receiver receive the both frame and keeps the first frame and discard the duplicate frame .each node of HSR has the same MAC address on both ports, each node operate with same IP address for both ports.

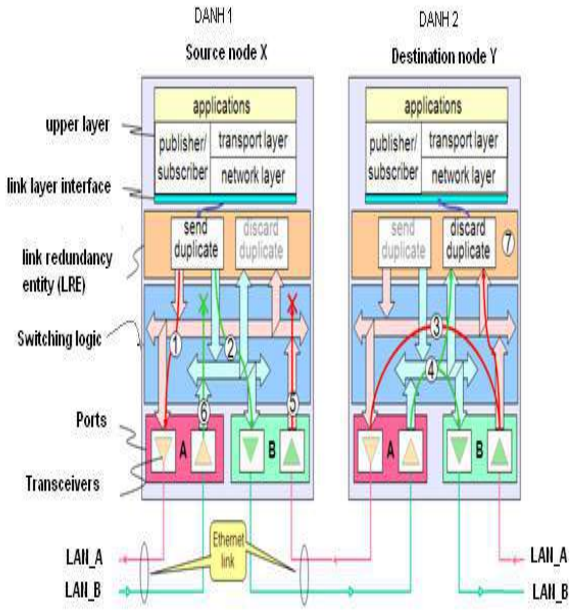

Figure 4: HSR with two DANHs communicating

III. FRAME INDENTIFICATION

In HSR and PRP the way to know if a frame has been seen before is remembering the frame that arrived to nodes , in order to do that frame must be easily indentified .In this protocol append extra information to Ethernet frame and using this and address of the frame the frames can easily indentified. In HSR frame HSR append a HSR tag after address:
As shown in figure 5

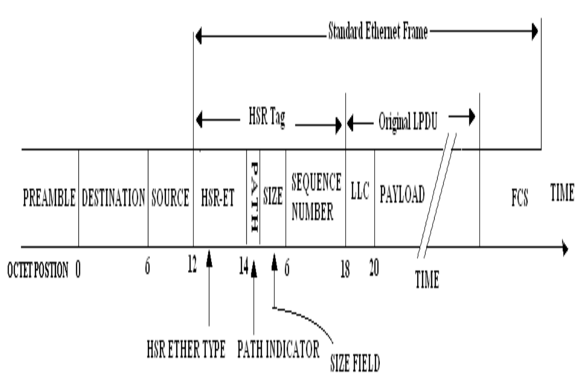

Figure 5: HSR frame

In PRP frame PRP append a trailer RCT (redundancy control trailer) the end of the frame as shown in figure 6. In HSR, Path ID indentifies the HSR regular frame direction .In PRP LAN ID indicate the network through the frame sent. in HSR and PRP have 16-bit sequence number [7]. Every node has a sequence counter where value is increment every time a HSR/PRP frame is send. the field sequence is filled with the value of the sequence counter each time a frame is duplicated and append trailer/tag to be sent so that the two copies sent the same sequence number .

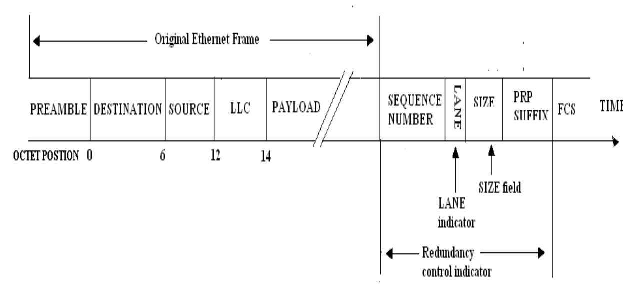

Figure 6: PRP Frame

.LSDU size is 12 bits, size of the link service data unit..and PRP-1 suffix and ETHER type both are 16 bits. Append in PRP/HSR frame [3].
The sequence number is common to both frame generated from original frame delivered from upper layer and to send through the two different path by each node then ,those frame can indentified by using source address and sequence number, so that nodes store this information to circulating frame and discard duplication[3]. This is a method used ti indentified the frame.

IV. RECOVERY TIME

Recovery time is the most important factor for the network redundancy protocol .it ability of fault tolerance performance. Recovery time is time from the fault factor to the time when the network region is required communication function in presence of the fault [8]. The recovery time include the two elements which is given in below:-

a) Fault detecting
b) Link switching time

Fault detecting is calculated by using this mathematical algorithm:

$$T_r = T_d + T_s \qquad (1)$$

Here Tr is recovery time, Td is fault detecting, Ts is link switch time for the single network or Dual network redundancy protocol detecting of link fault it is depend on sending and receiving of the frame. When the different sequence number of two frame reach to the maximum value ,the receiver link redundancy entity (LRE) consider that failure is occur in the local adapter so fault detecting time is:

$$T_d = Max\_Seq\_Diff * T_{smi} \qquad (2)$$

Where T_{smi} is time interval of the frame Max_Seq_Diff is the Maximum value the sequence number difference .when the failure is detect then LRE immediately called link switch algorism for the link switching time and is calculated by using this formula:

$$T_s = T_{path} + T_{send} + T_{rec} \quad (3)$$

Where T_{send} and T_{rec} are the processing of the sending and receiving LAN redundancy entity, T_{path} is the frame delivery through the link.

In parallel redundancy protocol receive data frame which is based on the principle of first come and first reserved. If one LAN is fails and then Data frame is missing, the duplicate data frame is transmitted in another LAN will be processed and forward to upper layer therefore then recovery time is zero.

V. DATA ANALYZING

For experiment of the data analyze of the recovery time is composed of the two DAN (Double attached node) and SAN (Single attached node), DAN work as redundancy node of sender and receiver based on EPA (Ethernet for plant control automation) .protocol .as shown in figure 7 and 8 [4]. The sender sends the packet to the receiver by using redundancy path in every 10 ms .by using the equation number (1), recovery time can be measured [7].

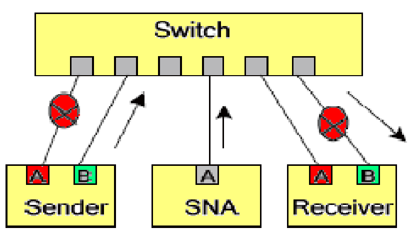

Figure 7 Single LAN mode Redundancy Protocol

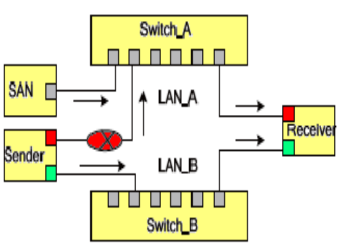

Figure 8 Double LAN modes Redundancy Protocol

The experiment describe as follow, whenever a frame each the end node then receiver will records the receiving time then the difference between this time value from that of previous received frame is recorded in $Time_{[n]}$ [7]. During the testing , a link failure is produced by cutting off the cable ,at this time the value of $Time_{[n]}$ indicate the fault time T_f after complete the testing, the average value of the element in array $Time_{[n]}$ is T and this is the normal interval of each frame.ao recovery time formula is :

$$T_r = T_f - T \quad (4)$$

FOR TESTING OF Single LAN redundancy protocol the max difference value of sequence number is fix value ,during the test the Max_Seq_Diff is set to 4ms and then T_{smi} is set to 8msfor Single LAN mode redundancy protocol the fault detection time is calculated by using equation (2) ;

$$T_d = Max\_Seq\_Diff * T_{smi}$$

$$T_d = 4ms * 8ms = 32ms$$

The value of T_{path} is a 40 us in a switched Ethernet .T_{send} and T_{rec} 15us through experiment, so calculate the switching time by using equation (3):

$$T_s = T_{path} + T_{send} + T_{rec}$$

$$T_s = 40us + 15 us + 15us = 70 us$$

After all these calculate the recovery time by using equation (1):

$$T_r = T_d + T_s$$

$$T_r = 32ms + 0.07ms = 32.07ms$$

Now using equation (4) we can find out recovery time :

$$T_r = T_f - T$$

$$T_r = 42 - 10 = 32ms$$

The graph is draw between fault recovery time versus average recovery time as shown in figure 9

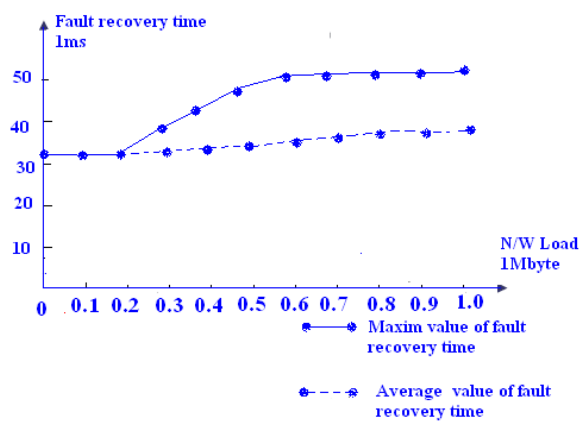

Figure 9 Recovery time of Single LAN mode protocol Network

For Dual-LAN redundancy protocol, set the Max_Seq_Diff is set to1ms and T_{smi} is set to 4ms.the value of fault detecting time is:

$$T_d = 1ms * 4ms = 4ms$$

For calculating of link switching time of Dual network redundancy protocol, the value of T_{path} is 30 us in switched Ethernet, T_{send} and Trec is less than 10us through testing so switching time is:

$T_s = 30us + 10us + 10us = 50us$

So theory value of Dual LAN of recovery time is

$T_r = T_d + T_s$

$T_r = 4ms + 0.05ms = 4.05ms$

Now using equation (4) we can find out recovery time:

$T_r = T_f - T = 14 - 10 = 4ms$

The graph is draw between fault recovery times versus average recovery time as shown in figure 10:

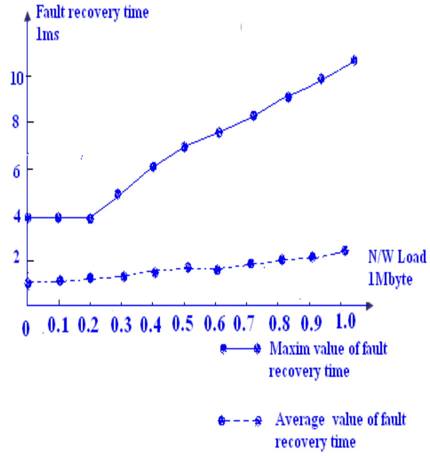

Figure 10 Recovery time of Dual LAN mode redundancy protocol

For Dual LAN parallel mode redundancy protocol recovery time is zero [7]. The graph is draw between fault recovery time versus average recovery time as shown in figure 11:

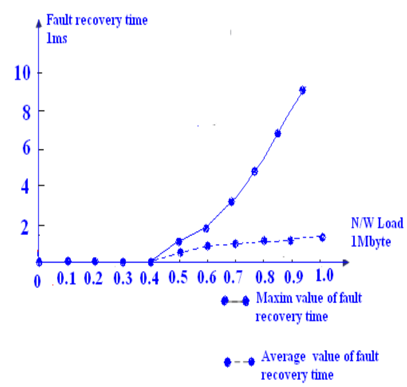

Figure 11 Recovery time of Dual LAN parallel mode redundancy protocol

Using equation (4) then recovery time is:

$T_r = T_f - T$

$T_r = 10 - 20 = 0$

In figure 10 and 11 we see that if network load is less than 0.2 Mbps then it does not affect the recovery time but if network load is more than 0.4 Mbps than the recovery time value is getting bigger.

VI. CONCLUSION:

HSR and PRP redundancy protocol providing high availability, transparency, compatibility, and stability characteristics for Ethernet plant automation. In this paper SAN mode, DUAL N/W simple and DUAL N/W parallel mode redundancy protocol is analyzed. If compare these three redundancy after analyzing only DUAL N/W parallel provide the zero recovery time. In this protocol append the LRE to detect the communication link failure or error easily and also this redundancy approach the high availability network. The PRP and HSR as a protocol for high availability will be a very useful for the implementation of the circulating and duplicate frame elimination method in real system and res boxes. These two protocols are implement in substation network, for station Bus and Process Bus with its characteristics traffic type [5].

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An Assessment of a Cost-effective Demand Response Scenario
A case study for Jordan

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Abstract

Jordan's electric energy needs are predominantly dependent on foreign supply of oil and gas. This complete reliance on foreign oil consumes a significant amount of GDP, making from demand response (DR) and energy efficiency (EE) an important option for the country's energy security and a tool to reduce vulnerability to changing global conditions. Improving electric demand side efficiency by reducing unnecessary consumption and improving the efficiency of the consuming sectors, where possible, allows for existing supplies to serve a larger demand base, thus delaying investment in costly supply side options, this led to plan investment of $ 15 billions in renewable and nuclear energy.

The national energy strategy for 2007 – 2020 was created which project within the next decade to boost reliance on domestic energy sources from 4 % to 40 % by of end of the decade the interconnected system in Jordan consists of the main generating power stations, 132 kV and 400 kV transmission network, interconnects the power stations with the load centers

The focus of this paper is to assess the economic viability of introducing an incentive scheme to Intelligent Demand Response Technology allows for loads to be automatically controlled and monitored without sacrificing production, product quality, or building comfort while generating additional revenue. Such technologies detect the need for load shedding, communicate the demand to participating users, automate load shedding, and verify compliance with demand response programs. This assessment is carried out by studying the impact of adopting DR Based on these assumptions, the present values of program net benefit of 4.6 million JD .

Key Words ; Energy efficiency, demand side management, avoided costs, demand response (DR) and rate making.

Introduction

Jordan is challenged by the lack of local natural energy resources critical for social and economic development. Jordan's expanding economy, growing population, and rising standard of living all depend on energy services. Currently, Jordan imports 96% of its energy supplies from across its borders, and the electricity demand is projected to rise at a rate of 6.4% between the years 2015-2030 . Many issues arise due to these challenges:

- Growing demand stresses the current system, increasing energy costs and investment requirements;
- Economic growth is reduced due to high financial burdens on households and businesses;
- New supply side investments are vulnerable to uncertainty of future prices; and

- Dependency on foreign sources increases vulnerability of the energy supply to factors outside of the control of the country.
- utilities manage energy efficiency and DSM programs and business operations to:
    - Reduce operating costs
    - Driving energy savings
    - Embracing DSM Business Process Management & Customer Engagement
    - New Strategies to Drive Energy Savings, Cost-Effectiveness, and Customer Satisfaction

Jordan Electricity sector

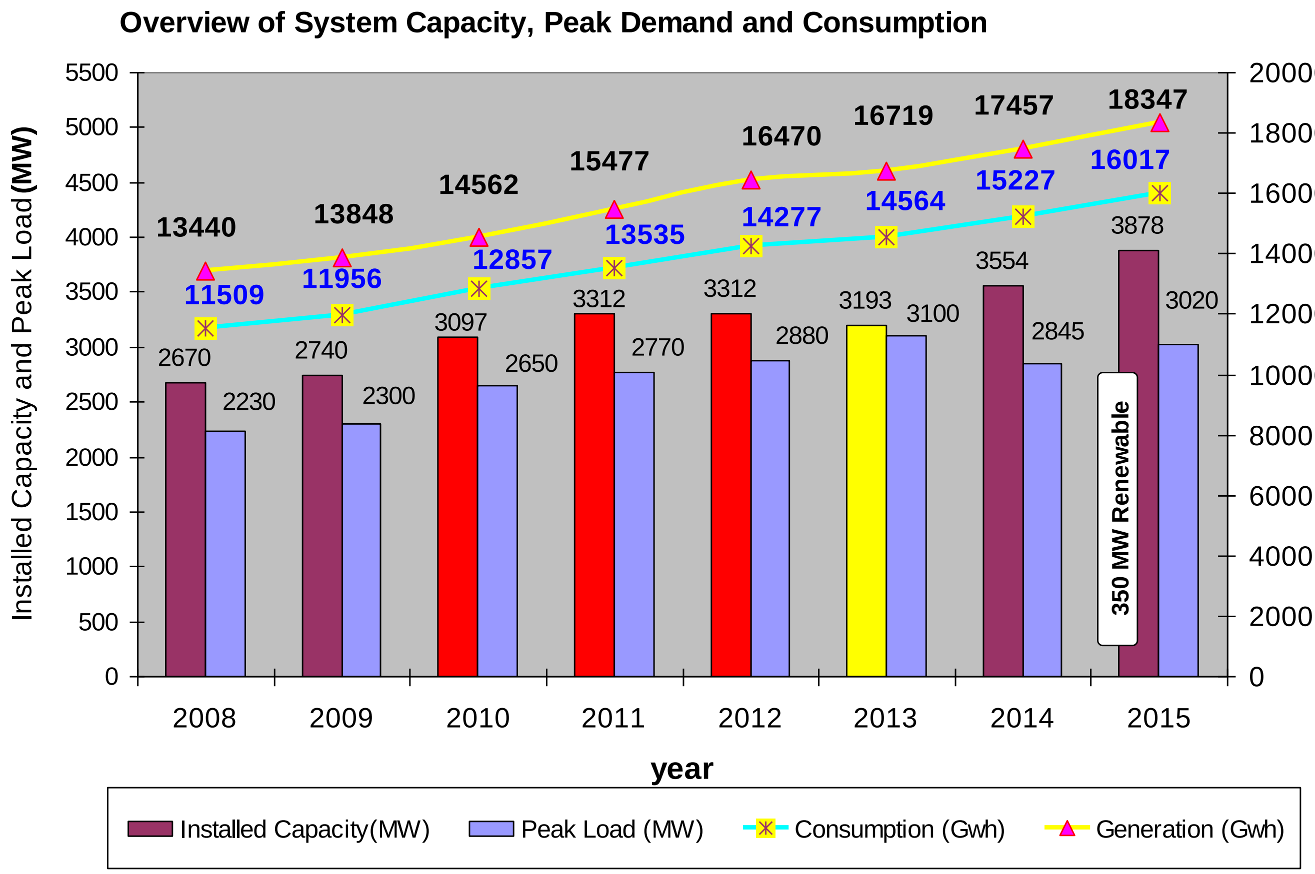
Electricity sector in Jordan is going to be one of the major ‗growth enhancing expenditure' for the economy. Current pricing regime do not reflect international market prices, and numerous, complex subsidies exist. Provision of reliable energy supply at reasonable cost is a crucial element for strong economic sustenance of Jordan.
Thus energy remains perhaps the biggest challenge for continued growth for Jordan's economy. 96% of the country's energy needs come from imported oil and natural gas from neighboring Arab countries. And economic and political development of neighboring country immediately and directly impacts the economy of Jordan. Jordan will begin importing liquefied natural gas (LNG) from several other countries in June 2014 following the completion of a gas terminal in the Red Sea Port of Aqaba

The key players in the electricity supply industry in Jordan and their respective roles and duties are as follows:

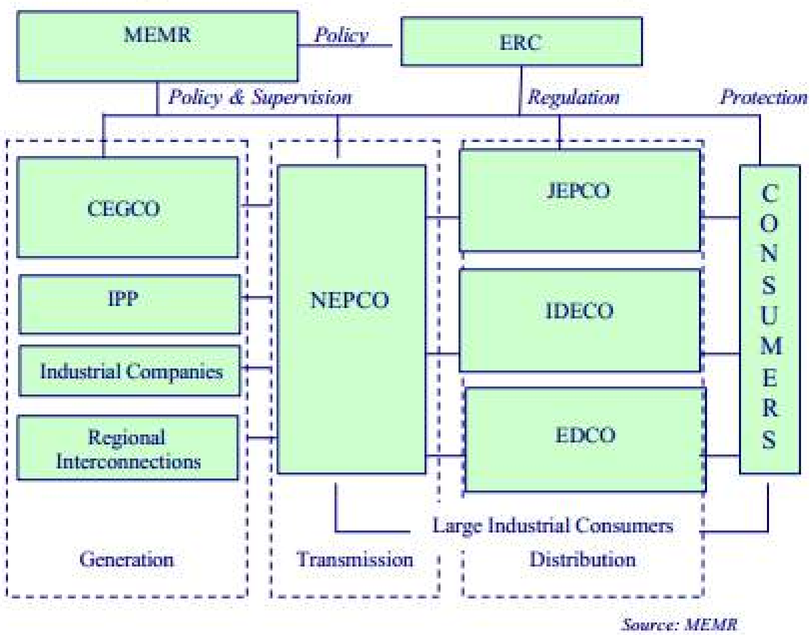
- Ministry of Energy and Mineral Resources (MEMR): overseeing the overall energy scene, formulating the strategy including electricity, and negotiating with other countries for the purpose of reaching beneficial exchange agreements.
- Electricity Regulatory Commission (ERC): Licensing generation; transmission; and distribution companies, setting electricity tariffs, and monitoring the performance of the licensed companies.
- National Electric Power Company (NEPCO): Purchase of power from generation companies, controlling power exchange through interconnections with other countries, purchase of natural gas on behalf of government and supplying it to generation companies, economic dispatch of generation and transmission systems, sale of electricity to distribution companies. This is a 100% government owned company operating on commercial basis.
- There are Nine Principal Consumers connected to NEPCO network. The Jordan Grid Code defines principal consumer as a consumer that is directly connected to the Transmission Network (132 kV and above) to which Energy is supplied to these Consumer.
- Three distribution companies: each company is given a concession area to sell electricity to consumers within its area. These companies are:
    - Jordan Electric Power Company (JEPCO),
    - Electricity Distribution Company (EDCO),
    - Irbid District Electricity Company (IDECO).
- Central Electricity Generating Company (CEGCO): private generating company operating several plants including some renewable energy plants.
- Samra Electric Power Generation Company (SEPGCO): 100% government owned Generation Company operating one plant.
- Four independent power producer companies (IPP1), (IPP2), (IPP3) and (IPP4)

The set up is clearly dependent on opening up the generation and distribution components for private investors. There are three privately owned distribution companies in Jordan. On the other hand there are five privately owned generation companies and one government- owned Generation Company.

Jordan Electricity Sector



This latter will be subject to privatization soon. Finally the transmission company is fully owned by government. This is called the "single buyer" scheme whereas this transmission company (NEPCO) is responsible for the purchase of power from producers and sells it to the distribution companies; each with a geographical area to serve. NEPCO is also responsible for the purchase of natural gas needed for the generation of power on behalf of the government. It is also responsible for power exchange with Egypt, Syria and The Palestinian Authority. The electric sector structure in Jordan is depicted in figure below.



Benefits of Program

Changes in energy consumption management practices and installed energy efficient measures utilized by the consuming sectors are what provide these benefits. These benefits are accrued by avoiding the costs of increasing capacity and supplying energy. As energy is reduced throughout the entire year, the supply curve is shifted downward, therefore reducing marginal energy and capacity costs. This program is divided into two stages;

Stage One.

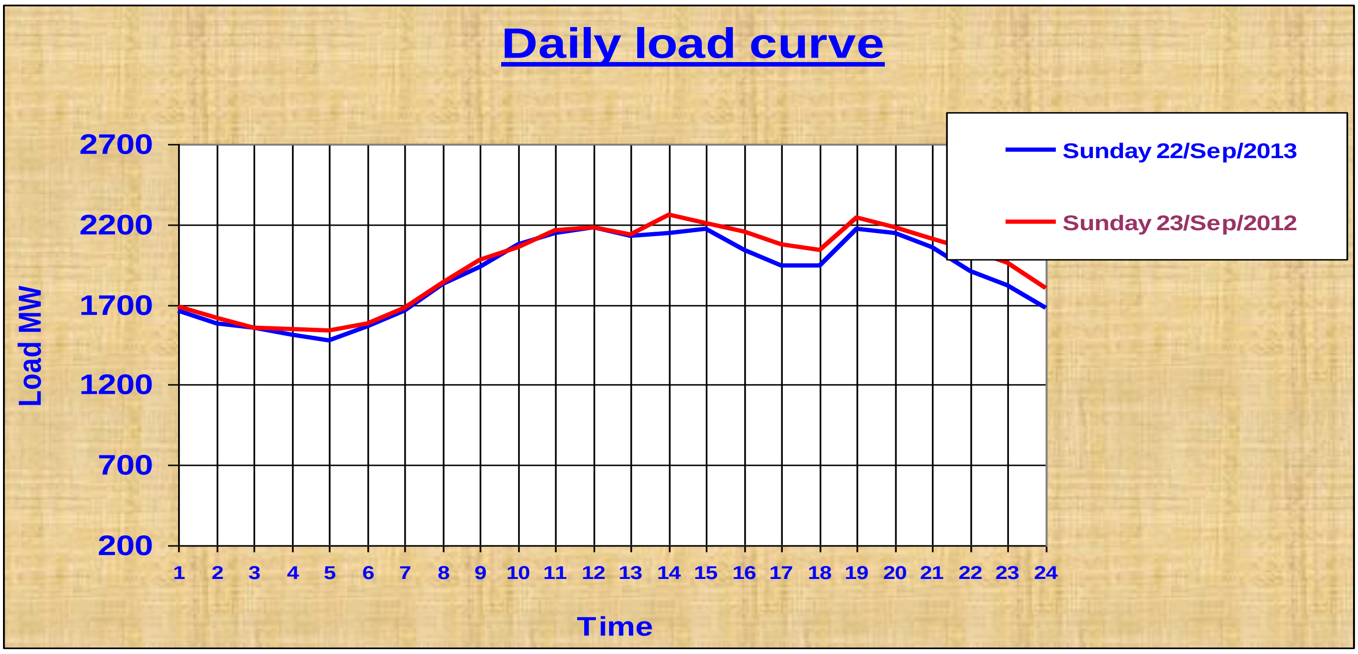
In mid-2012, the organizing committee of the electricity sector (ERC) with the National Electricity Company (NEPCO) study to assess the economic feasibility and market potential for the development of the electricity system operation ;

i. pilot project to cover the a significant increase in the maximum load during coincide morning in the summer high temperature (25 - 35 Co) with the decline in the ability to generate units, and the system peak loads in the season summer mean (daily load) come in two time morning maximum load and evening maximum load,

There are Principal Consumers connected to NEPCO network with supply tariff as;

a- The Maximum Load Tariff **(19:00 p.m. to 22:00 p.m.)**	**2.98 JD/kW/month** for maximum monthly load
b- The Day Energy Tariff **(7:00 a.m. to 12:30 p.m.)**	**124 Fils / kWh** for sold during the day Period
c- The Night Energy Tariff **(0:00 p.m. to 7:00 a.m.)**	**101 Fils / kWh** For sold during the Night period.

Change the maximum load tariff period, for the Principal Consumers from system peak load to become (am 12:00 to 15:00 pm) instead of time period (19:00 p.m. to 22:00 p.m.)



Actual program result

The benefits from this project reduce the maximum load in the morning about 60 megawatts;

- Avoid the load shedding in the system in case of power generation deficiency, or
- In case of availability power generation to run 60 megawatts. Emergency Gas-turbine
- The cost of run 60 megawatts. Emergency from Gas-turbine about 5 million US $

Stage Two.

Demand Response is a globally accepted practice to keep system load within manageable limits to avoid costly generation. The success of a demand response program depends upon active consumer participation.

NEPCO in cooperation with their Principal Consumers to assess the impact of Demand Response. Later on, if the results of this pilot project are beneficial, then the DR program would be extended to other segments like commercial, small industrial and residential consumers;

Once system DR potential has been estimated. These are very critical parameters of program design as they directly impact the consumer's convenience and production. The analyzed these parameters from two aspects; avoiding high cost generation and system load considerations

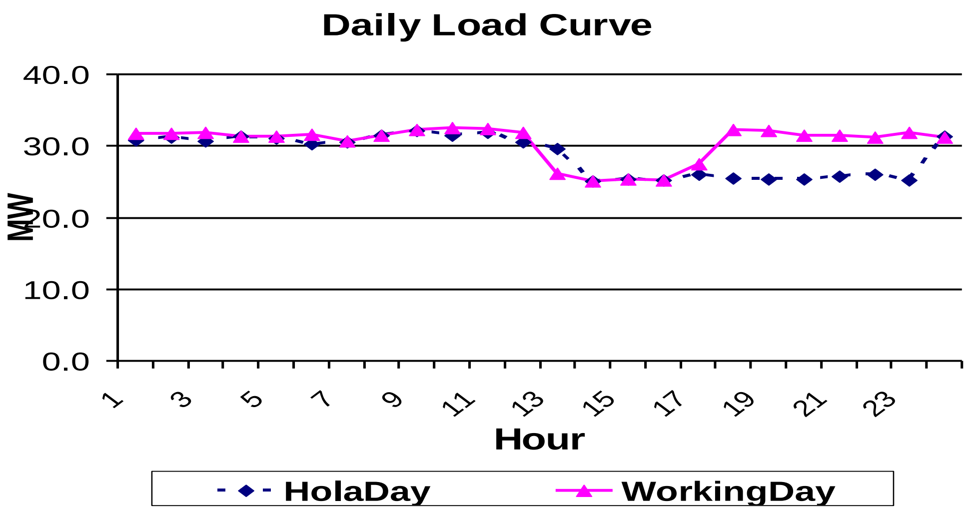
While analyzing generating plants, the highest cost generating plants followed 175 Fils/kWh that the installed capacity of these four plants is just between 20-30 MW. Thus, it is possible to only partially avoid the generation of these plants. DR can only partially meet the system requirement. Demand response programs like technology, regulatory and Policy challenges, business models and program impact

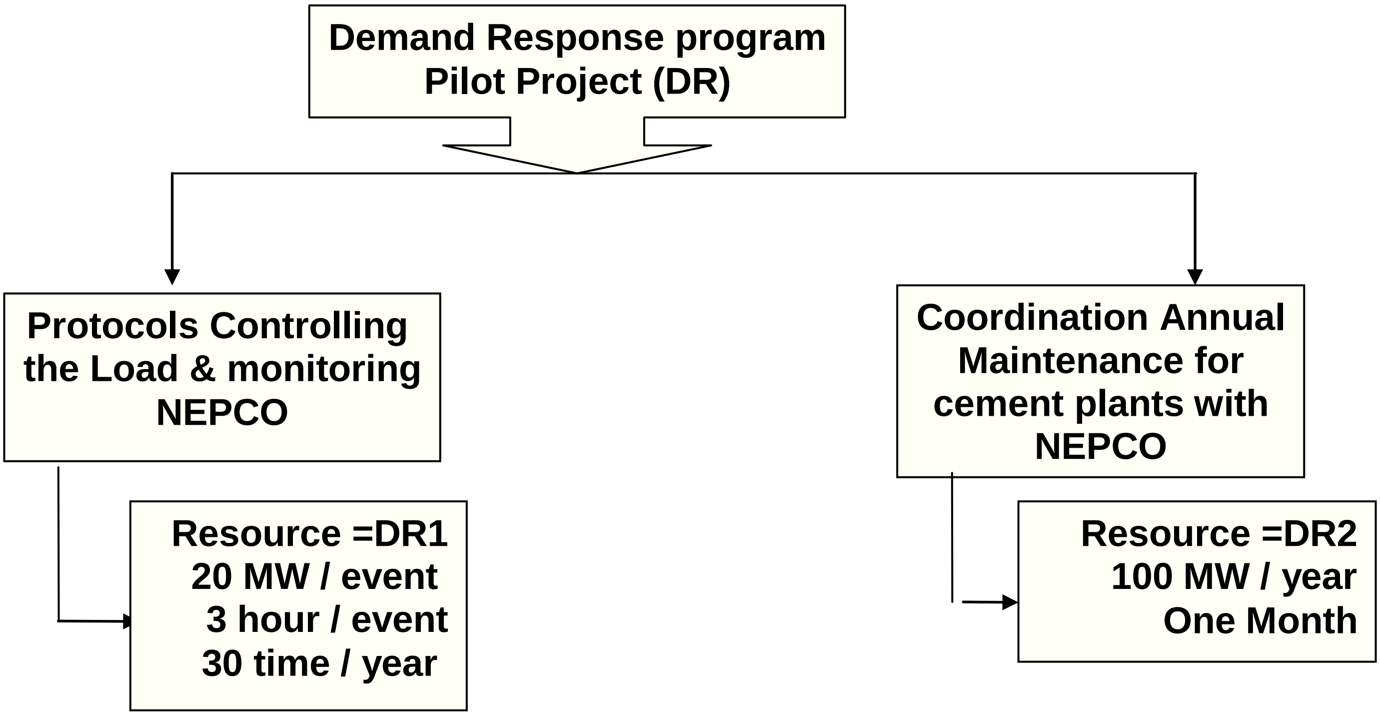
Demand Response Program for Jordan Pilot (Cement Companies)

The main Structure for pilot demand response project on 4 principal consumers are:

- smart meters, communication and IT systems
- Incentive /compensation cost
- Non-peak time Penalty
- Program administration costs including consumer outreach, awareness, Monitoring and Evaluation and marketing etc.

Behavior (Cement Companies)





Results Expected from the DR program

DR program Pilot Project	NEPCO	principal consumers
Direct Benefits	Operating Costs ≈ 6 Million $	As Incentive ≈ 0.6 Million $
Indirect Benefits	Operating system More Efficient and healthy, bottlenecks in the network Unforeseen Events.	More Efficiency, & Reduce the Costs

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Automating LV Distribution networks using sensor technologies

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Abstract— Low voltage network automation has seen rapid strides due to the advancements of Sensors and sensor technologies. Newer sensors have made it possible to monitor the electrical grid with much more accuracy and advanced telemetry systems to process sensor data at remote locations for intelligent information gathering and decision making for a host of applications of a smarter grid. The use of sensor technologies have not only led to better operational efficiency, but has also contributed significantly to energy efficiency, from the intelligence gathered from sensor data from key locations of electrical distribution network. This paper analyses the various applications of sensors in LV distribution network automation and the way they are revolutionizing the development of smart grids using real time information and data analytics, and contributing to environmental benefits.

***Index Terms*— Asset management, Business Intelligence, Distribution automation, Energy management system, Fault management system, Low voltage network automation, Network analysis, Outage management system, Power quality management, Real time analytics, Smart Grid**

1. INTRODUCTION

In today's competitive environment, there is an increased pressure on the Distribution network operators to manage the state of the networks in real time to ensure reliable services. The regulators have enforced stringent guidelines and performance benchmarks (such as CAIDI, CAIFI, CI and CML), and there are heavy penalties for not adhering to these standards. This combined with the growing awareness of the customers of their rights to demand better services under the new electricity regulations have driven the distribution utilities to introduce innovative ways of managing their networks more efficiently and effectively. As a result, sensor-based technologies have assumed significance in managing low voltage networks down to the last mile.

Some of the key application where sensor based technologies are being used by the utilities for improving operations, revenues and energy efficiency are:

1. Asset management system
2. Transformer monitoring system
3. Fault management and service restoration
4. Real time network analysis
5. Power quality monitoring
6. Peak load management
7. Automated demand response

2. ASSET MANAGEMENT SYSTEM

One of the main challenges of the distribution utilities is track their network assets throughout the life cycle, in order to manage assets costs with greater efficiency and higher profitability. Utilities are exploring new technologies for precise inventory control, with the ability to manage, track and secure critical assets in real-time, as part of the strategy.

The most commonly used technology is the "wireless" tracking devices. Tiny wireless RFID (radio frequency identification) tags can be placed on a network asset such as distribution transformer or smart meter. These RFID devices communicate with the intelligent asset management system, which helps the utilities in asset planning, deployment, tracking and optimization.

The active RFID tags are attached to assets which are to be tracked or monitored. These tags communicate with RF sensors strategically located near the assets and linked via wireless repeaters or a data communication bus to the asset management application, which then displays the real-time location of the tagged assets. The complete history of an asset or its movement is logged by the system through the use of active asset tags.

3. TRANSFORMER MONITORING SYSTEM

Distribution transformer is the heart of the LV distribution networks. The health of the Distribution transformer has to be monitored at all times to ensure continuous and reliable supply of electricity services. Introduction of sensors for on-line monitoring of key operating parameters reduces the risk of transformer failure and cuts maintenance costs.

The parameters which can be monitored on a Distribution transformer are:

1. Surface temperature
2. Winding temperature
3. Transformer oil level
4. Oil temperature
5. Gas and moisture in transformer oil

Monitoring of the above parameters involves on-line collection of data using sensor based measurements and transmitting the data to the remote monitoring application through suitable communication systems e.g. RF or ZigBee communication. The failures of transformers in service are broadly due to temperature rise, low oil levels, over load, poor quality of connections or improper installation.

Monitoring sensor data of distribution transformer for critical parameters of surface temperature, low oil level and over load could be utilized to take proactive action in fault prevention, thus increasing the reliability of distribution network.

4. FAULT MANAGEMENT AND SERVICE RESTORATION

Fault passage current sensors on LV distribution systems can measure the current flow in real time and help in the early detection of overloading, short circuit or earth fault. The current signals can be graphically displayed on a remote Digital Fault Recorder (DFR) and the information could be utilized to validate the location of possible fault occurrence. Early detection of an impending fault can provide operators with a better understanding of the vulnerable sections of the network and the maintenance crew can be dispatched to reinforce those sections before a catastrophic fault may occur.

There is increased pressure from regulators and customers to reduce the number and duration of outages. Imposition of stiff penalties on utilities for poor network performance is incentivizing the use of sensors for better management of power distribution system, early fault detection and pre-empting power outages. Utilities are therefore considering deployment of current sensors (Rogowski Coils, Hall Effect sensors) for better fault management and achieving regulatory targets of network performance through:

1. Quicker detection of a fault condition
2. Accurately determining the location of fault
3. Isolating of the faulty section of the LV network
4. Re-energizing heathy sections – upstream and downstream - outside the isolated faulty section

Any abnormal data from the sensors are analyzed and used to isolate the faulty sections and switch to alternate network plans to minimize the impact of power disruption and facilitate early restoration of services in case of a fault. The sensor data help in optimal design of the switching plans of LV networks, considering all network constraints, system interlocks, protective devices and safety issues, and facilitate early restoration of services to a large part of the network and customers, without overloading.

5. REAL TIME NETWORK ANALYSIS

Earlier, for traditional distribution networks without sensor-backed automation, utilities had to rely on customer calls to be aware of network outages. Now Supervisory control and data acquisition (SCADA) at the substation get regular data from remote sensors via remote terminal units (RTUs) in real time, which is analyzed to know the state of the networks.

Sensor-based technologies have made predictive analysis possible on the electrical networks, which helps in network fault prevention, optimization and planning. With real time analysis, it is possible to detect sudden sags or swells in feeder voltages and current, any abnormal load variations or physical conditions. Integrated with Transformer monitoring system, outage management system and electrical protection systems, real time analytics can help estimate the current state of the network and identify the characteristics which might need immediate attention to prevent major failures.

The intelligent Distribution Management System (DMS) rely on sensor data for real-time modelling of the distribution network. Signals from the fault sensors, help the DMS perform real time analytics to operate the protective devices in a coordinated manner to isolate the faulty sections and restore the network through alternate switching plans, in a safe and reliable manner.

6. POWER QUALITY MONITORING

The quality of electrical power is an issue of increasing concern for industry players. The power quality of an electrical distribution network is affected by power line disturbance such as wave shape faults, overloading, capacitor switching transients, impulse transients or harmonic distortions. The rapid proliferation of energy efficient equipment, renewable energy sources and power electronics is increasing the presence of harmonics in the electrical supply. This can often damage circuits and equipment, by overheating and failure, or by the inefficient use of increasingly expensive energy. Ideally, the best electrical supply would be a sinusoidal waveform of a constant magnitude and frequency. However, many loads are not purely resistive and the presence of magnetizing current, effect of rectification and inherent impedance of certain loads may result in creation of harmonics or transients, which may degrade the power quality and cause technical losses.

Various measurement instruments of smart grids e.g. smart meters, protection relays and fault recorders may not measure all the power quality parameters. By using appropriate sensors and telemetry systems, it is possible to monitor power quality problems at regular intervals and analyze these data to reduce their effects, thus making the electrical network trouble free and more efficient. These sensors allow distribution network operators and high electrical load consumers to record vital information regarding power quality.

Sensor-based technology solves energy quality problems by timely identification of specific sources of harmonics. Each sensor unit measures and records harmonic and inter-harmonic frequencies, present on the main electricity supply at specific locations. The recorded data is then periodically transmitted through a wireless or wired communications network to a centralised database, where the information can be analysed and stored. The low cost of each sensor, combined with the convenience of wireless communication, enables monitoring electrical power quality at multiple locations of the network. This method significantly reduces costs by eliminating expensive diagnostic instrumentation, such as power quality analysers.

The sensor platform incorporates data management and visualisation software, which allows maintenance and operation personnel to use it for power quality measurements and analysis.

7. Peak Load Management

Sensors are transforming the operation of LV networks in combination with information and communication technologies (ICT) to build intelligence into the network for peak load management. Modern applications in energy generation, power distribution and energy consumption use sensors to make efficient use of green energy, increase automation in distribution and enable peak load management.

Interconnecting consumer devices with the home area networks, and at the same time, communication with the utility networks through a home gateway facilitate residential energy management. Residential energy management uses utility-driven price signals which vary depending on the time of the day, called Time of Use (ToU) pricing. In TOU pricing, electricity consumption during peak hours costs more than electricity consumption during off-peak hours. In peak hours, demands of the consumers rise, and utilities are compelled to deploy spinning reserves at a higher cost of energy and environment. Reducing peak load decreases the expenses for energy generation with corresponding decrease in greenhouse emissions.

Wireless sensors can play a key role in sensing the growth in energy demand and prompting actions to control this demand during peak hours. Intelligent electronic appliances fitted with sensors can communicate with the electric grid in real time to switch off or defer operation to cheaper off-peak hours, thus helping in energy balancing during peak loads. Another faster and reliable way of managing peak loads and balancing demands is through automated demand response.

8. Automated Demand Response

Automated demand response refers to a smart grid device or application interacting with customers to influence their consumption of electricity or their load demand during select time periods. This signals customers to decide to lower their consumption or shed electricity during peak periods, and shift their demand to off-peak periods to save energy costs. Utilities use automated demand response to achieve a balance between electricity generation and electricity consumption, thus helping in load optimization and grid stability.

Traditionally demand response interactions were manual, but with the introduction of sensors and advanced control systems, the LV network interacts directly with its customers' load control systems to manage peak loads and balance consumption. Automated demand response combines the inherent benefits of automation to bring more reliable, faster and cheaper responses to the load demand signals.

Automated demand response requires both the grid and the demand-side entities to install infrastructure to support the exchange of signals. The grid entity puts in place sensors capable of communicating demand response signals to their customer's automation equipment and the customer installs equipment capable of receiving these signals. Further, the demand response signals are relayed to the control systems where demand response strategies have been pre-programmed to execute the appropriate load control. Depending on the type of customer facility, such control systems could be as simple as a thermostat in a residence or as sophisticated as an industrial process control system. The smart network will receive feedback of the demand response signal on the facility's consumption via a smart meter or the control system. With automated demand response, the customer can respond to smart meter or sensor signals indicative of desired levels of demand response as opposed to manual load control. Automated demand response represents a way for distribution network operators to avail of more demand-side resources as a cheaper option for grid balancing.

9. Conclusion

The assessment studies on the impact of sensor technology on LV distribution networks reveal that the technology has a high potential in improving operational efficiencies through proactive fault management, improving power quality, network reliability and controlling technical losses. Other advantage of sensor-based technologies is the contribution to the reduction of greenhouse gas emissions, being able to maintain the health of LV networks in a sustainable and energy-efficient manner. Sensor based applications being used in smart power grids and combined with demand side management contribute to efficient use of energy resources and optimized network operation, thus helping to reduce the carbon footprint.

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About the author

Jayant Sinha is a graduate in Electronics and Instrumentation from BITS, Pilani with a post-graduate degree in Operations Management, and an Accredited Management Teacher (AMT), certified by AIMA. He is working as the Lead Consultant (Smart Networks) in Enzen Global Limited - a global Energy and Environment solutions company - in United Kingdom. He has over 29 years of domain experience in executing turn-key solution in Power sector automation in areas of generation, transmission and distribution.

At Enzen, he is a part of the Network operations team, engaged in the design of smart grid solutions for power and gas networks, covering Enterprise Asset/ Outage Management, Smart metering, SCADA, Distribution automation, Power quality management, Demand response management, Energy management systems, Real-time network analytics and Business intelligence. He has earlier served as a leading team member in implementing distributed digital controls and SCADA/ PLC systems for process automation of large thermal and gas power plants in various NTPC projects at Rihand, Dadri and Auraiya.

As head of business process transformation in Uttarakhand Power Corporation Ltd. (UPCL), he led his team in implementing R-APDRP project for automating distribution networks, business processes and revenue operations. As a senior team leader in UPCL, he was associated in planning and successful execution of automation projects in distribution management system and automated metering infrastructure, and a core committee member for business blueprinting of smart grids for power distribution system.

He has published several technical papers on Energy management systems, GIS for Utilities, AMR/ AMI, Demand side management, SCADA and Distribution management system in reputed journals, and presented them in national and international conferences. His email id is: jayant.sinha@enzen.com.

Real-Time Control Of Power Distribution using LT and HT Smart Grid Switches

Also Retrofit substitute for segregation of agricultural feeders

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***Abstract*— The rapid growth of the Indian economy over the past few years has brought a large portion of the population into the middle class and consequently generated tremendous demand for electricity. This rise in demand has created major problems for distribution companies on three fronts. First, for multiple reasons the expansion of the power sector has not kept pace with this growth. Second, the distribution network itself is antiquated and heavily burdened with inefficiencies. Finally, state governments have continued to follow a policy to supply subsidized power for agriculture and rural population, thus leading downward pressure on revenues. As a result, to maintain grid integrity, scheduled and unscheduled interruption of power has become a necessity. To overcome this issue in the near team, there is a critical need to implement controlled power distribution through the utilization of smart power switches on LT as well as HT lines.**

I. INTRODUCTION

Emerging economies all over the world today, face a grim reality - electricity supply is both inadequate and unreliable. India is one of those economies and is probably one of the most critically impacted. Scheduled and unscheduled power shutdown occurs frequently throughout the country. India's power grid is overloaded to the point where state governments have resorted to notifying the public of scheduled power outages so as to enable residents to plan accordingly. In fact, the power distribution companies, in most states have introduced the concept of a "Power Holiday"[1] – a rationing system whereby industries are asked to take mandatory holidays during different days of the week so as to reduce the load on the Power Grid. Such incidents have enormous social and economic repercussions.

