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Decoding power systems' integration for clean transportation and decarbonized electric grid

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***Abstract*— Accelerated electrification of clean transportation, charging infrastructure, and the 21st century electric grid are key contributors to future-proof global energy security, environment, and clean-air objectives. Leapfrogging these contributions is causality for India's national initiatives – National Electricity Mobility Mission (NEMM) Plan 2020 and National Smart Grid Mission (NSGM), renewable generation, and reducing greenhouse gas (GHG) emissions. The United States (U.S.) transportation sector is responsible for 28% of the total energy consumption and 27% of the nation's total GHG emissions. In India, increasing transportation sector growth is also a major contributor to the deteriorating air quality in the urban centers, accounting for 30% of the total fine particulate ($PM_{2.5}$) emissions. For the diffusion of clean transportation in India, this paper reviews deployments in the U.S. and quantitatively evaluates transformative and cost-effective communication standards for electric vehicle (EV) and electric grid interoperability. The paper recommends strategies for accelerated diffusion of light-, medium-, and heavy-duty EVs and their integration with the 21st century grid to mitigate supply-side variability from renewable generation. Applying these strategies to infrastructure investment can help India leapfrog its clean transportation and energy systems through the NEMM and NSGM initiatives, allowing it to create a resilient and de-carbonized infrastructure.**

***Keywords*—** *Clean Transportation, Smart Grid, Electric Mobility, Internet of Things, Systems Interoperabilty, Power Systems*

I. Introduction And Background

Diffusion of zero-emission electric mobility and the 21st century electric grid with large-scale renewable generation are inextricably linked. While internal combustion engine (ICE) vehicles rely on fossil-based fuels (petroleum and diesel) to generate energy, electric vehicles rely on electricity to power the vehicle's electric motors. This transition from traditional ICE-based vehicles to electric vehicles (EV) requires adequate electricity infrastructure and mechanism to address variability from renewables. Both these objectives are critical to advance clean transportation and decarbonized grid objectives. The United States (U.S) transportation sector uses 28% of the total energy, mostly from petroleum-based sources [1]. In 2012, this sector contributed 28% of the total greenhouse gas (GHG) emissions, whereas the electricity generation sector's share is 31% [2][3]. GHG emissions also deteriorate air quality, impacts human health, and leads to premature deaths [4]. To address the resulting climate-change impacts, the 21st century grid is primarily characterized by transition to clean renewable generation and its integration to decarbonize the electricity infrastructure and to significantly lower the GHG emissions.

The 21stcentury electric grid is defined by – integrated and interoperable power systems; distributed generation; two-way power flows, and the network-enabled secure real-time communications and control of the energy resources. The transition to electric mobility and the 21st century electric grid could future-proof global energy security, reduce the GHG emissions, and advance clean air objectives.

Improved air quality and human health are and best promoted by electric mobility powered by renewable generation [5]. When fossil-based fuel is the majority of electricity generation mix, electric transportation provides petroleum and carbon savings through higher miles per gallon of gasoline-equivalent (MPGe).[1] Miles per-kilowatt hour (MPkWh) is the new relative metric of electric mobility's range. The net benefits of clean transportation are similar to the use of alternate fuels (e.g., hydrogen) or improvements in the fuel economy. In a city, electric transportation improves air quality and public health. Innovation in the electric mobility industry provides IoT-based infrastructure management services the benefit of being a grid-resource to manage intermittency from renewable generation., similar to other electric loads, it can also enable an arbitrage of peak electricity shortfalls and price volatility [6].

A. *Goals and Objectives*

The goal of this paper is to encourage leapfrogging of clean transportation and decarbonized electric grid by the diffusion of battery-based EVs (BEV), adequate charging infrastructure, and better integration of renewable generation growth through interoperable electric grid power systems and markets.

The paper focuses on two key objectives:

1. Identify complementary relationships between automated BEV infrastructure management and grid connectivity.
2. Propose interoperable and integrated power system fundamentals to leverage the resource flexibility of BEVs.

The objectives should guide the regulators, electricity providers, systems operators, and electric mobility users to efficiently and economically leverage clean transportation as an environmentally friendly grid resource and support aggressive clean energy generation through renewable resources.

B. *The Indian Context:*

India's energy security and air quality future rely on aggressive adoption of clean energy and clean transportation, which will also help accelerate economic development. India imports more than 80% of its crude oil, but has one of the lowest vehicle to owner ratios: one vehicle for every 1,000 people.[2] Even with low adoption rates, the transportation sector is a major contributor to the deteriorating air quality in India's urban cities. The particulate matter ($PM_{2.5}$) levels experienced by daily-commuters have an annual-mean of 15 to 20 times higher (~60 times in winter) than the World Health Organization's guidelines of 10µg per-m^3 for $PM_{2.5}$ and 20µg

[1] The MPGe is a measure of the total distance an EV can travel using the same energy content in a gallon of gasoline (petroleum).

[2] World Bank; 2011 Motor Vehicles (per 1000 people) – includes cars, buses, and freight vehicles, but does not include two-wheelers.

per-m^3 for PM_{10} [7][[8]][9].[3] In Delhi, 30% of the total fine particulate ($PM_{2.5}$) emissions are from transportation [10]. India's transportation sector is projected to add more than 250 million cars, 185 million two- and three-wheelers, and 30 million trucks and vans by 2040 [11]. These vehicle ownership rates will further strain oil supply and deteriorate air quality.

India's fast-growing urban cities have increased importance on electric transportation. The Government of India's (GOI) Ministry of Heavy Industry (MoHI) National Electric Mobility Mission (NEMM) 2020 plan has an ambitious target to deploy six to seven million EVs in the next five years, a majority of them in the cities. Within NEMM, GOI has proposed budget for charging infrastructure, technology advancements, incentives, and case studies to accelerate EV adoption. Previous studies have reviewed electricity customers' role as a resource to the grid using the Ministry of Power's (MoP) National Smart Grid Mission (NSGM) [12][13]. These studies have also looked at India's grid modernization and how to better integrate for modern electricity infrastructure to improve reliability [14]. The Ministry of Renewable Energy's (MNRE) aggressive renewable generation policies will help India transition from two-thirds coal-based generation to key contributor in addressing the climate-change impacts.

C. *Study Methodology and Paper Structure:*

This paper reviews the U.S. EV infrastructure deployments to understand the significance between connecting electric vehicles to the grid, and quantitatively evaluates transformative and cost-effective options to manage the BEV infrastructure, power systems integration, and grid interoperability.

In particular:

Section II describes the links between electric mobility and electric grid, and interoperability and integration framework.

Section III provides quantitative analysis and case studies to accelerate the diffusion of light-, medium-, and heavy-duty BEVs and integration with the 21^{st} century grid.

Section IV summarizes key conclusions and future research.

Each section also summarizes the relevant Indian context, and Section IV provides India-specific recommendations.

II. Electric Mobility and Grid Integration

There are many technical requirements for transforming the 21^{st} century electric grid to meet electric vehicle driver's needs. IoT technologies must enable interoperable data communications with electric grid infrastructure.

Previous studies have reviewed how demand side management can address challenges in renewable generation variability. [15][16]. While zero-emission vehicles improve air quality, they also present system wide challenges with increased energy use and demand-side variability. To reduce stress on the grid, smart or managed EV charging enables BEVs to charge batteries under varying energy supply conditions [17]. Fig. 1 shows an example of a highly variable EV charging demand profile at a location in the U.S.

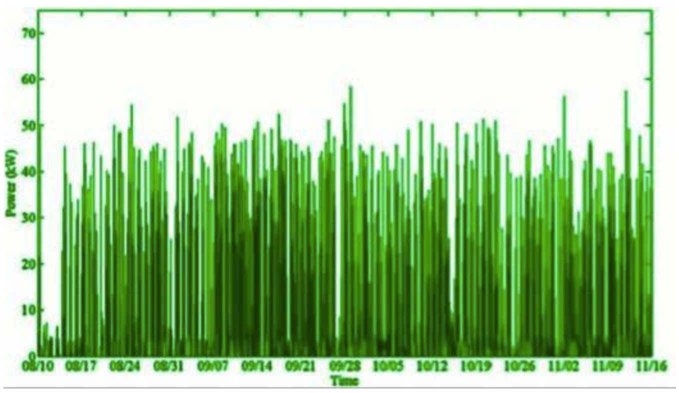

Fig. 1. High Variability of an EV Charging Demand Profile (1 no., 50 kW fast charger and 8 nos., 7 kW chargers with a high peak demand of 58.4 kW).

The EVs role as grid resources is best understood by evaluating the 21^{st} century electric grid and its unique characteristics.

A. *The 21^{st} Century Electric Grid*

In the context of this paper, Smart Grid refers to increased renewable generation, a two-way power flow, and networked communications among distributed energy resources (DER) and Smart Grid domains [18]. The 21^{st} century grid is enabled by networked communications and control, and real time grid analytics. This infrastructure can better balance supply-side variability and electricity demand, playing a key role in integrating renewables for decarbonized generation.

Fig. 2 shows electric vehicles within the framework of the 21^{st} century grid. In particular, the charging stations (also referred to as EV supply equipment or EVSE) can be connected to different electric sources within different Smart Grid domains. The most common charging station location is "behind-the-meter" at a residence, office/workplace, or public space (e.g., mall, campus).[4] With increasing adoption of EVs and long-range driving needs, "front-of-the-meter" locations (e.g., city, highway) are necessary.[5] This is a key requirement for interoperability and integration with power systems and electricity markets. The BEV (also referred as Plug-in EV or PEV) charging needs necessitate the deployment of EV charging infrastructure, and interoperability to provide a seamless and convenient charging experience to the drivers.

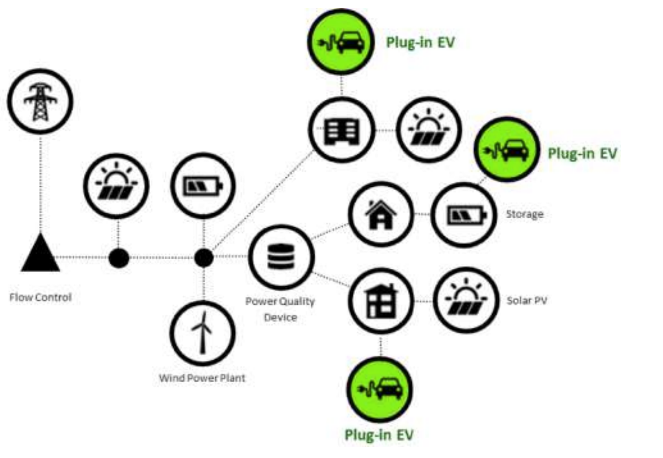

Fig. 2. Behind-the-Meter Plug-in Electric Vehicle and Charging Station Infrastructure within the Distributed Energy Paradigm

[3] Mass concentrations of airborne particles with aerodynamic diameters less than 2.5 and 10 mm, respectively.

[4] The term "behind-the-meter" references electricity customer as an energy services boundary with the electric grid distribution systems.

[5] The term "front-of-the-meter" references T&D domains of a Smart Grid.

B. *Electric Mobility Infrastructure and the Electric Grid*

Understanding the unique characteristics of electric vehicles and how drivers and electricity-customers use BEVs within the distribution domain or the "grid edge," is important. The key unique characteristics for electric mobility are:

- BEV integration, as a **"roaming" DER**, occurs at all Smart Grid power-flow domains and behind-the-meter [19].
- The **distinct relationship between BEVs and charging stations**. Different ownership and operation models, and technologies provide "charging-as-a-service" to drivers.
- **Advanced power electronics and communication systems** are capable of automated smart charging and vehicle-to-* (V2X) services to grid or local resources.[6]

These characteristics define interoperability and integration for EV management and grid services. Grid services are in reference to the use of electric mobility as a grid resource. Other DERs (e.g., solar, storage) are stationary within a specified domain. Studies have shown that the flexibility value of energy storage increases from T&D domain to behind-the-meter siting [20]. Connected-BEV characteristics are similar to stationary storage at all spatial and temporal points of time. The four features for BEV, as a grid-resource are: (1) availability, (2) grid location, (3) response speed, and (4) response duration.

Fig. 3 proposes a framework with three layers that constitute electric mobility infrastructure: (1) EV network management (roaming), (2) charging systems (stationary), and (3) electric grid domains. Two behind-the-meter resources campuses and buildings are distinctive. A building has a one-to-one meter and service agreement with a utility, and a typical campus has a one-to-many meter(s) service agreement(s) and feeder(s). The fourth layer that the smart grid leverage describes service needs and value. There is an increased need for integration and interoperation of power systems and markets, as a BEV roams between T&D and behind-the-meter domains. In this instance, a Smart Grid enhances BEV's value as a grid resource.

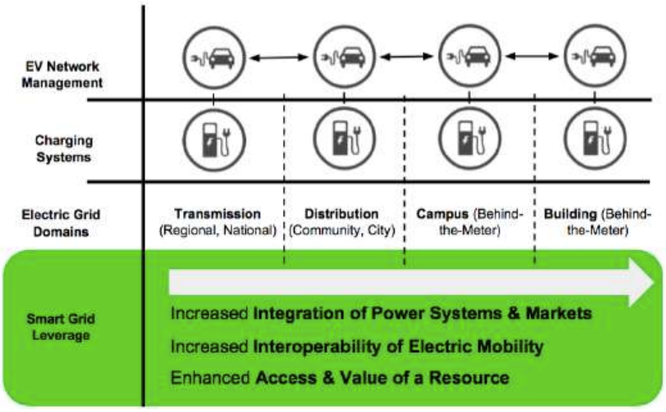

Fig. 3. Framework for Electric Mobility Infrastructure Integration and Interoperability with Electric Grid Domains, as Grid Resource (green shade).

Electric vehicle infrastructure is comprised of network management and grid-connected charging systems that support power, communications, and control functions within all smart grid domains to provide roaming charging services. A Smart Grid leverages existing power systems and markets interfaces so that EV infrastructure has seamless interoperation.

[6] V2X services such as V2-Grid (V2G) or V2-Home (V2H) face inherent problems such as battery degradation and voided manufacturer's warranty when a BEV is used for functions external to driving needs.

C. *Open and Interoperable Platforms*

Standards are key enablers for open interoperable platforms and encourage innovation because; it enables new business models and services. The benefits of interoperability standards for customer-side transactions are well studied [21]. BEV interoperability, as a DER, requires integration among all three power-flow domains: systems operators, electricity service providers, and customers. Fig. 4 describes these interfaces and interoperability standards that are adopted by the industry. Common communication standards for electric mobility are: Open Charge Point Protocol (OCPP), Open Automated Demand Response (OpenADR), and Smart Energy Profile 2.0 (SEP 2.0). This list does not include power-flow and inverter interconnection standards. While these standards support a distribution network that electricity providers need for information exchange with users, the International Electotechnical Commission (IEC) standards, common information models (CIM) and 61850 play a dominant role for power-systems' interfaces within and with transmission network system operators. Secure Internet-based protocols (IP) and automated metering infrastructure (AMI) are widely used as transport mechanisms between customer and distribution networks. Due to the perceived risk from IP-based communications, distributed network protocol 3 (DNP3) and inter-control center communication protocol (ICCP) support the cyber-security requirements for communications among the traditional operation and power generation networks.

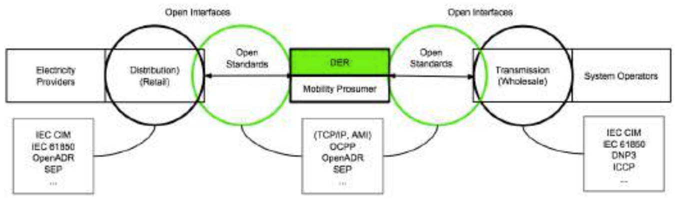

Fig. 4. Electric Mobility Interoperability with Power Systems and Markets

Technology innovation, electric vehicle and charger adoption is still nascent. Relative to the 21st century grid transformation, there is a need for significant advancements. On-board EV telematics and standards-based networked charging stations can be used for V2X services, including third party, cloud-based EV charging network management, which already support key V2X services. Power-flow connectors from "level 1" and "level 2" charging ports, which use low-voltage alternating current (AC), to BEVs support the Society of Automotive Engineers' (SAE) J1772 standard. The situation is complicated with direct current fast chargers (DCFC), because they use medium- and high-voltage to connect to BEVs. There are three connector standards widely used today – SAE combo-coupler standard (CCS) in the U.S. and Europe, CHAdeMO in some Asian countries, and automotive original equipment manufacturer (OEM), Tesla Motors', Supercharger. However, there is ongoing consensus to standardize communications between BEV and charging stations using the International Organization for Standardization (ISO)/IEC 15118 and SEP 2.0. The characteristics of different charging levels and supported standards is summarized in TABLE I.

TABLE I. CHARGING LEVEL CHARACTERISTICS AND BEV CONNECTIVITY

Charge Levels	Volt/Current (V/A)	Power (kW)	Charging Station-to-BEV Connection	
			Power	**Communication**
Level 1	108-120/15-20	~1.4	NEMA 5.15	N/A
Level 2	208-240//≥30	~7.2	J1772	ISO 15118 (BEV) OCPP (Grid)
DCFC	400-800/≥120	≥50	CCS/CHAdeMO/ Supercharger	

The Indian Context: Aggressive electric mobility adoption has potential for grid services, using the framework for electric mobility infrastructure and electric power systems integration. To best integrate BEVs, regulators should mandate smart grid interoperability using open standards that have been adopted by the electric grid participants and technology providers. This will address industry issues with vendor lock-in, and cost-effectively connect BEVs with all charging network types, metering, and Smart Grid domains, to encourage innovation and advance the industry/customer experience.

III. QUANTITATIVE ANALYSIS AND RESULTS

Due to size, weight, and range priorities, BEVs use a lithium-ion (Li-ion) battery for energy storage. Albeit the chemical compositions of Li-ion technologies vary, their characteristics, as a proxy for a grid resource, are negligible. TABLE II. The fit for Li-ion in the 21st century grid is shown in TABLE II. Electric mobility infrastructure requires a tighter association amongst BEV drivers, charging station owner/operators, revenue meters, and markets. The BEV value for off-grid applications (e.g., V2H, PV integration) is not considered.

TABLE II. U.S. ELECTRICITY MARKETS AND LITHIUM-ION BATTERY FIT

Electricity System/Markets	Benefits of BEV Li-ion Battery
Transmission System & Peak Generation	• Resource aggregation to improve performance of the transmission grid by better integrating variable renewable generation. • Resource aggregation for flexibility products to charge/discharge from large-scale un-forecasted renewable generation ramps (up/down). • Support contingency reserves for fast response to any change in supply-side conditions. • Support capacity, as a cost-effective alternate to or replacement of peak generation plants.
Distribution System & Demand Response	• Smart charging to manage power-constrained local distribution transformer from increased BEV load. • Provisioning of flexible peaking capacity and grid-stability improvements at the substation-level. • Fast responding demand responsive resources for peak-load reduction, emergency load curtailment, dynamic pricing, and reduce/shift energy use.
Reserves – Spinning & Non-Spinning	• Suited for high-frequency data exchange for load forecasting and better supply-side planning. • Resource capability for smart charging and fast-response with short notification and response times.
Regulation	• Ability to respond with rapid charge/discharge in response to random deviations of the net load (*forecasted demand – scheduled supply*). • Aggregation and rapid dispatch for smart charging, as a resource to balance grid and maintain frequency tolerance boundaries (up/down).

A. Charging Station Ownership Models and Locations

BEV charging infrastructure ownership models relative to their Smart Grid domains are used to understand their network management needs of electric mobility infrastructure and spatial and temporal availability of BEVs, as a grid resource. The three evolving own and operate models of BEV charging infrastructure is shown in TABLE III.

TABLE III. BEV CHARGING STATION OWNERSHIP MODELS

Customer	Most widely used model for level 1 with any available 108-120 V outlets and, partially, for level 2 charging by the owners of home, building, and campus
Third-Party	Increasingly popular model for level 2 and DCFCs, where a charging station OEM, or a city/county deploys charging infrastructure in public-spaces for BEV adoption.
Utility	Evolving business model to deploy level 2 and DCFCs in public spaces, along highway corridors, and disadvantaged communities to support aggressive national- and state-level BEV adoption and zero-emission vehicle mandates.

B. Types of BEVs, Battery Sizes, and Ranges

The all-electric drive distance of a BEV and high cost, relative to ICE vehicles, were key adoption barriers.[7] In recent times, the costs of Li-ion have fallen largely from technological innovations and increased adoption. For each-category of BEVs – 2-wheelers, light-, medium-, and heavy-duty – battery sizes and drive ranges of top-selling and popular OEM models in the U.S. were analyzed. While it is obvious that the battery capacity is proportional to the size of the vehicle, hybrid-BEV has smaller battery capacity, as the ICE extends its range. This analysis is summarized in TABLE IV.

TABLE IV. BEV CLASS, MODELS, BATTERY SIZES, AND DRIVE RANGES

BEV-Class and OEM Models		Rated Battery Capacity (kWh)	Range (Miles)
2-Wheelers	Zero S/SR/DS	9.4–15.3	87–125
Light-Duty	Nissan LEAF	25	80
	Chevy Volt*	18.5	55
	Tesla (Model S)	60–85	180–250
Medium-Duty	Enova ZE Van	40-120	50–150
Heavy-Duty	Proterra Bus	257	255

* Hybrid BEVs with ICE for extended range following full battery discharge.

C. Electric Mobility for Grid Services – Case Studies

Numerous studies by U.S. federal and state agencies have shown the impacts of electric mobility for grid services [22][23][17]. The results of five relevant case studies are summarized in TABLE V.

TABLE V. CASE STUDY RESULTS FROM ELECTRIC MOBILITY GRID SERVICES

Southern California Edison	One of the largest workplace DR charging study project leverages the networked-BEV charging station management services to extend it for DR. Using OpenADR and OCPP, the project successfully demonstrated the value of standards for utility power system interoperability and DR with successful network management and smart charging of level 2 stations.
Sacramento Municipal Utility District	The project by Sacramento Municipal Utility District (SMUD) focused on residential level 1 and 2 charging infrastructure, and evaluation of technical performance and grid impacts using time-of-use and dynamic rate. The project results showed high-customer satisfaction and problems with driver behavior and meter-to-charging station interoperability.
University of Delaware	One of the first projects for V2G services has led to commercialization of V2G technology with industry partners. The project enabled aggregated market participation of the BEVs to show driver and grid operator benefits for grid-stability resources. The 15 BEVs are capable of providing a total connected power of 180 kW and economical value of $5/day.
Ft. Carson	Study focused on V2G and microgrid simulation has identified signification potential for EVs (both smart charging V2G). The project captured 45% of the total connected power capability of two EVs, and demonstrated the potential of and improvements in the system and BEVs to follow regulation signals.
Open Vehicle Grid Integration Platform	The project is collaboration among automotive OEMs, utilities, research institutes, and technology providers to develop standards-based communication platform to support BEVs for grid integration. The project demonstrated cloud-based platform for interoperable interfaces using OpenADR, SEP, and AMI. The next phase of the project is considering on-board vehicle telematics option for direct business-to-BEV driver interactions.

The Indian Context: Public charging stations such as gas stations, malls, populated highway corridors, etc., will encourage BEV adoption. Charging station manufacturers can leverage economies of scale and grid-integrated systems to lower costs. Fixed routes and flexible schedules allow targeted charging infrastructure for the public and city transportation system. Batteries are the most expensive component of a BEV, so a smaller battery capacity supports shorter commute

[7] The "usable" capacity of a battery is accurate metric for driving distance, as opposed to the "nominal" rated capacity, which is typically 15% higher.

distances, and regenerative braking can extend the electric-drive range, thus lowering the total ownership costs. India can evaluate BEV-specific battery sizes and voltages to further lower costs. Quantitative analysis suggests that BEV drivers also save money on maintenance and fueling. BEVs can also be of value to the grid and can support India's grid reliability, unlocking additional revenue streams for the BEV owners.

IV. Conclusions and Recommendations

Smart Grid technology infrastructure and network – sensing, communication, and control – must be enhanced and extended to every level of power systems to provide ubiquitous grid resources and mitigate BEVs "new load" impact on the grid, and to address variability from renewable generation. BEV technologies, when integrated with electricity markets, enable BEVs to become a dispatchable resource. Decoupled driver and charging station ownership models, proprietary technologies, and distinct charging station and automotive OEMs relations must offer interoperable systems for the diffusion electric mobility and to enable them as a resource to the grid.

Open standards and power systems integration prevent charging assets from being stranded, and provide drivers with access to technological innovation with improved experience and upstream integration to the 21st century electric grid. Inclusion of standards for communications and controls interoperability at the Smart Grid interface-edge will future-proof electric mobility infrastructure-as-a-grid resource. Early studies from nascent industry have shown technological and regulatory dependence to derive value to-and-from the grid. Widespread global electrification of transportation, potentially 100%, and its adoption is vital for us to address climate change and provide sustainable energy security and air quality for all.

To accelerate and scale electric mobility, future technological advancements must address the technical and regulatory challenges through case studies, and use the findings to design policies that incentivize EV ownership. Open standards will also be critical to scale EVs and integrate them onto the grid.

A. Specific Recommendations for India

Electric mobility adoption and grid integration lessons can be learned from developed-nations and can serve as a model for India to accelerate zero-emission vehicles and a decarbonized electric grid. The road motor vehicle adoption rate per capita is still one of the lowest in the world and with India's history in leapfrogging innovation cycles (e.g., telecom and the Internet), electric mobility policies can support sustainable growth and new economy. India will face unique challenges for EV acceleration and adoption and will require regulatory interventions to address concerns from traditional practices. Urban cities with deteriorating air quality can be at the frontline for 2-, 3-, and 4-wheeler EV adoption, including electrification of public transportation.

Learning from the United States' smart grid and electric mobility successes and failures can de-risk India's clean transportation and energy investments. A reliable, resilient, and decarbonized electric infrastructure is attainable with renewable generation, NEMM and NSGM initiatives. This, however, both inter- and intra-ministry coordination between the MoHI, MoP, and MNRE, is necessary to execute the integrated clean energy and clean transportation goals.

Acknowledgments

The author acknowledges MissionCTRL Communications for review-comments and the India Smart Grid Forum for support.

References

[1] U.S. Energy Information Administration (EIA), *Annual Energy Outlook 2014*, DOE/EIA-0383.

[2] U.S. Environmental Protection Agency (EPA); *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2012*, EPA 430-R-14-003

[3] U.S. Department of State (DOS); *U.S. Climate Action Report 2014*

[4] Lelieveld J, et al; *The Contribution of Outdoor Air Pollution Sources to Premature Mortality on a Global Scale*, Nature 525, September 2015.

[5] Tessum C W., J D. Hill, and J.D. Marshall; *Life cycle air quality impacts of conventional and alternative light-duty transportation in the U.S.*

[6] Ghatikar G., R. Yin, R. Deshmukh, and G. G Das, *Characterization and Effectiveness of Technologies for India's Electric Grid Reliability and Energy Security*, Proceedings of the ISGW, March 2015. LBNL-6994E.

[7] Steven, D. and Ghosh, A, *The New Politics of Strategic Resources: Energy and Food Security Challenges in the 21st Century* (eds Steven, D., O'Brien, E. & James, B.) 40–70 (Brookings, 2014).

[8] Apte J. S, T W. Kirchstetter, A H. Reich, S J. Deshpande, G. Kaushik, A. Chel, J D. Marshall, W. Nazaroff; *Concentrations of fine, ultrafine, and black carbon particles in auto-rickshaws in New Delhi*, 2011.

[9] World Health Organization; *WHO Air Quality Guidelines for Particulate Matter, Ozone, Nitrogen Dioxide, and Sulfur Dioxide*, 2005.

[10] Resource: http://www.dw.com/en/study-offers-new-insight-into-new-delhis-air-pollution-woes/a-18105674, 2015 (*Accessed December 2015*).

[11] International Energy Agency (IEA); *India Energy Outlook*, 2015.

[12] Basu C., G. Ghatikar, and P. Bansal; *Enabling Efficient, Responsive, and Resilient Buildings: A Collaboration Between the U.S. and India*, IEEE Smart Grid and the New Energy Economy, 2012. LBNL-6594E.

[13] Ghatikar G., V. Ganti, and C. Basu, *Expanding Buildings-to-Grid (B2G) Objectives in India*, 2013. LBNL-6369E.

[14] Yin R., G. Ghatikar, R. Deshmukh, and A. Khan, *Findings from an Advanced Demand Response Smart Grid Project to Improve Electricity Reliability in India*, India Smart Grid Week, Delhi, 2015. LBNL-6982E.

[15] California Independent Systems Operator (CAISO); *Demand Response and Energy Efficiency: Maximizing Preferred Resources*, 2013.

[16] Olsen D., N. Matson, M D. Sohn, C. Rose, J. Dudley, S. Goli, S. Kiliccote, M. Hummon, D. Palchak J. Jorgenson, P. Denholm, O. Ma; *Grid Integration of Aggregated Demand Response, Part 1: Load Availability Profiles and Constraints for the Western Interconnection*, 2013. LBNL-6417E.

[17] The U.S. DOE; *Evaluating Electric Vehicle Charging Impacts and Customer Charging Behaviors – Experiences from Six Smart Grid Investment Grant Projects*, Smart Grid Investment Grant Program, 2014.

[18] National Institute of Standards and Technology; *NIST Framework and Roadmap for Smart Grid Interoperability Standards, Release 3.0*, 2014.

[19] Ruth M. F, B. Kroposki; *Energy Systems Integration: An Evolving Energy Paradigm*, The Electricity Journal, Volume 27, Issue 6, 2014.

[20] Fitzgerald G, J. Mandel, J. Morris, H. Touati; *The Economics of Battery Energy Storage: How Multi-Use, Customer-Sited Batteries Deliver the Most Services and Value to Customers and the Grid*, RMI, 2015.

[21] Ghatikar G., J. Zuber, E. Koch, and R. Bienert, *Smart Grid and Customer Transactions: The Unrealized Benefits of Conformance*, IEEE Green Energy and Systems Conference (IGESC), 2014.

[22] Charged: Electric Vehicle Magazine; *Workplace Charging with Smart Grid and Demand Response*, Issue 20 – July/August 2015.

[23] *Multi-lab EV Smart Grid Integration Requirements Study*, Technical Report NREL/TP-5400-63963, 2015.

Biography

Girish (Rish) Ghatikar is the Vice President of Technology at Greenlots, an electric mobility and network management leader, and Research Affiliate at the U.S. Department of Energy's Lawrence Berkeley National Laboratory with focus on advancing global clean energy and clean transportation innovations. Ghatikar is an honorary Board of Governors member for the India Smart Grid Forum and holds Master of Science degrees in Infrastructure Planning, and Telecommunication Systems (Computer Technologies Specialization).

Advancement and Innovation in Substation Design with Introduction of Self Protected Green Transformer in Indian Power Sector.

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Abstract

In recent times, Indian Electrical Distribution sector has witnessed advances and new trends in technology to cope up with the concerns like safety, space, protection and ease of operation. Transformer forms the integral part of Electrical Distribution system. These transformers are generally located in the vicinity of public areas and are prone to fire hazards and human interventions, causing danger to life and property. The pole structured substations usually occupy huge space and are difficult to install in confined space with electrical Clearance. These substations are very much prone to fire accidents, electricity theft causing a major problem for installation in public areas. The number of fire accidents causing due to these installations is increasing rapidly. Also, frequent failures of these transformer lead to sustained Power interruptions. It is of prime importance for every utility to supply Safe, green, uninterrupted and cheap power to their consumers. Hence, to achieve this goal, it is the need of day to step ahead in the era of new Technology and set a revolution in Indian Distribution sector.

Keeping in view of this requirement and technology advancement, as an utility Tata Power has recently introduced new self protected Distribution Transformer in Indian Distribution sector with a view to supply safe green and reliable power to the consumers and eliminate the installation of pole mounted and conventional substations.

Generally the conventional substation comprises of High Tension Breaker, Transformer and Low Tension distribution system. The compact design of Self Protected Distribution transformer comprises of High Tension Compartment, Transformer and Low Tension Compartment enclosed in a single touch proof enclosure, making it best suitable and safe to install in rural and urban areas. The design of the transformer unit is such that it reduces the footprint by almost 70 per cent as compared to conventional substations. In addition, the transformer is generally installed on a simple Pad foundation, considerably reducing the time and cost of installation. Importantly, the safe and green design of transformer is attributed to the use of Natural Ester which have a Fire point more than 350 Deg C as against 160 Deg C of Mineral Oil and are biodegradable. Also, the sealed design of transformer makes it completely maintenance free and add to reduction in O&M cost of the asset. These substations are best solution for eliminating major concerns of Safety, Paucity of space, Cost, Environment, and transformer protection. Installation of the substations would bring in a paradigm shift in the way that substations (Conventional plinth mounted and Pole Mounted Substation filled with Mineral oil) are being erected today in public places so as to virtually make them fire safe. The Introduction of this transformer in Indian Distribution sector shall definitely mark a big change in a way to look forward towards technology with different perspective.

1) Introduction: Self protected transformers installed with Underground Distribution system, are best suited for installation in public access areas. These transformers meet modern design requirements for flexibility, reliability, safety and provide a visually pleasing installation. Tamper proof Construction of the substation allows installation in locations accessible to the general public without the need of protective fencing or vaults. These units are ideally suited for apartment buildings, schools, hospitals, shopping centres, commercial buildings, gardens, road sides, traffic junctions and industrial sites.

2) Rating: These transformers can be designed in range of 75 KVA to 1 MVA, with the high-voltage upto 33 kV, in single and three phase configuration. Design impedances and BIL voltage is similar as that of Conventional Mineral oil Transformer. (Refer IS 1180 Part I).

1) Design: The transformer tank and terminal compartment are designed to make one complete, weather and tamer proof assembly. The basic design of the Self protected transformer is same as that of the conventional liquid filled, self cooled transformer with sealed construction, except that of the high tension compartment and low tension compartment enclosed in a single unit. The HT compartment comprises the functionality of breaker that is isolation, protection along with transformer cable termination. Similarly, LT compartment comprises of LT distribution system along with breaker and LT outgoings. These compartments are bolted to the transformer tank front wall and are mechanically interlocked to prevent exposure to high voltage side. Refer Figure (2, 3 and 3A) for general arrangement.

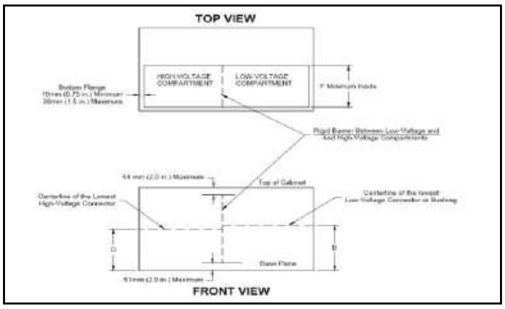


Figure 1: Top and Front View

The transformer is designed for both radial and loop feed distribution system. The major factor which distinguishes the self protected transformer (substation) from conventional substations, are the specific components assembled with proper protection philosophy in HV and LV compartment of the transformer. The major elements of self protected transformer are (Table 1):

Function	Components	Location
Cable Termination	Dead & live front Bushing with Load Break elbow connector	HV Section
Isolation	Load Break Switch	HV Section
HT Protection	HT Expulsion Fuses	HV Section
LT Protection	LT Breaker	LV Section
LT Distribution	HRC Fuses/Connectors	LT Section

Table (1): Components of Self protected transformers

Figure (2): General arrangement for Three Phase

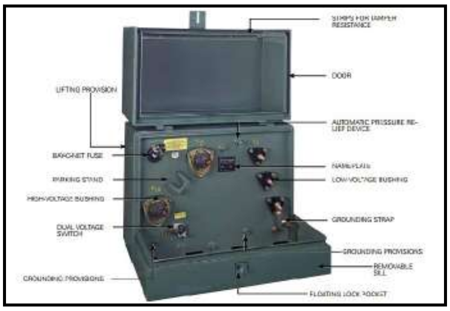


Figure (2A): General arrangement for Single Phase

a. ***HV Termination:*** The HV compartment which performs the function of ring main unit, consist of dead front and Live front bushings with load break Elbow connectors suitable for plug and play termination of the HV cable. The Dead front bushing assembly is preferred for safe access and operation of HV part. Parking Bushing and Voltage cap is used for parking cable and safeguarding. Refer figure 3.

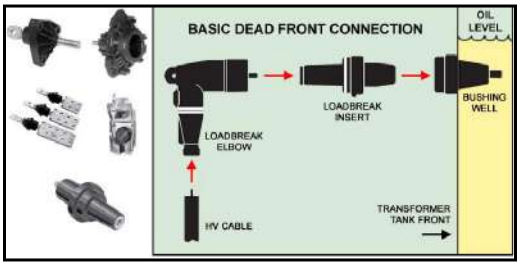


Figure (3): Dead Front Bushing assembly

b. ***Operation & Isolation:*** Single/Three phase OFF/ON oil immersed Load break switches are used for phase operation of the incomers to the transformer. The use of the switches facilitates the radial/loop network operation of the transformer. The switches are equipped with two/three/four position operation which has a spring-loaded activating mechanism ensuring quick load break action and positive contact engagement through all positions. Refer fig (4 and 4A) for internal construction and positions of Load break switch.

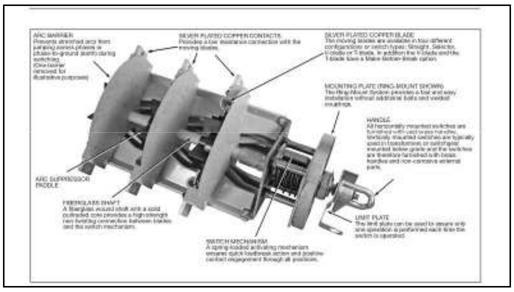


Figure (4): Internal Construction

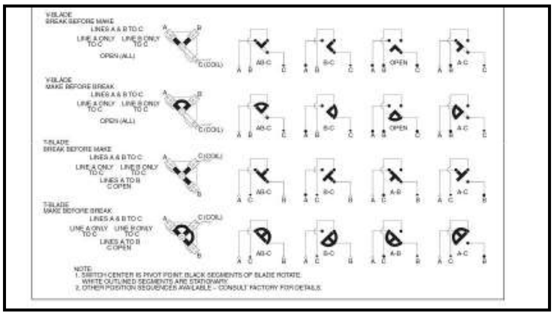


Figure (4A): Switch positions

c) Overload and Internal fault Protection: As per CEA guidelines, for voltage not exceeding 33 kV having aggregate installed capacity upto 1000 kVA linked switch with fuse can be used for HT protection .The protection scheme can be achieved by using Expulsion fuses (bay-o-net fuse with partial range current limiting fuse) with proper coordination, magnex interrupter and Dry canister fuses. The expulsion fuses are immersed in the dielectric liquid used by the transformer, under the same tank.

The Bay -o net fuse in coordination with partial current limiting fuse are used for Overload, thermal and internal fault. Bay o- net fuse operates on secondary faults, overloads and have thermal sensing capability whereas current limiting fuse which is mounted under-oil operates on internal high-current faults only. These fuses are economical, easy, field-replaceable. Factors like Magnetizing inrush current, hot load and cold pick up current are considered while designing. When connected in series with a low current primary protection device, the fuse becomes an element of a two-

part protection system that gives a full range of fault protection.
Magnex Interrupter and Dry Canister fuses are the options used for transformer protection.

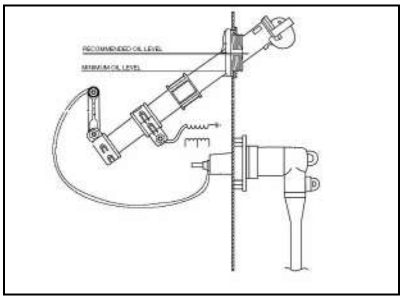
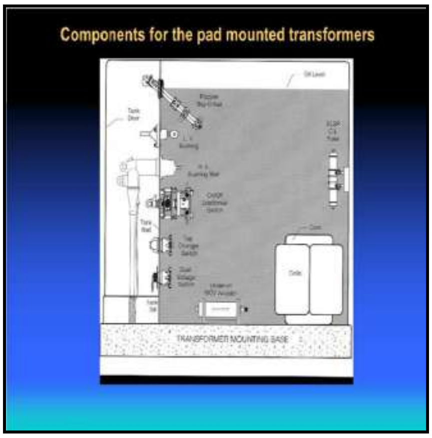


Figure (5) : Bay-o-Net fuse

Figure (5A): Types of Fuses

d) LV Compartment: The LV Compartment of the self protected transformer can be equipped with breaker for LT protection and Fuse or Link connectors for Distribution purpose. The transformer assemblies are mounted inside the LV compartment.

e) Transformer accessories
Minimum Oil level and temperature indicator, Pressure relief valve, Oil Sampling valve and off load tap chamber are the accessories which can be used in self protect transformer, rating and specification are similar to the conventional transformer accessories.



. **Figure (6): Internal design**

e) Cooling Medium, Natural Ester: The Dielectric Medium used in self protected transformer is Natural Ester. Natural esters are derived from renewable vegetable oils and provide improved fire safety, transformer life/load ability, and environmental benefits that are superior to mineral oil and unsurpassed by any other dielectric coolant. Because it is derived from renewable raw materials, it has a very low carbon footprint – unequalled by any other dielectric fluid option. These fluids have a typical fire point of >350 °C, much higher than that of Mineral oil (170-180 °C).Due to their inherent high fire point >350 °C, they are classified as K Class Fluids. The proven permissible temperature rise with these natural ester fluids will not exceed the limit of 65°C for transformer winding and 60°C for oil .With Natural ester semi hybrid insulation system is used while designing the transformer winding. The special type of insulating system used is thermally upgraded paper (TUP). The design of self protected transformer with natural ester makes it virtually fire proof and permits 120% overloading of transformer.

4) Installation: Self protected transformer can be used installed on a pad foundation with a minimum electrical clearance of 0.6 m from three sides and 2 m from front side.

5). Benefits:
Natural Ester filled self protected distribution transformers are designed for achieving benefits like

compactness, space reduction, safe operation, tamper proof , fire safe and fast installation. Installation of such Compact, totally enclosed touch proof substation shall eliminate the use of pole mounted substation which are very unsafe, prone to accidents, fire hazards, power failures and electricity theft.

a) Space Reduction: - Estimated in reduction in size of substation space is by 70%.

b) Cost Savings: As self protected Transformers come as a single unit, there are cost reduction implications in civil cost, separate equipment cost, Operation & Maintenance cost.

c) Installation Time: Single unit installation requires less time as compared to installation of substation with Conventional substation comprising of oil filled Transformer and HV and LV Switchgear.

d) Environment friendly & Safe: The dielectric medium used for self protected Transformer is natural Ester. The inherent properties of this Natural ester fluid makes transformer Environment friendly and safe for installation and operation.

e) Aesthetic Look: The Self protected transformers are so design that none of its part/ accessories is exposed to the surrounding and is enclosed in a unit. This improvises the aesthetic look of the surrounding unlike the pole mounted and conventional substation.

f) Tamper Proof: The Self Protected transformer design is very much tamper proof and shall help in reducing commercial distribution losses.

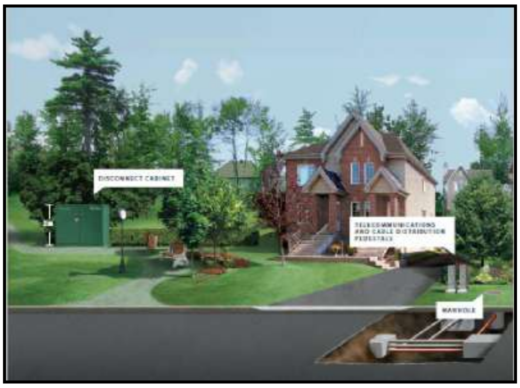


Figure (7): Safe Installation

6) Case Study: As a pilot project Tata Power has recently successfully installed and commissioned Natural Ester filled Self protected transformer. During the design of this transformer. The design of the transformer was achieved with dead front bushings with elbow connector for and proper fuse coordination.

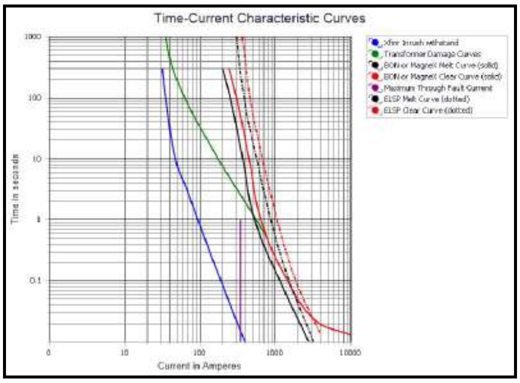
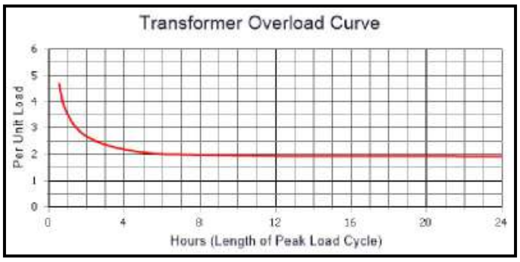


Fig (7 and 7A): Fuse Coordination



With this innovative design a total foot print saving of about 70% is achieved and is complete fire safe. The Design is type tested for guaranteed temperature rise of 60 ◦C and 65◦C temperature rise and is capable of 120% overloading.

Figure (8): Installation at Mumbai site

Parameter	Pole Mounted substation	Self Protected Transformer
Area	4.1 x 2.6 x 5.8 (H)	3.7 x 3 -11.1 Sq. Mtr
Fire	Risk of Fire Exists.	Totally Fire Safe.
Environment	Environmentally Non-Biodegradable	Environmental Benign
Electrical clearance	Fencing and clearances are required.	No requirement of fencing
Spares	Spares Inventory to be maintained	No Spares Inventory to be maintained
Protection	External Protection required.	Electrically Self-Protected
Period installation	Gestation Period :30 Days	Gestation Period < 20 Days

References

a. ***IS 1180 Part 1: for Oil filled distribution Transformer.***
b. ***CEA guidelines: HT and LT Protection as per.***
c. ***3.IEEE C57.12.34 2009 for Definition, Ratings, Construction and terminal arrangements with dimensional clearances.***
d. ***IEEE C57.12.28 2009 for Transformer Enclosure.***
e. ***IS 2026:1977/ IEC 60076 -2004 Comply Specification for Power Transformers.***
f. ***IEC 62770: Specific Standard for Unused Natural Esters Liquids for Transformers and similar electrical equipment.***
g. ***IS 10028: 1981 Code of Practice for Selection, Installation and Maintenance of Transformers.***
h. ***IEC 62262: Degree of protection provided by enclosures for electrical equipment against mechanical impacts (IP Code).***
i. ***Eaton Fuse Coordination program for selection of fuses.***

Development of Enhanced Capacity, Fire Safe, Green and Compact Power Transformer

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Abstract:
This paper highlights the journey of Tata Power towards development of reduced footprint transformer installation through use of Natural Esters and an optimised design collaboratively developed with transformer manufacturer. The development achieved 17% smaller installation whilst increasing transformer capacity from 20 MVA to 28 MVA whilst ensuring Safe, Compact and Eco-friendly Electrical Installations. Natural esters are becoming the preferred alternative to replace mineral oil, in order to improve fire safety and reduced environmental impact. It also enhances Performance with reduced footprint at higher temperatures with high temp class insulations.

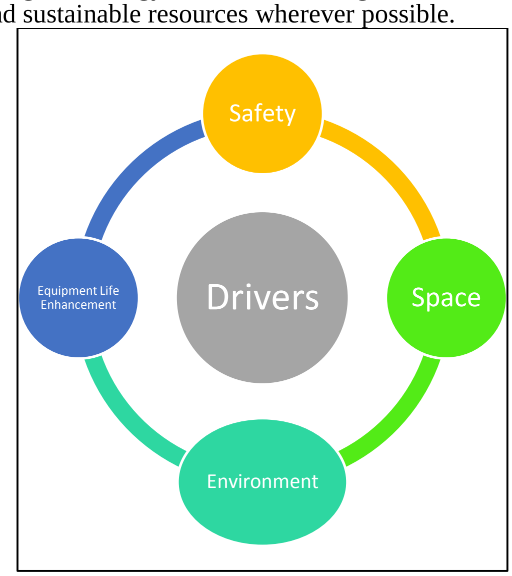
Use of Natural Esters for Power Transformers:
Over the years Tata Power Mumbai has been using Power Transformers with typical rating of 33 /11 kV, 20 MVA. With the changing landscape of Mumbai in terms of high load density, paucity of space, stringent environmental and safety norms; need was felt for relook into design of conventional Power Transformers.
Dwelling upon Tata Power `s core values of "SACRED", intent of delivering Safe and Green Power to its Consumers ,Tata Power ventured into developing a Ester Filled Power transformer so as to reap the multiplier benefit of Safety, Environment, Compactness and Capacity Enhancement. We have successfully designed, developed Ester Filled Power Transformer with OEM`s to cater to firstly site specific constraints and then deploy across the area of operation. This Fire Safe and Green Power Transformer has been put into operation for the First time by any utility in India.

Drivers
The main drivers for improving network quality for power and distribution utilities in urban cities like Mumbai are Safety, Space, Environment and Equipment/Asset Life.

Safety: Ensuring safety of Electrical Installation whilst coping with increasing loads is of utmost importance.

Space: Availability of clear space in metropolitan cities like Mumbai is getting difficult as well as prohibitively expensive. Equipment footprint is important, as is the ability to cope with future increase in demand from same equipment.

Environmental Concerns: Electrical installations should be future ready without environmental concern, using technology that offers ecological CO2 neutral and sustainable resources wherever possible.