There are three primary causes for this dramatic situation.

A. *Utilization:* The rapid growth of the economy over the past decade has led to a huge demand for power in addition to the need of industries. This demand for power is manifested in five major areas:

- An emerging middle class that demands comforts such as washing machine, air conditioners, induction heater, grinding machine, computers to name a few.
- The rapid growth of the Information Technology (IT) sector in India has led to a population exodus towards major hubs resulting in issues such as sporadic construction of houses and apartments, resulting in substantial demand for power and water.
- A significant rise in the price of cooking gas has led to people switching to electrical gadgets such as water heaters, electric cookers, induction heaters and microwave ovens especially in rural areas where the power supplied is subsidized [2].
- The rise in the utilization of power for mass transit systems, and battery operated vehicles within metropolitan areas.
- Rampant power theft in numerous parts of the country.
- Depletion of the water table resulting in usage of more power to extract the same amount of water.

B. *Government Regulation:* Government regulations in the power sector have stymied the implementation of several power generation projects from both traditional and clean technology areas. In fact, a cursory glance of data from the Indian Planning Commission indicates that India is yet to meet an annual power capacity addition target since the 1950s[3,4]. Cumulatively, these issues have led to a widening gap between demand and supply of reliable power.

Until recently, despite the on-going power issues, the country's GDP grew at a rapid rate of 8%. The recent slowdown of GDP growth to 6% has put fresh focus on the problem as the government works hard to maintain a strong GDP growth rate. Estimates indicate that the lack of consistent and adequate power has historically reduced GDP growth by up to 2%. Further, the recent "Make In India" policy declared by the central government will continue to push up utilization rates in specific parts of the country.

C. *Subsidization:* This takes the form of support provided to agricultural and rural needs of the country. This is primarily done in two methods:

- Free/subsidized power provided to farmers to run agricultural pumps, which are a major source of electricity utilization. This problem has been exacerbated over the past decade due to depletion of water table, and use of inefficient and rewound motors.
- Distribution of gadgets such as televisions, grinding machines and mixers to name a few, free of cost to people of lower economic classes to improve the quality of life.

I. LOSSES IN THE SYSTEM

According to data from the World Bank, India ranked 133 out of 147[5] countries in terms of inefficiency in the grid. In a country struggling to meet demand, losses in the distribution system amount to almost 25% - one of the highest in the world; in stark contrast to advanced economies where losses amount to a meager 6%.

Specifically within the Indian scenario, the utilization of 11KV distribution lines warrants special mention. These are high tension lines used for the distribution of power over long distances. Simultaneous demand of power on these lines that can run for distances from up to 15 to 30 KM, leads to issues of high voltage on distribution points and low voltage on the consumer end. In turn, this phenomenon leads to an increase in losses in motors, electrical gadgets, transformers and distribution system thereby significantly shortening the lifespan of such devices.

Essentially, the grid reliability is poor. Power outages occur frequently as a result of uncontrolled overload on an aging power grid infrastructure, poor maintenance, and demand that outstrips supply.

II. IMPACT

The cumulative impact is that state Electricity Boards have been running at a loss for several years. Bankrupt and unable to implement the extensive power upgrades necessary, state governments are caught in a limbo of inactivity.

In such a scenario, the development of smart grids holds promise. The U.S Department of Energy defines smart grids as a network with a combination of the following features:

- Increased use of digital information and controls technology to improve reliability, security and efficiency of the electric grid.
- Dynamic optimization of grid operations and resources with full cyber security.
- Deployment of smart technologies, appliances and consumer devices for metering, communications and distribution automation.

The benefits of a smart grid system are numerous:

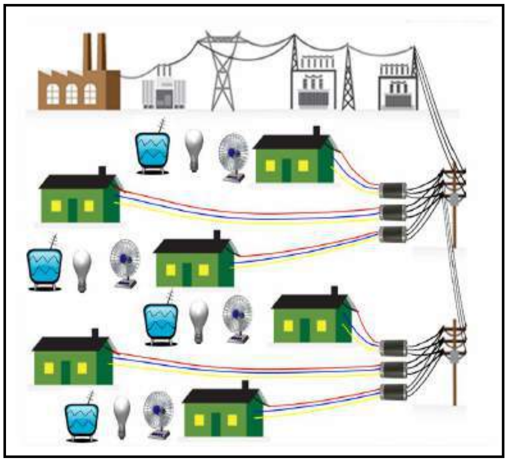
- Management of peak load capacity.
- Enable active participation by consumers.
- Anticipate and respond to system disturbances.
- Integration of transmission and distribution systems to enable improved overall grid operations.
- Improved reliability and "self-healing" of the distribution system.

It is within this context that we, at Prapati - a Chennai based company, have developed a portfolio of "Smart Grid Switch" solutions. Through a combination of solutions targeted at the specific needs of individual distributors, Prapati enables power distributors to utilize the available capacity in an efficient manner.

III. PROBLEM DESCRIPTION

In the current scenario, distribution of power from power stations is conducted at very high voltages of 11KiloVolt (KV) for distances up to 40km. This form of distribution is highly efficient and thus reduces losses in the system. To make this power utilizable, a 11KV "distribution transformer' is used periodically throughout the line to "step down" the voltage from 11,000 volts to 433 volts in 3 phases. This form of supply is necessary for high intensity activity such as running large motors, industrial power plants and water pumps for irrigation. For residential uses such as lights, fans, televisions, air conditioners and washing machines to name a few, three phase supply is re-distributed as single phase supply – a lower form of electricity supply.

To make this intricate process work, depending on the length of the 11KV line, nearly 40 to 60 "step down" transformers are connected to each line. These in turn provide three phased power to all industrial and commercial entities as well as most domestic entities. This form of distribution leads to two major issues.



A. Imbalance of load across all three phases. Since ~ 37% of power consumption is domestic and commercial utilizing single phase (primarily), large imbalances occur between the amounts of loading across the three phases, particularly in urban areas. As a direct consequence of this, large amounts of power are lost in the form of neutral current. This is an issue that is further exaggerated during peak loading hours.

B. Unmanageable "peak loading" i.e. all entities demanding power simultaneously; for example, imagine a scenario where households switch on water heaters, domestic pumps, air-conditioners and industrial areas turn on large motors and machines and farmers turn on irrigation pumps, at the same time. Such "peak loading" leads to a failure of the grid as a whole. To prevent this specific scenario power distribution companies resort to planned and unplanned "rolling blackouts" and other drastic measures.

IV. CURRENT RESOLUTION

As identified above, there are two primary concerns brought about due to three phase power distribution. We take a look at the current solutions present for both scenarios described above.

A. Currently, there is no viable solution to issue A. identified in the previous section.

Newer communities and urban developments can be hard-wired with single-phase connections to minimize the issue but even in these scenarios, utilization cannot be accurately predicted and thus leads to load imbalances further up the distribution chain. A recent analysis of a power distributor in a very dense urban area indicated dramatic imbalances across the three phases; in some instances the loading on one phase was 5 times that on another phase.

B. The intelligent rationing of power is achieved through separation of agricultural feeders at 11 KV level; a practice that has been utilized on a fairly extensive basis to address the problems associated with issue B. identified above. In this scenario the probability is high that farmers would switch on motors simultaneously and utilize 3 phase power when it is available for short periods of time. This collective action results in a substantial drop in voltage at the tail end and increases distribution losses. To gain better control over the supply of electricity, state governments are resorting to a 2 step approach.

Step 1: Segregation of agricultural feeders from domestic, commercial and industrial feeders so as the balance the demand more equitably.

Step 2: Segregation of distribution lines into High Tension (HT) and Low Tension. The idea is to supply single phase power for 24 hours/day and three-phase power at specific intervals.

As a combination of the two strategies, power distribution companies can regulate when industrial areas and farming communities draw three-phase power for heavy industrial applications. By regulating supply, distribution companies can smoothen out the capacity utilization over a 24 hour period. The process of segregating lines has so far proven to be cumbersome and expensive. A good example of this is the case study of the state of Gujarat.

The state of Gujarat has been a pioneer in numerous technical advances within India. Specifically with respect to the power sector, Gujarat started the process of segregating feeders as early as 2001. Key highlights of the project are below [6,7]:

- 56,307 km of high tension lines
- 22,146 km of low tension lines
- 18724 transformers
- 1.7M new electricity poles
- In 1000 days

As a result of this initiative, the state of Gujarat was able to:

- Ration free power to farming communities in a methodical and efficient manner
- Collect steady tariffs from industrial units that were assured of good quality power during the day

The implementation, however, came at a high cost.

1) The state of Gujarat spent $300M and 3 years to implement this model putting the ROI timeframe at over 10 years.
2) Additionally, a major implementation issue arises with this scenario. When power is available for agricultural pumps, most of the consumers tend to utilize the available power for irrigation. In the process, voltage drops from high voltage at the distribution point to low voltage at the consumer end, which shortens motor life span as well as increase the distribution line losses substantially.
3) In the absence of any overload disconnection on low voltage distribution side, consumers tend to overload the power distribution.
4) When feeder faults arise as a result of the above mentioned scenarios, it could sometimes take days to isolate and fix the fault.

Research conducted at IIT Kanpur [8] indicates that in the absence of switches at different points in the distribution network, it is not possible to isolate certain loads for load shedding when required. The only option available in the present distribution network is the circuit breaker (one each for every main 11kV feeder) at the 33kV substation. However, these circuit breakers are actually provided as a means of protection to completely isolate the downstream network in the event of a fault. Using this as a tool for load management is not desirable, as it disconnects the power supply to a very large segment of consumers. Clearly, there is a need to put in place a system that can achieve a more precise resolution in load management.

V. PRAPATI SOLUTION

Prapati – a Chennai based company backed by highly experienced engineers in the field of power electronics, embedded software and communication network applications has developed an array of "Smart Grid Switch" solutions. The switches are designed to provide 3 main functions:

1. Act as a replacement for the practice of segregation of agricultural feeders.

2. Enable remote dynamic control of supply so as to regulate peak demand times in areas where segregation of feeders has already been completed.

3. Finally, enable dynamic load distribution among the three phases at the transformer terminal.

Essentially, Prapati's solutions enable power distributors to utilize the available capacity in an efficient manner. The SGS portfolio enables power distribution companies to meet dual objectives. First, the election mandate of supplying single phase power for 24 hours in all three lines of the existing distribution network and second, three phase power in the same three lines at a specified time for a pre-determined length without disturbing the existing distribution network.

The SGS is a specially designed electro-magnetic switch with the unique advantage of a contact that opens/closes with an accuracy of +/- 1 mili second.

This enables movement of contact during 2 specific periods:

1. While the current is passing through zero during opening and

2. While the voltage is passing through zero during closing.

In addition, the utilization of multiple contacts enhances the reliability of the system and the utilization of an efficient design makes the switch rugged and thus suitable for deployment in numerous conditions.

Through proper planning, the voltage fluctuation on the grid and at the consumer terminal will be minimized substantially. Periodically and dynamically the load at the transformer terminal will be balanced by transferring the load from one phase to the other as per demand. Further, the reduction in neutral current leads to dramatic improvements in efficiency and thus in turn to financial savings. During emergency the power can be rationed with interaction with the consumer to avoid total blackout due to overload on the grid.

The company has been granted a patent for the process and has applied for patents for the product. Professors at IIT Chennai have shown appreciation for the invention.

The main features of the system are outlined below:

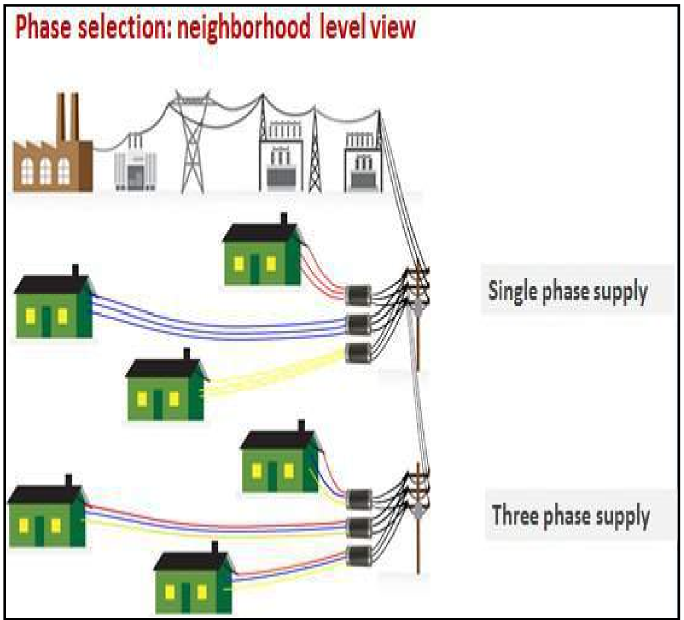
- *Integration with the existing distribution network:* SGS will supply single phase power for 24 hours in all the three lines or selected two lines in a cyclical manner; a process being utilized today as part of a method called "Restriction and Control". In addition, three phase supply is done in the same three lines at a specific guaranteed time for a specified time. As a result, re-wiring of the entire state is not necessary. (copy of the photo of switch on pole attached)
- *Low cost:* Installation of switches can be done at a very low price point. A basic calculation for utilization in Gujarat indicates that the same functionality could have been achieved through the installation of switches at half the price ~ $150M
- *Rapid Deployment:* The installation of new wires is a lengthy and disruptive process. Disconnection of the existing lines leads to extended disruption in service and laying new lines takes large teams of people. On the other hand, the installation of switches can be done in a rapid manner by smaller teams and since the switch is latched on to a pole, the outage time is minimized as well. Again, comparisons to the Gujarat model indicate that the same functionality can be achieved in 1/3rd of the timeframe, i.e. ~ 1 year.
- *Granular Control:* One of the primary issues with segregating lines is that while distribution companies are able to achieve control over supply, this can be done only over a large grid such as10 sq.km of an agricultural area or a small town. The SGS on the other hand provides granular control on a street level thus providing granular control.
- *Real Time Data:* The SGS can also transmit utilization information back to a central hub. Distribution companies can thus monitor their networks with real-time data and a high level of precision.
- *Dynamic Phase Selection:* The SGS also provides the functionality of switching the load from one phase to another based on loading and quality of power supplied on those specific phases. As a result, consumers can be assured of consistently good quality of power. Distribution losses due to over load of one phase and, joints will come down substantially (diagrams attached)
- *Fault Isolation:* Built in high speed breaker will isolate faulty feeder instantaneously (in less than 10 millisecond from the time of the command) .One feeder fault will not affect other consumer. Switch opening at current zero crossing ensures no voltage transients.
- *Rapid Response:* Reconnection of feeder fault through remote will improve reduce downtime due to fault will improve consumer satisfaction substantially. Switch closing at voltage zero crossing ensures reduced inrush current.
- *Consumer device protection:* Proper load management will reduce voltage fluctuation substantially, resulting in reduced motor losses and burning of motors, and other electrical gadgets
- *Reduction in distribution losses:* By utilizing a time differentiated process, an SGS switch can allocate 3 phase power at different time intervals to different DTs on the same 11KV line. This particular feature dramatically improves tail end voltage and reduces distribution losses in contrast to the practice of segregation of feeders.
- *Theft Prevention:* Theft detection can be done in a rapid manner through the use of analytics. For example: If the utilization in a specific area rises dramatically on one day, it could be an indication of theft.
- *High Speed Circuit Breaker:* This feature will disconnect the load from the supply in less than 10 mili second from the time of command. This also facilitates the disconnection of that particular consumer connection, without interrupting other consumer connections. Reconnection can also be done remotely through SMS/GPRS. Additionally, disconnection during unauthorized power consumption and automatic reconnection after removal of unauthorized power consumption can be done through statistical analysis and interaction with consumer.

VI. CASE STUDIES

1. We take the example of the state of Tamil Nadu to analyze the impact of the first utilization of the SGS portfolio: To act as a replacement for the practice of segregation of agricultural feeders.

The state of Tamil Nadu has allocated Rs.6,000 Crores ($1.2B) for the segregation of feeders. Our estimates on the deployment of the SGS indicate that the same and higher benefits can be leveraged instead within a deployment time frame of just 1 year and an ROI timeframe of just 5 years.

According to BRIEF (9) 85% of the industries in Tamilnadu, Andhra Pradesh, and Odisha are prepared to pay higher tariff for reliable power supply and in rest of the country, 61% of the industries are willing to pay higher tariffs. This will help power distribution companies overcome their financial losses.



2. We analyze the case of the state of Gujarat in the 2nd instance: To enable remote dynamic control of supply so as to regulate peak demand times.

The segregation of feeders causes high distribution losses, in particular on the HT lines. Our analysis indicates that the installation of the Prapati HT SGS unit will dramatically reduce these distribution losses and provide an ROI period of just 4 years.

3. Finally, we analyze the case of a distributor in a dense urban environment for the 3 utilization scenario: To enable dynamic load distribution at the transformer terminal.

As previously mentioned, our analysis indicates load imbalance of up to 5 times on different phases and in turn, high neutral current. Our analysis indicates that neutral current can be reduced by up to 50% with the installation of Prapati LT SGS units with an ROI timeframe of just 3 years.

VII. SUMMARY

The rapid growth of the Indian economy has been good news for millions. The socio-economic benefits of this growth have been tremendous. Unfortunately, consumers are not able to enjoy these benefits completely due to the lack of a basic facility – consistent, good quality electricity. The continued predicted expansion of the economy means that this gap between demand and supply will continue to grow in the near future. There is popular consensus among analysts in various publications that there is a need for a methodology to control distribution in a more precise manner. It is in this context that the SGS portfolio developed by Prapati adds significant incremental value. The versatility in operation, robustness and low cost of the switch makes it a superior alternative to the current solutions employed. Essentially, the Prapati suite of switches provides power distribution companies the ability to reduce distribution losses substantially and provide good quality power to meet the needs of their consumers at a low cost and within a short timeframe. In addition, the SGS portfolio will provide positive externalities in terms of the life of transformers, motors and other appliances utilized at the consumer end.

In effect, the “Smart Grid Switch” (SGS) portfolio developed by Prapati, provides simple solutions to a complex problem

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Simulating a Connected Micro-Smart Grid

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Abstract—India is a power deficit country with average peak power deficit of 9% and average energy deficit of 8.7% in 2012-13. This results in power blackouts for firms who resort to back up systems and may have to bear some output loss in production. Micro-smart grids provide a way forward where, in grid responsive buildings, renewable electricity generation such as roof top solar PV, and smart grid initiatives are integrated to provide benefits to both end users and distribution companies along with reduction in global greenhouse gas (GHG) emissions. End users gain by getting reliable power supply and reduced power bills, distribution companies reduce their peak power shortages, and GHG emissions come down due to integration with renewable energy. The networks operate at micro level with 5-10 consumers bunched together and become more manageable than large grids. The grid stability also increases if these micro groups are managed well within themselves. Micro grids can also be provided with capabilities of isolating themselves from the main grid in case of problems in the main grid. In this study, a 5 consumer based connected micro grid with a total capacity of 1.15 MW is simulated (Bangalore setting). The results indicate that a connected micro-smart grid indeed provides benefits to all concerned. The cumulative energy consumption reduces by over 25%, financial returns accrue to the tune of 40% excluding lower loss of production to the firms (revenue from renewable power sales would be additional), and GHG emissions come down by 25%.

Keywords—Micro-smart grid, demand response, distributed generation, passive measuring device

I. INTRODUCTION

Electricity is a critical component in economic growth, business expansion and infrastructure development. With a production of 1102 Terawatt hours (TWh), India is the third largest producer of electricity in the world behind only US and China. Power sector in India is an expanding market with a CAGR of 5.9% (03-13) [1]. While the consumption of power in India stands at 5% of the world's average, electricity production stays at just 4%. There has been an increasing demand for electricity and is only expected to grow further in the years to come.

There have been a number of developments in Indian power sector like the Electricity Act, National Tariff Policy, UMPP Schemes all aimed at meeting the growing demand [2]. Despite the efforts, India is still a power deficit country with average peak power deficit of 9% and average energy deficit of 8.7% in 2012-13 [3]. One of the major issues identified is the demand side management (DSM). Electricity produced can be used more efficiently than it is being used currently. DSM involves demand management, developing and promoting energy efficient technologies. Electricity grid intelligence and advanced control and communication technologies are the requirements for the same. A smart grid serves this purpose and helps transform the current grid to one that functions more cooperatively and responsively. By enabling devices at all levels within the grid to independently sense, anticipate and respond to real time conditions through real time information sharing, a smart grid helps save money by efficient usage of electricity and also make money by selling unused power back into the system.

II. MICRO-SMART GRIDS

Smart micro-grid with solar PV systems has been promising for electrification of remote villages and rural areas in India [4] [5] [6] [7] [8]. Smart micro-grid integrated with renewable energy system either grid- connected or off-grid provides many benefits to all the electricity stakeholders. Utilities can provide more reliable power by managing their cost more effectively through efficiency, reduced power theft, reduced T&D losses, and reduced peak demand, reducing power outages and power failure through demand response (DR). Consumers can be benefited with reduced power outage because of reliable power as well as incentives to install their own micro-grid infrastructure through TOU pricing and DR. The electrification in rural areas can provide social improvements and subsequent economic growth with sustainably lower relative cost. The society will benefit from more reliable power for services, businesses and consumers sensitive to power cuts with increased economic development of the country [8] [9] [10].

This study focuses on addressing this problem and making the grid system more efficient. Micro-smart grids improve the grid resilience and also have the potential to increase the usage of renewable low carbon energy sources. Alongside, they contribute in reducing the costs for micro-grid participants including the end users as well as the distribution companies. Micro-grids can also be generators of revenue for the participants by supplying services back to the central grid. Local power generation, demand response, and real time pricing are useful in this aspect. Local power generation and storage options allows the grid to work independently of the central grid aiding in times of power fluctuations and blackouts. The grid also ensures that the local communities are better equipped to handle the knowns and unknowns of the future electricity supply.

The objective of this study is to simulate a connected micro smart grid system that includes multiple loads and distributed energy resources that can be operated in parallel.

III. MODEL

A. Model Brief

In this study, a 5 consumer based connected micro grid with a total capacity of 1.15 MW is simulated. The load patterns for the load centers were obtained from the smart meters installed in buildings. All the load centers were in Bangalore setting and were IT based firms.

B. Model Framework

The model takes into account various factors related to basic power calculations such as fixed and variable rates (including time of the day pricing), penalty rates (for case of over-drawl), cost of running a backup power (diesel generator) and minimum energy consumption requirement.

For solar PV generation as a distributed power source, the model includes efficiency, investments, solar incidence (Bangalore data) and solar selling prices. The simulation can also run taking into account the decision to sell or not to sell the solar power. Passive energy efficient devices can be modeled in the simulation taking into account their life, different options (CFLs or LEDs) and initial costs.

Finally the model can simulate various DR scenarios given the demand depth cut, the type of DR system used (fully automated, semi-automated, or manual), lifespan, investments, maintenance charges and incentives from utility for DR. The DR model can also simulate the response times required for a particular demand by the utility. The DR model also takes into account the priorities between different types of loads in the load centers (critical vs non-critical, lighting, motor, space cooling and IT).

The simulations were performed for various scenarios on the framework shown in fig. 1.

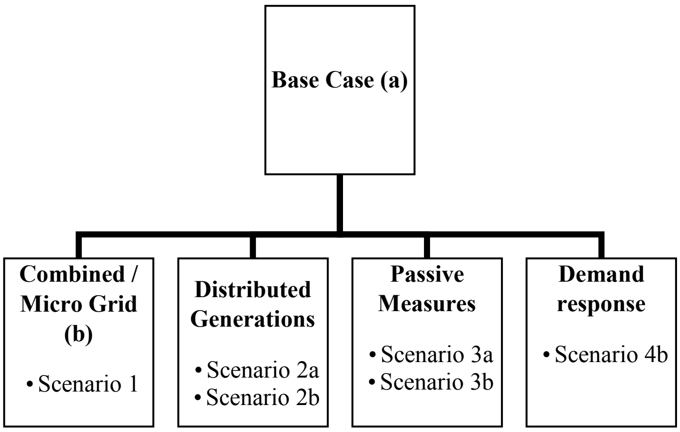


Figure 1: Framework of scenarios

The various scenarios that were tested are is listed below.

- Micro-grid:
  - **Scenario 1:** Combining the loads of load centers
- Addition of distributed generations
  - **Scenario 2a:** Base case + Distributed generations (Solar PV)
  - **Scenario 2b:** Scenario 1 + Distributed generations (Solar PV)
- Addition of passive energy saving devices
  - **Scenario 3a:** Base case + Passive energy devices
  - **Scenario 3b:** Scenario 1 + Passive energy devices
- Demand response
  - Reduction in the costs by creating smart responses to the grid to counter constraint scenarios and uneven power requirements
  - **Scenario 4a:** Base case + Demand response

- **Scenario 4b:** Scenario 1 + Demand response

- Efficient Smart Grid
    - Combined effect of all the various initiatives
    - **Scenario 5:** Scenario 1 + Distributed generations (Solar PV) + Passive energy devices + Demand response

C. Control Parameters

The set of control parameters used are given in table 1 in the annexure. These include the electricity rates, distributed power source (solar) profile, passive energy devices data, and the load profiles of the 5 centers considered.

D. Results

The load curves of individual load centers shows huge peaks and valleys at different hours of the day. By combining these loads as a single micro-grid, valley filling DSM gets simulated resulting in a smoother load curve profile. This can be observed in fig. 2. Passive energy efficiency devices help in simulating effect of strategic conservation DSM. Our DR module helps in simulating effect of peak clipping DSM. For peak clipping, the simulation accounts for the criticality of load – non critical load demands are shed without any penalties while critical loads are usually not shed unless adequately compensated by the utility.

The response of the smart grid could also be simulated in terms of the two output variables – response depth cut as a percentage of the commissioned wattage and advanced warning time required by the micro-grid to respond (response time).

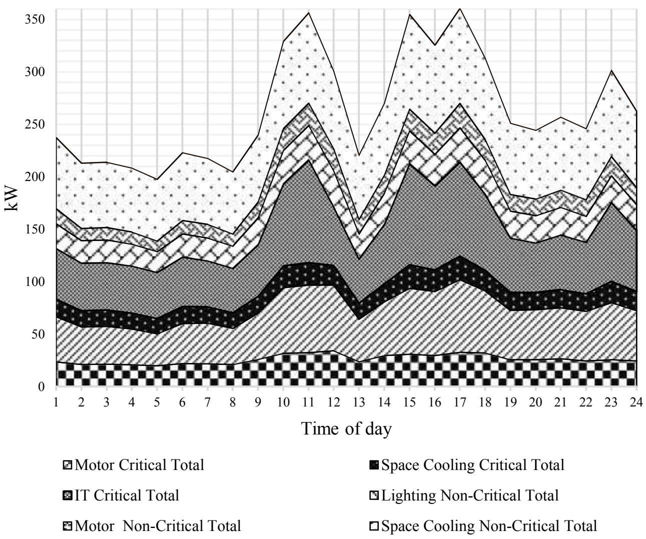


Figure 2: Load profile on implementing a micro-grid across the 5 load profiles

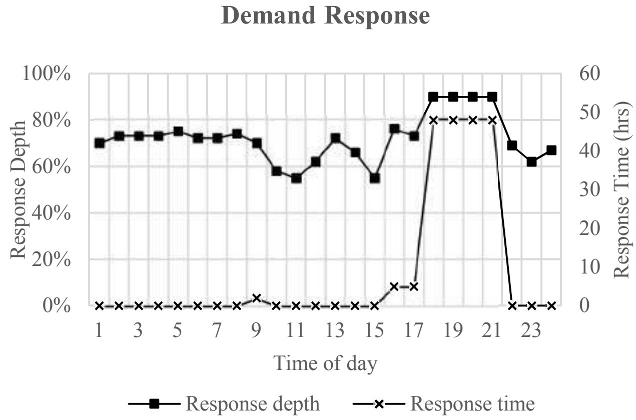


Figure 3: Response of the smart micro-grid to a utility demand of 90% depth cut from 1500 hours to 2100 hours

Two main performance measures – cost and energy consumption were observed to understand the real impact of micro-grid and other related measures.

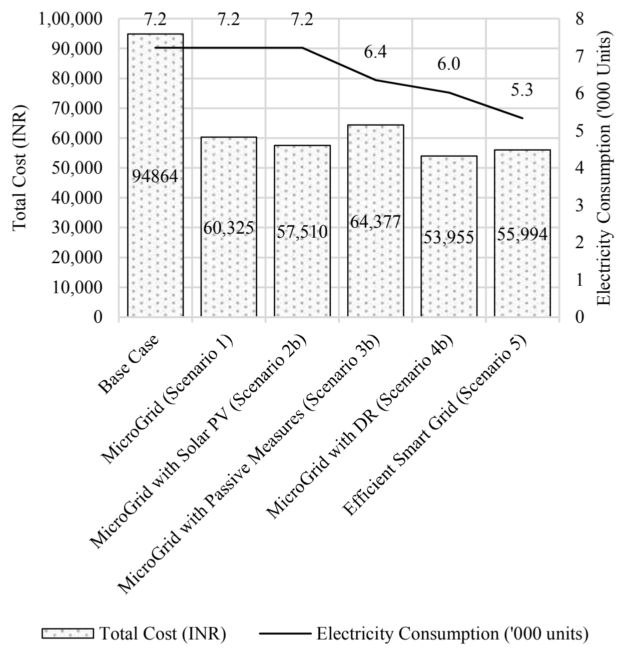


Figure 4: Effect on cost and electricity consumption is demonstrated in this chart

Fig. 4 illustrates how the various measures implemented have an effect on consumption of electricity and the cost of implementation.

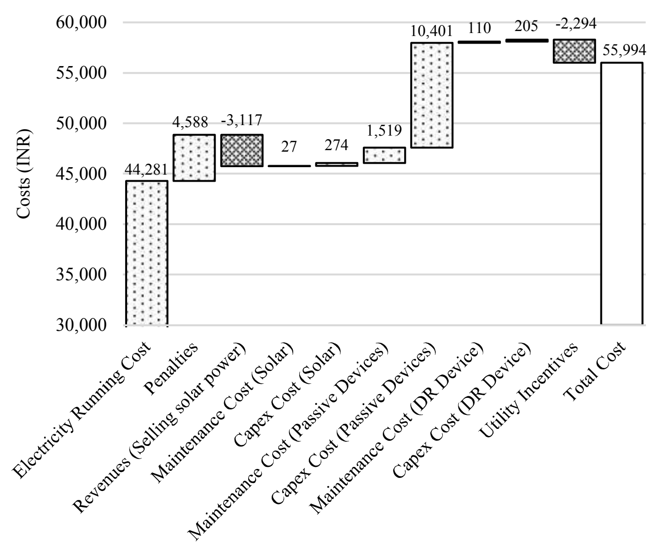


Figure 5: Total cost being used as a performance measure includes a number of individual costs along with revenues received through sale of solar power and utility incentives for switching off critical loads. Illustration represents the cost split for Scenario 5 (efficient smart grid)

Fig. 5 shows the components contributing to the total cost including the revenues from the sale of solar power and incentives from utilities for switching off critical loads. Cost reduces by around 36% by merely making individual load centers a micro-grid. With solar PV generation, a 4% savings in electricity consumption is observed with cost increasing minimally. This cost increase can be covered up in a few years as the savings made will lead to a breakeven of the capital investment needed for installation for solar power generation. It is also interesting to note that 5% additional savings in cost can be made over a micro-grid if solar is used for power generation which is thereby sold back to the grid.

Implementing demand response in an existing micro-grid resulted in considerable savings in both the parameters – 11% in electricity consumption and 17% in the cost. It can be observed that the total cost for an efficient smart grid (Scenario 5) is more than that of a micro-grid with DR (Scenario 4b), but the former results in higher energy savings. Reductions in GHG emissions are directly proportional to the energy savings. Observing the overall effect, the efficient smart grid (Scenario 5) can save up to 40% in costs and 26% in energy consumption per day.

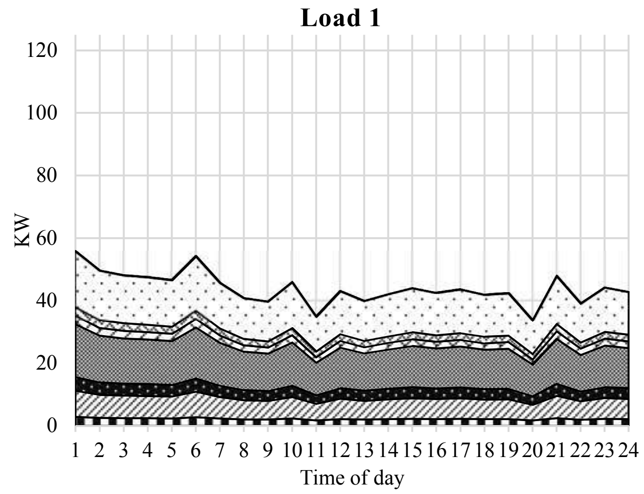
IV. Conclusion

Post this study, we were able to quantify the impact a micro-grid could make. The savings in terms of cost and energy saving is considerable. Considering the need in today's electricity market, using the resources efficiently is highly important. We can conclude that micro-grid, passive devices, demand response, solar generation are all feasible options. As observed, the results and savings are highly dependent on the input load profiles, costs of installments, per unit electricity cost and other such parameters. Considering the location and the kind of load centers, the right measure for energy efficiency can be implemented to get the best returns. This model can be run to find this optimal combination.

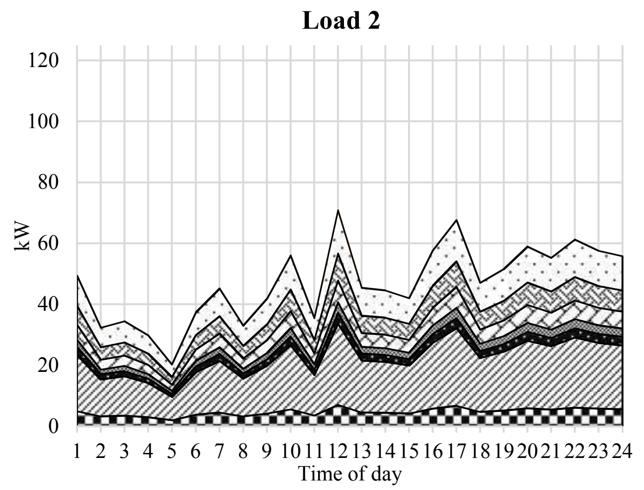
V. Annexure

Table 1: Control Parameters

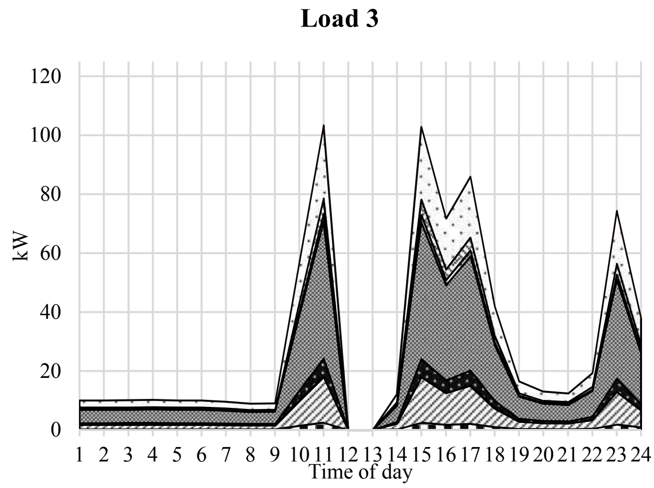
Electricity Rates	
Variable rate / kWH from time of the day	18 hrs to 22 hrs : 8.25
	Other Times: 7.25
Fixed rate / commissioned wattage / month	200
Penalty factor if power exceeded	14.5
Generator diesel penalty INR / kWh	16
Minimum level consumption	20%
Distributed Power Source Profile	
Total area of panels (sq mtrs)	1000
Efficiency of conversion to electricity	15%
Load Center where solar panels installed	1
Initial investments	20000000
Lifetime of panels (years)	20
Maintenance charges per year	100000
Solar selling price (INR)	7.5
Solar sold or not	Yes
Passive Energy Load profiles	
Load 1	LEDs
Load 2	LEDs
Load 3	LEDs
Load 4	LEDs
Load 5	LEDs
Passive Energy Saving Devices	
Percent Tubelights Energy (Load 1)	10%
Percent Tubelights Energy (Load 2)	20%
Percent Tubelights Energy (Load 3)	5%
Percent Tubelights Energy (Load 4)	30%
Percent Tubelights Energy (Load 5)	25%
Power Ratings (kW)	
Tubelights	0.04
CFLs	0.023
LEDs	0.016
Lifespan (hours)	
Tubelights	10000
CFLs	15000
LEDs	60000
Initial cost / per unit (INR)	
Tubelights	30
CFLs	90
LEDs	200
Load Profiles	



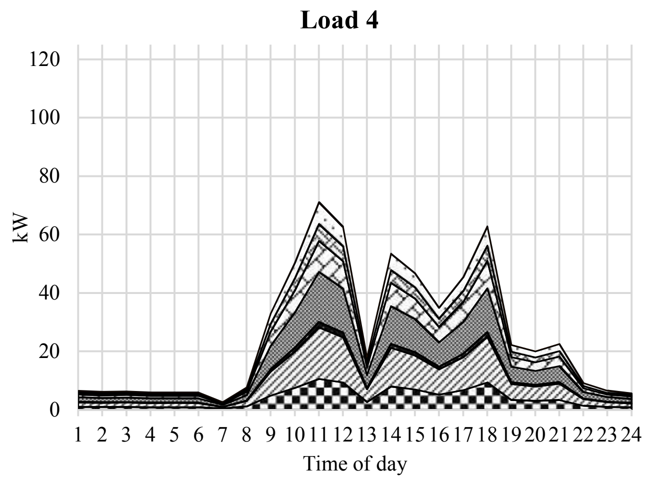
Commissioned Wattage	100			
Load Profile	Priority	Critical	Non-Critical	% of Load
Lighting Load	5	50%	50%	10%
Motor Load	10	75%	25%	20%
Space cooling load	20	20%	80%	40%
IT Load	15	100%	0%	30%
Response Times	**Critical**		**Non-Critical**	
Lighting Load	48		2	
Motor Load	48		2	
Space cooling load	24		2	
IT Load	24		2	



Commissioned Wattage	300			
Load Profile	Priority	Critical	Non-Critical	% of Load
Lighting Load	6	50%	50%	20%
Motor Load	12	75%	25%	50%
Space cooling load	9	20%	80%	25%
IT Load	3	100%	0%	5%
Response Times	**Critical**		**Non-Critical**	
Lighting Load	48		3	
Motor Load	24		3	
Space cooling load	24		3	
IT Load	48		3	

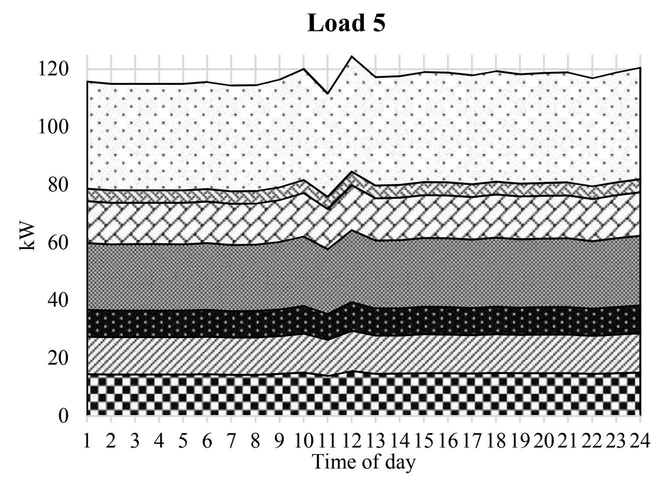


Commissioned Wattage	500			
Load Profile	Priority	Critical	Non-Critical	% of Load
Lighting Load	4	50%	50%	5%
Motor Load	8	75%	25%	20%
Space cooling load	13	20%	80%	30%
IT Load	16	100%	0%	45%
Response Times	**Critical**		**Non-Critical**	
Lighting Load	48		5	
Motor Load	48		5	
Space cooling load	24		5	
IT Load	24		5	



Commissioned Wattage	100			
Load Profile	Priority	Critical	Non-Critical	% of Load
Lighting Load	14	50%	50%	30%
Motor Load	7	75%	25%	33%
Space cooling load	1	20%	80%	13%
IT Load	2	100%	0%	24%
Response Times	**Critical**		**Non-Critical**	
Lighting Load	24		1	
Motor Load	24		1	
Space cooling load	48		1	

IT Load	48	1

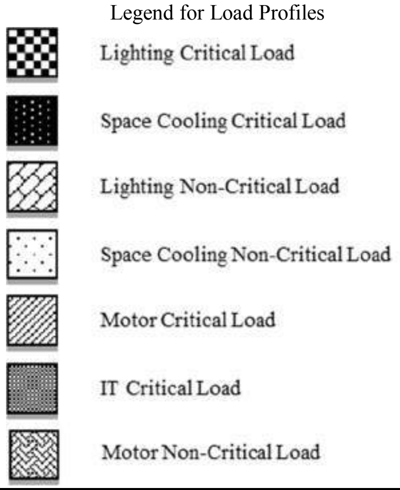


Commissioned Wattage	100

Load Profile	Priority	Critical	Non-Critical	% of Load
Lighting Load	11	50%	50%	25%
Motor Load	17	75%	25%	15%
Space cooling load	19	20%	80%	40%
IT Load	18	100%	0%	20%

Response Times	**Critical**	**Non-Critical**
Lighting Load	24	2
Motor Load	48	2
Space cooling load	24	2
IT Load	48	2

Legend for Load Profiles



Demand Response	
DR System Type	Manual DR
Investment/ kWH (in $)	1
Dollar rate (INR)	60
Lifespan	30
Maintenance Charges	40000
Demand Depth	90%
Demand Start Time	15 hrs
Demand Time Range	6 hrs
Micro-grid Critical Load Penalty	16
Incentive from Utility for DR	8

Solar PV Generations	
Mean Sunshine Hours at Bangalore	Values taken from [11]
Mean Monthly Global Solar Radiant Exposure (MJ/m^2/day)	

TABLE 2: RESULTS FOR VARIOUS SCENARIOS

Cases	**Electricity Consumption ('000 units)**	**Total Cost (INR)**	**Remarks**
Base Case	7.2	₹ 94,864	
MicroGrid (Scenario 1)	7.2	₹ 60,325	
Base Case with Solar PV (Scenario 2a)	6.9	₹ 93,105	Solar not sold
Base Case with Solar PV (Scenario 2a)	7.2	₹ 92,048	Solar sold
MicroGrid with Solar PV (Scenario 2b)	6.9	₹ 58,539	Solar not sold
MicroGrid with Solar PV (Scenario 2b)	7.2	₹ 57,510	Solar sold
Base Case with Passive Measures (Scenario 3a)	6.4	₹ 101,049	
MicroGrid with Passive Measures (Scenario 3b)	6.4	₹ 64,377	
MicroGrid with DR (Scenario 4b)	6.0	₹ 53,955	90% DR depth from 1500 to 2100 hrs
Efficient Smart Grid (Scenario 5)	5.3	₹ 55,994	

Results will tend to change based on the input parameters, parameters need to be optimized to get the best possible outcome

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Estimation of Potential and Value of Demand Response for Industrial and Commercial Consumers in Delhi

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Abstract*—Demand response (DR), especially from larger commercial and industrial consumers, can significantly contribute towards improving India's grid reliability. The industrial and commercial consumer's share of the total electricity consumption is 40-50% for most electricity utilities in India. Automated DR (a form of DR that uses advanced metering infrastructure and automated signals between utilities and consumers) can efficiently enable these consumers to shed or shift their loads when electricity prices are high, or during times of scarcity, providing not only financial benefits for themselves, but also benefits to utilities, system operators, and other consumers. Estimating both the technical and economic potential of automated DR can enable regulators and utilities to design appropriate policies and incentives for consumers, and for system planners to consider DR as a dependable capacity resource. Using data and analysis from a DR pilot program conducted by the Tata Power Delhi Distribution Limited (TPDDL), we estimated the potential of DR for industrial and commercial customers in the state of Delhi. Further, we valued DR assuming various potential savings opportunities for utilities that include avoided high-price wholesale day-ahead market purchases, reduced unscheduled interchange exchanges during low frequency-high penalty periods, and avoidance of generation from expensive marginal generators.

Keywords—Automated Demand Response; Demand Response Potential; Economics of Demand Response; Delhi; India

I. INTRODUCTION

Over the past several years, the Indian electricity sector has been experiencing severe energy and peak power shortages. In 2013–14, India had an average peak power deficit of 4.5% and an average energy deficit of 4.2% [1]. Demand response (DR) through the provision of incentives or varying prices can reduce peak demand by either shedding load or shifting demand to non-peak hours [2]. In the short run, reduction in peak demand can avoid high-price wholesale energy purchases, reduce penalties due to unscheduled interchanges (UI), avoid generation from high-cost marginal generators, and prevent uncompensated load shedding. In the long run, a dependable demand reduction through DR can enable capital expenditures deferral, both in generation capacity and in transmission and distribution upgrades. Demand response is also becoming an important balancing resource, with increasing shares of variable and uncertain renewable energy generation sources like wind and solar [3], especially in jurisdictions such as India's that have relatively inflexible coal generation as their dominant electricity source.

Regulatory agencies in India do note the importance of DR as a resource. The 2014 regulations of the Delhi Electricity Regulatory Commission recommends that electricity utilities implement DR programs to "reduce or shift demand away from periods of peak/higher cost electricity to periods of non-peak/ lower cost electricity periods" [4].

Given this significance, it is important to understand the potential of DR and its value to the electricity sector. While several studies in the U.S. and elsewhere have quantified DR potential based on existing DR programs, there are few, if any, studies conducted for jurisdictions in India, mainly because pilot DR programs have only recently started being conducted in India. In this paper, we use data from one of the first DR pilot programs in India to estimate the potential of DR for commercial and industrial customers in the state of Delhi. The DR pilot program was conducted by the Tata Power Delhi Distribution Limited (TPDDL), one of the four electricity utilities in the state of Delhi. Commercial and industrial customers account for approximately 44% of the total electricity consumption in Delhi. In our study, we used data from 144 out of the total 173 commercial and industrial customers that participated in the TPDDL demand response pilot program over a period of six months (May to October 2014). We also estimated the value of DR within the context of India's electricity sector, from both the customer's and the utility's perspective, using TPDDL as an example.

The work described in this paper was coordinated by the by Lawrence Berkeley National Laboratory, and by the U.S. Department of Energy (DOE) under Contract No. DE-AC02-05CH11231.

The paper is organized as follows: In Section II, we describe the methodology, data, and results for the DR potential estimation. In Section III, we discuss the methodology and approach to valuing DR in India's electricity sector. Section IV provides our conclusions.

II. Estimating demand response potential

Previous studies (specifically from U.S. jurisdictions) have estimated the DR potential during specific peak hours for a utility or a larger jurisdiction, such as a state or country [5], [6]. The Federal Energy Regulatory Commission, in its national assessment of DR potential, used two different approaches [5]. For non-price based DR options, such as direct load control or interruptible/ curtailable load programs, the load impact estimates were based on average values determined through analysis of data from existing programs. For price-based DR options, the same estimates were determined using normalized load shapes for different consumer categories, and estimates of the percentage in energy use during peak periods were estimated using price elasticities and the assumed change in prices during peak periods for DR tariffs relative to non-time varying rates. Our approach is similar to the one adopted for non-price-based DR options given that the TPDDL pilot study used automatic demand response (AutoDR) to send signals for customers to curtail their load, without varying any price-based incentives.

In this study, we estimated the DR potential for the state of Delhi, using results from TPDDL's demand response pilot program. We briefly describe the program and its results before outlining the methodology for our study.

A. TPDDL Demand Response Pilot Program

The TPDDL demand response pilot program employs AutoDR with advanced metering infrastructure, smart meters, data analytics, and interoperability standards. AutoDR enables customers to receive an automated signal from the utility and automatically respond by either reducing or increasing their demand for the requested time duration. The details of TPDDL's pilot program and technologies used for AutoDR are discussed in our complementary study [7]. We used energy use data for 144 commercial and industrial customers at a 15-minute time resolution from May 2014 to October 2014. During this time period, TPDDL executed 17 AutoDR events, ranging from 0.5 to 1 hour each. We estimated the demand reduction during these AutoDR events for each consumer category by computing the 75th percentile of the maximum DR shed over all the DR events using a 5/10 (pronounced 5-in-10) baseline with a morning adjustment factor. The details are provided in our complementary study, and the summary of the results are shown in Table I [8].

The maximum demand reduction (75th percentile) as a share of each category's coincident peak demand during May to October 2014 ranged from 2% (for Education) to 28% (for Packaging). Note that the share of demand response shown in Table I is not the reduction over the baseline peak demand, but over the six-month peak demand. We restricted our analysis to demand reduction only during the DR events, and have ignored any potential rebound effects in other periods.

TABLE I. Peak demand and demand response estimates by consumer category from the TPDDL pilot program. Share of demand response shown is not reduction over baseline peak demand, but over six-month peak demand

Category ID	Customer Category	No. of customers in DR pilot (available data)	Peak demand May–Oct 2014 (kW)	Max demand reduction (75th percentile) (kW)	Demand reduction as % of peak demand
1	Auto parts	4	620	110	18%
2	Chemicals	2	430	60	14%
3	Cold Storage	6	1100	170	15%
4	Commercial	11	4600	350	7%
5	Education	3	1900	40	2%
6	Flour Mills	25	7300	1100	16%
7	Food products	9	2700	370	14%
8	Glass manufacturing	2	770	90	12%
9	Home products	5	1000	250	24%
10	Hospitals	2	1400	230	16%
11	Medical products	3	430	50	12%
12	Others	14	1900	360	19%
13	Packaging	1	170	50	28%
14	Plastics manufacturing	18	2200	300	14%
15	Printing	7	1000	140	13%
16	Pumping	3	560	90	15%
17	Retail stores	3	60	20	26%
18	Shoe manufacturing	7	920	140	15%
19	Steel industry	17	2000	160	8%

B. Methodology

Estimation of the potential of DR by extrapolation of data from a pilot study has some uncertainties, given that several different factors determine the actual DR that may be realized at a particular time that may not be represented by the results of the pilot program. However, it is useful to estimate the potential of DR to gain broader insights about the extent that DR can serve as a future resource. We outline our methodology, and then discuss the limitations.

For each customer category, the DR potential can be estimated by Equation 1.

$$DR\ potential = (Aggregate\ customer\ peak\ demand) * (DR\ as\ \%\ of\ peak\ load) * (Participation\ rate) * (Response\ rate) \quad (1)$$

The key requirements in estimating DR potential are data on aggregate load profiles, energy use during peak periods, and peak demands of different consumer categories within a utility. To estimate the DR potential in Delhi, we used different extrapolation strategies for different consumer categories, depending on the availability of data, in order to extrapolate our results from the TPDDL pilot program to the entire state. Note that Delhi is served by four utilities: TPDDL, BSES Yamuna Power Limited, BSES Rajdhani Power Limited, and the New Delhi Municipal Council.

We assumed the aggregate load profile of the participants in the pilot study from each consumer category to be representative of the aggregate load profile of the entire corresponding consumer category in Delhi. This assumption enabled us to apply the load factors of the pilot program participants that belonged to a particular customer category to the annual electricity consumption for those types of customers across Delhi, and to estimate their total coincident peak demand (See Equations 2–4).

We then estimated the total DR potential for each customer category from the peak demand for that category and the 75th percentile of the maximum DR shed determined in our complementary study, and provided in Table I [8]. The implicit assumption is that DR events happen during the same timeframe and weather conditions as the ones in the DR pilot program. Since we are using demand reduction estimates from the pilot study, the response rate of the participants (which is the response that is expected from the participants that are already enrolled in the DR program) is included in the demand reduction that we observed. However, in our estimation, we do not include the participation rate, which is the share of total utility consumers that are expected to participate in the DR program.

$$\widehat{LF}_c = \frac{\widehat{AD}_c}{\widehat{PD}_c} \quad (2)$$

$$PD_c = \frac{AE_c}{\widehat{LF}_c * 8760h} \quad (3)$$

$$DR_c = PD_c * \widehat{DR\%}_c \quad (4)$$

Where

c	: Customer category
$\widehat{AD}_c$	: Average aggregate demand of pilot participants
$\widehat{PD}_c$	: Peak aggregate demand of pilot participants
$\widehat{LF}_c$	: Load factor of pilot participants of a category
AE_c	: Average electricity consumption for a category across a jurisdiction
PD_c	: Peak demand for a category across a jurisdiction
$\widehat{DR\%}_c$	: Demand response as percentage of peak demand estimated from pilot program
DR_c	: Technical demand response potential without considering participation rates

For most of the industrial customer categories (1, 2, 6–9, 11, 13–15, 18, and 19 from Table I), we used their corresponding National Industrial Classification codes to extract annual electricity consumption by state (Delhi) from the Annual Survey of Industries [9], [10]. The latest financial year for these electricity consumption data was 2011–12, three years before the pilot program was conducted.

Customer categories designated as “commercial” and “retail stores” in the pilot study are part of the “non-domestic” consumer category as reported by the Delhi utilities. While the small rain water pumping and sewerage loads that were part of the pilot program were not operated by the Delhi Jal Board (Delhi water utility), the main water supply and sewerage pumping loads of the Delhi Jal Board could make a significant contribution to DR in the future, making it important to estimate their DR potential. We attributed 75% of the total annual electricity consumption of the Delhi Jal Board to pumping loads (extrapolated from electricity expenditure and electricity consumption for pumping from [11]). We further assumed that these loads are similar in their characteristics as the pilot participants in the customer category of “pumping”. We computed the total electricity consumption of the consumer categories of “non-domestic” and Delhi Jal Board across the state of Delhi from the tariff statements of all four utilities in Delhi [12]–[15].

For the customer category of “cold storage,” we were not able to access data on total electricity consumption or aggregate peak demand in Delhi. As an alternative, we scaled the peak demand of three cold storage facilities that were part of the DR pilot program using a ratio of their aggregate cold storage capacity (13,000 metric tonnes) and the total cold storage capacity in Delhi (125,000 metric tonnes) [16], [17].

We were unable to estimate the DR potential for customer categories of “educational institutions,” “hospitals,” and “others” (5, 10, and 12 from Table I) due to unavailability of aggregate electricity consumption and peak demand data at the state level.

C. Demand Response Potential Results and Discussion

Figure 1 shows the DR potential estimates for the industrial customer categories included in our study. The total non-coincident technical DR potential for these industrial customer categories across Delhi is approximately 25 megawatts (MW). However, this estimate is only an illustration of the methodology, and should not be interpreted as an upper bound. Further, the total electricity consumption for these customer categories, based on the Annual Survey of Industries [10], was only a tenth of the total electricity consumption for industrial customers in Delhi, as reported by the four utilities [12]–[15]. This difference in electricity consumption is likely due to both: an underestimation of total electricity consumption by these customer categories, and the presence of other types of industries not represented by the DR pilot participants. With greater participation rates, we may find a higher potential for DR than that estimated in our study.

In 2013–14, non-domestic customers accounted for 6700 gigawatt-hours (GWh) or 30% of Delhi's electricity consumption [12]–[15]. Assuming load factors of 0.5 and 0.3, and demand reduction of 7% and 26% relative to their aggregate peak demand (parameters estimated from the pilot program participants), the "commercial" and "retail store" customer categories could provide a demand response of approximately 20 MW and 50 MW, respectively, if future DR participants in these categories were to account for 10% each of the total non-domestic electricity consumption.

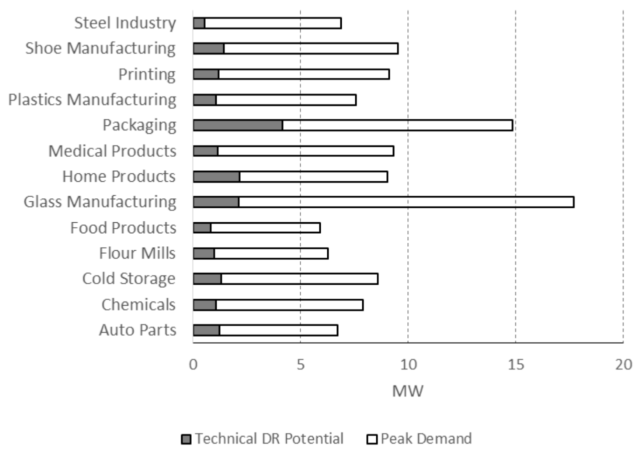

Figure 1: Demand response potential of certain industrial customers in Delhi

The Delhi Water Board's annual electricity consumption for 2013–14 was 550 gigawatt-hours (GWh), of which we attributed 75% to pumping loads. The pumping stations that participated in the pilot program provided a demand reduction of 15% relative to their aggregate coincident peak demand. Assuming a load factor of 0.25 (estimated from [11]) and participation rates between 20%–50%, the demand response potential could be in the range of 6–15 megawatts.

D. Assumptions and Limitations

Due to certain limitations, we made the following assumptions that should be considered while interpreting the results. First, we assumed that the participants in the pilot program are representative of their customer category for the entire utility or jurisdiction in terms of their load curves, strategies for demand reduction, price elasticities, behavior, and other factors. However, the peak demand and load factors for the pilot program participants were based on data that were collected over six months (May to October 2014), and not an entire year. While the peak demand estimates might not change if measured over the whole year, since Delhi customer loads peak during the summer months, the load factors can change significantly, thus affecting the estimates of the aggregate peak load for each customer category across Delhi. Given that the pilot program was in its first six months of operation, the estimates are likely to be improved as data on more DR events and additional customers are measured over a longer period of time.

Second, due to the unavailability of time-series load profile data for different customer categories aggregated at the state level, we needed to estimate the coincident peak demand for each of the customer types or categories from the load profiles of the participants from the pilot program. The number of participants in many customer categories was small, and may not be representative of the population.

Third, we assumed that the DR events in the pilot program are representative of future DR events for which the potential is being estimated, an assumption that may not hold, as utilities may design different incentives and programs in the future. Also, the DR events called during the pilot program do not all coincide with the peak demand hours of TPDDL (see Figure 2). If TPDDL were to call DR events at different times during the day or year with different weather patterns, the response rate and peak demand could be different, thus affecting the DR potential estimates.

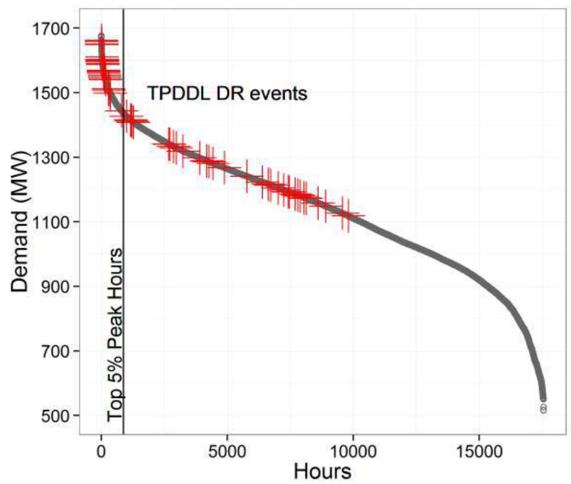

Figure 2: TPDDL's load duration curve and DR events (15-minute resolution)

Given these assumptions, our estimates should be considered as indicative, and further detailed analyses with better data are necessary to arrive at more accurate estimates.

III. Economics and Valuation of Demand Response

Demand response can result in significant savings for both utilities and customers through reduction in demand during peak hours. However, these savings can vary depending on several factors that include, but are not limited to, utility rate structures, the utility's generation mix, supply-side markets, DR program costs, and customer participation and response rates. Understanding the economics of DR, particularly in the context of a particular utility and electricity sector, is important in order to determine the appropriate incentives for eliciting and realizing the expected levels of DR. Here we outline the methodology for valuing DR in the short run in the context of the Indian electricity sector.

A. Methodology for Valuing Demand Response

Since DR can result in savings for both the utility and the customer, we value DR from both perspectives. From a utility's perspective, the savings through the DR program need to be greater than its loss of revenue due to reduced energy sales, its share of costs for setting up and operating the DR program, and the DR incentives that it has to pay the participants (Equation 5).

$$DR\ incentives \leq (Utility\ savings - Utility\ loss\ of\ revenue - Utility\ DR\ program\ costs) \quad (5)$$

The short-run utility savings include avoided costs due to reduced unscheduled interchange (UI) drawal (or earnings due to UI injection during periods of low frequency), lower purchases on the wholesale day-ahead market (DAM), or avoiding generation from high-cost marginal generators. Unscheduled Interchange (UI) are the differences between the scheduled and actual drawal/injection of energy by a utility or generator. UI, in India, is a penalty mechanism tied to the real-time system frequency that discourages over-drawal and encourages injection during periods of low frequency, and vice versa. If the DR events result in reduction in energy consumption (DR shed), utilities could lose some revenue, especially if both fixed and variable costs are bundled in the per-unit consumer tariffs (which is the case for most utilities), and if the participant customer category cross-subsidizes other customer categories (e.g., commercial and industrial customers in India often have rates that are higher than the average cost of supply for the utility). If the DR event results in a shift in energy consumption from peak hours to non-peak hours, the utility could recoup some of these fixed costs and cross-subsidy charges. The utility share of DR costs include the fixed costs of infrastructure as well as the ongoing operating costs of the DR program. These costs will change on a per unit of energy (kVAh) basis depending on the participation and response rates of the customers, as well as the type of DR program (AutoDR versus less infrastructure-intensive programs, which in turn may have lower reliability and response rates).

The benefits of the DR program for a participating customer include financial incentives for participating in the DR program, and also the savings that result due to reduced energy consumption during peak hours (Equation 6). In a time-of-use rate structure where tariffs during peak hours are higher than non-peak hours, customers are likely to save by shifting their consumption from peak hours to non-peak hours, assuming that they do not experience any significant rebound (i.e., the increase in energy consumption in non-peak hours becomes greater than the reduction in consumption during peak hours).

$$DR\ Incentives \geq (Customer\ opportunity\ costs + Customer\ DR\ program\ costs - Customer\ Savings) \quad (6)$$

From a customer's perspective, benefits associated with DR need to be greater than their opportunity costs, as well as their share of the actual hardware and operating costs involved in the DR program (especially in an automated demand response program) (Equation 6). Opportunity costs for the customers include costs due to inconvenience, rescheduling, loss of production, and additional maintenance, among others that the customer experiences for reducing its demand during a DR event. For a particular customer, these opportunity costs can change, depending on the time of day, frequency of DR events, and its particular activities.

There are other benefits of a DR program that are not captured by this model. These include long-run benefits from capital expenditure deferral, especially in generation capacity (in other words, providing more service through the same generation capacity), and transmission and distribution upgrades. Reducing peak demand could reduce carbon and particulate emissions, especially if the marginal generator is carbon intensive (such as an open-cycle gas turbine or an expensive coal turbine), or save precious water resources if the balancing unit is a hydropower plant. Customer audits conducted by the utility to identify DR opportunities and non-critical loads could also identify opportunities for energy efficiency (EE), resulting in greater overall energy savings. Finally, DR has the potential to limit uncompensated load shedding, that is likely to result in both increased welfare for those who would have otherwise been left without electricity supply, and financial and carbon emissions savings for those who would have operated a diesel backup generator during deficit periods.

B. Valuing Demand Response for TPDDL

We analyzed the wholesale DAM prices, UI rates, and the generation costs for TPDDL to get insights into the valuation of demand response. We avoided estimating the savings for the actual DR events in the TPDDL pilot program for three reasons. First, the goal of the TPDDL pilot program was to establish technology effectiveness, and later to maximize the gains from DR in the interest of the customers [7]. Second, while the energy savings resulting from the DR events can be estimated, the avoided cost estimation depends on the counterfactual, which for TPDDL could have been higher purchases on the wholesale DAM, increased over-drawl (or decrease in injection) in real-time through UI, or increased generation through high marginal cost generators. Third, for the last counterfactual of potential increased generation from high marginal cost generators, we do not have data on the merit order or marginal generation unit during the actual DR events. Hence, we restricted our analysis to examining broader trends and potential savings per unit of energy avoided.

We analyzed the DAM prices from the India Energy Exchange (IEX) and the UI rates that are based on system frequency over the six-month duration of TPDDL's pilot program. Figure 3 shows the DAM prices and UI rates against TPDDL's demand, as well as the DR events (15-minute resolution) from the pilot program.

A DR event called during the top 5% peak hours for TPDDL (events that fall to the right of the vertical lines in Figure 3) would have resulted in an average savings of INR 4 per kWh from the UI mechanism or INR 4.5 per kWh from avoided purchases in the wholesale DAM (see boxplots in Figure 3). While these avoided costs are approximately equal to TPDDL's weighted average cost of generation of INR 4.2 per kWh [15], additional savings result due to avoided transmission charges and losses. From Figure 3, the hours of high DAM prices and UI rates, a sign of overall stress in the Indian national grid, are not closely correlated to the peak demand hours of TPDDL. Calling a DR event during the top 5% hours with the highest DAM prices or UI rates may had resulted in savings of at least INR 6 or INR 7 per kWh or higher through DAM or UI, respectively. Avoiding high cost purchases in the day-ahead market, which clears 24 hours before actual dispatch may allow for sufficient time to plan a DR event. At the same time, anticipating a high UI rate (i.e. low overall system frequency dictated by the entire Indian national grid) during a specific time period may be a difficult task and may require calling a DR event at a short notice.

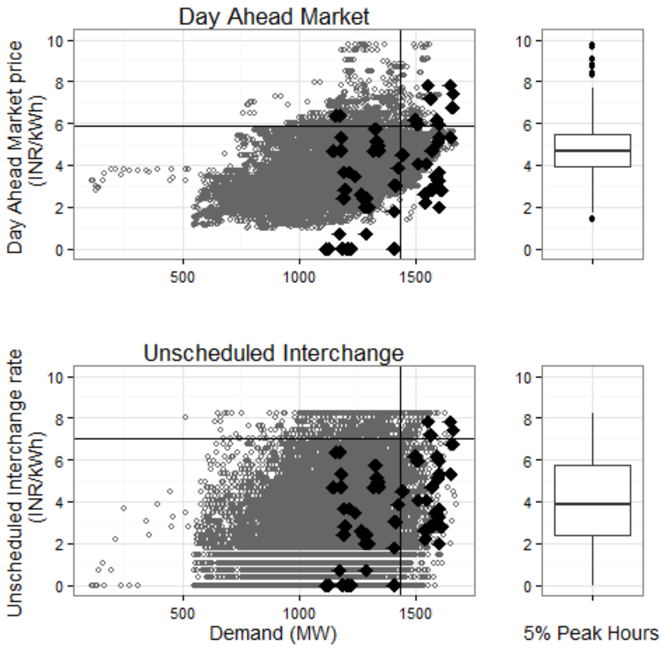

Figure 3: TPDDL's demand is slightly correlated to India Energy Exchange's day-ahead market (DAM) prices but poorly correlated to UI penalty rates based on system frequency (Data from May–Oct 2014). Vertical lines mark the top 5% peak demand hours for TPDDL. Horizontal lines mark the top 5% of hours with the highest DAM price or UI rate. Dark markers represent demand response events from the pilot program. Box plots show the distribution of DAM prices and UI rates in the top 5% peak demand hours.

TPDDL's savings can also come from the avoided generation from the marginal generation units. Often times, during peak demand hours, utilities find it difficult to purchase power through DAM or UI due to congestion in the transmission network. To avoid inadvertent load shedding, utilities are required to purchase electricity from marginal high-cost gas-based generators, which in turn may need to purchase fuel from the spot market at a high price given the limited availability of natural gas in India. Figure 4 shows the supply curve for TPDDL's generators, along with the annual peak demand for 2013–14 and the average cost of generation [15]. TPDDL's savings would depend upon the generator that will be on the margin when the DR event is called. Savings will be especially significant when the marginal cost of supply is INR 6 per kWh and above, which is higher than the average cost of generation of INR 4.2 per kWh. TPDDL's average power purchase cost for 2012-13 was INR 5.45 per kWh, which included transmission charges and losses [15]. Avoided energy purchases from marginal generators, DAM, or UI will result in additional savings by avoiding transmission charges and losses.

Note that the savings in UI and DAM prices assumes that the frequency of the system and DAM price are determined exogenously. In other words, we assumed that the utility's reduction in peak demand is small enough to not affect these two parameters. However, as larger and more number of utilities call coordinated DR events, greater reductions in demand could lead to increases in system frequency or suppress the DAM price, an effect that will need to be incorporated to better estimate the utility savings due to demand response.

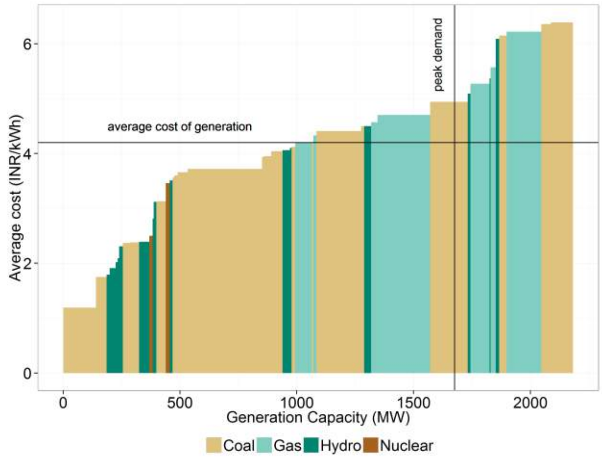

Figure 4: TPDDL's supply curve for available generation capacity in 2013-14, peak demand during 2014, and actual weighted average cost of generation for 2012-13.

In this study, we did not estimate utility loss of revenue and customer savings, since both these parameters depend not only on demand reduction during the DR event, but also on the rebound effect and shift in energy consumption to non-peak hours. Further, we do not estimate the opportunity costs for customers, since these would require elaborate research designs that vary incentives in a randomized control trial setting, a subject for future research.

IV. CONCLUSIONS

Demand response can provide significant benefits to both utilities and consumers by reducing consumption during peak hours. We estimated the DR potential by customer categories in the state of Delhi, which provides the scale of DR as a resource, and also understand the data requirements that would increase the accuracy of our results. We also provided an approach to value DR in the short run that provides useful insights to utilities that they can use to schedule their DR events to help reduce their own peak and maximize the value of DR while improving the overall reliability of the larger interconnected grid. In TPDDL's case, DR events that were called during the top 5% hours with the highest DAM prices or UI rates, which may not always coincide with TPDDL's peak demand hours, could result in savings of INR 6 per kWh and above in generation costs as well as avoided transmission charges and losses during the DR events. The overall realized savings will depend on the extent of the shift in energy consumption to non-peak hours, and their associated costs.

Commercial and industrial customers have a significant potential to provide DR services. Better datasets in terms of larger samples (more customers), longer durations to capture all seasons, and more events at different times of the day will enable better analysis. Further, the quantum of DR that can be elicited from their customers depends highly on the incentives provided by the utility. While the pilot study did not offer varying prices for DR, in the future, TPDDL and other utilities may offer price-based incentives to elicit different levels of DR, in which case, determining price elasticities for different consumer categories during peak hours will be a significant area of research. Future research can include quantifying customer response rates by varying the number and frequency of events, pricing, type of signal, and information content. Quantifying both demand reduction and demand shift to non-peak hours, and rebound effects can enable more realistic estimates of realizable DR. Finally, innovative pilot programs using AutoDR with fast responses, specifically to balance variability introduced by increasing shares of renewables such as wind and solar, should be designed as DR plays a more prominent role as a resource to improve grid reliability.

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A Draft Specification for Demand Response Ready Appliances in India

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Abstract— The following overlapping and converging trends require a careful consideration of what ought to constitute demand response (DR) ready capability: a) Increasing peak load from air conditioners (ACs) b) Plans for increased intermittent renewable generation capacity and c) increased numbers of appliances with "smart" functionality. In India, given the likely estimated future growth in ACs will add load of ~60-100 GW, DR ready ACs can provide an opportunity to mitigate this demand. However, DR solutions in India will require considerations that are different from those in the US and Australia. For example, cell-phone penetration in India is higher than broadband internet penetration. In this paper, we present a draft specification for DR-ready appliances in India, building from international experiences and from existing IEC standards. We present this specification in order to begin the debate about what such a specification ought to consider, including issues such as the need for automation, bi-directional communications and low latency (or fast response time).

Keywords— demand response, smart appliance, air conditioners, renewable energy integration, standards

INTRODUCTION

Rising incomes and large population centers in hot climates make India poised for rapid increase in peak electricity demand for air conditioning (Figure 1). Since 2004, room air conditioner (AC) sales in India have been growing at more than 15% per year, with more than 3 million units sold in 2012. Although India currently has very low room AC penetration, large growth in AC sales is expected to result in a peak demand addition of 60 GW to 100 GW by 2030 (Phadke, Abhyankar, and Shah 2013; Planning Commission 2014).

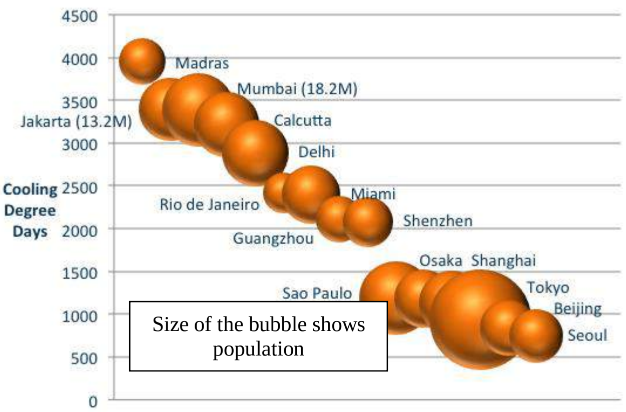

Figure 1. Many of India's large urban centers have among the hottest climates Source: (Sivak 2009)

Meeting such additional demand would require a massive increase in electricity generation supply and have implications for energy security and balance of trade. This rise in electricity demand can be managed through a combination of policies to enhance the efficiency of air conditioners being sold in the Indian market, and through the adoption of demand response technologies and policies. Furthermore the recent announcements by the government of India of a targeted 100GW of solar generation capacity also necessitate increased penetration of energy storage and demand response technologies in order to integrate this intermittent renewables generation capacity. Finally, there is a global convergence toward the "Internet of Things" (IoT), with appliances, smartphones and vehicles all increasingly connected to each other. Each of these trends, namely: a) increased AC sales, b) increased intermittent renewable generation and c) increased penetration of smart appliances creates an opportunity for the

Indian economy to deploy "demand-response ready" or "smart" ACs in order to ensure peak load management and grid stability. In the US, about 60,000 MW of DR capacity exists in various DR programs, and the combination of demand response and energy efficiency programs has the potential to reduce non-coincident summer peak demand in the US by 157 GW by 2030, or 14–20% below projected levels (Siddiqui 2009). Demand Response (DR) can, therefore, be considered a valuable resource for managing the electricity grid. It can effectively mitigate peak demand and also reduce the costs associated with integrating intermittent renewable electricity generation (Klobasa 2010).

Depending on the type of DR program and technology, DR-enabled or "smart" appliances will need to consider different requirements. A clear and flexible definition of "DR-ready" or "smart" space cooling equipment is needed in order to accommodate the various types of DR programs, technologies and frameworks.

- ***Demand Response*** refers to changes in the operating mode of appliances or equipment in response to changes in electricity prices, the state of the electricity network, or external requests for load modification. The user may respond manually, or may willingly permit automated changes in return for lower energy costs or cash incentives.
- ***Smart Appliance*** has been variously defined as: 1) "a product that uses electricity for its main power source which has the capability to receive, interpret and act on a signal received from a utility, third party energy service provider or home energy management device, and automatically adjust its operation depending on both the signal's contents and settings from the consumer" (AHAM/ACEEE, 2011), alternatively, 2) "the automated alteration of an electrical product's normal mode of operation in response to an initiating signal originating from or defined by a remote agent" (Standards Australia, 2012)

SCOPE

In this paper we discuss current developments in the IEC standards process and a possible specification and architecture for DR-ready or smart ACs in India, based on the draft IEC standard being developed by IEC TC59 WG15, which sets out a reference framework for defining appliances as "smart" or "demand-response ready". We do not discuss communications protocols which are being developed separately under the IEC Project Commmittee (PC118) on "Smart Grid User Interface", which focuses on the user interface and types of information exchange between the smart grid and consumer systems and devices.

RELEVANT STANDARDS

Standards for Demand Response and "smart" appliances have been in development since 1997 in Japan, since 2003 in Australia and are still being revised internationally under IEC TC59 and in the US under the ENERGY STAR program. As can be seen from Figure 2, this is a lengthy process requiring consultations with many stakeholders in order to arrive at an acceptable consensus framework. The field of smart appliances is currently at an early stage of development with IEC TC59 WG 15 expected to publish a draft technical specification in mid-2015. It is thus important for Indian stakeholders to participate in this international process currently under way.

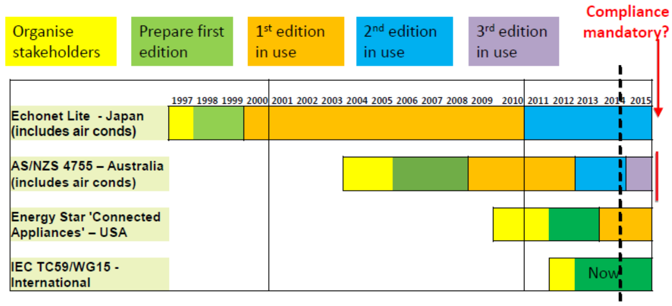

Figure 2 Timeline for standards development (Source: Wilkenfeld, 2014).

We will now discuss various issues that have a bearing on requirements for a specification for demand-response ready appliances.

LATENCY (OR RESPONSE TIME)

As shown in Table 1 below, space cooling equipment such as ACs and chillers can be used in many different types of demand response programs.

Table 1: Cooling equipment use in Demand Response programs [adapted from (Walawalkar et al. 2010)]

Customer Type	Equipment/ Building Component	Control Strategy	DR programs		
			Emergency or Energy Resource	Capacity Resource	Regulation Service or Reserves
Residential	Air conditioners	Cycling/forced demand shedding	√	√	√
Commercial	Chillers	Demand limiting during on-peak period	√	√	
		Pre-cool building over night-storage		√	
		Forced demand scheduling	√	√	
Industrial	Chillers	Demand limiting on time schedule		√	

For example:

- as an "emergency" or "energy" resource during a time of high demand
- as pre-scheduled "capacity" that can reduce load according to a pre-planned schedule
- as a means of providing regulation services and reserves in real time or on short notice.

In order to accommodate these different types of demand response functionality, response times from seconds (for regulation services or emergency energy resources) to minutes to hours (for pre-scheduled capacity) may be required.

Integration of intermittent renewable energy resources may also require response times of the order of minutes or seconds if demand response is used for regulation services.

Hence any specification for DR-ready appliances should account for such widely varying latency (i.e. response time) requirements.

AUTOMATION AND BIDIRECTIONAL COMMUNICATION

Automated DR, which enables energy service providers to control the usage of end use equipment remotely and

Technology	Communication Medium	Capabilities	Pros	Cons
Radio controlled chip that communicates with the appliance microprocessor	Radio signal	Modulate energy consumption (uni-directional communication only)	Lower cost than cell or WiFi	Easier to bypass; actual participation in the program cannot be confirmed and could raise issues for compensation
Frequency controlled chip that communicates with the appliance microprocessor	Grid frequency	Modulate energy consumption (uni-directional communication only)	Lower cost than cell or WiFi	Unidirectional communication capability; easier to bypass;
Wifi chip that communicates with the appliance microprocessor	WiFi network	Modulate energy consumption + report back the status of the device (bi- directional communication)	Hard to bypass; reports back if bypassed/overridden; compensation to consumers can be based on actual participation	Higher cost compared to radio/frequency based switches; Costly for retrofit; Requires WiFi network
Cellular chip that communicates with the appliance microprocessor	Cellular network	Modulate energy consumption + report back the status of the device (bi-directional communication)	Hard to bypass; reports back if bypassed/overridden; compensation to consumers can be based on actual participation; ubiquitous availability of cellular network (in cities)	Higher costs compared to all options discussed above
Smart plug that can be remotely turned off/on	WiFi network (or cellular network)	Switch on/off the power to the device + report back the status of the plug (bi-directional communication)	Can enable auto DR capabilities in existing stock of appliances; reports back if bypassed/overridden; compensation to consumers can be based on actual participation;	Higher costs; can be easily bypassed

Table 2 Auto DR technology options

automatically, is one of the key DR strategies/programs that have been found to improve load response and peak load reduction (PowerCents DC 2010). For example, during evening peak periods, AC temperature set points could be remotely increased by a few degrees, resulting in significant load reduction without major discomfort to consumers. [1] Alternatively, the AC can be switched off remotely for a certain interval, or instructed to reduce load by a set percentage. ACs can be equipped to automatically respond to remote signals to alter their demand (Bode 2013).

If most room ACs sold in India starting in 2016 had this capability, by the end of 2020, about 20 million ACs with a connected load of 30 GW (1.5kW of connected load on average for a Room AC) and peak load contribution of more than 20 GW (assuming 70% of ACs are on during peak load), would have the potential to reduce 8 GW of demand if signaled to reduce their loads by 30% (for example by increasing their temperature set point by a few degrees). Actual load reduction that could be achieved will depend on the level of consumer participation in demand response programs.

Various auto DR technology options are shown in Table 2, above. The simplest and the least expensive technology for automated DR is radio signal based automated load control technology which has been used for more than two decades for automated DR.[2] However, this technology is unidirectional and cannot report back any status from the device it controls which makes it easier to bypass particularly on smaller units with easily accessible electronics.

WiFi or cellular based technologies allow bidirectional communication between the device and the remote control and various parameters related to the status of the appliances can be reported back. For example, if the signal was used to remotely change the temperature setting on a room AC, whether and when that temperature setting was changed again can be reported back. Such bidirectional systems are likely to provide the most reliable information on DR program compliance, but also have higher costs. Developers of DR programs need to assess the trade-off between reliability of DR participation and cost of equipment and evaluation, monitoring and verification when designing financial compensation schemes. A specification for a DR-ready appliance needs to be allow these various types of auto DR technology solutions to be deployed in order for the market and DR-program developers to have the flexibility to implement the appropriate kind of DR technology.

DRAFT IEC TC59 WG15 SPECIFICATION

The current specification being drafted by the IEC TC59 WG 15 defines a “Customer Energy Manager” (CEM) as “a component or set of functions which has the capability to receive and process Grid Information, Appliance Information and User Instructions and which manages one or more Smart Devices”. The CEM could be analogous to the radio, frequency, Wi-Fi or cellular controlled chips shown in Table 2. The current draft specification requires the CEM to:

- be able to receive and pass on Grid Information to at least one device,
- be able to receive Appliance Information(e.g. its state or energy consumption level etc.)
- be able to transmit information to the grid (i.e. bi-directional communications).
- be able to receive/pass or act on emergency and other types of load control signals
- be able to be programmed with preferences (by user, remote agent or both) and act on them.

CONCLUSION

The IEC TC59 WG15 specification framework for “smart” or “Demand-response ready” appliances is still in draft stage and being developed further. However, Indian stakeholders including manufacturers, utilities, and government regulatory agencies such as the Bureau of Indian Standards (BIS) or the Bureau of Energy Efficiency (BEE) could participate actively in its development, and ensure that the requirements of the Indian consumer, electricity grid and manufacturers are considered in its development, for example by ensuring:

- bi-directional communication
- ability to deploy technologies with low latency (or fast response time) e.g. Wi-Fi or cellular and
- ability to deploy auto Demand Response

Involvement in the international development and also possible adoption of such a specification for smart appliances in India may be increasingly necessary in order to manage the increasing peak load due to increasing demand for space cooling and increasing penetration of intermittent renewable energy resources on the Indian grid.

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Electric Vehicles - V2G Technologies

EV Charging Infrastructure; Payment Collection Systems

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Abstract

Electric vehicle technology has become the integral part of grid operation. The vehicle is not only used as means of zero emission transportation but also as source of power. Over the time this concept has emerged and it is being researched and developed continuously which has led to emergence of reliable and low price electric vehicle. Many companies have launched their Electric vehicles like Reva by Mahindra which run on Vehicle-to-grid power (V2G) technology. V2G can also provide storage for renewable energy generation such as hybrid electric vehicle. In order to effectively tap the V2G technology it is necessary to combine the complementary strengths and to merge the complementary needs of the vehicle user and grid. The charging needed by the vehicle can be done in approximately four-five hours' time in the parking lot, street side or in a garage. The payment collection system can be either RFID based or the money can be deducted automatically from the credit card when the card will be swiped. The paper focuses on the recent software development in measuring the range of an electric vehicle that can be covered before it needs to get recharged, the requirement of systems and processes which are needed to tap energy in vehicles and better implementation of V2G technology and the efficient development of payment collection system for electric vehicles.

Keywords— zero transmisson,V2G technology,charging,payment collection

INTRODUCTION

Typical vehicles are powered by fuels such as diesel, petrol and natural gas. It is observed that energy conversion efficiency of a fuel input in a conventional vehicle is only around 14%–30% depending on the distance covered. The remaining of the energy is either lost to engine or inefficiencies or it is used to power accessories. Therefore, there is immense potential to improve efficiency of fuel with advanced technologies .Hybrid and plug-in electronic vehicles are seen having potential for petroleum as well as carbon footprint reduction. Increase in energy security, improvement in fuel economy, lower fuel costs, and reduced emissions are some of the benefits of electric vehicles.

The PHEV vehicles use V2G technology as driving force for the vehicle. Under this technology the electricity can be also sent back or feed into the grid.

The mass implementation of this technology will prove beneficial to not only the energy producers but also the vehicle owners. As it will help them recover the cost of their vehicle over a period of time bearing in mind the feed in cost is considerable enough. . As an incentive to the vehicle owner, the utility might offer a vehicle purchase subsidy, lower electric rates, or purchase and maintenance of successive vehicle batteries. For a utility tapping vehicle power, the increased storage would provide system benefits such as reliability and lower costs, and would later facilitate large-scale integration of intermittent-renewable energy resources.

The V2G Technology

The simple features of electric vehicles whether they are powered by batteries or fuel cells or hybrids is that they consists of an energy source which is capable of producing the 60 Hz AC electricity that can power homes and offices. When connections are done in such a manner that the electricity flows from vehicles to power lines, it is called vehicle to grid power or V2G. Like the renewable technology the electric vehicle is the key to realizing economic value from V2G are grid-integrated vehicle controls to dispatch according to power system needs (2).

There are three different versions of the V2G technology.

1. **Hybrid or fuel celled vehicle** which generates power from storable fuel and uses its generator to produce power for a utility at peak electricity usage times.

2. **Battery powered or plug in hybrid vehicle:-** This type of vehicle uses its excess rechargeable battery capacity in order to provide power to the electric grid in response to peak load demands

3. **Solar vehicle:-** This type of vehicle uses its excess charging capacity to provide power to the electric grid when the battery is fully charged.

CHARGING SYSTEM

The data shows that in the United States, there are about 9,000 electric stations and 22,443 charging outlets. The charging parameters of PHEV includes power requirement, energy needed, and cycles and time duration of charging, which can be analyzed by evaluating the daily vehicle trips and distance traveled.

Charging conditions plays a crucial role in determining the energy storage condition (i.e., battery size) for PHEVs. In the absence of charging infrastructure while traveling it is observed that around 40 miles is considered as charge depleting range for an average PHEV. In case of availability of public charging infrastructure the charge depleting range can be decreased to 13 miles. Thus it is important to calculate charging accessibility for both residential as well as commercial surroundings.

The proposed charging infrastructure models assessed includes the following
(1) Charging in a home garage when required,
(2) Overnight charging at an apartment complex, and
(3) Charging at a commercial facility at prescribed rates.

Above described scenario proves to be advantageous as it will

- Eliminates the requirement for a battery room that take up immense warehouse space
- Eliminates the need for dedicated battery room personnel
- Reduces costs by eliminating the need to buy battery handling and changing equipment
- Lift truck operators do not need to travel from their work area to the battery room to change out batteries, saving thousands of dollars in lost productivity.
- Batteries weighing thousands of pounds no longer need to be hoisted in and out of lift trucks, reducing the potential for employee injuries

Idle losses which are around 3% can be used to store the can be used to Charging parameters involve Actual PHEV driver behavior and an evaluation of charge power requirements (based on experience with charge characteristics of various battery chemistries) bring additional light to charging infrastructure requirements for PHEVs. Upon conducting these evaluations, it was concluded that 40 miles of charge depleting range is necessary for an average PHEV if no infrastructure is available outside of the owner's primary residence. If public charging infrastructure is available, allowing PHEV charging outside of the owner's primary residence, the charge depleting range can be lowered to 13 miles. It is, therefore, considered important to evaluate charging infrastructure in both residential and commercial settings because the availability of a rich charging infrastructure can reduce the onboard energy storage requirement (i.e., battery size) for PHEVs.

Typical charging infrastructure scenarios evaluated include (1) overnight charging at a home garage, (2) overnight charging at an apartment complex, and (3) opportunity charging at a commercial facility. Each scenario was described, the infrastructure and onboard power electronics requirements determined, and the typical cost for the infrastructure and onboard power electronics developed.

Payment Collection

Introduction to Payment Collection System:-
Electric vehicle Payment collection system is one of important feature which needs to be taken care of while focusing electric vehicle system. Design of a reliable system should be there for calculating and collecting electric charge fee for electric vehicle. A electric vehicle payment collection system consist of a charge control unit, a power usage amount, cost calculation unit and a collection means.
The function of charge control unit is to receive power from a power supply means and charges battery of the electric vehicle. Function of a power usage amount is to measure the amount of power which is supplied to the battery from the power supply means and to calculate an electricity rate corresponding to the measured power usage amount. A collection is also provided which primary function is to collects the electricity rate from a user.

VARIOUS DETAIL OF PAYMENT COLLECTION SYSTEM:-

Probably a charge control unit may consist of a plug which is to be electrically connected to Power supply mains. The charge unit will charge the battery by using the power supply which is being supplied with the help of plug from power supply mains. The power usage amount and cost calculation unit consist of power usage amount measuring unit with a database and an electricity rate calculation unit. The amount of Power supplied to the battery from power supply mains is measured by power usage amount measuring unit. Database will store information about the electricity rate according the amount of power usage amount. The function of electricity rate calculation unit is to calculate an electricity rate for a preset time period or at each charge from a power usage amount for a preset time period or at each charge on the basis of information stored in the database.
Further system will consist of a double metering blocking unit which delivers a metric prohibition request signal to the power supply means. The request signal include a power usage amount of a vehicle and specific information of the vehicle. Accordingly, the metric prohibition request signal will be transmitted together with a power usage amount of a vehicle and specific information of a vehicle (3).
In a particular viable scenario, collection system will consist of data transmission unit, data receiving unit and controller. The Data Transmission unit will deliver an electricity rate

generated in a preset time period or at each charge to an electronic payment means of a user for payment request. With the help of the electronic payments means, the data receiving unit will receive an electricity rate payment success signal or an electricity rate payment failure signal.
The controller will update electricity rate record for a preset period stored in the database 24 with the newly paid electricity rate if the payment success signal is received from the electronic payment means, while it may deliver a charge prevention request signal to the charge control unit if the payment failure signal is received from the electronic payment means. By this technique, the electric charge fee can be paid in a convenient and secured manner without dual billing problem.