Equipment Life Expectancy: Ageing assets of any electrical utility are a reality, the challenge is not in replacing these assets incurring huge capital expenditure but in enhancing and increasing the life expectancy of existing assets. This involves Re-fitting existing installations and to accommodate the reengineered solutions in the existing space.

APPLICATION of ESTER FLUIDS

Mineral Oil has been traditionally used as an Insulating and Cooling medium for Transformers. Mineral Oil has limitations in terms of low fire and flash point and limited biodegradability and its toxic effects in case of a spillage.
As an alternative to mineral oil, natural esters are used as dielectrics and coolants. Natural Esters have the highest high fire point that makes them safer with the added benefit of being readily biodegradable and thus more environment friendly. Their unique ability to continuously dry the insulating material though hydrolysis can increase lifetime of the asset along with allowing compact designs. Natural esters, with these benefits, form a suitable choice to be used in transformers. Comparative properties of both these insulating fluids are summarized below:

	Mineral Oil	**Natural Esters**
Fire Point	170-180 ^{0}C	>350 ^{0}C
Flash Point	160-170 ^{0}C	>250 ^{0}C
Biodegradability	Slow to biodegrade	Fully biodegradable
Breakdown Voltage	70kV	>75kV
Cellulose ageing transformer life	Poor	Slower ageing- more transformer life
Compact Transformer Design	No	Yes

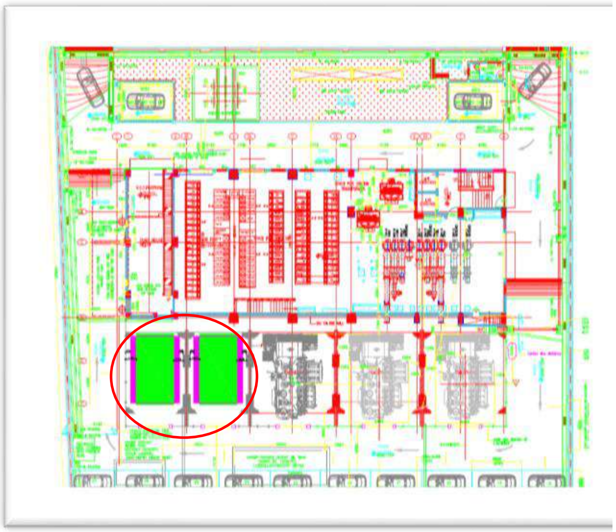
DEVELOPMENTS AT TATA POWER

With the initial success of Tata Power in developing Natural Ester Filled Distribution transformers, it ventured into design and development of Natural Ester filled Power Transformer. This development would impact the whole of Mumbai City. Over the years Power Transformers have seen only incremental changes in design and have essentially remained the same since invention. With the drivers of Space Constraints, Safety, Environment and Enhanced Capacity for utilities, need was constantly felt to optimize on the design of transformers to make it Green, Compact and Safe. One such opportunity came knocking at the doors of Tata Power wherein there was a predefined pocket of space for accommodation of Power Transformer to feed a densely populated area of Mumbai Suburb . Conventional Mineral Oils are used as Insulating and Cooling medium in any Transformer, this insulating medium has drawback of being not readily biodegradable and igniting at a low temperature thus getting into fire very easily .This also limits the capacity and enhances the space requirements for a higher capacity transformer. Natural Esters are Insulating Fluids that overcome the drawbacks of Mineral Oil and by virtue of their properties can be used to develop a Safe ,Compact and Environment friendly Transformer. Natural Esters have a very High Fire and Flash Point (rendering them fireproof) and environmentally benign. Tata Power has designed and developed higher capacity, smaller footprint 33/11 kV, 25/28 MVA Power Transformers collaboratively with Original Equipment Manufacturers (OEMs) using Natural Esters as Insulating and Cooling medium.

Development of Design-Particulars

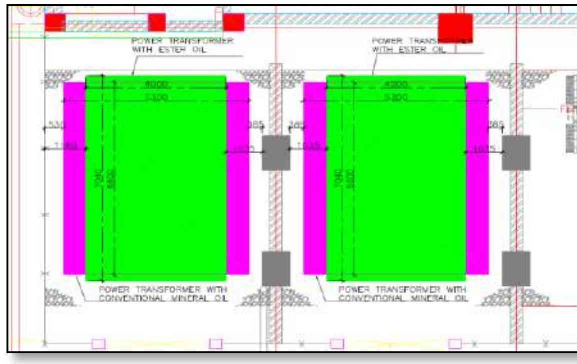
In a prestigious new smart city hub with many prestigious financial institutions, a 33/11 kV, 2 x 20 MVA Distribution Substation in the commercial district of Mumbai had space constraints for accommodating conventional mineral oil filled Power Transformers. However it was imperative to install both the transformers in the available space considering the load requirement of the area.

The solution was to introduce Natural Ester Filled Power Transformers which could give the benefits of reduced footprint, enhanced capacity and fire safety. All of this while keeping the same loss levels.
The layout of the particular site with the transformer pockets is depicted below in Figure 1:



The encircled area was the one earmarked for positioning of the 2 x 33 /11 kV, 20 MVA Transformers. With the conventional transformers, the clearances to be maintained around the transformer could not be achieved and hence the need to optimize on the dimensions

On a closer look of the area in Fig 2, the reduction in area in terms of the footprint with the use of an Ester filled transformer is apparent.



The area highlighted in purple is the one for Conventional Power transformer and the one highlighted in Green is the area of an Ester filled transformer.

Tabulated below is the comparison between Mineral Oil Filled and Natural Ester filled Power Transformer:

Comparsion of Mineral Oil Filled Vs Natural Ester Filled Power Transformer						
	Particulars	Unit	33/11KV,20 MVA Mineral Oil Power Transformer	33/11KV ,25/28 MVA Natural Ester Power Transformer		Observations
1	Dimensions	L*B*H	6600*5300*5050	7280*4000*5030		16.75 % lesser footprint with Natural Esters
2	Area	sq mtr	34.98	29.12		
3	Guaranteed Temp Rise Deg C	Oil	45	70	70	Higher by 25 Deg C with Natural Esters
		Winding	55	80	80	Higher by 25 Deg C with Natural Esters
4	Sound Level in DB	Fans	73		63	Better than guarnteed Noise level of 73 dB as per NEMA
	(Amb.+Tx)	Without Fans			59	

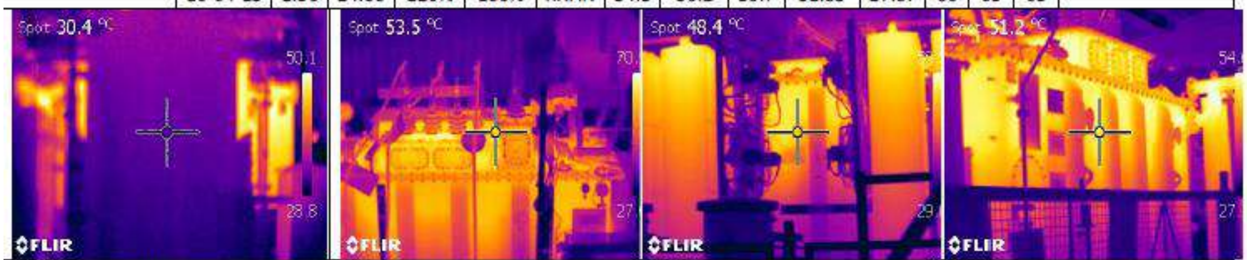
Results of Heat Run on the Ester Filled Power Transformer:

The resulting transformer showed in the heat run test bay some surprising results, indicating that further capacity increase – adding value for money- was going to be possible.

1) At 100 % Loading of 20 MVA and 90 % of 24 MVA, temperature rise for both Oil and Winding well below the guaranteed temperature rise.

10. 16.04.2015, 0150: 108% of 20 MVA (90% of 24 MVA)

Date	Time	MVA	% of 20 MVA	% of 24 MVA	Cooling	Radiator Top (°C)	Radiator Bottom (°C)	Top Oil (°C)	Avg Ambient (°C)	Temp Rise (°C)	OTI (°C)	HV WTI (°C)	LV WTI (°C)
16-04-15	1:30	24.00	120%	100%	KNAN	54.5	36.2	59.7	31.83	27.87	60	65	65



OLTC Side | LV side | Radiator side | HV side

2) At 120 % Loading of 20 MVA and 100 % of 24 MVA, temperature rise for both Oil and Winding well below the guaranteed temperature rise.

11. 16.04.2015, 0235: 120% of 20 MVA (100% of 24 MVA)

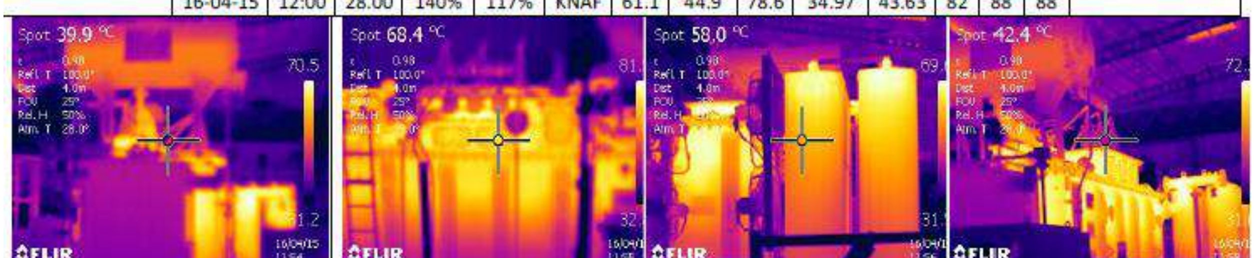
Date	Time	MVA	% of 20 MVA	% of 24 MVA	Cooling	Radiator Top (°C)	Radiator Bottom (°C)	Top Oil (°C)	Avg Ambient (°C)	Temp Rise (°C)	OTI (°C)	HV WTI (°C)	LV WTI (°C)
16-04-15	2:30	24.00	120%	100%	KNAN	59.1	38.3	65.3	31.47	33.83	65	70	70

OLTC Side | LV side | Radiator side | HV side

3)At 140 % Loading of 20 MVA or 28 MVA, temperature rise for both Oil and Winding well below the guaranteed temperature rise.

19. 16.04.2015, 1200: 140 % of 20 MVA i.e. 28 MVA

Date	Time	MVA	% of 20 MVA	% of 24 MVA	Cooling	Radiator Top (°C)	Radiator Bottom (°C)	Top Oil (°C)	Avg Ambient (°C)	Temp Rise (°C)	OTI (°C)	HV WTI (°C)	LV WTI (°C)
16-04-15	12:00	28.00	140%	117%	KNAF	61.1	44.9	78.6	34.97	43.63	82	88	88

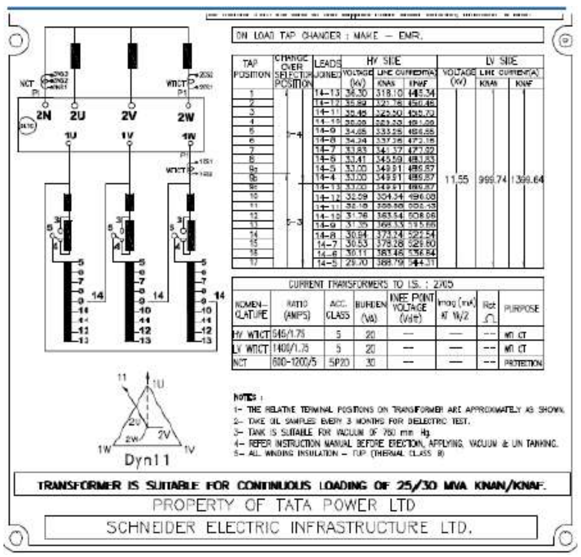


OLTC Side | LV side | Radiator side (LV side) | HV side

The results of the Heat run clearly demonstrate that the Transformer can be continuously run at 25 MVA with Natural Cooling and at 30 MVA with Forced Cooling.

Enhanced Capacity:

The enhanced capacity of the transformer on the Name Plate has been named as seen:



THE PRODUCT

CONCLUSION

This single product innovation is fulfilling several pressing requirements of the utilities, consumers and society alike:

1) Safety of installation is increased manifold and the installation is rendered virtually fireproof. The risk of fires in electrical installations is totally eliminated.

2) Due substantially High Fire and Flash Point of Esters, a capacity enhancement of 5 MVA is ensured.

3) Reduction in footprint and converting the land saved for developmental purposes.

4) Esters are readily biodegradable and Carbon Neutral Fluids.

5) Longevity of equipment life is ensured by Esters.

All the values of Tata Power are touched upon.

How to integrate more Distributed Energy Resources in Low Voltage and Medium Voltage networks? *

The GRID4EU experience in Europe

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Abstract

GRID4EU is a leading European Smart Grids project supported by the European Union. Driven by large scale demonstrators, it focuses on increasing the distribution networks hosting capacity without jeopardizing the quality of supply.

In four locations, GRID4EU develops patterns of DER integration to articulate best practices and solutions:

- ✓ In Germany, GRID4EU improves the surveillance and advanced control of the medium voltage (MV) grid based on an autonomously acting Multi-Agent-System.
- ✓ In Italy, the system makes possible a new network management system model with Distributed Generators (DG) actively supporting voltage regulation at the MV level.
- ✓ In Czech Republic, GRID4EU enhances MV & LV grids supervision and remote operations with a local SCADA system, fast communication infrastructure and remote controlled devices. Additionally, in case of failure on superior network level, the solution allows automated islanding operations powered by local generation, which includes a 1,6 MW Combined Heat & Power unit.
- ✓ In France, a Network Energy Manager (NEM) using solar generation and load forecasts puts together an optimization program based on load flexibility bids. These bids, proposed by aggregators, ease the voltage and current constraints resulting from a high level of Photovoltaic (PV) tied into the LV distribution grid. A 250 kW islanding test with no spinning machines has been carried out!

Thanks to its replicability assessment, GRID4EU brings turnkey solutions, for all Smart Grids players, to better integrate DER.

This session will be the opportunity to present the final project results in the field of DER integration.

Keywords

Distributed Energy Resources, Photovoltaic, Wind energy, CHP, islanding, demand response

Introduction

While the traditional challenges of Distribution System Operators (DSOs)—such as the reliability and resilience of supply and energy security—remain, new realities introduce another set of imperatives. Embracing evolving distributed generation technologies (such as rooftop photovoltaic and smaller-scale wind) and still balancing consumer concerns around rising electricity costs add further levels of complexity. As a result, utilities are being driven to innovate and transform using digital technologies. With this in mind, pilot projects are springing up across Europe and the rest of the world to help grid companies understand the implications of the new energy world.

One emblematic project is GRID4EU, an innovative four-year smart grid project which began in November 2011, co-funded by the European Union (EU). The project is managed by a group of six major European DSOs (from Czech Republic, France, Germany, Italy, Spain and Sweden) in close partnership with a set of electricity retailers, manufacturers and research organizations; in all, the project includes 27 partners. At the core of GRID4EU lies the implementation of six complementary large-scale demonstrators in the above mentioned EU countries, to test innovative system concepts and technologies, highlighting and helping to remove some of the most important barriers to the smart grid deployment, in particular to integrate RES.

Overall, GRID4EU integrates 140MWp of RES. In practice, in three locations representative of the current European RES landscape, GRID4EU develops patterns of RES integration to identify and articulate best practices and solutions:

- In Germany, GRID4EU improves the surveillance and advanced control of the medium voltage (MV) grid based on an autonomously acting Multi-Agent-System (MAS). Dynamic topology reconfiguration, a new operational concept facilitating RES integration, is enabled.
- In Italy, the project increases the hosting capacity and maximizes the integration of RES in the MV network. The system makes possible a new network management system model with Distributed Generators (DG) actively supporting voltage regulation.
- In France, a Network Energy Manager (NEM) using

solar generation and load forecasts puts together an optimization program based on load flexibility bids. These bids, proposed by aggregators, ease the voltage and current constraints resulting from a high level of Photovoltaic (PV) tied into the LV distribution grid. A 250 kW islanding test with no spinning machines is being carried out, which is, to our knowledge, a world premiere!

Thanks to the real, large-scale networks used and the project structure covering a wide range of technical, economical, societal and regulatory conditions, the maximization of the potential replicability of the solutions implemented is expected.

This paper focuses on how the three GRID4EU Demonstrators mentioned above integrate RES with a particular focus on the approach and first outcomes of NICE GRID.

The German Demo, an autonomously acting and switching grid control system to increase the Medium Voltage network hosting capacity of RES

Background

The German site already shows a balance between installed distributed generation power (feeding capacity: 25.9 MWp) and the highest demand observed so far (peak load: 25,5 MW). A further increase in renewable generation is forecast, making grid operation and observation even more complex, especially because Germany is not especially equipped with surveillance facilities or grid automation in medium voltage (MV) networks.

Purpose

To overcome this challenge in the German site, GRID4EU extends the automation level of MV networks based on an autonomously acting and switching grid control system as an industrial solution for network operation. It enables to achieve, in a context of growing penetration of RES, higher reliability, shorter recovery times after grid failures and loss reduction by increasing the surveillance and remote-control level of the grid. The added value of the proposed agent system compared to a conventional one is its robustness and low need for maintenance. Whereas any central approach needs important maintenance in case of system modifications, decentralized agents supervise and analyze their direct environment themselves and draw their own conclusions to act on this environment.

Approach

This approach in Germany enables an autonomous interaction between the installed modules and their responsibility for a defined part of the MV network in order to implement an autonomous system able to manage the grid without a high level SCADA system (i.e. in a decentralized approach).

Results on the reduction of outage time

The expected shorter outage times of the complete network are measured through a System Average Interruption Duration Index[1] (SAIDI) and an Average System Interruption Duration Index[2] (ASIDI). Simulation results showed that the outage time in the whole network has been divided by two (e.g. SAIDI dropped from 12.8 min/a to 6.1 min/a), without sacrificing RES's high share of total generation.

The Italian Demo, an advanced Control System, communicating with all the network relevant nodes to increase the Medium Voltage network hosting capacity of RES

Background

The Italian site presents a high penetration of renewable energy production (feeding capacity: 105 MWp), mostly photovoltaic, along with low consumption in comparison (peak load: 80 MW). Reverse power flows from the distribution network to the transmission network have been registered several times.

Purpose

The Italian site realizes an advanced control system allowing to increase the Medium Voltage network hosting capacity of RES. The underlying outcomes are the implementation of a Voltage Control and Power Flow Control in the MV network, the enablement of the dispatching of the renewable generation on the MV network, the assessment of the use of a storage facility for optimized Network Operations and Energy Management. It also includes the development of new procedures for managing efficiently and reliably generation units disconnection in the event of unwanted islanding.

Approach

This advanced Control System, communicating with all the network relevant nodes through an “always on” IP standard-based communication solution, relies on two main algorithms:

- A state estimator: starting from actual network topology and measurements from field, and taking

[1] *SAIDI is the average outage duration for each customer served*

[2] *ASIDI is the annual system non-availability.*

into account load and generation curves, it estimates the state of the system (voltage at nodes, current in branches, power flows) and communicate it to the following "block";
- A voltage Regulator (VR) implementing a power flow control: its aim is to maintain the technical parameters (voltages, currents) within the allowed limits, minimizing the total functional referred to the 'cost' of the control strategies. The VR relies on HV/MV digital substations, OLTC, batteries and reactive power injection/absorption from third-party controllable generators.

Results on resources increasing the network hosting capacity

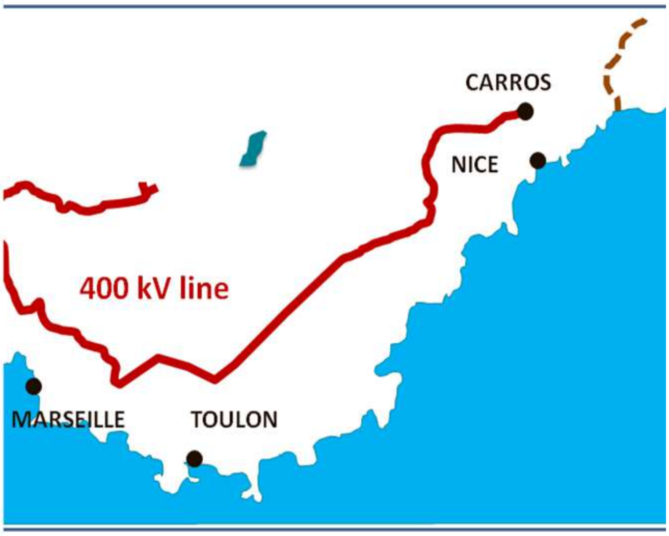
The OLTC regulation is normally the most important resource: it affects all the nodes and it has a great influence on the voltage profiles. The OLTC action could hovewer be neutralized in case of unbalances between the feeders or current congestions. In the first case the reactive modulation of the generators is important, while in the second case only the storage system can overcome the congestion.

With only the action of OLTC, the increase of the hosting capacity in a primary substation has reached 53%. In another Primary Substation, the increase of network hosting capacity is about 10%, since it is mainly a passive network with few voltage congestion. In this condition, the HC is already high in the baseline scenario (about 97 MW) and the advantages of the control solutions are then inferior than the network of the other primary substation.

The French Demo, a dynamic load management solving grid constraints due to high PV generation in Low Voltage networks

Background

The French site is in a region considered to be an "electricity peninsula" within the French power system, with a single 400 kV line supplying the French Riviera down to Carros. Although Carros lies on the periphery of France's transmission grid (Nice Côte d'Azur metropolitan area in the Alpes-Maritime département) and therefore subject to a structural handicap with respect to its electricity supply, the town has abundant RES, especially solar. 2.5 MWp of PV are installed, including 120 residential installations, within a 11,500-inhabitant city (peak load: 25 MW).



Source: NICE GRID

Figure 1: Location of Carros in the French Riviera region

Purpose

The project, which makes use of a high proportion of local intermittent energy sources, seeks to demonstrate an optimal approach to electricity management, at the level of a district or town. It taps into flexibilities in order to locally adapt the load curve to the generation curve, and thus to avoid voltage and current constraints. Flexibilities involve the large-scale integration of dispersed photovoltaic (PV) power generation, load-shedding capacities, and energy storage systems (lithium-ion batteries with 1.5 MW total capacity), at different points in the overall system: distribution grid, electricity producers and consumers.

Some 2,500 potential residential and seven business customers are likely to be affected by this project. 110 of these customers have been equipped with PV roof top panels. The project relies on an advanced metering infrastructure (AMI) to facilitate more accurate consumption forecasts and allows participating grid customers or external aggregators to control and monitor devices such as hot water tanks without additional Internet boxes or parallel communication infrastructure.

Regarding active demand, the NICE GRID project also aims to develop methods for assessing the behavior of "prosumers." As is known, photovoltaic power is not always generated when the consumer needs it, especially in areas with low penetration of HVAC systems. To deal with this challenge, the NICE GRID project strategy is to shift a part of consumers' consumption to the periods when a surplus photovoltaic power is generated locally. For this purpose the generation and consumption forecast are key inputs to the power flow calculation tool of the Network Energy Manager (NEM).

To support these objectives, NICE GRID has developed a “Network Energy Manager” that can optimize the balance between power consumption, solar generation and storage at the district level by:

- Forecasting the next day’s consumption and solar power production
- Integrating batteries at different grid levels, from the substation to host consumers
- Identifying and locating in-time and space network constraints that are likely to occur the next day
- Soliciting aggregators that can act on the active energy passing through the LV network
- Selecting flexibility offers according to technical and economic parameters.

This system communicates with three aggregators (one for private individuals, one for businesses and one for batteries on the grid) and technologies, which helps to:

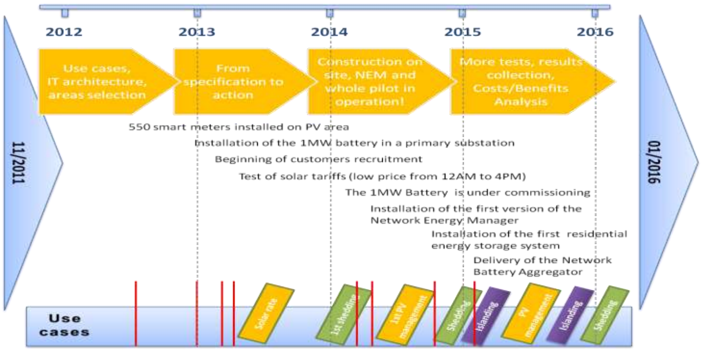
- Encourage participating customers to play an active role in their electricity consumption
- Test innovative IT and communication technologies to remotely control some energy uses.

<u>Approach</u>

The French site's approach relies on two types of “flexibilities”, i.e. means to activate in order to locally adapt the load curve to the generation curve:

- The residential & industrial flexibilities encompass load shifting through lower "off peak" electricity rates (from noon to 4 PM on sunny days) and remotely controlled water heaters (charged from 2 PM onwards on sunny days) and 4.6 kW / 4 kWh residential batteries (remotely controlled by the residential aggregator). These flexibilities are aggregated and managed by a residential or industrial aggregator and the shifts in consumption patterns of customers are measured.
- The grid flexibilities combine the activity of an OLTC and of three grid batteries located at strategic positions on the low voltage grid. The flexibilities from grid storage assets are managed through a Network Battery Aggregator. Power flow calculations run on a day-ahead basis and rely on historical metering data, meteorological data and forecasts, as well as load and generation forecasts.

In the experimentation, these flexibilities have been activated following specific planning stages. See Figure 2 for the planning stages and the main milestones of the project.

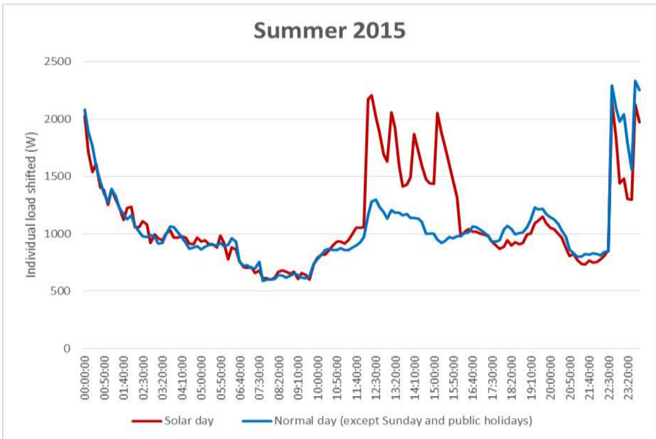


Source: NICE GRID

Figure 2: Planning stages and main milestones of the French Demo

<u>Results on residential flexibilities</u>

76 households participated in the summer trials in 2015 in the seven solar districts (i.e. 15% of eligible households[3]). In households who tested the Smart Water Tank offer, a difference of 56% on average was recorded in their consumption between a solar day and a "normal" day between the hours of 12:00 noon and 4:00 PM (i.e. 2.4 kWh).

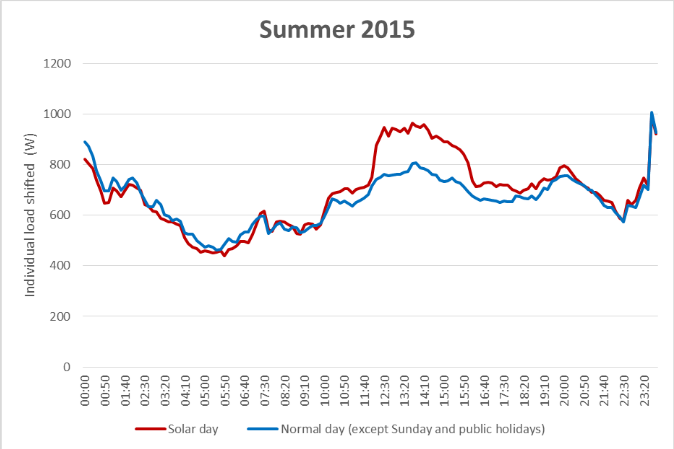


Source: NICE GRID

Figure 3: Averaged daily load curves with and without request for participants testing the Smart Water Tank (SWT) offer

In households who tested the solar bonus offer, a difference of 22% on average was recorded in their consumption between a solar day and a "normal" day between the hours of 12:00 noon and 4:00 PM (i.e. 0.35 kWh).

[3] Eligible household: resident of one of the **solar district**s fitted with Linky smart meters



Source: NICE GRID

Figure 4: Averaged daily load curves with and without request for participants testing the Solar Bonus offer

During the summer, the encouragement to postpone some daily household tasks to solar hours proved fruitful. The experimenters played the game fairly and did shift some of their domestic tasks to the 12:00 noon – 4:00 PM - time bracket. Efforts addressed essentially the use of household appliances (dishwasher, washing machine, etc.) and to a lesser extent ovens, vacuum cleaners, irons and swimming pool filtration systems.

Figures and Tables

References

GRID4EU Videos on Renewable Energy integration:

- Project video : https://www.youtube.com/watch?v=M5YWPxGHczQ&feature=youtu.be
- German Demo video: https://www.youtube.com/watch?v=EbAnm2hhj_
- Italian Demo video: https://www.youtube.com/watch?v=JGqqhByPaDk
- French Demo video: https://www.youtube.com/watch?v=Ozmc3OBHjcA

Latest GRID4EU deliverables on Renewable Energy integration (published in 2015):

- System development and field implementation in the German Demo: http://grid4eu.blob.core.windows.net/media-prod/23398/grid4eu_demo1_deliverable_dd13_final.pdf
- Results of the laboratory tests and of the real field trials prior to the demonstration activities in the Italian Demo: http://grid4eu.blob.core.windows.net/media-prod/23481/grid4eu_demo4_deliverable_dd43_final.pdf
- Halfway assessment of the Smart Solar District in the French Demo: http://grid4eu.blob.core.windows.net/media-prod/23655/grid4eu_demo6_deliverable_dd66_final.pdf

Latest GRID4EU technical papers on Renewable Energy integration:

- 2015 CIRED, Jun. 2015, Lyon, France: Thomas Drizard, Christophe Lebossé, France, Benoit Chazottes. 1170 Integration of distributed PV generation: the NICE GRID project
- 2015 CIRED, Jun. 2015, Lyon, France: Lars Jendernalik, Thomas Wiedemann, Peter Noglik, Anton Shapovalov. 0184 The German large scale demonstration project inside GRID4EU: Challenges of an autonomous Medium Voltage control system
- 2014 CIGRE Session, Aug. 2014, Paris, France.: Diana Moneta, Claudio Carlini, Giacomo Vigano, Lilia Consiglio, Daniele Stein et al. Active MV distribution networks: functional validation of the advanced voltage controller in the Grid4EU Italian demonstrator. http://grid4eu.blob.core.windows.net/media-prod/19124/cigre_c6_210_demo4_poster.pdf
- 2014 CIRED session, Jun. 2014, Rome, Italy. Tullio Zannoni, Fabio Campagna, Matteo Quarantelli et al. LTE and PLC technologies for MV network supervision and automation: http://www.cired.net/publications/workshop2014/papers/CIRED2014WS_0107_final.pdf
- 2014 CIGRE Session, Aug 2014, Paris, France Guillaume Foggia, Matthias Muscholl, Jean-Christophe Passelergue, P. Gambier-Morel, Cyril Vuillecard, et al.. The Nice Grid project : Using Distributed Energy Resources to Reduce Power Demand through Advanced Network Management: http://grid4eu.blob.core.windows.net/media-prod/19120/nice-grid_cigre-poster-c6-301-v4.pdf
- 2014 CIRED session. Jun. 2014. Rome, Italy. Andrea Michiorri, Georges Kariniotakis, Fiona Foucault et al.. An aggregator for distributed energy

storage units under multiple constraints in the NICE GRID Demonstrator":	http://www.cired.net/publications/workshop2014/papers/CIRED2014WS_0371_final.pdf

Connected Services in a Responsive Grid

- a new value proposition

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Abstract — **Capping of revenue from the traditional energy selling business, advent of new regulations around sustainability, consumerization of energy technologies along with blurring of industry boundaries as a result of competition from outside service providers are forcing utilities to identify new sources of the revenue around the energy service business. Rise of smart metering is also changing the Grid from a dumb one to responsive one with the self-healing and monitoring facility, even from newer business perspectives.**

Utilities are leveraging the forces of digital and composite technologies like Internet of Things (IoT) around new energy technologies like Energy Efficiency, Demand Side Management, Distributed Generation & Storage and Plug in Hybrid Electric vehicle to create a connected service around a responsive grid. Our paper will highlight the various new connected services such as managing the energy storage for consumer, PHEV charging location optimization and how utilities can earn revenue from the new services and business propositions that seldom existed before. The paper will also analyze the challenges in each of these new services along with defining the business models.

Simultaneously, this paper will tap the latent need of the end consumer by piggybacking technologies to give the end consumer the future which was never dreamt by him before. The responsiveness of this industry will change courts from the consumer side to the utility side, as consumer choice and empowerment takes a front seat. Utilities, on the other hand, will flourish on the newer business models catering to the consumer needs.

Keywords— **Connected services, DSBR, SBR, PHEV, Grid stability, empowered consumers, LOLE, De-Rated capacity margin, Battery storage optimization.**

I. INTRODUCTION- CHALLENGES OF DIGITAL DISTRUPTION AND THE INCREASED IMPORTANCE FOR CHANGE.

A common question that has been posted on the face of the utilities world over is how they are going to sustain the test of being profitable in the face of various developments in the field of enhanced technology and its penetration up to the customer level and to prioritize the most important task of grid stabilization. Today almost every customer has tasted the finest of services provided by the sectors like Banking, telecommunication, online retail and they expect the same service from utility industry which is severely lacking in this aspect. New breed of customers want to have more control on their consumption of energy. Better utilization of energy efficiency measures have also caused the reduced demand from the utilities.

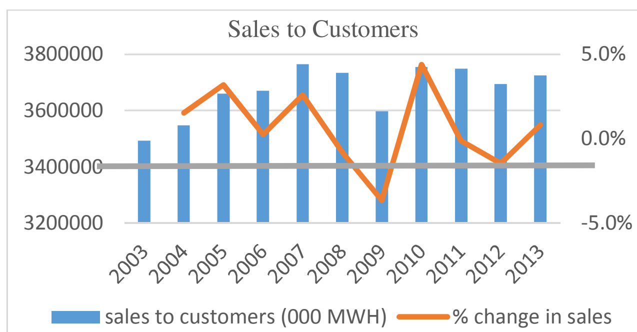

FIGURE 1- SALES TO CUSTOMERS AND % CHANGE IN SALES [1]

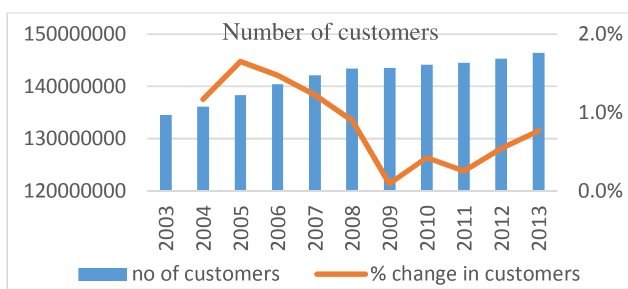

FIGURE 2- NUMBER OF CUSTOMERS AND % CHANGE IN CUSTOMERS [1]

The demand of load growth in advanced countries is becoming near stagnant or increasing at a very slow pace. Electricity retail sales in USA increased by only 0.8% in 2013 from 2012 figures while increase in number of customers marginally increased to 1.5% for the same period concerned [1]. This stagnancy in the sale of electricity can be attributed to various factors like increase in the installation of captive (domestic / commercial) solar power and other distributed generation giving birth to the new class "Prosumers" who are capable of delivering power back to the grid owing to excess generation in the installed rooftop solar power system. The USA solar (PV and Thermal) installation has increased by 108.93% in 2013. The greatest impact of this proliferation is that it is bound to impact the grid in a negative way due to its intermittent nature and uncertain forecast of future generation.

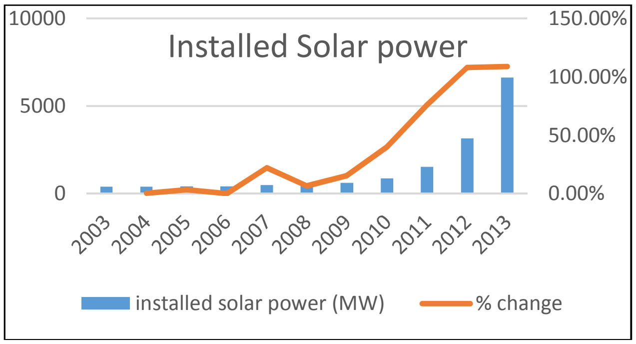

FIGURE 3- INSTALLED SOLAR POWER [1]

As the electricity transmission and distribution are regulated monopoly businesses, so network tariffs are based on a regulated return on their asset base at the start of each regulatory period. If underlying energy growth rates decline, (due to the hollowing out of the day time load by the Solar PV) network tariffs (which form nearly half of final electricity prices) have to be increased if regulated returns are to be met under the current regulatory framework. Falling underlying energy consumption results in higher tariffs, because the heavy fixed costs of networks are spread across fewer units of output, (primarily non Solar PV user) holding all other variables constant. These in turn results further shifting towards solar PV by the consumers (having solar PV) resulting further increase in tariff for the consumers without solar PV. The following figure highlights the "Vicious Cycle "arising out of this situation.

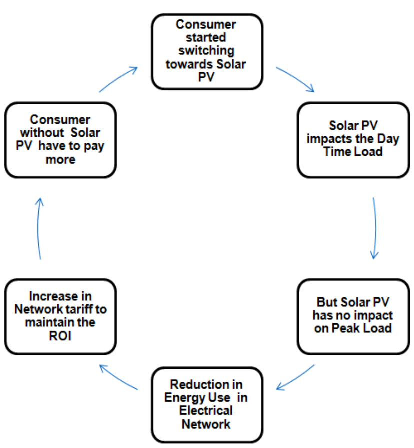

FIGURE 4- PV INDUCED VICIOUS CIRCLE

II. INNOVATIONS BY UTILITIES TO FACE THE CURRENT SCENARIOS

Utilities have now put themselves in a firm gear to combat the challenges present in their face. It is clearly understood by them that in future course of action, only the traditional means of selling electricity will no longer let them stay in the green pastures. They have to innovate otherwise they will succumb to the increasing competitions and challenges in front of them.

FIGURE 5- TIME TO INNOVATE FOR UTILITIES

In this bid to innovate, many utilities world over are re-imagining the business processes so as to have better control over the operational efficiencies and for revenue maximization along with grid stability. Utilities, along with electricity, are now selling new offerings like home insulation, boiler insurance and repair, community solar PV rooftop installation and maintenance etc. to grab more space for them and to interact with customers through multiple channels of emails, calls, letters and messages. Better customer care is identified as a major factor to retain customers with this downstream integration approach.

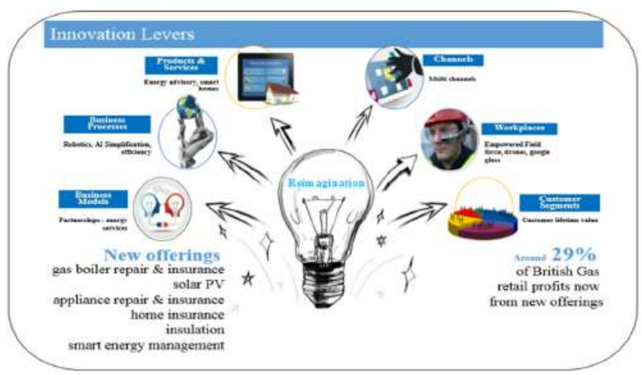

FIGURE 6- RE-IMAGINATION OF PRODUCT & SERVICES BY UTILITIES

New business models and services are now visible in the utility market like Energy saving and energy advisory consulting services, smart and connected homes for a better control by the customers. Advanced artificial intelligence, machine learning and deep learning algorithms are being implemented in homes for an automatic adjustment of heating and lighting based on the historical usage and customer behavioral patterns. Utilities are now empowering its workforce and making it more and more technology fortified. Utility industry is rated at number 7 out of 10 most deadly jobs by Forbes [3]. In a bid to reduce the risks to life and property, utilities are now adapting to latest technologies, some utilities are now using advanced devices like Drones for line and remote area inspection which are hazardous, and this also reduces the cost as previously line inspection was used to be done my hiring helicopters which are costly [4]. Further, products like Infra-red Camera, Google glasses and virtual reality devices are being used to monitor the grids in a more efficient manner [4]. Utilities are at a vantage point in the sense that they possess colossal data related to customers. They are using progressive predictive analytics to segment the customers and targeting the segmented customers as per their needs.

Why need to Innovate?	Example
Empower Consumers , who decide what they need	More conscious consumers turning into "Prosumer" desires much control over their expense towards electricity spending.
Consumerization of Energy technology	Shift from centralized generation to distributed generation. Tesla's Power For All solution which provides a battery power pack installed at home.
New Technologies leapfrogging business	In developing and poor countries, the customers are installing solar rooftops and are by-passing the need to have connected to the centralized grid for their electricity requirements.
Advent of New Regulations	RIIO- Ofgem's framework for setting price controls for network companies. Other examples- EMIR, REMIT, MIFID-2
Decrease in Revenue from Energy selling business	Increased energy efficiency programs and distributed generation has forced utilities to have lesser electricity sales.
Blurring of Industry Boundary	Technology players like Google and Apple are foraying in the electricity market to provide various services like Google glasses, home automation systems etc.

FIGURE 7- WHY NEED TO INNOVATE

III. PRACTICAL SCENARIOS WHERE UTILITIES HAVE IMPLEMENTED INNOVATIVE PRODUCT AND SERVICES.

In a bid to improve the grid stability and counter the forces that pose threat to energy security and to avoid complete blackouts and brownouts, UK's electricity system operator National Grid, in consultation with energy industry and the regulator OFGEM, has proposed and implemented two balancing services so as to balance demand and supply scenarios during the peak time of winter on non-holiday weekdays- 1) Demand Side Balancing Reserve (DSBR) and 2) Supplemental Balancing Reserve (SBR).

Two major parameters driving the market design for Security of Supply are- 1) Loss of Load Expectations (LOLE) - the mean number of hours per year in which supply does not meet demand in the absence of intervention from the system operator and 2) De-rated capacity margin- the average excess of available generation capacity over peak demand, expressed in percentage terms.

UK National Grid	2013/14	2015/16	2018/19
Installed Capacity (GW)	77.9	76.8	83.6
De-rated Capacity Margin (Winters)	6.3 %	3.8%	7.7% (appox.)
LOLE (hours/year)	0.7	2.9	0.3

TABLE 1- INSTALLED CAPACITY, DE-RATED CAPACITY MARGINS AND LOLE [8]

Drawing the graphs for LOLE and De-Rated Capacity Margin clearly evinces the higher degree of negative co-relation between these two quantities and displays the higher possible instances of blackouts/brownouts for three years starting from 2014/15.

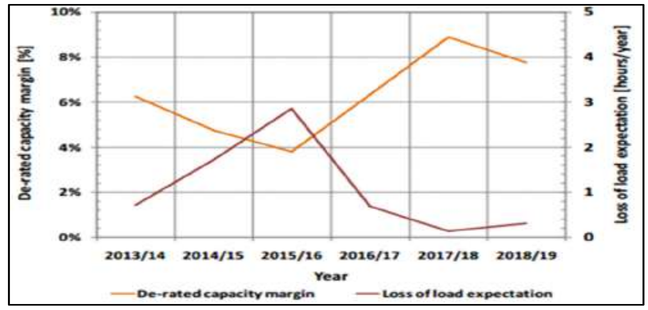

FIGURE 8- DE-RATED CAPACITY MARGINS AND LOLE [8]

The Demand Side Balancing Reserve (DSBR) is aimed at large customers who have at least 1 MW demand and are flexible to reduce their load voluntarily, for example by restoring to captive mode of generation when the demand on the grid is highest between 1600hrs and 2000hrs on winter weekdays in the months November to February after exhausting all feasible balancing mechanism actions.

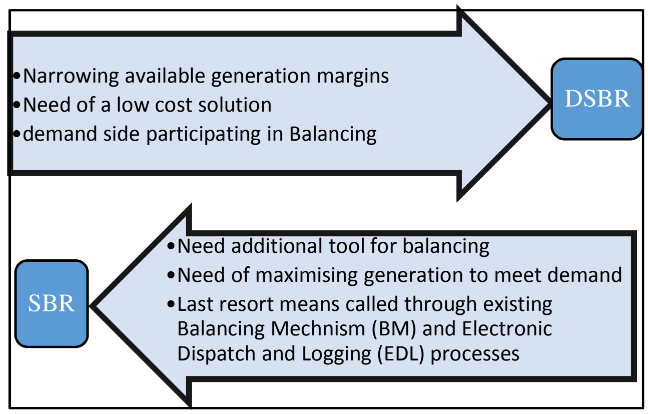

FIGURE 9- DRIVERS OF DSBR AND SBR

By doing this, utilities will not only avoid the costs to build and dispatch new generating plants and the capital for doing the same is distributed as incentives to the providers, but also will not be required to purchase high cost power to meet the demand. While SBR (Supplemental Balancing reserve) is targeted at contracting for reserves from those generating plants that would otherwise be closed or mothballed. Plant would need to be available on winter weekdays between 0600hrs and 2000hrs [7]. These services are estimated to cost around $75m per year and will only increase the cost of consumers' bills by around £1.

Winter of	Max. Volume Needed (MW)	Service to Use
2014/15	330	DSBR
2015/16	1,800	DSBR and SBR
2016/17	1,300	Decision based on on-going need
2017/18	800	

TABLE 2- MW SOURCES PROCURED THROUGH DSBR AND SBR

IV. NEW PRODUCT AND SERVICES WHICH HAVE THE POTENTIAL TO CHANGE THE WAY UTILITIES ARE DOING BUSINESS

Utilities are now taking a leaf from the books of banking and Telecommunication industries and are becoming more and more comfortable in opening up to come face to face with the latest industry trends. The transgression of technology is now clearly evident in everyday functioning of the utilities in the way they used to accomplish various tasks and to manage the stability of the grid. Three areas which have very high potential for utilities to make some business sense and on the other hand to strengthen revenue streams are-

1) Storage Optimization; 2) PHEV Charging Optimization &
3) Empowering the users and tapping their latent needs

1) STORAGE OPTIMIZATION MODEL

On account of greater transgression and acceptance of solar power in the commercial sector and industrial sector, there is a huge opportunity for the utilities to take first movers advantage to provide services to optimize the battery storage which these industrial players are employing at a bigger level. Management of battery storage will help in strengthening the stability of grid by providing power from storage as and when needed. Industrial units install solar and storage units to assure reliable and cheap power 24x7 to continuously run the industrial processes. Utilities can grab this untapped field which is practically untouched by any other industry player till now.

Industrial units are concerned more about their continuous production and are not much concerned whether their battery storage is being used optimally or not. Utilities can provide this service to use the storage optimally in the best interests of industries and can get handsome revenue in return.

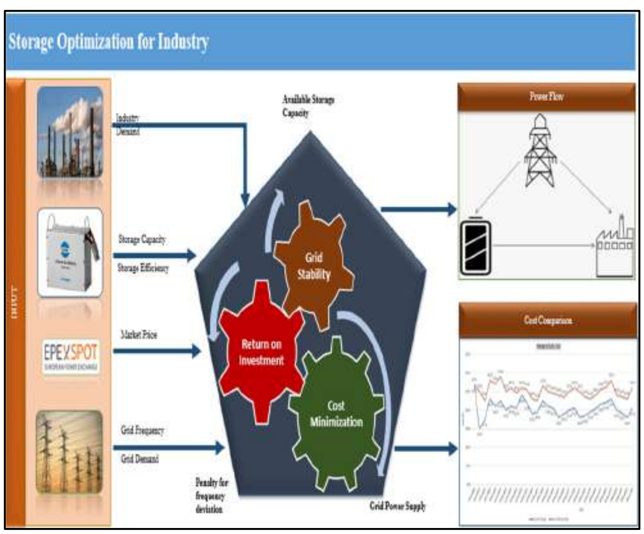

FIGURE 10- STORAGE OPTIMIZATION FOR INDUSTRY

Utilities can better manage the optimization services thanks to the experience gained in this sector from the past years. The optimization model will work upon the real time frequency and price of electricity at the grid. For example- when the frequency is low, it is a threat for overall grid stability, drawing more power at that time can imply huge penalties for the industrial units and this will also dwindles the grid stability. Utilities can thus at this time make arrangement either to take power from the storage or provide power from storage to industry, thus decreasing the load from its own pool of real time electricity demand. This will ensure the double benefit of strengthening the grid and providing reliable power to the industrial unit. There can be four scenarios based on the price and frequency at the real time on the grid.

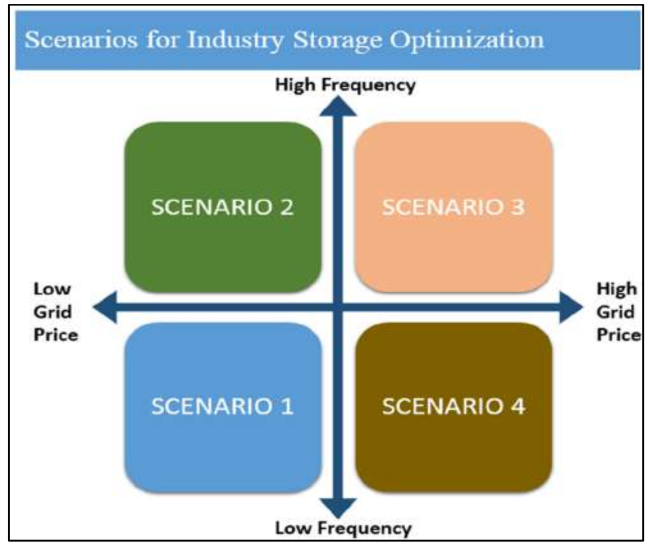

FIGURE 11- SCENARIOS FOR INDUSTRY STORAGE OPTIMIZATION

Based on these four scenarios, each with a different price and frequency match, utilities can choose which can be the best option to have the best utilization of the storage for the industrial unit and at the same time to maintain grid stability.