Fig 1

A detailed flow chart is being shown in above figure which describes a system for calculating and collecting an electric charge fee for an electric vehicle. As shown in flowchart a user will inserts the plug of a vehicle into the outlet of the power supply. The charge units of the charge control unit will charges the battery by using the power supplied from the power supply means. The power usage measuring unit of the power usage amount and cost calculation unit measures the power usage amount supplied to the battery from the power supply.

The electricity rate calculation unit of the power usage amount and cost calculation unit calculates the electricity rate for a power usage amount for a preset time period or a power usage amount measured in each charge on the basis of the electricity rate table by power usage amount stored in the database. The double metering blocking unit delivers the metric prohibition request signal of the power usage amount to the power supply. The collection means a guides a user by using the additional guide unit (not shown) in a preset time period or at each charge with regard to the payment of the electricity rate so that the electronic payment contacts the data transmission/data reception unit of the collection means (4). The collection delivers the electricity rate(s) generated to the electronic payment through the data transmission unit and requests the payment. The data reception unit of the collection receives the electricity rate payment success signal or the electricity rate payment failure signal from the electronic payment.

In the case of receiving the electricity rate payment success signal from the electronic payment means, the controller updates the electricity rate record for a preset period stored in the database with the newly paid electricity rate. On the other hand, in the case of receiving payment failure signal is delivered from the electronic payment means, the controller delivers the charge prohibition request signal to the charge control unit .

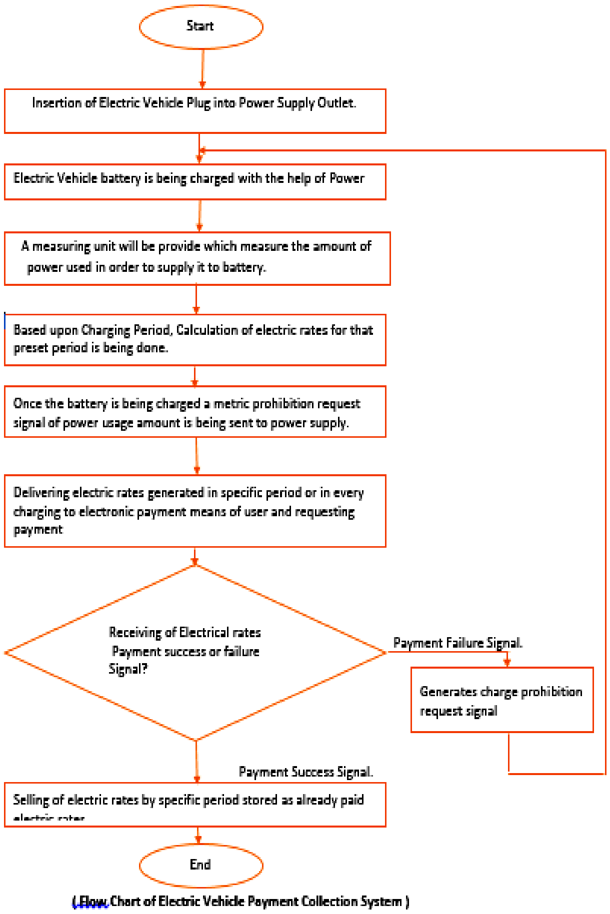
SHORTCOMINGS OF THE TECHNOLOGY

The obstacle in the mass penetration of this technology is that the life span of the battery may be reduced due to more discharge and charging cycles. The other obstacle that arises is the availability of charging stations at after every few miles. This short coming can be overcome by keeping a spare charged battery as in the case of spare tyres.

Summary

With the rigorous development in right direction and combining all of the research a predicted 40-50% improvement can be achieved.
In many areas with suitable driving conditions we can drive up to around 400 miles even. Many established companies are coming up with electric cars in the market and soon this technology will be able to supersede the existing system. Electric vehicles are the future.

FIGURE



Start
Insertion of Electric Vehicle Plug into Power Supply Outlet.
Electric Vehicle battery is being charged with the help of Power
A measuring unit will be provide which measure the amount of power used in order to supply it to battery.
Based upon Charging Period, Calculation of electric rates for that preset period is being done.
Once the battery is being charged a metric prohibition request signal of power usage amount is being sent to power supply.
Delivering electric rates generated in specific period or in every charging to electronic payment means of user and requesting payment
Receiving of Electrical rates Payment success or failure Signal?
Payment Failure Signal.
Generates charge prohibition request signal
Payment Success Signal.
Selling of electric rates by specific period stored as already paid
End
(Flow Chart of Electric Vehicle Payment Collection System)

Fig 1

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End User Engagement

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Abstract— *Traditionally, Electricity business has mainly been a one side participation by the utility and consumers were never aware of happenings other than just consuming the electricity and paying the bills. This has been a detrimental factor for the Distribution Companies (DISCOMs) as people do not use electricity efficiently while there are many households without electricity for their basic needs and depend on other sources.*

AMI tries to address this issue by using Demand Response and Time of Use methodologies. Bringing in AMI is the basic step in the introduction of Smart Grid in any country and this fundamental step is also an important one in using electricity efficiently. Each category of users i.e., Agricultural, Commercial, Industrial, Domestic and General Purpose have varied consumption levels and its important to make consumers understand the importance of electricity being generated in India.

In this paper, we try to analyze the quantitative benefits for various categories of consumers and their level of participation which can yield better results now and in the long run. These analysis considers three situations i.e., Business as Usual (BAU), Optimistic and Pessimistic approaches.

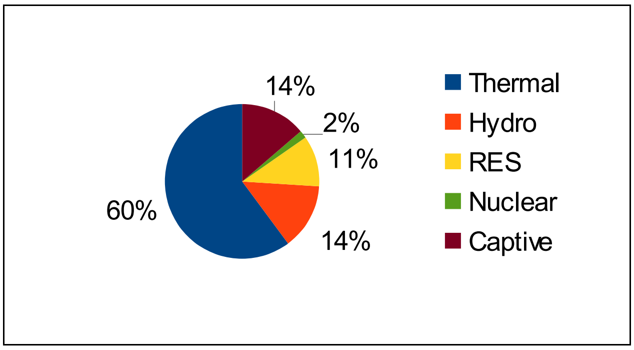
Key Words*—Demand Side Management, Demand Response, *Net-metering

I. Introduction

Utilities need to develop articulated strategies for end user engagement to ensure the success of smart grid rollouts. Only a meaningful customer experience of enablement, empowerment and education will produce the fully engaged end user who fully exploits what the smart grid has to offer and paves the way to the smart city and a smarter planet.

India is among the top 5 countries in the world with an installed capacity of 255.6GW (excluding 40.7GW of captive generation) behind China, USA and Japan. All India per capita consumption of electricity for the year 2012-13 is 914.41 kWh which is very low compared to the other countries mentioned earlier.

India is heavily reliant on thermal sources where 60% of the total installed capacity is from them. The following table shows the fuel mix ratio of the total installed capacity in the country.



Fuel Mix ratio of the Installed Capacity

II. Consumer Category Profile

Indian electricity consumers are broadly categorized into Domestic, Commercial, Industrial, Agricultural and Miscellaneous. Industrial Segment has the highest consumption trends and generates high revenue. The following table shows the consumption share for different consumer segments.

TABLE I. Consumption Share Of Consumers

Table Head	**Consumption Share**		
S.No	***Segment***	***Consumption (MU)***	***Percentage***
1	Domestic	157451	25.00%
2	Commercial	54206	9.00%
3	Industrial	188362	30.00%
4	Agricultural	142810	23.00%
5	Miscellaneous	81220	13.00%
6	**Total**	624049	100%

TABLE II. Revenue Share Of Consumers

Table Head	**Revenue Share**		
S.No	***Segment***	***Revenue (Crs)***	***Percentage***
1	Domestic	58180	21.00%
2	Commercial	40819	14.00%
3	Industrial	116384	41.00%
4	Agricultural	21231	8.00%
5	Miscellaneous	44990	16.00%
6	**Total**	281604	100%

As seen, the consumption share and revenue share as a percentage of total do not match up and a wide variation is seen in Agricultural and Industrial Segment.

95.84% of the villages in India are electrified but definition of electrification can mislead us as nearly one-third of the households are yet to see a lamp glowing under their roof. Average Peak Demand for the year 2014-15 was estimated to be around 150GW but there is nearly 2% deficit and about 5% supply-demand deficit for the same period.

Consumers of any category expect quality and reliable power but so far they had nothing to do other than just being spectators watching the inefficient practices and enduring the difficulties.

Advanced Metering Infrastructure (AMI) comes to the rescue of both consumers and utilities which encourage efficient utilization of electricity by two-way communication network that is facilitated by the introduction of AMI. Depending on the requirement various functions/features of AMI can be adopted for different category of consumers.

III. Advanced Metering Infrastructure

AMI (Advanced Metering Infrastructure) is the collective term to describe the whole infrastructure from Smart Meter to two way-communication network to control center equipment and all the applications that enable the gathering and transfer of energy usage information in near real-time. AMI makes two-way communications with customers possible and is the backbone of smart grid. The objectives of AMI can be remote meter reading for error free data, network problem identification, load profiling, energy audit and partial load curtailment in place of load shedding.

AMI is comprised of various hardware and software components, all of which play a role in measuring energy consumption and transmitting information about energy, water and gas usage to utility companies and customers. The overarching technological components of AMI include:

•*Smart Meters*- Advanced meter devices having the capacity to collect information about energy, water, and gas usage at various intervals and transmitting the data through fixed communication networks to utility, as well as receiving information like pricing signals from utility and conveying it to consumer.

•*Communication Network*- Advanced communication networks which supports two way communication enables information from smart meters to utility companies and vice-versa. Networks such as Broadband over PowerLine (BPL), Power Line Communications, Fiber Optic Communication, Fixed Radio Frequency or public networks (e.g., landline, cellular, paging) are used for such purposes.

•*Meter Data Acquisition System*– Software applications on the Control Centre hardware and the DCUs (Data Concentrator Units) used to acquire data from meters via communication network and send it to the MDMS

•*Meter Data Management System* (MDMS)- Host system which receives, stores and analyzes the metering information.

IV. Consumer Engagement

As discussed in the earlier section, AMI covers multiple things and different feature serves different purpose. Here we talk mainly about three features of AMI to engage the customers i.e.,

1. Real time energy consumption data (DSM).
2. Demand Response (ToU).
3. Net Metering.

The following paragraphs explain these three features in brief

Real time energy consumption data can be utilized to help aid in demand side management i.e. Demand-side management involves reducing electricity use through activities or programs that promote electric energy efficiency or conservation, or more efficient management of electric energy loads. These efforts can be:

- •Promote high efficiency building practices.
- •Promote the purchase of energy-efficient ENERGY STAR products.
- •Encourage the transition from incandescent lighting to more efficient compact fluorescent lighting.
- •Encourage customers to shift non-critical usage of electricity from high-use periods to after 7 p.m. or before 11 a.m.
- •Consist of programs providing limited utility control of customer equipment such as air conditioners.
- •Promote energy awareness and education.

Practically speaking, electricity cannot be easily stored on a large scale. As a result, supply and demand must remain in balance in real time. Traditionally utilities have leveraged peaking power plants to increase power generation to meet demand. Demand response works from the other side of the equation – instead of adding more generation to the system, it pays energy users to reduce consumption. Utilities pay for demand response capacity because it is typically cheaper and easier to procure than traditional generation.

In a net-metering arrangement, the focus is primarily on self-consumption of the electricity generated by the consumer. The excess/surplus power is either sold to or banked with the local utility. Net metering arrangements, thus, combine elements of captive consumption and exchange of power with the utility.

One unit of energy saved at the consumer end avoids nearly 2.5 to 3 times of capacity augmentation due to PLF, auxiliary consumption and T & D losses .The conservative estimate of potential of energy saving in India is creating nearly 55,000 MW of new capacity.

Energy saving potential for various consumer categories is as shown in the table

TABLE III. Energy Saving Potential

Consumer Category	*Saving Potential (%)*	*Installation Capacity avoided (GW)*
Domestic	Upto 20%	14
Commercial	Upto 20%	5
Industrial	Upto 25%	22
Agricultural	Upto 30%	18
Economy as a Whole	Upto 23%	60

Industrial Consumers (Both LT and HT) contribute significantly to the revenue of the utilities but do not get reliable power and so have to depend upon costlier alternative sources such as Diesel Generator Sets. An effective way to compensate for this is through employing DSM measures after thorough audits and also setting up of captive generation plant like solar PV plant under net-metering.

Domestic consumers consume 25% of the generated electricity but the population contributing to this sector is much more than the population contributed by the Industrial segment consuming 30%. Here DSM measures can be implemented by utilizing the data generated and solar rooftop installations through net-metering mechanism can be encouraged which reduces the burden on the utility to supply to this segment while it can get additional input which it can supply to other revenue generating consumers.

Utility can employ Demand Response measures on the commercial consumers during peak consumption period so as to cater to the needs of other segments. Rooftop solar PV plants help reduce the consumption.

The following table shows the priority mapping for each of the consumer segments.

TABLE IV. Consumer Mapping Preference

Consumer Mapping	**AMI Features**		
Consumer Category	***DSM***	***Demand Response***	***Net metering***
Domestic	2	3	1
Commercial	3	1	2
Industrial	1	3	2
Agricultural	1	-	-

Highest Priority for Domestic Consumers is Net-metering mechanism while its DSM for Industrial consumers. Nothing much can be done with the Agricultural Category other than employing efficiently operating pump-sets.

V. Scenarios And Benefits

The implementations discussed in the previous sections cannot be implemented for all consumers as in a particular category of consumers there are again many categories of consumers and not everyone is expected to be on-board with such ideas.

The following table shows optimistic and pessimistic projections for the electricity that can be generated in kWh from the applications that have been received under net-metering mechanism by Telangana State Southern Power Distribution Company Limited (TSSPDCL) in the state of Telangana.

TABLE V. Net Metering Projections

Optimistic and Pessimistic Projections		
Category	***Optimistic Projections (kWh)***	***Pessimistic Projections (kWh)***
Domestic - 600kW	864000	432000
Commercial - 400kW	576000	288000
Industrial – 5000kW	7200000	3600000
Total - 6000kW	8640000	4320000

With such implementations consumers will now become prosumers (producers+consumers) where the excess electricity generated after consumption can be sold to DISCOMs who in turn can sell it to Commercial or Industrial Consumers. Going for a rooftop solar PV system is a win-win situation for both the consumer and the utility.

The following tables show the investment outlay required for installing solar PV system on rooftop and their payback period for Domestic and Commercial/Industrial consumer.

TABLE VI. PAY BACK PERIOD FOR NET-METERING IMPLEMENTATION

Parameters	*Domestic*	*Commercial*
System Capacity	3kW	100kW
Cost Incurred	250000Rs	10000000Rs
Avg Monthly Consumption	600kWh	75000kVAh
Avg Monthly Generation	360kWh	12000kWh
Monthly Savings	3000Rs	80000Rs
Annual Savings	36000Rs	960000Rs
Pay Back Period	7 Yrs	10 Yrs

Tariff structure of TSSPDCL has been assumed for calculating the payback period and all the figures have been rounded off to make things easy to understand. All the other assumptions are based on the Central Electricity Regulatory Commission (CERC) guidelines.

India‘s energy intensity per unit of GDP is higher compared to Japan, US and Asia by 3.7, 1.55 and 1.47 times respectively. This indicates inefficient use of energy but also substantial scope for energy saving.

The following table shows the savings when a residential consumer goes for energy efficient equipments rather than cheapest equipment available in the market.

TABLE VII. SAVINGS PERCENTAGE FOR DOMESTIC CATEGORY

Appliance	*Cheapest Model (W)*	*Energy Efficient Model (W)*	*Savings (%)*
Incandescent Bulb to CFL	55	15	73.00%
Direct cool Refrigerator	350kWh	179kWh	49.00%
Flat Screen TV	73	51	30.00%
Fan	70	50	29.00%
Tube light	49	36	27.00%
Window AC	1892	1406	26.00%
Air Cooler	162	125	23.00%

We can see huge saving potential by using energy efficient equipments but the catch is that these energy efficient devices are costlier than the normal ones and so not all consumers can afford them. Consumers with high consumption should be mandated to use energy efficient devices while energy conservation should be encouraged for others.

In the same way energy saving potential for different industries vary differently and this can be seen in the following table.

TABLE VIII. ENERGY SAVING POTENTIAL ACROSS INDUSTRIES

Industry	*Saving Potential (%)*	*Installation Capacity avoided (GW)*
Iron and Steel	10.00%	2
Fertilizer	15.00%	2.4
Textile	25.00%	3
Cement	15.00%	2.4
Paper	25.00%	3
Aluminum	10.00%	2
Sugar	20.00%	2.7
Petrochemicals	15.00%	2.4
Refineries	10.00%	2

These industries are also identified as Designated Consumers (DC) where such industries are mandated to reduce their consumption levels by auditing their energy consumption from time to time. This will help in cutting down their production costs by a certain amount.

The following table shows the energy saving potential for Agricultural consumers by using energy-efficient equipments.

TABLE IX. ENERGY SAVING POTENTIAL FOR AGRICULTURAL CONSUMERS

Code	*Equipment*	*Saving Potential (%)*
R1	Low resistance foot valve and suction pipe	Upto 25%
R2	R1+Low friction delivery pipe	Upto 35%
R3	R2+Higher efficiency Pump	Upto 45%
R4	R3+Lower rating motor	Upto 60%

Utilities can encourage different consumers by mandating some consumers to change to energy efficient devices while subsidizing those consumers who cannot afford and also by providing incentives to consumers for shifting their loads from peak hours to off-peak hours.

VI. CONCLUSION

The three features discussed to encourage efficient usage of electricity i.e., Real time energy consumption data, Demand Response and Net-metering are dependent on the development of AMI in the region where such measures are being envisioned. Demand Side Management and Time of Use are already in use in most of the states, with this two-way flow of energy and information both the consumers and utility are more informed and equipped to understand the consumption pattern on real time basis which can help take necessary measures.

Replacement of the existing electro-mechanical meters with smart meters will help track the energy consumed from the grid and pumped into the grid in net-metering mechanism. It also helps in keeping track of hourly consumption and helps avoid any energy wastage. The saving potential for both consumers and Utilities are quite significant through net-metering mechanism and DSM activities.

Participation level of consumers might vary across consumer segments and the results also vary proportionately based on how the consumers are engaged by the Utilities through one of these features or one among the many options available to them. Current level of operations are not satisfactory and the consumers have to be aware of their consumption levels and energy conservation measures should be inculcated which can be possible only with the development of AMI.

Adopting all the features of AMI is highly optimistic which can take another 10-15 years where every consumer is part of such energy efficient measures which is good for the economy of the country to have a growth rate of 8-9%.

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Comparative assessment of Passive Islanding Techniques in an inverter based Distributed Generation Environment

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***Abstract*—The island is an unregulated power system. Its behavior is unpredictable due to the power mismatch between the load and generation and lack of voltage and frequency control. According to IEEE Std. 1547-2003, fast and accurate islanding detection is of great importance for safe and reliable operation of micro grids. In past, researchers have presented various methods for islanding detection. The aim of this paper is to compare various passive islanding techniques based on various parameters such as non detection zone (NDG), nuisance tripping of DG due to diversified non-islanding events, capability to handle multiple Distributed Generators (DGs) etc. Simulations for various islanding and non-islanding events have been carried out using Real Time Digital Simulator (RTDS). The voltage and current data are sampled at a sampling frequency of 1 kHz. The results obtained for various existing passive islanding detection methods such as rate of change of frequency, active power, reactive power, voltage and impedance are compared and final conclusion is drawn in such a way that new researchers do not face any difficulty in carrying out research in any specific area of the next generation's islanding detection.**

***Keywords*—Distributed Generation, Islanding detection, passive methods, non detection zone.**

I. Introduction

Nowadays distributed generations (DGs) are been integrated into the distribution system because of the increased demand of the electric supply. Although, conventional protection system has been modernized and upgraded such that modern distribution network can be protected effectively, but still there are some issues to be taken into account. One such issue is islanding [1].

Islanding is very important protection issue when concerned with the DG. Islanding is an unregulated power system. Islanding of a grid connected inverter is a phenomenon when the local networks containing such inverters gets disconnected but the local loads are been supplied by the inverters without the control of utility [2]. Failure to islanding detection can lead to many negative impacts on the generators and connected load. According to IEEE Std. 1547-2003, fast and accurate islanding detection is of great importance for safe and reliable operation of the distribution system with the DG [3].

There are various methods to detect the islanding condition like, passive methods, active methods and communication between the utility and the grid. This paper focuses on the passive islanding techniques based on various parameters such as non detection zone (NDG), nuisance tripping of DG due to diversified non-islanding events, capability to handle multiple Distributed Generators (DGs) etc.

II. System Under Study

Fig 1 shows the single line diagram of a power distribution network. In this network, a transmission system of 220 kV, 50 Hz is modelled using voltage source and impedance [4]. A 66 kV substation (emanated from 220 kV substation) connects two 66 kV sub-transmission lines between buses B1 and B2. In this system, there are two transformers (TR-1 and TR-2) of 15 MVA each which are used to convert 66 kV into 11 kV. Ten distribution feeders are emanated from the bus B3 at 11 kV. The details of line parameters, distribution feeder parameters, and generator and exciter parameters are given in the Appendixes. In this distribution network, there are three DGs each of 6 MVA capacity and connected to 11 kV systems through a 0.415-kV/11-kV, 1-MVA transformer. This system is implemented in RSCAD software. Voltage and current signals are acquired using Real time digital simulator (RTDS). Test data are generated using the RSCAD software, and the performance of the proposed method is evaluated in MATLAB software (The MathWorks, Natick, Massachusetts, USA). The Bergeron line model is used to represent the transmission and distribution lines in the system. The other components of the power system, such as synchronous generator, transformers, loads, etc., are designed according to the collected data and specifications which are given in the Table I and Table II.

The different islanding and non-islanding conditions that can be simulated are as follows [4]:

(a) Islanding conditions:

- tripping of one or more DGs (DG-1/DG-2/DG-3),

- islanding of DG due to three-phase fault on GEN BUS, which is cleared by CB GEN breaker instantaneously, and
- tripping of the main circuit breaker (CB1 and CB2).

(b) Non-islanding conditions:

- sudden change in the load located at DG (DG-1/DG-2 in this case),
- switching (ON/OFF) of load on 11-kV (point of common coupling [PCC]) bus,
- switching (ON/OFF) of capacitor (*C*) located on 11 kV bus,
- switching (ON/OFF) of 66-kV transmission line,
- switching (ON/OFF) of transformer (TR-1/TR-2),
- tripping of other DGs apart from the target one (DG-2/DG-3), and
- short circuit on an adjacent feeder (on L4 in Figure 1).

III. CONVENTIONAL PASSIVE ISLANDING DETECTION METHODS

Passive methods are based on measuring system parameters such as voltage, frequency, harmonic distortion, etc. at the DG output when islanding occurs. These parameters vary greatly when the system is islanded. To differentiate between the island and grid connected condition, there is a threshold point required for these parameters. There should be special care for selecting the threshold value. Passive local detection schemes are inexpensive and easy to implement, since the meters required to measure local parameters are already installed at the DG interface points. These techniques are fast and do not introduce the disturbance in the system but they have a large non detectable zone (NDZ) where they fail to detect the islanding condition [5]. There are various passive islanding detection techniques and some of them are as follows:

A. Rate of change of output power

Once islanding occurs, the rate of change of output power i.e. *dP/dt*, at the DG side will be much higher than that of the rate of change of output power before the DG is islanded under the same load change. Practice tests have demonstrated that this method is much more effective when the distribution system with DG has unbalanced load rather than balanced load [6]-[7].

B. Rate of change of frequency

Rate of change of frequency (ROCOF) is a passive method which works inside a measurement zone and is based on the mismatch between DG real power and loads at the instant of islanding [8]. When islanding occurs if the active power mismatch goes below 15%, ROCOF relay may fail to detect. The basis for using the rate of change of frequency as a means for island detection arises from the generator swing equation given by:

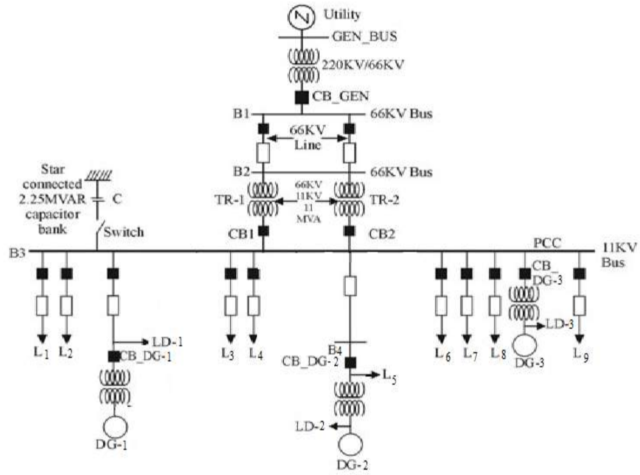

Fig. 1. Single line diagram of a power system network

$$df/dt = \Delta P_{DG} f/(2HG) \tag{1}$$

where:

ΔP_{DG} is power mismatch at the DG side;
f is the power system frequency
H is the moment of inertia for DG/system
G is the rated generation capacity of the DG/system

The rate of change of frequency, *df/dt*, will be very high at the time of islanding. Large systems have large H and G while small systems have small H and G giving the large value of *df/dt.* Rate of change of frequency relay will trip when the measured value of ROCOF is higher than the preset value for the certain period of time [8]. The setting is chosen in such a way that relay operate only for islanding not for load change.

This method is very useful when there is a large power mismatch of power but it may fail to detect when DG's power capacity equals the local loads. Hence it is preferred to use rate of change of frequency along with the rate of change of power, if they fail to operate at the instant an islanding condition occurs, any subsequent local load change would generally lead to trip actions.

C. Rate of change of frequency over power

Rate of change of frequency over power i.e. *df/dP* in a smaller system is larger than that of the power system having large capacity. This concept is used to determine islanding condition. It has been proved by the test results that for a smaller power mismatch between DG and local loads rate of change of frequency over power is more sensitive to detect island condition than rate of change of frequency over time [9].

D. Voltage unbalance

Once the islanding occurs, DG has to take charge of the loads in the island. If the load change is large, it is easily detected by measuring the parameters like voltage magnitude,

TABLE I. LINE PARAMETERS

Type of conductor	Voltage (kV)	Area of cross-section(mm^2)	R (Ω/km)	X Ω/km)
Rabbit	11	61.9	0.5449	0.305
Dog	66	118.45	0.2745	0283

TABLE II. DISTRIBUTION FEEDER PARAMETERS

Load	Length (km)	P (kW)	Q (kVAR)
L_1	2.70	1693	914
L_2	3.10	1919	631
L_3	5.20	1480	588
L_4	2.50	1791	650
L_5	5.30	1036	542
L_6	3.70	794	492
L_7	11.11	1772	0
L_8	2.90	1490	635
L_9	4.50	1970	715
LD-1	3.10	570	187
LD-2	6.20	570	187

phase displacement and frequency. But these methods will not work if the load change is small. It is highly possible that the islanding will change the load balance of DG, since the distribution networks generally include single-phase loads. Furthermore, even though the change in DG loads is small, voltage unbalance will occur due to the change in network condition [10]-[11].

E. Harmonic Detection

For inverter based DGs, change in the amount and configuration of load might result in different harmonic Currents in the network [10]. The presence of certain voltage harmonics has been used to detect islanding. One approach has been to monitor the change of total harmonic distortion of the terminal voltage at the DG before and after the island is formed. The change in the third harmonic of the DG's voltage also gives a good picture of when the DG is islanded [12]-[13].

F. Change in the reactive power

In the distribution networks the islanding detection methods based on voltage, frequency, active power use the aforementioned parameters either in direct (itself of signals) or indirect (existing energy in the harmonics of signal) forms. The active power imbalance detection procedure is based on the difference between active power generated by DG and active power consumed by the loads [14].

While the reactive power imbalance is the voltage based detection method. In this method, the rate of change of DG's voltage over consumed reactive power of loads i.e. $\partial V_{DG}/\partial Q_{load}$ is used as the detection index.

It has been found by the simulation results in islanding and non-islanding conditions that this approach is very effective even though the one percent of the reactive power mismatch is tested whereas the ROCOV relay cannot detect this situation. Also, this method has smaller NDZ than ROCOV relays.

G. Change of impedance

Passive islanding detection methods which are based on voltage and frequency are fast and they do not introduce disturbance in the system but they have a large NDZ, where they fail to detect the islanding condition. Also, ROCOF relays are not capable of detecting loss of mains when the load and generation in the formed island is exactly matched. In impedance monitoring method, the impedance measured between two phases is processed to calculate the change of impedance at the Point of common coupling (PCC) of DG [15]. The three phase voltage and current signals acquired from each DG location are used to calculate the change of impedance, which, in turn, is utilized for effective islanding detection.

In this method, samples of currents and voltages of all phases are acquired using Real time digital simulator (RTDS). Afterwards, the impedance value of all phases are calculated as:

$$Zab = (Va - Vb)/(Ia - Ib)$$

$$Zbc = (Vb - Vc)/(Ib - Ic)$$

$$Zca = (Vc - Va)/(Ic - Ia) \quad (2)$$

Where $V_{a,b,c}$ and $I_{a,b,c}$ are the fundamental phase quantities of voltage and current, respectively. Then, the average value of change of impedance is calculated considering a sampling frequency of 1 kHz. The utility impedance is considerably smaller than the impedance of a power island. When one part of the system is islanded from the utility, then the impedance of a section of network will increase. Continuous monitoring the source impedance will give the idea of whether the system is islanded or not.

IV. SIMULATION RESULTS

Different islanding and non-islanding conditions have been simulated for ROCOF scheme and results are shown for the islanding condition when main circuit breakers CB1 and CB2 are opened.

Figure 2 shows that simulation results given by the rate of change of frequency scheme during islanding condition (simulated by the tripping of circuit breakers CB1 and CB2) at 60% active power mismatch. A non islanding condition is also simulated in the figure by load switching at PCC. It has been observed that ROCOF during the islanding condition is much higher than non-islanding condition. Hence ROCOF relay will trip when the measured value of *df/dt* will be higher than threshold value for a certain period of time. Figure 3 shows the islanding condition at different active power mismatch percentages. According to figure, it is clear that this method is useful only when the large active power mismatch occurs at the DG's site. Hence if active power mismatch goes below

15% this method fails to detect.

V. COMPARISON OF THE PASSIVE TECHNIQUES

Performance of the different passive techniques has been evaluated by simulating an islanding condition. For comparison, ROCOF method is only useful when there is a large power mismatch of power but it may fail to detect when DG's power capacity equals the local loads. Hence, when islanding occurs if the active power mismatch goes below 15%, this method fails. Also the islanding detection methods based on voltage and frequency have large NDZ. ROCOP method is much more effective when the distribution system with DG has unbalanced load rather than balanced load. The change of impedance method is easy to implement and provide fast islanding detection It correctly identifies islanding during operating conditions in which more established forms of protection fail to operate and remains stable during system disturbances.

VI. CONCLUSION

In this paper, various passive islanding detection techniques based on voltage, frequency, power and impedance are described and compared. Simulation results are also generated to verify these techniques. Fast and accurate detection of islanding is one of the major challenges in today's power system with many distribution systems already having significant penetration of DG as there are few issues yet to be resolved with islanding. Islanding detection is also very important to improve the reliability and quality of the supply.

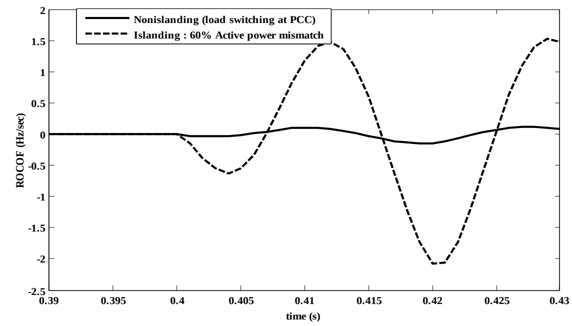

Fig.2. Rate of change of frequency during islanding and non-islanding at 60% active power mismatch.

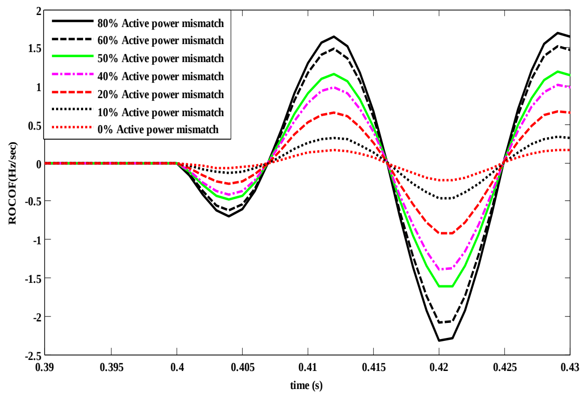

Fig.3. Rate of change of frequency during islanding at different percentage of active power mismatch.

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Enhanced Role of Phasor Measurement Unit in Power System Adaptive Protection

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***Abstract*—Wide area monitoring system (WAMS) consists of advanced measurement technology, information tools and operational infrastructure that facilitate the understanding and management of the increasingly complex behavior exhibited by large power systems. In the context of WAMS, Phasor Measurement Unit (PMU) and Phasor Data Concentrator (PDC) find their application in power system mainly as advanced measurement units. Effort has been made in this work to harness the capabilities of PMU and PDC to execute new functions which may replace additional components like relays/relaying software and hardware and aim to make the power system protection and control work as a part of smart operating system.**

The present work is done to detect generator out of step condition due to loss of excitation using an extended feature of the FPGA-based PMU prototype that has been developed on the NI sbRIO-platform. Tracking the phase angle difference between different generating stations and formulating an algorithm operational from the embedded platform of the PMU, this system acts like an adaptive relay to detect the onset of generator out-of-step conditions based upon the capability curve & steady state stability limit. This adaptive feature eliminates the conservative protection logic for loss of excitation as well as opens a new horizon for extended use of PMU.

Keywords—Adaptive Protection, Phasor Measurement Unit (PMU), Phasor Data Concentrator (PDC), FPGA-Field Programmable Gate Array

I. INTRODUCTION

Adaptive protection of power system changes the protection characteristics to suit with continuously changing power system parameters and operating conditions. With the appearance of digital protective devices the concept of responding to changing power system parameters got a new dimension. Digital relays have two important characteristics; their functions are determined through digital sampling software and they have communication capability, which makes them vital to the adaptive protection concept. This allows the software to be altered in response to higher level supervisory software, under commands from a remote control center or in response to remote measurements [1].

One of the driving forces that led to the introduction of adaptive protection was the change in the power industry wherein the margins of operation were being reduced due to environmental or economic restraints. Consequently, the philosophy governing traditional protection and control performance and design has been challenged. Adaptive relaying schemes address existing relaying deficiencies, making false trips less likely and improving the speed and dependability of the protection system. The result is an improvement in the reliability of the bulk power system and in some cases an increase in allowable power transfer limits. The adaptive relaying applications of interest have been tried here with the help of Phasor Measurement Units [2].

A Phasor Measurement Unit (PMU) or Synchrophasor is a device which measures the electrical parameters (voltage, currents, phase angles etc.) on an electricity grid, using a common time source for synchronization. Time synchronization allows synchronized real-time measurement of multiple remote measurement points on the grid. Synchrophasors are considered as one of the most important measuring devices in the future of the power system applications [3].

PMUs as a component of WAMS are used for improving monitoring, protection and control of power networks. The occurrence of major blackout in many power system networks around the world has given a new impetus for large-scale implementation of WAMS using PMU and PDC in a hierarchical structure. Data provided by PMU are very accurate and these data help to analyze the sequence of events leading to blackouts. As experience with WAMS is gained, it is natural that other possible uses of PMUs will gain momentum.

II. OBJECTIVE

An adaptive setting scheme for generator protection relay based on Phasor Measurement Unit (PMU) is the main focus of our work. The work in the initial stage comprises of loss of synchronism due to loss of excitation. Thereafter the pre-fault and fault conditions are ascertained and a generic algorithm for generator out of step protection is framed. Adaptability needs to be introduced to ensure reliability of the system and hence the post fault system conditions have also been taken into account while framing the algorithm.

PMU is selected to be installed at the proper location to monitor voltage and frequency phasors constantly because once the generators are desynchronized from the main-grid, PMU needs to check the frequency excursion and the variation of rotor angle of the generators with the measurement of corresponding voltage and load angle shift.

III. Description of Scheme

The scheme comprises of designing of a loss of excitation relay, which has the ability of adjusting itself to the steady state stability limit (SSSL) or generator capability curve (GCC) characteristics as per the system operating condition. To do this the trajectory of the SSSL and GCC in complex power plane with system reactance (X_e) and voltage at generator terminal (V_t) as parameter during loss of excitation has been studied. The loss of excitation relay is then set properly by coordinating with the changing SSSL and GCC in the complex power plane.

A. *Generator Capability Curve*

The capability curve of a synchronous generator represents the generator thermal limits in the complex power plane. It is normally published in terms maximum MVA output that generators can carry without overheating at rated voltage and power factor (usually 0.85 or 0.9 lagging).The active power output is limited by the prime mover capability to a value within the MVA rating while the continuous reactive power output capability is limited by three considerations; armature current limit, field current limit and armature end region heating limit [4].

1) *Armature Current Limit*

Armature current limit is defined as the maximum current that can be carried by the armature winding without exceeding the heating limitations. It results from the stator copper losses. The complex output power is given by

$$S=E_tI_a(cos\phi+jsin\phi) \tag{1}$$

where ϕ is the power factor angle.

Therefore, in the complex power (P-Q) plane the armature current limit defines a circle with center at the origin and radius equals to the MVA rating (E_tI_a) at rated voltage.

2) *Field Current Limit*

Copper loss in the field winding imposes a second limit on the operation of the generator. The field current locus may be developed from the steady-state equivalent circuit with neglecting saliency effect.

The active power is given by

$$P=E_tI_acos\phi=\frac{E_tE_q}{X_d}sin\delta \tag{2}$$

and the reactive power is

$$Q=E_tI_asin\phi=\frac{E_tE_q}{X_d}cos\delta-\frac{E_t^2}{X_d} \tag{3}$$

where,

E_q : Generator internal voltage

E_t : Generator terminal voltage and

X_d : Direct axis (or quadrature axis) reactance.

Therefore in P-Q plane the field current limit defines a circle centered at $\left(0,-\frac{E_t^2}{X_d}\right)$ with a radius of $\frac{E_tE_q}{X_d}$.

For a balanced design, armature current limit and field current limit intersect at a point which represents the machine nameplate MVA and power factor rating [5].

3) *Armature End Region Heating Limit*

The localized heating in the end region of the armature imposes a third limit on the operation of a synchronous machine. The generator magnetic flux is a radial flux which is also parallel to the stator laminations. However, the armature end-turn leakage flux is an axial flux and this is perpendicular to the stator laminations. The resulting eddy currents in the laminations produce localized heating in the end region [6].

In overexcited condition, the field current is high and the retaining ring is saturated by the resulting high magnetic flux. The high reluctance of the retaining ring keeps the armature end-turn leakage flux in a low value. On the other hand, for under excited generator operation, the field current is low, the retaining ring is not saturated as the resulting magnetic flux is poor, and as a result the leakage flux is high. Furthermore, in the under excited generator condition, the flux produced by the armature currents adds to the flux produced by the field current; as a result, the end turn flux enhances the axial flux in the end region. The resulting heating effect in the armature end region limits the generator output, particularly in a round-rotor machine [7].

Assuming the thermal energy is proportional to the square of the end region magnetic flux (also to the square of eddy current), the armature end region heating limit of the capability curve is represented by a circle centered at $\left(0,\, K_1\frac{E_t^2}{X_d}\right)$ with a radius of $\left(K_2\frac{E_t}{X_d}\right)$.

where,

$$K_1=\frac{N_fN_a-N_f^2}{N_f^2+N_a^2-2N_fN_a} \tag{4}$$

$$K_2=\sqrt{\frac{\Delta T}{T_k\left(N_f^2+N_a^2-2N_fN_a\right)}} \tag{5}$$

N_f: Number of turns of the field winding

N_a: Number of turns of the armature winding

ΔT: Maximum permissible temperature rise above no load temperature in stator end core region and

T_k: Proportionality constant

B. *Steady State Stability Limit*

The steady state stability limit represents the ability of the system to adjust under conditions of gradual or relatively slow load change. The load is assumed to be applied at a rate which is slow when compared wither with the natural frequency of oscillations of the major parts of the system or with the rate of change of field flux in the rotating machine in response to the change in loading.

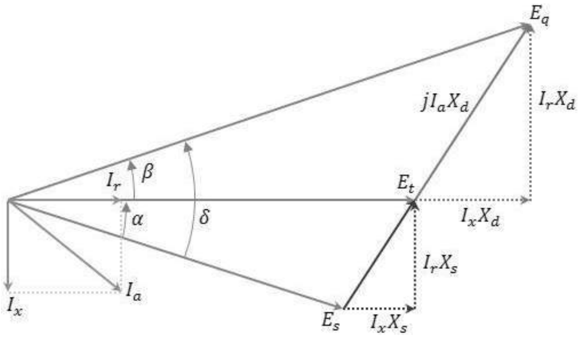

Fig.1. Phasor diagram of a synchronous generator

For an ideal lossless system ($R=0$), the transmitted power is given by,

$$P_e = \frac{E_q E_s}{X} sin\delta = P_{e_{max}} \sin\delta \tag{6}$$

$P_{e_{max}}$(value of P_e for $\delta=90°$)is known as the steady state stability limit of the system which represents the maximum power that can be transmitted and synchronism will be lost if an attempt is made to transmit power more than this limit.

If P_m be the mechanical power, then the ideal system operates at the point where the mechanical power input equals the electrical power delivered to the system. Hence, for this type of system the value of δ is constant. The sudden increase of load leads to increase of δ. Although the system remains stable until the power angle $\delta=90°$. Beyond this limit, an increase in load causes a decrease in the power transfer and the system loses synchronism.

On the other hands, if P_e decreases due to decrease in E_q for a fixed value of mechanical power, P_m, the power system may also lose synchronism. This loss-of-synchronism could occur if the operator reduces generator excitation to absorb reactive power from the system. If generator internal voltage reduces from an initial value to a lower value, the power angle increases and the system reaches the steady state stability limit. Any further decrease of the internal voltage makes the system unstable.

The steady state stability limit is a function of the generator voltage and the impedances of the generator, step-up transformer and system. This method assumes field excitation remains constant (no AVR) and is conservative. When making the calculations, all impedances should be converted to the same MVA base, usually the generator base.

The complex power relationship for a synchronous generator connected to a grid is

$$P^2 + \left[Q - \frac{E_t^2}{2}\left(\frac{1}{X_s} - \frac{1}{X_d}\right)\right]^2 = \left[\frac{E_t^2}{2}\left(\frac{1}{X_s} + \frac{1}{X_d}\right)\right]^2 \tag{7}$$

So for the ideal lossless system, the SSSL plot in the complex power plane is a circle centered at $\left(0, \frac{E_t^2}{2}\left[\frac{1}{X_s} - \frac{1}{X_d}\right]\right)$with a radius of $\frac{E_t^2}{2}\left[\frac{1}{X_s} + \frac{1}{X_d}\right]$ [8].

IV. DEVELOPMENT OF LOSS OF EXCITATION LOGIC

Fig.2 and Fig.3 shows the generator steady state stability limit (SSSL) and generator capability curve (GCC) for a strong and weak system connected to the generating station. For strong system the SSSL curve is outside of the GCC region. So for risk free operation LOE relay should follow the relatively conservative curve which is GCC curve.

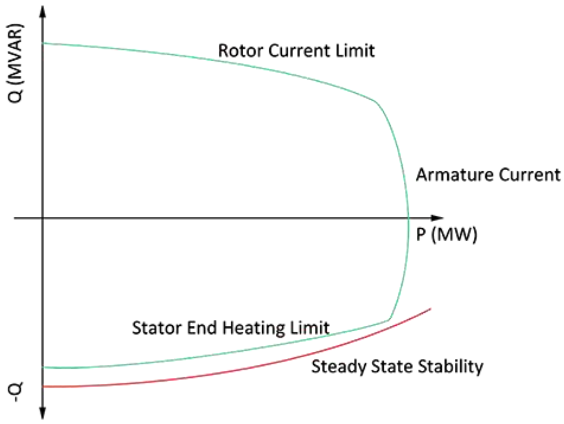

Fig.2. SSSL and GCC for strong system

For a weak system, SSSL curve is inside the GCC region. So the LOE relay should follow the SSSL curve.