Scenario 1- when the grid frequency and price both are low. To ensure the stability of the grid, minimum power should be consumed from the grid. Maximum power is given from storage to industry to reduce the load on the grid.

Scenario 2- when the grid frequency is high and grid price is low. To meet the high frequency condition on grid and taking it to a lower level, maximum load should be taken from the grid. So power is supplied to both industry and the storage.

Scenario 3- when both grid frequency and grid price is high (This scenario is very unlikely in the real world situation). In this case to stabilize the grid, the frequency must be reduced by taking more and more power from the grid. But taking the high price in consideration, storage power is used to offset the increased price.

Scenario 4- when grid frequency is low and the price is high. In this case, we have to minimize the load from the grid. Maximum power will be taken from the storage to supply to the industry and minimum power is taken from the grid. In case industrial load is not much and storage is having surplus power, the power can be transferred from storage to the grid.

FIGURE 12- SCENARIO 1

FIGURE 13- SCENARIO 2

FIGURE 14- SCENARIO 3

FIGURE 15- SCENARIO 4

In case, if industrial load is not sufficient enough to utilize all the storage power, utility can take that power during the period of high demand and thus compensating the industry for the same. This will optimize the already existing infrastructure and reduce the threat of stability misbalance on the grid.

2) PHEV CHARGING OPTIMIZATION MODEL.

With the phenomenal improvements in the battery technology, innovative companies like Tesla motors, Toyota, Nissan etc. are finding it easier to pursue the traditional customers to get shifted from conventional internal combustion engine vehicles to more advanced PHEVs (Plugged in Hybrid Vehicles). Result is that consumers have given green node to the electric vehicles which is palpable in the numbers of their sales with greater number of electric cars on the road and increasing percentage of electric car out of total car sales.

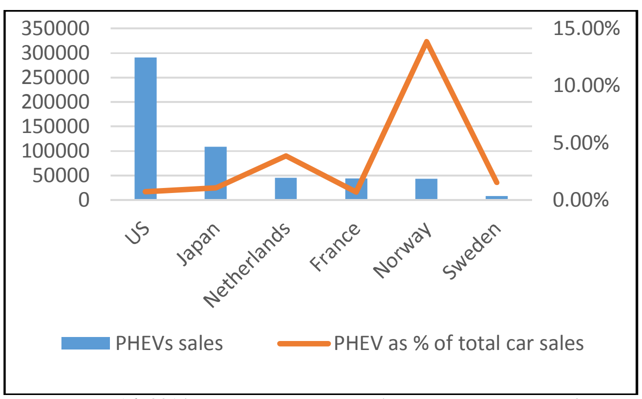

FIGURE 16- 2014 PHEV SALES AND ITS % OF TOTAL CAR SALES [9]

The good news of increased electric car sales is not only a good news for people advocating climate change and reduced carbon emission but also for utilities industries too. Utilities can provide services by setting up stations in the city for the charging of the electric cars or either providing services to third party charging stations by providing information to their customers where they can charge their vehicles in most economical way coupling with minimum time frame to get the same task being accomplished.

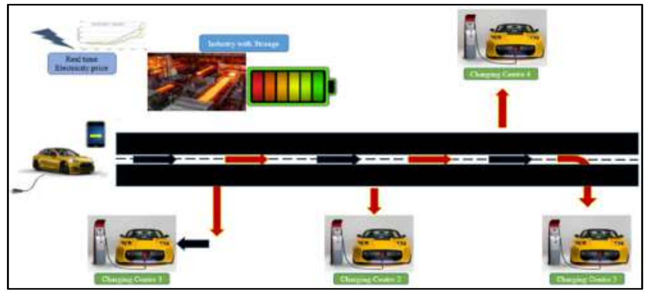

FIGURE 17- PHEV OPTIMIZED CHARGING STATION LOCATION [10]

PHEV charging will employ a perfect blend of the various different real time data like Market data, User data, Demographic data, car console data, Social data, utility internal IT data, partner's data and other miscellaneous/3rd party data.

The customer looking for getting his/her battery charged will simply has to make a simple search on the mobile phone app regarding what is the nearest and most convenient charging station to get the charge at minimum charging rate. The inputs required to find the optimum charging station will depend upon the inputs obtained by the user like- current location, desired level or charging, maximum amount of time that the customer can spend in queue at charging station, charging level in the car, station preference, fuel use priority and station preference etc. This information will be coupled with the other information like charging station output- location of charging station, rush and waiting time at peak hours etc. Third party data will be used to find out traffic congestion to calculate the time reaching at a particular charging station. Partner's data will be utilized to know the offers and footfalls, parking space capacity and occupancy. Further social data will be used to find out the average satisfaction level associated with each charging station. Analytics for identifying the optimized PHEV charging location will be based on the driving patterns (routes), charging habits, car operational data (tire pressure , acceleration etc.) & real time pricing based on the market demand & supply. The output that will be visible on the mobile app screen of the consumer will be- which charging station is best for the consumer to have his/her char charged, what is the current price at the charging station, time in reaching the station and the waiting time at the station with other special offers from other promoters.

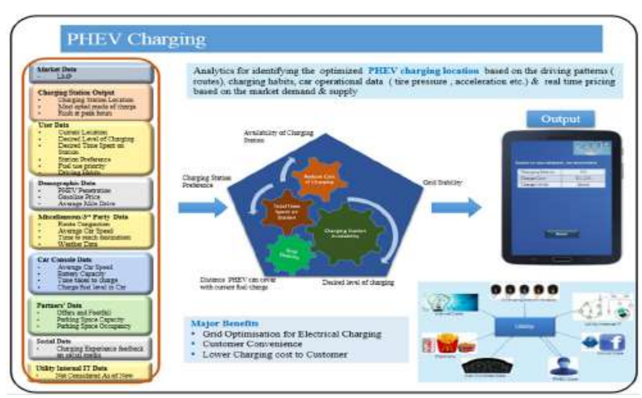

FIGURE 18-PHEV CHARGING MODEL

The charging station location optimization will also help utilities to maintain the grid stability to a greater extent. When the grid frequency is high, they can offer a lower price at a particular geography so as to encourage more and more electricity to be taken out of the grid so as to balance the grid. In case of low frequency, utilities can prompt PHEV owners to get their cars connected to the charging station in order to supply electricity from PHEV to the grid which will provide more available power to the utility so as to manage its demand and supply condition.

3) EMPOWERING THE USERS AND TAPPING THEIR LATENT NEEDS –

a) Marketing through utility platform - The usage pattern of any consumer can now be discretely monitored with the help of meters which can measure the detailed parameters of consumption even up to blocks of minutes or seconds. Thus the detailed pattern of consumer usage of electricity is now at the disposal of the utility, which by utilizing predictive analytics can quite accurately deduce the nature of load switched on and the duration of the same. Dissecting the pattern of consumption with respect to current drawl (initial and steady state), voltage dips, reactive power and active power consumed, harmonics generated etc., there is a possibility of zeroing upon the brand of the product that is being used. This obviously is against benchmark parameters of standard products and their rated usage.

   Such an analytics will help the utility to suggest consumers the best brand according to the nature of usage of the respective consumer and the volume of savings that can be achieved in case the consumer changes his old apparatus for new. This opens a complete new window of marketing that could never have been thought of earlier. A new revenue model can be envisaged by leasing out the utility platform and data to marketing agencies. Simultaneously consumers will get to know that the fan that he is using, if replaced, will save him a couple of hundred bucks per month.

   This definitely involves complex analytics and data from the market, but is a doable one and a perennial revenue spinner, considering regular advances being made in electricity products and appliances.

b) Allowing the consumer to choose his own tariff – Inception of Smart meters now allows to measure data at a very granular level. Piggybacking on the same, tariff can be made dynamic. It will be based on availability over and above an assured minimum, and there can be various packages emphasizing on quality of power (fixed voltage level all throughout), uninterrupted power flow 24 x 7 (less than ‘x’ hours of outage per year), allowed fluctuations on demand etc. On one hand this will give the consumers an insight to their own consumption which they can tailor-make and on the other they can pay as per their need. The utility can put a premium on special services for which the consumers will be glad to pay. Obviously, these services will be over and above the regulatory norms.

V. CONCLUSION

Success of the Connected Service in the responsive grid depends heavily on the adoption and complementation of the proper technologies. Smart metering in utility industry started with a focus towards the efficiency and reliability. The Time of Use tariff along with the interval consumption data will allow the consumer to use energy efficiently resulting lower energy bill and grid stability. However empower consumer is not only happy with the reliability and efficiency but also wants control & convenience. Internet of Things (IoT), which has a tremendous potential in utility industry, will bring the control and convenient element to the empowered consumer. It is already predicted that around 50% of overall machine to machine connections will be accounted by global utilities by 2023 and around 30 billion smart, wirelessly connected devices will be connected in home across global utilities industries by 2020.

For example in UK today, there is already 3 leading service provider around the computerized thermostat technology- British Gas-owned Hive; Google subsidiary Nest Labs and German firm Tado providing the user to control and convenient of adjusting the central heating from anywhere like taking signals from a mobile GIS app to fire up the heating when a resident is heading home to set up schedules that respond automatically to the weather.

The success lies in complementing the Smart Metering infrastructure with the IoT devices to move beyond the grid.

REFERENCES

[1] US Energy Information Administration-Electric Annual Report 2013

[2] http://newsroom.cpsenergy.com/rooftop-solar-expansion/

[3] http://www.forbes.com/sites/jacquelynsmith/2013/08/22/americas-10-deadliest-jobs-2/#2f1d092e5095

[4] http://www.intelligentutility.com/article/15/11/utilities-send-drones

[5] http://www.greentechmedia.com/articles/read/the-virtual-reality-google-glass-assisted-utility-workforce

[6] National Grid open letter. National Grid to contract for new services. (June 10, 2014)

[7] https://www.ofgem.gov.uk/sites/default/files/docs/2013/11/national_grids_proposed_new_balancing_services_-_draft_impact_assessment.pdf

[8] OFGEM Electricity Capacity Assessment Report 2013. (June 27, 2013) https://www.ofgem.gov.uk/ofgem-publications/75232/electricity-capacity-assessment-report-2013.pdf

[9] Wikipedia- Electric car use by the country. https://en.wikipedia.org/wiki/Electric_car_use_by_country

[10] Images taken from websites - https://www.emaze.com/@ALCQTCRL/Sustainable-cars ; http://www.bearing-news.com/tag/steel-industry/

Asset Performance Management : New Predictive Maintenance tool for Indian Utilities to manage the vast assets cost-effectively

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Abstract— Utilities have grown into much wider dimension with the introduction of networked Smart Grids and installation of intelligent devices on the grid network. Major faults and outages on power distribution system have a significant economic and social impact and the availability & reliability of supply becomes a more and more important issue. Hence outage times should be as short as possible. Smart grid technologies such as Predictive Asset Management can help in reducing the outage times after a disturbance. Traditional asset management techniques are no longer sufficient enough to handle the additional complexities that are introduced due to the recent technological advancements. Usage of predictive analytics in asset management business can be an enabler for these Infrastructure heavy utilities to optimize their asset life cycle management costs and to effectively implement Smart Asset Management

Keywords- Maintenance, Reliability, Utility, Predictive, Reactive, Preventive, Online Monitoring, Asset Management.

I. INTRODUCTION

The Electricity Utility industry is an asset and labor intensive sector with geographically dispersed assets such as Generators, Transformers, Equipments, Switchgear, Substations, Feeders etc. It has a much higher rate of usage driven asset degradation than other utility industries and stringent safety considerations due to over utilization of assets beyond rated specifications. On top of that, Utility operations are highly dependent on the health of these assets. Any failure affects the efficiency and reliability of operations, in addition to the huge safety and cost implications. General observation suggests that about 50 percent of all delay minutes are technical in origin and the remaining are attributed to human error and external factors such as weather, vandalism, trespassing, and so on.

Electricity Utilities manage and depend on several critical assets spread across vast geography to ensure Reliability and Availability of Power to end user i.e Consumers. With pressure from new regulations and consumers' awareness, operating with the highest levels of efficiency, reliability and safety is a top priority for utilities.

The growth of distributed generation and diversification of power sources bring more criticality to operational system challenges, including loading issues, less switching flexibility and the potential for reverse power flow, among others. In addition, an aging infrastructure and workforce is also driving the need for asset renewal prioritization and knowledge capture.

This challenge has put Utility operations at center stage. Utilities are continually looking for ways to effectively overcome these industry challenges and remain relevant in the changing energy marketplace. Adapting to new rules, innovating new offerings and investing in cost-saving technologies are just a few of the avenues for transforming these challenges into opportunities.

To achieve high Availability —whether measured in terms of performance indices (SAIDI), Service excellence, revenue growth, profitability or customer satisfaction, utilities are adopting more sophisticated asset management approaches that make it possible to manage diverse and often widely dispersed assets with a single, more easily scaled and deployed system.

II. ASSET MANAGEMENT

Asset Management is for customer centric, end to end integrated operations, that provides total cost of ownership for critical equipments.

Traditional asset and operations management procedures are either fix-on-fail (reactive), or planned maintenance strategies (Preventive), both plagued by high operating or maintenance costs, and lack of reliability of operations. Utility networks are vast and spread over large geographies, passing through difficult and remote terrains with harsh climatic conditions. This makes regular manual inspections and asset condition monitoring a daunting and expensive task, and also puts at risk personnel who must work under pressure during outage conditions.

Some assets require daily and frequent inspection to minimize risks; however, frequent manual inspections are expensive. These practices are dependent on find-and-fix rather than predict-and-prevent, which is more cost-effective.

Predictive maintenance methods use operational and historic data to predict failures before they occur—enabling condition-based maintenance that can considerably reduce operating costs, and improve productivity through uninterrupted operations.

Adopting Remote Condition Monitoring technologies is imperative in order to cover all aspects of Utility asset management and safety systems. Using various types of sensors, it is possible to conduct non-intrusive and automated measurements to report faults and asset condition, allowing preventive maintenance and automated self-correction.

Many leading Utility organizations have started embracing sensor-based technologies to remotely monitor assets to improve their asset management capabilities. Each of these firms is at varying levels of maturity and has a long way to go yet.

III. MAINTENANCE PRACTICES

When considering new investments in predictive monitoring software, Utility organizations should first ensure that a solid maintenance foundation is in place. Reactive Maintenance is the most basic strategy and involves letting an asset run until failure. It is only appropriate for non-critical assets that have little to no immediate impact on safety or the reliability of electricity and have minimal repair or replacement costs so that they do not warrant an investment in advanced technology.

On the other hand, Preventative Maintenance (PM) approaches are designed in hopes that an asset will not reach the point of failure. The PM strategy prescribes maintenance work to be conducted on a fixed time schedule or based on operational statistics and manufacturer/ industry recommendations of good practice.

Condition-based Maintenance (CBM) focuses on the physical condition of equipment and how it is operating. CBM is ideal when a measurable parameter is a good indicator of impending problems. The condition must be definable using rule-based logic, where the rule does not change depending on loading, ambient or operational conditions.

If a potential asset failure could result in significant damage, safety issues or power outages, the risk is obviously much higher, and an even more proactive maintenance approach is required. Predictive Maintenance relies on the continuous monitoring of asset performance through sensor data and prediction engines to provide advanced warning of equipment problems and failures. Predictive Maintenance typically requires predictive analytics software for real-time insights of equipment health and performance.

Predictive asset analytics solutions are a key part of a comprehensive maintenance program to ensure that assets are operating optimally and with little risk to the organization. According to the recent report "Proactive Asset Management with IIoT and Analytics" by ARC Advisory Group, only 18 percent of assets have a failure pattern that increases with use or age. This means that preventative maintenance alone is not enough to avoid failure in the other 82 percent of assets and a more advanced approach is required. Predictive analytics software uses historical operational signatures for each asset and compares it to real-time operating data to detect subtle changes in equipment behavior. The software is able to identify changes in system behavior well before the deviating variables reach operational alarm levels, creating more time for analysis and corrective action.

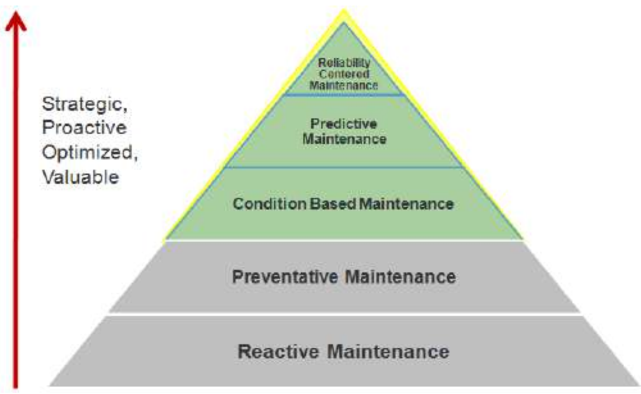

Figure 1. Maintenance Practice Model

All of the aforementioned maintenance approaches create the foundation for Reliability Centered Maintenance (RCM). RCM is a complex prognostic strategy focused on outcomes and is a process for determining what should be done to ensure that an asset operates the way the user intended. RCM is the capstone of a fully integrated maintenance program and can't be sufficiently deployed without a repeatable process for the foundational maintenance practices, which includes using a predictive analytics solution in support of predictive maintenance.

IV. CONDITION MONITORING

Although there are some automated methods for asset and operations data collection and management, manual inspections are still the norm at most Utility companies. These methods suffer from several limitations:

- Asset inspections are carried out as per pre-defined schedules, intermittently, rather than on a continuous basis.

- The asset condition is not known until the next scheduled inspection, and abrupt disruptions are often undetected making it difficult to predict possible failures

- The reasons for operating disturbances can often not be assigned

- The process of manual inspection often makes the asset temporarily unavailable for revenue generation.

Remote Condition Monitoring on a continuous basis enables prediction of asset failures, timely intervention, and informed decisions on intervention strategies.

Beyond infrastructure management and maintenance, RCM data provides useful inputs for numerous business applications in the Utility industry. These include:

- Smart Utility operations to improve operational performance (on parameters such as throughput, reliability, safety, and security)
- RCM data integrated with mobility applications to positively impact the way the Utilities are working
- Predictive and preventive maintenance resulting in operational expenditure (OPEX) and capital expenditure (CAPEX) planning and optimization
- Warranty management of assets and life cycle cost minimization
- Condition-based speed advisory systems to promote safe operations.
- Insights into the performance of products under various field conditions—leading to better product planning and development at the Original equipment manufacturers (OEMs) and other manufacturers end.
- Historical data analysis of asset performance and risk assessment carried out by Utility can drive better supplier selection and informed negotiation

Development of asset deterioration models and depreciation calculations that are more accurate.

V. MAINTENANCE & RELIABILITY BENEFITS

Predictive asset analytics software enables operations and maintenance personnel to address equipment issues before they become problems that significantly impact operations. Unscheduled downtime of the electrical assets can be reduced because personnel receive early warning notifications of developing issues. These advanced analytics solutions can identify problems days, weeks or months before they occur, creating time for personnel to be proactive. Instead of shutting down the operation immediately, the situation can be assessed for more convenient outcomes. Asset constraint could be reduced or the necessary maintenance could be scheduled during a planned outage, if possible. Maintenance costs can also be reduced due to better planning; parts can be ordered and shipped without rush and equipment can continue running. Additionally, some suggested maintenance windows can be lengthened as determined by equipment condition and performance. Other benefits include increased asset utilization and the ability to identify underperforming assets.

Not only do Utility reduce expenses by extending equipment life, lengthening maintenance windows, increasing asset efficiency and increasing availability, other savings are realized when considering the costs that “could have been,” including loss of equipment, replacement of equipment, lost productivity, additional man hours, etc., when a major failure is avoided. Additionally, predictive analytics solutions that transform raw data into easy-to-understand and actionable insights help personnel to further improve availability, reliability and decision-making.

With predictive analytics, personnel know and understand the actual and expected performance for an asset’s current ambient, loading and operating conditions. They know where inefficiencies are and their impact on financial performance and can use this information to understand the impact of performance deficiencies on current and future operations. This information also helps Utilities assess the risk and potential consequences associated with each monitored asset and can be used to better prioritize capital and operational expenditures.

Predictive analytics solutions also provide the capability for knowledge capture, which is increasingly important as many utilities are facing an aging workforce due to an influx of workers retiring. Knowledge capture ensures that maintenance decisions and processes are repeatable, meaning that after more experienced personnel leave the company, the information and decision-making insights remain available for other staff

VI. VALIDATION

In one catch, engineers were alerted via an email notification from the software that aging equipment experienced a vibration step change. The appropriate personnel verified that a proximity probe and casing vibration had both changed, and further analysis indicated a likely loss of mass in the turbine blade path. They immediately suspected shroud material had been lost, based on the unit's history. It was determined that the unit could continue to run at a reduced output, under increased observation, until a more convenient and strategic time to bring it offline. Once it was brought offline, a borescope inspection verified missing shroud material and several other segments that were close to liberating. Had this issue not been identified with predictive analytics software, it could have caused immediate unplanned downtime, loss of generation, possible catastrophic failure and danger to personnel. The vibration step change had not been significant enough to alert the operations staff of this impending condition through standard monitoring practices. The early warning notification and the following staff action resulted in a potential estimated savings of more than $4 million in lost of revenue and repair costs with this one catch alone, in addition to maintaining the safety of the operating engineers

VII. CONCLUSION

The intelligent asset management software allows customers to continuously evaluate and implement improvements and plan for a more efficient workforce, allowing companies to maintain high standards for service and reliability and meet the challenges of future expansion even as budgets and resources tighten. Customers can also use the software as a helpful tool when preparing to purchase, test or accept new Utility Assets and it provides complete visibility into all assets and services, allowing companies to better address regulatory requirements, inventory conventions and international standards

Predictive asset analytics solutions help organizations, systems engineers, controllers, and many other personnel to take advantage of the massive amounts of data available today and use it to make real-time decisions that have a significantly positive impact on impact on the maintenance and reliability of equipment. Early warning detection and diagnosis of equipment problems helps personnel to work more effectively by increasing lead time to plan necessary maintenance, ultimately avoiding potential equipment failure.

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He has more than 20 years of experience in Design and Deployment of Advanced Solution for Power Utilities like SCADA/EMS/DMS/OMS/Feeder Automation for Power Utilities. He played an important role in deployment of Smartgrid Projects in Transmission & Distribution Utilities in India

He is instrumental in promoting and educating oranizations towards the benefits of Advanced Utility Solutions which help Utility in improving Effective and Efficient grid management and thereby achieving end user (Consumer) satisfaction.

Sandeep is active member of various Smartgrid Forums and Organization and has significantly contributed towards Standardization & Specification through various seminars.

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- Member (Power), BIS Smartcity Standard Committee (CED59)
- Member, IEEE Low Voltage DC Forum (LVDC).

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Power flow Control for Energy Resource Connected in Smart Micro-Grid for Unbalanced Condition

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Abstract— **The electric grid is now shifting from centralized generation towards de-centralized generation. Smart micro-grid is gaining momentum as it addresses many grave concerns like climate change and energy security. This paper presents power flow control algorithm for a voltage source inverter (VSI) used in a smart micro-grid under unbalanced voltage conditions. Energy Storage and local energy source are the key components of the smart micro-grid that is required to help stabilize grid having a high percentage of variable, uncontrollable energy sources such as wind or solar, and improve energy security and reliability. Inclusion of storage provides the network operator the ability to stabilize energy supply from un-despatchable sources. There is a variety of technologies that can be used to store energy, but all these technologies have a controllable power electronic interface like VSI to mains (as per IEC 60038 Standard Voltage: 400V± 10%, 50Hz, 3 phase Supply). The control algorithm for VSI in this paper is based on dual vector current control (DVCC). It gives robust operation of the VSI under generalized unbalanced input conditions like unequal conductor impedance of power supply wiring, and load unbalance like delta load that draws unbalanced current. The control algorithm is based on the separate regulation of positive and negative sequence components, allowing the delivery of flattened active power to the mains, while suppressing oscillations at twice grid frequency. The presented control scheme solves power quality problem like unbalanced supply in smart micro-grids in cases of grid disturbances. The control scheme is implemented in MATLAB/ Simulink model and the simulation results are presented. The results show the effectiveness of control scheme and are found in accordance with IEC standards and Engineering Recommendation P29.**

Keywords—Smart micro-grid, dual vector currenrt control, energy storage, local energy source, power qualilty.

I. INTRODUCTION

In the last two decades, the nature of electric grid is changing from centralized power generation, towards renewable distributed power generation. Economic, technological and environmental incentives are changing the face of electricity generation and transmission [1]. Limited conventional energy resources, high energy consumption, environmental pollution (GHG emission) and sustainable energy requirement calls for exploiting renewable energy resources [2], [3]. Especially photovoltaic and wind power stations have entered into distribution network. On account of these new problems are emerging, as many of these distributed generators (DG) uses power electronic interfaces like voltage source inverter (VSI) to mains [4], [5].Current controlled VSI are widely used in power conversion applications due to decoupled power flow control, fast dynamic response, and high power quality injection [6], [7]. Micro-grids are becoming popular now a days owing to its advantages like network operational benefits such as loss reduction, as it is near to customers, improved energy efficiency, reduced environmental impact, reliability of supply, congestion relief, more cost effective electricity infrastructure replacement.

US department of energy (DOE) defines micro-grid as "A group of interconnected loads and distributed energy sources (DER) with clearly defined electrical boundaries that acts as a single controllable entity with respect to the grid [and can] connect and disconnect from the grid to enable it to operate in both grid connected or island mode". This definition is also adopted by EPRI. Unbalanced grid voltage sags, are quite common particularly on weak grids. Another cause of unbalance is the insertion of three phase loads with unbalanced impedances: a delta load that draws unbalanced currents will determine positive as well as negative sequence components in the voltage across the system. So an optimized control strategy for power flow can support grid [4]. A flexible converter current control strategy providing grid voltage support for different types of voltage sag was introduced in [8]. A novel three phase four leg VSI based load unbalance compensator (LUC) including its control algorithm is proposed in [9].

As a consequence of unbalanced conditions, oscillating components at twice grid frequency in both the active and reactive powers, as well as in dc link voltage, can appear [10], [11]. A DVCC is proposed in [12] to achieve robust operation of the voltage source converter under unbalanced input conditions. In [4] modified DVCC with grid current limitations, and elimination of reactive power oscillations at twice grid frequency is proposed. In this paper the same method is extended to unbalanced voltage condition in a micro-grid. The micro-grid is operating under droop control method for voltage and frequency stabilization [13].

This paper is organised as follows. Section II presents the definition of voltage unbalance and its mathematical description for analysis. Section III describes the DVCC scheme. Section IV explains the simulation model and results are discussed in section V. Section VI is the conclusion of this paper.

II. Voltage Unbalance: Definition and Mathematical Description

By 2003 the 380V, 400V and 415V, three phase, 50Hz final distribution voltages in many countries will comply with the IEC60038, 400V standard supply voltage of 400±10% [14], [15]. In a three phase system, the degree of voltage unbalance is expressed by the ratio (in percent) between the rms values of the negative sequence component and the positive sequence component of the voltage [14]. This ratio may be approximated (for values of voltage of a few percentage) as:

Voltage Unbalance (%) = (Maximum deviation from the average of three phase voltages) / (average of three phase voltages)*100

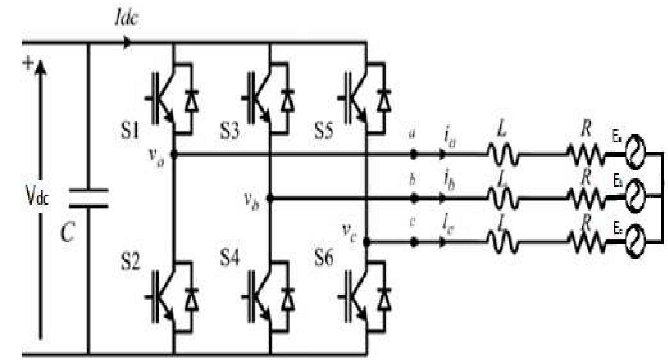

Fig. 1 Structure of VSI

An unbalanced three phase input voltage without a zero sequence, can be represented as the orthogonal sum of positive and negative sequence [12]. This is applicable to grid disturbances, such as voltage sags, phase jumps, or amplitude variations also [4]. The system voltages and currents could be represented by their positive and negative sequence components. Therefore, an unbalanced system of the three phase voltages (E*a, Eb, Ec*) could be represented with its positive sequence component ($E^p_{dq} = E^p_d + jE^p_q$) and negative sequence ($E^n_{dq} = E^n_d + jE^n_q$) as

$$E_{\alpha\beta} = e^{j\omega t}\, E^p_{dq} + e^{-j\omega t}\, E^n_{dq}$$

where $E_{\alpha\beta} = \sqrt{(2/3)}\,(E_a + E_b\, e^{j2\pi/3} + E_c\, e^{-j2\pi/3})$ is the grid voltage vector expressed in stationary reference frame, in its power invariant form. Similarly grid current can also be represented in stationary reference frame $i_{\alpha\beta}$.

From the structure of VSI in Fig. 1 the inverter pole voltage in stationary reference frame can be written as

$$v_{\alpha\beta} = E_{\alpha\beta} + \frac{L\,d\, i_{\alpha\beta}}{dt} + R\, i_{\alpha\beta}$$

where R is the grid resistance and L is the grid inductance and

$$v_{\alpha\beta} = \sqrt{\frac{2}{3}}\,(v_a + v_b\, e^{j2\pi/3} + v_c\, e^{-j2\pi/3})$$

$$i_{\alpha\beta} = \sqrt{\frac{2}{3}}\,(i_a + i_b\, e^{j2\pi/3} + i_c\, e^{-j2\pi/3})$$

where $v_{\alpha\beta}$ and $i_{\alpha\beta}$ denote inverter pole voltage and line current respectively. The equations are explained thoroughly in [4], [12].

The instantaneous power could be expresses as

$$s = E_{\alpha\beta}\, i_{\alpha\beta} = p(t) + jq(t)$$

where active power $p(t)$ and reactive power $q(t)$ are

$$p(t) = P_0 + P_{c2}\cos(2\omega t) + P_{s2}\sin(2\omega t)$$

$$q(t) = Q_0 + Q_{c2}\cos(2\omega t) + Q_{s2}\sin(2\omega t).$$

Terms P_0 and Q_0 are the average power and P_{c2}, P_{s2}, Q_{c2}, and Q_{s2} are magnitude of power oscillations caused by the unbalance [12].

In [12] with the use of DVCC active power is transferred to grid by suppressing twice grid frequency component and at zero average reactive power. But its performance is seen to be poor for sever voltage sag with high grid current values. This issue is also taken care of in [4] by generating a proper current reference as follows:

$$\begin{bmatrix} I^2_{grid} \\ Q_0 \\ P_{c2} \\ P_{s2} \end{bmatrix} = \begin{bmatrix} I^2_{Lim} \\ 0 \\ 0 \\ 0 \end{bmatrix} = \begin{bmatrix} i^{pf*}_d & i^{pf*}_q & i^{nf*}_d & i^{nf*}_q \\ E^{pf}_q & -E^{pf}_d & E^{nf}_q & -E^{nf}_d \\ E^{nf}_q & -E^{nf}_d & -E^{pf}_q & E^{pf}_d \\ E^{nf}_d & E^{nf}_q & E^{pf}_d & E^{pf}_q \end{bmatrix} \begin{bmatrix} i^{pf*}_d \\ i^{pf*}_q \\ i^{nf*}_d \\ i^{nf*}_q \end{bmatrix}$$

The superscript f indicates that the quantities are filtered. The first condition in conventional DVCC is replaced by current limiting condition, as $I_{grid} = I_{Lim}$ instead of $P_0 = P_0^*$ by doing this the actual active power is now determined by set current limit and grid voltage. The current reference is obtained as

$$i^{pf*}_d = \frac{I_{Lim}\, E_d^{pf}}{D}$$

$$i^{pf*}_q = \frac{I_{Lim}\, E_q^{pf}}{D}$$

$$i^{nf*}_d = -\frac{I_{Lim}\, E_d^{nf}}{D}$$

$$i^{nf*}_q = \frac{-I_{Lim}\, E_q^{nf}}{D}$$

where $D = \sqrt{((E^{pf}_d)^2 + (E^{pf}_q)^2 + (E^{nf}_d)^2 + (E^{nf}_q)^2)}$

The power delivered to grid is smaller than the conventional one [4].

III. Dual Vector Current Control Scheme

The presence of negative sequence components in the voltage during unbalanced condition causes negative sequence current and ripple in the power injected to the grid. This can causes critical grid current peaks and dc bus voltage fluctuations. The conventional controller gives poor performance under unbalanced voltage conditions. Fig. 2 shows VSI control using DVCC scheme.

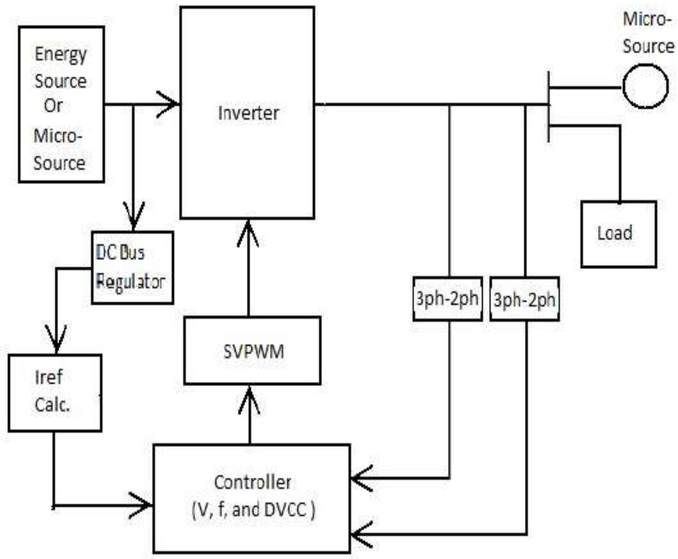

Fig. 2. VSI control using DVCC scheme

In DVCC two synchronous rotating frames (SRF) are used, one for measuring positive sequence in positive SRF by eliminating the negative sequence with signal delay cancellation. And other, for negative sequence in negative SRF. These two separately measured currents are used for two feedback proportional integral (PI) controller hence the name dual vector current control. One regulates positive sequence in positive SRF and other negative sequence in negative SRF. Each appears as dc signal in its own SRF, hence there is no need to increase control gain which makes the system unstable. This also ensures complete dc regulation and zero reactive power.

To implement dual current controller, the measured current is represented in stationary frame as:

$$i_{\alpha\beta} = e^{j\omega t}\, i_{dq}^{\,p} + e^{-j\omega t}\, i_{dq}^{\,n}$$

multiplying $i_{\alpha\beta}$ by $e^{-j\omega t}$ and $e^{j\omega t}$, will give the expressions in positive and negative SRF's respectively.

$$i_{\alpha\beta}\, e^{-j\omega t} = i_{dq}^{\,p} + e^{-2j\omega t}\, i_{dq}^{\,n}$$

$$i_{\alpha\beta}\, e^{j\omega t} = e^{2j\omega t}\, i_{dq}^{\,p} + i_{dq}^{\,n}$$

The positive and negative sequences can then be separated.

In the positive SRF, the positive sequence inverter pole voltage v_d^p, v_q^p are determined by

$$v_d^p = E_d^p - (PI)(i_d^{p*} - i_d^p) + \omega L i_q^p$$

$$v_q^p = E_d^p - (PI)(i_q^{p*} - i_q^p) - \omega L i_d^p$$

where PI denotes a controller. Similar equations for negative sequence are

$$v_d^n = E_d^n - (PI)(i_d^{n*} - i_d^n) - \omega L i_q^n$$

$$v_q^n = E_q^n - (PI)(i_q^{n*} - i_q^n) + \omega L i_d^n$$

The cross coupling terms $\omega L i_p^q$, $-\omega L i_d^p$, $-\omega L i_q^n$, $\omega L i_d^n$ are feed-forward and added with outputs of PI controller to decouple d-q axes dynamics [12], [10]. The procedure for obtaining voltage components E_d^p, E_q^p, E_d^n, E_q^n is identical to that of obtaining current component.

Finally the controller output in SRF is brought back to stationary frame and is summed to yield voltage vector for Space vector PWM (SVPWM).

IV. Overall Simulink Model for DVCC

The overall simulink model is shown in Fig. 3. The energy storage block consist of battery and dc link capacitor whose voltage is feedback to the dc link voltage controller. The inverter block consist of IGBT switches, whose gating signal is obtained from the SVPWM block, in accordance with the DVCC scheme.

The micro source block, consist of a SEIG as wind generator, coupled to ac to dc converter, a solar PV with MPPT controller, and a battery for stabilising dc input, finally all the three dc is given to a dc to dc converter. This dc to dc converter feeds the inverter which operates on droop control method to generate a stable voltage and frequency.

The unbalance is brought in the model with the help of a circuit breaker and impedance combination. At a pre-determined time the CB operates to introduce the unbalance in the system. The unbalance is sensed by the measuring device and is given to the sequence separation block.

The sequence separation block consist of abc to αβ transformation block, SRF transformation block, and signal delay cancellation block (Fig. 5). These separate the unbalanced voltage and current into its positive sequence dq components and negative sequence dq components.

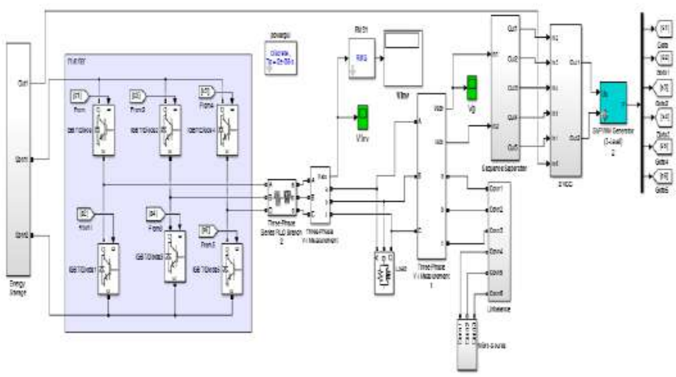

Fig. 3 Overall simulink model for DVCC scheme for unbalanced grid voltage condition.

For separating twice grid frequency negative sequence component from positive SRF, a low pass filter could also have been used, but signal delay cancellation (SDC Fig. 4) is used here, because it is much faster than the other [10]. The blocks for sequence separation are shown in Fig. 5. The three phase currents and voltages is converted to two phase stationary reference frame. With the help of three phase PLL block the two phase stationary frame is converted to two phase synchronous rotating frame. Then with SDC method the positive sequence and negative sequence is separated.

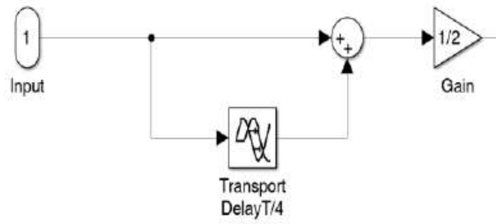

Fig. 4 Signal delay cancellation for separating negative and positive sequence components in SRF.

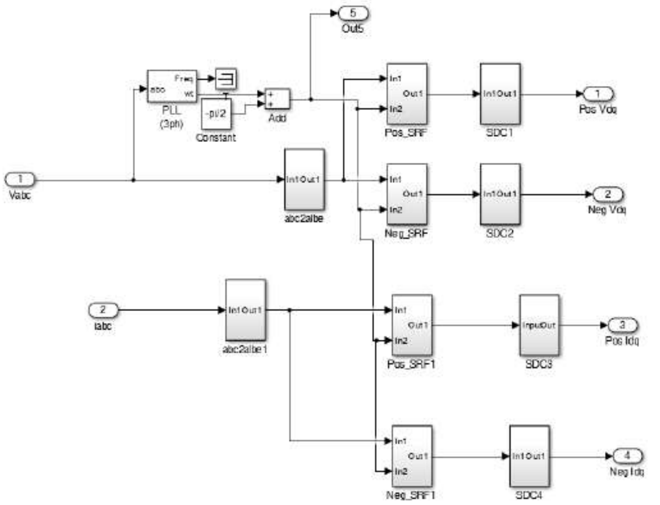

Fig. 5 Separation of positive and negative sequence

The DVCC block shown in Fig. 6 in consist of elements which implement the control logic.

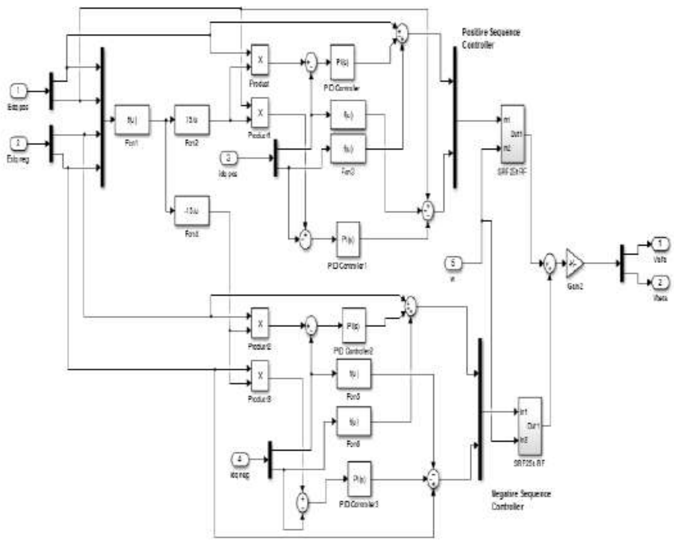

Fig. 6 DVCC block

The controller output is then converted to stationary reference frame and is given to the SVPWM block to generate appropriate gate pulse to turn on the VSI accordingly.

V. Simulation Results

The International Electrotechnical Commission (IEC) recommends that the maximum voltage unbalance of electrical supply systems be limited to 2%. Concurrently, NEMA, the developer of ANSI C84.1-1995, in the standard NEMA MG1-1993 "Motors and Generators" recommends that for voltage unbalance greater than 1%, induction motors should be de-rated by the appropriate factor. IEC standards also restrict the permissible voltage unbalance on induction motors to 1% and require a de-rating of the machines if unbalance is greater [14], [15].

As is clear from these standards unbalance is a sever issue and often go undetected, it can cause damage to consumer equipment. The effect will be more common in weak grids like micro-grid. With these VSI becoming common to interface either energy storage or energy source to smart micro-grid. A small modification in power flow control can also improve the voltage profile of the micro-grid. Fig 7 and 8 shows grid voltage without and with DVCC in pu.

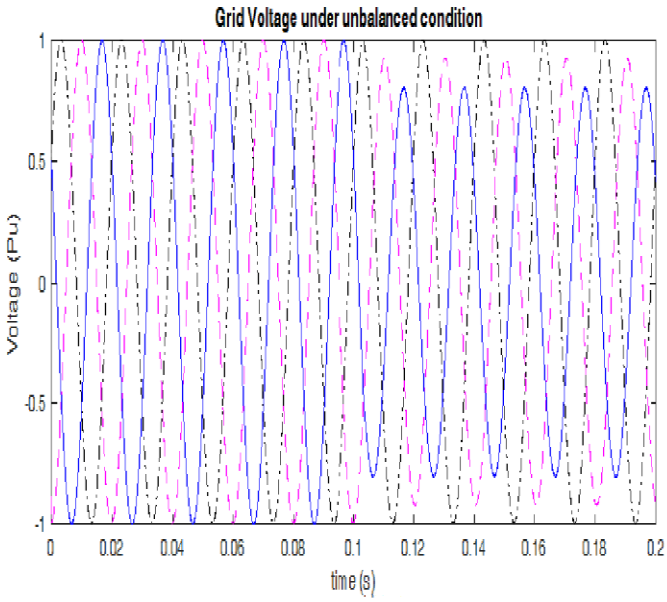

Fig. 7 Grid Voltage under unbalance in pu

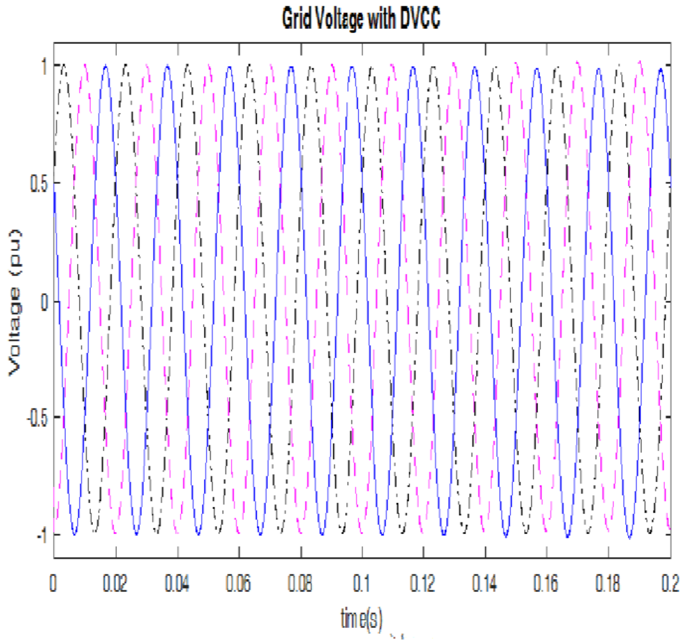

Fig. 8 Grid Voltage with DVCC in pu

Different amount of unbalance is also applied till 40% and the results are within 1% unbalance, and are acceptable as per standards. But as the system being considered is three phase three wire an unbalance applied to one phase is reflected to other phase also. And also in this method zero sequence components is not considered. Fig. 9 and 10 shows inverter output with and without DVCC.

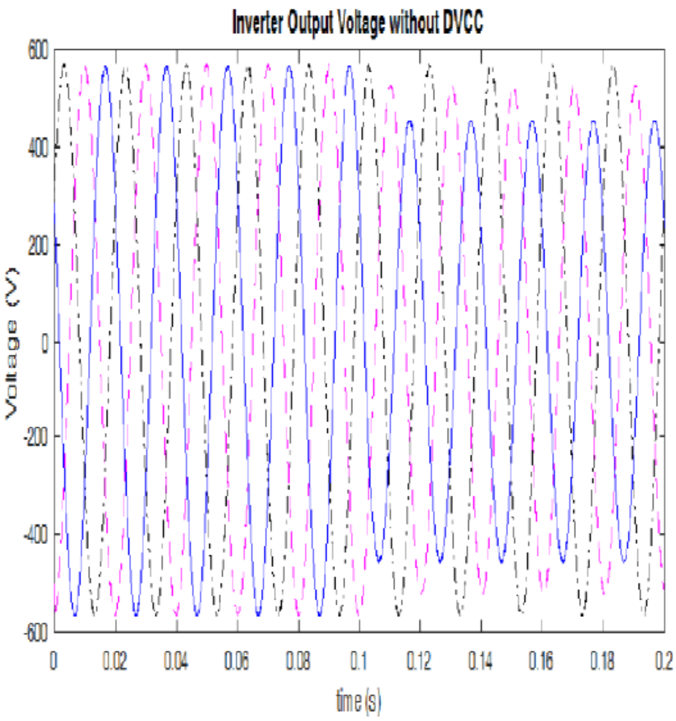

Fig. 9 Inverter output with conventional controller

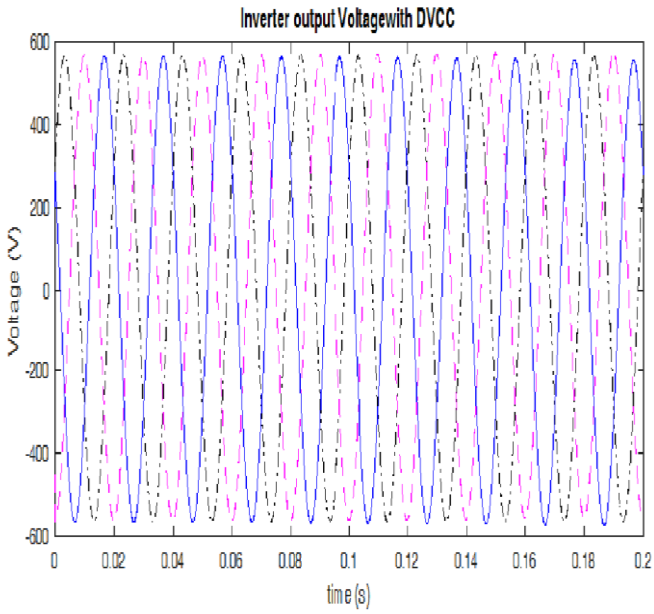

Fig. 10 Inverter output with DVCC

Different load conditions were applied and it was seen that the unbalance effect was becoming prominent as the load increases. Fig.11 shows a marginal unbalance in inverter output voltage as the load increases to full load, but the unbalance is well within limits as per the standards.

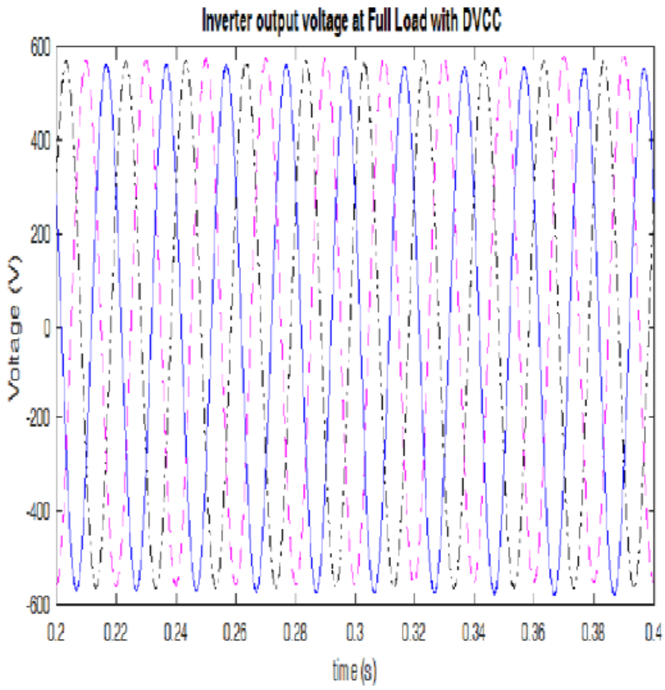

Fig.11 Inverter output with DVCC and full load.