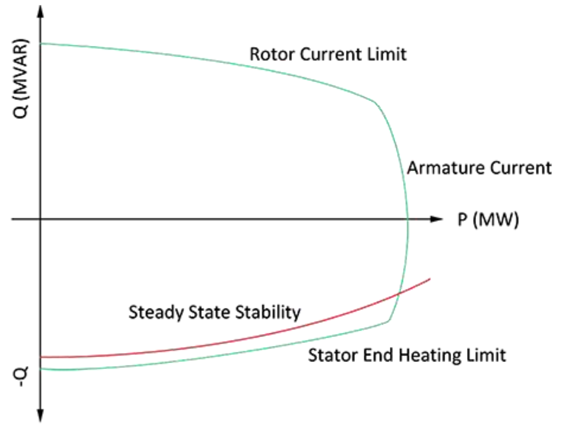

Fig.3. SSSL and GCC for weak system

V. FLOWCHART OF PROPOSED SCHEME

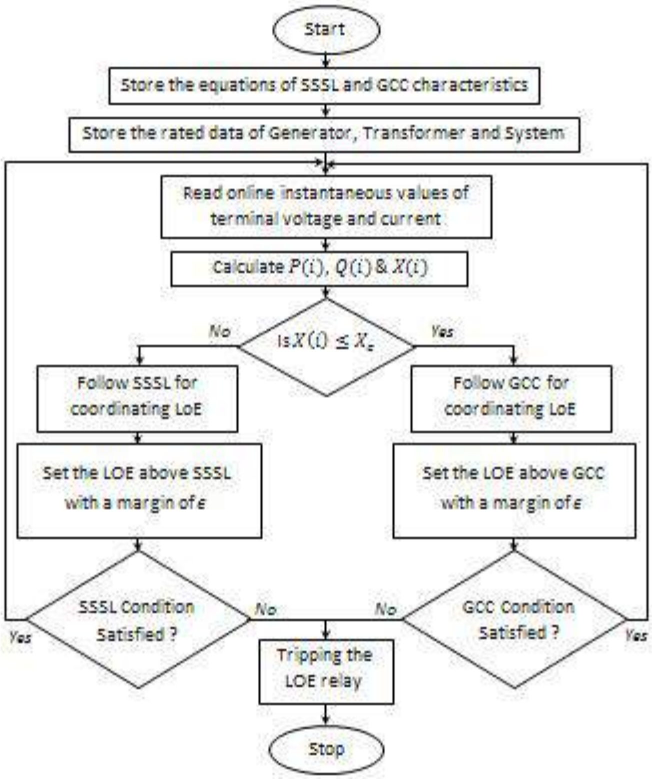

Fig. 4. Flowchart of the proposed scheme

VI. FPGA POWER CALCULATION

The LOE algorithm is developed in LabVIEW FPGA environment on NI sbRIO board. NI sbRIO products are small, deployable devices that feature a real-time processor, reconfigurable FPGA, and I/O interfaces. The NI sbRIO-9611 embedded control and acquisition device integrates a real-time processor, a user-reconfigurable field-programmable gate array (FPGA), and I/O on a single printed circuit board (PCB). It features a 266 MHz industrial processor, a 1M gate Xilinx Spartan FPGA, 110 3.3 V (5 V tolerant/TTL compatible) digital I/O lines, and 32 single-ended/16 differential 16-bit analogue input channels. It also has three connectors for expansion I/O using board-level NI C Series I/O modules. The sbRIO-9611 offers a -20 to 55 °C operating temperature range along with a 19 to 30VDC power supply input range. It provides 64 MB of DRAM for embedded operation and 128 MB of non-volatile memory for storing programs and data logging. This device features a built-in 10/100 Mbits/s Ethernet port that can be used to conduct programmatic communication over the network and host built-in Web (HTTP) and file (FTP) servers.

The complex power delivered by the generator is calculated using system voltage and currents which are taken as inputs. Based upon these inputs, the powers are calculated as follows:

Apparent power, *S*: The calculation of apparent power is quite straight forward. To start with the RMS values of voltage and currents are calculated which are multiplied in the later stage to obtain apparent power.

Active power, *P*: To measure the active power, first the instantaneous values of the voltage and current are multiplied and then the average of this result is calculated.

Reactive power, *Q*: Reactive power is calculated using the following equation

$$Q = \sqrt{S^2 - P^2} \tag{8}$$

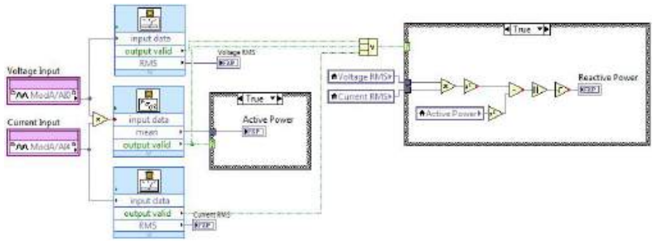

Fig.5. Complex power calculation in FPGA based platform

VII. OUTPUT RESULT

A. *Output for Strong System*

For a strong system when all lines are in service the SSSL is expanded much above the GCC. The LOE relay characteristic now adapts itself to the GCC and initiates tripping when the point is outside the GCC curve. Fig.6 displays the condition as the operating point goes inside or outside of the GCC region.

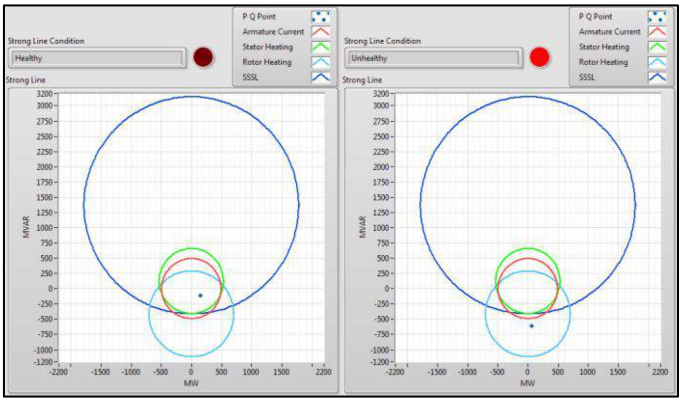

Fig.6. Output result for strong system

B. *Output for weak system*

When strongest line is out of service, due to increase in system reactance, the system becomes weak. The loss of excitation relay characteristic has been made adaptable for changes in the system. For weak system the LOE relay characteristic merges with the steady state stability limit. Fig.7 displays both the healthy and unhealthy condition as the operating point *(P,Q)* is inside or outside of SSSL region.

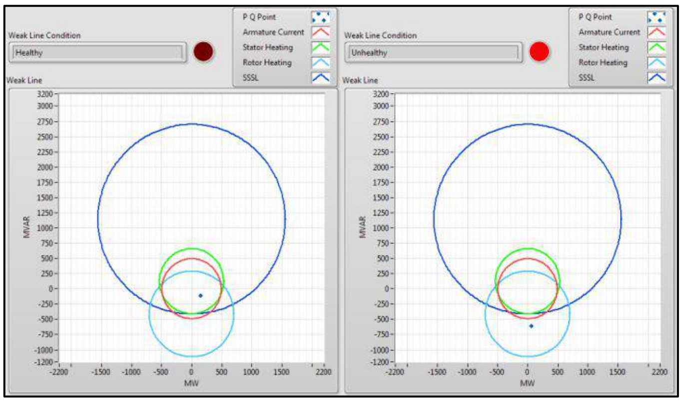

Fig.7. Output result for weak system

VIII. CONCLUSION

In the present study, an adaptive coordination logic operating through FPGA based sbRIO PMU Board where a graphical platform for detection of generator out-of-step condition due to loss of excitation is developed. The method first calculates the online active and reactive power of the system. At the same time the condition of the system is determined and the equations required to generate the complex power boundary, using a predefined transmission model, are also derived. The calculated complex power values are then plotted against appropriate steady state stability limit and generator capability curve in order to determine stability of the system.

Conventional protective systems respond to faults or abnormal events in a fixed predetermined manner. Accurate real time measurement of power system parameters by PMUs has opened a new horizon [9] and application of PMU measurements in the adaptive protection fields such as "Out of Step Protection", "Generator Pole Slipping", "Line Protection" etc. are now the active field of research in the era of real time monitoring, protection and control of power system.

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Examination of Smart Grid Architectures, Technology Demonstrations, Demand Response and their relevance in the Indian Context

Kartik Arunachalam, Venkateswaran PS, Jitendra K Pandey, Sanket Goel

Abstract— **Growth of the Indian power industry is being hindered by numerous challenges. Power enterprises, electrical utilities and agencies are facing enormous challenges like expansion of grid, more complex structures, risk of safe and reliable operation of power systems, theft of electricity. Smart Grid is the best possible option at present for India to overcome the existing challenges and move forward in the power sector. This choice offers the much needed open platform for the electricity market and transaction of power offering high quality service and optimizing resource allocation to endorse the much needed development between the power industry and socio-economic environment. Several concepts of smart grid, architectures, details of associated technological demonstrations executed internationally based on European Union and IEA initiatives and report of projects carried out in USA and Europe have been deliberated in this paper. Various smart grid concepts ranging from virtual power plant, aggregation of Distributed Energy Resources business models, active distribution network, ICT applications in intelligent Future Grids have been encompassed realizing the importance of smart grid implementation in India have been discussed. Importance of Demand Response (DR) and Demand side Management (DSM) is increasing as both of them play an integral role in maintaining the balance between the supply and demand in the electricity market. Review of DR and DSM under the smart grid archetype has also been discussed.**

Index Terms—**Virtual Power Plant, Demand Response, Decentralized Distributed Generation**

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I. INTRODUCTION

India has been facing the issue of not being able to bridge the gap between the ever increasing energy demand and energy supply since independence. This has directly impacted the country's economy and development. The transmission and distribution set-ups have persistently operated in the same method since decades. The lack of venture for innovative proficient installations along with ageing grid constituents has resulted in highly inefficient and insecure power system in India. It is highly expected that renewable energy and decentralized distributed generation will take a pivotal role in decreasing the greenhouse gas emissions in the coming years. This raises concerns regarding the future of the Indian electrical systems, as improved control and monitoring of existing networks is a must to inculcate these new power generation modes. Real-time monitoring is required for appropriate grid reliability and stabilization. The snapshot of the smart grid frame work has been depicted in Figure 1.

To accommodate these changes and the latest technological advancements an intelligent smart grid system is required to accomplish the increasing complexity of the electric grid efficiently [1, 2] . Organization of smart grid technologies will transpire over a stretched duration of time in India which would involve the addition of sequential stratums of functionality and capability to the existing systems.

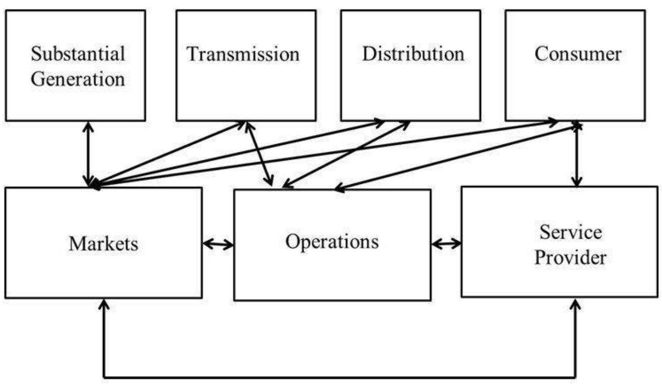

Figure 1: Smart Grid Frame work [3]

II. Impetus to Shape Upcoming Intelligent Grids

The factors forcing the change in the present energy arrangement is the combination of India's commitment to provide energy access to all, keeping in mind the energy security and also its pledge towards combating climate change at global level. One of the key drivers is the National Action Plan on Climate Change in which India has committed itself claiming that its per capita consumption will not surpass the levels of the developed nations. The present electric grid is not performing efficiently and the transmission and distribution losses are still in the range of 20% to 30% currently. Distantly located places are served through centralized generation plants over long transmission networks which are the major cause of concern. This is due to high security issues in the design of the electric grid. Environmental friendly sources of power generation such as mini-hydro, solar and wind are gaining importance at a rapid rate but their integration with the existing power network is the biggest challenge on the technical fronts. Major hurdles include power quality, security and reliability. In addition to this issue, the increased awareness of the consumers regarding their usage of energy substantiates the need for smart grid in India. A snapshot of India's energy challenge has been depicted in Figure 2.

Figure 2: India's Energy Challenge

III. Smart Grid Architectures and Concepts

This section gives a snapshot on various smart grid conceptions and planning which have been established based on the projects instigated in Europe and North America.

A. Virtual Power Plant Development

With increasing Distributed Energy Resources (DER) and establishments of Renewable Energy Systems (RES) in India, there is a requirement of a power system which integrates all these sources in a secure and robust manner. Virtual Power Plant (VPP) is the solution to this issue; VPP aims to aggregate the different DERs/RESs through an advanced Information & Communication Technology (ICT) platform for better utilization of these resources. VPP isn't a true power plant but it is a plant locked in the digital domain that can shift from traditional generation to smart grid enabled renewables. The VPP exists only on software which can be used to manage different options, measure real time situations and dispatch solutions in the electric form. VPP provides the opportunity to integrate thousands of DERs at a single place. Utilities will play a major role in the evolution of the VPP market since their dependence upon the distribution grid infrastructure comprising smart meters and custom-made billing service envelopes is high. VPP offers the pathway to move forward on the distributed control paradigm from the traditional central control viewpoint.

Europe's progress with the VPPs acts as a lesson for India. In the past few years, the European Union has tested the VPP concept via a project titled "FENIX" which aims to promote DER. FENIX depicts the way in which distributed energy can contribute to the power system through large-scale virtual power plant and demonstrations on decentralized energy management. FENIX project achieved its objective of conceptualizing, designing and demonstrating the technical architecture of VPP by two specific projects in Europe. One of which was in Spain and the other one was in the United Kingdom. The business stakeholders with distributed resources and the various stakeholders involved in the electricity sector were attracted towards the cost-benefit analysis of the project [4-6].

Considering the success of VPP in Europe and USA combined with the abundant availability of renewable energy sources in India, VPP is surely one area which can revolutionize the Indian power sector. The expending VPP would surely help channelize energy generated in one part of India to the other parts where energy demand is extremely high.

B. DER Aggregation Business Development

Accretion is the course of associating trivial groups of industrial, commercial and residential customers into a superior unit in order to make them perceptible from their view point of the electric power system. Creation of hamlets in the Decentralized Distributed Generation (DDG) projects is an example of such a scenario. At present, demand and generation silhouettes of individual consumers and generators appear as negligible units on the power system. Creation of enormous and flexible assortment empowers aggregators to operate DER and provide services to the power system in an efficient manner. Smart grid concept implementation becomes extremely easier through this accumulation model; since this process of combining the consumers and generators decreases operating costs, increases profitability and introduces more flexibility [7, 8].

For enhanced DER deployment EUropean Distributed EnErgy Partnership (EU-DEEP) was created. The core objective of the project was to develop and validate a pioneering approach based on future energy market scenarios for efficient DER arrangement. EU-DEEP examined three diverse business prototypes of Distributed Generation and individual load amassing. One business model aimed at balancing the intermittent generation by combining commercial and industrial Demand Response (DR). The other intended on integrating residential scale flexible micro-CHP into the electricity markets. The latter business model targeted at extending the conventional energy service company business through the flexibility of aggregated CHP units and DRs [9, 10].

C. Development of Intelligent Grid through ICT Applications

Effective solutions for counteracting climate change effects are demand side control, energy efficiency and RES. Therefore, the reorganization of the power distribution network is extremely necessary for implementing these elucidations. Unique ICT-based applications are required for real-time process control, communications, portfolio management and adaptive protection for the efficient operation of smart grid.

The IntelliGrid charter in Europe was initiated in order to integrate electrical and intelligent infrastructure. This project had two primary objectives; one which involved the determination of business needs of the present power system and other possible power systems of the future. Understanding the requirements of the power system and utilizing these as the sources of information, a tactical approach with various migration paths and technology independent routes was built. These two intentions validated that the future energy systems would be an architecture blend of two arrangements: energy delivering setup and an ancillary distributed computing infrastructure.

A specific thematic network under the CIP-ICT PSP Programme of the European Commission titled Supporting Energy Efficiency in Smart GEneration grids through ICT (SEESGEN-ICT) was developed. It intended to provide a set of priorities to fast-track the introduction of ICT into the Smart Distributed Power Generation Grids; investigate the requirements, barriers and propose appropriate solutions according to the requirements. SEESGEN-ICT gave suitable policy recommendations, identified superlative practices and drew scenarios and roadmaps for the impending distribution network. ICT was successfully implemented in various domains of this project which has been depicted in the Figure 3 [11, 12].

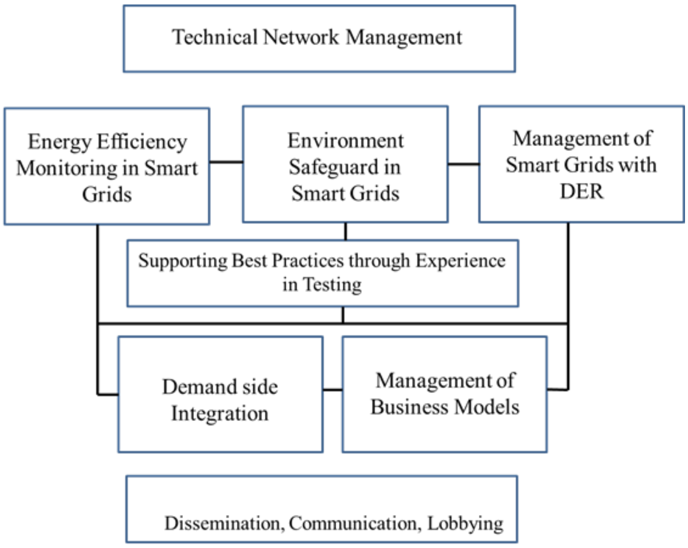

Figure 3: Arrangement of SEESGEN- ICT Project

In India there is a need to integrate the Computer and Electrical domains under a single frame. Right from universities research centers to the working organizations, both the departments are treated as different entities. The bringing together of both the domains will be the stepping stone for the development of the Indian power sector. This would be helpful in security maintenance; system balancing and system reliability which are the most important and urgent need in the Indian power sector.

D. Enlargement of Active Distribution Network

With the evolution of DDG in India, the Indian power distribution sector should prepare itself for Active Network Management (ANM) rather than following the traditional submissive network management. Demand Side Management (DSM), reactive power compensation and direct load control are the existing controllable resources to which DDG can be added in the active network scenario. ANM increases the potential of renewable energy by efficient utilization of distribution network assets and by supporting distribution network through subordinate facilities from customer owned resources.

The Active Distribution NEtwork (ADINE) project established newfangled methods for electrical distribution network management comprising of various DERs. A set of technical solutions were established and validated in realistic environment to make ANM possible. The ANM concept of the ADINE project was based on systems like Supervisory Control and Data Acquisition (SCADA), Advanced Metering Infrastructure (AMI), Distribution Management System (DMS), substation and distribution automation. The ANM model at the decentralized control system level includes local voltage, frequency control, Power Quality (PQ), production reduction and load shedding. Fault location schemes, islanding operations and automatic network restoration are the additional features present in this model.

SCADA and PLC systems are used only be certain organizations in India for their operations. There is a need to fast track the implementation of these systems with the latest versions and developments in all the working organizations of the India power sector.

IV. Importance of Demand Response

Demand response plays a vital role in the electricity arcade for sustaining the balance between supply and demand through the introduction of load flexibility instead of only concentrating on the adjustment of generation levels at all operational time periods. According to the Federal Energy Regulatory Commission (FERC), DR is defined as: "*Changes in electric usage by end-use consumers from their normal consumption patterns in response to changes in the price of electricity over time, or to incentive payments designed to induce lower electricity use at times of high wholesale market prices or when system reliability is jeopardized.*" [13]
The classification of DR based on electric usage has been depicted in the Figure 4 a, b & c [14].

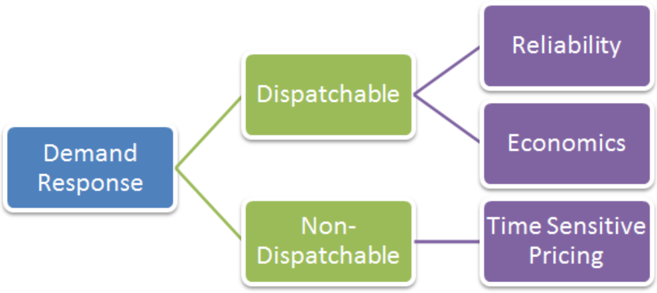

Figure 4 a : Basic classification of Demand Response

Figure 4 b : Classification of Demand Response in Economic Terms

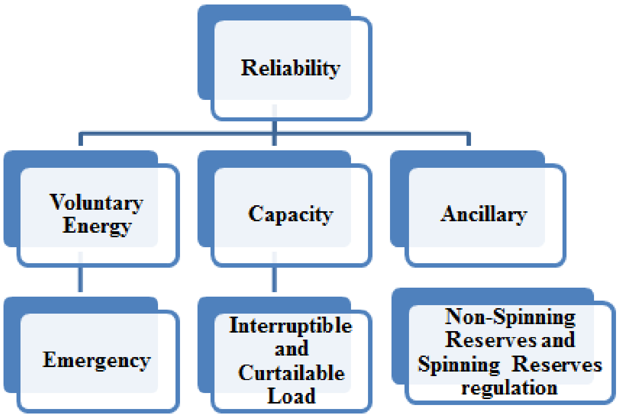

Figure 4 c : Classification of Demand Response in Terms of Reliability

The various benefits of DR are mentioned below:-

- System peak load can be reduced in the longer term via DR thereby postponing the need for building new sophisticated power plants, leading to environmental impacts and helping India in climate change mitigation at global level.
- The reliability of the transmission network can be improved immensely thereby benefitting the Transmission System Operator (TSO). DR will help reduce electricity demand at critical times and also decline the probability of forced outages when system reserves fall below the preferred levels. Thereby improving the reliability of the network. Peaking of the power plant takes a minimum of thirty minutes to ramp up to full capacity during peak critical periods but DR can be dispatched within five minutes of the peaking.
- The network constraints at the distribution level can be overcome through DR thereby helping the Demand System Operator (DSO).

  Demand Response also helps in the following:-
- Releasing the voltage constrained power transfer problems.
- Discharging congestion in the distribution substations.
- Improving quality of supply by simplifying outage management.
- There is a gain in service and reliability quality due to the relieving of distribution components from

undesirable stress during peak periods through the implementation of DR.

- DR can help decrease the financial risks of retailers who buy the electricity from the wholesale market and sell it at flat rate to their consumers. This exposes them to high financial risks due to spot price precariousness in real time crunch situations. Consumers can be requested to reduce their consumptions during volatile spot pricing and high peaks through DR thereby decreasing these financial risks.
- Decentralized Distributed Generation (DDG) and new technologies of energy storage prompt the inclusion of DR as a key component of smart grid [15, 16].

Various challenges in the implementation of Demand Response (DR)

- Coordination of the implementing agency with the energy efficiency programs is a must as DR helps upsurge the customer receptiveness of energy consumption.
- Lack of communicative meters is major area of concern.
- The potential of DR should always be taken into consideration while demand and load forecasting processes.
- There is lot of uncertainty about new types of metering equipments, communication technology and metering standards.
- The concerns of standards & protocols regarding design, operation and functioning of AMI need to be finalized at the earliest.
- DR programs should be balanced such that there is equilibrium between the customer rewards and inconvenience occurred through participation.
- Reasonable lead time should be provided to retort to demand response events with a concentration to balance operational needs by providing ability to the customer to respond. [17, 18]

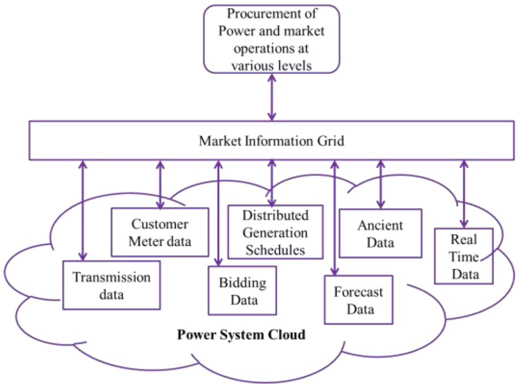

Figure 5: Indian Market Information Grid at various levels on the initiation of Smart Grid paradigm [19]

V. Conclusion

India was not designed for great capacity, long distance power transfer as is the instance in the rest of the world. India needed to interconnect its regional grids which were performed recently. This interconnection would be a stepping stone towards rapid development in Indian grid infrastructure. But still the Indian power sector is not in appropriate order and requires handy improvement and monitoring. Integrated energy planning is the way forward. Efforts should be made towards strengthening the existing grid via advanced technology rather than going for expansion of the same. Keeping in mind the future compatibility new technologies should be adopted in a strategized manner. Customer active involvement and awareness is highly essential for smart grid deployment and functioning. India is bound to benefit through intellectual energy efficiency through DR and grid responsive applications as a result of increased use of renewable energy. The evolution of smart grid would result in extreme data surge due to high complexity of operations as a result of increased registration of DG systems, end consumers and micro-grids in the markets as depicted in Figure 5. Therefore data standardization and management along with secure communication and standard protocols is a must for India to continue its growth in the smart grid sector.

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Feasibility Analysis of LVDC Distribution System in Buildings

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***Abstract*—Increasing demand and environmental concerns have focused attention on designing power systems with both high efficiency and green technologies. Currently, power system infrastructures that wish to incorporate solar photo-voltaics, wind power must first convert the DC power produced by these energy sources to AC. This adds complexity and reduces efficiency of the power system due to the need of a power converter. Furthermore, an ever increasing number of DC consuming devices such as computers, televisions, telephones and other electronic device types are being incorporated into our buildings. For supplying power to these devices, AC has to be converted back to DC, adding further losses and complexity to the power system. Instead of using multiple converter s to convert DC to AC and then AC to DC, the power system could solely be based on DC. This would eliminate the need for two sets of converters for each DC load, reducing the cost, complexity, and possibly increasing the efficiency. However, a definitive analysis on a DC distribution system is needed to determine the net benefits of eliminating the converters. In this paper, low voltage DC house is compared with AC counterpart. The models are compared in terms of efficiency.**

Keywords— DC , AC , Efficiency

INTRODUCTION

Electrical science and practical applications of electricity began with Direct Current. The advent of transformers , poly phase circuits and induction motors later led to AC power systems. At that time no method existed for boosting and controlling DC voltage eat the load, so transmission of DC power from generation to load resulted in a large amount of losses and voltage variations at the different load locations. Back then the DC distribution had more difficulties than advantages. Increasing demand and environmental concerns now have forced engineers to focus on designing power system with both high efficiency and green technologies. Due to recent development in power converters and DC energy sources like solar ,wind , interest in DC has returned. D.C has superior compatibility with energy storage devices. These devices can also help make renewable energy, whose power output cannot be controlled by grid operators, smooth and dispatch able. Now –a –days a large number of appliances in households, offices, industries run internally on low voltage dc. Therefore, the distribution companies and consumers want their electricity distribution to be more reliable, efficient and of better quality. From these needs the interest towards DC systems is on the rise.

STUDY METHODOLOGY

In this work a low voltage direct current (DC) distribution system for a house or an apartment has been investigated with respect to the existing alternating current AC system of homes. Most of the household appliances use DC internally except some appliances such as stove, refrigerator, and microwave oven. Resistive loads can run on DC supply easily. 48V DC / 380 V DC is used due to the fact that the user can handle this voltage without any problem different sources, rectifier that converts 230 voltage AC to 48 V DC or 380 V , renewable energy sources such as solar cells and batteries. This work also investigated on DC solution for some major AC power consuming devices to run all the home appliances from low voltage DC outlets at home . as to if the energy consumption by using low DC voltage is reduced.

The feasibility of the low voltage DC systems for a home is investigated by evaluating the advantages and disadvantages with respect to the existing alternating current (AC) system of homes. The goal is to make an energy efficient system that would be able to cope with local electricity generation and storage systems at the end-user level, from DC sources. Data obtained from measurements of power consumption for different household appliances have been used to evaluate the systems. The performance of the 230V AC system and the proposed low voltage DC system is analyzed.

The comparison has been made on the basis of energy efficiency . A survey for DC equipment in the market as well as finding the alternatives for the remaining equipment's was made. Further voltage level was decided based on the findings of appliances and other losses. A line diagram is proposed for both AC well as DC homes and annual energy consumption is calculated for DC home and it is compared with existing AC homes.

MODEL

This section mainly covers the key points and the assumptions that were made during the course of this work. Some of the major points are listed below:

i. As per IEC recommendations, for medium and low voltage of distribution system in AC house , 230/400V as given in IS 12360 has been chosen.

ii. The voltage level for DC home has been decided based on market survey of DC appliances and also the standards proposed by IEEE LVDC Forum India. 48V DC is recommended for appliances consuming less than 100 W and 380V for appliances consuming more than 100 W

iii. For 48V line 2.5 sq.mm cable has been used up to sockets and 1.5 sq.mm cables beyond the socket. For 380V line 4 sq.mm throughout.

iv. The incoming AC voltage of home has been converted to two voltages which are 48V DC and 380V DC. The AC voltage will be converted using two AC to DC converter i.e. one for the 48 V line and other for 380V line. As per the products available in the market, AC to DC converter (230V to 48V) has efficiency of around 85% and DC to DC converter (48V to 12V) has efficiency of around 95%.

v. The solar panels have chosen such that the DC output from them is 48V and no converter is required.

vi. The solar and batteries would only be working for the 48V line.

vii. The house hold that has been chosen is a 1 BHK apartment with a study room in the northern region of India. There is more variation in the loads during different seasons of the year so the energy consumptions has been calculated for each season

INTEGRATION OF SOLAR

Integration of Solar as well as batteries would be done only in the 48V line. The Solar installed in DC home would be connected to the 48V line and directly DC power will be used and no conversion to AC would be involved as shown in Figure 1. Solar power will be used as the top priority for the load so that solar energy is exploited at the maximum level. Also solar would be used to charge the batteries during the lean period so that batteries can feed the load during peak period.

The battery storage would also be connected to the 48 V line and similar to solar no conversions would be done. The battery would be used in such a way that it is used efficiently by not only using it during black out but also during peak period. For this purpose source selector would be used whose functionality is discussed in next section. It will be charged both from DC supply and from solar as well. The battery would not only used during cut off periods but also during peak period.

Two source selectors would be used whose functioning is described below:

i. Source Selector 1: Its functionality is to choose which source of power would be used to charge the battery. Preference would always be given to solar. The battery would preferably be charged during lean periods and used during peak periods. Suggested source selector is an under voltage relay (one bipolar double throw).

ii. Source Selector 2: Its functionality is complicated because it has to choose between three sources i.e. battery, DC source and solar. The preference would always be given to solar and then to ensure an efficient use of battery the battery would be discharged up to 50% and then if solar is not available as well as the battery is discharged up to 50% then DC source would be given preference. In case of blackout, if solar is available load should be fed by solar and then battery should be preferred.

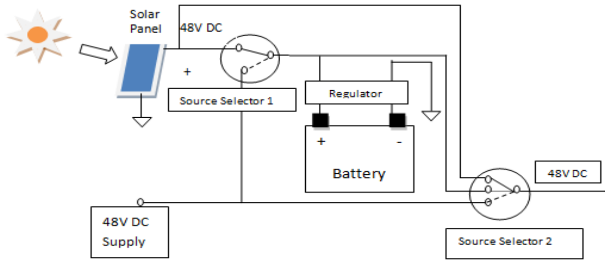

Figure 1- Line diagram of solar and backup power integration

ANALYSIS OF AC AND DC HOUSEHOLD

This study involves the interpretation of all types of usage pattern of electrical appliances on an ordinary day that we believe to be a typical day of a family home life. The electrical consumption of the assumed home is estimated from the number of appliances used, usage hours, and rating of appliance. The loads have been chosen such that maximum equipment could be covered. Figure 1 and Figure 2 shows the line diagram of a 230 V AC house and LVDC house respectively. Appliances used during summer, monsoon, normal and winter have been divided in order to obtain a percentage of different end uses in total electricity consumption for both seasons. The load ,its duration, seasonal variations, and energy consumption for summer and winter / monsoon/ normal) for AC and DC house is given in Table 1. For monsoon and normal season the energy consumption for AC and DC house is given in Table 2.

During summer, air conditioning and refrigeration are the major contributors to electricity consumption whereas in winter, water heating and refrigeration are the major electricity consuming appliances.. Other appliances such as televisions, washing machines, vacuum cleaner, electric iron etc. also contribute to the consumption but their effect is not significant as they are not used for longer duration.

Table 1: Energy consumption in Ac and DC House in Winter and summer season

			Winter			Summer		
Appliance		**Rating**	**No.**	**Duration (hrs)**	**Energy (Wh)**	**No.**	**Duration(hrs)**	**Energy (Wh)**
Air conditioners	AC	1900	-	-	-	2	3	11400
	DC	660	-	-	-	2	3	3960
Room Heater	AC	1200	2	1	2400	-	-	-
	DC	900	2	1	1800	-	-	-
Fan	AC	60	4	5	1200	4	5	1200
	DC	22	4	5	440	4	5	440
Hair Blow dryer	AC	1000	1	0.25	250	1	0.25	250
	DC	670	1	0.25	168	1	0.25	168
Hand Iron	AC	750	1	1	750	1	1	750
	DC	150	1	1	150	1	1	150
Refrigerator-	AC	380	1	4	1520	1	4	1520
	DC	75	1	4	300	1	4	300
Television LED	AC	60	1	5	300	1	5	300
	DC	30	1	5	150	1	5	150
Washing Machine	AC	700	1	0.7	490	1	0.7	490
	DC	250	1	0.7	175	1	0.7	175
Geyser	AC	2000	1	2	4000	1	0	0
	DC	2000	1	2	4000	1	0	0
Food Mixer	AC	250	1	1	250	1	1	250
	DC	240	1	1	240	1	1	240
Microwave Oven	AC	1450	1	1.5	2175	1	1.5	2175
	DC	1450	1	1.5	2175	1	1.5	2175
CFL*	AC	15	5	2	150	5	2	150
	DC	10	11	2	220	5	2	220
Tube Light	AC	55	2	3	330	2	3	330
Exhaust fan	AC	50	2	0.5	50	2	0.5	50
	DC	20	2	0.5	20	2	0.5	20
Dish washer	AC	1450	1	1	1450	1	1	1450
	DC	1450	1	1	1450	1	1	1450
Printer	AC	30	1	0.2	6	1	0.2	6
	DC	20	1	0.2	4	1	0.2	4
Vacuum Cleaner	AC	800	1	0.3	240	1	0.3	240
	DC	600	1	0.3	180	1	0.3	180
Laptop	AC	90	1	3	270	1	3	270
	DC	48	1	3	144	1	3	144
Cell Phone	AC	8	2	3	48	2	3	48
	DC	5	2	3	30	2	3	30
Chimney	AC	200	1	0.5	100	1	0.5	100
	DC	95	1	0.5	47.5	1	0.5	47.5
	AC		Energy Consumption		**15979**			**21979**
	DC				**11693**			**10253**

Table 2: Energy consumption in Ac and DC House in monsoon and normal season

		Monsoon			Normal		
Appliance		**No.**	**Duration(hrs)**	**Energy (Wh)**	**No.**	**Duration (hrs)**	**Energy (Wh)**
Air conditioners	AC	2	1	3800	2	0	0
	DC	2	1	1320	2	0	0
Room Heater	AC	-	-	-	-	-	-
	DC	-	-	-	-	-	-
Fan	AC	4	5	1200	4	5	1200
	DC	4	5	440	4	5	440
Hair Blow dryer	AC	1	0.5	500	1	0.25	250
	DC	1	0.5	335	1	0.25	167.5
Hand Iron	AC	1	1	750	1	1	750
	DC	1	1	130	1	1	150
Refrigerator-	AC	1	4	1520	1	4	1520
	DC	1	4	300	1	4	300
Television LED	AC	1	5	300	1	5	300
	DC	1	5	150	1	5	150
Washing	AC	1	1.4	980	1	0.7	490
	DC	1	1.4	350	1	0.7	175
Geyser	AC	1	0	0	1	0	0
	DC	1	0	0	1	0	0
Food Mixer	AC	1	1	250	1	1	250
	DC	1	1	240	1	1	240
Microwave	AC	1	1.5	2175	1	1.5	2175
	DC	1	1.5	2175	1	1.5	2175
CFL*	AC	5	2	150	5	2	150
	DC	5	2	220	5	2	220
Tube Light	AC	2	3	330	2	3	330
Exhaust fan	AC	2	0.5	50	2	0.5	50
	DC	2	0.5	20	2	0.5	20
Dish washer	AC	1	1	1450	1	1	1450
	DC	1	1	1450	1	1	1450
Printer	AC	1	0.2	6	1	0.2	6
	DC	1	0.2	4	1	0.2	4
Vacuum Cleaner	AC	1	0.3	240	1	0.3	240
	DC	1	0.3	180	1	0.3	180
Laptop	AC	1	3	270	1	3	270
	DC	1	3	144	1	3	144
Cell Phone	AC	2	3	48	2	3	48
	DC	2	3	30	2	3	30
Chimney	AC	1	0.5	100	1	0.5	100
	DC	1	0.5	47.5	1	0.5	47.5
	AC	Energy Consumption		**14119**			9579
	DC			**7555.9**			**5893**

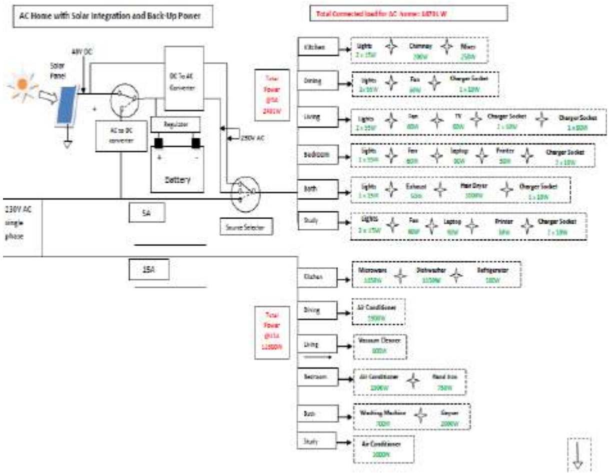

Figure 2 Line Diagram of 230V AC house

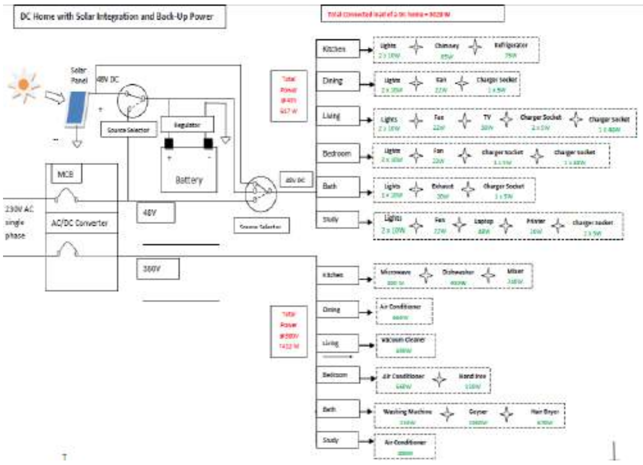

Figure 3 Line Diagram of LVDC house

COMPARISON OF AC AND DC HOUSE

The energy consumption calculations are done on per day basis for different seasons of the year for both AC and DC home.. This energy consumption in in kWh i.e. in units per day for AC and DC house are then compared and are given in Figure 4.

The per day energy consumption in winter for an AC home is around 16 units whereas energy consumption per day in winter for a DC home is 11.7 units. In summers per day energy Consumption Of an AC home is 22 units whereas per day consumption of DC home is 10.2 units. The difference is significant. Also the consumption during summer is greater than winter due to the usage of Air Conditioners

Energy Consumption per day for AC home during monsoon is 14.2 units whereas for DC home it is 7.5 units. The major difference in monsoon is that the humidity is much more than summer during some parts of the season so there is need of Air Conditioner. Hence, this counts for a major change in consumption during monsoon.

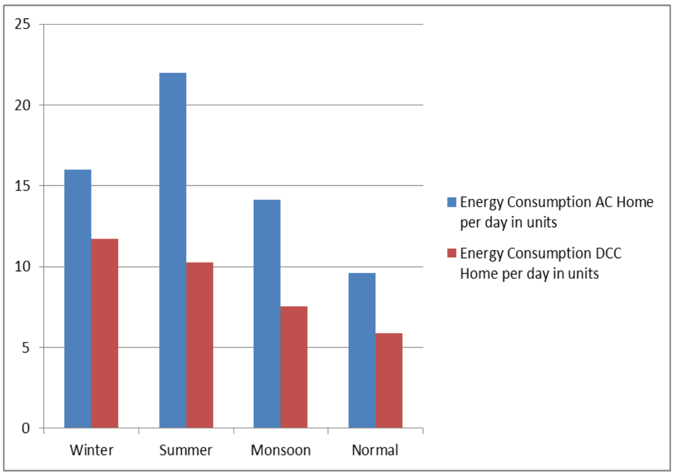

Figure 4: Graphical Comparisonof Energy Consumption

Considering a rough estimate of the number of days in summer, winter, monsoon and normal weather the year has been divided as given in Table 3 below

Table 3 Comparison of Annual Energy Consumption

Season	**Winter**	**Summer**	**Monsoon**	**Normal**	**Annual Consumption (in units)**
No. of Days in Year	61	91	61	152	
AC Home / day	15.97	21.97	14.11	9.57	5292.075
DC Home / day	11.69	10.25	7.55	5.89	3002.948
				Total Savings (%)	43.26

CONCLUSIONS

The energy consumption of AC and DC house has been estimated. The savings that comes out in DC house is around 43%. The cost factor has not been considered because this project focuses on reducing the consumption which will ultimately help in reducing the generation. Also in the coming future the equipment making companies will also compete for DC products hence the price of Dc equipments will come doen further. There is a need for working at standardizing the DC voltage for homes so that each and every one working on this concept works on a common ground.

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AC led 48v

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Findings from an Advanced Demand Response Smart Grid Project to Improve Electricity Reliability in India

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***Abstract* – Two significant challenges for a reliable supply of electricity in India are increasing demand and generation deficits. Commercial and industrial buildings in India consume approximately 44% of the nation's electricity. India had a 4.7% supply deficit during the period of April to September 2014.[1] A smart grid initiative by Tata Power Delhi Distribution Limited (TPDDL) evaluated the technical capability and potential for increased reliability and readiness of commercial and industrial buildings for automated demand response (AutoDR). The advanced Smart Grid project included smart meters and an interoperable communication and DR management system with advanced data analytics for automated dispatch and load reduction when the grid is under stress. The project covered an area of more than 250 square kilometers and included about 167 high-end industrial and commercial customers in TPDDL territory. The study identified and characterized each consumer sector's load duration curve and aggregated power demand. A total of 144 consumers' 15-minute interval meter data was analyzed to identify the DR potential of each consumer sector using well-established baseline methodologies. The study characterized each customer sector's load profile and AutoDR measures and evaluated baseline models for the measurement and verification of customer's AutoDR performance. The study estimates the DR shed performance of AutoDR implementation for each type of consumer in the field study.**

Keywords— *Demand Response Potential; Automated Demand Response; Baseline Methodologies; Measurement & Verification; Load Duration Curve, Data Analytics*

I. INTRODUCTION AND BACKGROUND

India's peak demand deficit—the shortfall in electricity supply when demand is at the maximum—stood at 4.7% during the April to September 2014 period, according to data by the Central Electricity Authority (CEA) [1]. India's grid reliability has been improving with an increase in generation capacity and synchronization of the southern grid with the national grid. Even so, along with increasing power demand from the region, the peak power deficit is still an issue that needs to be resolved in the near future. The power deficit situation is worse in certain regions of the country (i.e., northern, southern). Solutions to address the deficit are either to increase the supply-side generation capacity or to reduce the electricity peak demand. With a focus on peak demand reduction, energy efficiency and demand response (DR) have been promoted as preferred resources. The Indian government has promoted energy efficiency through initiatives such as equipment levels, building codes, and others [2]. As a key demand-side management resource, demand response resources will provide the low-carbon flexible capacity needed to maintain real-time system balance and reliability with the integration of increasing levels of renewable energy resources [3].

A Smart Grid initiative by Tata Power Delhi Distribution Limited (TPDDL) was lunched to conduct a field study of Automated Demand Response (AutoDR) with smart meters in New Delhi. AutoDR involves communication and control systems, where customer facilities respond automatically in receipt of an external grid signal. The goal was to evaluate the technical capability, potential for increased reliability and readiness of commercial and industrial buildings for AutoDR. The advanced Smart Grid project included smart meters and an interoperable communication and DR management system with advanced data analytics for automated dispatch and load reduction when the grid is under stress. The project covered an area of more than 250 square kilometers with plans to enroll about 250 commercial and industrial customers in TPDDL territory. In this study, a total of 144 AutoDR customers' 15-minute meter data out of a total of 167 customers were analyzed for performance in 17 AutoDR events.

This study presents the measurement and verification (M&V) methods that are used to quantify AutoDR performance [4]. Each sector is grouped based on identified building types provided by TPDDL. Two types of baseline models were used to calculate the AutoDR performance during the event hours: (1) 5 out of 10 baseline days (used by TPDDL), and (2) 5 out of 10 baseline days with morning adjustment (research assessment) [5]. In summary, this study presents the statistical summary of the AutoDR performance for each customer sector and the aggregated load of the field

1 Central Electricity Authority (CEA), http://www.cea.nic.in/

study, in terms of kilowatt (kW) shed and percent kilowatt (%kW) shed over the whole building power (%WBP). The results of this study were deployed by two other companion studies that provided (1) characterization and effectiveness of DR technologies, and (2) scale up of the field study to the Delhi region [6, 7].

TPDDL uses 5/10-baseline with 24-hour data from smart meters for to assess customer performance of DR events. TPDDL selected this baseline after a thorough study of different baseline models that would be applicable (e.g., 10/10, 3/10 and 5/10 models with 8-hour and 24-hour of meter data) to the Indian conditions. The 5/10 with morning adjustment (MA) baseline for this study is evaluated as part of the research and extrapolated from the smart meter data. The analysis carried out using 5/10 MA baseline model requires further review with similar set of customers. This analysis, which uses the smart meter data during AutoDR event days, is different from TPDDL baseline methodology that uses 5/10.

II. Methodology

The main objective of this study was to provide a statistically valid evaluation of the AutoDR performance of all participating customers in the field tests with TPDDL.

A. *Consumer Characterization*

A total of 167 customers included various types of load characteristics, so we grouped those customers according to types of categories (cold storage, commercial, education, flour mill, hospital, industrial, pumping, retail, and "others"). We report a high-level overview of those customers in terms of the number of customers in each sector category, peak demand power, and load duration curve.