VI. CONCLUSION

In this paper the dual vector current control scheme is extended to a smart micro-grid during unbalanced voltage condition. A smart micro-grid due to its lack of inertia, is inherently a weak grid, and the chances of occurrence of unbalanced voltage is more here. The effectiveness of control strategy is showed by simulation results. Its effectiveness is tested by different load conditions varying from 10% load to 100% load. And for different percentage of unbalance upto 40%. The percentage unbalance after implementing the controller is found to be well within the limits as per IEC standards, and Engineering recommendation P29.

The system under study is three phase three wire and in future can be extended to three phase four wire system which would be more realistic. Unbalance due to short circuit faults are to be addressed. DVCC scheme does not take care of zero sequence component, which can also be addressed properly in future.

REFERENCES

[1] N. Phuangpornpitak, and S. Tia, "Opportunities and challenges of integrating renewable energy in smart grid system", *10th Eco-Energy and Material Science and Engineering Symposium* (EMSES 2012), SciVerse ScienceDirect.

[2] J. A. Pecas Lopes, N. Hatziargyriou, J. Mutale, P. Djapic, and N. Jenkins, "Integrating distributed generation into electric power systems: A review of drivers, challenges and opportunities", ScienceDirect *Electric Power System Research*, Oct. 2006.

[3] Mamatha Sandhu and Tilak Thakur, "Issues, Challenges, Causes, Impacts and Utilization of Renewable energy Sources – Grid Integration", *International Journal of Engineering Research and Applications* ISSN: 2248-9622, Vol. 4, Issue 3, (Version 1), pp. 636-643, March 2014.

[4] Zoran R. Ivanovi´c, Evgenije M. Adˇzi´, Marko S. Veki´, Stevan U. Grabic, Nikola L. Cˇ elanovic´, and Vladimir A. Katic, "HIL Evaluation of Power Flow Control Strategies for Energy Storage Connected to Smart Grid Under Unbalanced Conditions," *IEEE Trans. Power Electron.*, vol. 27, No. 11,pp.4699-4710, Nov. 2012.

[5] S. Sumathi, Ashok Kumar L., P. Surekha, Book on "Solar PV And Wind Energy Conversion Systems - An Introduction To Theory, Modeling With Matlab/Simulink, And The Role Of Soft Computing Techniques" – *Green Energy and Technology, Springer;* 2015 edition (20 April 2015) , ISBN-10: 3319149407, ISBN-13: 978-3319149400.

[6] Viktor Valouch, Martin Bejvl, Petr Šimek, and Jiˇrí Škramlík, "Power Control of Grid-Connected Converters Under Unbalanced Voltage Conditions," *IEEE Trans. Ind. Electron.,* vol. 62, No. 7, pp.4241-4248, July 2015.

[7] S. Chacraborty, B. Kramer, and A. Kroposki, "A review of power electronics interfaces for distributed energy systems towards achieving lowcost modular design," *Renew. Sustainable Energy Rev.*, vol. 13, no. 9, pp. 2323–2335, Dec. 2009.

[8] A. Camacho, M. Castilla, J. Miret, J. C. Vasques, and E. Alarcon-Gallo, "Flexible voltage support control for three-phase distributed generation inverters under grid fault," *IEEE Trans. Ind. Electron.*, vol. 60, no. 4, pp. 1429–1441, Apr. 2013.

[9] Gyeong-Hun Kim, Chulsang Hwang, Jin-Hng Jeon, Jong-Bo Ahn, Eung-Sang Kim, "A novel three phase four leg inverter based load unbalance compensator for stand alone micro-grid," *Elsevier Electrical power and Energy system*, vol.65, pp. 70-75, Sept. 2014.

[10] Yi Zhou, Paul Bauer, Jan A. Ferreira, and Jan Pierik, "Operation of grid connected DFIG under Unbalanced grid voltage condition," *IEEE Trans. Energy Conv.*, Vol. 24 No.1, Mar. 2009.

[11] Martin Bejvl, Jan Svec, Josef Tlusty, and Viktor Valouch, "Control strategy of PWM rectifiers connected to unbalanced grids," *Renewable Energy and Power Quality Journal*, No.11, Mar. 2013.

[12] H. Song and K. Nam, "Dual current control scheme for PWM converter under unbalanced input voltage conditions," *IEEE Trans. Ind. Electron.*, vol. 46, no. 5, pp. 953–959, Oct. 1999.

[13] Li- Jun Qin, and Wan-Tao Yang, "Micro-grid droop control strategy and isolated island operation system stability analysis," *WSEAS Trans. Power Systems*, Vol. 10, 2015.

[14] *Technical Report EPRI*, "Voltage Unbalance: Power quality issues, related standards and mitigation techniques- Effect of Unbalanced voltage on end user equipment performance," B. Banerjee, June 2000.

[15] *Engineering Recommendation P29*, 'The Electricity Council, Planning limits for voltage Unbalance' in the United Kingdom March 1990.

Survey on Smart City Frameworks

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***Abstract*—In view of the global trend of growing urbanization, especially in the developing countries, the concept of smart cities is becoming critical in framing the thinking of policy makers, government officials, decision makers, local authorities and general public. On the other hand, Smart Cities have already become a reality in many parts of the developed world. In this context, this paper surveys the existing frameworks for smart cities to provide a guideline for formulating frameworks for smart cities in the developing countries. The contributions of this paper are twofold. (1) survey and analysis of some of the prominent smart city frameworks, (2) brief review of ongoing initiatives for the development of smart cities in India. It is observed that, certain modifications are needed to map the existing frameworks to suit the requirements of specific cities, on a case to case basis.**

***Keywords*—Smart Cities Mission, Frameworks, Urban Development, AMRUT**

I. INTRODUCTION

In 1992, "Smart Growth" became a new paradigm which replaces the urban sprawl and was primarily driven by architects, planners and community activists. This concept targets the growth in city which takes place in small, where the particular community involves in taking development decisions that are predictable, fair and cost effective. Different ways of urban planning and design arrived during this period. This approach became more popular during 1990s, but later a new concept of "Intelligent cities" evolved which faded the old one. Intelligent cities includes how the data acquisition can be done and applying the information technology to the cities function based on the data available. The inception of 'Smart City' has taken place based on the arguments on smart growth and intelligent cities. During the same period different companies, laboratories came up with smart technology initiatives for cities. In 2008, there was a global economic crisis where all the urban finances were cut and even private sector was asked for assistance in public services. This is the point where smart city model was evolved in which a city is considered as a complex information flow. This model assumes a common goal i.e., increasing efficiency in all sectors such as health care, transport, energy, water and gas management, etc [1].

A. Need for Smart cities in India

The three factors that are driving the world towards smart cities are Urbanization, Economic Growth and Environmental Factors.

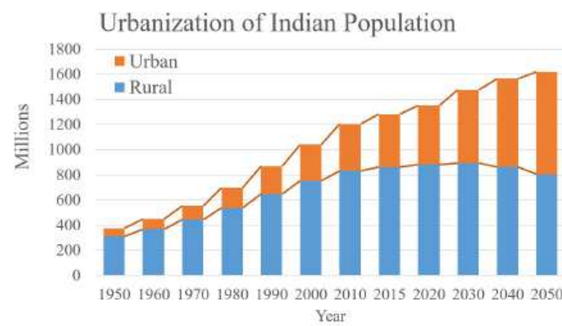

Fig. 1. Trend of Urban of Population of India [2]

1) Urbanization: After the World War II in 1950, according to United Nations population division, urban population was just 29% of the total population in the world whereas rural population was 70% of total population. In 2010, urban population was 51% of total population and rural was 48% of total population. It is predicted by United Nations that in 2050, urban population may rise 66% of total population and rural population will decrease to 33%. This statistics shows that urban population is increasing depicting the migration of people from rural areas to urban cities [2]. Similar is the case with India which shown in Fig. 1. In India also there is a clear trend of shifting population from rural to urban areas. This trend is projected to continue upto 2050 and beyond.

2) Economic Growth: As the population is increasing the cities must be able to provide the resources that are required for the people. According to World Bank 80% of GDP share is from urban cities [2]. In the Indian scenario the share of cities in the GDP has been project to increase from 37.7% in 1970-71 to 75% by 2030-31 as shown in Fig. 2. Thus, the cities are going to become engines of development and hence have become the focus of developing countries. are driving the countries to build smart cities.

3) Environmental factors: Urbanization leads to the environmental issues like increase in CO_2 emissions as shown in Fig. 3. As it can be observed from the figure that there is almost linear increase in carbon emissions since 1960 to 2010. There are several reasons for carbon emission growth in urban cities. One of the main reason is carbon emission from vehicles, which can be decreased by using electric vehicles which are pollution free. Similarly by adopting the renewable technologies for power generation may decrease the carbon emissions in power generation. Thus by adopting new smart technologies the carbon emissions can be reduced. This is one

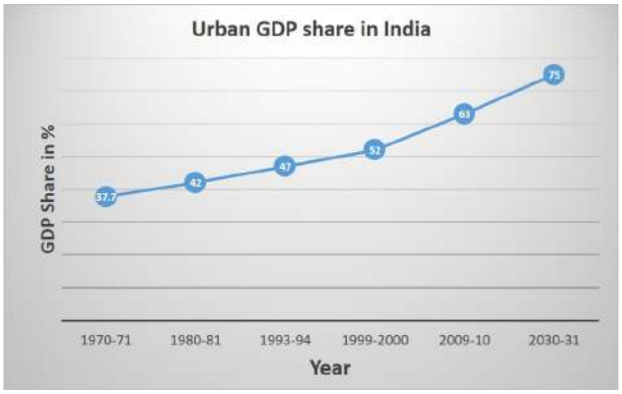

Fig. 2. Share of cities in GDP of India [8]

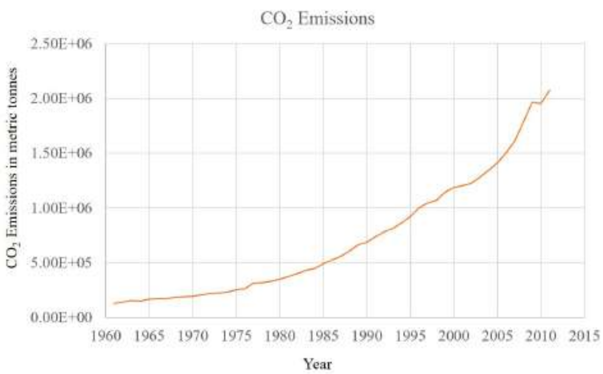

Fig. 3. CO_2 emissions in India

of the serious factor that is driving the world towards smart cities [2].

B. Definitions of Smart City

Several definitions have been proposed in the literature for the term smart city. Here we present a few prominent definitions for quick reference.

- Giffinger et al. [3], defined smart city as the governance of cities which includes citizen participation in order to achieve quality of life.
- Smart cities council [4] defined smart city as - a digital technology that combines all city functions for achieving livability, workability and sustainability.
- According to Caragillu and Nijkamp [5] a city is said to be smart if there is intelligent management of natural resources though customer participation.
- Frost and Sullivan [6] defined smart cities with eight features which include “smart governance”, “smart energy”, “smart building”, “smart infrastructure, “smart technology, “smart health-care, “smart mobility” and “smart citizen”.
- Institute of electrical and electronics engineers (IEEE) smart cities initiative working group, smart city is a technology that brings economy, mobility, environment, people, living, governance under one platform for enabling quality life [7].
- According to smart cities concept note by the ministry of urban development, Government of India - smart city offers continuous solutions in terms of economic and employment opportunities to a large section of people based on their skills [8].
- According to US India business council (USIBC) white paper [11] - Smart cities are the integration of information technology, telecommunications, urban planning, smart infrastructure and operations in an environment geared to maximize the quality of life for a city’s population.
- Based on the above definitions we define smart city is a city which improves the quality of life by involving the citizens, using the digital technologies or ICT technologies with effective utilization of resources.

II. Survey of Smart City Frameworks

A framework is a conceptual structure which provides a skeleton of interlinked components to provide necessary guidelines for developing an understanding and establishing a common background for discussion of solutions. This section explains different frameworks from various companies, countries and organizations that are available in literature of smart cities.

A. Smart city initiative design (SCID) framework

The SCID framework is designed based on the reference architecture and conceptual model. The reference architecture contains core aspects and specifies the impact of smart city initiatives on policy domains of government. The reference architecture comprises of three core concepts of relevance to the city policies, design in accordance with the government policies and stakeholder knowledge needs, and the knowledge base is developed based on the available sources of information. In the research framework design process the major steps are:

- Identification and motivation of problem.
- Definition of objectives for the framework.
- Design and development of the SCID Framework.
- Demonstration of use of the Framework.
- Evaluation of framework and
- Communication of the framework.

The obvious objectives of the smart city initiatives are to be recognized through real strategies. In order to realize the larger city transformation outcome which are desired by the stakeholder group, the design has an impact on policy domains and specific aspects of the city. Also the initiatives need to address the environmental factors, which are possessed with certain challenges and at the same time considering the past lessons. It is the responsibility of the managers of the smart city to recognize the ways for institutional and governance mechanism for addressing the critical success factors and challenges. The model provides the clear link between the outcomes and the initiatives. [9] In similar to the conceptual

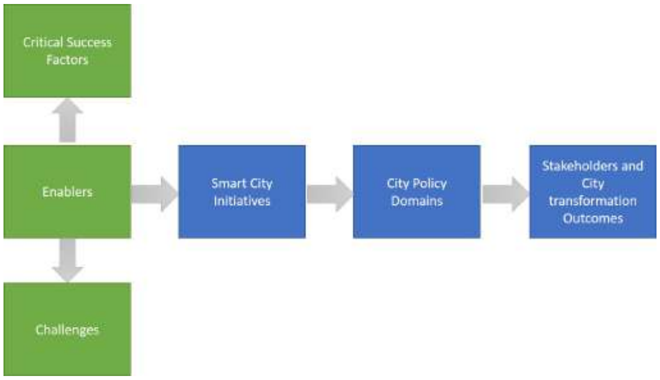

Fig. 4. Framework by SCID

Fig. 5. Cisco Framework

model SCID framework shown in Fig. 4 also contains six elements such as

1) Smart City Initiatives- specific smart city related program or project to be implemented.
2) City Polity Domains- impact by the initiatives on related city aspects.
3) Stakeholders and city transformation outcome- predictable effects on whole city and anticipated results by wider stakeholder group of smart city.
4) Enablers- institutional, partnerships and governance mechanisms for addressing challenges and critical factors.
5) Critical Success Factors- set of factors that contribute in achieving success in initiatives of smart city.
6) Challenges- problems that appear to policymakers in the implementation of smart city initiatives.

B. CISCO framework

According to CISCO "a Smart City Framework is a simple decision methodology that enables both the public and private sectors to plan and implement Smart City initiatives more effectively. Cisco proposed a structural method for evolving smart cities which will enable efficiency of city infrastructure, also improves the transparency in development of city. Cisco proposed smart city framework is shown in Fig. 5. Policy makers, city leaders will decide on initiatives based on the impact on city objectives. That is the reason for this framework having city objectives at the primary layer. Overall framework is divided into four layers. First layer where city objectives are framed based on the environmental, social and economic. For example a city leader wants to make a city a sustainable city. Linking of objectives to projects in the city plays major role in the deployment of smart cities. So, the objectives will be at the higher level in the framework of a smart city. Second layer, indicates the city indicators which are case dependent. Because if the city is focusing to become a financial city then green city indicators may not work. In such a case global city indicators facility (GCIF) is required. In an ideal case there could be only single set of indicators, but because of the complexity in cities leads to different type of indicators. Third layer, indicators the city components which is more concentrating at the physical level. This layer includes the utilities, transportation, city services and real estate. For suppose in the case of transportation it consists of four ways in general i.e., air, water, road and rail. The location of the station which is physical needs to be considered for ease of accessibility. Thus linking this layer in the framework with the objectives and indicators is really important. Based on the physical location i.e., at layer 3 there is direct connection with layer 4 which involves implementation of smart city solutions. Based on the objectives and physical assets a regulation policy will be made for implementation of the smart city. It is also important at this level to decide upon the stake holder responsibilities. Financing of smart city solutions is also done at this step only. Again there is link from layer 4 to layer 1, which enables the policy makers to refine or redefine the objective based on the information and government policies. This circular flow of information provides the advantage of better understanding of smart city initiatives based on the information available to the stakeholders. The outcomes of this type of city framework includes taxonomy, stakeholder rules, catalog system. Taxonomy or this type of classification provides cities to create standards relevant to the content based on the physical city components. Stakeholder rules decides the responsibilities of the concerned persons which provides better understanding on the smart city solutions. A catalog system enables easily accessible content. So based on the outcomes of the framework the optimal way for implementing the ICT solutions to the cities becomes easier Also this outcome provides the city gap analysis which provides city to become a standard themselves. It creases a structured case study to mimic the same business model to similar smart city initiatives [10].

C. United Nations and Singapore framework

This framework was designed based on the understanding of the environment of the smart cities and the interaction between the smart city elements. Fig. 6 shows the components of a smart city architecture. This is an architectural framework where there are six layers. Smart city initiatives are based on goals which often focus on sustainability, economic and social growth. These goals are achieved by specific strategies that are used for the implementation of smart cities. In the next level people are involved to make a citizen centric smart city. Citizen engagement and training needs to consider as a major task in the smart city deployment. The elements in ecosystems helps in

- Providing support to smart city.

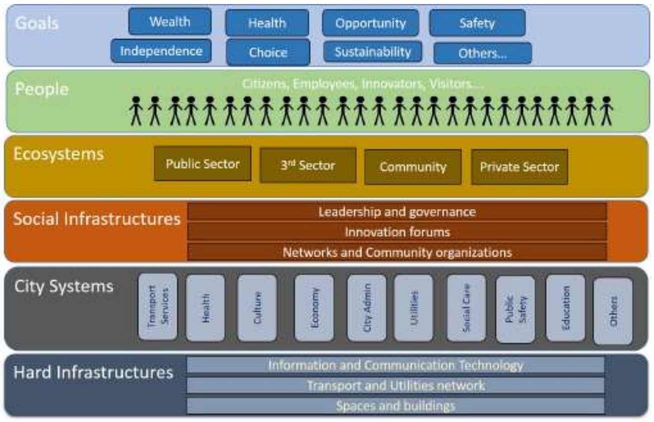

Fig. 6. United Nations and Singapore framework

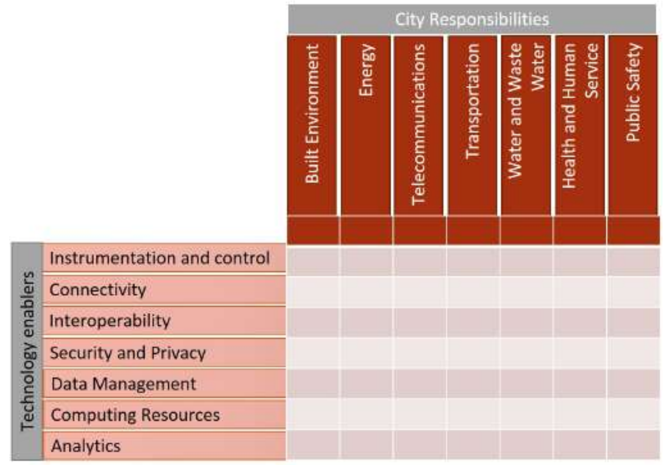

Fig. 7. Smart Cities Council Framework

- Expressions of social life.
- Shared capabilities and interests.
- Communication between city individuals and institutions.

This level also includes the social networking and families, faith and cultural groups, public sector organizations, private sector organizations, employers and retailers. Soft infrastructure elements includes the leadership and governance. This level inherently contains indicators for evaluating the progress and performance of the smart city. This level will have direct monitoring on the city systems. City systems are nothing but the city elements. The elements are like transportation, Health, Economy etc. Moreover city systems are at the physical layer. Which will be connected with ICT technologies at the hard infrastructure layer. Hard infrastructure includes the broadband technologies, communication tools such as telephone, cloud computing and modelling and analytic tools. So, the information flow control, analysis is done at this layer. Thus, as it is seen from the above layered structure this is more citizen centric. This framework includes citizens in the deployment of smart city

D. Smart cities council framework

According to smart cities council smart city is a city which uses ICT technologies to improve livability, workability and sustainability. The framework was developed by considering the relation between city responsibilities and technology enablers as shown in Fig. 7. The city responsibilities include Built Environment, Energy, Telecommunications, Transportation, Water and Waste-water, Health and Human Service, Public Safety, Payments and Finance. Although all the city responsibilities are not directly controlled but they are essential for day to day life. For example Homes and offices need water, Business needs power, and children need education and so on. For better way of meeting the responsibilities and effective utilization of resources ICT technologies are required for a city. So technology enablers will provide the technology that is required for automation of the city responsibilities. The advantage of making the city responsibilities automated is that as it can make the city safer, transparent and quicker in the sense of transportation. The technology enablers include instrumentation and control, connectivity, Interoperability, Security and privacy, Data Management, Computing resources, Analytics. For all the city responsibilities all the technology enablers are required. For example consider energy sector as the city responsibility, here instrumentation and control provides the metering data and control based on that, Connectivity provides the data transmission from the meter location to the centralized server, Interoperability provides the interaction between different types of meters and server, Security and privacy avoids the theft of manipulation of data, Data management includes the big data storage and format for the storage, computing resources will enhance computers for storage and computing power for operations needed in smart cities, Analytics gives the analysis and performance based results based on the data. Thus as mentioned in the example these technology enablers will merge with the city responsibilities and helps in making the city a smart city [4].

E. US India Business Council Framework for Smart Cities

As per the white paper by USIBC, - Cities are built on the three pillars of Infrastructure, Operations and People. In a Smart City, not only is each one of these pillars infused with intelligence, but more importantly the pillars work in an interconnected and integrated fashion to utilize resources efficiently. The framework is depicted in Fig. 8.

F. CSTEP India framework

CSTEO india developed smart city framework which was based on the following four guiding principles

1) Well-being
2) Equity
3) Efficiency
4) Foresight

This framework was developed for Indian context. According to this document on re conceptualizing of smart cities in India the city must have

1) A city needs to be sustainable to become smart.
2) Principles of good governance need to be fostered as they are important for achieving sustainability

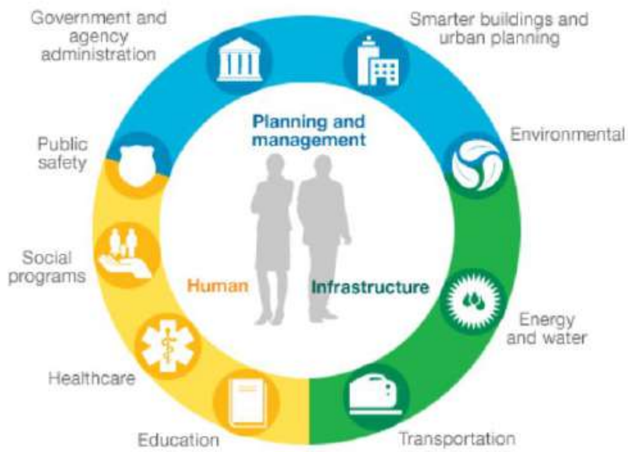

Fig. 8. US India Business Council Framework

3) Technology is an important enabler in achieving the above (a, b), along with a supportive policy environment, long-term vision and domestic stability. Innovation will follow as a result
4) Urban institutions need capacity to achieve and/or nurture a), b), through c)
5) India needs to build its own terms of reference for developing smart cities, being cognisant of the four imperatives (a, b, c, d,) mentioned above.

Smart city reference framework consists of different steps from governments and other relevant agencies. These are referred as smart city action stages (SCAS) in the framework. SCAS are to be augmented with enabling factors like processes, standards etc that will provide guidance to government for implementation of action stages. Therefore these will be referred as smart city reference guides (SCRG) according to this report [1].

SCRF has been conceived as a set of action steps that governments and relevant agencies need to follow while making decisions for a city. These are referred to as Smart City Action Stages (SCAS) in this report. SCASs need to be supplemented with points of references (enabling factors) like standards, processes, etc., that will guide governments to implement the action stages. These will henceforth be referred to as Smart City Reference Guides (SCRG) in this report.

Fig. 9 shows the reference framework proposed by cstep. The first and second action stages represents the national level and state level agencies and governments. Once the city selection is done the remaining actions are to be performed by urban local bodies (ULBs). This framework helps the states and cities that are participating in the city challenge programme for the selection of smart cities under smart cities mission. However even if the city is not selected for smart city this framework helps in managing cities for urban development.

III. Smart City Time-line in India

This section reviews the entire smart city initiative that is going on in India. Here you will find historical update of major events that occurred in the smart cities drive in India.

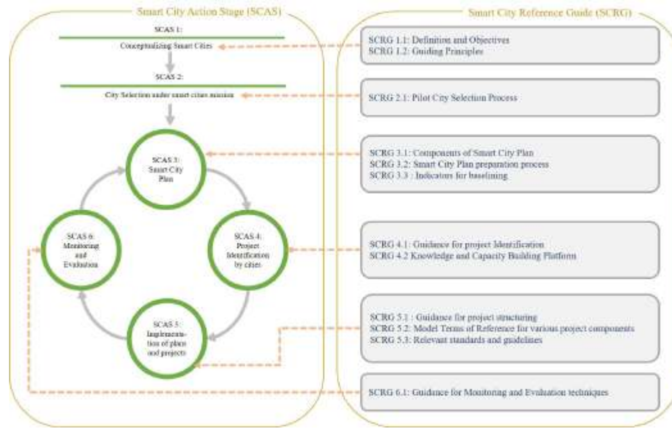

Fig. 9. CSTEP India Framework

- Jul-14: Rs. 7060 crore have been allocated in the Union Budget 2014-15 for urban development and smart cities.GoI suggested a draft list of 100 smart cities.
- Aug-14: the first MoU on a smart city for Varanasi has been signed between India and Japan
- Sep-14: GoI starts consultation with State governments, urban local bodies (ULB)s and smart city experts
- Sep-14: Kochi signs an MoU with TECOM, Dubai
- Sep-14: MoUD released a Draft 'Smart City Concept Note' defining the notion of smart city in Indian context, the pillars of smart city, and benchmarks for the same.
- Sep-14: A draft reference framework for smart city has been released by MoUD
- 12th Sep-14: A National conclave on Smart Cities Mission, has been conducted by MoUD. The key points of the conclave were - (i) states should take lead in smart cities project while center provides support (ii) this project will improve urban living, provide transparent governance, efficient and reliable power, water, health and transport services.
- Sep-14: An industry discussion white paper titled *A Nation of Smart Cities* has been published by the US India business council (USIBC) [11]. The public private partnership (PPP) model has been proposed as a suitable financial model for building smart cities.
- Dec-14: In a high level meeting chaired by the prime minister, the need for competition among city authorities to assess their preparedness and capability to undertake this ambitious project. The parameters also needs to be identified that will become a basis for selection of candidate smart cities.
- Jan-15: The Ministry of Urban development selected Bloomberg Philanthropies as their official Knowledge Partner for implementing the Smart Cities Challenge. The challenge will comprise of three rounds spanning the years, namely 2015-16, 2016-17 and 2017-18.

During June-July of the year, states nominate cities to compete. Then during august to December, cities enter the competition and develop a bold vision and smart proposals. Each city formulates its unique vision, mission and plan for smart city, incorporating local context, resources and priorities of citizens.

- Jan-15 GoI signs an MoU with United states for making Allahabad, Ajmer and Vishakhapatnam as smart cities
- Feb-15: In the similar lines India had an MoU with Spain for delivering Delhi as smart city.
- Feb-15: During the union budget 2015-2016, finance minister announced the funding of Rs. 6000 crore for AMRUT scheme. Also government of India taken a decision that there should be at least one smart city in each country's 12 major ports. In the aim of making smart cities in the state government of Andra pradesh created a digital repository of state data.
- Mar-15 Securities and exchange board of India (SEBI) approved regarding the norms for insurance and listing of municipal bonds in stock exchange as a part of channelising the household investments for urban development. A task force was setup for forming a concrete action plan for making Ajmer, Allahabad and Visakhapatnam as smart cities. These committees will have representatives from the MoUD, External affairs ministry, corresponding state governments and cities and the united states trade development agency (USTDA). As a first step of implementation confederation of Indian industry (CII) inked an agreement with Siemens and Hitachi. A consortium 'National mission on smart cities' was set up by confederation of Indian industry (CII) which includes industry leaders, experts for providing policy advocacy to government and stakeholders.The special purpose vehicle (SPV) is required for planning, approval, appraisal, releasing funds, implement, operate, manage, evaluate and monitor the smart city development projects. This SPV will be headed by CEO along with the nominees from the central and state governments and ULBs [12].
- On 29th April 2015: the Union Cabinet of Government of India, has cleared a project to develop 100 smart cities and rejuvenate another 500 in the country, allocating Rs. 98,000 crore for a period of five years, of which Rs. 48,000 crores will be for 100 development smart cities and 50,000 crores will be for rejuvenation of 500 cities.
- On 25th June 2015: simultaneously three missions where launched by the Prime Minister, namely, (i) smart cities mission (SCM), (ii) Atal mission for rejuvenation and urban transformation (AMRUT) mission and (iii) Housing for all mission. The Government of India launched the Smart Cities Challenge as a selection process to distribute central government funding to 100 cities over the first three years as part of Prime Minister's ambitious Smart Cities Mission. As a part of the mission National level, state level, and city level monitoring committees have been formed. Smart city advisory forums to be established at each city level, involving local government leaders, local experts and youth.
- In September 2015, CSTEP releases a report on Re-conceptualising Smart Cities, in which the SCM guidelines have been incorporated into a smart cities framework
- GoI announces 20 smart cities to be taken up in round 1 of smart city programme.
- In January 2016, a small number of cities with exceptional proposals are named as winners and thus become eligible for funding under the SCM.
- Round 2 of smart cities challenges starts on 1st April 2016 and will end on 15th April 2016.

IV. Conclusion

This paper presented a review of some of the different smart city frameworks which are existing in the literature. For developing countries CSTEP India initiative framework is presented. The survey presented in this paper serves as a ready reference of existing frameworks. These can be adopted with appropriate modifications for transforming a city into a smart city. Smart cities in India are undergoing dynamic changes on day to day basis. A time-line of significant events chronicling the development of smart cities in India has been presented. Major initiatives by GoI namely AMRUT mission and smart cities mission are going to transform the cities of today into smart cities of tomorrow. As this is an evolving area the future events would be interesting to watch for all the stakeholders.

References

[1] Bhattacharya, S., and Rathi, S, and CSTEP, 'Reconceptualising Smart Cities'. [Online]. Available: http://niti.gov.in/mgov_file/CSTEP\%20Report\%20Smart\%20Cities\%20Framework.pdf. [Accessed: Feb-2016]

[2] The World Bank. 2015. World Development Indicators. Washington, D.C.: The World Bank (producer and distributor). [Online]. Available: http://data.worldbank.org/data-catalog/world-development-indicators.

[3] Giffinger, Rudolf; Christian Fertner; Hans Kramar; Robert Kalasek; Nataa Pichler-Milanovic; Evert Meijers (2007). "Smart cities Ranking of European medium-sized cities" (PDF). Smart Cities. Vienna: Centre of Regional Science.

[4] Council, Smart Cities. "Smart cities readiness guide." (2013)

[5] Caragliu, A; Del Bo, C.; Nijkamp, P (2009). "Smart cities in Europe". Serie Research Memoranda 0048 (VU University Amsterdam, Faculty of Economics, Business Administration and Econometrics).

[6] Sarwant Singh (19 June 2014). "Smart Cities – A USD1.5 Trillion Market Opportunity". Forbes. Retrieved 4 November 2014.

[7] IEEE Smart Cities. [Online]. Available:http://smartcities.ieee.org/about.html

[8] Draft Concept Note on Smart City Scheme (PDF). Government of India - Ministry of Urban Development.

[9] Ojo, Adegboyega, et al. "Designing Next Generation Smart City Initiatives: The SCID Framework." Transforming City Governments for Successful Smart Cities. Springer International Publishing, 2015. 43-67.

[10] Gordon Falconer,Shane Mitchell, CISCO Framework,September 2012, http://www.cisco.com/c/dam/en_us/about/ac79/docs/ps/motm/Smart-City-Framework.pdf

[11] IBM, A nation of Smart Cities, An Industry discussion white paper, http://www.usibc.com/sites/default/files/A\%20Nation\%20Smart\%20Cities.pdf

[12] Indian Express, https://in.news.yahoo.com/10-quick-facts-know-smart-172200884.html

Role of Energy Storage Technologies in Providing Ancillary Services, Improving Power Quality and Reliability of the Indian Grid

(India need regulations for energy storage to implement grid ancillary services)

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Abstract— Managing variability of electricity load has been a nightmare for the grid operators in India, especially as over 59% of power generation capacity is met by coal thermal plants which do not have the capability to respond quickly to fluctuations in the power demand and supply. Apart from this, to make things worse for system operators in the country, rise in the wind power and other renewable energy supply, which consist of over 12% of the generation mix in India, has led to uncontrolled variability on the generation side. Such a scenario has led to questions on India's preparedness to maintain grid stability, especially after the grid failure in 2012.

In the structured power markets, like those in the US, ancillary services include the amenities that support the provision of energy to support power system reliability and security. The ancillary services markets are tied with the design of the energy market which needs careful consideration of the power system economics.

This paper is designed to provide an introduction to the ancillary services and their relevance to the Indian grid in current as well as future supply – demand scenarios. Here I also emphasized on various energy storage technologies that could become part of the solutions for meeting ancillary services in India in coming decade. Various policies in US that have facilitated introduction of both ancillary services as well as emerging technologies (such as energy storage and demand response) in past decade also analyzed in this paper. Finally by using the understanding of the Indian power system and international experiences, a roadmap is suggested for deployment of ancillary services and introduction of emerging technologies to the Indian electric grid.

Keywords—energy storage; Indian grid; ancillary services; renewables; battery

INTRODUCTION

Indian electricity sector is developing rapidly to support the ongoing economic development and social goals set up by policy makers. Currently India operates one of the largest electric grids in world with total installed capacity of over 250+ GW. Over past 2 decades various policies and initiatives have focused on meeting the energy needs through centralized generation (such as large hydro projects, ultra mega power projects, nuclear power generation) as well as distributed generation sources such as wind, solar and biomass power. The next step in the development of Indian grid is introduction of ancillary services, which are critical for providing reliability and power quality for the electricity supply.

This study is designed to provide an introduction to the ancillary services and their relevance to the Indian grid in current as well as future supply – demand scenarios. The study also provide information on various energy storage technologies that could become part of the solutions for meeting ancillary services in India in coming decade. I have taken insights from introduction of various policies in US that have facilitated introduction of both ancillary services as well as emerging technologies (such as energy storage and demand response) in past decade. Finally by using the understanding of the Indian power system and international experiences, a roadmap is suggested for deployment of ancillary services and introduction of emerging technologies to the Indian electric grid.

Ancillary Services: Ancillary services have been developed in many of the restructured power system regions especially in the developed and deregulated electricity markets. Ancillary services include the services that support the provision of energy to support power system reliability and security. The ancillary services markets are tied with the design of the energy market therefore need careful consideration of power system economics.

To support the scheduling of energy on power systems, operators require ancillary services. Ancillary services may include a number of different operations which include frequency support, voltage support, and system restoration. To encourage the individual participants of the market to provide these services, ancillary services markets need to be created.

ANALYSIS

Managing variability of electricity load has been a nightmare for the grid operators in India, especially as over 59% of power generation capacity is met by coal thermal plants which do not have the capability to respond quickly to fluctuations in the power demand and supply. Apart from this, to make things worse for system operators in the country, rise in the wind power and other renewable energy supply, which consist of over 12% of the generation mix in India, has led to uncontrolled variability on the generation side. Such a scenario has led to questions on India's preparedness to maintain grid stability, especially after the grid failure in 2012.

In the structured power markets, like those in the US, ancillary services include the amenities that support the provision of energy to support power system reliability and security. The ancillary services markets are tied with the design of the energy market which needs careful consideration of the power system economics. This study reviews the ancillary service markets in the US, the various technologies and the pricing mechanisms which these markets are following. As understood from the US market, energy storage technologies have better capabilities to cater to ancillary services like frequency regulation, load following, voltage support, reactive power supply, black start and others than the thermal, gas and renewable energy power plants. ESS (Energy Storage System) can provide ancillary services with much better response time.

		Frequency Regulation	Synchronous Reserves	Non Synchronous Reserves	Operating Reseaves	Voltage Support / Reactive Power	Load Following / Energy Imbalance
Thermal	Coal	25%	100%	0%	0%	25%	100%
	Gas - CC	100%	100%	100%	100%	50%	100%
	Gas - CT	100%	100%	100%	100%	50%	100%
	Nuclear	0%	25%	0%	0%	25%	0%
	Diesel Generator	50%	100%	100%	100%	0%	100%
	Hydro	100%	100%	100%	100%	50%	100%
Renewable	Wind	0%	25%	0%	0%	25%	0%
	Solar	0%	0%	0%	0%	50%	0%
Energy Storage Technologies	Lead Acid	0%	100%	100%	100%	50%	100%
	Li-Ion	100%	100%	100%	100%	50%	100%
	Flow Batteries	50%	100%	100%	100%	50%	100%
	Other batteries	50%	100%	100%	100%	50%	100%
	Flywheel	100%	100%	100%	100%	50%	0%
	Pumped Hydro	100%	100%	100%	100%	50%	100%
	CAES	100%	100%	100%	100%	50%	100%
	Demand Response	25%	100%	100%	100%	25%	25%

Table 1: Summary of technology suitability for various ancillary services

Although most of these technologies are technically viable for utility-scale systems, some are believed to have more potential than others for providing ancillary services as demonstrated by examples of various operational projects in this study.

Project Demonstration: Beacon 20 MW Frequency regulation plant, NY

Beacon's Stephen Town Frequency regulation plant utilizes 200 high speed flywheels to provide fast frequency regulation service to NYISO since 2011. The plant is rated at 20 MW – 5 MWh and was the largest energy storage facility providing frequency regulation US at the time of installation. Performance data from the Beacon project was critical in the policy dialogue that led to creation of FERC order 755 establishing pay for performance market design for frequency regulation in US. Beacon flywheels perform between 3,000 and 5,000 full depth-of-discharge cycles a year. Although only 10% of the NYISO market regulation market capacity, the plant provides over 30% of the Area Control Error correction, doing so with over 95% accuracy.

Figure 1: Beacon 20 MW Frequency Regulation Plant, NY (Source: Beacon Power)

Last 3-4 years have witnessed rapid reduction in prices in energy storage technologies due to the increasing commercialization and manufacturing scale up. India could accelerate this trend by providing a huge market for such technologies. Currently most of the international technology developers are exploring local manufacturing or localization of these technologies.

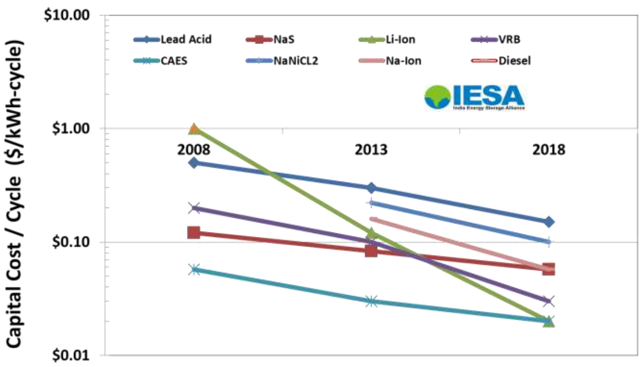

Figure 2: Capital Cost Trend

Introduction of ancillary service requirements in a technology neutral manner will accelerate such localization efforts and will help in bringing down the costs further. However, working of levelized cost of ancillary services may indicate that some of the technologies may require additional financial support during initial deployment phase for 2-3 years

Indian grid regulations have tried to address some of the technical characteristics of ancillary services through existing mechanisms such as Unscheduled Interchange (UI) mechanism and power factor incentives. These mechanisms have served their purpose by improving the grid conditions as compared to prevalent issues but need to get augmented / replaced by systematic introduction of ancillary services in the coming years.

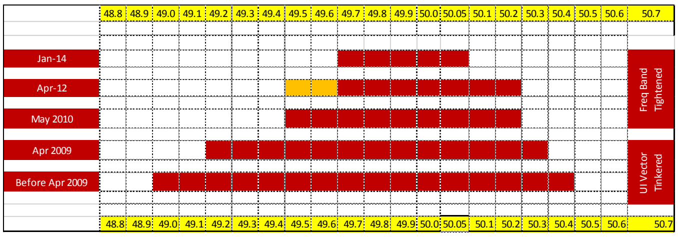

Figure 3: UI Frequency band changes over the years

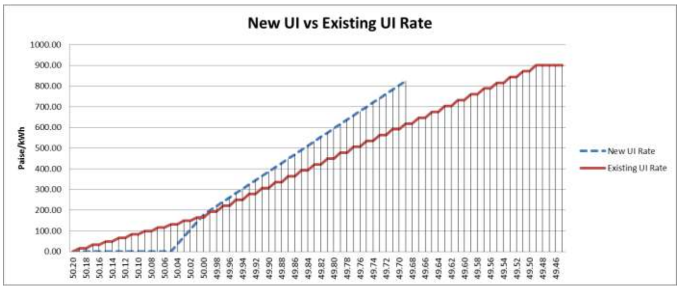

Figure 4: New UI vs. Existing UI Rate

CERC (Central Electricity Regulatory Commission) and NLDC (National Load Dispatch Centre) are considering on introducing ancillary services. Regulatory body should consider clear technology neutral specification for identification of various ancillary services and quantify the magnitude at regional / national level. Some of the ancillary services will need to be procured on state / regional basis considering the transmission infrastructure availability as well as nature of ancillary services.

Till date, the Unscheduled Interchange was being commercially settled as per the Deviation Settlement Mechanism regulatory framework notified by CERC for interstate transactions. The national grid faced major failures in July, 2012. Since then, there has been a demand for bringing in the framework which can take care of power quality and grid security & stability.

Over the years, CERC has tightened the frequency band. CERC had also issued a staff paper on Ancillary Services in December 2013. After having discussions with the appropriate authorities and stakeholders consultation meets, CERC has issued draft regulatory framework for introduction of Ancillary Services at Interstate level.

At present, around 5000MW interstate generating capacity is not getting requisitioned. CERC intends to tap this capacity for initiating Ancillary services. Objective of proposed Reserves Regulation Ancillary Services (RRAS) is to restore the frequency level at desired level and to relieve the congestion in the transmission network.

All Inter-State Generating Stations whose tariff is determined or adopted by the Commission and are operating on part load and have not received full requisition shall be eligible to participate in the Reserves Regulation Ancillary Services Market.

Although these rules are a step in right direction, relying on stranded capacity for ancillary services such as frequency regulation may not be most economical. As it has been seen in US, energy storage technologies are more efficient and cost effective for procuring fast frequency regulation service to the grid and thus help optimize the grid resources better than use of conventional fossil generators.

The Government is very serious on increasing RE mix. The proposed amendment in National Tariff Policy for higher RPO obligations, the commitment from investors for 266 GW in REINVEST 2015 suggest that in coming 4 to 5 years, we may find high RE based capacity installations in some RE prominent states. The RE generation is being effectively utilized to provide ancillary services in some of the Countries.

Regulations should have a clear roadmap for deployment of ancillary services under various scenarios (with storage options), which can provide clear investment signals for potential project developers and technology developers. There is a need for proper enforcement for procurement of ancillary services. Failure of enforcing ancillary service procurement and payment mechanism could create significant hurdles in meeting the goals.

Technical Benefits of Energy Storage

Emerging ESS (beyond traditional, pumped hydroelectric storage) may provide several technical benefits for utilities, power system operations, and users. The traditional applications for energy storage are described below:

Grid Stabilization: EES can be used to help the transmission or distribution grid return to its normal operation after a disturbance. Energy storage can be used to remedy three forms of instability: rotor angle instability; voltage instability; and frequency excursions.

Grid Operational Support: In addition to stabilizing the grid after disturbances, energy storage can also be used to support normal operations of the grid. Four types of support operations can be performed through the use of energy storage:

- Frequency Regulation Services: Energy storage can be used to inject and absorb power to maintain grid frequency in the face of fluctuations in generation and load.

- Contingency Reserves: At the transmission level, contingency reserve includes spinning (or synchronous) and supplemental (non-synchronous) reserve units, that provide power for up to two hours in response to a sudden loss of generation or a transmission outage.

- Voltage Support: Voltage support involves the injection or absorption of reactive power (VARs) into the grid to maintain system voltage within the optimal range. Energy storage systems use power-conditioning electronics to convert the power output of the storage technology to the appropriate voltage and frequency for the grid.

- Black Start: Black start units provide the ability to start up from a shutdown condition without support from the grid, and then energize the grid to allow other units to start up. A properly sized energy storage system can provide black start capabilities, provided it is close enough to a generator.

Power Quality and Reliability: EES is often used to improve power quality and reliability. The vast majority of grid-related power quality events are voltage sags and interruptions with durations of less than 2 seconds, phenomena that lend themselves to energy storage-based solutions.

Load Shifting: Load shifting is achieved by utilizing EES for storage of energy during periods of low demand and releasing the stored energy during periods of high demand. Load shifting comes in several different forms; the most common is peak shaving. Peak shaving describes the use of energy storage to reduce peak demand in an area.

Initially, some demonstration projects may be set up under the ownership of transmission companies and operated by State/Regional Load Dispatch Centers as these agencies may operate such assets in an unbiased way and may keep grid security as only priority. Simultaneously, market rules may be created for introduction of such services through exchanges. Powergrid Corporation of India ltd. (PGCIL) has already announced a tender for 3 demonstration projects at Puducherry for demonstration of LI-Ion, Advanced Lead Acid as well as other advanced batteries for frequency regulation. Indian regulators and policy makers could utilize learning from such demonstration projects for framing the ancillary service requirements.

Rapid advances in both conventional and emerging technologies will make it possible for India to significantly improve the power quality and reliability. Such transformation could be achieved by 2022 as most of the technologies required are already commercially available and sufficient insights are available for introduction of ancillary services based on experiences of developed countries from around the world. As estimated by Customized Energy Solutions and Indian Energy Storage Alliance, the ancillary service market in India has a potential of almost 5 GW through 2022 and ESS technologies can supply over 1 GW of this market.

A. Figures and Tables

Table 1: Summary of technology suitability for various ancillary services

Figure 1: Beacon 20 MW Frequency Regulation Plant, NY (Source: Beacon Power)

Figure 2: Capital Cost Trend

Figure 3: UI Frequency band changes over the years

Figure 4: New UI vs. Existing UI Rate

References

[1] PJM 101,
[2] CERC, draft ancillary serices regulations report 2012,
[3] CERC ancillary service notifaction 2015,
[4] CEA Ancillary Services Report,
[5] NLDC proposed procedure for Ancillary Services,
[6] IESA Internal Report

The Eagle Way: Future Ready Smart Meters and IoT

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Abstract

There is a famous story of eagle how it goes through a process of change by breaking its own break and waits until new, sharp one grows and then plucks its own aged, heavy feathers and waits for new, light feathers to grow. After this process of change, the Eagle again lives for another 30 years a joyful life. The similar perspective is put onto AMI network and its systems which have to undergo a big transformation to remain relevant and harness of potential of upcoming, 21st century's connected world of devices. The paper describes puts IoT devices and smart meter in a relevant context and how AMI network of smart grid can be used to carry the data of IoT devices within a home and in a city at larger level. The meter will no longer be seen a device which does just metering, it can be made a gateway where various sensors in the home can communicate with meter and it can in turn provide information to the user. This calls for a cutting edge technology equipped smart meter which is capable of doing much more than just "accurate" measurement of electricity.

Keywords—AMI network, Residential Gateway, Communication Technoligies, Internet of Things (IoT)

INTRODUCTION

We are surrounded by so many objects in our day-to-day life to make our living better, organized, safe and help us manage our resources, time better. For example, consider TV, refrigerator, water heater, clock, mixers, air-conditioner, phones, computer and so on. This list can be endless and varies from person to person. The primary requirement and expectation from these numerous objects is that they should perform their basic function accurately and conveniently. Clock should show accurate time, TV should display content with quality and without jitter and so on. Out of these objects, take an example of smart phone. It has so deeply influenced the living of people that it can perform so many useful functions other than its primary function that is to enable people to communicate via voice. But considering the revolution in semiconductor industry, form factors of chips being reduced drastically day by day, prices coming down, advancement in display technologies, rapid software development has resulted in packing so many useful features in smart phones that it is so deeply integrated in our routine life. For a normal house-hold, it was almost wiped out need of having camera as a separate gadget, wrist watch and even doing away with the need of computers. Almost everything that a user would want to do on a computer can now do on smart phone. On the other side, advancement in telecommunication technologies 3G, 4G, LTE allow us to share even real-time video content on wireless interface. Now the stage of technologists is getting set for smart "objects". In other words, we are not just going to have smart phones and smart objects. This means, every object, home appliance (AC, mixer, water heater, electricity meter, washing machine and so on), every small office, big building, residential societies, commercial establishments even complete cities are going to be smarter. How do we define "smartness"? The definition of "smartness" of an object may vary from one individual to other. But in the context of this paper, "smartness" of an object refers to the additional ability to communicate with other objects. All these object will not only perform their basic function but will also be able to communicate with other objects and user for status reporting and monitoring operations. In summary, it can be very well said that platform is getting set for "Internet of Things" (IoT).