Number of customers and peak demand of each sector category provide the market potential for DR and the value of the field study to be used for a large scale of the DR market. Demand response shed of each sector category can be quantified in the field study, and that helps allocate DR resources and reach out to new customers with high potential of DR shed. The load duration curve is one of the best ways to identify DR benefits because it shows the aggregate demand of all customers for all the hours in the year ranked in descending order.

The characterization of customer type can help utilities estimate the flexible load potentials that can be targeted to specific customers and to evaluate customers' value in different DR programs (e.g., day-of or day-ahead DR).

B. *Measurement and Verification for Demand Response*

Measurement and verification (M&V) of DR refers to the quantification of the DR performance in terms of the following metrics: Total DR (kW), DR per building's square feet or meter (W/ft^2 or W/m^2), and the DR percentage of the whole building power (%WBP) [8, 9]. Demand response M&V includes the settlement of the load changes achieved by each customer and the program-level. Different M&V methods are used for various purposes based on DR resource characteristics such as load variability, weather sensitivity, etc., for DR settlement. These baselines can also be used to estimate large-scale potential of DR, impact assessment of the DR program, and for operations and planning of DR [4]. Our primary focus is on the baseline used by the TPDDL. We review other baselines as a reference point for future activities.

We focus on the assessment of the AutoDR performance for each customer sector. Each customer had smart meter to measure the energy use at 15-minute intervals. In our study, all AutoDR test events, baseline loads were calculated using two baseline models: simple average over the highest 5 out of 10 recent good baseline days (5/10 baseline), with and without morning adjustment (MA) [5], which are described below.

- **5 out of 10 baseline model (5/10)**: The 5 days with the highest average load during the event period were selected from the previous 10 days of good data (excluding weekends, holidays, a DR event day, and any operation off day). The average of the load over these five days was calculated for each time interval.
- **5 out of 10 baseline model with MA (5/10 MA)**: The morning adjustment is a ratio of (a) the average load of the first three of four hours before the event to (b) the average load of the same hours from the selected five baseline days The adjustment factor is limited to ±20% of the customer baseline.

The 5/10 MA baseline is included in our study for research as a reference, as it is shown to reduce the bias and improve the accuracy of DR estimates for facilities that have variable load and where energy use is sensitive to weather changes. This reference allows us to better characterize AutoDR performance for any future studies. This study did not analyze additional baseline models such as weather-regression models, which could also be considered for future initiatives..

The AutoDR performance represents the difference between the building's actual power on an event day and two baseline models. Weather sensitivity and load variability are two important metrics of building characteristics. Weather sensitivity is a measure of degree to which building loads are driven directly by local weather. As we know, building heating, ventilation and air-conditioning (HVAC) loads are affected significantly by the outside weather condition (e.g., outside air temperature, humidity, solar radiation). For building loads with high weather sensitivity, the average baseline model may underestimate or overestimate the DR shed if the AutoDR event day is much warmer or colder than previous baseline days. Load variability is a measure of how different the load profiles are from one day to another. In our analysis, we used 5/10 MA baseline as a proxy to understand the AutoDR performance impacts for weather changes and load variability

III. Results from Data Analytics

A. *Customers' charactertics*

Data from 144 meters were received from all the participants in the field study. Table 1 shows the number of customers and the peak demand of each sector category. The industrial, flour mill, and commercial sectors comprise the largest percentage of customers—about 77%—excluding the "others" sector, which includes unidentified customer types. These three sectors also have the highest peak demand, which accounts for nearly 87% of the aggregated peak demand (over 25 megawatts [MW]). In the industrial consumer sector there are ten sub-level sectors that include manufacturers of food, glass, packaging, plastic, printing, shoes, and other goods.

TABLE I. NUMBER OF CUSTOMERS AND PEAK DEMAND OF EACH SECTOR CATEGORY

Customer Sector Category	Number of Customers	Meter Data Received	Peak Demand (kW)
Cold Storage	6	6	1,131
Commercial	12	11	4,646
Education	7	3	1,936
Flour Mills	27	25	7,265
Hospital	2	2	1,434
Industrial	94	77	10,044
Others	17	14	1,889
Pumping	4	3	556
Retail	4	3	62
All	173	144	25,259 (Coincident)

Of the aggregated demand presented in Figure 1, the 95th and 99th percentile of the demand are 21,477 MW and 23,322 MW, respectively. It means that reducing load during the top 70 hours would eliminate the need for 7.7% or 1,937 kW of the system demand for those customers.

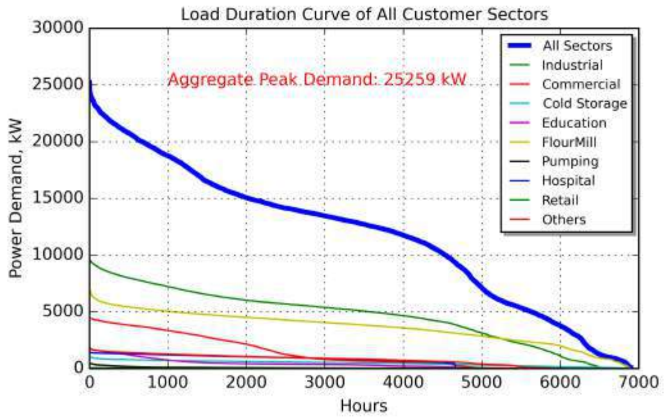


Fig. 1. Load Duration Curve of Each Customer Sector and Aggreated Load

B. *Automated Demand Response Performance*

We evaluated the effect of AutoDR in terms of those metrics: DR shed in terms of kW and %WBP (whole building power of the baseline).

- **kW shed**: The load shed potential of each customer sector, directly link to power supply and demand.
- **%WBP**: The percent of load shed over the whole building power baseline, which is used to identify each customer sector's end-use and relevant DR measures and quantify the aggregated load shed potential when scaling up the AutoDR implementation.

The metric to evaluate the AutoDR performance against the building size, W/ft^2 or W/m^2, was not reviewed, as we did not know the size of the building. As presented in Table II, a total of 17 test events were dispatched through TPDDL control center during the summer of 2014. More than 75% of the total test events lasted for an hour during the period of 3 PM~4 PM. The time scale covers most of high-demand hours from 12 PM to 6 PM, which helps us understand the DR shed potential of different times of high demand.

TABLE II. AUTODR TEST DATES, TIME, AND DURATION

Month	Day	Time	Duration (hr)
5	1	18:00~18:30	0.5
5	20	15:00~15:45	0.75
5	21	12:15~12:45	0.5
5	26	12:00~12:45	0.75
6	6	15:00~16:00	1.0
6	12	15:00~16:00	1.0
6	20	15:00~16:00	1.0
6	24	16:00~16:30	0.5
7	8	15:00~16:00	1.0
7	11	15:00~16:00	1.0
7	17	15:00~16:00	1.0
8	22	15:00~16:00	1.0
8	26	15:00~16:00	1.0
8	29	15:00~16:00	1.0
9	23	15:00~16:00	1.0
9	24	15:00~16:00	1.0
10	8	15:00~16:00	1.0

1) *Aggregated AutoDR Performance*

Figure 2 shows the aggregated AutoDR performance of two baseline models for all the 17 event days. The performance was not consistent for all the events. This study did not identify what contributed to the inconsistent performance. On June 6, 2014, performance was much higher than on other days. The load profile on this day is likely an anomaly, as there was a large load drop during the period from 12 PM to 7 PM, and requires further investigation. It is likely that missing meter data during the test period might be the reason. For the 5/10-baseline, which is used by TPDDL, the total reduction from all 144 customers for the best performing event was 8.6 MW; second-best performing event was 3.2 MW; and 75th percentile was 2.3 MW. Our analysis considers the 75th percentile, as it represents a conservative estimate of DR potential. The 75th percentile AutoDR performance was similar in both baselines, 5/10 and 5/10 MA.

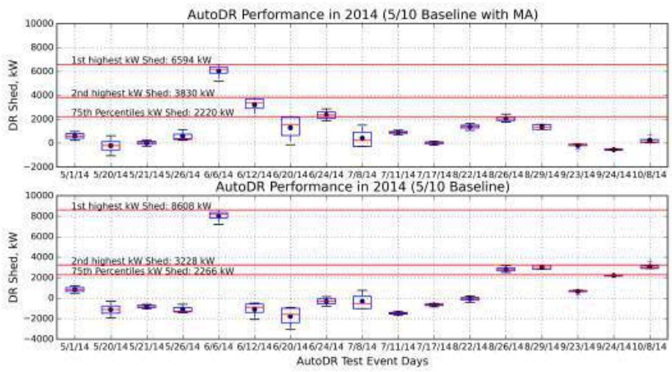


Fig. 2. Aggregated Load's AutoDR Performance on All the Event Days in 2014

Figure 3 shows the AutoDR performance of all customers on two AutoDR event days in 2014. The AutoDR event occurred from 3 PM to 4 PM on both days.

The analysis shows that the 5/10 MA baseline is better in closely matching the customer's load profile. This analysis identifies instances where the 5/10-baseline either under-, or over-estimates the AutoDR performance. For example, for the August 22, 2014 event, the 5/10-baseline underestimates the shed by about 1450 kW. For August 26, 2014 event, the 5/10-baseline overestimates the shed by about 760 kW. The findings from AutoDR performance against the two baselines indicates that, in future, it is important to review different baseline models to improve the accuracy customer's DR estimates.

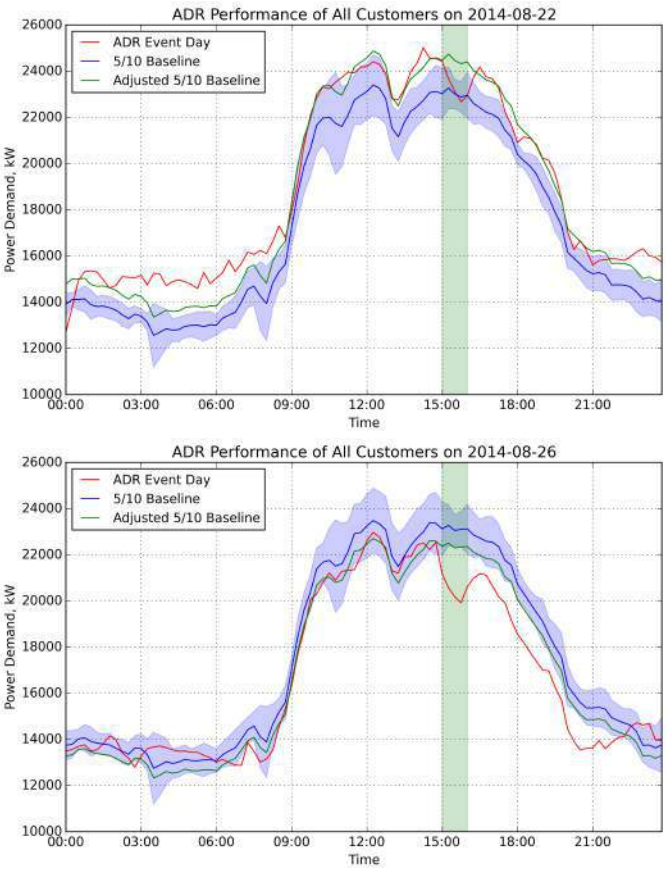


Fig. 3. AutoDR Performance of All Customers of Two AutoDR Events in 2014

Table III presents the AutoDR performance summary of these two events using 5/10 and 5/10 MA baselines. The results show that: (1) on August 22, 2014, the average kW shed accounts for -0.3% and 5.6% of each baseline's peak demand during the event hour; and (2) On August 26, 2014, the average kW shed accounts for 12.2% and 9.2% of each baseline's peak demand during the event hour.

TABLE III. AUTODR PERFORMANCE ON TWO EVENT DAYS

August 22, 2014			
DR Shed Metrics		**5/10 baseline**	**5/10 baseline with MA**
kW	Max	206	1647
	Avg	-74	1377
%WBP	Max	0.9%	6.7%
	Avg	-0.3%	5.6%
August 26, 2014			
DR Shed Metrics		5/10 baseline	5/10 baseline with MA
kW	Max	3,185	2,421
	Avg	2,817	2,053
%WBP	Max	13.8%	10.8%
	Avg	12.2%	9.2%

2) AutoDR Peformance for Customer Sectors

Figure 4 shows each customer sector's performance for all 17 DR events in 2014. It is clear that the AutoDR performance of each customer sector is not consistent through all 17-test events. Of those customer sectors, pumping, retail, and cold storage are the top three highest %kW shed over each sector's peak demand on the AutoDR event days. Pumping sector is a good resource in a regular DR program or an ancillary service DR program. Because the pumping operation schedule can be adjusted or allocated, this type of customer has significant DR potential; it can turn off all the pumping equipment for a short period. Similarly, due to the large amount of product mass stored in cold storage, this type of customer also has a large DR potential; it can shut down the storage equipment for a short period without affecting food quality [10]. Among those sectors, the flour mill, industrial, and commercial sectors provide the largest DR shed potential, which is 1,637 kW, 972 kW, and 360 kW, respectively, at the 75th percentiles of all AutoDR events. It should be pointed out that the aggregated DR shed is not equal to the sum of each sector's kW shed. The aggregated demand is calculated as the aggregation of data from all 144-customer meters. Because each customer's AutoDR performance and participation trend was not consistent through the 17 events, the aggregated kW shed is much less than the sum of each sector's DR shed potential.

As mentioned in the section on consumer characterization, information on each sector's DR shed potential can help a utility design the DR program, allocate the DR resource, and reach out to new market participants. Each type of consumer sector has specific DR characteristics in terms of time scale and DR shed potential.

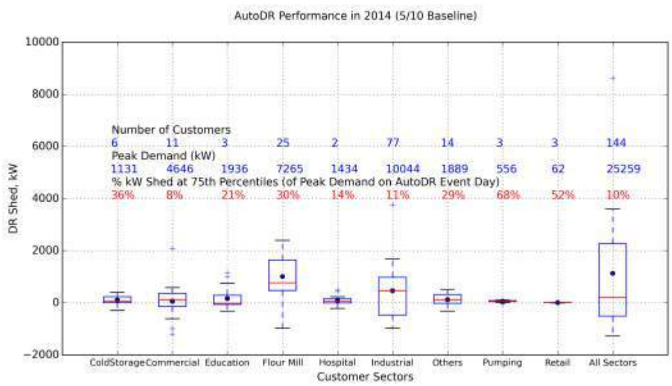


Fig. 4. AutoDR Performance of Each Customer Sector of all AutoDR Events in 2014

Table IV and Table V present the statistical summary of each customer sector's statistical AutoDR performance of all test events over the two baselines (5/10 and 5/10 MA). The kW shed and %WBP at the 75th percentiles match closely in both baseline models, while the mean aggregated AutoDR performance over the 5/10 MA baseline is about 460 kW higher than that of the 5/10 baseline, which is 40% of the mean aggregated kW shed. The 75th percentiles of kW shed, which can be a good representation of DR potential of each customer sector and the aggregated load, are 2,222 kW and 2,266 kW, respectively, for the 5/10 baseline with and without MA. For some customer sectors, such as commercial, education, and flour mill, there are large performance discrepancies between these baselines.

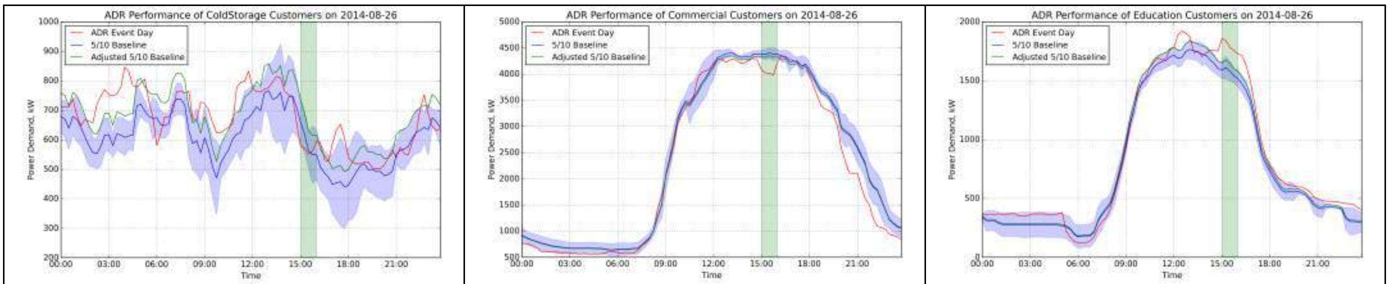
TABLE IV. AUTODR PERFORMANCE SUMMARY OF EACH CUSTOMER SECTOR (BASED ON 5/10 BASELINE)

Sector		Cold Storage	Commercial	Education	Flour Mill	Hospital	Industrial	Others	Pumping	Retail	Aggregated
kW	**Max**	403	2,086	1,154	2,397	482	3,741	512	103	28	**8,608**
	75th	229	360	289	1,637	160	972	318	80	12	**2,266**
	Mean	106	60	163	1,007	89	463	116	54	9	**1,133**
%WBP	**Max**	76%	59%	99%	62%	36%	50%	45%	84%	79%	**48%**
	75th	36%	8%	21%	30%	14%	11%	29%	68%	52%	**10%**
	Mean	19%	-2%	12%	20%	6%	6%	10%	44%	27%	**6%**

TABLE V. AUTODR PERFORMANCE SUMMARY OF EACH CUSTOMER SECTOR (BASED ON 5/10 BASELINE WITH MORNING ADJUSTMENT)

Sector		Cold Storage	Commercial	Education	Flour Mill	Hospital	Industrial	Others	Pumping	Retail	Aggregated
kW	**Max**	314	962	940	2,430	481	2,469	566	249	31	**6,594**
	75th	170	348	41	1,141	226	956	364	86	16	**2,222**
	Mean	110	316	28	778	131	612	199	64	12	**1,591**
%WBP	**Max**	54%	40%	94%	62%	36%	40%	46%	84%	78%	**42%**
	75th	34%	8%	3%	19%	18%	10%	26%	62%	50%	**10%**
	Mean	22%	9%	2%	16%	10%	8%	16%	45%	35%	**8%**

Figure 5 shows the AutoDR performance of each customer sector on August 26, 2014. The blue line in the graph shows the average 5 out 10 baseline days' load profiles, and the shading area indicates customers' load variability in terms of one standard deviation. In general, most customer sectors have a clear DR shed performance during the event hour from 3 PM to 4 PM, especially for industrial, flour mill, and commercial sectors. On this event day, the flour mill sector has a large load variability of the selected five baseline days. This results in the overestimation of shed that is almost twice that of the adjusted baseline. The use of facility equipment on the AutoDR event day may be much different from that of use on previous baseline days, as each customer in the flour mill sector has a different equipment operational schedule. MA baseline can be used to account for this change, to adjust the baseline for a better quantification of kW shed.



Cold Storage	Commercial	Education

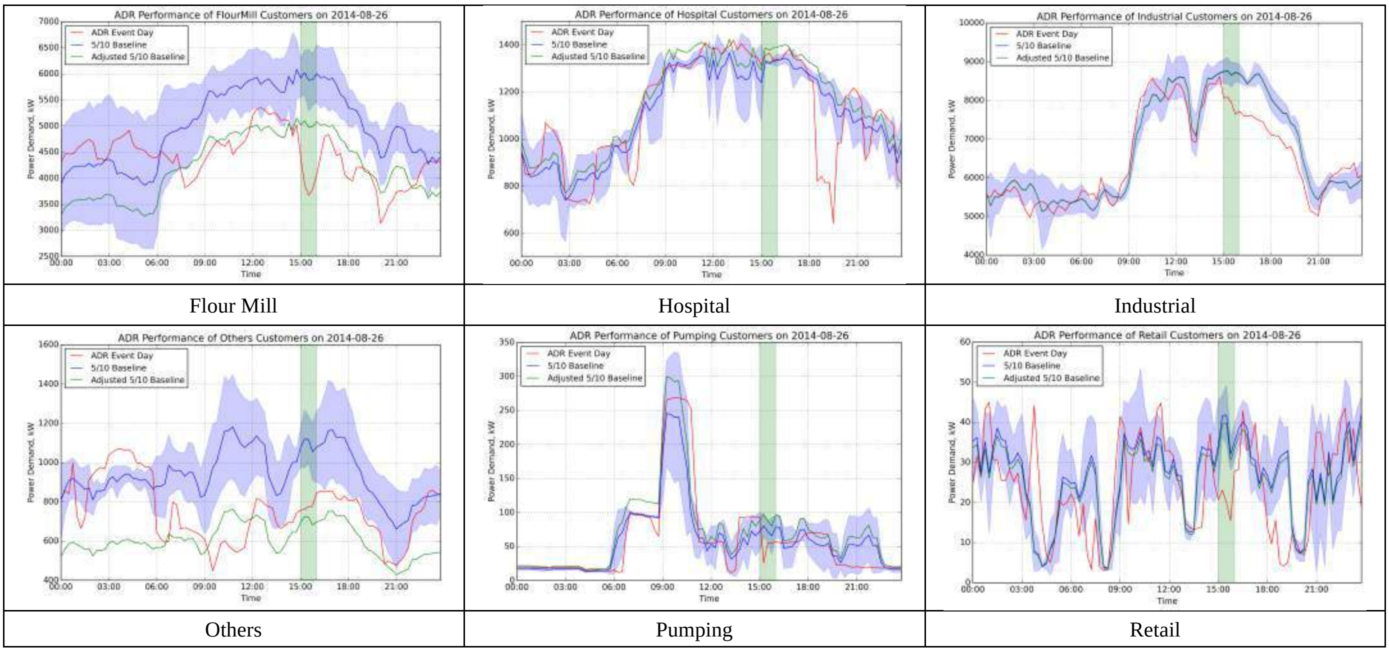


Fig. 5. AutoDR Performance of Each Customer Sector on August 26, 2014

IV. Conclusions and Future Work

In this paper, we introduced the Automated Demand Response (AutoDR) project launched by TPDDL and discussed the performance of all participating customers on 17 test event days. Smart meter data for 144 AutoDR customers were collected in this study and contributed towards an aggregated shed potential of nearly 10% of the peak demand (25,259 kW) against a 5/10 baseline. We grouped all the 144 customers into different sectors with similar functions, load profiles, and load shed characteristics. A data analytical framework was developed to calculate statistical analyses of AutoDR performance, based on the 5/10-baseline model, which is used by TPDDL. The 5/10 MA baseline model was also analyzed to study the impact of load variability in customer's AutoDR performance.

A. Conclusions

This study provided conclusions in the two key areas: (1) characterization of the customer sectors or groupings, and (2) DR performance assessment using measurement and verification methods for DR shed quantification. These results should aid utilities and regulators to identify improvements in the scaling of DR programs and market design.

1) Customer Groupings

A total of 9 groups of customer sectors were grouped based on each type of customers' specific load characteristics, which include cold storage, commercial, education, flour mill, hospital, industrial, pumping, retail, and "others." For the industrial sector, a group of 12 sub-level sectors are characterized; these include food processing, plastic, shoes, packaging industrial, etc. Of those groups of customers, industrial, flour mill and commercial sectors contribute the highest peak demand (~22 MW), which accounts for nearly 87% of the aggregated peak demand (~25 MW). In the future, each customer sector's load characteristics and DR shed potential will provide the value for scaling up this project that offers an additional DR shed potential to the market [7].

2) AutoDR Performance: Each Customer Sector and Aggreagted

Key information about the AutoDR performance of each customer sector and aggregated load are presented here, focusing on the M&V method, statistical summary of the load shed, DR measures, and cost.

M&V Methods: The 5/10 baseline and 5/10 baseline with MA provide similar kW shed and %WBP AutoDR performances at the 75th percentiles for all 17 AutoDR events. The use of 5/10 baseline models by TPDDL is a good start. For some customer sectors with high load variability, the 5/10 MA baseline can provide more accurate estimates of kW shed.

AutoDR Performance: (1) Overall the AutoDR performance of the field study was not consistent throughout the test events. We need to investigate if this is due to lack of financial incentives and credits for performance or customer/facility characteristics. (2) The flour mill, industrial, and commercial sectors contribute the largest of AutoDR load shed, which can shed up to 1,637 kW, 972 kW, and 360 kW, respectively, for 5/10 baseline (representing 19%, 10%, and 8% of each sector's peak demand on the AutoDR baseline day). The aggregated customer load can shed 10% of the aggregated peak demand at the 75th percentiles of all AutoDR performance for both 5/10 and 5/10 MA baselines.

DR Measures and Enablement Cost: TPDDL followed a common strategy for all the consumers; it involves the curtailment of non-critical load with consent of consumers. Non-critical loads were not clearly identified for this study; those loads are most likely weather-independent loads. Further investigation is required to identify the DR measures for each type of consumers and link them to the enablement cost for evaluating the cost effectiveness of DR in India's DR market.

More details can be found in our companion paper [6, 7]. Based on the methodologies of consumer characterization and M&V for demand response, the analysis results indicate that this field study is a successful implementation of AutoDR infrastructure and related technologies such as advanced metering infrastructure smart meters, wireless communication network, and DR and meter data management systems. The aggregated load shed up to 10% of the aggregated coincident peak demand over the entire period from April to October in 2014. However, the AutoDR performance was not consistent on each event day, which indicates that there is much more DR shed potential to explore, to see if there will be financial incentives and credits for customers with good performance. Demand response measures implemented in the field study were very effective by switching ON/OFF the non-critical load. More importantly, extensive baseline model studies will be required to evaluate the quantities of DR shed when customer load profiles are more likely weather sensitive and unpredictable using the simple average baseline model.

B. Future Work

In addition to MA baseline, future M&V framework must include the consideration of the impact of weather changes, and to develop a weather regression baseline model if the DR measures are related to building HVAC control strategies.. While there is no one baseline that is a best fit for all customers, the best baseline, specific to customer sectors could be used to estimate DR potential for a larger customer group. This exercise is useful to for better defining the value of DR and various DR measures for different types of customers. Future work will also focus on better understanding of customer sectors and end uses for load-effectiveness and cost-effectiveness of AutoDR. These activities will develop the value of DR in India's electricity grid, and increase DR implementation and customer acceptance.

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Power Flow Control in HEMS for Demand Response in Smart Grid

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Abstract—**Electricity has made modern society what it is today. Now it would be difficult to think of a world without electricity. By reason of undesirable faults, sudden outages and increase in power requirements, power grid is becoming increasingly overloaded and unstable. Finally to rectify those issues, flexible smart grid technology is emerging. Renewable penetration and Demand Management (DM) are important concepts in smart grid system. Proposed system assures renewable penetration and DM with power stability and power quality along consumer participation through Home Energy Management Systems (HEMS). HEMS consist of PV array, boost converter, battery, charger/discharger, smart appliance and bidirectional converter. Due to the uncertainty of solar power, battery is used for storage that power provided to grid under peak load conditions. Charging and discharging of battery, controlled by charger/discharger circuit. PV power gets boosted up by boost converter to match the grid power. Bidirectional converter acts as an inverter or rectifier depends on the power generation, home requirements, power demand and grid power availability. While making connection with grid, frequency gets monitored continuously. Frequency deviation (f<50Hz) manage by tripping smart appliances, by that power demand as well uncertain grid conditions can manage effectively. Hence to avail advanced control over this system, fast and efficient control is necessary. Proposed control strategy gets implemented using TM4C123GH6PM ARM microcontroller with the least response delay of 12.5ns. Various power availability conditions are tested and results are presented with hardware realization to bring out the prospect of the control algorithm.**

Keywords— Smart Grid, Demand Management, Distributed Power Generation, Appliance Control, HEMS, TM4C123GH6PM.

I. INTRODUCTION

Electricity is obvious and a major dependence of our modern society on electricity expands over time. Increasing electricity needs increases the burden on power grid and increases the need for installing more power plants. The overloading of power grid can reduced by effective electricity conservation with energy storage as proposed in this paper.

The newer smart grid structure is to improve power quality for the needs of 21st century economy with low carbon footprint, enabling customer participation and accommodating all generation and storage options [1], [2]. To avail the requirements of smart grid various systems are proposed in papers [3], [4]-[5], [6]-[7]. Demand management (DM) which is the main concept of smart grid [1], is not successive without consumer participation. Localized demand control system to improve grid dynamics is discussed in [8]. To engage consumer in the aid of DM, HEMS is introduced [7]. HEMS consists of smart appliances that can react with the changing power demand situations. Smart appliances are also named as Grid Friendly Appliance (GFA) because of their usability in peak load conditions [9]. Sudden increase in power demand leads to frequency deviation from its nominal value (50Hz). HEMS restores frequency and realizes DM by shedding smart appliances [3], [4], [10] and [11]. Smart appliances are scheduled according to the past behavior of the power grid [7] or in real time basis [6]. Frequency aberration below the threshold value, results in Under Frequency Load Shedding (UFLS) [9], is the most commonly used primary frequency control method. UFLS restores frequency to near its nominal value with the delay of tens of seconds. Secondary frequency control is to bring back frequency to its absolute value, is normally done by spinning reserves like gas or diesel power plants [4] with the delay of tens of minutes. In paper [3] frequency stability in power grid along with DM is attained by primary and secondary frequency control.

HEMS with solar power generation is presented in [5], provides uninterruptible power supply to DC loads while excessive power is given to grid. Solar power generation changes extremely rapidly with weather conditions. Due to the uncertainty of solar power generation, Battery Energy Storage System (BESS) is used to provide continuous power supply. Moreover is used to proficiently integrate distributed power resources into power grid [12]. By engaging storage options power wastage can be reduced and stored power can be used in peak load conditions. Study on future power system scenario and renewable resource availabilities are given in [13]. While go with the renewable it is important to continuously monitor or forecast the generated power and availability information. For monitoring and controlling renewable power generation, decentralized [10] or distributed [11] control method is well pertinent. Forecasting needs dynamic control over the synchronization of sensing and measuring elements. Synchronization is done by embedded control systems in [14], that present sequence of synchronism tests and measurement tests.

In this paper, a control strategy to manage power demand is presented. To espouse DM, primary frequency control is done by smart appliance and secondary frequency control is accomplished by the energy stored in BESS. Power flow direction is managed by the bidirectional converter. Advanced control over the smart appliance, BESS and converter is obtained by TM4C123GH6PM ARM microcontroller.

The rest of this paper is organized as follows: Section II, introduces demand management in smart grid system. In section III, power flow control strategy for HEMS is discussed. Section IV deals with the empirical results under various power availability conditions. Finally conclusions are summarized in section V.

II. Demand Management In Smart Grid

We consider a system consisting of solar panels for power generation, a battery for energy storage, battery charger or discharger circuit, DC load, bidirectional converter, smart appliance and microcontroller as shown in Fig. A. Parameters used are defined as:

P_{ge} Boost converter power output
P_b Battery power
P_{bo} Over threshold limit of battery
P_{bu} Under threshold limit of battery
P_l DC load requirements
P_{ac} AC power output of converter (Inverting Mode)
P_{dc} DC power output of converter (Rectification Mode)
P_d Demand requirement of grid
P_{gr} Grid power availability
P_{ap} Power requirement of AC appliance
f Measured frequency

All powers are measured in watts (W) and frequency is measured in hertz (HZ).

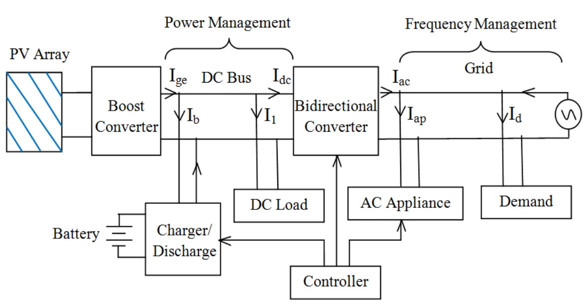

Fig. A. HEMS for Demand Management

Voltage in the grid and AC side of HEMS are maintained at 230V. DC side voltage of HEMS is maintained at 110V DC. Battery threshold power limits are maintained at constant level depending on the energy storage range of the home. Battery threshold has upper and lower limits functioning as over threshold voltage (P_{bo}) denotes the maximal capability of a battery can charge and under threshold voltage (P_{bu}) denotes the lowest limit of a battery can drain. These limits are need to be taken into consideration for safer control strategy.

Solar power is generated from PV array which is a pollution free and gratis resource. In countries like India it is a mostly available natural resource. Power generated from PV array is boosted up by boost converter which is a DC to DC converter with output greater than its input. Maximum point tracking technique is used to get constant power output from continuously changing solar power generation [5].The power is provided to DC load and after analyzing various conditions as given in chapter III, remaining power is stored in battery or supplied to AC appliances through converter (inverting mode). Battery charger/discharger circuit is shown in Fig. B, is the H type converter circuit. Charging and discharging is done by controlling the on and off operation of transistors.

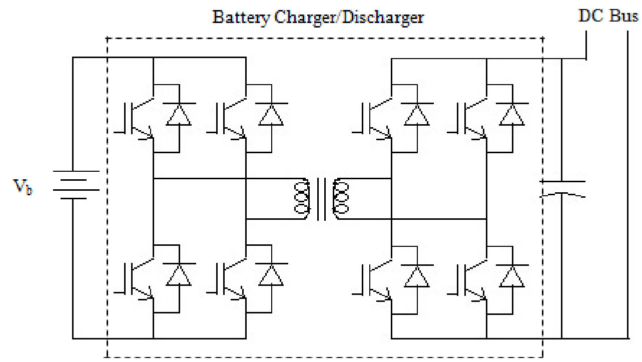

Fig. B. H-Type Converter

Bidirectional converter operates in three modes such as inverter mode, rectifier mode and idle mode. Circuit diagram of converter is shown in Fig. C.

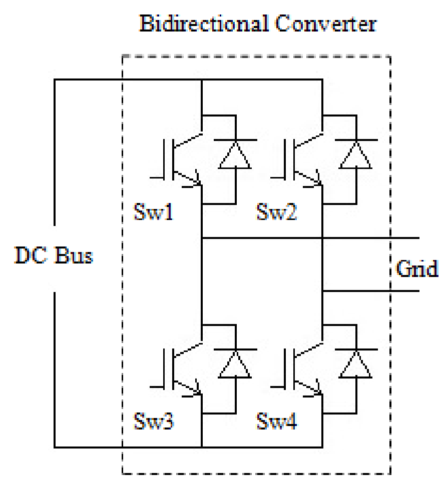

Fig. C. Bidirectional Converter

For higher power applications IGBTs or GTOs can yield better performance. When the converter acts in the inverting mode it is necessary to make the output to be synchronized with the grid frequency. Controlled gate pulses must be generated to maintain the synchronization.

Frequency management is done in AC side of HEMS to respond sudden demand requirements. To make active control over the frequency of the system, frequency is monitored continuously by controller. Threshold limit are set for allowable frequency deviations as 49.7HZ ≤ F ≤ 50.3HZ. UFLS is used here for appliance shedding. If measured frequency violates the threshold limit then appliance gets tripped off. Relay used in this control mechanism is operated in normally closed (NC) mode, whenever the trip signal is generated the relay opens and appliance is tripped off otherwise it is in normal operation.

III. Power Flow Control

Proposed system has AC supply grabbed through power grid and DC supply get from photovoltaic generation, needs advanced control over the power flow. Prior control was obtained by the developed Power Flow Control (PFC) algorithm, represented in a flow chart as shown in Fig. D.

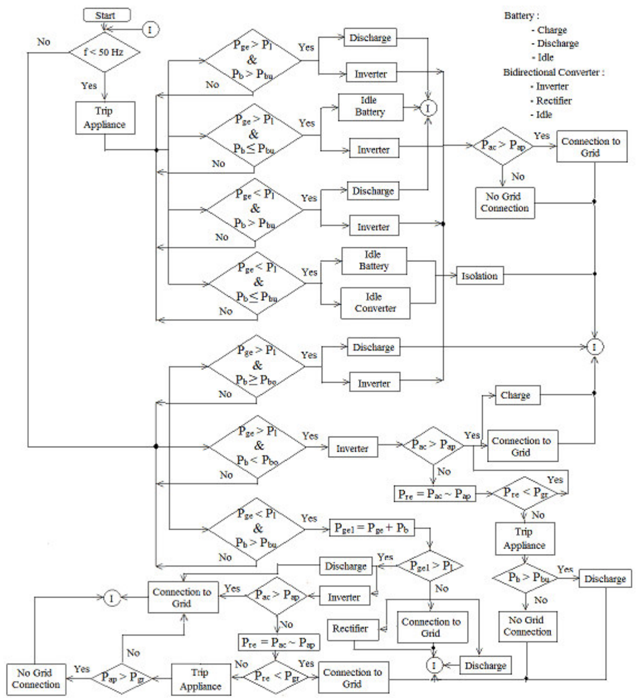

Fig. D. Flow Chart for Power Flow Control

Control algorithm is to be written in Embedded C code then plunk into microcontroller using Code Composer Studio (CCS). Controller used at this juncture is TM4C123GH6PM which has inbuilt ADC, PLL and PWM applications. As shown in Fig. A, the elements those want to be controlled are connected with the controller. Microcontroller controls the appliance for frequency management, battery charger/discharger circuit for storage management, bidirectional converter for power flow management. In grid there is constant voltage supply and the generated voltage is also made constant by using the boost converter. The real time current is given as input to the controller from current sensor/transformer (For testing, here current signal is generated from the function generator). From that power (P = V*I) gets measured with the constant voltage.

IV. Results And Discussion

Proposed control strategy was implemented and tested using TM4C123GH6PM ARM microcontroller. Due to its compact size it can be easily placed in the main supply board. Depends on PFC algorithm, control signals are generated as given in Table A, and are given to transistors of converter and battery charging or discharging circuit.

Table A. Control Signal for Converter

Name	Type	Value	Location
(x)= ui32Ch	unsigned int	0	0x200001CC
(x)= ui32Dch	unsigned int	1	0x200001D0
(x)= ui32Grid	unsigned int	1	0x200001C8
(x)= ui32Ib	unsigned int	3	0x20000194
(x)= ui32Ige	unsigned int	1	0x2000018C
(x)= ui32Igr	unsigned int	3	0x200001A4
(x)= ui32Il	unsigned int	2	0x2000019C
(x)= ui32Inv	unsigned int	1	0x200001C0
(x)= ui32Pb	unsigned int	330	0x200001AC
(x)= ui32Pbo	unsigned int	940	0x200001B8
(x)= ui32Pbu	unsigned int	60	0x200001BC
(x)= ui32Pge	unsigned int	110	0x200001A8
(x)= ui32Pgr	unsigned int	690	0x200001B4
(x)= ui32Pl	unsigned int	220	0x200001B0
(x)= ui32Rec	unsigned int	0	0x200001C4
(x)= ui32Vb	unsigned int	110	0x20000190
(x)= ui32Vge	unsigned int	110	0x20000188
(x)= ui32Vgr	unsigned int	230	0x200001A0
(x)= ui32Vl	unsigned int	110	0x20000198

For the condition presented here, total DC power available (generated power + battery power) is higher than the DC load requirements. So the remaining power is provide to the AC side of the system through bidirectional converter by operating that in the inverting mode (inv = 1). Control signals for entire system are getting from the GPIO pins as shown in Table B.

Table B. Control Signal for HEMS

Name	Type	Value	Location
(x)= ui32Ch	unsigned int	0	0x200001CC
(x)= ui32Dch	unsigned int	1	0x200001D0
(x)= ui32Grid	unsigned int	1	0x200001C8
(x)= ui32Ib	unsigned int	3	0x20000194
(x)= ui32Ige	unsigned int	1	0x2000018C
(x)= ui32Igr	unsigned int	3	0x200001A4
(x)= ui32Il	unsigned int	2	0x2000019C
(x)= ui32Inv	unsigned int	1	0x200001C0
(x)= ui32Pap	unsigned int	690	0x200001A4
(x)= ui32Pb	unsigned int	330	0x200001AC
(x)= ui32Pbo	unsigned int	940	0x200001B8
(x)= ui32Pbu	unsigned int	60	0x200001BC
(x)= ui32Pd	unsigned int	660	0x200001BC
(x)= ui32Pge	unsigned int	110	0x200001A8
(x)= ui32Pgr	unsigned int	690	0x200001B4
(x)= ui32PinData1	unsigned int	1	0x200001D4
(x)= ui32PinData2	unsigned int	0	0x200001D8
(x)= ui32PinData3	unsigned int	1	0x200001DC
(x)= ui32PinData4	unsigned int	0	0x200001E0
(x)= ui32PinData5	unsigned int	1	0x200001E4
(x)= ui32PinData6	unsigned int	1	0x200001E4
(x)= ui32Pl	unsigned int	220	0x200001B0
(x)= ui32Rec	unsigned int	0	0x200001C4
(x)= ui32Trip	unsigned int	1	0x200001D0
(x)= ui32Vb	unsigned int	110	0x20000190
(x)= ui32Vge	unsigned int	110	0x20000188
(x)= ui32Vgr	unsigned int	230	0x200001A0
(x)= ui32Vl	unsigned int	110	0x20000198

Control signals for inverter (PinData1), charger (PinData2), grid connection (PinData3), rectifier (PinData4), discharger (PinData5) and for appliance control relay (PinData6) are produced by microcontroller as shown in Table B. Those signals given to the particular elements through alloted pins. The hardware realization of the proposed system was tested with a prototype model. The model consists of function generator to produce waveform to measure current value instead of current sensor, charger/discharger circuit and single phase full bridge bidirectional converter circuit. The circuits are made with MOSFETs and passive elements. Generated control signals and outputs are monitored by DSO. PWM signal with 50Hz get generated from microcontroller GPIO pin, is configured as output pin by the code generated in the memory of microcontroller. When the converter acts as inverter the gate pulse generated need to be in a position to generate output with nominal frequency.

Input for gate of the transistors of bidirectional converter shown in Fig. E, want to be generated in such a way that transistor Sw1, Sw4 and Sw2, Sw3 of Fig. C are operated alternatively. By made proper switching sequence the output frequency has made synchronized with the grid frequency.

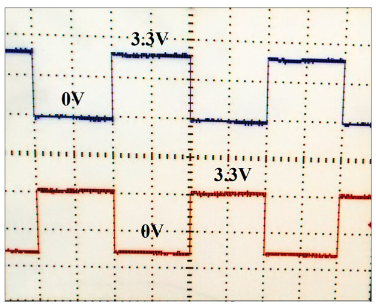

Fig. E. Gate Signal for Switches of Bidirectional Converter

Boost converter output is preceded with the inverter mode operation. Figure F shows generated voltage with absolute 50Hz frequency with 50% duty cycle. Noise associated with the output voltage, can be rectified by filtering circuits. The output can give to grid through step-up transformer.

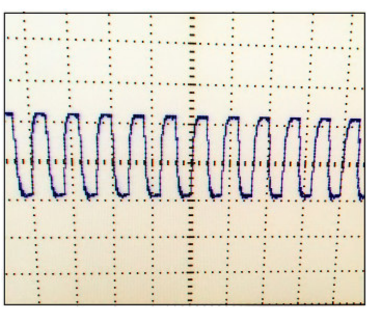

Fig. F. Output of Bidirectional Converter

Input for transistors of boost converter and relay are generated from the microcontroller according to the specified conditions. If the output from controller pin is high, then the 3.3V supply is given to trigger relay and transistors of converter as shown in Fig. G. 3.3V is sufficient to operate a relay that conducts 230V for both appliance and grid.

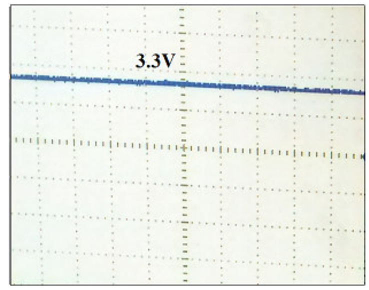

Fig. G. Control Signal for Relay

The output is low when the frequency is nominal, then the controller pin does not produce any output. So transistors and relays are not operated, appliance (here it is bulb to check operation) can work normally as shown in Fig. H.

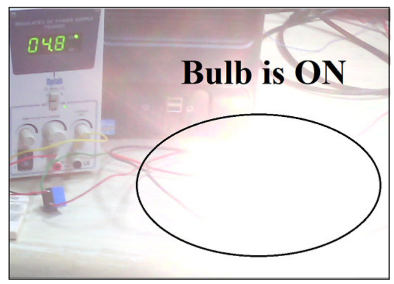

Fig. H. Operation of Relay Under Normal Frequency

Power demand increase results in frequency deviation. To make frequency to its nominal value microcontroller produces trip signal to appliance. Trip signal operates relay to cut off power supply to the appliance shown in Fig. I, makes primary frequency restoration process.

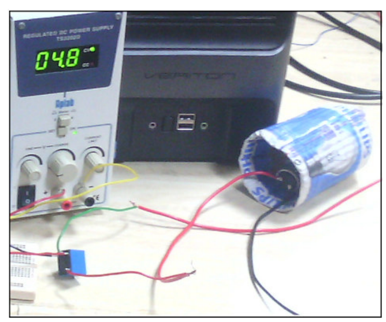

Fig. I. Operation of Relay Under Frequency Deviation

After primary frequency restoration (near 49.8 Hz), secondary frequency restoration did by controlling BESS. Battery power is given to meet the power demand as well to restore the frequency. The contribution of HEMS in DM is tabulated in Table C. By assuming a residential house with various power demand conditions at various time periods, the demand met percentage is calculated. During 6-7 PM the demand has not been met even though appliance (refrigerator) shedding done. If many houses come into action, that problem can be solved and leads to an ever power environment.