As explained above, on one side, we are surrounded by objects, smart objects to make our living convenient and better. On the other side, consider how we get power (electricity) in our homes. It comes via power grid which is network of electrical systems (power generation plants, transformers, substations and many others systems). The physical and technological infrastructure of power grid is almost a century old, not significant advancements have been done to make it perform at optimum level. There is a saying that goes "**If Alexander Graham Bell and Thomas Edison were somehow transported to 21st century, Alexander Graham Bell would not begin to recognize the component of modern telephony i.e cell phones whereas Thomas Edison, one of the powe grid's key early architects, would perhaps be totally familiar with the grid[1]**. This underscores the strong need of making the grid "smart". In other words, convert from power grid to "smart grid". As the communication is the key requirement for internet of things, same way, communication between systems of power grid is the key requirement for migrating from power grid to smart grid. One of the key components of the power grid is "electricity meter" that is installed in the house. The primary purpose of the meter is accurately measure the power consumed by the house hold.

This paper will describe how smart meter and Internet of Things (IoT) objects can be linked together and give way for future ready systems.

Key Consideration for an IoT Device

There are following key considerations that apply to IoT devices and differentiate them from regular devices that we have seen in the generation of WiFi, Bluetooth and Cell phones.

1. **Communication capability**: Apart from performing a specific function for which device is created in first place, the device must also have the communication capability. This means, it should be able to network with other devices through some way. In principle, it could be based on wired or wireless communication. But considering the future systems, it is likely to be equipped with wireless communication technology. This communication technology could be anything WiFi, ZigBee, 6LowPAN, Bluetooth and others.

2. **Remotely configurable**: Device should not require any manual intervention in order to modify its configurations. Since it is network device, it must be able to change its configuration remotely. Needless to say, these configurations should be defined by the user or controller of the device.

3. **Security:** The device must have the security protocols running on it in order to authenticate this device to the desired network. This is utmost importance in order to tackle various attacks which might hamper the device functionality if not prevented.

4. **Low-Powered:** The IoT devices may not always be always connected to the mains power supply. In fact, there are high chances that these devices will be battery powered. This means, the algorithms that will be running on these devices should be specially designed to have reduced power consumption so that user doesn't have to worry to charging or changing the batteries often. Usually, IoT devices battery should last for years.

5. **Cost:** The IoT devices add networking functionality to the usual objects or things. The cost of adding networking capability must not be higher than the cost of specific function that they have been designed for. Therefore, cost remains one of the key factors for success of IoT devices.

6. **IPv6 based IoT devices**: If IoT devices are running the IP stack on them, then it must be IPv6 based considering the IPv6 address space is already on the verge of getting exhausted.

Electricity Smart Meter and IoT Devices in a Home

Consider a use case where a normal house hold has many IoT devices installed. For example, air pollution detector, fire alarm (smoke detector), an IoT enabled door locking system, IoT water meter and IoT enabled electricity meter. The functionality of each of these devices is briefed below.

- Air pollution detector measures the pollution level of air present in the house and it is goes higher than a threshold then it has to send a message to user notifying about the event.

- IoT enabled water meter measures the amount of water consumed in the house every day. If water consumption increases than a threshold limit set by the user, it signals a situation where a water tap may have been left open and all family members may be out of home. Upon reception of this event, user may take the corrective action to close the running water tap.

- The smoke detector senses the presence of smoke in the house. If smoke is detected, it not only raises the sound alarm but it also has to inform to the user about it so that user can take corrective action in his home

- Likewise IoT enabled door locking system senses if someone tries to break-open the door. If such activity is detected, it not only raises the alarm sound but also has to send a message to the house owner for him to reach his home immediately to prevent theft.

All these IoT enabled devices perform their specific function. But there is one thing that is common in them. That is the need to notify to the user about the event that happened. The average user has access to two types of network. One is telecommunication cellular network and other is short range communication network i.e. WiFi, Bluetooth etc. But since IoT needs to information to the user about certain very important events and including those times of the day where user may be quite far from home, the obvious choice is to use telecommunication network. This means, every tiny, small, big IoT device must be equipped with cellular technology i.e. must have SIM cards to make communication. But there are challenges with this approach. One is cellular network infrastructure may not be yet ready to handle such large capacity of connections which is easily in billions of devices. And other is cost. The cost of IoT device will be significantly large in this approach. There may be many other challenges in using cellular communication for IoT devices, but limiting these challenges here, cellular communication is not a viable option to IoT device communication.

The other approach is to use electricity meter as a residential gateway device. Electricity meter is not an optional or luxury item for residential or industry segments in any country. It is a must have item in every house building which needs power. The smart meter not only measures the electricity but also has a network communication capability using which it keeps sending the information to its utility servers via various routers installed in it. It is a fully functional network device installed in every household.

The following figure shows the communication between a meter and IoT enabled devices in the home and associated infrastructure to achieve this communication.

Note that there are multiple communication technologies that are available to choose from for both inside home communication as well as outside home communication.

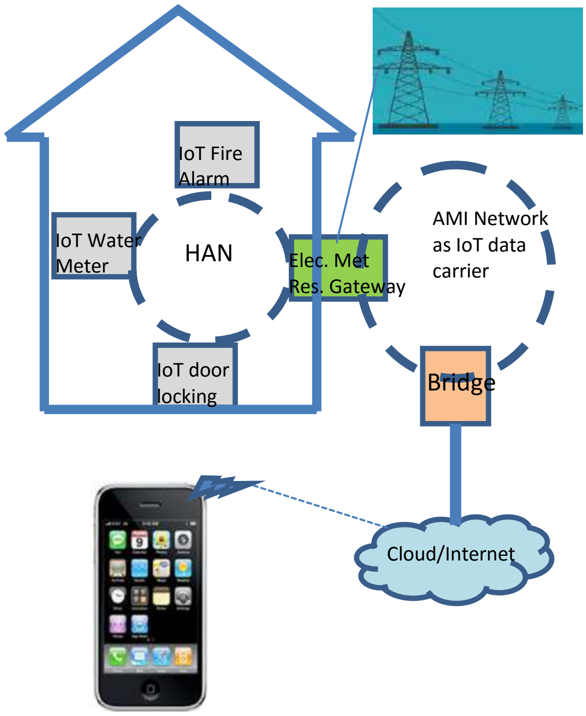

Figure1: Electricity Meter used a Residential Gateway

As can be seen from the figure above that electricity smart meter is a merging point for all three networks. One is HAN (home area network) of IoT devices present in a home, one is power grid network of AC lines by which electricity is coming in the home and other is AMI network which is used by Utility companies to manage the meter connection, remote connect/disconnect and get periodical profile information from the meter. The AMI network can be based on any communication technologies like RF Mesh, Power Line communication (PLC) or cellular communication. The selection of communication technologies will be based on geographic conditions, cost and reliability of communication among various other factors.

The key point is the same AMI network can be utilized to carry the IoT data of different devices present inside home and eventually give notification to the home owner (user). The bridge device which is part of AMI network, that carries data from one network to another network, in current case from PLC/Cellular/RF Mesh to legacy IP network and finally connects to the cloud servers. These cloud servers have multiple application and grid analytic software which process the data coming from different homes and immediately send SMS or make phone call to the user depending on preference set by the user.

Advantages of using AMI network for IoT Data Traffic

There is no separate infrastructure that is required for IoT devices in order to send the events and messages to the user's cell phone. Note that IoT devices cannot have cellular connectivity due to cost considerations. The figure 1 shows the IoT devices meant to be used within home only. But there are thousands of different devices which will be required to place outside the home environment i.e. to manage the city infrastructure, to manage residential societies, smart parking, smart traffic lights, to manage roads etc. Each of this needs the communication infrastructure to report the data to some servers for its processing. There will be AMI infrastructure already that will be required inside the city/country, so if same infrastructure can be used for carrying traffic from other devices too, it will be more cost effective and efficient. Note that AMI infrastructure especially in RF mesh case involves various routers that are installed in the city at strategic location to route the packets from home to Utility servers. So same routers can be configured to carry data not only from smart meters but also from various IoT devices placed inside homes and inside the smart cities. This will eventually help in saving the cost in the launch of IoT devices in the market.

Challenges in Using AMI Network for IoT Data Traffic

There are following key challenges in this approach to work

1. **Network capacity**: The AMI network is originally meant to carrying certain amount of data from different meters. Opening the scope of AMI network to numerous IoT devices placed inside the city needs the data carrying capacity of the network to be increased to a significant extent. One IoT device is not likely to send much data to the user but having numerous IoT devices to send small amount of data will eventually convert into huge data over the AMI network which will keep the AMI network extremely busy.

2. **Cost of AMI devices:** In order to handle high network processing, in case of RF mesh network will need to have more intelligent and processing intensive hardware and firmware running on them which will add to the cost of component in the AMI network.

3. **Priority of data managed by AMI network**: AMI network will have two types of data to be transmitted on it. One is metering data and other is IoT devices data. There will need to be a mechanism to define priority of data processing policy to indicate which data type take precedence over other. Most like

4. **Spectrum efficient for RF mesh**: RF spectrum is limited and is a scarce resource. Increasing the scope of AMI network for IoT devices will need larger ISM band to handle traffic from all such devices. Currently it is 2 MHz band that is license free in India.

5. **Absolute resilient AMI network**: Since data from so many devices, not only from home but also from smart cities will need to be travelled on single AMI network, this network must be remain up at all times. Otherwise, very critical information may be lost.

6. **Highly Security:** The AMI network must be highly secure from hackers considering the criticality of data being sent over AMI network.

7. **Privacy of users**: Currently Utilities are managing only grid information/data on their servers for their

customers. If AMI network carries data for other home devices and city devices then greater level of privacy of home owner gets disclosed to the Utility companies which need regulation from government bodies. Also some sort of authorization policy will be required to ensure that AMI network only remains carrier to the data, not the processing engine of the data. Ultimately, government bodies will be managing city, not the Utilities companies.

8. **Interoperability**: Smart meter is a gateway to carry data from home to AMI network hence IoT device placed inside home must be able to interoperate with smart meter. Hence communication technology selection will be the key point for Home Area Network processing so that IoT devices and smart meter can smoothly communication. Apart from this, AMI network routers must be able to interoperate with IoT devices using different communication technologies so that maximum IoT devices can be connected to the AMI network and make use of it.

Conclusion

Communication and networking will be the key driving area in the next phase of revolution where every device will be a smart device. Advancement in communication technologies has opened various options for devices to communication. We have communication technologies for short range (WiFi), long rage (cellular) and also for medium range communication (few miles, ZigBee NAN, 6LowPAN and many others are under development in standardization bodies). Just like road infrastructure which takes time and huge investment, communication infrastructure also needs time and huge investment from smart cities perspective. Hence, all options, corner cases must be thorough deliberated in the technology community so that investment of time and money happens for smart city development in the best direction for all stakeholders. This paper throws light on one of approaches to create the communication infrastructure for IoT devices by using AMI network of smart grid.

REFERENCES

1. http://energy.gov/sites/prod/files/oeprod/DocumentsandMedia/DOE_SG_Book_Single_Pages.pdf

Study of Future of Smart Cities in India

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Abstract

The first step for establishing the overall smart city framework and architecture is the smart city infrastructure. Now a day's many smart cities are recently established across the world. Some examples are: Malta, Singapore, Kochi (India), Dubai and many more proposed in India. The scope of these cities is vast for example it is mainly limited to construct a technology park converting the industrial real estate to state of the art information technology using newly emerged technology in telecom sector and IP networks including insignificant asset management automation system. The development mainly depends to create an operational platform that would handle the power consumption and operational resources in order to optimize the overall running operational cost. This paper will study the smart infrastructure development framework and the surveying floating accuracy of locating the devices as a base of the smart city development architecture integrated with all the facilities and systems related to the smart city framework. The paper will discuss also the main advantages of the proposed method to make a city smart city with its advantages and disadvantages.

***Keywords:** Smart Infrastructure, GIS, Smart City, Geospatial application, Infrastructure Development, Infrastructure Monitoring*

INTRODUCTION

Making a city "smart" is emerging as a strategy to mitigate the problems generated by the urban population growth and rapid urbanization. Yet little academic research has sparingly discussed the phenomenon.. Based on the exploration of a wide and extensive array of literature from various disciplinary areas we identify eight critical factors of smart city initiatives: management and organization, technology, governance, policy context, people and communities, economy, built infrastructure, and natural environment. These factors form the basis of an integrative framework that can be used to examine how local governments are envisioning smart city initiatives. The framework suggests directions and agendas for smart city research and outlines practical implications for government professionals.

Currently, 31% of India's population lives in cities; these cities also generate 63% of the nation's economic activity. These numbers are rapidly increasing, with almost half of India's population projected to live in its cities by 2030. Smart Cities focus on the most pressing needs and on the greatest opportunities to improve quality of life for residents today and in the future. An object equipped with a localization module can report traces of itself, such as trash tracking[1] and traces of cargos with radio frequency identification (RFID) tags. These floating sensors enable trace data collection for various kinds of moving objects.

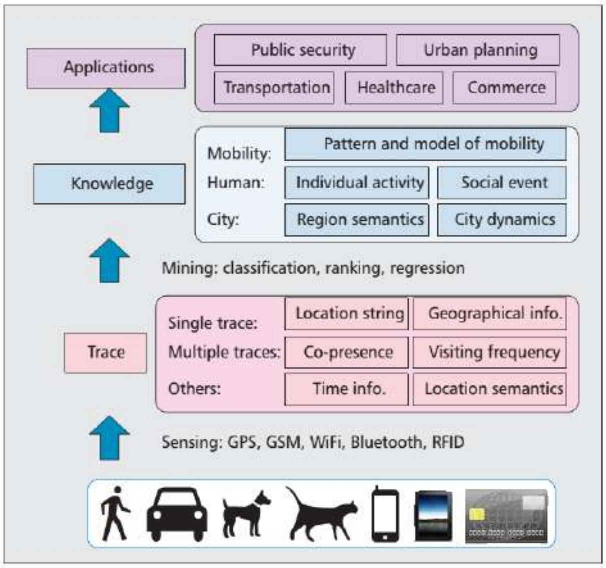

Figure 1. *Research issues of trace mining for smart cities*

1. CONCEPTUALIZATION OF SMART CITY

As discussed above, the concept of a smart city itself is still emerging, and the work of defining and conceptualizing it is in progress [2,3]. The concept is used all over the world with different nomenclatures, context and meanings. A range of conceptual variants generated by replacing the word smart with adjectives such as digital or intelligent are readily used and reused. Some are recognizing the use of *smart city* as an urban labeling phenomenon[3], noting that the label smart city is a concept and is used in ways that are not always consistent. Several working definitions have been put forward and adopted in both practical and academic use. This cacophony of definitions is resulting in calls for conceptual research in this regard [2]..

WORKING DEFINATIONS OF SMART CITY

A city well performing in a forward-looking way in economy, people, governance, mobility, environment, and living, built on the smart combination of endowments and activities of self decisive, independent and aware citizens. [4]

A city that monitors and integrates conditions of all of its critical infrastructures, including roads, bridges, tunnels, rails, subways, airports, seaports, communications, water, power, even major buildings, can better optimize its resources, plan its preventive maintenance activities, and monitor security aspects while maximizing services to its citizens.[5]

A city "connecting the physical infrastructure, the IT infrastructure, the social infrastructure, and the business infrastructure to leverage the collective intelligence of the city "[6]

A city striving to make itself "smarter" (more efficient, sustainable, equitable, and livable) [7]

A city "combining ICT and Web 2.0 technology with other organizational, design and planning efforts to dematerialize and speed up bureaucratic processes and help to identify new, innovative solutions to city management complexity, in order to improve sustainability and livability." [8]

"The use of Smart Computing technologies to make the critical infrastructure components and services of a city—which include city administration, education, healthcare, public safety, real estate, transportation, and utilities—more intelligent, interconnected, and efficient" [9]

In Harrison *et al*'s study [6], a smart city denotes an instrumented, interconnected, and intelligent city.

In contrast, the Natural Resources Defence Council [7] defines smarter in the urban context as more efficient, sustainable, equitable, and liveable. Toppeta [8] emphasizes the improvement in sustainability and liveability. Washburn *et al*. [9] view a smart city as a collection of smart computing technologies applied to critical infrastructure components and services. Smart computing refers to a new generation of integrated hardware, software, and network technologies that provide IT systems and real-time awareness of the real World and advanced analytics and actions that optimize business processes[9].

Given the conceptual comprehensiveness of a smart city, it could be thought of as a large organic system connecting many subsystems and components like the ones described above. Dirks and Keeling [10] consider a smart city as the organic integration of systems. The interrelationship between a smart city's core systems is taken into account to make the system of systems smarter. No system operates in isolation. In this sense, Kanter and Litow [11] consider a smarter city as an organic whole—a network and a linked system. While systems in industrial cities were mostly skeleton and skin, postindustrial cities—smart cities—are like organisms that develop an artificial nervous system, which enables them to behave in intelligently coordinated ways [12].

SMART GRIDS AS BACKBONE OF SMART CITIES

To efficiently attend to growing cities, providers of infrastructure services (utilities) and Governments are increasingly using IT solutions, coining the term 'smart cities'. There are several definitions for smart cities varying from 'instrumented, interconnected and intelligent' to those that 'use smart computing technologies to make the critical infrastructure components and services, which include city administration, education, healthcare, public safety, real estate, transportation and utilities – more intelligent, interconnected and efficient'. Fundamentally, information becomes an enabler for improvements, which span better measurements, better analysis, and better action (automation, where feasible).

In the developed world, Municipalities or City Councils are responsible for providing most infrastructure services through single ownership of assets and outsourcing to service providers, and many city authorities are now planning to use IT and automated systems to manage assets as well as analytical tools to predict: usage, behaviour, maintenance, emergencies and other incidents in order to optimize overall asset performance and improve services to the city. In the Indian context where management of services is more disparate, it becomes a herculean task to integrate all infrastructure and services onto a common platform. However, by extending the digital platform e.g. power to offer services to other domains e.g. water, gas, traffic, the Internet, security etc. a basis can be created. Smart cities in India can encompass two categories – existing cities that should be made smarter by integrating all services on digital platforms; and new cities to be built as smart cities from the start with fully integrated communication, IT and Automation architecture. The ideal features of a smart city in India include the following:

1.Building integrated GIS data for all infrastructure and services by one designated agency e.g. a DisCom, with clear rules for access to data and data protection etc.
2.Smart electricity grids that ensure 24x7 stable electricity to all citizens though city owned networks or service charters with DisComs (public/private).
3.High levels of distributed renewable energy integrated with the grid.
4.Green public transport, electric mobility and Electric Vehicle (EV) charging infrastructure with the ability to operate a large fleet of grid-connected EVs as a virtual power plant (VPPs).
5.Efficient water distribution networks with leakage detection systems and safe gas distribution networks
6. Integrated billing systems for a variety of services such as transport including tolls and parking, public amenities, electricity, water, gas, Internet, house tax etc. with user-friendly payment platforms and common customer care centres. Intelligent transportation systems with coordinated and active traffic management including traffic lights and advance alerts on congested routes.

Presently all State owned electricity distribution companies (Discoms) in India are implementing a set of basic IT and Automation solutions under the ongoing Restructured Accelerated Power Development and Reforms(R-APDRP) scheme of the Ministry of Power. Some of the digital assets created under this program that covers 1401 towns can be leveraged to build smarter cities at lower marginal costs. How infrastructure services providers can leverage IT and Automation Systems built under R-APDRP is briefly explained below :

1. GIS Mapping of towns: All electrical assets including 33kV, 11kV, Low Voltage lines and substations and consumers are digitally mapped and regularly updated to capture changes/ additions to the electrical network and new consumers/buildings. This data could be used effectively by other infrastructure services providers for planning and operation and maintenance of systems, including the laying of water pipes, telecom cables, gas pipes etc. as well as planning road networks. For example if the routing of underground power cables is known, then the same can be synergized to other utilities and all future road openings coordinated.

2. Billing and Customer Relationship Management (CRM) Systems: State of the art Billing and CRM systems have been implemented in all towns under R-APDRP and consumers have multiple options to make payments. Also Consumer Care Centres with increasingly popular interactive consumer portals are situated at strategic locations. Discoms have regular interaction with their customers through meter reading, bill distribution, payment collection, attending to complaints, information on planned outages etc.. All water and gas consumers are also electricity consumers. The Billing and CRM systems of Discoms could easily be adapted and used for collection of: water and gas revenues, house taxes and other municipal dues, and could even be extended to private utilities such as cable TV, the Internet, telephone, etc..This would not only reduce the overall collection cost, but also facilitate higher compliance in timely payment. Potentially if desired the consumer could even opt for a consolidated bill for all services.

3. SCADA(supervisory control and data acquisition)/ DMS(Distribution management system): For approximately 100 larger towns with populations of 400,000 and above, the DisComs are implementing SCADA/DMS systems for monitoring and controlling real-time power flows. The field infrastructure and dedicated communication bandwidth for SCADA/DMS could be equally be leveraged to automate water and gas supply networks and further extended to connect cameras for video surveillance of critical assets.

4. Common Command and Control Centre: Moving forward, a common command and control centre that can handle all customer issues related to municipal and utility services could be created, with incoming calls (on single number) diverted to the appropriate teams and crews. Therefore optimizing the cost of IT and communication infrastructure whilst at the same time enhancing the customer experience.

5. Outage Management Systems (OMS) and Mobile Workforce Management (MWFM): OMS and MWFM platforms can be shared by all services and and even appliance vendors for managing their maintenance activities.

The new Indian Government has set a target of building 100 smart cities. One practical approach is to leverage existing RAPDRP infrastructure and other initiatives to firstly build smarter grids and then extend those systems to other domains. For improved efficacy and asset/cost optimization, this initiative could also be dovetailed with other on-going programs of the Government of India such as the**:** Jawaharlal Nehru national urban renewal mission (JNNURM), Solar Cities Program, National Mission on Power Electronic Technologies, DMIC, National Mission on Electric Mobility, National Water Mission, National Mission on Enhanced Energy Efficiency, etc.

3.SUCCESS FACTORS OF SMART CITY INITIATIVES

The seven clusters of factors include (1) management and organization, (2) technology, (3) governance, (4) policy, (5) people and communities, (6) the economy, (7) built infrastructure.

3.1 Management and Organization

In contrast, a wide array of previous research on IT initiatives and projects has highlighted these issues as important success factors or major challenges [13, 14]. Thus managerial and organizational concerns in smart city initiatives need to be discussed in the context of the extensive literature on e-government and IT projects success.

For instance, Gil-Garcia and Pardo [13] suggested a list of success factors and challenges for e-government initiatives (see Table 1). Smart city initiatives might differ from more general e-government initiatives in the context and in some of the characteristics of specific projects, but there is much in common between those two types of initiatives because most smart city initiatives are also driven by governments and leveraged by the intensive use of ICTs to better serve citizens.

Table 1. Organizational and Managerial challenges and strategies

Challenges	Strategies
• Project size	• Project team skills and expertise
• Manager's attitudes and Behavior	• Well-skilled and respected IT leader (technical and social skills)
• Users or organizational diversity	• Clear and realistic goals
• Lack of alignment of organizational goals and project	• Identification of relevant stakeholders
• Multiple or conflicting goals	• End-user involvement
• Resistance to change	• Planning
• Turf and conflicts	• Clear milestones and measurable deliverables
	• Good communication
	• Previous business process improvement
	• Adequate training
	• Adequate and innovative funding
	• Current or best practices review

3.2 Technology

A smart city relies, among others, on a collection of smart computing technologies applied to critical infrastructure components and services. Smart computing refers to a "new generation of integrated hardware, software, and network technologies that provide IT systems with real-time awareness of the real world and advanced analytics to help people make more intelligent decisions about alternatives and actions that will optimize business processes and business balance sheet results" [9]. ICTs are key drivers of smart city initiatives [3].The integration of ICT with development projects can change the urban landscape of a city [15] and offer a number of potential opportunities [16], they can enhance the management and functioning of a city [16].

Despite proclaimed advantages and benefits of ICTs use in cities, their impact is still unclear [16].Indeed, they can improve the quality of life for citizens, but they can also increase inequalities and promote a digital divide [16]. Ebrahim and Irani [17] have outlined some of the challenges of using technologies in smart cities (see Table 2).

Table 2. Technological challenges

Dimension	Challenges
IT skills	• IT training programs • Lack employees with integration skills and culture
Organizational	• Lack of cross-sectoral cooperation • Lack of inter-departmental coordination • Unclear vision of IT management • Politics • Culture issues

3.3 Governance

Several cities have started transformational projects and initiatives called smart city initiatives to better serve citizens and to improve their quality of life [4,16]. These projects involve multiple stakeholders. Thus, several cities have felt an increased need for better governance to manage these projects and initiatives [18]. In general, (public) governance has been defined "as regimes of laws, administrative rules, judicial rulings, and practices that constrain, prescribe, and enable government activity, where such activity is broadly defined as the production and delivery of publicly supported goods and services." (p.235) [19]. Governance, hence, involves the implementation of processes with constituents who exchange information according to rules and standards in order to achieve goals and objectives [20].

Several cities have benefited from the emergence of ICTs that improve their governance. This ICT-based governance is known as smart governance. It widely represents a collection of technologies, people, policies, practices, resources, social norms and information that interact to support city governing activities. According to Forrester, smart governance is the core of smart cities initiatives [21,4]. Thus, it represents an important challenge for smart city initiatives.

Little literature on smart cities addresses issues related to governance. According to Mooij [22], the presence of leadership is important for good governance. In the same way, Lam [23] emphasized on the presence of a "champion" that collaborate with all stakeholders as an essential factor for good governance [23]. Smart governance is described as an important characteristic of a smart city that is based on citizen participation [4] and private/public partnerships [16]. According to Johnston and Hanssen [20], smart governance depends on the implementation of a smart governance infrastructure that should be accountable, responsive and transparent [22].

3.4 Policy and context

Transformation from an ordinary (non-smart) city to a smart city also entails the interaction of technological components with political and institutional components [24]. Political components represent various political elements (city council, city government, and city major) and external pressures such as policy agendas and politics that may affect the outcomes of IT initiatives [25, 26].The policy context is critical to the understanding of the use of information systems in appropriate ways. Hence, an innovative government stresses the change in policies, because a government cannot innovate without a normative drive addressed in policy [27]. Whereas innovation in technology for a smart city can be relatively easily observed and broadly agreed upon, subsequent changes in the policy context are more ambiguous [28]. The policy context characterizes institutional and non-technical urban issues and creates conditions enabling urban development[29].

Gil-García and Pardo's [13] study on e government success factors identified legal, regulatory, institutional and environmental challenges of e government initiatives. In making any kind of decision in IT projects, public managers need to take into account a large number of restrictive laws and regulations [30,31]. Federal systems, as like in the United States, Canada, or Mexico, present additional challenges derived from the particularities of the relationships (intergovernmental relationships) between different levels of governments [25,30,32]. There are also challenges related to a more general institutional framework and the policy environment, in which government organizations operate [33]. In this context, institutions are not only made up of laws and regulations, but also norms, actions, or behaviours that people accept as good or take for granted[34].

3.5 People and Communities

Addressing the topic of people and communities as part of smart cities is critical, and traditionally has been neglected on the expense of understanding more technological and policy aspects of smart cities. Projects of smart cities have an impact on the quality of life of citizens and aim to foster more informed, educated, and participatory citizens. Additionally, smart cities initiatives allow members of the city to participate in the governance and management of the city and become active users. If they are key players they may have the opportunity to engage with the initiative to the extent that they can influence the effort to be a success or a failure. Table 3 lists the factors related to smart cities and people and communities as found in the literature.

3.6. Economy

One of the key indicators to measure growing city competition is the capacity of the city as an economic engine [35].

A series of studies [10,36] released by the IBM Institute for Business Value identify business as one of core systems of smarter cities, which comprise city services system, citizens system, business system, transport system, communication system, water system, and energy system. Capacities for smart business systems include ICT use by firms, new smart business processes, and smart technology sectors. The smart city initiatives are designed to develop information technology capacities and establish an agenda for change by industry actions and business development [37]. Creating an environment for industrial development is pivotal to a smart city [38]. The economic outcomes of the smart city initiatives are business creation, job creation, workforce development, and improvement in the productivity.

3.7. Built infrastructure

The availability and quality of the ICT infrastructure are important for smart cities [4]. Indeed, smart object networks play a crucial role in making smart cities a reality [15]. ICT infrastructure includes wireless infrastructure (fibre optic channels, Wi-Fi networks, wireless hotspots, kiosks) [39], service-oriented information systems [40,41].

There is a little literature that focuses on ICT infrastructure barriers of smart cities initiatives. As done in the managerial and organizational section, we will refer to e-government technological barriers since smart cities' initiatives are similar to e-government initiatives in their use of ICT. Ebrahim and Irani [17] presented a set of factors related to the implementation of ICT. Table 4 presents a set of IT challenges grouped in three dimensions; IT infrastructure, security and privacy, and operational cost.

Table 3. Factors of built infrastructure

Dimension	Challenges
IT infrastructure	• Lack of integration across government systems • Existing internal systems have restrictions regarding their integrating capabilities • Lack of knowledge regarding interoperability • Availability and compatibility of software, systems and applications
Security and privacy	• Threats from hackers and intruders • Threats from viruses, worms and Trojans • Privacy of personal data • High cost of security applications and solutions • accessibility
Operational cost	• High cost of IT professionals and consultancies • High cost of IT • Cost of installation, operation and maintenance of information systems • Cost of training

4. INTEGRATIVE FRAMEWORK

Drawing on the conceptual literature on smart cities and the factors outlined above, we have developed an integrative framework to explain the relationships and influences between these factors and smart city initiatives. Each of these factors is important to be considered in assessing the extent of smart city and when examining smart city initiatives. The factors provide a basis for comparing how cities are envisioning their smart initiatives, implementing shared services, and the related challenges. This set of factors is also presented as a tool to support understanding of the relative success of different smart city initiatives implemented in different contexts and for different purposes. Similarly, this framework could help to disentangle the actual impact on types of variables (organizational, technical,contextual) on the success of smart city initiatives.

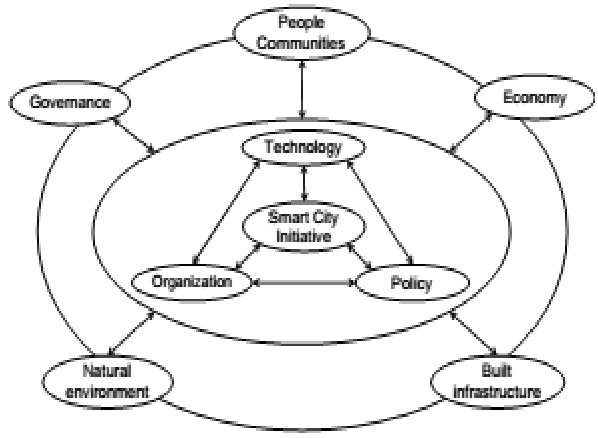

Figure2. *Smart city initiatives framework*

It is expected that while all factors have a two-way impact in smart city initiatives (each likely to be influenced by and is influencing other factors), at different times and in different contexts, some are more influential than others. In order to reflect the differentiated levels of impact, the factors in our proposed framework are represented in two different levels of influence. Outer factors (governance, people and communities, natural environment, infrastructure, and economy) are in some way filtered or influenced more than influential inner factors (technology, management, and policy) before affecting the success of smart city initiatives. This counts for both direct and indirect effects of the outer factors. Technology may be considered as a meta-factor in smart city initiatives, since it could heavily influence each of the other seven factors. Due to the fact that many smart city initiatives are intensively using technology, it could be seen as a factor that in some way influences all other success factors in this framework.

5. SMART CITIES PROGRAMME IN INDIA

A Smart City uses smart computing technologies to make the critical infrastructure components and services which include city administration, education, healthcare, public safety, real estate, transportation and utilities – more intelligent, interconnected and efficient.

Developed nations with reliable physical infrastructure (electricity, water, transport etc.) and minimal population growth are focusing on asset optimization, operations monitoring, data communications and analytics for making their cities smarter. However, developing countries where cities have inadequate physical infrastructure, need to focus on building modern physical infrastructure that are scalable, intelligent and interoperable to build smart cities.

The Government of India has embarked on an ambitious program of developing 100 Smart Cities on fast track. India with a federal democratic structure need the cooperation and coordination of federal government, state governments and urban local bodies to build smart cities. Ministry of Urban Development (MoUD) has been made the nodal agency for driving the smart cities program. MoUD conducted several brain storming sessions with various agencies and prepared a Concept Note for development of 100 Smart Cities (http://bit.ly/1xReZwt) that describes the basic principles, guidelines for selection of 100 cities; and process for implementation and capacity building.

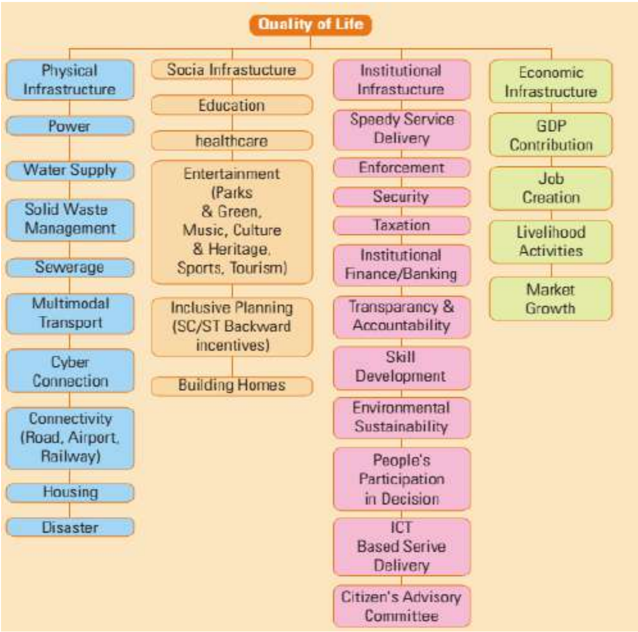

***Figure 3**: 4 Pillars of Smart Cities*

REFERENCES:

[1] A. Boustani *et al.* , "Investigation of the Waste-Removal Chain through Pervasive Computing," *IBM J. Res. Dev.* , vol. 55, no. 1.2, Jan. 2011, pp. 1–11.

[2] Boulton, A., Brunn, S.D., & Devriendt, L. (2011). Cyberinfrastructures and "smart" world cities: Physical, human, and soft infrastructures. In Taylor, P., Derudder, B., Hoyler, M., & Witlox, F. (Eds.), *International Handbook of Globalization and World Cities*. Cheltenham, UK: Edward Elgar.

[3] Hollands, R.G. (2008). Will the real smart city please stand up? *City*, *12*(3), 303-320.

[4] Giffinger, R., Fertner, C., Kramar, H., Kalasek, R., Pichler-Milanović, N., & Meijers, E. (2007). *Smart Cities: Ranking of European Medium-Sized Cities*. Vienna, Austria: Centre of Regional Science (SRF), Vienna University of Technology.

[5] Hall, R. E. (2000). The vision of a smart city. In *Proceedings of the 2nd International Life Extension Technology Workshop*, Paris, France, September 28,

[6] Harrison, C., Eckman, B., Hamilton, R., Hartswick, P., Kalagnanam, J., Paraszczak, J., & Williams, P. (2010). Foundations for Smarter Cities. *IBM Journal of Research and Development*, *54*(4).

[7] Natural Resources Defense Council. What are smarter cities?,

[8] Toppeta, D. (2010). *The Smart City Vision: How Innovation and ICT Can Build Smart, "Livable", Sustainable Cities*. The Innovation Knowledge Foundation.

[9] Washburn, D., Sindhu, U., Balaouras, S., Dines, R. A., Hayes, N. M., & Nelson, L. E. (2010). *Helping CIOs Understand "Smart City" Initiatives: Defining the Smart City, Its Drivers, and the Role of the CIO*. Cambridge, MA: Forrester Research, Inc.

[10] Dirks, S., & Keeling, M. (2009). *A Vision of Smarter Cities: How Cities Can Lead the Way into a Prosperous and Sustainable Future*. Somers, NY: IBM Global Business Services.

[11] Kanter, R. M., & Litow, S. S. (2009). Informed and interconnected: A manifesto for smarter cities. Harvard Business School General Management Unit Working Paper, 09-141.

[12] Mitchell, W. J. (2006). Smart City 2020, *Metropolis*. March 20

[13] Gil-García, J. R., & Pardo, T. A. (2005). E-government success factors: Mapping practical tools to theoretical foundations. *Government Information Quarterly*, *22*(2), 187-216.

[14] Scholl, H. J., Barzilai-Nahon, K., Ahn, J-H., Olga, P., & Barbara, R. (2009). E-commerce and e-government: How do they compare? What can they learn from each other?. *Proceedings of the 42nd Hawaiian International Conference on System Sciences* (HICSS 2009), Koloa, Hawaii, January 4-7.

[15] Vasseur, J. (2010). Smart cities and urban networks. In Vasseur, J. & Dunkels, A. (Eds.), *Interconnecting Smart Objects with IP: The Next Internet* (pp. 360- 377). Burlington, MA: Morgan Kaufmann.

[16] Odendaal, N. (2003). Information and communication technology and local governance: Understanding the difference between cities in developed and emerging economies. Computers, *Environment and Urban Systems*, *27*(6), 585-607.

[17] Ebrahim, Z., & Irani, Z. (2005). E-government adoption: Architecture and barriers. *Business Process Management Journal*, *11*(5), 589-611. 2295.

[18] Griffith, J. C. (2001). Smart governance for smart growth: The need for regional governments. *Georgia State University Law Review*, *17*(4), 1019-1062.

[19] Lynn, L. E., Heinrich, C. J., & Hill, C. J. (2000). Studying governance and public management: Challenges and prospects. *Journal of Public Administration Research and Theory*, *10*(2), 233-262.

[20] Johnston, E. W., & Hansen, D. L. (forthcoming). Design lessons for smart governance infrastructures. In Ink, D., Balutis, A., & Buss, T. F. (Eds.), *American Governance*

3.0: Rebooting the Public Square? National Academy of Public Administration.
[21] Belissent, J. (2011). *The Core of a Smart City Must Be Smart Governance*. Cambridge, MA: Forrester Research, Inc.
[22] Mooij, J. (2003). Smart governance? Politics in the policy process in Andhra Pradesh, India. *ODI Working Papers*, 228.
[23] Lam, W. (2005). Barriers to e-government integration. *The journal of Enterprise Information Management*, *18*(5), 511-530.
[24] Mauher, M., & Smokvina, V. (2006). Digital to intelligent local government transition framework. In *Proceedings of the 29th International Convention of MIPRO*, Opatija, Croatia, May 22-26.
[25] Bellamy, C. (2000). The politics of public information systems. In G. D. Garson (Ed.), *Handbook of Public Information Systems*. New York: Marcel Dekker.
[26] Rocheleau, B. (2003). Politics, accountability, and government information systems. In G. D. Garson (Ed.), *Public Information Technology: Policy and Management Issues*. Hershey, PA: Idea Group Publishing.
[27] Eger, J. M., & Maggipinto, A. (2010). Technology as a tool of transformation: e-Cities and the rule of law. In A. D'Atri & Saccà, D. (Eds.), *Information Systems: People, Organizations, Institutions, and Technologies* (pp. 23-30). Berlin/Heidelberg, Germany: PhysicaVerlag.
[28] Hartley, J. (2005). Innovation in governance and public services: Past and present. *Public Money & Management*, *25*(1), 27-34.
[29] Yigitcanlar, T., & Velibeyoglu, K. (2008). Knowledgebased urban development: The local economic development path of Brisbane, Australia. *Local Economy*, *23*(3), 195-207.
[30] Dawes, S. S., & Pardo, T. A. (2002). Building collaborative digital government systems. In McIver, W. J., & Elmagarmid, A. K. (Eds.), *Advances in Digital Government: Technology, Human Factors, and Policy*. Norwell, MA: Kluwer Academic Publishers.
[31] Mahler, J., & Regan, P. M. (2002). Learning to govern online: Federal agency Internet use. *American Review of Public Administration*, *32*(3), 326-349.
[32] Landsbergen, D. J., & Wolken Jr., G. (2001). Realizing the promise: Government information systems and the fourth generation of information technology. *Public Administration Review*, *61*(2), 206-220.
[33] Brown, M. M., & Brudney, J. L. (2003). Learning organizations in the public sector? A study of police agencies employing information and technology to advance knowledge. *Public Administration Review*, *63*(1), 30-43.
[34] Scott, W. R. (2000). *Institutions and Organizations*. Thousand Oaks, CA: Sage Publications.
[35] Giffinger, R., Kramar, H., & Haindl, G. (2008). The role of rankings in growing city competition. In *Proceedings of the 11th European Urban Research Association (EURA) Conference*, Milan, Italy, October 9-11.
[36] Dirks, S., Keeling, M., & Dencik, J. (2009). *How Smart is Your City?: Helping Cities Measure Progress*. Somers, NY: IBM Global Business Services.
[37] Cairney, T., & Speak, G. (2000). *Developing a 'Smart City': Understanding Information Technology Capacity and Establishing an Agenda for Change*. Sydney, Australia: Centre for Regional Research and Innovation, University of Western Sydney.
[38] Bronstein, Z. (2009). Industry and the smart city. *Dissent*, *56*(3), 27-34.
[39] Al-Hader, M., Rodzi, A., Sharif, A.R., & Ahmad, N. (2009). SOA of smart city geospatial management. In *Proceedings of the 3rd UKSim European Symposium on Computer Modeling and Simulation*, Athens, Greece, November 25-27.
[40] Anthopoulos, L., & Fitsilis, P. (2010). From digital to ubiquitous cities: Defining a common architecture for urban development. In *Proceedings of the 6th International Conference on Intelligent Environments*, Kuala Lumpur, Malaysia, July 19-21.
[41] Anthopoulos, L., & Fitsilis, P. (2010). From online to ubiquitous cities: The technical transformation of virtual communities. In Sideridis, A. B., & Patrikakis, C. Z. (Eds.), *Next Generation Society: Technological and Legal Issues* (Vol. 26, pp. 360-372). Proceedings of the Third International Conference, e-Democracy 2009 (Athens, Greece, September 23-25), Berlin, Germany: Springer.
[42] Barzilai-Nahon, K. (2006). Gaps and bits: Conceptualizing measurements for digital divide/s. *The Information Society*, *22*(5), 269-278.
[43] Norris, P. (2001). *Digital Divide: Civic Engagement, Information Poverty, and the Internet Worldwide*. New York: Cambridge University Press.
[44] Servon, L. J. (2002). *Bridging the Digital Divide: Technology, Community, and Public Policy*. Malden, MA: Blackwell Publishing.
[45] Barzilai-Nahon, K. (2009). Gatekeeping: A critical review. *Annual Review of Information Science and Technology*, *43*(1), 1-79. [8] Belissent, J. (2011). *The Core of a Smart City Must Be Smart Governance*. Cambridge, MA: Forrester Research, Inc.
[46] Castells, M. (1996). *Rise of the Network Society: The Information Age*. Cambridge, MA: Blackwell.
[47] Florida, R. (2002). *The Rise of the Creative Class: And How It's Transforming Work, Leisure, Community and Everyday life*. New York: Basic Books.
[48] Rios, P. (2008). Creating "the smart city".
[49] Partridge, H. (2004). Developing a human perspective to the digital divide in the smart city. In *Proceedings of the Biennial Conference of Australian Library and information Association* (ALIA), Queensland, Australia, September 21-24.

A Regulated Charging Scheme for Electric Vehicles Considering the Customers' Perspective

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***Abstract*—Electric Vehicles (EVs) are slated to play a dominant role in the smart electricity grid. A well managed charging system is thus necessary as random and unregulated charging of such active storage units stresses the power system by increasing peak loading and causing other complications. The prevalent charging scenario, active mostly at peak hours, also increases the charging cost burden on the customers. A controlled and optimally regulated vehicle charging scheme is developed and operated from the customers' perspective of minimizing the charging cost. The EV charging network also considers load aggregator as a major player and thus the developed scheme also tries to maximize its profit. Hence the aggregator adjusts the charging rate or power for each vehicle so as to stabilize the grid and also attain the objectives of maximum revenue and least charging cost. Based on the cost and revenue models for the considered power system, a mathematical optimization problem is formulated and solved using the interior-point method. The problem considers vehicle movement patterns as known to the aggregator. The aggregator revenue and the charging costs are obtained from solving the linear programming problem for a number of scenarios and their sensitivity to different parameters is analyzed. The results show interesting trends regarding the economics of EV charging, grid stability and charging rate regulation.**

***Keywords*– Regulation service, electric vehicle, charging rate.**

NOMENCLATURE

N	The number of EVs
T	Total number of time slots
M	The mark-up price (\$/kWh)
g_t	The electricity cost at time slot t (\$/kWh)
a_t	The regulation price at time slot t (\$/kWh)
P_i	The upper charging rate limit of EV i (kW)
$P_i^{'}$	The lower charging rate limit of EV i (kW)
C_i	The Battery capacity of EV i (kWh)
E_i	The battery charging efficiency of EV i
e_i	The initial SOC of EV i
$e_i^{'}$	The desired SOC of EV i
S_i	The starting time of EV i
f_i	The finishing time of EV i
R	The transformer delivery capacity (kW)
B	The cost upper bound (\$/kWh)
$h_{i,t}$	The EV connection time of EV i during time slot t (h)
$x_{i,t}$	The SOC of EV i at time slot t
$p_{i,t}$	The charging rate of EV i at time slot t (kW)
$P_{i,t}^m$	The maximum charging rate of EV i at time slot t (kW)
$r_{i,t}$	The regulation capacity of EV i at time slot t (kW)
$u_{i,t}$	The regulation-up capacity of EV i at time slot t (kW)
$d_{i,t}$	The regulation-down capacity of EV i at time slot t (kW)
$m_{i,t}$	The aggregator's revenue from EV i at time slot t (\$)
$c_{i,t}$	The cost of charging EV i at time slot t (\$)

I. INTRODUCTION

The rapid increase in the demand for transportation, which has a direct impact on the increase in the number of conventional vehicles, and the depletion of conventional fuels like petroleum and gas at the same time is compounding the global energy crisis. In response to this situation, the usage and wide-spread adoption of electric vehicles (EVs) is gradually increasing as the non-requirement of conventional fuels is the major argument in their favour. Not only in fuel saving but EVs also have a greater role to play in avoiding the vehicular emissions like CO_2, SO_2 and NO_x associated with conventional vehicles. Accordingly, the EVs are considered as environmentally friendly modes of transportation and that these vehicles are more advantageous when compared to traditional vehicles has been described likewise.

Another advantage of using EVs is the possibility of utilizing solar, wind and other renewable energy based sources for charging the vehicles. Such a practice can lead to further reduction in charging cost as electricity produced from such sources has reached parity with traditional power. This will also reduce the charging-related emissions from the utility plants. The growing paradigm of smart grids has even a greater scope for such a technology since EVs can act like mobile, distributed energy resources acting as active storage units. The concepts of grid to vehicle (G2V) and vehicle to grid (V2G) present an exciting opportunity of bi-directional power flows to support the power grid and smoothen the inclusion of intermittent renewable energy sources. The active storage and load-leveling abilities of EVs is an important asset that must be exploited strategically.

However, the integration of EVs into the power grid is very challenging [1]. Fig. 1 shows the typical arrangement of charging of EVs from the centralized grid using charging point installed in vehicle parking lots. Unregulated charging of EVs with fast charging speeds can result in a heavy load burden on the power system and may even cause the system to break down. The high amount of initial investment in purchasing an EV is also a concern among consumers, although this can possibly be compensated by government incentives, separately allocated funds and relatively lower power tariffs for charging. To maximize the benefits of using EVs, we need regulated and optimized charging control strategies. Individual residential customers are usually not able to perform the charging regulation for their own cars in the most efficient way [2], although they possess the motivation to save on charging costs. In the most usual scenario, such residential customers can provide their needs for controlled charging to load aggregators, which act as a control interface between consumers and the power grid operator to provide regulated charging for the connected vehicles with joint consideration for benefits of both consumers and the grid.

The aggregator earns profit by performing this controlled and regulated charging exercise. The profit of an aggregator usually consists of two parts: one is the price paid by the customers and other is the service charges paid by the grid operator. The customer charging cost also consists of two parts: one is the cost paid to the aggregator and the other is the tariff paid to the utility operator [3]. The structure of the aggregator revenue and customer cost is detailed in later sections

The basic intention in the optimal charging control schemes is improvement in financial dynamics along with the concerns for the power grid stability. A lot of work has been reported on charging control schemes but most of them are focused only on maximization of the aggregator's profit. In this paper we are considering maximization of the aggregator profit but are also targeting to minimize the customers' charging cost. In the global charging scenario that we have considered, the aggregator knows in advance about the vehicle information and charges them accordingly.

Fig. 1. Electric vehicle charging point in a parking lot

Rest of the paper is organized as follows. Section II gives a glimpse of related work done in this domain. Section III describes the system model adopted in the study. Section IV gives the definition and formulation of the problem in mathematical terms while Section V describes the results of mathematical optimization and their implications. Section VI concludes the paper.