Table C. Contribution of HEMS in Demand Management

Time (hrs) (AM to PM)	P_{ge}	P_b	Power Required in Home		P_{gr}	P_d	Control Signals						Demand Met (%)		
							Battery		Converter		Grid Conne-ction	Appli-ance Trip	By Grid	By HEMS	Total
			P_{ap} (AC)	P_l (DC)			Ch	Dch	Inv	Rec					
5-6	-	2000	1903	200	1300	40	0	1	1	0	1	0	100	-	100
6-8	154	2000	1830	-	350	321	0	1	1	0	1	1	44.52	55.48	100
8-9	154	2000	440	-	120	929	0	1	1	0	1	1	12.91	87.08	100
9-4	154	2000	1177	45	550	800	0	1	1	0	1	1	68.75	31.25	100
4-6	154	2000	1160	-	210	325	0	1	1	0	1	0	64.61	35.39	100
6-7	154	2000	1219	200	170	755	0	1	1	0	1	1	22.52	60.13	82.65
7-9	-	2000	1219	-	2200	375	1	0	0	1	1	0	100	-	100
9-5	-	2000	2172	145	4000	76	1	0	0	1	1	0	100	-	100

The results discussed were validating the effectiveness of the proposed system. Compared with previous works novelties and contributions of this paper are,

1. Response delay of this system is 12.5ns excluding wiring delays.
2. Detailed system structure with microcontroller based control strategy is presented.
3. PFC strategy is developed to make effective power demand management through HEMS with consumer participation.
4. Control strategy tested with hardware arrangement under various power availability conditions.

V. Conclusion

Building a smart grid will help power sector to achieve a more efficient and reliable power grid and revolutionize energy use for generations to follow. Proposed work is a pioneer to manage power demand with the participation of consumers. Here solar power generation is incorporated and generated power is given to DC bus. Energy storage did by the BESS to provide uninterruptible power supply to DC loads and to manage peak load epoch. PFC strategy is developed to manage frequency deviation, energy storage, appliance control and all for demand management. Control strategy was implemented and tested for various conditions with TM4C13GH6PM ARM microcontroller, and the results are verified with hardware realization. Proposed system meets many of the smart grid requirements, such as distributed resource penetration, energy storage, demand management and advance control. By implanting this HEMS more stable and quality power can provided to utility customers.

Future research work may be the detailed modeling of a real power system with more than one smart appliance to test the proposed method. And the new model will eliminate the burdens of wired control.

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Smart Grid & Renewable Energy System

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1.INTRODUCTION

Here we are discussing about smart grid. A grid which is smart , efficient , and reliable . we need and use a lot of energy to fulfill our needs in day to day lives . we use renewable energies like solar energy , wind energy & biomass energy etc .

Now smart grid is a developing network of transmission lines in sectors of power generation distribution , transmission and consume using technologies working together to respond immediately to our 21st century demand for electricity .

2. USE AND NECESSITY OF SMART GRID

Smart grid provides us a huge amount of benefit in energy as well as in financial prospect .by the use of this technology we can reduce the use of non renewable energies like coal , petrol etc . now if we reduce the use of these resources then the government can have a huge amount of financial profit , as the smart grid technology is only based on electricity or by producing electricity by some means . this technology is a kind of two way communication , that means we can not only take power but also we can provide power to power stations . this is the most important feature of this technology . by using this technology we can provide a non ending source of energy to our country for our future generation .

3.INFORMATIONS

We can make new ideas from science but we cannot change the science . so we can also make new ideas that how we can make a better smart grid .

3.1. Wind power.

The development of wind power in India began in the 1990s and has significantly increased in last few years . India has the fifth largest installed wind power capacity in the world in 2009 -10 . India's growth rate was the highest among the top four countries .the major states where the installed capacity of wind power is more are Tamil Nadu , Gujarat , Maharashtra , Rajasthan , Karnataka . India has the most needs of electricity , so we need to install more wind turbines in these areas as well as in sea side areas .

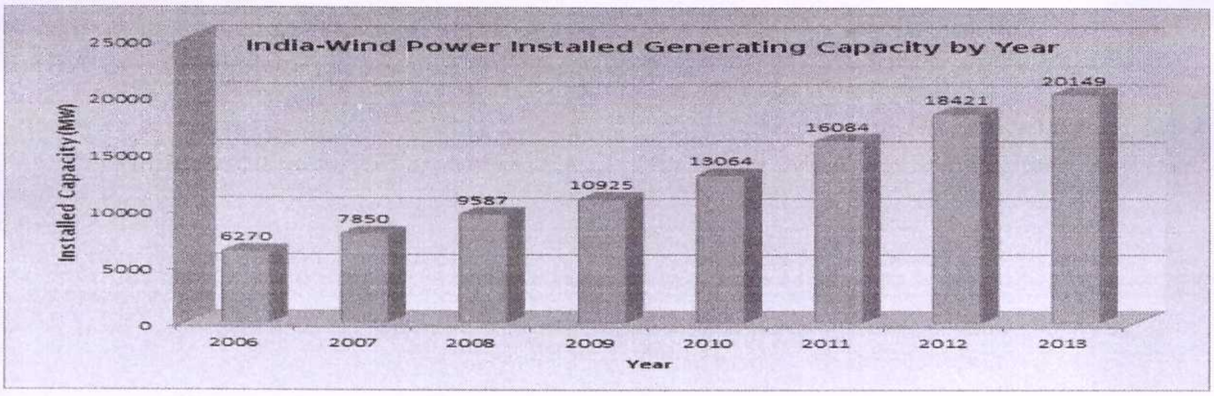


Fig- Progress in India's installed wind power generating capacity since 2006

3.2 biomass.

Biomass power plants in India are based mostly on agricultural wastes. Gasifier-based power plants are providing a great solution for off-grid decentralized power and are lighting homes in several Indian states. While for providing grid-based power 8-15 MW thermal biomass power plants are suitable for Indian conditions, they stand nowhere when compared to power plants being set up in Europe which are at least 20 times larger.Punjab has the highest power potential followed by Uttar Pradesh and Haryana .

3.3other renewable energy sources.

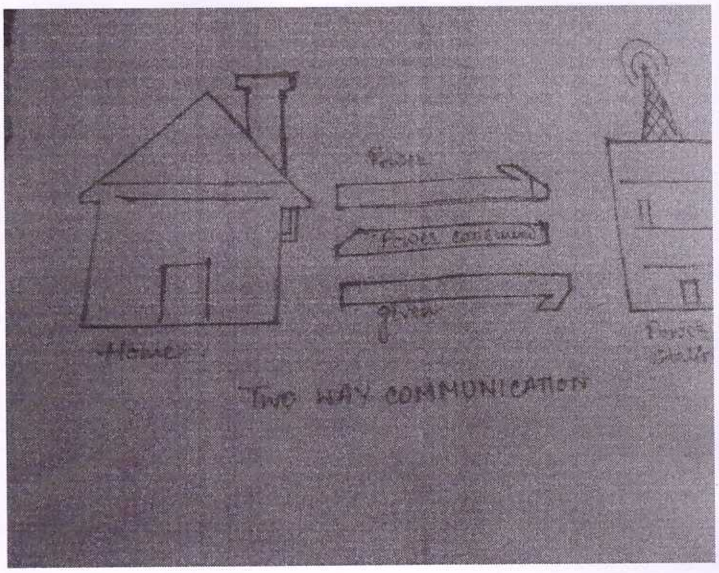
We can also use other renewable energy sources like hydroelectric power , solar power .

3.2.1 Hydroelectric power:

From the northern zone of India we get almost 10,931MW supply and from the southern zone we get 6,419MW , from the western zone we get 5,932MW , from the eastern zone we get 2,274.5MW and after some year we get additional 4,050MW . so our government should focus on this matter to get more power supply hydroelectric grids.

3.2.2 Solar power:

There are about 50 solar power plants in India .Charanka Solar Park ,Welspun Solar MP Project has the highest output in terms of solar energy .



4. IDEAS

4.1 Zero power house:

We can use the smart grid technology in a house where we can set up a number of solar panel on the roof which collects the solar energy throughout a day . If we have a advanced control digital monitor then it helps us to monitor about the storage and usage of the work like handling washing machine , micro oven very efficiently and at a low cost . Not only we can produce power from the solar cells but also we can supply the power or can store the power for our future use .we can also use a heat pump in a house which can produce heat by using the temperature difference in the ground . using this technology we cam make the insulated house and an provide a zero power house.

4.2 Automated power station :

Now we know that this smart grid technology is a two way communication technology , so we take as well as supply powers . so if we have a power station for atleast 500 or more such zero power houses then we can suply our consumed power to that power station , from where those power are transmitted to some rural area where there is a need of electricity. These stations must have a tariff records which helps them to maintain the distribution of power .this decides that how much power should be supplied at which cost . those power stations not only can supply power to the rural areas but also can supply power to power generating plants . We know that India is in wind energy but when wind is not sufficient but still the power stations require a certain amount of energy to run there output up and down to ensure that the power generation and consumption is balanced . in case if there is excess power then they can store the power for future use.

4.3 Smart meter:

Smart meter generally has five parts namely baseplate , metrology , display , cover , communication module .

Baseplate : The back of the meter connecting to the meter socket of the wall

Metrology: This includes sensors that enable the meter to accurately measure your usage .

Display: it cycles through readings , showing the electronics usage .

Cover: it protects the internalcomponents of the meter from environmental conditions .

Communication module: This is the most important part of the smart meter .its helps us to send your energy usage data to consume energy through a cell tower . the communication module is a new component of your smart meter that allows yours energy usage to be communicated to consumer energy.

4.4 Touchpad or monitors:

This touch pad is required to keep the ratings and also the consumption of power .we can use this pad in homes so that we can use the power according to our needs . we can also put the touch pads in every rooms so that we can use power for the needs only . using this pad we can get a idea about how much we can consume power . this consumed power can be send to the power station for the future use. Even this touch pads can be used in the power stations so that they can monitor the total energy consumed and how much they can provide to the rural areas .accordingly this touch pad is on high demand for the countries where this technologies has been started . using this pad one can know that how much he is spending according to the tariff s.

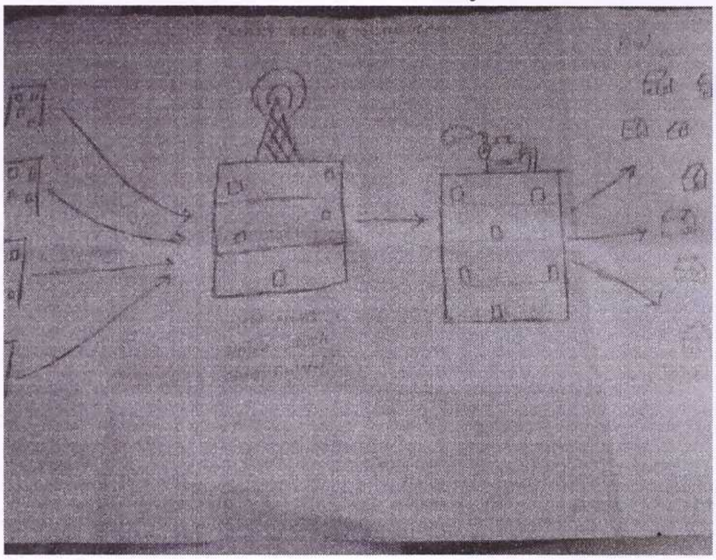
4.5 Electrical vehicle

Vehicle the means of transport which is used by us in our daily lives . but these vehicles can only be run through petrol . so if we use a electric vehicle instead of a normal vehicle then it will be better for us . we can charge the vehicles at night as in night we can save maximum amount of energy . we must need a charger through which we can charge the vehicle through smart grid technology . s we are saving our energy we can use the energy to charge our cars at night and we can use the energy to run the car for our needs .

4.6 Other

So apart all these we have a new thinking so we are about to describe it below

First we have to make an additional power station where we can store energy from atleast 2000-3000 house where the energy are stored from solar panel or by some other means . the automated power station which controls our electrical power system , will be the control room , from where we can supply power to the rural areas where there is the need of current like those villages where there is still no current has been supplied .by using this technology there will be no current loss and we can maintain the current supply in our country .it can be more efficient and reliable for our country



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5 . Conclusion

So , we can conclude that this use of smart grid technology can change the future of our country and can make future better . India is still working on this project . we can hope to see the of our country soon.

6. Reference

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Sizing and Strategic Scheduling of Distributed Generators in a Smart Microgrid for the Indian Pulp and Paper Industry

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***Abstract*—A microgrid that satisfies both electricity and steam requirements of an agro-based pulp and paper industry has been conceptualized and sized and its scheduling strategy devised. A Solar Photo Voltaic (PV) array and a biogas engine are intelligently integrated with an existing boiler based co-generation system in the proposed microgrid. Biogas is being generated from bio-methanation of the industrial wastewater. The solar PV array and biogas engine support the boiler in a coordinated manner to supply the auxiliary and process loads of the industry. Both are sized to basically supply the auxiliaries during the daytime while biogas can also support process loads. At night the boiler takes over the auxiliary portion. Such an operational strategy allows the boiler to run at rated capacity and sell excess power to the local utility grid during daytime while at night, it can save fuel by running at slightly lesser capacity and still sell some power. Smart features like intelligent control and monitoring enable the microgrid to perform dynamic dispatch of distributed resources to ensure that the industrial load is met all the time. The microgrid is connected to the local utility grid and can operate in an islanded mode whenever required. No storage has been incorporated and intermittent solar generation can be taken care of by connecting to the grid for stable power. In case of grid un-availability, the microgrid will simply become islanded and the boiler will take over to compensate for the reduction in PV array output.**

***Keywords*– Bio-methanation, Co-generation, Distributed Resources**

I. Introduction

An industrial facility requires considerable inputs of electricity, heat and water in a reliable manner in order to maintain production. The fragile nature of the centralized grid to which an industrial facility is connected poses serious challenges to its production. Frequent outages, blackouts, brownouts and fluctuating power quality hamper the industrial process. Most of the loads in an industry are critical while some can be shed during utility outages. The identification of such controllable loads is necessary for sizing and development of operational strategy for the microgrid which will power the industrial complex in an islanded mode. In absence of a microgrid setup, the industries usually rely on Diesel Generator sets which increase operational expenses and remain un-sustainable in all aspects. Usually industrial loads run for almost 24 hours a day and primarily consume 3-phase electrical power indicating a fixed-load profile which leads to a relatively easier approach for sizing of Distributed Energy Resources (DERs) and development of load-sharing and dispatch strategy. Microgrids are like a micro-utility system set up within the premises of the industrial facility that supply electrical power and thermal power generated from localized sources distributed in space, nature and availability. They can have an optional connection to the grid and can even help in selling the power saved back to the grid. Such a self-sufficient distribution network:
(1) Enhances local reliability
(2) Reduces GHG emissions
(3) Improves power quality by supporting voltage and reducing voltage dips
(4) Provides ancillary services to the main utility grid and gains carbon credit for energy savings
(5) Allows the industry to sell excess power.

Combined Heat and Power (CHP), also called co-generation, and waste to energy are two important enabling technologies for microgrids [1]. In the industrial microgrid segment, they make immediate sense [2] as industries have a huge requirement of both electrical power and heat which can be delivered efficiently using a single source through CHP and industries also discharge large amounts of waste streams which can be a potential source of energy recovery leading to improvement in energy efficiency of industrial processes and reduction in overall footprint. Generation of bio-gas from industrial wastewater is an example of waste to energy conversion used in the work. Such waste-powered distributed generators present a unique and interesting proposition for meeting the power requirements locally using freely available resources that have an energy- recovery potential but otherwise would have been simply discharged into the environment following the required treatment. The integration of both kinds of technologies in a microgrid involves considerable investment but the savings made can justify the investment [3].

Hybrid Optimization Modeling for Electric Renewables (HOMER) has been used for optimizing the size of the

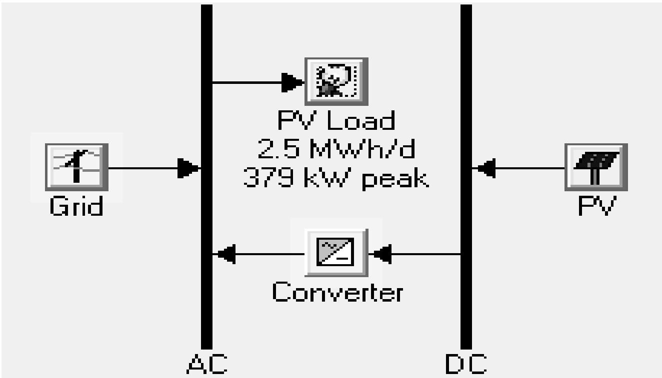

Fig. 1. HOMER model for PV-Grid integration in the microgrid

solar PV array with its power converters and simulating the integration of local grid with the solar PV array since it is the only intermittent DER in the microgrid, as shown in fig. 1.

II. The Industrial Microgrid Concept: Literature Review

A considerable amount of literature exists on the use of microgrids as a technology for decentralized rural electrification in India. However the Zpryme market research [4] shows that industrial application of microgrids will have a higher market share than that for the off-grid or rural market for all the nations combined. A lot of work has been reported in the United States of America (USA) that discusses the role of microgrids in implementing energy efficiency and providing [5] reliable power supply to industries. In [5] the authors talk about the creation of a micro-utility system in industrial set ups by integrating CHP and other DERs as an intelligent microgrid which can be a controllable entity. In the Indian context, [6] identifies the industrial sectors where different types of technologies based on solar energy can be used as DERs to replace fossil fuel based inefficient manufacturing processes but it does not talk about configuring a microgrid for the same sectors.

The present work proposes an islandable microgrid that integrates solar PV and biogas with a cogeneration boiler-Steam Turbine Generator (STG) system to create a self-sufficient power and heat network in the mill.

The microgrid has the ability to buy power from the local utility grid whenever either of the two DERs - solar PV and biogas is un-available as the cogeneration boiler is always online to power most of the process loads. In case of grid non-availability, the STG system powers the industry completely. The microgrid enables the mill to sell power to the grid depending on the coordination of the three DERs and also save boiler fuel.

Load and generation monitoring and intelligent control in the microgrid will enable:

(1) Real-time dispatch of grid power when required

(2) Power flow control during transition from solar to non-solar period to ensure supply to all type of loads.

These smart features and the presence of a non-intermittent generating asset that is rated to supply the complete heat and power requirement of the mill empower the decision of not including any storage in the microgrid. This unique feature can avoid large capital investment and maintenance & replacement costs as the interplay of power transfer between the utility grid and the DERs will always ensure that the loads are met by at least two sources unless the grid fails, in which case the boiler will take over the complete mill load. Number of such days and the hourly solar PV generation profile for one particular location where such systems can come up have been estimated and presented in this work.

The microgrid has been sized for a large-scale agro-based Pulp & Paper (P & P) mill which uses agro-residues like Bagasse typically found in regions of Northern India like Punjab and northern Uttar Pradesh. The decision to implement a microgrid for a P & P mill was based on some observations [7] that indicate a large environmental footprint and thus relate to the poor energy performance of the industry:

(1) Most of the mills, particularly small waste paper based mills still run on obsolete machinery and do not follow environmental guidelines relating to waste disposal and treatment

(2) The large scale mills that have co-generation systems draw a significant amount of power from the grid but are not net exporters of power like the sugar mills [8]

(3) The frequent grid outages and fluctuating power quality affect the industrial process and hamper production

(4) Prolonged reliance on Diesel Generator sets in case of black outs or outages has led to huge increase in energy bills

(5) In some cases, the boilers perform at sub-optimal levels

(6) Absence of process automation in some large scale mills leading to poor energy management

(7) Majority of the mills employ energy consuming aerobic processes for the treatment of their waste water that also causes problems of large sludge generation and associated challenges of management and disposal.

III. Microgrid Load Profile

The load profile is for 24 hours of a day. There are broadly two types of loads for the mill - process loads and auxiliary loads. The auxiliary load is the power consumed by the cogeneration system which is referred to as the power plant in table I [9]. It has been assumed to be equal to 10% of the rated capacity of the boiler/power plant/cogeneration system of the mill.

The capacity of 250 Tonnes per Day (TPD) is a typical average output observed in most of the agro-based mills on which this study is based. Correspondingly, loads have been calculated for the mill under consideration in table II. Since the actual load profile and relevant drawings and layouts of a particular unit are not available for a pre-pilot study like this, typical average figures and production capacities have been considered for conceptualizing and sizing the microgrid. After surveying the various large scale mills in the region, it was decided to include a rice-husk fired cogeneration boiler-STG system that was sized to satisfy the heat and electricity requirement of the mill. However in microgrid operation, under the normal/desired

TABLE I
SPECIFIC ELECTRICAL ENERGY CONSUMPTION IN KWH/TONNE

Mill Section	International	Indian
Chip conveying	20	20
Digestor	40	40
Washing & Screening	30	110
Oxygen delignification	75	–
Bleaching	100	80
Paper machine	253	600
Soda recovery	55	125
Power Plant	60	125
Kiln & recausticising	25	–
Hot water supply	32	50
Waste water	32	40
Miscellaneous	30	110
Total consumption	**750**	**1300**

TABLE II
LOADS FOR THE 250 TPD MILL

Load	Load type	Power consumption (KW)
Raw material conveying	Process	208.33
Cogeneration system	Auxiliary	1302.08
Hot water generation	Process	520.83
Waste water treatment	Process	416.66

conditions, the same cogeneration system will supply majority of the process loads except raw material conveyor system, hot water generation and waste water treatment and will not supply its auxiliaries in the day time when the solar PV output is available. Waste heat of biogas engine is used in hot-water generation replacing electrical heaters whose efficiency has been assumed to be 70% after referring to specifications used in the industry.

IV. SIZING OF MICROGRID DERs

The biomass cogeneration system otherwise is an existing centralized resource that satisfies the steam and electricity needs of the industry but because of the division of loads among the three resources, it is considered as a distributed resource. As discussed above, the cogeneration system has been considered as a typical unit of a typical large-scale agro-based mill found in the region and has been sized to supply the thermal and electrical requirements of the mill. Accordingly its size has been calculated as 1300 KWh/Tonne $\times$ 250 TPD divided by 24 hours of a day which comes out to be equal to 13.54 MW. The auxiliary consumption which has been considered as 10% comes to be almost equal to the value calculated from the average energy consumption figures.

The Boiler Process Controller (BPC) and Steam Turbine Controller (STC) are the two controllers which help the cogeneration system integrate with the other two DERs in the microgrid as shown in fig. 2. The biogas engine is an example of waste to energy based DER in the microgrid since the biogas used as the engine fuel is generated from bio-methanation of the P & P mill wastewater.

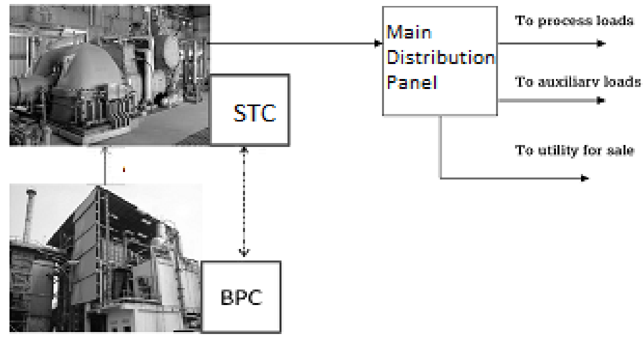

Fig. 2. Schematic of the existing cogeneration system integrated in the microgrid

The biogas is formed as a result of anaerobic treatment of a stream of waste water called Bagasse Wash-Water (BWW) in an Up flow Anaerobic Sludge Blanket (UASB) reactor which is a suitable technology for secondary stage biological treatment of the P & P mill effluent [10].

The Assumptions for calculating the biogas yield and engine sizing are:

(a) COD of BWW after 20% reduction in clarifier (mg/L) = 3900
(b) COD removal efficiency of the UASB reactor (%) = 85
(c) Volume of BWW in terms of total wastewater (%) = 30
(d) Specific Biogas production (m^3/Kg COD removed) = 0.5
(e) Biogas calorific value (Kcal/m^3) = 6400
(f) Methane content (% by volume) = 80
(g) Hydrogen Sulphide content (% by volume) = 1

Fixed load for the biogas engine = 416.66 KW
Dispatchable load for the biogas engine = 1.192 MW.

The solar PV array sizing is influenced by the power output of the biogas engine. This is because of the area constraint of the P & P mill which affects the location of the array.

Assumptions for Solar PV array sizing:
(1) 90% PV inverter efficiency
(2) 15% System de-rating including module de-rating.

The array can supply light process loads like raw material conveyor system. Hence the base/fixed load for PV array = 208.33 KW.

The array has to share the auxiliary load with the biogas engine therefore PV output required/dispatchable array load = 1.302 MW - 1.192 MW = 0.11 MW = 110 KW

Hence total PV array AC capacity = 208.33 KW + 110 KW = 318.33 KW.

PV array DC capacity $= \frac{318.33KW}{(0.90\times0.85)} = 416.12$ KW

The KWp capacity of the array will depend on the peak-sun hours of the respective location. Table III lists the capacities of all DERs in the microgrid.

To consider the intermittent nature of Solar PV as a DER, a simulation was carried out for the day-time solar load of the microgrid to estimate the performance of the array and visualize the pattern of the load supplied by the array in coordination with the local utility grid.

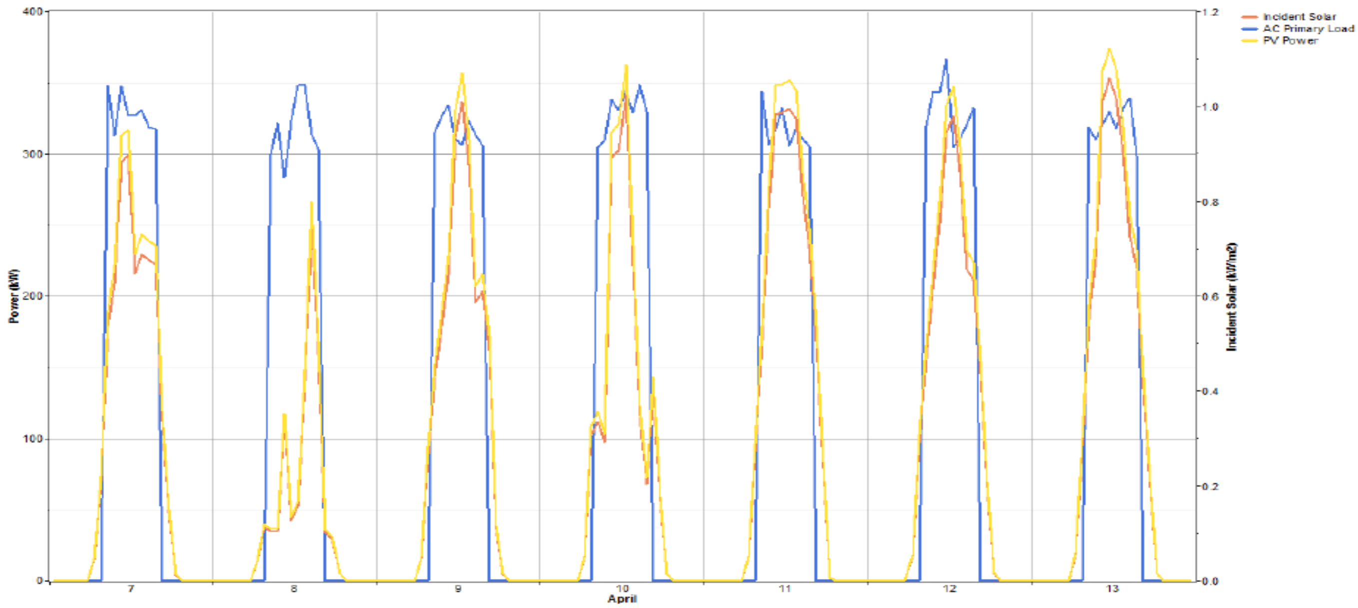

Fig. 3. Incident radiation, load and PV output for one week in April for a daily solar load of 8 hours

TABLE III
DERS AND THEIR CAPACITIES

DER	Electrical capacity (MW)	Thermal capacity (MW)
Cogeneration STG system	13.54	Not assessed
Biogas CHP system	1.608	1.616
Solar PV array	0.416	-

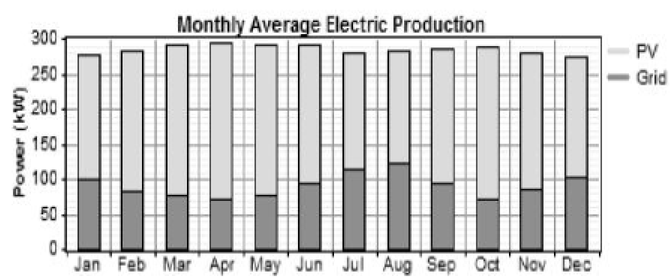

Fig. 4. Annual performance of the PV array

The simulation was carried out for Muzaffarnagar [11] which is a suitable location for implementing the idea as it has a number of agro-based mills arranged in an industrial cluster. The solar resource of the place and the Time of Use utility tariff was fed into HOMER to calculate hourly load, hourly power generated by PV and grid power purchased [12]. The fig.3 above displays one of the results of 8760 simulations done by HOMER for a year to assess the solar PV output against an almost constant load. For some days, the duration of solar radiation is greater than the load duration implying under-used solar capacity for the present case.
The colour codes for fig. 3 are as follows:
(a) Red: Incident solar radiation in KW/m^2
(b) Blue: PV array load in MW
(c) Yellow: PV array output in MW
The performance of the solar PV array portion of the microgrid in isolation has been shown in fig.4.

V. MICROGRID OPERATIONAL STRATEGY

The proposed microgrid will employ a distributed control system [13] to maintain coordination between the DERs and the loads to ensure desired operation. Peer to peer communication will be the key element of the distributed control system to enable the DERs to make decisions regarding load-dispatch and power flow control whenever required. Actions like buying power from the utility grid, opening the STS after the intermittency is over, issuing commands to the BPC to reduce fuel consumption and divert excess biogas engine power to the required process load must occur in real time and that is possible only through knowledge of real-time status of loads and DER generation. Each DER will be interacting to a local controller and each local controller will exchange its generation status and other data with one another over a secure Ethernet connection in order to make quick decisions to actions such as those mentioned above. Although not as efficient as the master-slave strategy of centralized control system because of network latency, the distributed control architecture ensures reliability and robustness because the control is localized and failure of one controller does not hamper the microgrid operation.
The microgrid operation is summarized in fig. 5, fig. 6 and table IV respectively.
With respect to figure 5, these abbreviations are expanded as
(a) STS - Static Transfer Switch
(b) ADP - Auxiliary Distribution Panel

TABLE IV
SUMMARY OF THE MICROGRID OPERATION

Situation	Action	Power imported from utility grid (MW)	Cogeneration STG gross output (MW)	Cogeneration STG net output (MW)	Power sold to utility grid (MW)
Solar ON, Biogas OFF	STS closes, power inflow	0.11	13.54	12.03	1.51
Solar ON, Biogas ON	STS opens, no power inflow	0	13.54	11.09	2.45
Solar OFF	Cogeneration STG supplies auxiliary load; BPC reduces fuel input	0	12.56	11.41	1.15

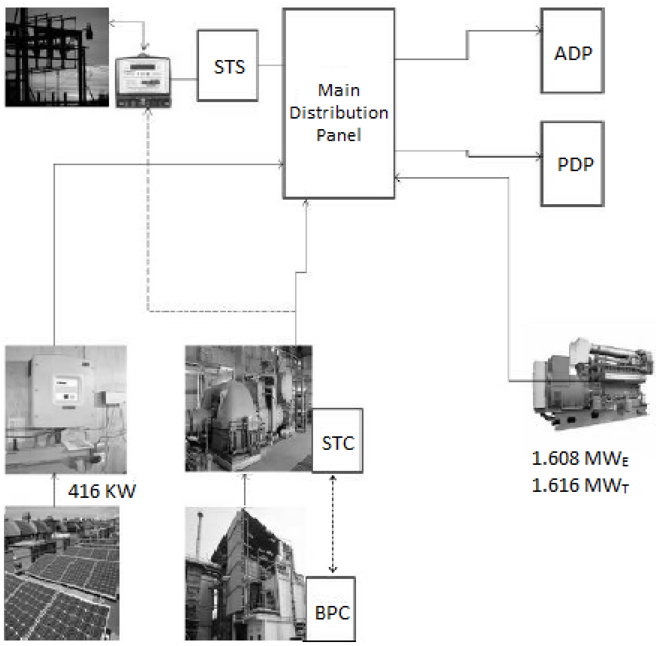

Fig. 5. Schematic of the microgrid

(c) PDP - Process Distribution Panel
The following situations represent the summary for which corresponding actions are taken:
(1) Solar ON, Biogas not online
(2) Solar ON, Biogas online
(3) Solar OFF.
These three situations actually represent the first column of table IV.
(a) Situation 1 corresponds to the action: STS closes and power flows in from the local grid
(b) Situation 2 corresponds to the action: STS opens and no power inflow from the local grid
(c) Situation 3 corresponds to the action: The cogeneration system supplies the auxiliary load and the real-time status monitoring and control alert the Boiler Process Controller (BPC) to reduce the fuel consumption as the load on the STG system has reduced because of load dispatch by the online biogas engine.
The real-time scheduling is described in table IV below and the same has been depicted graphically in fig. 6. The tabular and graphical summary show that during night time when the solar PV array is not available, the biogas engine has despatchable

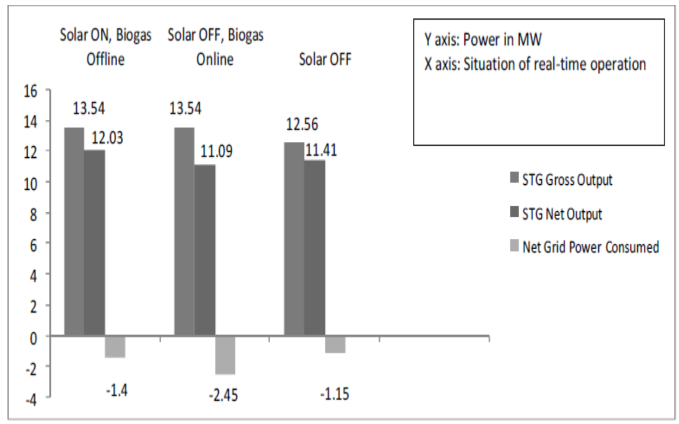

Fig. 6. Power Flow in the Real-Time Schedule

power in excess of requirement of the conveyor system hence it is diverted to other processes. This allows the boiler to save that much amount of power and hence save the equivalent quantity of fuel and run the STG at 93% of the rated capacity. The boiler-STG takes over the auxiliary load allowing the biogas engine to take care of the process loads only. The working of the microgrid without any storage system has been described but it is up to the mill operator to decide on the strategy of operating the boiler-STG system. Whether selling the excess power when boiler runs at full capacity is important over saving boiler fuel or vice-versa, this decision is entirely of the operator. However since the microgrid is islandable and can sell power to the grid, the operator must ensure that the schedule of power dispatch is communicated to the local utility grid operators well in advance in accordance with the grid code of the state in which the microgrid is located.

VI. CONCLUSIONS

The microgrid creates a self-sufficient power and heat network in the mill and works without an energy storage system because of the ability to draw power from the local utility grid during intermittent/unavailable renewable generation. When the grid is unavailable or during the event of an outage or a blackout, the microgrid can work in an islanded mode and rely on the boiler-STG system to supply most of the loads with support from the PV array and biogas engine.
The logic behind automatic dispatch of DERs according to the situation in real time has been explained but the working of the microgrid in real-time like environment could not be

simulated due to lack of proper simulation tools. However the performance of the solar PV array portion of the microgrid in isolation and its interaction with grid has been simulated in HOMER based on the time of use grid tariffs for a particular location considered for the simulation [14]. An intelligent monitoring and autonomous control system based on peer to peer communication empowers microgrid resiliency and increases the reliability although at the cost of some efficiency that could have been provided by a centralized control system. The biogas engine is the most critical part of the microgrid because its size determines the capacity of the solar PV array and the biogas used in it is generated from the treatment of waste water. The physical, chemical and biological characteristics of the waste water must be determined accurately in order to estimate the power output of the biogas engine. The proposed microgrid can be employed to meet the obligations under the Perform Achieve Trade (PAT) scheme [15] of the Bureau of Energy Efficiency (BEE) of India to enforce energy efficiency. This is more practical for cluster of small and medium agro based P & P mills as they can leverage the advantage of sharing of resources.

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Small Steps – Effective Results

Taking distribution utilities to the next step nearer to Smart Grid through Automation

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ABSTRACT –

A decade is over since reforms were initiated in the Indian power sector. We have seen APDP, APDRP and finally the ongoing part A and part B of the RAPDRP. Though RAPDRP encompasses all the vital pillars of distribution (after incorporating the learnings from APDP and APDRP), the practical implementations are mammoth and tedious. As a result we are perhaps falling tad short of the goal to be achieved. As on Jan 2015, around 743 towns are declared "Live" out of a total 1412. *(a)* And in a very optimistic figure, maybe 30% of consumers of the distribution utilities are actually getting exposed to total RAPDRP, where age old questions like improvement and standardization of operations by the utility, improvement in consumer service and overall reduction of AT&C loss are getting correctly answered. However, service and supply to more than 70% of the remaining consumers are completely on a different standard. Meanwhile the trend to get pilot Smart Grid projects deployed through the available grants have eaten up the primary focus to bridge the gaps of service within the utility itself (not to mention the fact that the financial outlay of these SMART Grid pilot projects are actually about a quarter of what actually is required – going by the trend of the bids that are happening).

As a result, on one hand, when the utility is planning to deploy SMART Grid in a confined area, in a major part within the same utility, it is taking more than a day to restore supply. The recent Integrated Power Development Scheme (IPDS) and Deendayal Upadyhaya Gram Jyoti Yojana (DDUGJY) booster by the Ministry of Power, Govt. of India is expected to go a long way to meet these open ends of the distribution reforms by ensuring 100% metering, proper voltage regulation, reduction of AT&C loss level, increase of HT to LT ratio, optimizing loading of transformers & feeders / lines, reactive power management, power factor improvement and strengthening of rural electrification. However, the implementation is obviously tedious, time consuming and having some amount of risk from the angle of actual execution at field level. Till such time a significant area of the utility will remain in the way it is functioning today and contributing substantially to the low service standards, lesser availability and reliability of power and higher volumes of losses.

This paper is aimed to identify small interim measures in operations with provisions for nominal investments that utilities can simultaneously undertake on their own, in strengthening the distribution system, to create some parity of improved operations across the utility through proper data management & interpretation, and small scale automations. Interestingly, these remedial measures in a larger scale can form the pillars of success to IPDS and DDUGJY.

Keywords— RAPDRP, Service Standards, Availability and Reliability, Automation, Improved Operations, Data Management.

INTRODUCTION –

Automation in distribution networks can be interpreted to doing repetitive tasks in a proper sequence without manual interference, and at a faster operation rate. Ideally this requires a synchronous orchestra of proper field equipment connected through a strong backbone of communication to a centralized data center where some relevant software programming gathers necessary information to monitor, analyze, and control various field level operations. These field level operations are now not merely restricted to control switching operations but are intended to be aiding self-heal in power system operations which respond quickly to real-time events with appropriate actions. In absence of a proper Energy Management System (real time monitoring, control and optimization packages) in most of the utilities, time becomes the only cost to be borne both by utilities and consumers.

Keeping in mind that the objective of automation is to ensure reliability and availability of power and reduce downtime to a bare minimum, let us have a look at some statistics. The anticipated shortfall of energy and demand respectively will be to the tune of 5.1% and 2%. The absolute figures are forecast as 53515 Million Units and 3027 MW. *(b)* Though these seem quintessentially low, what goes missing is the number of trips / outages of the feeders and distributions transformers. That what further goes unreported is the cost and time involvement in identification and rectification of the same in any standard utility.

A table is appended below with the aim to highlight the number of reported monthly tripping / failures of distribution feeders (33KV and 11 KV) and distribution transformers in a typical state utility. Needless to mention that this was compiled with the best available data from the respective divisions of some utility after some toil.

Parameters of a typical utility	33 KV Feeders	11 KV Feeders	DTRs
Total count in numbers	832	2858	190074
Trippings reported in one month	5643	76971	1883
Duration of outage (in hrs) for that month	1726.42	8477.06	Not reported

Table (1) – Typical Outage Statistics

The numbers, when cumulatively added up for all such utilities in India, can well account for an approximate annual nationwide average of a minimum of 8%-16% distribution transformer failures on a very conservative estimate. It goes up to 25% considering the site conditions of many distribution utilities. This way too high compared to international benchmarks which are below 2%. *(c)*

So a drop by about 5%-10% in the above figure will definitely have a positive impact on the reliability on the power supply. This drop can only be achieved by proactive maintenance, proper planning and above all getting a proper information above the real time system landscape to take adequate countermeasures.

INFORMATION GATHERING – THE FOUNDATION OF DISTRIBUTION AUTOMATION

Distribution Automation, from the system point of view, includes supervisory control of circuit breakers, switches, reclosers, sectionalizers, substation capacitor banks, load tap changers and regulators but to effectively utilize this supervisory control function, remote data acquisition and analysis at a real time level is required to be in place. On the consumer front, along with the reading of meters, the control to disconnect / restore services, loading pattern and program time of use meters is required; which again calls for data gathering on a near real time basis. Integration with other head end mainframe systems like Metering, Billing and Collection (MBC) software plus Customer Relationship Management (CRM) is also required for an effective implementation of Distribution Automation. Let us take three specific areas of importance to understand the importance of data gathering.

A. Transformer Failure -

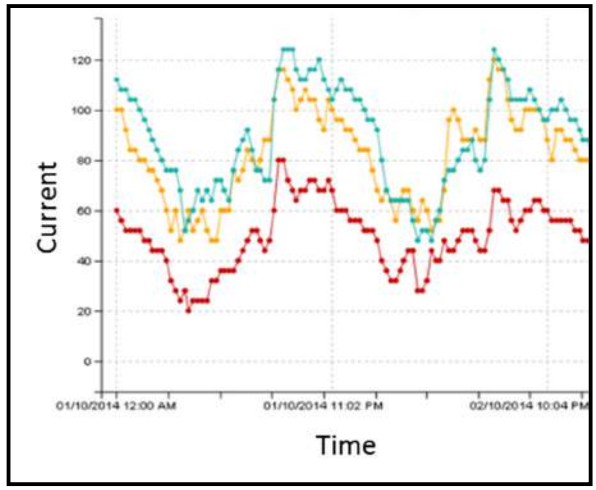
A transformer may fail due to multiple reasons. The most common causes of transformer failures can logically be divided in two components –

a) One of time defects/causes like Improper Installation, Faulty Terminations, Lightening Surges and Wrong Earth Connection.

b) Prolonged operational issues like Persistent Overloading, Continued Short Circuit, Less or No Maintenance, Deterioration of Insulation over a period, Single Phase Loading, Unbalanced Loading and Power Thefts.

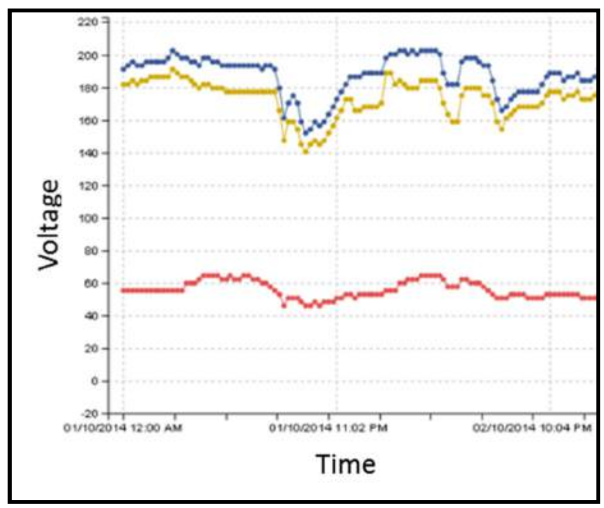
While the one time defects / causes can mainly be addressed by proper training and correct implementation procedure, the operational issues can be addressed in a proactive manner through proper data gathering and analytics.

Presenting a couple of graphs based upon the data from meters on distribution transformers, obtained through AMR devices retrofitted with the meters.



Graph (I) – Continuous Load (Current) Profile

In Graph (I), we see a typical three phase current (load) curve of a distribution transformer. Clearly the data gathered shows that the maximum red phase load is at par with the minimum of the corresponding blue phase, leading to severe unbalanced conditions.



Graph (II) – Continuous Voltage Profile

In Graph (II), the voltage profile of the same distribution transformer during the same period reveals the red phase voltage at a near 80 V, against a required 230 V. Even the red and yellow phase voltages are far below the acceptable standards. The quality of supply is no doubt hampered.

B. Feeder Outage –

Feeder outage is another very common occurrence in the sub-transmission (33 KV) and distribution level (11 KV) of any utility. Various factors like environmental conditions, external agents or failure of components are involved in the occurrence of faults in feeders. Faults are mainly short circuits caused by dielectric breakdown of the insulation system or snapping of conductors leading to open circuit. Power outage and voltage drop with high current inrush are the primary effects caused by faults in distribution networks. These interruptions not only cause inconvenience to end users but also account for revenue loss for utilities. Fast resumption of normal operation when faults and failures have occurred is the prime objective of the utility. However, in many a cases, mere identification and location of the fault in field takes a huge amount of time.

In a sample case study, a particular identification of fault in a semi urban 11 KV line was tracked. Following is the result –

Activity Performed	Time	Cumulative Duration
Fault reported	10:24 am day 1	-
Recharging done	10:28 am day 1	4 mins
Second recharging	10:34 am day 1	10 mins
Breakdown declared	10:35 am day 1	11 mins
Trials of charging after opening isolators one by one	13:35 pm day 1	3 hrs 11 mins
Rectification of fault	15:45 pm day 1	5 hrs 21 mins

Table (2) – Typical Duration of a Fault

In another extreme case study, a 96 km sub-transmission (33 KV without any booster station in-between) line fault was tracked in a utility, where ultimately the line patrol team had to spend a good six hours to detect the fault and it took around 26 hours for restoration of the overhead snap. It will not out of place to mention that the receiving end voltage at the end of the said line is normally around 25-26 KV. Needless to mention that the consumer end voltage hovers anywhere from 45 V to 100V for this particular feeder.