II. Literature Review

The area of optimal EV charge scheduling has been taken up actively in the domain of smart grids research. Quite a significant amount of work has been done in this area. The major differences between our work and these related works can be summarized as follows:

1) Unlike most of the papers, that address only the aggregators benefit [4], we consider the charge scheduling problem from a customers perspective and aim at satisfying customers demands and reducing their costs.

2) Our schemes determine the charging rate for each individual EV, whereas in [5] and the EV charging pool was treated as a whole operation unit, and the charging rate is assigned to the unit based on its statistical behaviour.

3) A whole lot of works are based on solutions related to heuristic algorithms that cannot provide any performance guarantees [6] while we have adopted the classical optimization approach best suited for the case considered and it gives a guaranteed solution. However, we present schemes to produce optimal solutions for the static charging problems.

4) Regulation services provided by EV charging control have not been considered in [7].

In some papers the authors have just presented conceptual frameworks [8] without presenting specific optimization algorithms whereas in our work, we have presented algorithms to optimize EV charging schedule with consideration for customer demands. We have made certain assumptions that seem to be quite valid for the current level of advancement in the practical implementation of such EV charging schemes in real time.

III. System Model

An EV charging network typically consists of a substation, group of associated transformers, vehicles connected to the leaf node transformers and the aggregator. A leaf node transformer is the one which is connected to the lateral of the node to which an EV is attached. A schematic of the network is shown in Fig. 2. In such a system, the aggregator acts as a controller who collects information from the both grid and the vehicles and charges them accordingly with a particular charging rate in each hour [9]. In this charging network configuration, the group of EVs are connected to the leaf node transformer and it is ensured that the delivery capacity of each of the leaf node transformers is not exceeded. This is to prevent overloading of transmission lines and other equipment. In the model considered in this study, it is assumed that an EV can come at any time and leave at any time, depending upon the customers' need. Each charging task, thus,

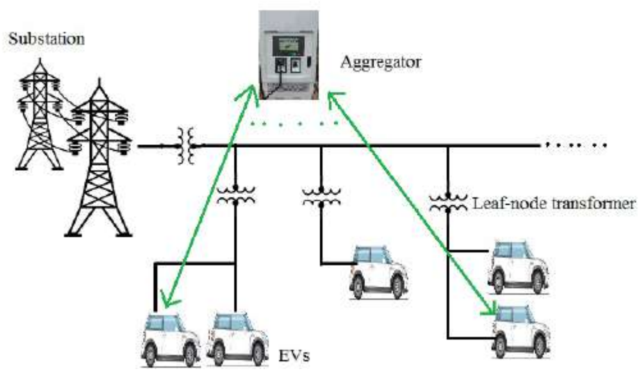

Fig. 2. EV charging network

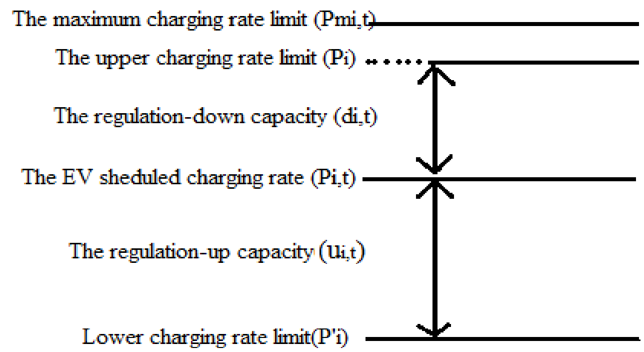

Fig. 3. EV regulation capacity

can be represented by 5 sets of data namely $i, S_i, f_i, e_i, e_i^{'}$ which have been defined in the nomenclature. At night, the load is low and that is why many vehicles prefer charging in this period only. We consider the charging tasks to be performed between 12.00 P.M. current day to 12.00 P.M. next day hence a 24 hours charging horizon.

An aggregator may charge the EVs at any appropriate charging rate depending upon the capacity of the battery and the load conditions (at peak load it may charge with lower charging rates and vice versa). It is also the aggregator's responsibility to control the EV charging rate in such a way that the total delivery capacity of leaf node transformers is not exceeded. In addition to executing these tasks, the aggregator also tries to improve its revenue. In general, the aggregator purchases power at a wholesale price from the power grid which varies from hour to hour within a day. For peak times during the day, this price becomes high and for off-peak hours, the same price becomes comparatively low. The aggregator adds some price to this wholesale price and then sells it to the customers. This added price is known as markup price.

The power grid operator prefers even load distribution and a stable frequency for the purpose of system stability and reliability. The aggregator can adjust the charging rates of the connected EVs to produce a flat or evened-out load distribution by charging the vehicles with higher charging rates during off-peak periods and with lower charging rates during the peak periods [10]. During emergency, if the grid calls for additional power supply, then the aggregator can respond with temporally increased or decreased charging rates. This action is referred to as regulation service in the electricity market. The amount of charging rate that an aggregator can increase or decrease in response to the grid requirement is referred to as regulation capacity. The amount of regulation capacity that one EV can provide to the grid is shown as a schematic diagram in Fig. 3. The difference between the upper charging rate limit or maximum charging rate limit (whichever is smaller) and the scheduled charging rate is the regulation down capacity. The upper charging rate limit depends upon the EV battery as it is the largest rate at which the battery can draw power. The maximum charging rate limit is the power needed to charge the EV to its desired SOC in one time slot which is calculated by the following equation:

$$P_{i,t}^{m} = \frac{(e_{i,t}^{'} - x_{i,t}) * C_i}{E_i}, \forall i, t \tag{1}$$

The charging rate for each EV cannot exceed the maximum charging rate limit in any time slot. In addition, when charging a group of vehicles, the total regulation down capacity should be further restricted by the delivery capacity of the transformer. The aggregator determines, for each time slot t, whether the charging rate for each connected EV (the total charging rate) added to the regulation down capacity is within the upper operational limit i.e. it ensures that $\sum P_{i,t} + d_{i,t} \leq R$. This way the aggregator can help keep the system frequency stable which is why the power grid operator willingly agrees to pay for the regulation service provided.

Regulation up capacity is the difference between the scheduled charging rate limit and the lower charging rate limit by which the EV can decrease the charging rate to help boost the system frequency. The regulation capacity is thus the sum of regulation up and regulation down capacities. The aggregator will be paid by the power grid operator based on the regulation capacities. Therefore the aggregator revenue consists of markup price paid by the customers and regulation price paid by the power grid operator. Accordingly the aggregator total revenue is calculated as follows:

$$m_{i,t} = a_t r_{i,t} + M p_{i,t} h_{i,t} \tag{2}$$

The customers' charging cost includes markup price paid to the aggregator and the wholesale electricity price paid to the grid. Therefore a customer's charging cost for an EV is given by:

$$C_{i,t} = (M + g_t) p_{i,t} h_{i,t} \tag{3}$$

This study describes mathematical optimization applied to minimize (3) and maximize (2) as well. The detailed mathematical formulation and the results are described in the following sections.

IV. Problem Definition and Formulation

Since the optimization problem being formulated is an optimal scheduling problem, the scheduling horizon considered is 24 hours, from 12 noon of current day to 12 noon next day, as mentioned above. Each interval is of 1 hour duration. This optimization exercise will result into different charging schedules with different charging rates at each hour t. Any resulting charging schedule will be considered to be feasible when both the customers' demand and the system loading requirements are satisfied. In this study, we are considering two objectives: to minimize customers' charging cost and to maximize the aggregator revenue as well. While maximizing the aggregator's revenue, customers' charging cost should not exceed its upper bound.

This study considers a charging schedule in which the aggregator knows in advance about the following information relating to a charging task: starting time, finishing time, initial SoC and expected final SoC for each vehicle taking part in the scheduling exercise. Although in reality the information for some of the charging tasks may not available in advance, such an assumption seems quite acceptable to begin with as the present EV charging schemes are also do not involve that much complexity and most of them operate on advance information given a regular vehicle movement pattern.

Before defining the scheduling problem in mathematical terms, we list a few necessary terms relating to a charging task namely $i, S_i, f_i, e_i^{'}$ that correspond to: vehicle ID, starting time, finishing time and initial SoC for every vehicle respectively. Base loads at each interval $(l_1, l_2, , l_T)$, regulation price at each interval a = $[a_1, a_2, , a_T]$, transformer delivery capacity R, EV battery capacity C, EV battery efficiency E and the upper and lower charging rates at each interval are some of the other related terms. The set of S_i and f_i were generated randomly based on a Gaussian probability distribution whose mean and standard deviation were taken from [6] and from which the transformer capacity was also taken. The base loads at each hour were taken from the load profile in [11] from which the markup price was also taken while the battery capacity and efficiency were taken form [12]. These specifications are given in Table I. Utilizing all these terms, the problem can be defined via two statements:

Problem 1: For the set of given charging tasks the aggregator revenue $\sum_{i=1}^{N}\sum_{t=1}^{T} m_{i,t}$ should be maximum among all the feasible charging tasks. Where $m_(i,t)$ is the aggregator revenue from EV i at time slot t.

Problem 2: For the set of given charging tasks the customers charging cost $\sum_{i=1}^{N}\sum_{t=1}^{T} c_{i,t}$ should be minimum among all the feasible charging tasks.

Considering the maximization of the aggregator's revenue, the problem can be stated in a mathematical form as follows:

$$max_{x_{i,t},p_{i,t},r_{i,t}} \sum_{t=1}^{T} a_t(\sum_{i=1}^{N} r_{i,t}) + M\sum_{t=1}^{T}\sum_{i=1}^{N} p_{i,t}h_{i,t} \tag{4}$$

In the above equation the first term is the price paid by the grid operator to the aggregator for providing regulation service and the second term is the price paid by the customer to the aggregator. This objective function is to be maximized subjected to the following constraints:

$$x_{i,t} = \begin{cases} e_i, \forall i, t = \lfloor S_i \rfloor \\ e_i^{'}, \forall i, t = \lceil f_i \rceil \\ x_{i,t-1} + \frac{E_i h_{i,t-1} p_{i,t-1}}{C_i}, otherwise \end{cases} \tag{5}$$

In the above equation we assign a value to the SoC of each connected EV in each hour. Here $h_{i,t}$ gives the actual connection time for each EV during each time slot. An EV may not come at the beginning of a time slot and may not leave at its end. Therefore the connection time of an EV may be less than 1 hour and this would have an effect on the calculation of regulation capacities, charging energy and cost. However it is to be noted that this $h_{i,t}$ value can be pre-calculated using the following formula:

$$h_{i,t} = \begin{cases} 1, \lfloor S_i < t < \lfloor f_i \rfloor \\ 1, t = \lfloor S_i \rfloor, S_i = \lfloor S_i \rfloor \\ \lceil S_i \rceil, t = \lfloor S_i \rfloor, S_i \neq \lfloor S_i \rfloor \\ f_i - \lfloor f_i \rfloor, t = \lfloor f_i \rfloor, f_i \neq \lfloor f_i \rfloor \\ 0, otherwise \end{cases} \tag{6}$$

The following have to be ultimately satisfied as a constraint:

$$P_i^{'} \leq p_(i,t) \leq P_i, \forall i, t \tag{7}$$

$$\sum_{t=1}^{T}(M + g_t)(\sum_{i=1}^{N} p_{i,t}h_{i,t}) \leq B \tag{8}$$

The upper bound cost B can be calculated by calculating the total cost of unregulated charging. In the unregulated charging scenario, we charge the vehicles with the maximum possible charging rate:

$$r_{i,t} = u_{i,t} + d_{i,t}, \forall i, t \tag{9}$$

The total regulation capacity is the sum of the regulation up and regulation down capacities. Here the regulation up and down capacities can be calculated using the following equations:

$$u_{i,t} = \begin{cases} p_{i,t} - P_i^{'}, \forall i, ts.th_{i,t} = 1 \\ 0, otherwise \end{cases} \tag{10}$$

TABLE I
CONSTANTS USED IN SIMULATION

Mean of S_i	6 P.M.
Mean of f_i	7 A.M.
Standard deviation of S_i	2 h
Standard deviation of S_i	2 h
R	200 kW
E_i	0.9
C_i	16 kWh
M	$ 0.05

$$d_{i,t} = \begin{cases} P_i - p_{i,t}, \forall i, ts.th_{i,t} = 1 \\ 0, otherwise \end{cases} \tag{11}$$

It has also to be ensured that the total load should not exceed the transformer delivery capacity. This constraint is expressed as:

$$\sum P_{i,t} + l_t + d_{i,t} \leq R \tag{12}$$

The primary problem of minimizing the customers' charging cost can be expressd by the following objective function:

$$min_{x_{i,t},p_{i,t},r_{i,t}} \sum_{t=1}^{T} (M + g_t)(\sum_{i=1}^{N} p_{i,t} h_{i,t}) \tag{13}$$

Considering (4) and (13) as two separate objective functions with common constraints (6) - (12) except (8) for the problem in (13), an optimization framework was set up in Matlab. Examining the nature of the objective functions and the constraints, it is seen that the complete optimization problem is linear. This linear programming problem was solved using the Interior-point method in Matlab and the results are detailed in the next section.

V. Results

The starting time S_i and finishing time F_i for the vehicles has been calculated using normal distribution with a mean time of = 6 P.M and = 7 A.M respectively with a standard deviation of 2 h, as mentioned above. The initial SOC e_i was set to be distributed in the range of [0.3, 0.9]. The charging rate varies in the range of 0 to 4.4 kW.

A. Impact of number of electric vehicles on system performance

The results shown in Fig. 4 summarize that with the increase in number of vehicles, the total charging cost for customers is decreasing i.e., with large number of customers having electric vehicles the overall charging cost per customer significantly reduces. From Fig. 5 we can say that the aggregator also gets more revenue with large number of EV customers. The results shown in subsections A and B have been compared with the results in [6] from which the objective function formulation has been inspired.

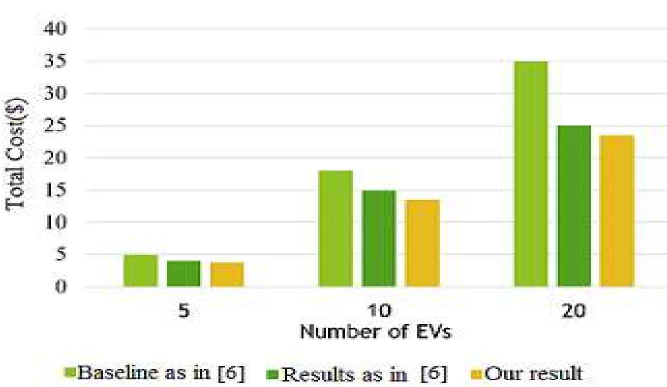

Fig. 4. Minimum total charging cost vs number of EVs

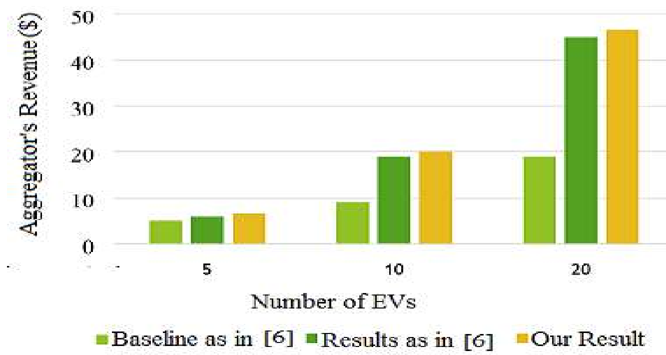

Fig. 5. Maximum aggregators revenue vs Number of EVs

B. Impact of Upper Charging Rate Limit on System Performance

The impact of upper charging rate limit on maximum aggregators revenue and minimum total charging cost is shown in Figs. 6 and 7. We performed this set of simulation runs for N = 5 EVs by changing the upper charging rate limit from 3.3 kW to 8.8 kW with a step size of 1.1 kW. The maximum revenue is computed by using (4) and minimum charging cost is calculated by using (13) with their respective constraints.

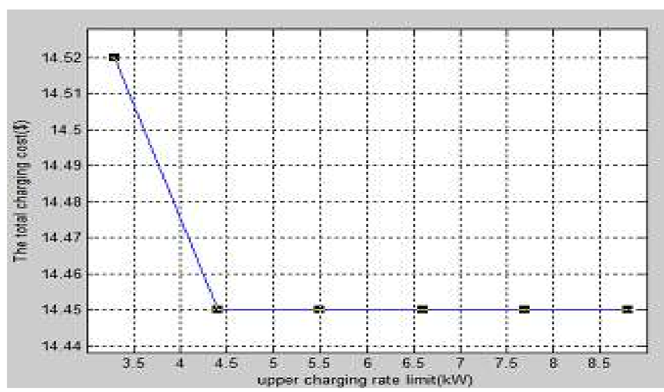

Fig. 6. Minimum total charging cost vs the upper charging rate limit

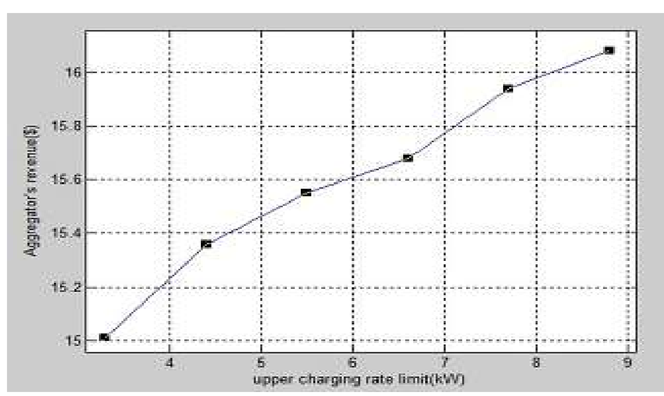

Fig. 7. Maximum aggregators revenue vs upper charging rate limit

We can make the following observations from Fig. 6: The increase in the upper charging rate limit does not benefit the customers much. However, the upper charging rate limit shows a positive impact on the aggregators revenue, i.e., the revenue increases with the upper charging rate limit as shown in Fig. 7. This is because the increment in this limit improves the regulation capacity, which determines the revenue. However increasing the charging rate can only be made possible and realized effectively by improving the aggregator installed hardware. However the transformer delivery capacity R is also an important issue alongside the upper charging rate which causes an increase in the revenue slow down.

VI. Conclusion

A mathematical optimization problem for development of a regulated EV charging scheme has been formulated considering the customers' cost alongwith aggregator's revenue. The linear programming (LP) problem has been solved using interior-point method. The aggregator revenue and the charging costs are obtained from solving the LP problem for a number of scenarios and their sensitivity to different number of vehicles and the upper charging rate has also been analyzed. We have studied LP-based optimal schemes for the static charging scheduling problem where the EV movement information is known in advance. The results show that the total charging cost can be reduced by 18.5% and aggregators' revenue can be improved by 119% on average when compared with an unregulated baseline approach.

References

[1] A. Y. Saber and G. K. Venayagamoorthy, "Optimization of vehicle-to-grid scheduling in constrained parking lots," in *Proc. IEEE Power & Energy Society General Meeting 2009*, 2009, pp. 1–8.

[2] S. Shao, M. Pipattanasomporn, and S. Rahman, "Challenges of PHEV penetration to the residential distribution network," in *Proc. IEEE Power & Energy Society General Meeting*, 2009, pp. 1–8.

[3] M. Honarmand, A. Zakariazadeh, and S. Jadid, "Optimal scheduling of electric vehicles in an intelligent parking lot considering vehicle-to-grid concept and battery condition," *Energy*, vol. 65, no. 2014, pp. 572–579, 2014.

[4] E. Sortomme and M. A. El-Sharkawi, "Optimal charging strategies for unidirectional vehicle-to-grid," *IEEE Transactions on Smart Grid*, vol. 2, no. 1, pp. 131–138, March 2011.

[5] M. Moeini-Aghtaie, A. Abbaspour, P. Dehghanian, and M. Fotuhi-Firuzabad, "PHEVs centralized/decentralized charging control mechanisms: Requirements and impacts," in *Proc. North American Power Symposium (NAPS)*. IEEE, September 2013, pp. 1–6.

[6] C. Jin, J. Tang, and P. Ghosh, "Optimizing electric vehicle charging: A customer's perspective," *IEEE Transactions on Vehicular Technology*, vol. 62, no. 7, pp. 2919–2927, September 2013.

[7] S. Han, S. Han, and K. Sezaki, "Development of an optimal vehicle-to-grid aggregator for frequency regulation," *IEEE Transactions on Smart Grid*, vol. 1, no. 1, pp. 65–72, June 2010.

[8] C. Guille and G. Gross, "Design of a conceptual framework for the V2G implementation," in *Proc. IEEE Energy 2030 Conference*, 2008, pp. 1–3.

[9] G. Higgs. (2010, June) Electric vehicle charging infrastructure. [Online]. Available: http://www.westtrans.org

[10] A. Foley, B. Tyther, P. Calnan, and B. O. Gallachir, "Impacts of electric vehicle charging under electricity market operations," *Applied Energy*, vol. 101, no. 2013, pp. 93–102, 2013.

[11] NYISO Whole-sale Power. [Online]. Available: http://www.eia.gov/cneaf/electricity /wholesale/ new_yorkiso.html

[12] Chevy volt specifications. [Online]. Available: http://www.chevrolet.com/volt

Defining a sustainable working model for SMART Grid implementation

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Abstract — Smart Grid implementations, both in India and across the world have taken a huge momentum over the last few years. Every utility is desiring to have a responsive grid with minimal breakdown time and for the sake of that, multiple projects are getting bundled under the umbrella of SMART, which ironically has no single line approved direct definition yet. However, advancement of technology in metering, communication, protective devices and capturing of huge volumes of data (as the case may be), have enabled utilities to

i) Ensure a reliable, greener and commercially competitive service to consumers in advanced countries with total automation and bare minimum workforce
ii) Try to ensure 24x7 electricity in emerging economies in a semi-automated mode
iii) Try to ensure electricity for all in underdeveloped countries

There can be differences with respect to availability, reliability and cost effectiveness of power in different geographies and accordingly the definition of "Smart" might vary, but what can never be ignored is that at least consumers now are more aware of per capita consumption, increasing pollution levels, green energy, service standards and last but not the least the control of usage as per demand and not as per supply. So whether India needs to pitch in for 10 million electric vehicles by 2025 or ensure 24x7 power for all by 2017 or Germany needs enlarge the pie of its green generation to 45% by 2020, or Netherlands wishes to generate 100% from wind power by 2019, completely depends upon the collective objective, roadmap and a workable sustained plan to achieve those backed up by adequate infrastructure.

The objective of this paper is to benchmark the objectives of Smart Grid for a utility vis-à-vis its practicality in a defined time frame.

***Keywords*— AMR, OMS, GIS, CIS, PQM, PLM, SCADA/DMS, DG, Sustainable model, KPIs.**

1. INTRODUCTION.

The common question that is now moving across quarters is whether the SMART Grid roadmap of India is taking a correct shape, whether the framework is sustainable and apprehensions remain that if pilot projects are getting delayed in such manner, what exactly will happen to utility wide implementations. Utilities on one hand are struggling to be profitable in the face of various developments in the field of enhanced technology and its penetration up to the customer level and to prioritize the most important task of grid stabilization. Today almost every customer has tasted the finest of services provided by the sectors like Banking, telecommunication, online retail and they expect the same service from utility industry which is severely lacking in this aspect. New breed of customers want to have more control on their consumption of energy. So it's time that we should take a closer look into the pilot Smart Grid implementations till date and see whether any difference to the same makes any difference to the implementation success.

2. THE BACKGROUND

Here, I would like to bring in two pertinent questions –

i) What exactly is the Smartness of Grid we are discussing here?
ii) Does the same smartness applies to ALL in a time-location warp?

The Smart Grid Maturity model speaks of grading the utilities from Initiating to Pioneering, according to the preparedness and execution status with respect to Strategy, Organization Structure, Grid Operations, Work and Asset Management, Technology, Customer, Value Chain Integration and Societel & Environment.

In advanced countries, smartness of a grid is mainly defined more by distributed energy resources, demand response and large scale renewable generation because the rest elements like automation, grid operations, asset management, technology were already addressed or at least had a definite roadmap prior to this Smart Grid hype.

The main issue that the advanced Smart Grid implementers are facing now is – what to do with such volume of data that is getting generated every day. Decision support systems are getting redefined in the light of the BIG Data and newer analytic models are taking over to give insights which were never before thought of.

But in India it is not quite likely so. It's been over three years after MoP's visionary declaration of implementing pilot smart grid projects. Today, out of the initial 14 pilots scheduled, two are cancelled, two are being retendered, eight are evaluated/awarded and only two are actually being executed. The summary is not quite impressive for the Smart Grid road map in India, but the experiences gained thus, gives definite insights to move ahead.

Indian Smart Grid projects are necessarily restricted to the following –

A) Automated Meter Reading (all 14 pilots)
B) Peak Load management (9 pilots)
C) Outage Management (7 pilots)
D) Power Quality Management (4 pilots)
E) Integration of Distributed Generation (2 pilots), and
F) SCADA/DMS implementation (1 pilot)

If we divide the above six projects according to the primary beneficiary, Power Quality Management and maybe Outage Management to some extent directly helps the end consumer. All the others are directly benefitting the utilities, or if put in other words, utilities are trying ways and means to capitalize the government grants to ease out their own operations.

But if we take a closer look at the scope of implementation of each of the projects, we find that all of these (except integration of distributed generation) are informative in nature and is giving the utility the data it seeks at a much faster pace than the existing systems (and perhaps nothing more than that). Needless to mention that each of the projects have multiple dependencies on other projects and third parties (like network service providers). Processing the information and taking corrective / preventive actions thereof still remains upon the existing infrastructure, operational procedure and human resources of the utility, which perhaps needs to be relooked into.

3. INTROSPECTION

Let's introspect the practicality of the projects in the Indian context one by one –

A) Automated Meter Reading – the easiest way for a utility to reduce its cost is to reduce the number of meter readers and put things in automated mode, with additional benefits of enhanced accuracy, reduced meter to cash cycle and "real time monitoring (?)". Little did we take into account the following -
   i) The connectivity network across the utility is not merely poor but literally non-existent at places and telecom

service providers do not take into account utility expansion to set up their towers.

ii) On paper, all meters should be on standard DLMS protocol, whereas DLMS covers only about 5-7% of the meter population of the utility; not to speak of cases where electromechanical meters are adoring consumer premises.

iii) The site conditions are not at all conducive to deployment of sophisticated communication devices.

WAY OUT – a) Hybrid models of communication should be considered with GPRS, ZIGBEE, WAN (Fibre/copper) etc but network service providers should be brought under an SLA.

b) All meters should be replaced by standard DLMS ones as a primary prerequisite.

B) Peak Load Management System– the peak load management system consists of monitoring and arranging actions for peak clipping or load shifting through direct and indirect measures like rate designs and using utility controlled devices. What were overlooked are

i) TOD tariff exists for more than two decades in India, which failed to deter the industrial usage to any significance during peak times

ii) None of the electricity regulatory authorities in India provide for utility load control devices to be instated at consumer premises. Consumers too are adaptive to mass scale load shedding rather than micro controlled shedding at specific premises.

WAY OUT – India has power shortfall and not abundance. Thus only erring consumers (drawing more than the permissible load) can be directly brought under this scope to start with. Regulation also needs to be aligned with such concepts. To summarize, micro controlled peak load management is not the current cup of tea for India under prevalent circumstances.

C) Outage Management System – this indeed has a scope and will be a definite booster to operations, reducing downtime (at least by reporting incidents in real time). A couple of things will put the outage management system in proper perspective –

i) Success of OMS is heavily dependent on the following –

a. Geographical Information System (GIS), with regular update in system
b. Consumer Information System (CIS) integrated with both GIS and OMS
c. Interactive Voice Response (IVR) handling customer complaint at Call Center, and a
d. Successful AMR system or SCADA for real time reporting.

Individually these projects in themselves have multiple dependencies and even if call center and IVR can be implemented successfully, GIS remains a far-fetched cry from reality despite the booster from RAPDRP.

ii) To add to the woes the rectification/restoration process, time taken and outcomes remain as they were before.

WAY OUT – Successful OMS implementations should have GIS, CIS, IVR, AMR implemented and running in a steady state, as a mandatory prerequisite. The workforce and fault restoration management needs a thorough overhauling.

Last, but not the least, the site infrastructure needs to be in good shape with proper preventive maintenance from time to time.

D) Power Quality Management – utilities hardly cared about the quality of power, as long as power was made available. Regulations are there for control of voltage fluctuations over and under a stipulated value, but effective implementation of the same is hardly seen anywhere. Power Quality Management definitely helps is getting the proper information in real time regarding voltages, frequencies power flow from various nodes in the utility, but not without the following blockades –
   i) Infrastructure to counter the outliers in maintaining power quality is too scarce
   ii) System is heavily dependent on communication backbone, which is not one of the strongest points in India.
   iii) Control of Harmonics, flickers and surges require adequate field level infrastructure up to consumer end points, which requires a thorough revamp.

E) Distributed Generation – the primary requirement of integration of distributed generation is proper infrastructure, which is missing at most of the places. Generation in a distributed manner is required to be integrated to the grid at a 33KV level, where dearth of the balance of equipment for evacuation of power makes it quite impossible at times, despite having the generation in place.

F) SCADA – a full-fledged distribution management system necessarily requires SCADA to be its backbone not only for a real time monitoring or supervision perspective but also ensuring to keep outliers and downtime in check, while optimizing the power flow to the end consumer. But to keep up with this advanced technology, the basic infrastructure and assets require to be responsive to the said technology. This requires a thorough overhauling of lines, gears, transformers and metering apparatus.

4. A PRACTICAL SMART GRIS MODEL – IN MATURITY TIME FRAME

Execution of Smart Grid Projects depends a lot on the capability and performance of the respective utility – both of which are quite qualitative in Nature. We need to draw a quantitative demarcation to ensure greater success rates of specific Smart Grid projects that is required and also suits the respective utility

Utilities in India fall under three major categories according to the capability to execute projects (benchmarking the implementation of RAPDRPs) –

a) Trend setters, who completed within the prescribed time frame
b) Generic Executers, who are completing in the extended time frame
c) Laggards, who are still struggling

Utilities can also be divided in to another three categories based on the performances of the standard KPIs

a) Forerunners
b) Mediocre
c) Backbenchers

Detailing the KPIs is also very necessary in this context, since that shapes the criteria of the SMART Grid project to be undertaken. Numbering a utility on the basis of the KPIs will automatically set the label as A, B or C against them. For example, the following KPIs are normally measured in any utility and their corresponding benchmark standards are defined by the Distribution Reforms, Upgrades and Management program pioneered by the Ministry of Power, Govt. of India - way back in 2007-2008.

Key Performance Indicators		Unit of Measurement	Target
Supply Availability & Reliability	System Average Interruption Frequency	Hours	< 2
	System Average Interruption Duration Index	mins per occasion	< 90
	Customer Average Interruption Duration Index	No.	< 1.3
	Distribution Txr failure	Percentage	0
	HT Line Failure Rate	faults per 100 ckt km	< 2
Consumer Service	Consumer Satisfaction	Percentage	100
	No. of Voltage Complaints	No.	0
	% of new services provided within 3 days	Percentage	100
	% of supply complaints resolved within 2 hrs	Percentage	100
	% billing complaints resolved within regulatory time limits	Percentage	100
Cost	O& M expenses per unit of energy input	Paise per unit purchased	< 10
	ROCE – Return on capital employed	Percentage	> 10
	Aggregate Technical & Commercial Losses	Percentage	< 8

Table 1 – Key Performance Indicators for Utilities

Based upon the benchmark standards, performance of each utility in the light of the individual KPIs can be graded as below –

Parameters	Grading Criteria					
SAIFI	< 2 = A	2 - 10 = B	10 - 50 = C	50 - 100 = D	> 100 = E	NA = F
SAIDI	< 90 = A	90 - 120 = B	120 - 240 = C	240 - 360 = D	> 360 = E	NA = F
CAIDI	< 1.3 = A	1.3 - 5 = B	5 - 20 = C	20 - 50 = D	> 50 = E	NA = F
Txr Fail	0 = A	0 - 2 = B	2 - 5 = C	5 - 10 = D	> 10 = E	NA = F
Line Fault	< 2 = A	2 - 5 = B	5 - 10 = C	10 - 20 = D	> 20 = E	NA = F
CSI	100 = A	95 - 100 = B	90 - 95 = C	80 - 90 = D	< 80 = E	NA = F
Voltage Complaint	0 = A	0 - 5 = B	5 - 10 = C	10 - 20 = D	> 20 = E	NA = F
New Meter	100 = A	95 - 100 = B	90 - 95 = C	80 - 90 = D	< 80 = E	NA = F
Technical Complaint	100 = A	95 - 100 = B	90 - 95 = C	80 - 90 = D	< 80 = E	NA = F
Billing Complaint	100 = A	95 - 100 = B	90 - 95 = C	80 - 90 = D	< 80 = E	NA = F
O&M Expense	< 10 = A	10 - 12 = B	12 - 15 = C	15 - 20 = D	> 20 = E	NA = F
ROCE	> 10 = A	8 - 10 = B	6 - 8 = B	4 - 6 = D	< 4 = E	NA = F
AT&C	< 8 = A	8 - 10 = B	10- 15 = C	15 - 25 = D	> 25 = E	NA = F
	A = 5	B = 4	C = 3	D = 2	E = 1	F = 0

Table 2 – Grading Criteria on KPIs

Any utility scoring 50 – 65 will be graded as a Forerunner, those scoring in between 30-49 will be a Mediocre and any score below 30 is a Backbencher.

Thus we have a two way matrix based on capability to execute a Project and performance of the utility.

Grading of Utilities				
Performance	Forerunner (A)	CA	BA	AA
	Mediocre (B)	CB	BB	AB
	Backbencher (C)	CC	BC	AC
Matrix to identfy high success rates in Smart Grid Projects		Laggard (C)	Generic Executers (B)	Trend Setters (A)
		Execution		

Table 3 – Grading Criteria of Utilities

Utilities falling in the green box are considered capable of executing Smart Grid projects and can safely form an objective of which Smart Grid Project(s), they should execute. Those in yellow needs specific guidance on their capabilities and not all projects are for them to execute. The red box requires a complete handholding else project timelines and cost will go spiral.

5. HOW ROLL OUTS SHOULD HAPPEN

The choice of the projects should be a guided from the above criteria with another look at the KPIs – especially those in which the utility has scored poorly. For example, low scorings in supply availability and reliability will prompt the utility to take up OMS and PQM, but without a proper infrastructure and asset management in place, none of the projects will be a full-fledged success.

All the prerequisites as detailed in the respective projects needs to be addressed before any execution is contemplated.

6. A WORKABLE FINANCE MODEL

The main bottleneck in the existing deployments is financing and all the pilot projects have undergone modifications at least a couple of times to adjust to the financing. The irony is that a one-time pumping of money for Smart Grid project implementation is never sufficient. The entire execution and subsequent maintenance needs to run on a self-sustainable model. And this includes maintaining the infrastructure and assets in the field.

The low hanging fruits of RAPDRP can easily be utilized in this aspect. A centralized billing system with improved billing and collection efficiency gives added cash flow to the utility. The meter to cash cycle also reduces significantly upon successful RAPDRP implementations. The only point is that this cash needs to be set apart consciously for funding requisite asset augmentation and infrastructure modernization.

However for not so successful RAPDRP deployments, a PPP model is the default way out, where the reduction of costs and AT&C losses can be shared in proportion to fund the asset augmentation.

A unique proposition of financing is alternate business model which does not fall under the regulation – like giving special services to utilities at premium cost or utilizing the utility platform for other alternate revenue earning methods

The grants from PFC and any other authorities needs to be necessarily treated as added incentives to give a shot to the utility arm.

7. REGULATION ALIGNMENT AND STAKEHOLDER EXPECTATIONS

The present Smart Grid project implementations lack the regulator boost in a dynamic way on one side and the stakeholder (primarily consumer) convincing on the other. These two can be treated as compliments to one another, since if consumers are enlightened about positive outcomes, regulation will have no issue in allowing Smart Grid projects in the ARR filings. On the other, if the first step is taken by the regulator in the conscious way, consumers will gradually get convinced. The second approach is decisive and has deep penetration. To do the same, all the state regulators need to adopt a baseline framework in the performance-capability time warp, deciding how much to allow respective utilities to execute Smart Grid projects. The said framework necessarily has to include the gradation of the following criteria

i) Infrastructure development
ii) Goal Setting in a scheduled time frame
iii) Work Force development and technology upgrade
iv) Operational Effectiveness
v) Effectivity of regulation implementation

8. CONCLUSION

Thus in India, we need not talk about implantation of Smart Grid. All we need to talk about is specific projects that suits the capability and performance of the respective utility since it is quite tough to bring all at the same level within a short period time. But gradual implementations in smaller perspectives will pave the road map for all utilities to be at par over a course of time and easily solve the bigger puzzle called SMART Grid.

9. REFERENCES

1. Newsletter (ISGF monthly Bulletins) published at www.indiasmartgrid.org.

2. Papers published on KPI in the Distribution Reforms, Upgrades & Management (DRUM) program

3. Performance Report of State Power Utilities published by PFC at http://www.pfcindia.com/Content/PerformanceReport.aspx

4. Paper on Smart Grid Projects in Europe: Lessons Learned and Current Developments 2012 update by the European Commission

5. Smart Grid Maturity Model

6. Customer Participation in SMART Grid by US Dept. of Energy.

Advance Metering Infrastructure for India

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Abstract

Advance Metering Infrastructure (AMI) is considered to be pivot of smart grid as it provides gateway of communication with customer and his appliances. AMI is also required for services related with customer such as remote connection/disconnection, demand response, pre-payment, real time pricing beside remote measurement of export and import of electricity from customer.

Studies conducted by EPRI, KEMA and our own analysis in several countries including India, indicate that AMI contribute to around 30% of total investment required for smart grid. In US and Europe, investment in AMI is a good business case due to significant reduction in meter reading costs. This is not the case in India and other South East Asian countries where manual meter reading cost is low due to cheap labor and about 15% of total customers have no requirement of reading as they are under fixed monthly billing tariff based on sanctioned load in KW or free agriculture consumers. Thus, it becomes difficult for utility and regulator to justify investment in AMI. India and other South East Asian Countries, need low cost AMI solution or customers be connected with differentiated AMI services based on their specific requirement. This issue becomes more important as in the new tariff policy announced by Government of India (GOI) last month mandates to provide smart meters to all consumers by 2019.

This paper will analyze these issues and present a solution to address this problem for India and South East Asian Countries. This will save cost without sacrificing the objectives of the new tariff policy.

Keywords—AMI, Smart Meters, India

INTRODUCTION

The consistent and biggest problem afflicting Indian power sector is Aggregate Technical and Commercial (AT&C) Losses. As per Central Electricity Authority Executive Report of December 2015, provisional AT&C losses for financial year 2013-14 is 22.7%. But experts believe it will be more than 30%. Several reforms in Indian power sector including attempts to manufacture of robust metering solutions are directed towards reduction of AT&C losses. . They have met with limited success. The most recent attempt in this direction has been made by the Ministry power in the tariff policy notified on Jan 28, 2016. The policy states that

"Appropriate Commission shall, therefore, mandate smart meters for: (a) Consumers with monthly consumption of 500 units and more at the earliest but not later than 31.12.2017; (b) Consumers with monthly consumption above 200 units by 31.12.2019. Further, two way smart meters shall be provided to all prosumers, who also sell back electricity to the grid as and when they require." In addition to reduction of AT&C losses the other argument in favor of smart meter deployment is, it would become essential in future for load-generation penetration of intermittent type of generation like wind and solar power.

AMI/SMART METER

A smart meter helps in accurate and real time recording of electricity consumption. It also helps in instantly communicating the consumption at central place for analysis and control action. However, all this cannot be done by smart meter alone, it will require other infrastructure also such as communication support, meter data management (MDM) and other software tools for analysis and control. Technically, it is called Advance Metering Infrastructure (AMI) and it covers all these things. Smart meter alone will not serve the purpose. Learning's captured from several utilities that have installed smart meters operating in different geographies, with different management control and consumer profile (Such as Enel Italy, Pennsylvania Power and Light, Puerto Rico Energy Authority, EDESUR Dominican Republic, Southern California Edison etc.) provide following key conclusions:-

1. Plan for AMI including MDM from the very beginning rather than smart meter alone.
2. Include all consumers. Implementation can be done in phases.
3. Establish separate unit within organization for implementation.
4. Prepare detailed implementation plan and involve all stakeholders including vendors from the very beginning.
5. Business case should be based on holistic benefits such as loss control (remote connect disconnect, loss control & surveillance, demand response, load management, better consumer service etc.)

Financing AMI/Smart Meter

Calculations indicate that installation of AMI for all electricity consumers of the country will require an investment of INR 2757 billion and will increase the tariff by 75%.[1] If only the cost of smart meter is considered, tariff will go up by 30%. How can utilities who are already in bad financial position afford these investments? Through which route can regulator ensure compliance of Government of India's (GOI) latest tariff policy? The answer is difficult to guess. Then, next question comes, is GOI prepared to fund it partially or fully. Even if GOI is prepared to invest, does it justify an investment of approximately INR 2757 billion for change of meter with the history of limited success in AT&C loss reduction, due to change in meter (From electro-mechanical to Electronic)? Or there are better ways and approaches to address this issue. This paper attempts to suggest costing saving approach for implementation of the directives in new tariff policy of GOI and higher possibility of AT&C loss reduction.

Consumer Profile

Table 1 below presents the consumer profile based on the data for 2012-13 published by CEA in its latest "All India Electricity Statistics".

Table 1: Consumer Profile Analysis

Consumer Category	Number	Connected Load	Consumption
Domestic	78.36%	37.86%	25.92%
commercial	9.66%	11.52%	10.27%
Industrial LV and MV	1.45%	10.68%	6.60%
Industrial HV	0.09%	15.23%	28.74%
Public Lighting	0.45%	0.86%	1.14%
Traction	0.00%	0.84%	1.99%
Agriculture	8.92%	17.93%	20.80%
Public Water Works	0.35%	1.52%	2.29%
Miscellaneous	0.72%	3.56%	0.02

The domestic, commercial and agriculture consumer constitute about 97% of the total consumers but presents only 67% connected load and 57% energy consumption respectively. Thus by changing the meters of remaining 3% consumers we can take care of 33% connected load and 43% consumption. There is no concreate consumption based consumer bifurcation is available for all the consumers of India. However, on the basis of availability of data of few utilities and experience it can be concluded that about 70% consumers in domestic and commercial Categories have average monthly consumption lower than 500 units. In agriculture category, about 60% consumers are still on either pump KW based billing structure or under free tariff category. This adds to 66% of the total consumer base whose monthly consumption is less than 500 units, KW based billing structure or under free tariff category.

These 66% consumers are those consumers who neither have surplus power to feed back into the grid nor likely to participate in demand response. Let us call these 66% consumers as Consumers under category 'A' and remaining 34% consumers under category 'B'. However, category 'A' consumers can be source for theft and other mal practices for the usage of electricity. Before we decide the features of such device and go in further details, let us understand the functionalities available with Smart Meter/AMI.

Functionalities of Smart Meter

The functionalities of smart meter/AMI are summed up in Table 2 below:-

Table 2: Functionalities of Smart Meter/AMI

Core Functions	Optional Functions
1) Interval (15 min) consumption and profile data (active and reactive energy, demand, voltage and current) recording	**Payment option**
2) Remote reading	1) Pre-payment option
3) Daily or real time reading	**Switching and Load Control**
4) Local Reading – hand held device and visual display on meter	1) Remote connect/disconnect
5) Tamper detection	2) Supply capacity control (load control)
6) Remote time clock synchronization	**Customer Interaction**
7) Pre-payment operation	1) Interface with Home Area Network (HAN)
8) Import/export metering	2) Ability to communicate with In-Home-Display (IHD), Energy Management System (EMS) and Building Automation System (BAS), Load Control
9) Remote Time of Use (TOU) Configuration	
10) Remote Software Firmware upgrade	

[1] Assuming 275 million consumers' annual consumption of 708843 GWh and average tariff of INR3.5/kWh according to CEA All India Electricity Statics General Review for 2014. Based on market, estimated AMI cost is INR10000 per consumer.

	Switches, Programmable Communicating Thermostat
11) Quality of Supply & other event recording	
12) Meter loss of supply and detection (last gasp)	
13) Remote Configuration	
14) Plug and Play device commissioning	
15) Communication and Data Security	

RECOMMENDATIONS

Our major recommendation is category 'A' consumers need not be provided with meters or display of their consumption at their premise. At premise of such consumers a Switching and Load control device only be provided which can connect/disconnect their supply automatically if load increases beyond sanctioned load and supply can be connected/disconnect remotely for non- payment or due to any other reasons. The remote connection/disconnection should take place not only at consumer premise but also at junction point.

The consumption can be measured at the junction point (Pole, pillar box, transformer etc.) from where service line is being drawn. This measured consumption be communicated to MDM and be recorded in MDM. Each consumer has an option to know his consumption at any point of time by sending an SMS through his mobile to MDM server, from the website of the utility or at the end of month by bill. The biggest obstacle/difficulty in this recommendation can be no display of meter consumption at consumer premises of which consumers are traditionally accustomed. Although several consumers never reads their meters in spite of display been provided at their premises. Secondly in multistory apartments generally meter of all consumers are at common place. Most of the consumers even do not know the place. However, in spite of never or limited use of existing display of electricity consumption, consumer advocates and regulators may not digest it easily. We have parallel example of this recommendation where it is prevalent from inception e.g. in case of land/mobile telephone consumption is not displayed at premise of consumer. The land/mobile phone consumption is informed to consumer on request; he can see on website and communicated to him in the monthly bill. I see no reason why this practice cannot be adopted for electricity consumers. This will save about 47% cost (INR1456 billion)[2] in implementation of new tariff policy of GOI. In addition to cost saving this will help immensely in reducing the AT&C losses as any increase in load will cut the supply immediately, any drawl from neighbor will cut supply of neighbor as the neighbor load will exceed his sanctioned load. Since there is no meter, tampering of meter will vanish. Since consumption recording is at pole, pillar box or transformer, direct hooking from service line will also get stopped.

To avoid any legal dispute it is suggested to made provision of this in section 55 of the Electricity Act 2003. CEA can further clarify it in the meter regulations.

The category 'B' consumers can be further sub divided into two categories. Category 'B1'consumer who neither want to export power supply nor want to participate in demand response. Category 'B2' consumer who are interested in export of power as well as in demand response. The Category 'B2' consumers should be provided with full functionality AMI while category 'B1' consumers should be provided smart meter without functionality of measurement of electricity exported to the grid. However, if later they want to export power to the grid same meter can be used by adding a one plug in unit into it.

All the suggestions made above are technically possible but require work with institutions and manufacture to develop robust industrial product particularly for category 'A' consumers. Some software changes at MDM level may also require. Although, latest MDM have the features to incorporate above suggestions.

It will of great help to involve smart meter manufacturers in the process from the very beginning. Share the idea with them, product be developed and lab tested, pilots be conducted and then full scale roll out may take place. Institutions such as Central Power Research Institute (CPRI), National Physical Laboratory (NPL), Institute of Indian Standards (IST) and IITs can play the role of standardizing the product for uniformity and quality.

Above suggestions are for India specific requirement but can be used in other South East Asian countries such as Bangladesh, Pakistan and Nepal where ground realities are similar.

REFERENCES:

1. Executive Report of December 2015 published by Central Electricity Authority, Ministry of Power, Government of India.
2. Tariff Policy dated January 28, 2016 issued by Ministry of Power, Government of India.
3. All India Electricity Statistics-General Review 2014 published by Central Electricity Authority, Ministry of Power, Government of India.
4. Estimating the cost and benefits of the smart grid-2011 Technical Report published by Electric Power Research Institute, USA.
5. Smart Grid Road Map for CESC Ltd-a report prepared by Tetra Tech and available at website of US Trade and Development Agency.
6. AMI Case Book Version 2.0-Spotlight on Advance Metering Infrastructure published by International Smart Grid Action Network.
7. Website of India Smart Grid Forum- www.indiasmartgrid.org

[2] It includes INR 2000 per consumer cost for Switching and Load Control device for 66% consumers.

Case Study on a Commercial Demand Side Response Implementation in the UK

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***Abstract* - The UK's National Grid has numerous DSR programs or Balancing Services to pay demand aggregators. The aggregators pass on the payment to energy users who reduce their grid supplied consumption during times of peak demand. This paper first examines the important role of DSR in 21st century Electric Grids, the benefits of DSR to utilities as well as end users and details how DSR is implemented. The paper then discusses the role played by DSR aggregators in efficiently managing a commercial DSR implementation in the UK.**

***Index Terms*—Smart Grid, Demand Response, Aggregator, United Kingdom, Implementation**

I. Introduction

As a result of concerns about carbon emissions, constraints to electricity supply and rising energy costs, the role of Demand Side Response (DSR) is growing in importance [1]. DSR is a method of reducing electricity consumption at times of high wholesale market prices or when system reliability is jeopardized, allowing System Operators to avoid using outdated, expensive and polluting, "peaking" power stations.

The UK's National Grid has numerous DSR programs or Balancing Services to pay demand aggregators [2]. The aggregators pass on the payment to energy users who reduce their grid supplied consumption during times of peak demand. The aim of this paper is to provide an overview of DSR services and how they are implemented using a case study of KiWi Power, a DSR aggregator in the UK. The paper will firstly examine the conceptual framework of DSR, including comparing various balancing programmes in the UK market, the important role of DSR in 21st century Electric Grids, and the benefits of DSR to utilities as well as end users. The paper will then discusses how a DSR aggregator such as KiWi Power implements and operates a commercial DSR solution in the UK.

II. Conceptual Framework

A. Overview

Unlike most other environments and industries, the electricity grid cannot tolerate any imbalance between supply and demand. Any momentary deviation from this equilibrium will result in costly blackouts.

To avoid such catastrophic scenarios, UK's National Grid has a wide range of balancing mechanisms (BM) that could be used to maintain such equilibrium [2]. The general idea is simple – when the overall demand is approaching the available electricity supply, the clients are asked to either increase generation (if they a primary electricity producer), or reduce their consumption, or switch to locally generated electricity (such as back-up generators). The opposite scenario could happen when supply exceeds demand, in which case the reverse actions are taken.

DSR is one balancing mechanism used by the National Grid to maintain equilibrium and is enabled through a number of different programmes the fall into two categories. The first category covers DSR services aim at providing a fast response rate (within seconds) based on a grid frequency trigger e.g. if the frequency in the UK goes below 49.7 Hz then the balancing mechanisms like turning off assets or turning on batteries are achieved. The second category covers the more traditional DSR services that provide a slower response rate (up to 20 minutes to start demand reduction) to grid conditions and are activated based on a human decision process at the National Grid.

Figure 1 below provides an example of how an event would proceed for the second category of DSR. In short, KiWi Power will aggregate together a number of sites that provide demand reduction and sell this contract to the National Grid. When required the National Grid will request that this

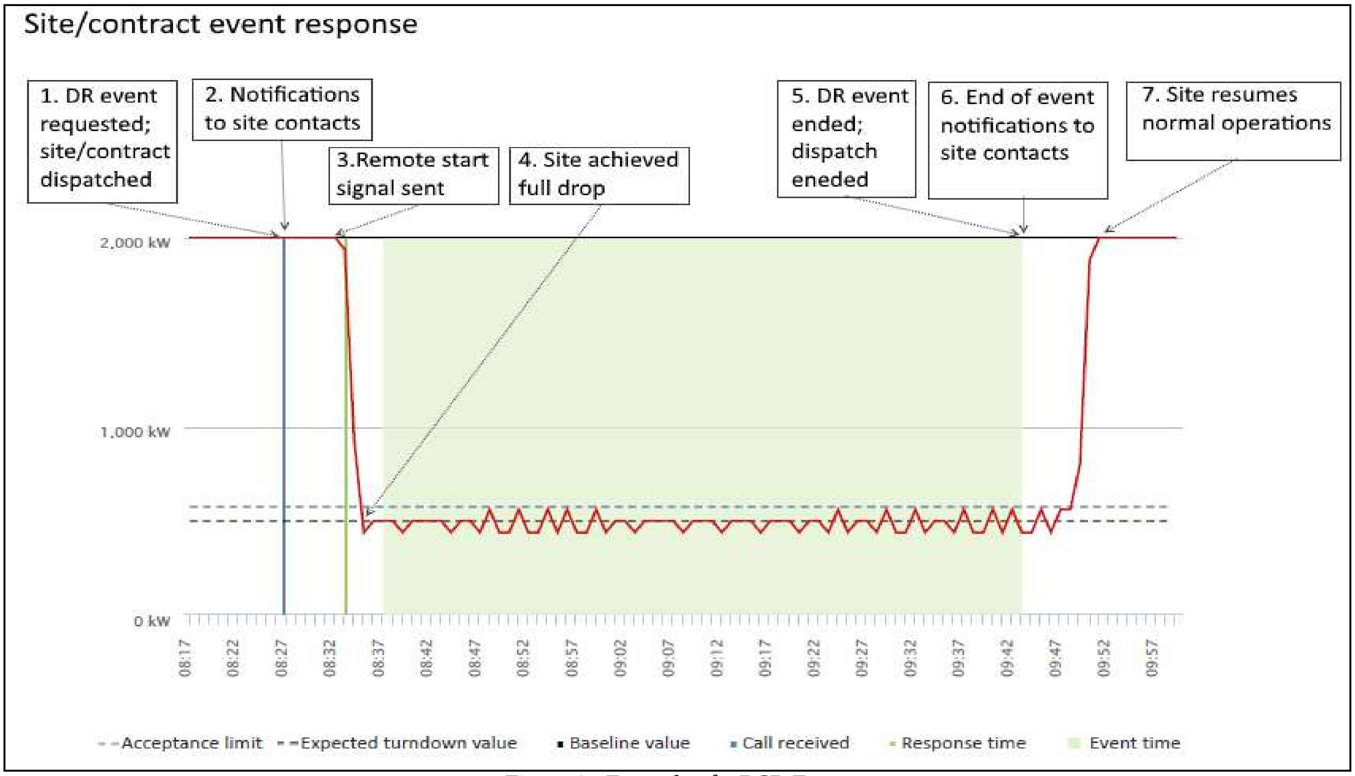

Figure 1 - Example of a DSR Event

contract is dispatched at which point the sites will be activated via a remote start signal (or manually by phone call) and must achieve the contracted certain drop level (reduction of electricity consumption). Once the network stress that caused the contact to be dispatch has been resolved then the National Grid will request that the assets are returned to their normal operation and a stop signal will be sent to each asset. There are some important conceptual considerations on how DSR can achieve a demand reduction, with the three main methods being:

(1) Through real turn-down where sites turn various energy consuming assets off (down).
(2) Through "generation behind the meter", where site's load is displaced via locally generated electricity (i.e. using back-up generators will reduce the energy draw of the site from the electricity grid).
(3) Where a site's back-up generator is big enough to (1) offset 100% of the site load and (2) export the extra energy back to the grid. This in effect will simultaneously reduce the demand and increase the supply of electricity.

All three methods lead to the same effect – reducing the demand of the site for electricity from the Grid.

B. *Programmes*

There are a number of different balancing programmes in the UK that can be used for DSR and cover both fast and intermediate response rates as previously described. Details of each of these programmes is provided in Table 1 [2].

Table 1 - Demand Response Programmes Summary

Programme	Short Term Operating Reserve (STOR)	Frequency Control by Demand Management (FCDM)	Firm Frequency Response (FFR)	Triad
Type	Reserve Power	Frequency response	Frequency response	Charges avoidance scheme
Method of dispatch	Dispatch instruction via the STOR SRD terminal	Automatic activation when frequency drops below 49.7Hz	Automatic activation when frequency drops below 49.7Hz	Dispatch based on the likelihood of peak demand
Response time	10 or 20 minutes	2 seconds	30 seconds	N/A
Duration of event	Up to 2 hours	15 minutes	30 minutes	Usually 1-2 hours
Availability	All year with Predefined daily windows	24/7	24/7	Winter time workdays (4-6PM)
Capacity commitment	Depending on contract	Varies	Varies	N/A
Availability declarations	Weekly	Weekly	Weekly	Same day

III. Demand Response Programme Implementation

A. *General Description*

The current primary DSR programme in the UK is STOR. STOR is required because at certain times of the day (window periods normally 07:00-14:00 and 16:00-22:00), the National Grid needs reserve power in the form of either generation or demand reduction to be able to deal with actual demand being greater than forecast demand and/or plant unavailability [3]. Where it is economic to do so, National Grid will obtain part of this requirement ahead of time through STOR. Contracts to provide STOR services are auctioned using a tender process three times a year by the National Grid. The process requires companies to tender set levels of capacity (minimum 3MW) at different per MWh availability (how much will be paid to have the capacity available for usage, currently around £1-£4 per MWh) and utilization prices (how much is paid if used, currently around £100-£200).

In this section, the approach taken by KiWi Power will be used to demonstrate the key stages involved in implementing and managing a DSR service. This will be covered in five sections - the client onboarding, client availability management process, the DSR event activation, the client reporting and payment process, and finally the troubleshooting methods.

B. Client On-Boarding

While the exact sequence of steps in terms of client on-boarding varies (sometimes significantly) depending on a particular client, assets and programmes, the following general steps are taken:

(1) Initial contact between new client and DSR aggregator.
(2) Acquire high level site data (business details, half-hourly electricity dataset, DSR potential assets lists).
(3) Perform initial DSR potential assessment and make decision to continue or stop process.
(4) If continuing, then undertake detailed onsite survey to verify potential and confirm setup costs.
(5) Agree contract with client if survey shows sufficient DSR potential and acceptable costs.
(6) Install DSR control equipment, test, and then go live.

Generally, all administrative documentation that is required by the programme regulating entity, is acquired by KiWi Power's sales and/or technical team, verified by the operations manager and submitted to the regulator. After the technical team has installed a processing station and commissioned the site, a User Acceptance Test (UAT) and a spot test will be performed with the assistance of the operations team. Once the technical director and the operations manager are satisfied with the result of the testing, the site is declared as available (operational) in a live STOR contract / programme.

C. Managing availability

KiWi Power records each site's availability weekly. Every Monday at 11 AM, KiWi Power will send out an automated email asking the site to confirm their availability for the following week. The site is expected to respond to the request by 12PM Wednesday. The Operations team will collect and record the responses. KiWi Power will confirm the windows for the following week by email every Friday at 4.30pm. If the site's availability changes after they have submitted their availability response, they are expected to call immediately the operations centre, at which time the site's availability will be updated.

D. Responding to a DSR Event

When a demand response event is requested (or scheduled) by the National Grid, KiWi Power's operations team will dispatch the contract in question. This will initiate the following actions:

(1) Event notifications will be sent to all relevant contacts via the following communication channels: Automated phone call (to primary and secondary contacts), SMS, Email.
(2) A remote activation signal will be sent to the asset (if applicable).
(3) The site's assets will respond to the request/signal.
(4) The operations team members monitor that all messages and signals are sent successfully and the assets respond accordingly.
(5) When a cease notice from the National Grid is received, the Ops centre will end the dispatch and send "end of event" messages and remote stop signals to the site's assets (when applicable).

E. Reporting and Payments

After every event, a report detailing the site's performance will be automatically generated and available for review on KiWi Power's client portal. Additionally, within 48 hours, the operations team will send the report to the site's contacts.

Within 10 days month of the end, the operations manager will review the client's earnings and produce an earnings statement detailing all revenue streams for the previous month. The statement will be sent to the site's commercial contacts and will be also available on KiWi Power's client portal.

Payments are normally made on quarterly basis and the client is expected to send KiWi Power a quarterly invoice for the appropriate amounts. Payments are divided into Site Availability payment depending on MW capacity made available for the contract duration and a Site Utilisation payment depending on number of hours that a Demand Side Response event is conducted.

F. Troubleshooting

The KiWi Operation Management Platform (KOMP) is constantly tracking the connectivity status with each of the client sites. When the processing station on-site stops sending readings, KOMP will issue a warning to the Operations team. If the issue cannot be resolved within the Operations domain, the Operations manager will escalate to KiWi Power's IT or

Technical teams and make changes to the availability declarations of the site (or contract) if necessary until resolved.

IV. Operations Environment

A. System Environment

Figure 2 provides an overview of the system environment used by KiWi Power to provide DSR services. To describe how KiWi Power interacts with clients, two example clients, X and Y will be used to illustrate the key interaction points. The first step involves the sales department subscribing clients (X & Y) to participate in various DSR programmes with their assets (X1, X2, Y1 & Y2). The technical team then installs processing stations (aka the KiWi Power - Power information Pod (PiP)) at those assets to ensure that (1) KiWi Power has control over the asset (i.e. are able to send start/stop signals) and (2) has visibility of its performance (i.e. witness and record their response to the event).

All site readings are then wirelessly transmitted and recorded on KiWi Power's cloud based servers. The cloud based service then allows the clients to access the Client App that offers visibility of their assets – including current and historic readings, declared capacity, availability schedule, revenues etc. The KOMP system allows KiWi Power to configure and control all assets, clients, contracts etc. Via KOMP, the Operations team will use various scripts to initiate and stop an event, manage sites availability, produce reports and so on.

B. Visual Operations Environment

The KOMP system in Figure 3, provides operations team with five key screens of information to provide live monitoring and control of all DSR sites. These screens can be

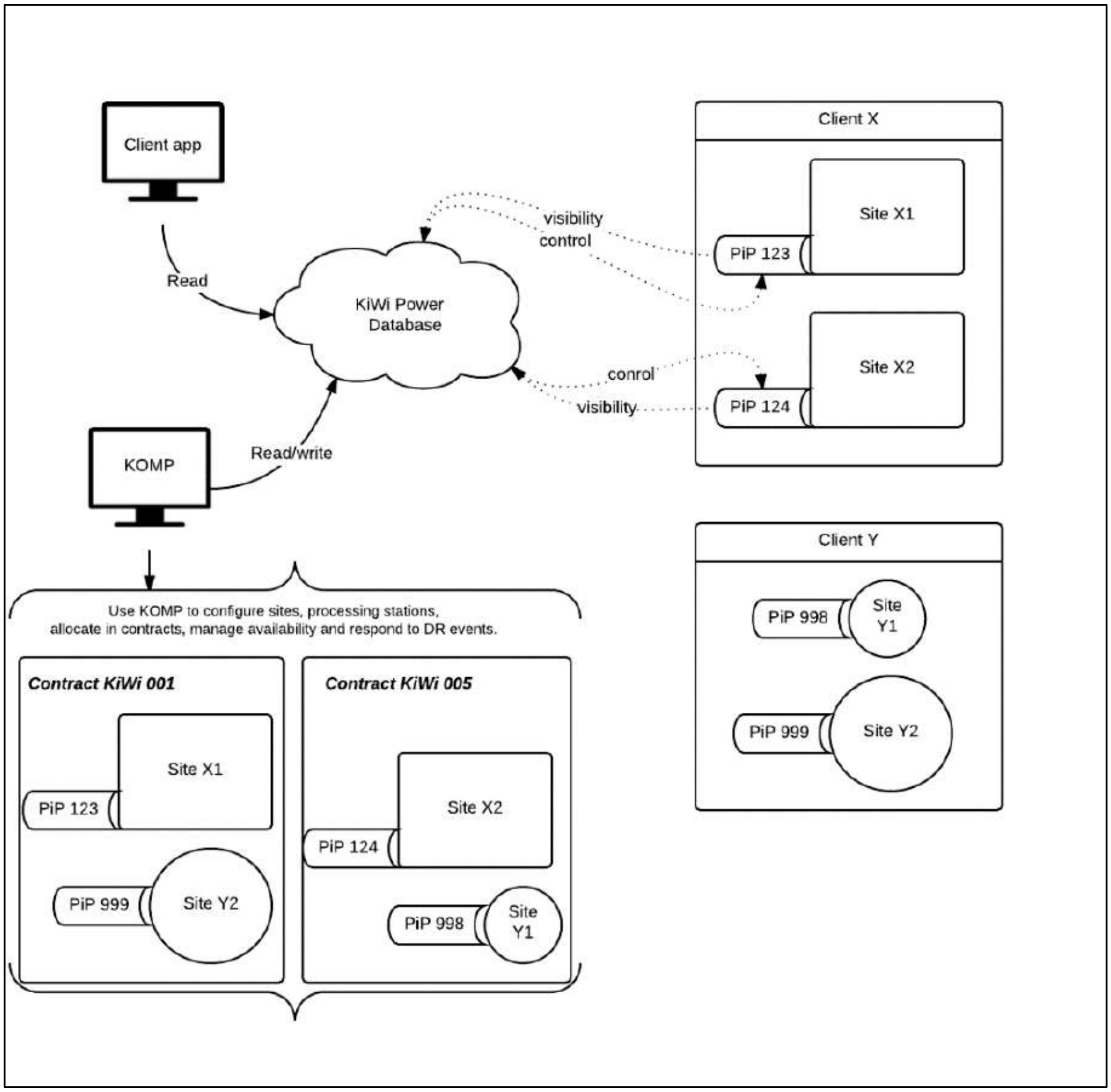

Figure 2 - System Environment

accessed via a number of methods, including on tablets, PC's or even individual displayed on wall mounted displays.

Figure 3: Visual Operations Environment

Screen one displays a map of the UK and provides color coded dots to show customer sites that contain processing stations. The dots are used to provide a quick reference check for operators on the status of the site. A green dot represents a processing station which is sending meter readings virtually in real time. An amber dot represents a processing station at an undeclared site which is sending delayed meter readings or not sending meter readings at all. A red dot represents a processing station at a declared site which is sending delayed meter readings or not sending meter readings at all. When a site is dispatched it will be changed to purple

Screen two displays the monitoring tool which includes the following key information points:

- Current time for each DSR location is displayed as accurate time keeping is a vital part of the demand response process.
- Live demand and system peak forecast.
- Power balance of the UK electricity grid that displays live data of the frequency of the grid from the National Grid.
- Availability requests that shows the date, time and number of sites that availability requests have been sent out to as well as the response rate.
- System status that will display any issues with the servers and systems.

Screen three displays any meter not operating as expected so that issues are highlighted faster and resources are not wasted monitoring systems which are working correctly.

Screen four displays the current meter readings of a specific site. This graph can be used by the operators to show the meter readings for a site at which an event or spot test is taking place.

Screen five displays information about the contracts that are declared or will be declared in the near future. It also provides details of the sites that are or will be live in these contracts.

V. Conclusion

DSR aggregation is a relatively new concept. Due to a wide range of DSR programmes, an issue of complexity can act as a barrier to the uptake of DSR. Nevertheless, these complexities can be overcome with clear processes and intelligent systems as described in this paper. Any DSR implementation will require the collaboration of multiple stakeholders. A strong drive from electricity regulators and government policies coupled with demand from utilities and end users will hasten the implementation of DSR. Additionally, DSR aggregators with the right tools and technology will be key to ensuring efficient and successful implementations.

References

[1] Postnote 452, "Electricity Demand-Side Response," 2014. [Online]. Available: http://www.parliament.uk/business/publications/research/briefing-papers/POST-PN-452/electricity-demandside-response. [Accessed: 06-Feb-2014].

[2] National Grid, "National Grid Balancing Services," 2015. [Online]. Available: http://www2.nationalgrid.com/uk/services/balancing-services/. [Accessed: 20-Dec-2015].

[3] National Grid, "Short Term Operating Reserve," nationalgrid.com, 2014. [Online]. Available: http://www2.nationalgrid.com/uk/services/balancing-services/reserve-services/short-term-operating-reserve/. [Accessed: 21-Nov-2014].

The role and interaction of microgrids and centralized grids in developing modern power systems

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***Abstract*—An extension of microgrids is now underway, primarily to allow increased electrification in growing economies but also to meet the need to reduce global CO2 emissions and to provide ancillary services to centralized grids. Energy Access constitutes one of the fundamental building blocks for economic growth as well as social equity in the modern world. Access to sustainable energy is needed to achieve sustainable development. Through examination of several implemented cases from different parts of the world the following topics are considered: i) Analysis of the interaction between centralized grids and microgrids ii) Analysis of stakeholder decision parameters for electrification iii) Analysis of design differences and requirements for microgrids, depending on the intended purpose and the need of the end customer.**

It is determined that good planning, suitable requirements and clear regulations for microgrids (in relation to centralized grids) limits the risk of stranded assets and enables better business cases for the involved stakeholders.

Keywords*—*Energy Access, Microgrids, Rural Electrification

I. INTRODUCTION

The recent increased activities in the microgrid sector serves primarily to allow increased electrification in growing economies but also to remove some of the barriers against large-scale deployment of renewable electricity production (to reduce global CO2 emissions) and provide ancillary services to centralized grids. In 2015, 15% of the global population still lacked access to electricity [1]. Energy access constitutes one of the fundamental building blocks for economic growth as well as social equity in the modern world, and access to sustainable energy is needed to achieve sustainable development. To improve the lives of the 1.2 billion people with the lowest income and to reach the vast potential of rural electrification, the decade 2014-2024 has been declared by the UN General Assembly as the decade of Sustainable Energy for All [2].

This paper intends to act as an input document to the global discussion regarding the interaction between centralized grids and microgrids. The objective of the work has been to investigate the decision parameters when deciding between bottom-up and top-down solutions. Also, how the need of the end customer is reflected on the design of the microgrids has been analyzed. The objective has been met by sharing main findings from cases in different parts of the world. The paper is based on a coming discussion paper from ISGAN (International Smart Grid Action Network) Annex 6: Power T&D Systems [3]. ISGAN 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) [4].

II. THE ROLE OF CENTRALIZED GRIDS

The mission of the Transmission System Operator (TSO) in the power market is to transmit electrical power from the generation side to regional electricity distributors. The Distribution System Operator (DSO) is responsible for the final stage, i.e. delivering electric power to the customer. Due to the high cost of building the grid and the need of coordination within a transmission area, the market model built around the TSO/DSO has been a natural monopoly on the infrastructure side. In today´s power market, electricity is considered a commodity and most of it is centrally produced by large generation facilities. These are often owned by independent power producers and electricity is sold to retailers and some individual customers in a market. The utility then provide electricity to the retail customer [5]. The traditional model and the existing rules used by public utilities envision a particular regulatory or service model. However, this model is becoming increasingly strained due to the introduction of new entities to the grid, such as PV, net energy metering, batteries and microgrids [6]. One challenge for the traditional model is how to deal with these new entities. For countries with large scale hydro- and wind power, the most energy effective way can still be to produce in large scale and use a centralized grid to distribute the energy produced.

III. THE ROLE OF MICROGRIDS

Microgrids are defined by Cigré WG C6.22 as *"electricity distribution systems containing loads and distributed energy resources, (such as 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 [7]".* One important benefit with microgrids is that they are faster to build (weeks to months) whereas it can take several years before the centralized grid is extended. However, microgrids should not necessarily be considered as a competitor but rather as a complement to the centralized grid when it comes to solutions for electrification. IEA forecasts that 60% of future electrification needed to reach the goal of energy for all by 2030 will take place through microgrids and other small stand-alone systems (see figure 1) [2].

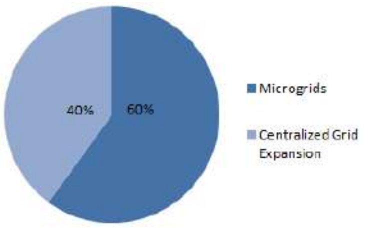

Fig. 1. Forecasted generation needed to reach universal access to energy for all by 2030, divided by grid-type [2].

Several approaches have been suggested for connecting microgrids and building the grid from "the bottom-up". The microgrid can then be considered a "cell" in a matrix of interconnected nodes such as Distributed Energy Resources (DER) and customer loads. In that context, control will be based on the interaction between the microgrid operator and the distribution utility and the system created will enable the microgrid to support the centralized grid, and vice-versa [6]. During a successful integration of a microgrid in a larger centralized grid, the microgrid can support with ancillary services (such as load shedding).

IV. CASE STUDIES

This chapter aims to present case studies on the interaction between the centralized grid and microgrids. Case studies include India, Canada, Uganda and Tanzania. Additional and elaboration of the case studies can be found in the ISGAN discussion paper on which this work is based.

A. India

India has the fourth-largest energy producing capacity in the world, with an installed capacity of 284 MW [8]. However, in 2010, 36% of the population (404 million people) still had no access to electricity [9]. Also, the centralized grid has had problems ensuring stability and adequate and consistent supplies to avoid major load shedding. One example of poor grid resiliency is the major black out in 2012, leaving 670 million people without electricity supply [10].

The goal in the 12th 5-year plan is to reach electricity access for all by the year of 2017 and therefore the government has initiated different programs to work with financing and funding [11]. The main driver for deployment of microgrids in India is to electrify the large part of the rural population that are either under-electrified or does not have access to power at all. In affect of this, India is one of the leading countries in the field of microgrids with over 100 deployed systems. The Government of India is also devoted to continued expansion of the centralized grid. However, there is an implicit understanding that some rural parts of the country are improbable to be reached by the centralized grid within foreseeable time and hence are suited for microgrids [12]. Most microgrids are being developed in communities located far from the grid. Therefore the potential interaction with the centralized grid has not been actualized yet. However, in cases where the microgrid will be operating in parallel with the grid, it can offer a higher reliability due to the frequent power outages of the centralized grid.

Currently the microgrids deployed in India are not connected to the centralized grid and are not considered "Smart". However, plans are to build a smart 15 MWpeak microgrid in the region of Tamil Nadu. This microgrid would have the possibility to be connected to the centralized grid as well as operated in Island mode. It also provides services such as load shedding and demand-response with the help of a 5MWh battery. The system would connect 29 000 customers and is planned to start early 2016 [13].

There is currently no consolidated policy in place for the sector of microgrids. There have been indications that there will be a Renewable Energy Act that would include all microgrids in a single framework. The lack of policy can give some degree of freedom for the actors in the field, but can make it hard to secure funding due to the unclear future [12]. Central Electricity Regulatory Commission (CERC) is critical to provide rules and regulations for development, funding, ownership and operation of such smart grid.

The main findings from this case are the following:

- In India, microgrids are built primarily to provide energy to all within a foreseeable future but also to increase the reliability by providing ancillary services to the centralized grid.
- The investor risk of grid expansion and stranded assets can be decreased if the issue of grid interconnection is given more attention. Regulators should provide legal framework to prevent risk of stranded assets due to central grid takeover.

B. Canada

Canada is a sparsely populated country where the whole population has access to electricity. Some communities receive electricity through microgrids due to being distanced from the centralized grid (although only a minor part of the total households with electricity access). This case example comes from northwest Ontario where 27 remote first nation communities are located. Out of these, 25 are not connected to the provincial electricity grid. Instead they are using diesel-based microgrids. Diesel generation costs are often three to ten times higher than the cost of the generation in the provincial grid [14]. Due to the drawbacks associated with diesel generation (and the fact that many of them are reaching the end of their lifetime [15]), three strategic options for energy supply for the remote communities have been assessed by Ontario Power Authority (OPA) in co-operation with the communities [16]:

1. Microgrids - using diesel generation (Status Quo)

2. Microgrids - using integrated solutions of renewable generation and the existing diesel solutions.
3. Transmission connection – connecting the communities that are considered economically feasible to the Independent Electricity System Operator (IESO) controlled provincial grid.

Constraints to load growth, cost and adverse environmental impact was used as the factors for evaluating the alternatives. Also the question of short-term but labor intensive jobs with building a transmission line compared to long-term jobs of maintaining a community microgrid was an aspect taken into consideration [15]. The financial study process of deciding if it is feasible to connect the remote communities to the provincial grid can be seen in Fig.2.

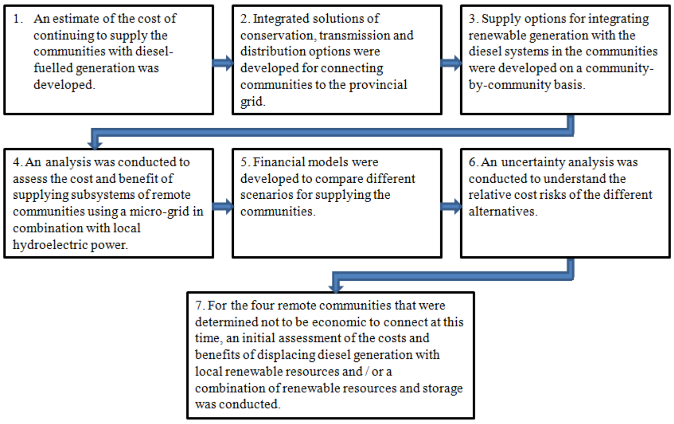

Fig.2. Study process for deciding feasibility of grid connection of remote communities [14].

Out of the 25 communities assessed, 21 were considered feasible to connect with the transmission line. For the communities considered feasible to connect to the centralized grid, the generation curves of locally available renewable resources, especially wind and solar, was found not to match well with the projected community demand, and would need to be coupled with diesel generation [14]. Therefore, the transmission line was considered a better alternative also from an environmental perspective [16]. Introducing storage as an alternative to handle the mismatch of the load and the generation curve of renewable resources was not included in the investigation of transmission connection compared to renewable-diesel microgrids. However, it was included in the assessment of the 4 communities found not economic to connect. IESO has conducted preliminary studies on how to provide electricity for the remaining communities in a sustainable and economic way. They have found that it is possible to reduce the cost of supply by using renewable generation combined with battery storage and diesel generation [14].

Already some attempts have been done in the field of remote diesel-renewable hybrid microgrids. A community whose diesel system was at max capacity and unable to connect any additional buildings in northern Ontario contracted Canadian Solar to install a 152 kW rooftop solar array in an elementary school to offset diesel consumption. Canadian Solar is considering expanding its off-grid microgrid project portfolio across Canada, and has identified more than 80 off-grid communities for potential microgrid solutions [17].

The main findings from this case are the following:

- With only one feeder line microgrid systems could also serve as increased reliability.
- Load growth, cost and environmental benefits where the three weighted factors when deciding between grid-connection and microgrids.
- Matching between load patterns and generation curves of locally available renewable resources is an important aspect when comparing solutions.

C. Uganda

Uganda is a country in sub-Saharan Africa with a population of 37.6 Million people and an electrification rate of 18.2 % [18]. The lead ministry for the development of the energy sector in Uganda is The Ministry of Energy and Mineral Development (MEMD). The network in Uganda is owned by the Government but operated by private companies. During the current 10-year planning period (2012-2022), the Government's strategy is to achieve a rural electrification access of 22% from the current level of 5% [19]. About 10% of the new connections are expected through microgrids.

The ambition to electrify the country as fast and cost-efficient as possible has lead to a governmental program to work with third parties, handled by the Rural Electrification Agency (REA). REA invests in extension of the national grid but also provides subsidies for the development of microgrids. To be allowed to generate and distribute power, licenses or Power Purchase Agreements are required, which are received from the Electricity Regulatory Authority (ERA). Small decentralized microgrids need an exemption of license.

The license or exemption of license enables the electricity utilities to obtain subsidies and leasing agreements with REA. The leasing agreement gives the right to operate a microgrid for a certain period of time. This is an insurance that the centralized grid will not take over the customers in this area as long as the agreement is valid. REA owns the microgrid, but the entrepreneur will get a leasing agreement to operate it.

The leasing system is a strategy for the government to attract investment in both centralized and decentralized power [20]. This also makes sure that the microgrid operator does not risk stranded assets since the microgrid plans are being developed together with REA.

Mostly private actors, but also NGOs are players in the rural electrification area in Uganda. Today most microgrids in Uganda are built to provide energy access in rural areas. They are mainly to support household demands like lighting loads and mobile phone charging, but some small industrial loads in the villages could also be supplied with electricity.

The main findings from this case are the following:

- Uganda has an established policy for co-operating with private companies to increase the number of connected customers, utilizing decentralized electrification.
- The fact that the authority that provides subsidies for the development of microgrids is also responsible for investing in extension of the national grid increases the possibility of long-term entrepreneur commitment and decreases the risk of stranded assets.

D. Tanzania

The ambitious vision of Tanzania's government is to have moved Tanzania from a low to a middle income economy by 2025 [21]. Electricity is regarded as one major factor in the social and economic development [22]. The national electricity access has increased from 13% in 2008 to 35% in 2014. In rural areas, the electricity access is 11% (in 2014) [23]. Tanzania's Power System Master Plan expects the national grid to supply 75% of the population by 2035 [24]. As most other sub-Saharan African countries (see case C: Uganda), a two track electrification strategy is promoted in Tanzania [25]. The centralized track focuses on extension of the national grid. In the decentralized track, distributed system solutions like microgrids are promoted for communities, villages and institutions like schools and hospitals.

Here, we are looking at the interaction between the centralized grid and microgrids at a micro level - from the system owner's and/or user's perspective. What options does a user have when the national grid enters the area where a microgrid is already in operation, and what are the advantages and disadvantages associated with different alternatives? The content in this case is based on yet unpublished work on a system near Mwanza in Tanzania [26-28].

Basically, the user has three main alternatives to consider when the national grid reaches the microgrid; to continue to use the microgrid as before, to shift to the national grid, or to convert the stand-alone microgrid into a grid connected microgrid. For grid connected microgrids, one can further consider using or not using batteries. If the user has the possibility to do a proper investigation of what the different available system solution alternatives would imply, access to uninterrupted electricity together with associated costs would certainly play important roles in the decision making.

In Tanzania, as in many other countries, there are interruptions in power supply from the national grid. In 2012, the average number of hours with blackouts was 54, declining from 71 hours in 2006 [29]. On average, 5.5 % of the annual sales in the country is lost due to power outages, and over 40% of enterprises identify electricity as a crucial factor for doing business [30]. In interviews, owners, operators and users of PV and PV-diesel systems have expressed their concerns regarding the power availability in the national grid. Although microgrids have their limitations in terms of power extraction, sometimes resulting in blackouts, they are often perceived as more reliable than the national grid.

When searching the optimum system configuration in terms of energy access and economic advantage, choosing between stand-alone operation of a microgrid, grid connection of a microgrid with or without batteries, and using the national grid only, a number of factors influence the results. In areas close to the national grid, it is generally speaking difficult to reach grid parity for PV and PV-hybrid solutions (i.e. that the cost of using a stand-alone system is the same or lower than the cost of using the national grid)[31]. Tanzania has in recent years lowered the connection fee to the national grid enabling for more people to connect, but also resulting in stand-alone systems being somewhat less competitive [22].

A system configuration offering high redundancy to power outages is to have a microgrid connected to the national grid. This is especially valid if intermittent energy sources (PV, wind) are combined in the microgrid with technologies which can be used upon demand (generators), and batteries can serve as immediate backup. The economic viability of different system configurations, enabling continuous access to power, however varies from system to system [30], [32]. It depends on what components the microgrid consist of, which of these can be used in a grid-connected system configuration and how reliable the national grid is.

In a situation, for example, where interruptions in the national power grid are rare, and the microgrid is equipped with a generator, it may be economically viable to not use any batteries. The cost of generator operation at times with blackouts in the central system does in this case not reach the costs of battery replacements. Generally speaking, using batteries is a good idea both from an economic perspective as well as a power access perspective if blackouts in the grid are frequently occurring. The power availability in the national grid obviously plays a major role in choice of system configuration. If PV is a part of the microgrid, it is often economically beneficial to keep the PV and use it within the microgrid, and buy only the remaining needed power from the national grid. To what extent though depends on whether the load curve matches the solar irradiation curve well or not.

The main findings from this case are the following:

- An unreliable centralized grid can sometimes lead to microgrids being considered as a superior solution, and access to both can increase the reliability of the electricity access.
- The viability of batteries in a microgrid is dependent on the reliability needed, frequency of grid outages as well as if there is access to dispatchable generators.

A summary of the main findings from the analyzed cases can be seen in Table 1.

TABLE I. COMPARISON OF MAIN FINDINGS FROM ANALYZED CASES

Case	Main Findings
India	• In India, microgrids are built primarily to provide energy to all within a foreseeable future but also to increase the sustainability by providing ancillary services to the centralized grid. • The investor risk of grid expansion and stranded assets can be avoided if the issue of grid interconnection is given more attention. Regulators should provide legal framework to prevent risk of stranded assets due to central grid takeover.
Canada	• With only one feeder line microgrid systems could also serve as increased reliability. • Load growth, cost and environmental benefits where the three weighted factors when deciding between grid-connection and microgrids. • Matching between load patterns and generation curves of locally available renewable resources is an important aspect when comparing solutions.
Uganda	• Uganda has an established policy for co-operating with private companies to increase the number of connected customers, utilizing decentralized electrification. • The fact that the authority that provides subsidies for the development of micro-grids is also responsible for investing in extension of the national grid increases the possibility of long-term entrepreneur commitment and decreases the risk of stranded assets.
Tanzania	• An unreliable centralized grid can sometimes lead to microgrids being considered as a superior solution, and access to both can increase the reliability of the electricity access. • The viability of batteries in a microgrid is dependent on the reliability needed, frequency of grid outages as well as if there is access to dispatchable generators.

V. ISSUES RELATED TO GRID INTEGRATION OF MICROGRIDS

Many countries are proceeding to expand the centralized grid and at the same time trying to reach many unserved costumers by microgrids. With this two-way approach, the two electrification solutions will certainly come to cross each other's paths, and there should be a distinctive plan on what to do when the two grids meet for this two-way approach to work. If no such policy or regulations exist, investors could be reluctant to invest in microgrids since it can result in stranded investments once the centralized grid is reaching the area of the microgrid [25]. There is a possibility for the centralized grid and microgrids to support each other in a way that is beneficial for all actors. However, there are still some issues arising in the situation of grid integration of microgrids, also due to the fact that the practical experience from interconnecting centralized grids and microgrids is limited.

Technical issues with integrating microgrids into distribution grids includes specific elements such as dual-mode switching functionality (going from islanded to grid-connected mode and back again), reliability, power quality and protection. Also from the markets point-of-view, several questions remain: i) How can markets be formed where microgrids can help support the centralized grid? ii) What technical, policies and regulatory solutions are needed for this to become a reality? iii) What market barriers are still to be solved from a local and global perspective? iv) What regulatory support is needed for decentralized grids to thrive as a supporting entity to the grid?

VI. CONCLUSSIONS

An increasing number of microgrids will be seen in the future. Both for the purpose of reaching the UN goal of Sustainable Energy for All, but also for functioning as a cell of the centralized grid providing the possibilities of ancillary services like increase resilience, demand side management and facilitation of selling generated electricity. Depending on the hosting capacity of the centralized grid, microgrids can be seen as both a way to achieve end-of-the-line grid strengthening or as a way to avoid load shedding when strain is high on the centralized grid.

Governments providing clear regulation and co-operating with private companies to increase the number of connected customers using both microgrids and grid extension can be a very powerful tool for making sure that an optimal solution to electrification is reached. When evaluating the best alternative of electrifying a rural area, distance alone is not enough to determine if it is feasible to build a microgrid. Factors such as i) poor development of infrastructure, ii) challenging terrestrial conditions, iii) low density of rural population and iv) low income levels of communities also play an important role. In countries with a limited number of isolated communities, a case-to-case evaluation is beneficial. For the design of a microgrid without a connection to the central grid, considerations should be taken regarding when a potential connection will become a reality. If this could be seen in a reasonable time, the potential increase in energy demand should be considered when specifying the electrical requirements of the equipment.

With good planning and suitable requirements (i.e a connection to the centralized grid is technically feasible at a later stage) on new isolated microgrids, the risk of stranded assets if the centralized grid reaches the area will be limited. It will also increase the potential for the microgrid to become a long-term solution leading to better business cases for the involved stakeholders.

Building a strong relationship with the customer, as well as understanding the customer-need in a specific area should be in focus when designing the microgrid. Also, a sustainable revenue model to support investment funding as well as Operation and Maintenance (O&M) of such projects is important. The design will differ regarding the capacity, potential need of energy storage, type of production, the level of grid intelligence, the communication possibilities etc.

Even though the benefits are clear, microgrids can sometimes be considered to be inferior to a reliable centralized grid since power extraction can be limited. In other cases, where the centralized grid is unreliable, they can be preferred due to higher reliability. Even though there are still several issues to solve regarding the interaction between microgrids and centralized grids, it is clear that it is an area that will receive increased attention as the two methods of electrification come to cross paths.

REFERENCES

[1] The World Bank - SE4ALL, ”Progress Towards Susatinable Energy - Global Tracking Framework,” 2015.

[2] International Energy Agency, ”Energy for All - Financing access for the poor,” 2011.

[3] J. Tjäder och S. Ackeby, ”The role and interaction of microgrids and centralized grids in developing modern power systems - ISGAN Discussion Paper,” Not yet published, 2016.

[4] ISGAN, ”International Smart Grid Action Network,” 2015. [Online]. Available: http://www.iea-isgan.org/. [Accessed 12 01 2016].

[5] W. J. Hausman, P. Hertner och M. Wilkins, Global Electrification: Multinational Enterprise and International Finance in the history of Light and Power, 2008.

[6] California Public Utilities Commission, ”Microgrids: A Regulatory Perspective,” 2014.

[7] WG C6.22, "Microgrids 1: engineering, economics, & experience - Capabilities, Benefits, Business Opportunities, And Examples Microgrids Evolution Roadmap," *ELECTRA*, December 2015.

[8] Ministry of Power, India, ”Power Sector at a Glance,” [Online]. Available: http://powermin.nic.in/power-sector-glance-all-india. [Accessed 28 10 2015].

[9] U. Remme, N. Trudeau, D. Graczyk och P. Taylor, ”Technology Development Prospects for the Indian Power Sector,” 2011.

[10] The New York Times, ”2nd day of power failures cripples wide swath of India” [Online]. Available: http://www.nytimes.com/2012/08/01/world/asia/power-outages-hit-600-million-in-india.html?_r=0.

[11] Planning Commission - Government of India, ”Twelfth Five Year Plan - Economic Sector 2012-2017,” 2013.

[12] Energimyndigheten, ”Landscape Assessment: Off Grid Energy in India,” 2015.

[13] R. K. Pillai, Interviewee, *President India Smart Grid Forum.* [Interview]. 27 10 2015.

[14] Ontario Power Authority, ”Draft Technical Report and Business Case for the Connection of Remote First Nation Communities in Northwest Ontario,” 2014.

[15] J. Hiscock, Interviewee, *Science & Technology Advisor at Natural Resources Canada.* [Interview]. 13 10 2015.

[16] Ontario Power Authority, ”Discussion on Remote Community Connection Concepts,” 2012.

[17] Canadian Solar, ”Canadian Solar Partners in Providing a Hybrid System for a Remote Community.,” [Online]. Available: http://www.canadiansolar.com/solar-projects/deer-lake-first-nation-elementary-school.html. [Accessed 25 10 2015].

[18] World Bank, ”SE4ALL Database,” 2016. [Online]. Available: http://data.worldbank.org/indicator/. [Accessed 13 01 2016].

[19] The Government of the Republic of Uganda: Ministry of Energy and Mineral Development , ”Rural Electrification: Strategy & Plan,” 2012.

[20] N. Fouassier, Interviewee, *Director, Pamoja Cleantech.* [Interview]. 18 08 2015.

[21] The United Republic of Tanzania Prime Minister´s office, ”Big Results Now - BRN,” [Online]. Available: http:/www.pmoralq.go.tz/quick-menu/brn/. [Accessed 17 11 2015].

[22] International Energy Agency, ”Africa Energy Outlook, a focus on energy prospects in sub-saharan Africa (World Energy Outlook Special Report),” 2014.

[23] African Development Bank, ”Renewable Energy in Africa: Tanzania Country Profile,” 2015.

[24] The United Republic of Tanzania: Ministry of Energy and Minerals, ”Power system master plan 2012 update,” 2013.

[25] B. Tenenbaum, C. Greacen, T. Siyambalapitiya och J. Knuckles, ”From the Bottom Up. How Small Power Producers and Mini-Grids Can Deliver Electrification and Renewable Energy in Africa,” The World Bank, 2014.

[26] C. Nielsen och F. Fiedler, ”Evaluation of a Micro PV-Diesel Hybrid System in Tanzania,” i *6th European Conference on PV-Hybrid and Mini-Grid* , Chambéry, 2012.

[27] F. Fiedler och C. Nielsen, ”Design Study of a PV-Diesel Hybrid System for a Micro-Grid in Tanzania,” i *6th European Conference on PV-Hybrid and Mini-Grid*, Chambéry, 2012.

[28] C. Bastholm och A. Henning, ”The use of three perspectives to make energy implementation studies more culturally informed,” *Energy, Sustainability and Society*, 2014.

[29] World Bank Group, ”Country Highlights, Tanzania 2013,” 2015.

[30] C. Cader, ”Is a grid connection the best solution? Frequently overlooked arguments assessing centralized electrification pathways,” *Micro perspectives for decentralized energy supply* , Bangalore, 2015.

[31] M. Sadhan, ”Rural electrification: Optimising the choice between decentralised renewable energy sources and grid extension,” *Energy for Sustainable Development,* 2012.

[32] P. M. Murphy, S. Twaha och I. S. Murphy, ”Analysis of the cost of reliable electricity: A new method for analyzing grid connected solar, diesel and hybrid distributed electricity systems considering an unreliable electric grid, with examples in Uganda,” *Energy,* 2014.

Impact of Renewables on DISCOMs under DSM Regulations

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Abstract— The Indian Electricity Grid had historically been plagued with grid disturbances as a result of indiscipline by constituents in maintaining their drawl from the Grid as per their schedule. To counter this, the Central Regulator brought in the Unscheduled Interchange (UI) mechanism in the year 2000. Though the UI mechanism was quite successful, its shortcomings came to front during the twin grid collapses of 30th and 31st July 2012. This led to the introduction of the much more stringent Deviation Settlement Mechanism (DSM) regulations in February 2014. The regulations put a huge amount of responsibility on Distribution Companies (DISCOMs) for maintaining Grid discipline and as such put up new challenges. Most of these challenges stem from areas outside the control of the DISCOMs. While the regulator expects DISCOMs to maintain a high level of performance, the quality of supporting agencies like weather forecasting, IT infrastructure of Load Dispatch Centers are found wanting.

At Tata Power Delhi Distribution Limited (TPDDL) we have always strived to maintain high performance standards and as such have adopted several measures to adapt to the new environment. We will look into the process changes aided by IT intervention that TPDDL brought in to maintain grid discipline without resorting to excess load shedding. But the challenge for the future is to maintain the same standards with integration of renewables in our energy mix in a large way. This paper outlines and analyses the challenges for TPDDL to maintain the energy balance in such a scenario under the current regulatory framework with possible solutions.

Keywords—Solar Power, Power Scheduling, DSM Regulations,

I. INTRODUCTION

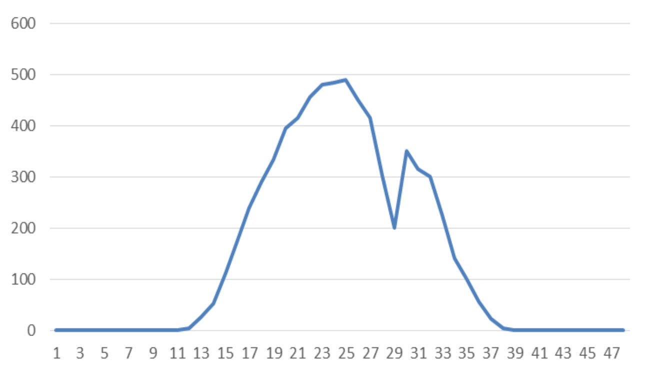
The Government of India has announced very ambitious targets for solar power generation. Under the Jawaharlal Nehru National Solar mission launched in 2010 a target of deployment of 20 GW of solar power was taken for 2022 [1]. The current government has scaled it up to an even more ambitious target of 100 GW by 2022 [2]. Of the total 100 GW, 40 GW is planned to be achieved through rooftop solar. These targets seems farfetched, particularly considering that the installed capacity currently is only about 4 GW till date. But if we consider the fact that the cost of solar PV panel is sharply declining (it has dropped by 75% in the last six years [3]), it may well be done.

Delhi has a good average solar irradiation level of 5 KWh/m^2/day [4] with almost 300 sunny days a year. Which makes it suitable for the state to take a leading role in solar power generation. It has an area of 1484 km^2 with 700 km^2 of built up area, which is rapidly expanding. Rooftop solar potential of Delhi has been estimated at 2.5 GW [5]. The Delhi Government has recognized the same and has come up its own Delhi Solar Energy Policy (Draft) in September 2015. The policy has recognized that the focus in Delhi will have to be on rooftop solar and it has taken a target of 1 GW installed capacity by 2022 [6].

Of this 1 GW, approximately 300 MW is expected to come up within TPDDL's licensee area. Delhi Electricity Regulatory Commission (DERC) has already come up with its Net Metering for Renewable Energy Regulation in 2015, paving the way for grid-connected privately owned rooftop solar plants without storage. TPDDL has already rolled out its own plans for facilitating the same. Although Greenpeace's Bridge to India Report gives the highest share of potential for rooftop solar in residential buildings (at 49%), we expect that the maximum growth, at least for the foreseeable future, will be in commercial and industrial sector. This is due to the fact that residential tariffs are much lower than commercial and industrial (C&I) and the area available per building is much higher in C&I sector. In fact the initial applications that have come in till now point to very much the same. The city plan for Delhi has clearly demarcated areas as per land use. Which means the C&I sector is concentrated in a number of clusters around the city. Another sector where we expect the rooftop solar to come in is government, public and semi-public buildings, which are also clustered in specific locations as per Delhi's land use plan.

Thus our expectation is that the bulk of the 300 MW installed capacity will be concentrated in pockets around our licensee area. Now solar generation is much more stable in its output as compared to other renewables, such as wind. But it is still susceptible to sudden short term dips in generation due to cloud cover as can be seen form the sample load server data of 1 day of TPDDL's 1 MW Keshavpuram (KPM) plant.

Figure 1: Sample Load Survey of KPM plant (KW)



As the generation of the consumer owned grid connected solar drops, the drawl of the consumer from the TPDDL network will accordingly increase and hence TPDDL's drawl from the grid. This behavior of solar generation raises issues for a DISCOM where scheduling of power from the Grid is concerned as exact timing and quantum of the dip in generation is not possible to predict with the required amount of accuracy.

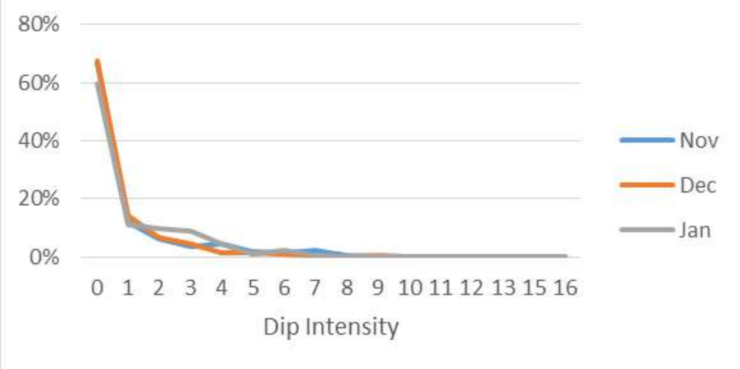
The Indian Electricity Grid had historically been plagued with grid disturbances as a result of indiscipline by constituents in maintaining their drawl from the Grid as per their schedule. To counter this, the Central Regulator brought in the UI mechanism of ABT in the year 2000. Though the UI mechanism was quite successful, its shortcomings came to front during the twin grid collapses of 30th and 31st July 2012. This led to the introduction of the much more stringent Deviation Settlement Mechanism (DSM) regulations in February 2014. Under the DSM regulations, TPDDL has to manage its drawl from the grid within +/- 38 MW of its scheduled power. Currently with only about 2 MW of embedded solar in our network, we are not facing any difficulty. But with 300 MW of solar, such dips will have the potentially spiking up our drawl from the Grid for short durations to the effect of violation of the DSM regulations. In this paper we will try to measure the impact of the abovementioned momentary loss of generation in the future and its impact on our power supply brought about by the restrictions of the DSM regulations.