C. Inadequate planning and forecasting –

A sample region of a typical utility was studied which was catered by 34 distribution substations (33 / 11 KV), of which around 16 are having singular source. The growth w.r.t customer count in the urban area was found around 10.46% in the FY 13-14. Now the historical growth figure w.r.t the individual substations is missing. Low voltage problem and frequent outages of lines was persistent. At points of time demand increased manifold in the rural area due to seasonal cultivation requiring artificial irrigation. So load growth and planning in the short and long term durations are not fault free due to inadequacy of data. Decision makings between system augmentation and refurbishment are tough calls to take.

As a direct consequence, load growth forecast and planning remains an area of expertise by grey haired professionals and in absence of them, becomes a routine exercise with little merit.

MEANS OF INFORMATION GATHERING –

We are obviously not talking of full-fledged economically unfeasible SCADA or DSM implementation to get remedy for the maladies stated above. What we are talking about are small scale deployments piggybacking on the existing infrastructure or making minimal investments which will empower the utility with that missing information, which will not only help in taking correct decisions but also reduce downtime – thus increasing reliability and adequate availability of power.

Information, in the context mentioned, can either be an instantaneous one or a historical data gathering and then deduced one. But at the end of the day, both of these require the golden steps of gathering, correct processing and then initiating appropriate action in the short term and long term perspective. Some of the easy deployable, financially self-sustainable solutions which act as interim stepping stones to SMARTness are discussed below -

A. Automated Meter Reading –

Automated Meter Reading (AMR) is in vogue for the last couple of decades, but the effectivity could only be harnessed through the RAPDRP implementations. There are conflicting remarks about the success of data acquisition in RAPDRP in different utilities due to various factors, but those utilities which have been able to bring data from the DTR meters to a desktop in a real time mode, has automatically enhanced its own system performance by reducing time taken for correct decision making. The load and voltage graphs as referred above are the results of AMR implementation by utilities. The continuous load and voltage curve reported from distribution transformers were earlier never ever collected or properly analyzed in this way.

Reports shown in tables (3) & (4) also are eye-openers to the field conditions on a real time basis for different transformers

	AVERAGE VOLTAGE				MINIMUM RECORDED VOLTAGE				MAXIMUM RECORDED VOLTAGE				PHASEWISE RELATIVE UNBALANCE (In%) Side		
	VR	VY	VB	V Avg	VR min	VY min	VB min	V Avg Min	VR max	VY max	VB max	V Avg max	VR	VY	VB
Site 1	233.54	238.02	234.65	0.00	211.60	207.00	207.00	0.00	250.70	253.00	253.00	0.00	7.35	6.29	7.82
Site 2	235.48	235.26	237.45	0.00	213.90	213.90	216.20	0.00	241.50	239.20	241.50	0.00	2.56	1.68	1.71
Site 3	235.68	237.32	238.63	0.00	209.30	207.00	209.30	0.00	253.00	255.30	255.30	0.00	7.35	7.58	6.99
Site 4	235.79	237.32	236.70	0.00	209.30	207.00	209.30	0.00	253.00	255.30	253.00	0.00	7.30	7.58	6.89
Site 5	241.00	238.24	238.34	0.00	209.30	211.60	209.30	0.00	259.90	257.60	255.30	0.00	7.84	8.13	7.11
Site 6	233.42	242.17	241.10	0.00	200.10	181.70	202.40	0.00	278.30	264.50	278.30	0.00	19.23	9.22	15.43
Site 7	237.21	240.45	238.37	0.00	211.60	207.00	209.30	0.00	255.30	259.90	257.60	0.00	7.63	8.09	8.07

Table (3) – Voltage Imbalance

	TRANSFORMER KVA RATING	MAXIMUM PERMISSIBLE CURRENT PER PHASE	MAXIMUM LOAD(CURRENT IN AMPS)				PHASEWISE RELATIVE UNBALANCE (In%)		
			R-PHASE	Y-PHASE	B-PHASE	AVG CURRENT	R-PHASE	Y-PHASE	B-PHASE
Site 1	100	139.12	8	92	8	36.00	-77.78	155.56	-77.778
Site 2	100	139.12	88	80	88	85.33	3.13	-6.25	3.129
Site 3	63	87.65	88	8	8	34.67	153.82	-76.93	-76.925
Site 4	100	139.12	96	88	80	88.00	9.09	0.00	-9.091
Site 5	100	139.12	96	88	88	90.67	5.88	-2.94	-2.945
Site 6	100	139.12	80	96	92	89.33	-10.44	7.47	2.989

Table (4) – Current Imbalance

With red bands clearly demarcating areas of gross voltage and current imbalance, the analysis helps in the decision making of taking suitable measures in the field.

Simultaneously value added services like instant SMS reporting to field persons for outages, alarm configuration for over voltages and overloading have helped in passing of information with zero lag. The data gathered when stored and analyzed over a period of time gives exact directions to the need of the respective DTR – whether a load balancing is required, whether the DTR calls for an augmentation or maintenance, whether an additional source is required at any area and so on.

Needless to mention that with AMR, energy audits at DTR levels and HT billing can be done faster than before by any utility. The meter to cash cycle is drastically reduced for HT consumers with reduction of field resource for the same. Some of the tamper reporting becomes instantaneous.

And contrary to the belief of extravagant cost, AMR can be deployed in short phases area-wise with an average ROI period of less than two years. *(d)* This is quite a small component compared to total outlay currently being done by utilities to gather DTR wise energy report (some utilities spend crores annually in manual data gathering, which again is not human-error free)

B. Fault Passage Indicator –

Fault Passage Indicator (FPI) is another important device that can be deployed in the field to reduce feeder downtime considerably. These are installed on the individual phases of the line conductor at logical sections selected depending upon the length of the feeder so as to restrict the number of consumers affected in case of breakdowns.

These devices can detect the nature and intensity of the fault with built-in electromagnetic field sensors and gives a flashing light indication. In the event of a fault, all such devices through which the fault is passing located between the substation outgoing feeder and the section at fault, start flashing in a predefined manner according to the fault and helps in identifying the exact location of the fault. The blinking pattern of an FPI is different for transient faults and breakdowns. This is extremely helpful as normally the cause of transient faults never get logged or investigated. As per prevalent practice, a manual recharging is done at scheduled intervals to ensure steady state supply in case of transient faults.

FPIs can be easily installed on a live or de-energized line – they are clipped on to a line using mounting rod supplied with the equipment. They are also communicable and can send radio messages to a remote supervision enclosure to which they are linked. FPIs coupled with effective communication equipment can immediately communicate the location of the fault in the feeder to a head-end application, thereby saving precious time and resource for mere location of the fault. Even the type of the fault is reported thus enabling the restoration team to take countermeasures with little lead time.

Last, but not the least, the solution and devices are economically viable for any utility and the ROI time period is calculated to be less than two and half years. *(d)*

C. Capturing data using Mobility

Let us now explore areas where we can utilize the modern day infrastructure to gather, store and build data especially in operational situations where it was never conceived in this way before. A fault / break down of an equipment at field needs to be reported at a minimal time lag and restored at the earliest to ensure high reliability and availability of supply. Field persons are deployed to address such situations and the fault details are later supposed to be registered in a log book. A weekly / monthly summary of the log book is consolidated across the utility and placed in review meetings. Even if we take into account that the reporting is meticulous, what goes missing is the bigger picture – why a specific kind of fault is predominant in an area, what happened after a specific date when there were multiple breakdowns on a single feeder and so on. Simultaneously, it is quite difficult to obtain a real-time dashboard of faults persistent in any utility at any given point of time. In absence of such reporting and probes – the essence of planning and forecast gets diluted.

We can use a mobile app to capture the necessary data of a breakdown in real time, and store the same in a head end server. Thus utility associates from field person to decision makers can have a dashboard reporting of the entire system, specific history of fault for that apparatus and many others, thus building valuable blocks of information for ease of decision making and proper planning. Figure (I) explains the architecture.

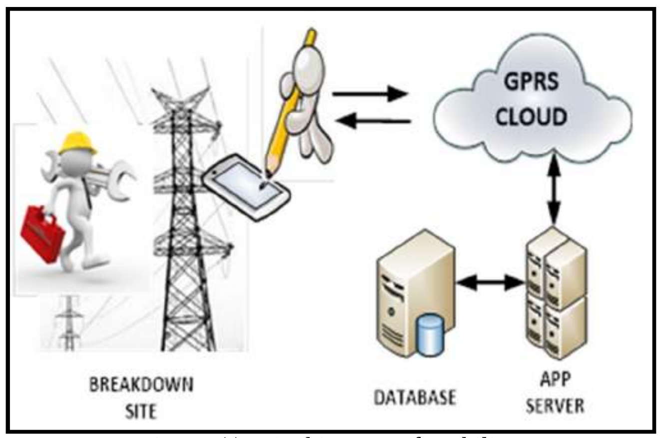


Figure. (I) – Architecture of Mobility

An integration of this system with mainframe data like load growth, consumer growth and so on can be really effective in forecasting the energy requirement in near and far future, and even specific to a particular division.
The app is very user friendly where each individual field person will be having a unique login id.

After logging in as shown in Fig. (II), he has to select the asset required to be attended from a drop down list. Fig. (III).

Figure. (II) - App

Figure. (III) - App

The reason of the fault – again from a list of values is required to be selected Fig (IV). The duration of the breakdown will come from the times entered – start of fault and restoration. Thus the data gets captured by the field person without much of a fuss and gets stored at the database.

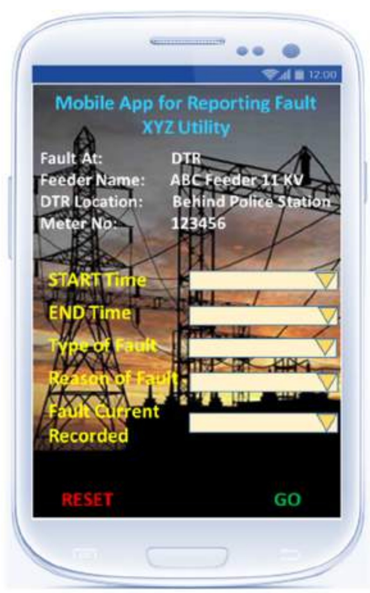


Figure. (IV) - App

Once this data is started to be built up, there are tremendous benefits out of it. A real time dashboard can be published and refreshed at scheduled intervals which will give the system information at any given point of time. There can be analysis of data with respect to plans and means of augmentation or refurbishment, requirement of additional sources, layout of future growth and many more. This will help in documenting effective maintenance policies (preventive, based on condition monitoring, etc) to reduce the impact of the faults on the network. Also, fault prediction based on the early identification of symptoms, or incipient faults, leading to the appearance of faults will be feasible which will help to maintain accurate fault diagnoses and predictions. Above all, a database gets built up monitoring the performance of the field person also – connecting the same with HR database can help his attendance and skill monitoring.

CONCLUSION

The three small steps elaborated in this paper are definitely not economic burdens to the utility and will go a long way in reducing outage time significantly, with minimal circuit reconfiguration resulting in improved reliability indices. There will be enormous reduction of travel to identify and isolate faults, reducing time, fuel and labour costs. Scheduled Line Patrols will also get reduced. The information will not only get reported to back-office immediately, but also will get analyzed in a proper way with built blocks of information providing a clearer picture of what is happening in the field and what requires to be done.

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Smart Grid Programs and Projects Round-up and Experiences

Smart Grids – The South Korean Experience

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Abstract— the necessity of enhancing energy efficiency, tackling climate change and triggering a green revolution is among the top agendas of all progressive national governments. This paper tracks the journey of this effort by the Korean Government, which got initiated in 2008, the progress so far and the future directions. This document also details the various domains and phases planned to be covered by the Smart Grid Program, until 2030. Reference to the Legislative support mechanisms as they prevail in Korea has also been made in this document. The present state of international cooperation also finds a mention, albeit briefly in this document.

I. GOVERNMENT'S ROLE & SMART GRID POLICY

A. Background

On 15th Aug' 2008, President Lee Myung-Bak of Korea launched the national vision of 'Green Growth, Low Carbon'. The national targets were set – To achieve an energy efficiency of 46% benchmarked against energy consumption of 2002 and to reduce CO_2 emissions by at least 30%, until 2020, normalized for other usual growth parameters.

The Ministry of Knowledge Economy (MKE) and the Presidential Committee on Green Growth undertook the responsibility for implementing the 'Green Growth, Low Carbon' vision, using Smart Grid technologies as the driver for this initiative. Hence, the Government established Korea Smart Grid Institute (KSGI). KSGI was made responsible for executing the Smart Grid policies, overseeing Smart Grid deployment, planning establishment of related infrastructure and initiating various domestic and international Smart Grid projects.

B. Korea Smart Grid Institute (KSGI)

Affiliated with MKE, KSGI was launched in Aug'2009 as the prime mover for the Smart Grid Initiative and projects in Korea. The main target of the initiative is to modernize the electric power systems and manage comprehensively the government's roadmap.

KSGI works towards the development of technology for Smart Grids – convergence of electric power and IT networks. KSGI also fosters support and cooperation among industry, academicians and research Institutes, pursues international cooperation and certification, standardization and security.

The end objective being achievement of low carbon green society and improve the environment.

II. NATIONAL SMART GRID ROAD MAP

A. The Progress so far

Chronologically, the Smart Grid progress roadmap so far has been as follows –

- Aug'2008: The national vision of 'Green Growth, Low Carbon' was defined.
- Mar'2009: Korea was identified as one of the Smart Grid. leading country in the G8 summit of major economies.
- Dec'2009: Consortium members were identified to begin Jeju Smart Grid test bed.
- Jan'2010: The National Smart Grid Road Map was released.
- May'2010: The first phase (plan) of the Jeju Smart Grid project was completed.
- Jun'2011: The second phase (Operation) of Jeju Smart Grid project was launched.
- Jun'2011: Korea hosted the first executive committee meeting of International Smart Grid Action Network (ISGAN) at Seoul.
- Jul'2011: KSGI was designated as the ISGAN secretarial for a period of 3 years.
- Nov'2011: The Smart Grid stimulus law gets enacted.
- May'2013: Completion of Jeju Smart Grid Pilot Project.

The deployment of Smart Grid across the country is planned to be covered by 2030, with intermediate milestones.

B. Conceptualising Smart Grids

Smart Grids are the next generation networks that integrate Information Communication Technologies into the existing power Grid to optimize the energy efficiency through two-way exchange of information. This intelligent exchange of information can be extended over a wide continuum from Power Producer to Power consumer.

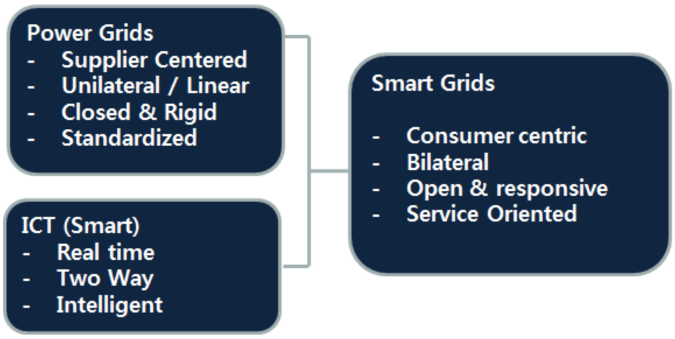

Fig. 1. Conceptual framework for Smart Grid

C. *Constituents of the Smart Grid*

The long term Smart Grid road map at Korea is spread over 3 broad phases and 5 vertical domain areas. The domains covered in the road map include Smart power Grid, Smart consumer, Smart transportation, Smart renewable and Smart Power market /electricity services. The roadmap planned to be spread over three phases wherein the first phase will focus on a pilot city. The Phase 2 will be to spread and roll out the pilot experience over few urban areas. The last phase, targeted to finish in 2030 will be for a complete nation wide deployment of the Smart Grid.

Fig. 2. The Smart Grid Roadmap

A finally implemented Smart Grid at the end of 2030 will be an intelligently integrated eco-system of the various domains, at the center of which will be a consumer centered Power market.

Fig. 3. The Smart Grid Constituents

c. Implementation goals of various domains

The five domains are targeted to achieve specific performance metrices during the implementation until the final Phase 3, as mentioned below -

1) *The Smart power Grid*

- Delivery of high quality and reliable power, failure prediction and have enough resilience for automated self recovery.
- To provide opportunities for a flexible two way interaction betweenthe power suppliers and consumers, opportunity to create newer businessmodels.

Korea, which already has one of the lowest Power Transmission & distribution losses expects to achieve the losses to get further reduced to 3%. The overall power outage is also expected to drop to 9 minutes per consumer per year by 2030, once the Smart Grid are deployed nationwide.

2) *Smart Consumer*

- To reduce Energy consumption by shifting to AMI based, two-way communication energy supply system
- To ensure energy saving by inducing consumers to shift to 'green' appliances and reduce electricity bills.

From the current levels of Smart energy meters, 100% penetration is tragetted by 2020. It is also tragtted to reduce energy consumption by 10% overthe perod, by use of green and efficient devices.

3) *Smart Transportation*

- To reduce natural fuel based energy dependence by shifting to a nationwide charging infrastructure that will allow the electric vehicles to be charged anywhere.
- Also build a V2G (vehicle to Grid) infra where the batteries of the Electric vehicles can be charged during the peak off time.

Korea plans to have 2.5 Million Electric vehicles by 2030 and almost 27,000 charging stations across the country.

4) *Smart Renewable*

- To establish a better infrastructure to handle the intermittency of renewables
- To build green homes, net-zero energy building and green communities capable of self-sufficiency.

By proportion, Korea is targetting at least 11% of renewables to be a part of the total Energy portfolio by 2030. Also, electric energy self-sufficiency is targetted to be at 30% of the households.

5) Smart Power Market

- To implement dynamic electricity pricing and create opportunity for active consumer participation
- Provide a range of ancillary services interconnecting electricity, information and communication technologies. And also establish a real time power exchange system that enables consumer to engage in electricity and derivative trading.

By 2020, it is targeted that consumers will be able to choose their electricity rate plan and at least 30% of the consumers can be an active participant in the power exchange.

D. Technology Overview

A host of initiatives have been planned across the above mentioned domains to ensure that each of them responds to the common purpose of creating a resilient, reliable and efficiently operating Grid, in conjunction with ICT technologies. Some of these areas of development / improvement include the following –

- Smart Transmission System by including use of Smart power equipments/systems such as superconductors, HVDC, digital sub stations etc.
- Smart Distribution system by use of distributed energy system, AMI, Smart switching etc.
- Electric Vehicle Part and systems.
- Charging Infrastructure Technology for high speed charging, interface components, certification & billing systems.
- V2G (Vehicle to Grid) technology that results in efficient Grid-connected operation based on real time pricing.
- Micro Grid technology that supplies regional electric-thermal energy and integrates diverse renewable generation sources with distributed loads.
- Energy storage and operations technology e.g. battery, flywheel, compressed air etc.
- Electric Quality compensation technology that works on controlling Grids voltage and frequency caused by intermittency of renewable energy.
- Power Exchange Technology for real time energy bidding and output metering via real time pricing.
- AMI technology to measure and record various instantaneous parameters in real time, during the course of power supply to consumers.
- Communication network technology for a two-way communication to share energy consumption and control via wired and wireless communication channels.
- Demand Response system that induces consumers to control their energy consumption by responding to electricity pricing and consumption rates.
- Power Exchange to maximize energy use and efficiency by allowing various participants in the trade (supply-demand) to buy and resell power resources.

E. Standardisation

With so many activities being carried out by different entities, the serious need for standardization was also formalized under the aegis of Korea Agency for Technology Standards (KATS).

Fig. 4. The Smart Grid Standardization Approach

There were work groups and domain committees responsible for a uniform and standardized approach to planning, implementing and sustaining the Smart Grid efforts. A high level Smart Grid Standardization organisation structure overview is as below

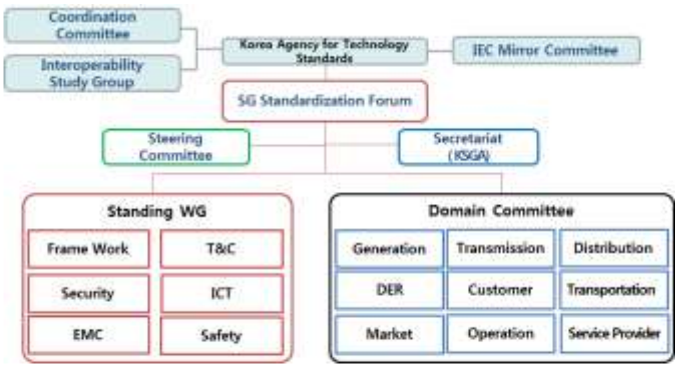

Fig. 5. The Smart Grid Standardization Framework

An interoperability was created to ascertain the verify the interoperability over various aspects of the project e.g. Data Format, security, Privacy, etc.

III. THE JEJU SMART GRID DEMONSTATION PROJECT

A. An Overview

The Jeju Smart Grid Project was launched in Dec'2009 with duration of 40 months planned activities spread over two broad phases. The venue for the project was identified at Gujwa-Eup, Seoguipo-City, JEJU.

The Phase 1, initiated in Dec'2009 was to build, install and commission the physical facilities and infrastructure for demonstration. This phase ended during May'2011. Immediately thereafter, Phase II, for operation and verification of the facilities was taken up.

The overall budget earmarked for the demonstration test bed was 200 M $, which was shared between Korean Government and leading Korean Technology players in a 3:7 proportion. All major Korean corporate groups including KEPCO, GS, POSCO, LG, SK, Hundai Heavy Industries (HHI) etc. became a major contributor and partner in this Government's initiative.

There were no quantitative goals identified out of this test bed. However, the test bed targeted to accomplish two major areas –

- Technology Development: to provide system level test environment and establish a baseline technology for larger implementations of Smart Grid.
- Business Model Development: Use the test site to postulate various likely models of customer and provider engagement. Also identify the roles of various stakeholders and technology providers from the private sector.

The five domains identified were taken to be a apart of the test bed and various consortiums got involved in the establishment, as follows –

- Smart Power Grid: KEPCO
- Smart Consumer: KEPCO, KT, SKT, LGE
- Smart Renewables: KEPCO, POSCO ICT, HHI
- Smart Transportation: KEPCO, SK Innovations, GS
- Smart Service: KEPCO, KPX

In most of the areas, the presence of more than one consortium ensured that more open standards and interoperability got introduced, besides a fair level of competition.

Few specific areas were identified and established as an outcome of this Test bed. These areas included areas of Infrastructure installation and specifications, Technology verification, Business Model verification. Thereafter six areas were identified as potential areas of large scale commercialization.

B. Next Steps

The next step of the Jeju Smart Grid test bed has been to operate the existing infrastructure. It is expected that the above mentioned consortiums will create and refine newer business models to operate competitively and transparently. And the Government is committed to be a persistent enabler in the commercialization process. The Smart Grid model established also needs to be extended to commercial and industrial establishments.

The Smart Grid project has now been extended to the city at Jeju, from Jan'2015. The overall budget outlay for this project is 876 M $, with major participation coming from KEPCO, KT, SK Telecom, POSCO ICT, LSIS, HAE & GIMCO. The project is expected to finish in Dec'2017 and will be spread over 26 locations under 14 different local governments.

The government will continue to w0rk on deregulation & system improvement, Market creation and expansion, Research & Development and overall Infrastructure improvement and development.

C. Expected Benefits

After the pilot project at Jeju, the government has quantified certain targets for achievement. Some of expected benefits at the end of 2030 are illustrated below

Fig. 6. Anticipated Benefits of Smart Grid deployment

IV. SMART GRID STIMULUS LAW

During 2007, the CO_2 emission levels from fuel combustion reached 489 MT – almost 1.7% of the global combustion level, and the 9th highest in the world. Once the 'Green Growth' vision started getting pushed by the Korean Government, the initial activities and R&D was dependent on voluntary participation from corporates. So a need to provide legislative support was felt to ensure this initiative was wide reaching and sustained. Also the existing Electricity Enterprise Act of Korea restricted the convergence of business. Hence there was a need to transcend the legislative constraints to regulate a law that advocated converged business and infrastructure. In view of this, a proposal was brought to the National Assembly of Korea in Apr'2011and the Smart Grid Law was approved.

The government expected this law to allow technological and institutional progress for Smart demonstration and Smart pilot city project. This law also provided adequate foundation for Smart Grid related businesses and induce greater investments

The Smart Grid Stimulus law formalized the following areas –

- Periodic Plan: The Government was instructed to have a five year plan on policy goals, the development, practical application, dissemination and popularization of related technologies, industrial promotion, standardization, the protection of information etc. In addition the Ministry of Knowledge Economy was directed to have annual implementation plans for Smart Grid every year to accomplish the set out objectives.

- Register Business License: for individuals, wishing to initiate a business for managing and supporting Smart Grid industries to be issues=d by Ministry of Knowledge Economy.
- Support for Smart Grid Investments: by allowing a basis for companies to receive subsidy in the case of making business investments for the benefit of pulic.
- Select Smart City Pilot: if necessary, select pilot city and manage portion of required expenses.
- R&D Support: Provide the administrative, financial support for various associated activities.
- Catalyze International Smart Grid collaboration: Provide Technological and resourcing support regarding international support in technical and project implementation areas
- Technological Verification & standardization: Enforce Technology verification and standardization to secure safety and compatibility.
- Compiling Smart Grid Private information: including provisions for information sharing and exchange.
- Sharing of private information: Provide efficient services for Grid users and consumers and sharing of private information collected by one service provider to another.

V. Conclusions

For the South Koreans, environmental security is almost a matter of national security. The government is acutely sensitive to the adverse impact of environmental change on the country. Over the past several years, South Korea has experienced repeated flooding and droughts caused by extreme weather events (which are expected to worsen), and these occurrences have caused significant human and economic loss. While it is not an Annex-I member to the Kyoto Protocol, South Korea has committed to a voluntary emissions reduction target of 30% by 2020, the highest reduction level that the Intergovernmental Panel on Climate Change recommended for developing nations.

Because innovating (and exporting) green technology is a pillar of Korean economic strategy, the South Korean government is very active in Smart meter / Smart Grid activities, both domestically and internationally. The government plans to install comprehensive AMR/AMI by 2020. In 2011, the South Korean legislature approved the Smart Grid Promotion Act (2010) which provides a framework for sustainable Smart Grid projects and a plan for Smart Grid development, deployment and commercialization. The Korean government has actively collaborated with the American government on energy development, Smart Grid standard development and on cybersecurity and Grid trustworthiness projects, skills training and development, and Smart building initiatives. Energy and Climate held as part of the July 2009 G8 Summit.

What is most striking about the Korean example is the level of coordination and support between government and industry in achieving the objective of economic growth based on green innovation. The Korea Smart Grid Association plays a critical role as a mediator between government and private-sector stakeholders on the Smart Grid. It helps develop Smart Grid projects, conducts standardization work, and engages in important research and development. South Korea's Jeju Smart Grid Demonstration Complex, highlighted earlier reflects the massive scale of government and industry investment and high level of cooperation in the Smart Grid space. Moving forward, for any economy that wants to embrace a major technology direction, the South Korean model of stakeholder cooperation will be the first are to emulate.

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Wide Area Control Systems (WACS) Implementation Based On Sensor Network Concepts

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***Abstract*- Wide Area Control Systems (WACS) are introduced to respond to the real time control requirements of a smart grid. The control messages in smart grid can be of different levels of criticality. Therefore priority based routing, depending on criticality of messages, is very essential in control message communication. The topology of the system considered, involves control units connected to five buses in a smart micro grid. The performance metrics are identified and threshold values are fixed. Different communication technologies are simulated and the performance is compared. Multi hopping communication is established between the nodes and heterogeneous communication architecture is implemented. The need for dynamic routing protocol in the grid, as the traffic on the network changes over time, is also met. A communication scenario which dynamically routes the control message from central station to control units depending on priority, through the shortest path available, is identified here.**

Keywords: WACS, Smart grid, Communication, routing protocol

1. INTRODUCTION

Energy being a major factor in the economic growth of a nation, advances in energy sector has a direct impact on the economic growth of the nation. Power grid provides the energy to the consumers, but problems in conventional power grid like power quality, supply-demand gap, non-availability of real time grid status etc. are plenty [1]. The issues faced in the conventional power grid can be addressed and overcome by the smart grid which is an automated version of the conventional grid that improves reliability and stability of the system and makes good quality power available to the customers at affordable rates by enabling bidirectional flow of power and data [2]. The communication backbone of the smart grid is the wide area network which will connect the small area networks located at different nodes in a grid. Measurement and control actions should take place on the grid in distributed fashion [3]. Conventionally the control in the power grid is done manually after observing the grid parameters for a predefined period of time. In the automated grid, manual operation is replaced by SPS (Special Protection System) which will send signals to control centre for taking decision and then to the target area where action has to be taken [4]. Wide Area Control System (WACS) is introduced to respond to such real time requirements of the power system [5]. The control centres and substations may be separated by a large distance, so the control actions generated at the control centre will be communicated to the utilities by the wide area communication network and the status is communicated back.

This paper proposes a communication scheme which will communicate the control signals generated at the control station to the desired units in a shortest time. The control decision is generated after receiving the grid status and informs the same to the control centre. At a given instant the network carries different control messages of varying criticality, and there is a need to assign priority to these control messages to ensure respective deadline requirements of all. The task with the highest priority at any instant can use the channel and reach the destination.

The paper is organised into four sections: (i) introduction, (ii) literature survey, (iii) the system description, and (iv) the simulation results.

2. LITERATURE SURVEY

Unidirectional power and data flow is a limitation of conventional grid. The possibility of adding new and distributed sources to the grid is also limited, i.e., lack of flexibility is another problem of the earlier grid. The faults in the grid were noticed by the operator and rerouting of power was also done by the operator. The current state of the grid was not be known in a real time fashion which resulted in poor quality of power as the demand was not met by the supply[1]. So a system which can overcome these issues of the grid, became a necessity. Thus Smart grid was evolved by adding automation, communication technologies and networking to the conventional grid [5]. Initially protection of the grid was taken care by the operator, later protection system was introduced. SPS (Special Protection System) [6], the classical protection event triggered system, only does the protection but failed to respond to the unpredicted events. To overcome the drawback of the special protection system, WACS was introduced [4]. WACS is simpler than SPS and will respond to any disturbances of the system in real time.

The different sectors of power system such as distribution, transmission, consumers and other substations are connected together with the communication paths to make them interoperable. In smart grid, reliable and real-time information plays a major role for systematic delivery of power from the generating units to the customers. The communication technology should be selected depending on the type of the message to be transmitted. Mainly there are two broad classification for the communication technologies- wired and wireless, which can be employed depending on the requirements of the communication needed. The various communication technologies [2][3] include ZigBee, PLC, Wi-Fi, GSM, Ethernet, Bluetooth etc. There are different measures to evaluate the performance of the communication technology which is commonly termed as the performance metric which should be met by the selected communication technology. The performance metric include delay, security, throughput, execution rate, bandwidth, range, traffic and reliability.

Routing protocol is essential in smart grid as any defect in choosing the path to communicate, will cause catastrophic effect in the grid. Control message has criticality depending on the type of action it is going to perform, so dynamic routing is needed as far as control message is concerned [7]. The routing protocols which can be simulated in ns2 includes Ad-hoc on demand protocol distance vector routing protocol (AODV), Dynamic source routing (DSR), Dynamic Source distance vector (DSDV) routing protocol etc. [8].

After fixing the communication technology and routing protocol, the network must be simulated in a simulation environment to observe how it performs because even with readily available sensor nodes, testing the network in the desired environmental conditions can be time and money consuming and also a difficult task. The various sensor network simulation softwares [9] include ns2, ns3, GNS3, NetSim and QualNet. Network simulator (Ns) is a discrete event simulator aimed at networking research. Ns provides support for simulation of TCP, routing protocol, and multicast protocols over wired and wireless networks and performance metrics can be found out by writing and running a awk file.

3. SYSTEM DESCRIPTION

The communication scenario of a smart grid is explained in Figure.1. The communication in a smart grid can be mainly for three different purposes. One for communicating the meter readings to the control station, the second is for the distributed real time measurement data and the last for control message passing. The data from Real Time Data Collection Unit (RTDCU) as well as smart meters are received by the cloud network. Decision will be taken in the cloud based on the received data, and the control decision is communicated to the central node (data collector). The block diagram of WACS communication network is shown in Figure.2. The central node will receive the control decision from the cloud and the same will be communicated to the control devices. Sometimes if the control devices are located nearer to the cloud hosting the database than the central node, then the control decision is communicated directly to the control devices from the cloud. The status of the control action is communicated back to the control centre. Thus a bidirectional communication is needed for the control message communication in a smart grid.

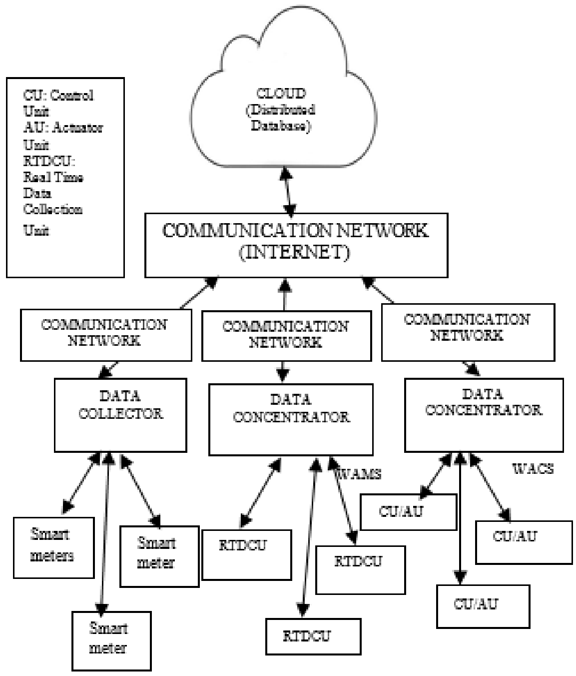

Figure.1. Communication Scenario in a Smart Microgrid.

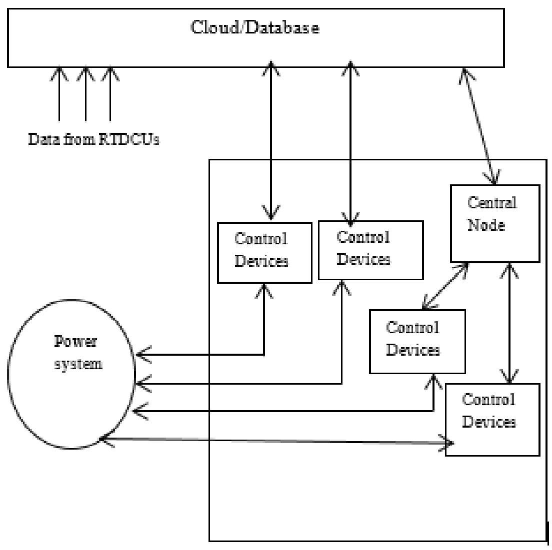

Figure.2. WACS communication network

Some of the control actions required in smart grid include generator tripping, reactive bank switching, supply cuts, adding or deleting supply to/from grid, load shedding etc. which will be communicated from the cloud and carried out by control devices [10].

Control message communication is very critical as any unwanted delay could spoil the purpose of sending the message. Control decision taken by the control station is on a real time basis as it receives measurement data via RTDCU, and meter readings from smart meters. Cloud is a collection of computers with databases housing RTDCU and smart meter data which will collect information from the grid, process the information and generates the control decision. The WACS communication network for a laboratory scale 5 bus smart microgrid in [11] is shown in Figure 3. There is a fixed distance separation between each of the five buses as mentioned in [11].

The location of control station is chosen as centre position of the micro grid structure because it is almost equidistant to all nodes and the overhead of more intermediate nodes for a single communication link can be avoided.

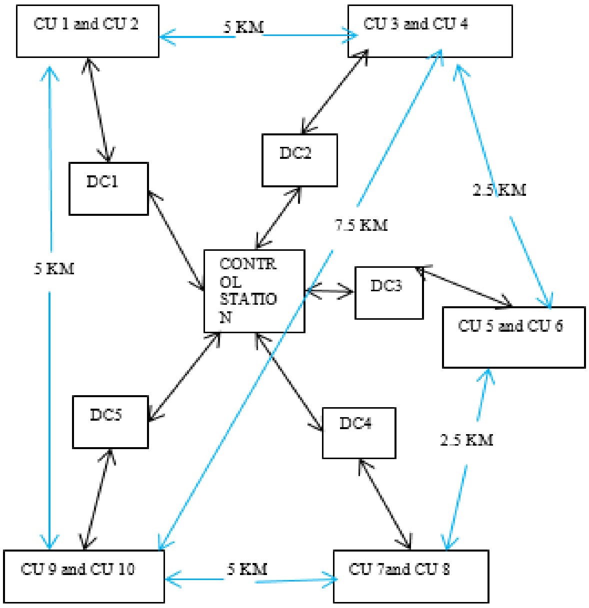

Figure.3. Topology of the communication network

Bus 3 of grid was connected with a solar panel and battery, and bus 4 with hydel plant and pumped hydro generator, and bus 5 with wind plant and battery. Similarly bus 1 and bus 2 can also be used for controlling the activities on the grid. As each of the buses are associated with two components which can be controlled, topology for WACS communication system allots two control units for each bus for controlling grid activities. Data collector is assigned to every bus and hence the topology has five DCs. Depending on the selected communication technique, required number of intermediate nodes will be added on the network to make the communication possible between the control station and the control unit.

4. SIMULATION RESULTS

Simulation is done in ns2 simulation software. The communication technologies like wireless local area network (WLAN), ZigBee and wired LAN (Ethernet) were simulated for the selected topology in ns2. The size of the packet to be sent in WACS is 64 bytes and the rate at which packet sent is 20 packets per second [12].

The different performance metric like throughput, delay and packet delivery ratio for the above mentioned communication technologies were also found out from the simulation results. The performance metrics would help in sorting out the best communication technology which can be employed for each link in the network.

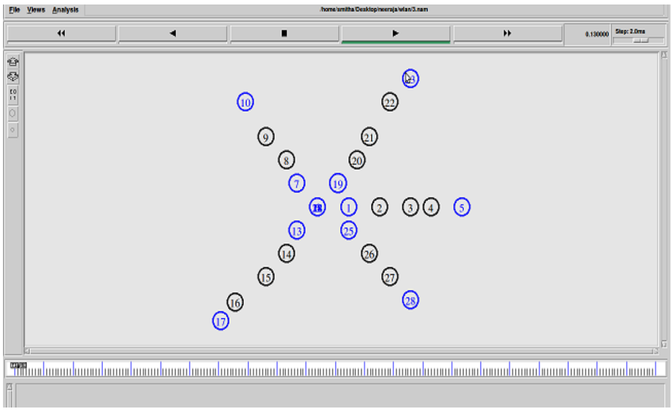

Figure.4. Simulation of WLAN in ns2

Table.1. Simulation Result for WLAN

	Throughput (Kbps)	Delay (s)	Packet Delivery Ratio	No. of inter-mediate nodes
Control Center to DC	14.40	0.22936	86.90	5
DC1 to CU1	21.83	0.25881	55.10	21
DC2 to CU3	21.38	0.24432	86.90	13
DC3 to CU5	22.12	0.25921	86.64	22
DC4 to CU7	21.66	0.24451	86.90	17
DC5 to CU9	21.07	0.24392	86.84	15
Overall Topology	27.48	1.81845	21.84	93

Wireless LAN uses radio wave for the communication and the delay for the message to reach the destination is more.

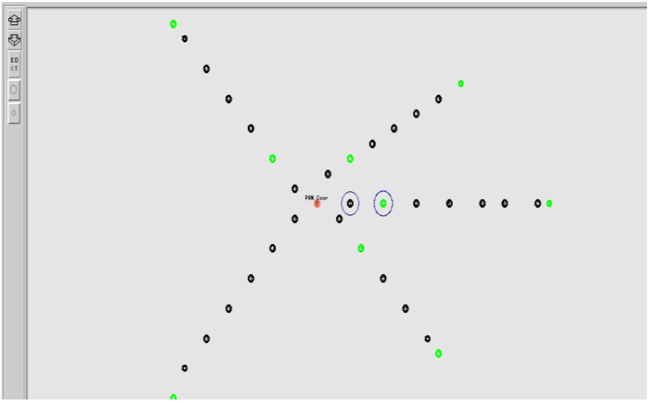

Figure.5. Simulation of ZigBee in ns2

ZigBee consumes low power for its transmission and the delay incurred is less as compared to the WLAN.

Table.2. Simulation Result for ZigBee

	Throughput (Kbps)	Delay (s)	Packet Delivery Ratio	Intermediate nodes
Control Center to DC	9.26	0.00941	75.02	1
DC1 to CU1	11.63	0.01194	74.48	4
DC2 to CU3	12.40	0.01191	75.05	4
DC3 to CU5	13.59	0.01210	76.61	5
DC4 to CU7	10.30	0.01085	74.27	3
DC5 to CU9	11.47	0.01188	76.04	4
Overall Topology	19.21	0.01819	76.28	21

Wired LAN is tested only for the distance between control station to the DC as DC is of short distance from the control station, it would not create much interference and the control message can be effectively communicated.

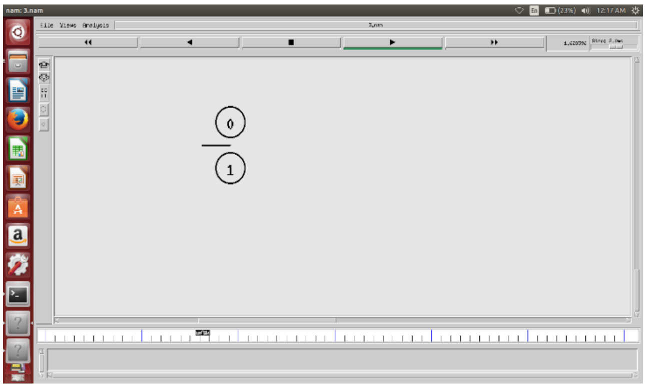

Figure.6. Simulation of Wired LAN in ns2

The simulation results are presented in the Table.1.for wireless LAN, Table.2. for ZigBee and Table.3.for wired LAN.

Table.3. Simulation Result for Wired LAN

	Throughput (Kbps)	Delay (s)	Packet Delivery Ratio
Control center to DC	5813.30	0.003504	89.56

Throughput gives number of transmitted bits per second and thus defines the transmitting capability of the node. Delay gives the time taken by the packet to reach the destination node from the source node and the intermediate nodes were placed in the network to make the nodes within the communication range of the technology used. Packet Delivery ratio gives the ratio of packets which were successfully reached the destination to the total packet sent. Delay will be more by adding more intermediate nodes between the source and destination. Packet delivery ratio increases as the number of repeaters increases because the signal to noise ratio increases with the addition of nodes. But while taking overall topology, the packet delivery ratio was decreased because there was congestion and packet loss was increased while using WLAN as communication technology.

WLAN has more bandwidth than ZigBee but the range of WLAN is comparably less than ZigBee and hence the number of intermediate nodes will be more for WLAN which will further increases the node density. As the control message is to be transmitted, the technology offering least delay, more range and a fair data rate have to be selected. So by analysing the simulation results, WLAN can be ruled out as it has more delay compared to others. Wired LAN can be employed from control station to the DC as it gives least delay out of three technologies. WACS is a distributed network, hence it is not practical to employ wired LAN from DC to control unit (CU), so ZigBee can be used from DC to the control unit.

Now the routing strategy has to be selected and implemented. The routing protocol for ZigBee is AODV and as the network is in heterogeneous nature different routing protocol should be implemented for different parts of the network. While simulating the heterogeneous communication architecture for WACS by using AODV routing protocol, the total delay incurred is 0.018 seconds and for DSDV, delay is 0.023 seconds.

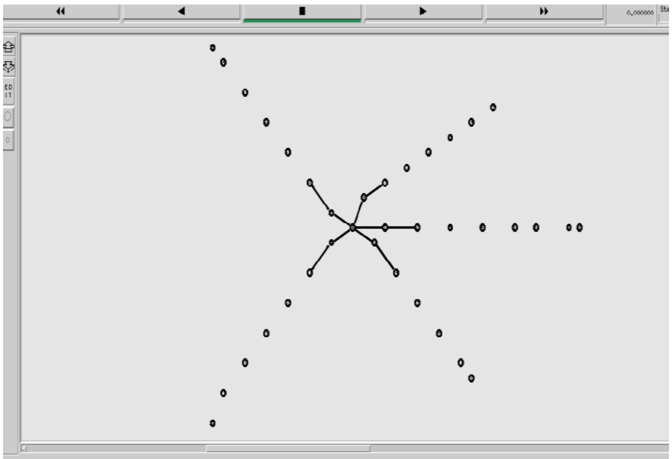

Figure.7.Simulation of communication network for WACS

Table.4. Simulation results for proposed communication network for WACS

	Through put (Kbps)	Delay (s)	Packet Delivery Ratio	Intermediate nodes
Control Center to DC	5813.42	0.00353	88.52	1
DC1 to CU1	11.83	0.01082	74.48	4
DC2 to CU3	12.49	0.01190	75.05	4
DC3 to CU5	13.87	0.01204	76.61	5
DC4 to CU7	10.34	0.01075	74.27	3
DC5 to CU9	11.47	0.01158	76.04	4
Overall Topology	19.26	0.01792	76.28	21

As the primary concern is to reduce the delay as minimum as possible, from the results obtained, it is clear that AODV gives the least delay and it can be implemented for better results.

5. CONCLUSION

Smart grid has to enable bidirectional flow of power and data by introducing automation, networking and communication technologies to the conventional grid. This study has focused on the communication network between the control station and the control devices that can route the control message to the desired destination in the shortest time through the shortest path available at that time. The communication technology is selected on the basis of the performance metrics. The WACS topology was tested in a laboratory scale smart microgrid simulator. Some of the communication technologies like WLAN, ZigBee and wired LAN were simulated in ns2 for the topology and results were analysed. A heterogeneous communication architecture using ZigBee and Wired LAN has been found to be the fastest in WACS communication network.

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