II. ESTIMATION OF THE INTERMITANCY OF SOLAR GENERATION

TPDDL currently has 15 solar plants with a total installed capacity of 1.75 MW distributed across its geographical area. We have taken load survey data of 12 plants for the period – 15th November 2015 to 15th January 2016. We have scaled the generation of each plant to 50 KW capacity to simulate 12 clusters of solar generation, of almost equal capacity, distributed across our area. The load survey data of each is added to get a picture of the overall generation.

The count and quantum of dips observed in the combined generation have been noted. The scale of the quantum is converted to percentage (intervals of 2%) of peak generation of the month. A frequency distribution histogram of the dips is given below.

Figure 2: Frequency Distribution of Dip Intensity



This distribution has been found to be same for each month. And is thus taken to be same for the entire year. From a study of the generation curves vis-à-vis the standard curves, dips up to 8% of the peak load were found to be noise and were excluded from the count.

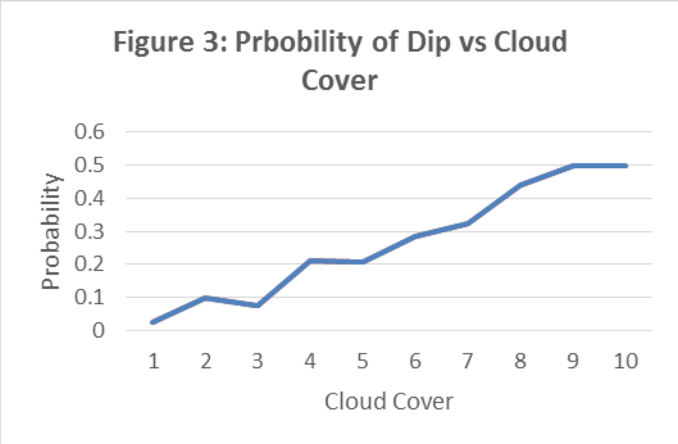
The peak generation is dependent on the solar radiation intensity. The expected peak monthly generation for the rest of the months is derived from a regression model of the form.

Peak Output = B1*Average Solar radiation + C

We also have weather data for the period. The data contains cloud cover of each slot of the day in percentage. The cloud cover data was converted to a scale of 1 to 10, (1 covering cloud cover of 0 to 10% and so on). The probability of a dip in each interval of cloud cover was calculated from sample data as

P_i = (No slots with Dips in slots with cloud cover *i*)/(Total no of slots with cloud cover *i*)

The result is shown in the figure below.



The graph shows a clear relationship between the intensity of clod cover and the expected probability of the occurrence of a dip. The frequency distribution of number of dips per day was found to follow the negative binomial distribution. However negative binomial regression did not provide good results due to data availability for a period of two months only. The number of dips for the rest of the year was calculated with the expected probabilities and actual cloud cover data available for the remainder of the year.

No of Dips = $\sum p_i$ * (No of slots with cloud intensity i), $i = 1, 2, \ldots 10$

The distribution of intensities of the dips as a percentage of peak load of the month are taken to be the same as that of the sample. The dip intensities were multiplied with the peak of each month, adjusted for 300 MW installed capacity, and subsequently compiled to get the overall distribution of dips in MW.

Table 1: Distribution of Dips

MW	No.of dips
10-20	554
20-30	362
30-40	62
Total	977

As per the DSM regulations, DISCOM must change from OD to UP once every 12 slots or 3 hours. The result will be that the DISCOM will be overdrawing 50% of the time and overdrawing 50% of the time. Also on about 20 days in a year, there is rainfall during the day which results in simultaneous loss of demand as well as solar generation. The solar generation is affected for an average of 10 slots during rainy days, or at total of 200 slots or 18% of the calculated dips. Also dips with intensity greater than 20% of peak generation, which account for 10% of the dips were found to occur on these days. Adjusting for the same, the number of dips by intensity against OD at the time is given in the table below. As all the dips are within 40 MW, there is no possibility of overdrawl in case the DISCOM is already in underdrawl.

Table 2:

OD in MW	Dip in Solar generation		
	10-20 MW	20-30 MW	30-40 MW
40+	66	43	7
30-40	56	37	6
20-30	46	30	5
10-20	53	35	6
0-10	55	36	6

The region in red signifies where drawl will go beyond permissible limits. The region in orange is where the system will go into overdrawl in some of the cases. The region in green signifies the safe zone.

III. IMPACT ON TPDDL

Managing the deviation of drawl from the grid vis-à-vis the schedule is one the major challenges TPDDL has faced since the DSM regulations have come into effect. The current challenge is due to the quality of weather forecasts we have access to. The mean absolute percentage error (MAPE) of forecasted temperature is over 10% and of humidity over 20%. Which leads to a MAPE of 3 to 4 % in our day-ahead demand forecasts, on which our schedule planning is dependent. To put the same into perspective, our peak demand in the summer is 1700 MW, so the allowed 38 MW of deviation is just over 2% of the load.

To counter the same we at TPDDL have come up with a process of revising our forecast every 4 to 5 hours for the immediate future based on hourly weather forecasts and then revising our schedule to match the forecast. The revised forecasts have an average MAPE of 1.5%. By adopting this process TPDDL has been able to limit the penalty for deviation beyond permissible limits to around 5 paise per unit energy served in FY14-15 (Total of INR 4.5 Cr). In the current year (FY15-16), the same is around 3 paise per unit energy served. However this process is based on revision of the schedule from one or more of the generating station by sending a request to the State Load Dispatch Center (SLDC). Which revises the schedule after getting consent from the generator. This process takes 4 time blocks of 15 minutes each or approximately 1 hour. The penalty is particularly important from the financial viewpoint as it is subtracted from the profits of the company.

From the data in table 2, and considering the fact that grid frequency is below 50.05 Hz in 85% of the slots, 50.05 Hz being the threshold value below which penalty is imposed, TPDDL will violate the permissible overdrawl (OD) limits in an additional 150 slots and overdrawl beyond limits will increase in an additional 100 slots. The choice before TPDDL will be to pay an additional INR 0.3 Cr in penalty or resort to load shedding of 1 MU (Million Units). Neither of which are acceptable solutions.

This loss of generation due to cloud cover is based upon the local climatic conditions at the exact location of the generator. Forecast of such granularity is not available till date, nor seem very likely in the near future. As such the overdrawl due to loss of embedded solar generation due to stray cloud cover cannot be predicted – it will appear as well as disappear with no warning and DISCOM will have to react on the spot. For a DISCOM like TPDDL without any generation of its own, the process of revising generation even from state generation takes at least 45 minutes. But a majority of the observed dips have a duration of 2 to 4 slots only. Also the schedule will have to be backed down as soon as the dip disappears. So the current process is inadequate to meet the demands of a grid which has a significant amount of solar generation. In the current scenario the only solution for the DISCOM to avoid penalties and maintain Grid discipline will be to resort to load shedding.

IV. DEMAND RESPONSE AS A SOLUTION

The solution to the problem lies in development of demand response (DR) programs or ancillary services. Such services are mainly of the following types:

1. **Emergency/Standby:** The basic idea behind emergency or interruptible load demand response programs is that the utility pays participating customers to shed a portion of their load during peak load events or during contingencies. Participating customers receive payments for being on stand-by (capacity payment for kW promised) and/or payments when they are actually called (energy payments for KW avoided) [7]. The typical types of demand reduction actions taken in such programs include
   a. Shutdown of some non-critical process equipment or part of lighting load.
   b. Modification of temperature set-points of heating and cooling equipment.

2. **Synchronized Reserve:** Also called spinning reserves. Such DR programs compensate customers for the ability to provide a predetermined amount of energy to meet a reliability standard. Both generators and demand resources cab provide this response. However in calling upon a generator to provide this service a DISCOM must have a process of calling upon the services in a manner where the generator will be able to respond within 10 minutes [7].

3. **Frequency Regulation:** frequency regulation DR programs compensate customers for the ability to modulate demand up or down in order to maintain grid frequency. The customer gets real-time signals from the grid and must have the ability to react quickly through automated equipment control systems. A full response is usually required within 5 minutes [7].

4. **Storage:** Battery banks which store power during low demand periods and supply back into grid during contingencies is another solutions that is being looked at.

5. **Distributed Generation:** Many large C&I customers have diesel generators installed as backup in their premises. Some DR solutions provide the capacity for a DISCOM to call upon these generators to provide power for a short duration to tide over contingencies.

These programs come under the umbrella of Ancillary Services. Ancillary Services are defined by the Indian Electricity Grid Code 2010 (IEGC) as “the services necessary to support the power system (or grid) operation in maintaining power quality, reliability and security of the grid, e.g. active power support for load following, reactive power support, black start, etc;”. The IEGC, under Regulation 2.3.2 (g) also made operation of Ancillary Services as an exclusive function of Regional Load Dispatch Centers (RLDCs). The Central Electricity Regulatory Commission (CERC) has released a draft regulation for Ancillary Services in May 2015. However this regulation only covers use of ancillary services at RLDC level for management of Grid frequency. The payment to the ancillary services is to be given from regional DSM pool [8]. It will not have any impact on the deviations of drawl of individual DISCOMs from the grid.

However the impact of intermittent solar generation will be more at individual DISCOM levels, rather than at regional level. It is the need of the hour that DR programs run directly or through an Aggregator by DISCOMs be also covered in the regulations. An Aggregator being a company which ties up individual customers for DR programs and offers their aggregated capacity as a service to the DISCOMs.

V. DEMAND RESPONSE IN TPDDL

TPDDL has always been at the forefront of technology adoption in the Distribution sector in India. With an eye on the future it has already implemented a pilot project of Emergency DR covering 250 consumers with 11 MW of contracted standby capacity. The project has been implemented primarily in the premises of large industrial and commercial consumers. Study of the processes of the consumers was done and non-critical equipment and lighting load were identified. Smart meters and remotely operated event controller devices were installed at the consumer premises. Events can be planned from the TPDDL control room and the DR system will automatically send the commands to a selection of the controllers based on the quantum of DR required. We are currently creating events at least 4 hours in advance with the consumer having the option of opting out till just before start of the event. After one year of operation in FY 14-15 to prove the technical feasibility of the project, Delhi Electricity Regulatory Commission (DERC) has now allowed financial compensation to participating consumers on basis of energy payments for KW avoided. The project is however to be kept in observation for 2 years with quarterly review. At the end of the two years period, we expect the regulator to approve a full scale rollout.

Apart from the issue of compensation, another roadblock to the rollout of DR programs is the cost. At TPDDL we have also looked into DR solutions using storage or a combination of Standby-Storage and Distributed Generation. The approximate costs for the same are currently just over INR 10 Cr/MW. To reduce the possible load shedding due to solar generation dips by 80%, TPDDL will need an available DR capacity of 15 MW directly or through an Aggregator. In our experience from the pilot project actual availability varies from 40% to 60% of contracted capacity due to consumers opting out from time to time. So to have an available capacity of 15 MW, the contracted capacity should be around 40 MW. The same works out to an investment of INR 400 Cr. This would have to be allowed as a CAPEX cost if the DISCOM sets up its own system. If a DISCOM is buying services from Aggregator, then the cost should be allowable as a part of the power purchase cost.

VI. CONCLUSION

The Indian Government has taken an exemplary step for sustainability by its efforts to increase the role of renewables in the Indian Power Sector. But the inherent intermittency in the output of renewable generation makes it a challenge for maintaining power quality and reliability for DISCOMs which will acquire significant amount of gird connected solar. Ancillary Services, and particularly Demand Response programs look to be the best solutions for tackling this upcoming challenge.

However the necessary thrust for development of the Ancillary Services Market in India is lacking. CERC has taken the first step by releasing the draft regulation for Ancillary Services. But the scope of the regulations is very limited. It should be expanded to include Demand Response at DISCOM level and should cover norms for compensation to participating consumers, role of Aggregators, etc. The role of Ancillary services will be even greater for DISCOMs where wind power is connected which is even more intermittent in nature. The setting up of Ancillary services should go hand in hand with the expansion of renewable power or managing the drawl from the schedule will become a major challenge in the future.

REFERENCES

[1] No.5/14/2008-P&C, Ministry of New and Renewable Energy, Government of India, Jan 2010.

[2] Power to the People, Bill McKibben, The New Yorker, 29 June 2015.

[3] Indian Solar Resource Map, NREL, 2010

[4] Rooftop Revolution: Unleashing Delhi's Solar Potential – Bridge to India Report by Greenpeace India, June 2013

[5] Delhi Solar Energy Policy (Draft), September 2015

[6] DEMAND RESPONSE: A MARKET OVERVIEW, Institue for Efficiency Building, Jhonson Controls, Feb 2014.

[7] Ancillary Service Operations Regulations 2015 (Draft), CERC

Geographical Information system (GIS) and its integration with other enterprise systems at Tata Power

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Abstract

Tata Power has implemented Geographical Information system (GIS) in Mumbai in past which provides a comprehensive view of Tata Power's network elements with geographic advantage and helping numerous distribution business processes for planning, designing and implementation of distribution projects, network monitoring, customer acquisition and compliance to regulatory queries etc. Moving forward Tata Power has successfully completed a project of integrating GIS with other enterprise systems such as SAP, Electronic Land Record Managements System (eLRMS), Network Planning System, Distribution Management System (DMS), Customer Relationship Management (CRM), Vehicle Tracking System (VTS) and Personal Digital Assistant (PDA)/mobile. The integration augments work flow management, automated and timely updating/synchronizing of equipment/asset information, real time analysis of power failure complaints, connection management services, large scale elimination of manual and duplication of data entry etc. The integration implemented was planned, focused and driven by exhaustive requirement study and business results envisaged. Technical challenges due to varying technological platforms were mitigated by careful mix of customization and out of box features of both the systems. Being the IT enabled systems the compatibility issues of different versions of software were handled with proper deployment approach and proper planning. Exhaustive internal testing and UAT ensured that the deployed integration is meeting the requirements of the business.

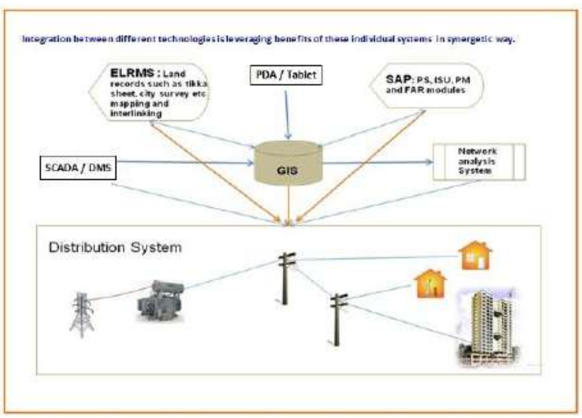
Introduction: Majority of Utility business is required to work with in the frame work of regulators. This makes it necessary for optimising the resources and effective handling of information/data with efficient processes and workflows. Application of innovation and technology for value added benefits to its customers is now not an added service but a basic requirement. Geographical Information system (GIS) provides a comprehensive view of utility's network elements with geographic advantage. The purpose of this technology is to help in location based analysis for numerous business processes, short and long term distribution business planning including network feasibilities, technical planning, designing and implementation of distribution projects, network monitoring, asset management, customer acquisition and compliance to regulatory queries etc.

Tata Power has now integrated GIS with other enterprise systems such as SAP, Electronic Land

Record Managements System (eLRMS), Network Planning System, Distribution Management System (DMS), Customer Relationship Management (CRM), Vehicle Tracking System (VTS) and Personal Digital Assistant (PDA). The integration augments work flow management, automated updating of data, synchronisation and tracking of equipment/asset information.

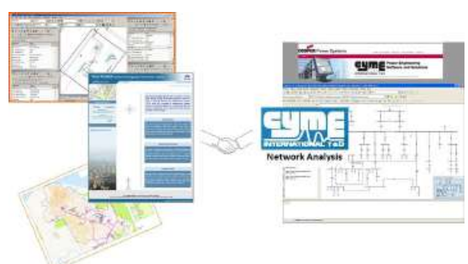
About Integration:

A well planned integration approach which will effectively meet the business requirement is primary objective of enterprise level integration. GIS being a location based technology leverages many business processes with the integration and enhances decision making process. The integration implemented was planned, focused and driven by exhaustive study of requirement and study of business results envisaged.



1. Integration with Network analysis system:

An advance version of Network analysis software is procured and is successfully integrated with GIS. Required network objects are mapped between GIS and Network analysis system environment. Required attributes, connectivity rules and database relationships are also mapped in both the systems. Critical customisation is done in migration tool. The integration is mainly of mapping and matching required NW objects in GIS environment and in CYM. The data in GIS is to be migrated to CYM along with this mapped form and also with connectivity, attributes, database relations etc. The data modelling done in the GIS is based on the business requirements, user requirements etc. This required a lot of quality efforts in matching with CYMdist model. The customisation of the data definitions, NW modelling and connectivity rules in addition to proprietary approach to data designing of individual systems was done. In addition to this version, differences between different SW interfaces makes the integration affaire a complex. In our case the delivered interface versions were not matching due to different delivery timings. This made the issue more complex. By studying both the systems in detail, studying the data models of both systems, highly customising the migration code and creating some work around the necessary solution is created and deployed.



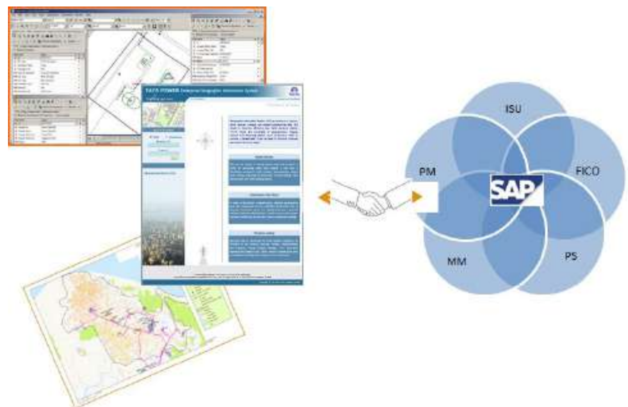
2. Integration with SCADA and DMS system:

The operational parameters like transforming loadings, feeder loading etc are now available on GIS through SCADA interface. The DMS network is built with same GIS platform which is also integrated with many other enterprise systems. Latest operational data and archive data is now available in GIS. And all this is thereby now available to the Network Analysis Software. The operational data, design data available on GIS and tremendous power of analysis of GIS has made it as one of the important decision making tools for organisation. Network updating is done only at one place ie in GIS where QA/QC is also done. No need to build the network again in DMS thereby saving huge efforts. As the same network platform is used for Network analysis system the analysis is supported be common network model which is used for DMS also. All topological and geometrical rules are taken care in GIS ensuring proper connectivity in DMS

3. Integration with SAP

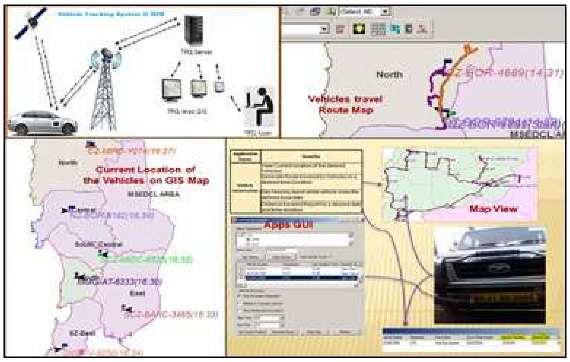
The integration of GIS is done for PS, ISU, PM, MM, CRM and FICO module. Mapping of distribution and transmission operational assets between SAP and GIS is being done while creation of assets in SAP. Asset movement & Asset retirement information flows from SAP to GIS to notify a change in geographical location or removal of the Asset in GIS. For PM Mapping of PM equipment for distribution is being done while creating the equipment in SAP. For ISU Mobile GIS is being used for filling new meter installation form and for capturing location of Consumer. Data and location of new consumers is ported in bulk in SAP-ISU. On daily basis data of meter and consumer is synchronized between SAP ISU and GIS .

Latest data of consumer and meter is always available on GIS for all user departments making synchronized data available on both the systems. GIS DM and SAP PS are integrated for having integrated workflow for new distribution project creation and completion. The BOM and cost planning is happening in the GIS and is an automatic input for SAP budgeting seamlessly. Status updating and status synchronization between both the sides is achieved with this integration. It operates directly on network data of GIS repository & allows planners and designers to work on most up-to-date network data CRM Integration depicts on GIS the status of affected consumers on real time basis on receiving the power failure information from CRM based on call creation at call-centre. The call centre agents are now supported with a real time important information on GIS related to each power failure complaints. With this information a logical and accurate interpretation is now possible resulting into proactive actions from agents in responding to customers and also to help O and M teams to restore the failures fast.



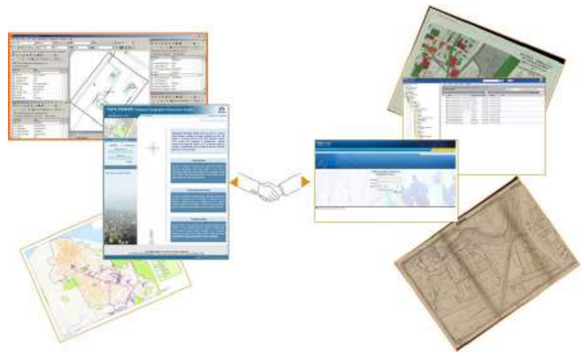
4. Integration of Vehicle tracking system:

Operational fleet management is supported with VTS system. A vehicle tracking system combines the use of automatic vehicle location in individual vehicles with software that collects these fleet data for a comprehensive picture of vehicle locations. Modern vehicle tracking systems commonly use GPS technology for locating the vehicle. Vehicle information can be viewed on electronic maps such as google or GIS via the Internet or other communication methods. TATA POWER has implemented GPS+GPRS+GSM based Vehicle Tracking System and integrated it with GIS. Through this implementation TATA POWER aims at tracking, monitoring and managing its vehicle fleet in reference to its network assets to fulfil operational responsibilities. Locating nearest support vehicle from the fault location, identifying current location of Vehicles, route travel, discrepancy in vehicle movement etc. can be easily tracked on system.



5. eLRMS Integration :

Quick access to key information / relevant documents pertaining to the company's land assets from GIS. Linking between Tata Power (MLA) land records stored in eLRMS with their respective land parcels in GIS is established. Estate Department require to keep track of all the properties of Tata Power. They are required to keep the attribute data (total area, locality, sub locality) regarding these Land Assets. The activity of locating a particular property was required to be carried out by looking into the hard copies of the Development Plan Sheets or the scanned soft copies of the DP Sheets which was a laborious and time consuming task and always required an experienced persons help to locate. With the help of GIS Maps and DP Sheets information these GIS maps one can now easily identify the DP sheet for a particular locality or sub locality within few minutes. This is very essential for communicating with the statutory / municipal authorities regarding future development plan. For development and spreading the network in new areas the easy accessible information is able to help while procuring the new lands and land assets.



6. Mobile/PDA Integration:

TATA Power network and meter data is made available on Mobiles. Meter Installation process integrated with PDA/Tablet. Changes in network and land base can be captured using redlining and then ported in GIS. Cycle time reduction for meter mapping in GIS improved. Manual data entry of Meter Installation forms eliminated thus considerable savings in daily efforts. Reduction in manual data entry has improved quality of data entry from 95% to 99%.

Benefits:

One of the greatest benefit of integration is cycle time reduction for many activities. Integration has also helped for less dependency on hard copies for many business processes. It has enabled and strengthen the digitisation initiative of the organisation. Complete elimination of manual work in many processes has improved efficiency and quality of data. The data is now getting updated timely at all points. Spatial analysis capabilities of GIS is directly impacting and helping Relationship management tools of system such as CRM. The spatial capabilities is also aiding the business transaction management tools of ERP system such as SAP. The integration of GIS with Network Analysis System and DMS has resulted in the modelling of the networks more closely and accurately to physical property which has ultimately aided planning, designing, operations with data consistency and common network models. Latest and up to date network is available for planners at all time. GIS enabled business transaction has made effective and strategic decisions making for distribution business.

Challenges faced:

Realistic and proper project scheduling is always one of the success factors for any project. For GIS-integration the realistic scheduling was the biggest challenge as this integration developing and deploying was almost new to all stake holders. Plan for surprises during development phase was essential for final scheduling. Different approaches of interfaces were required to be evaluated. Real time data synch, regular scheduled data synch methodologies were evaluated based on the real business requirements. As the systems were of varying technological platforms it was critical that pilots and POC were required for considerable number of interfaces to avoid conflicting situation and surprises. Careful mix of customization and out of box features of both the system was necessary for handling technical challenges due to varying technological platforms. The developed product was required to be tested to see whether they were meeting the requirements of business. Clear balance between “wish” and “necessity” was a critical for successful development and deployment of this type of projects so that slipping of budget and time can be avoided.

Conclusion:

Availability of multiple standalone systems in isolation with no road map of integration would mean that the benefits accrued by one system would be diluted by the other and vice versa. It is therefore a must to have a integration road map of various systems deployed for achieving a Common Goal. Also one of other major goals of the Company is to migrate to Systems based approach and minimize the manual intervention to a bare minimum. GIS is implemented in Tata Power as an enterprise system. To leverage its benefits fully, the integration with other enterprise system was envisaged and is also critical. The future is all about technology based secure and convenient solutions and we are working towards making our systems robust and leveraging the advantages of an integrated landscape to enhance Business Intelligence, data analytics capabilities and improve consumer services. The GIS system and its integration with other enterprise system has enabled Tata Power to become more effective and more agile to daily business requirements.

Aggregation of Smart Facilities in a Smart city- A Case Study

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***Abstract* - Smart cities ensure sustainable and efficient usage of resources; improving the standard of living. The operations in a smart city depend on the communication network and the related data exchanges. Small scale implementations of smart cities, their analysis and outcomes can aid in determining the strategy for a bigger city. This article presents the design of smart solutions for a small geographical area having all the amenities of a larger city. Smart operations in the domain of electric power, water supply and transportation are considered; the communication requirements and the design aspects are discussed.**

Keywords – Smart city, ZigBee, Smart Charging, EV movement.

INTRODUCTION

The Indian budget plan 2015-2016 allocated $1.2 billion, primarily for the development of smart cities and urban areas [1]. The smart cities, that incorporate smarter power systems, transportation, water, gas etc., are expected to ensure better living standards [2]. Though the term ”smart city” is very well known, only partial research has been done in that area and the degree of smartness remains undefined in academic and engineering perspective. An extensive survey in this domain yielded articles trying to fill these gaps and evidently define the various challenges and their solutions for a smart city. Smart city operations could be considered as a blend of principal components such as (i) applications (ii) business (iii) process management, and (iv) information management [4]. The managerial aspects, technology, governance and policies have been reviewed by Hafedh Chourabi *et.al.* and an integrative framework has been proposed. Smart city domains and sub domains are discussed and an empirical analysis of current smart city scenario is presented by Neirotti et al [6].

Advancements in information and communication technologies (ICT) enable efficient use of resources establishing smart practices and living [3]. In [5] an information framework for smart city, modelled as an application of Internet of Things (IoT) is presented. Data sensing, data collection, processing, Quality of service (QoS) and network design for smart applications are also deliberated. Several Smart city projects were initiated by EU and article [6] details the findings of such an initiative called “SmartSantander”, which is based on IoT. Applications such as smart parking, environmental monitoring, smart metering, precision irrigation and gardening are considered; the communication challenges, big data management and cloud computing aspects are investigated.

The role of renewable energy in reducing the carbon emission for buildings and thus empowering the concept of “Zero Energy Buildings” (ZEB) is discussed in [7] and identifies ZEB as an integral part of smart cities. The authors extensively reviewed the role of ZEB in smart cities and estimated a two by third reduction of energy consumption in ZEB With the help of Building Management Systems (BMS). The use of Battery Energy Storage System (BESS) with Vehicle to Grid (V2G) for a Smart building is considered in [9] and dynamic programming based optimum management is proposed.

Considering all the possibilities accessible for smart cities, numerous challenges are to be encountered in the implementation of smart facilities in an existing city, due to the sheer size of population affected. A better approach will be to (i) select a small geographical location having all facilities and amenities of a larger city, such as hospitals, educational institutions, office buildings and domestic consumers, (ii) analyse and (iii) progressively apply it on a wider scale. This article presents the design of smart solutions for such a facility and discusses the smart operations.

Figure 1: Ahalia Campus and amenities

FACILITY UNDER CONSIDERATION

The facility chosen, Ahalia Health, Heritage and Knowledge Village, Palakkad, Kerala, involves an area of about 1500 acres of land housing four hospitals, four colleges, several residential apartments, agricultural farms and associated irrigation system, drinking water and gas supply, medicine manufacturing industry, electric vehicles (EV) for local transport and the most importantly captive wind electricity generation of 2.1 MW. Figure 1. shows the Ahalia campus and the amenities.

SMART OPERATIONS CONSIDERED

The smart operations considered are (a) smart load management (b) green charging of EV, and (d) smart management of EV movement in the campus. All these are based on an advanced metering and sensing infrastructure.

LOAD MANAGEMENT BASED ON WIND PENETRATION

The main objective of load management is to plan the operation of motor-pump loads depending upon the wind availability and penetration level. Ahalia campus has around 45 pumping stations, for drinking water as well as irrigation. The total installed capacity of pumping loads would be around 112kW. These pumping stations are scattered throughout the campus. Each of these pumping stations will be equipped with a smart energy meter, customized to have bidirectional communication capabilities, which can receive command signals (ON/OFF) from the central server to control the pumps. The smart meters will be equipped with wired/wireless connectivity depending upon the distance from the central server/data concentrator. In Figure 2 a subset of the pumping stations, water tanks and gardens in the campus are depicted along with the possibile Zigbee network. The entire campus is interconnected with optic fibre links forming a backbone network for data transfer and wireless modems, like ZigBee, could be used to aggregate data from inaccessible locations to the central data concentrator.

The drinking water storage tanks will be filled during periods of high generation from wind farm. The water levels in each storage tank will be monitored continuously and updated in the central server with the help of sensing nodes with ZigBee wireless modems as the communication links. The water tanks are assigned priority with respect to criticality, for example the tanks at minimum water level will be powered immediately. The interest is to shift the loads from utility grid to local renewable sources as far as possible and thus reduce the overall energy import and environmental effects. Figure 3 shows the proposed load management strategy and the communication network.

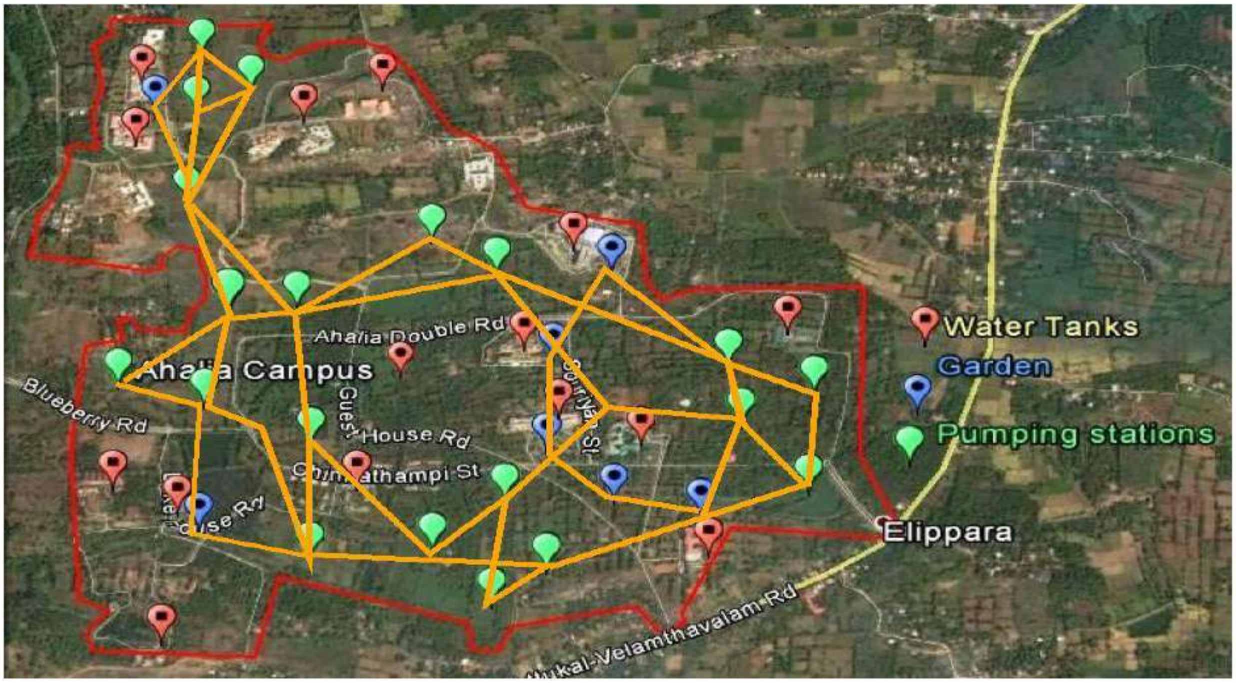

Figure 2: Zigbee Network for Load management.

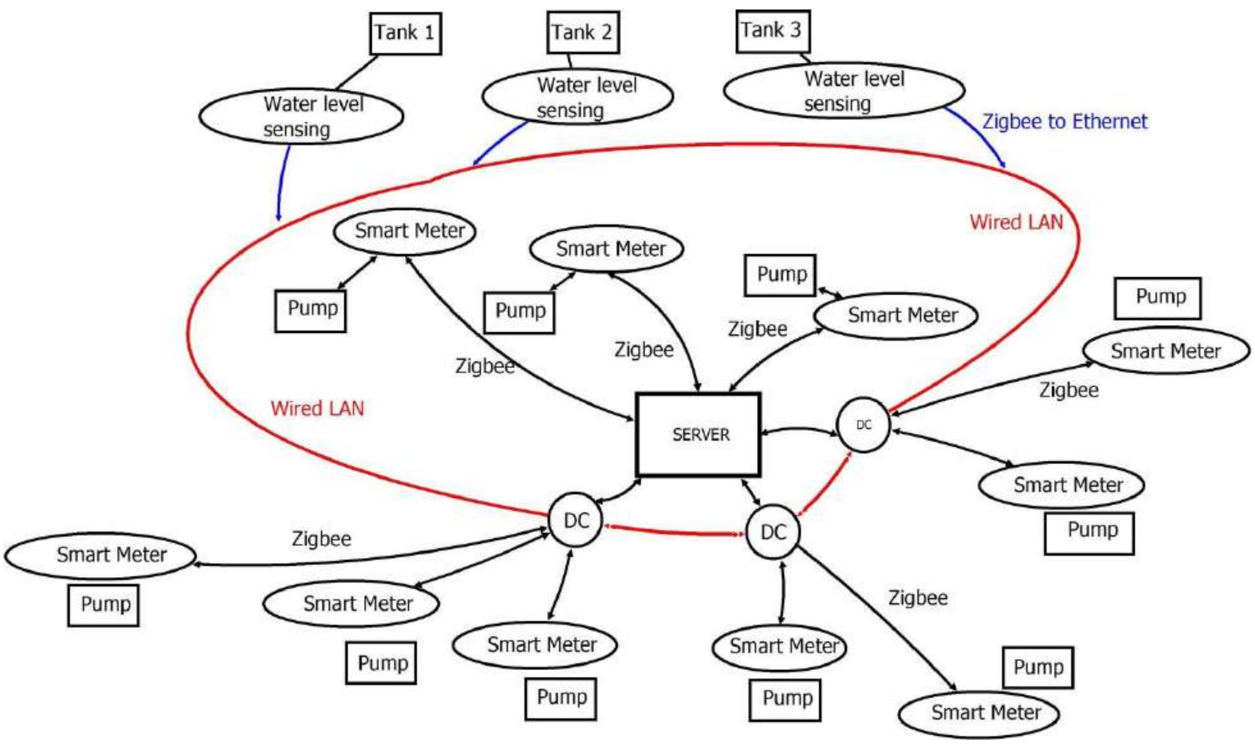

Figure 3: Load Management scheme

The water level sensors will be communicating via Zigbee directly to the optic fibre network with the help of a protocol converter, as the water tanks are on top of buildings which are already connected by optic fibre. These informations will be passed to a central server/data concentrator located at the Eye Hospital which is at the the midpoint of the campus. An application running in the central server process the information and suitable decisions are made. The water level is sensed once in every 15 minutes, wind eletric generation is continosly monitored with the help of associated SCADA system and exchanged with the server. The application at the server provides moniotring aswell as data storage. The buildings within the campus have gardens and there is a "Star garden/Zodiac garden" all of which are watered manually. The wireless network created for load management could be extended and used for a time based drip irrigation for gardens. The soil moisture level and temperature could be sensed and appropriate amount of irrgation could be provided.

GREEN CHARGING OF EV

The campus has internal roads connecting the buildings, and to provide transportation the campus relies upon two electric shuttle services. One EV will be servicing while the other is at standby/charging. The EV charging schedule could be optimized for maximum utilization of wind energy. The wind electricity generation is monitored at the central server; the State of Charge (SoC) of the EV batteries is also monitored. As the vehicle is moving from point to point wireless communications would be preferred for vehicle to server communications. A driver assistance system should be fixed on the EV, to inform the driver with respect to the battery state and charging schedule.

SMART EV MOVEMENT

The EV movement within the campus covers around five to six buildings/waiting stations in each route per trip as depicted in Figure 4.

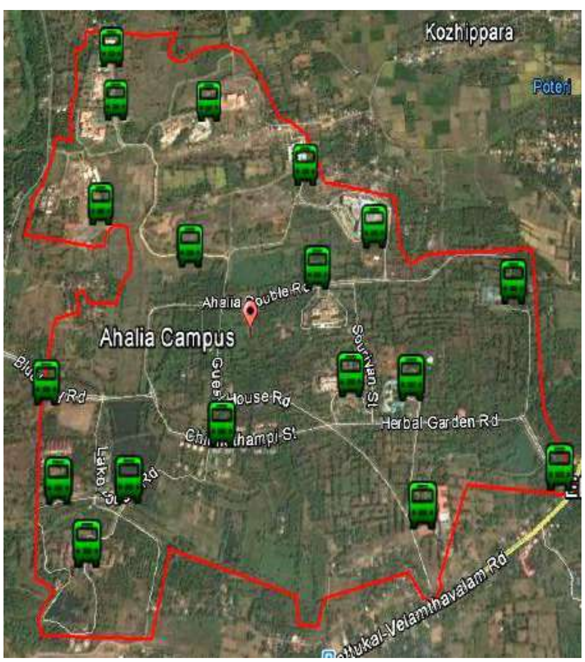

Figure 4:Smart waiting stations/Bus bays

The waiting stations could be equipped with sensors to detect the presence of passengers in waiting, along with a manual switch with which the passenger can call the driver. The driver assistance system on the EV will tell the driver the request from each waiting station and the optimum path to be selected. This optimum path selection will be based on reducing the waiting time for passengers, the battery capacity of EV and the charging schedule based on wind power. The waiting stations will be equipped with wireless modules and the information from the sensors is given to a dedicated server and decisions are made. The EV position could be detected with the help of a GPS system or else, the driver assistance system in the EV can send information to the waiting stations as and when it passes/stops at one.

COMMUNICATION NETWORK CONSIDERED FOR SMART OPERATIONS

The academic and hospital buildings are spread across the whole campus. Considering future expansion all the buildings are interconnected through high capacity optic fibre links which serves as the backbone for the smart city network. The optic fibre links will be useful in asset monitoring, CCTV for security and to transform the academic areas to be Wi-Fi enabled. Creating an optic fibre backbone will aid in future expansions considering smart class rooms, and Smart buildings. The entities which are isolated from this optic fibre network can have wireless connectivity, establish a wireless network and terminate to the optic LAN. ZigBee is selected for the load management as well as water level sensors as it is a low cost solution. For load management and irrigation schemes ,as the loads are widely spread ZigBee repeater units are needed. The routing and scheduling of EV also demands communication and for the last mile connectivity ZigBee is considered. The bus waiting stations can communicate to the EV through ZigBee based modules. The bus bays are provided with emergency telephone systems, which also could be used for sensor data exchange. The overall bandwidth requirement for these operations will be in the range of a few kbps.

CONCLUSION

The two designs, those of transport management and load management, are under implementation. More of smart facilities are under planning. Each system upon successful implementation will be integrated with the central server. A similar methodology can be followed in making a city smart irrespective of its population and geographical sizes.

REFERENCES

1. Indian budget plan 2015-2016, available at http://indiabudget.nic.in/.
2. Al-Hader, Mahmoud, Ahmad Rodzi, Abdul Rashid Sharif, and Noordin Ahmad. "Smart city components architicture." In *Computational Intelligence, Modelling and Simulation, 2009. CSSim'09. International Conference on*, pp. 93-97. IEEE, 2009.
3. Calvillo, C. F., A. Sánchez-Miralles, and J. Villar. "Energy management and planning in smart cities." *Renewable and Sustainable Energy Reviews* 55, pp. 273-287.2016.
4. Chourabi, Hafedh, Taewoo Nam, Shawn Walker, J. Ramon Gil-Garcia, Sehl Mellouli, Karine Nahon, Theresa A. Pardo, and Hans Jochen Scholl. "Understanding smart cities: An integrative framework." In *System Science (HICSS), 2012 45th Hawaii International Conference on*, pp. 2289-2297. IEEE, 2012.
5. Jin, Jiong, Jayavardhana Gubbi, Slaven Marusic, and Marimuthu Palaniswami. "An information framework for creating a smart city through internet of things." *Internet of Things Journal, IEEE* 1, no. 2 pp. 112-121. 2014.
6. Neirotti, Paolo, Alberto De Marco, Anna Corinna Cagliano, Giulio Mangano, and Francesco Scorrano. "Current trends in Smart City initiatives: Some stylised facts." *Cities* 38,pp. 25-36. 2014.
7. Theodoridis, Evangelos, Georgios Mylonas, and Ioannis Chatzigiannakis. "Developing an iot smart city framework." In *IISA 2013*. 2013.
8. Kylili, Angeliki, and Paris A. Fokaides. "European smart cities: The role of zero energy buildings." *Sustainable Cities and Society* 15,pp.86-95.2015.
9. Lamedica, Regina, Sabrina Teodori, Giovanni Carbone, and Ezio Santini. "An energy management software for smart buildings with V2G and BESS."*Sustainable Cities and Society* 19,pp.173-183.2015.

Geographic Information System (GIS) for OPTCL Network

A Viable Approach to Smart Transmission Network

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***Abstract* — GIS had a reflective influence on the capabilities of geographic analysis, and in retrospect marked a turning point in strengthening of geography as an explicitly spatial discipline. In a vast country like India, with much demographic diversity, GIS promises immense opportunity for power transmission sector in India. This paper emphasizes the aspects of OPTCL, for implementation of GIS package integrated with other business systems to make the infrastructure within the company more complete. In addition, the paper highlights about the GIS package can actually assist in various other applications like asset management, outage management, and network planning and expansion study, which vitalizes a comprehensive strategy to smart grid deployment. With the data of soil layer to availability of pollution and wind zones, identification of outage points by successful incorporation of GIS with Supervisory Control And Data Acquisition (SCADA), integration with ERP module accessed via internet provisionally, makes it a viable approach to a smart grid development. Restoration activities can be planned quickly using GIS once the fault location is identified. The impact of GIS in restoration planning can be better seen during severe natural disasters. Using various visualization techniques, the power flow within our system with terrain information and integration of revenue data optimization routing for addition lines can be acknowledged with lesser Right-Of-the-Way (ROW) issues. When EHT lines and electrical asset survey is done and the feed are given to the GIS, potential threats to the transmission system like vegetation, sag increase and any other physical damage to the assets can be studied and analyzed. The paper explains the roadmap of GIS implementation and concludes with the challenges of the project, executed in the system to spawn into a smarter grid in the future.**

Keywords* — *GIS, Smart Grid, ERP, Asset Management, Outage Management, SCADA. WAMS, Disaster Management.

I. Introduction

The electric power transmission has been progressively urbanized for over one century [1], from primary designed local DC network in LV level to 3-Φ HV AC network, with up-to-date bulk interconnected networks with multiple voltage levels and plenty of complex electrical components. The economic growth of the developing nations like India depends heavily on reliability and eminence of its electric power supply. As in that case the backbone to deliver electricity from points of generation to consumers, the need of transmission grid revolution has been highly recognized to deal with more diversified challenges than ever before [1]. Today in the country the transmission sector has progressed in a very subsequent rate, currently at installed capacity of 6,33,056 MVA at 765, 500, 400, 220 kV voltage levels with 3,36,460 circuit kilometers (ckm) of HVAC and HVDC transmission network, including 765 kV transmission system of 23,789 ckm [2][3].

The progress in the electricity sector in Odisha requires huge investments in generation, transmission and distribution propelling up new challenges and at the same time opening up newer opportunities. The state's political, social and financial development solely depends on the growing demand of electric power and energy. The energy demands are anticipated to grow by 70% over the next 25 years subjected to three significant factors; population growth, rate of gross domestic product (GDP) and energy intensification.

OPTCL is carrying out the integrated task of transmission of electricity in Odisha since 2005. With an asset of Extra High Voltage (EHV) Transmission system of 12,172 ckm of transmission lines at 400 kV, 220 kV, 132 kV levels with transformation capacity of 14,032 MVA, the system entails for planning for development of a robust and cohesive intra-state transmission system for the country for achieving the different schemes like Rajiv Gandhi Grameen Vidyutikaran Yojana (RGGVY), Biju Gram Jyoti Yojana (BGJY), etc. implemented to cater to basic needs of the people. These assets across the state are located in diverse geographies for transmission of power including some in most difficult terrains. For proper management of all the assets, knowledge and database of the asset location, condition and approach to the asset are essential to achieve a smart transmission network [4].

In the present day, the advent of technology like GIS, GPS, Remote Sensing, DEM, ERP, WAN and Internet (Web Applications) plays an important role for preparation and managing the asset database. As Web GIS becomes an affordable and easy way of disseminating geospatial data and processing tools, many organizations are keen to distribute digital maps and processing tools without time and location restriction to users.

The high resolution remote sensing satellite images are excellent sources to understand the complex scenarios easily for utilities. It provides integrated information of focused Assets along with geo-information like terrain and Revenue data etc. which are directly or indirectly controlling the spatial relationship and helpful in the mapping of electrical utility [5].

Thus, OPTCL took the initiative for fulfilling the above schemes and basic needs by proper planning with cost effective manner, implemented the Web Based Power Atlas for proper decision making with the assistance of Odisha Space Applications Centre (ORSAC) the nodal agency of state of Odisha in the field of remote sensing, GIS, Web GIS and DGPS survey.

The organization of the paper is as follows: In section II, role of GIS in Smart Grid and its development towards smart transmission grids has been presented; Section III describes the GIS in OPTCL Transmission System along with section IV debriefing about the implementation and performances. Section V reveals about the challenges and complications in the project. Section VI is dedicated to general conclusion followed by references.

II. Role of GIS in Smart Grids

Due to the consequence of cutting edge technology, buzzwords like energy conservation and emission reduction, green energy, sustainable development, safety factor, reduction of T&D losses, optimal utilization of assets, have turn out to be the core of discussion. As India is struggling to meet its electricity demands, both in terms of energy and peak load, smart grids can help better manage the shortage of power and optimize the power grid performance in the country.

A “Smart Grid” is a perception of remodeling the scenario of the nation’s electric power grid, by the convergence of information and communication technology applied to electrical grid, allowing sustainable option to the customers and upgraded security, reliability and efficiency to utilities [6].The elite vision of Smart Grid (SG) Technology allows energy to be generated, transmitted, distributed and utilized more effectively and efficiently.

Up-gradation of transmission network by increasing high capacity multi-circuit/bundle conductor lines, High Surge Impedance Loading (HSIL) Line, High Temperature Low Sag (HTLS) Line, and EHV under Ground Cabling etc. facilitates the quality of power transmission with the crux of reliability and economy of the system [7]. But still there are some thriving challenges and issues such as; environmental concerns, AT&C losses, age old infrastructures, conventional protection system, power quality disputes, reliability and theft of assets, which are being faced off by todays’ transmission network

With the state of art technology advances in the areas of remote sensing, Information and communication Technology (ICT), control, computing and Substation Automation System (SAS) Solutions, it has quarried a unique vision for the smart transmission grids by identifying the major smart characteristics and performance features to handle these challenges. With this unique vision of smart transmission grid, GIS aims in promoting technology innovation to achieve an inexpensive, reliable, flexible and sustainable delivery of electric power.

Geographic Information System or Geo-Spatial Information System (GIS) promises immense opportunity for power transmission sector in India to emerge in to a smarter transmission system with advance state of art technology with the geographical location of assets in the network. GIS are now widely accepted as powerful and integrated tools for storing, manipulating, visualizing and analyzing spatial data. Since the inception of the technology in early 1970s, GIS had a reflective influence on the capabilities of geographic analysis, and in retrospect marked a turning point in strengthening of geography as an explicitly spatial discipline [8].

In a vast country like India, with much demographic diversity, GIS in power transmission system facilitates towards asset management, outage management, network operation, planning, refurbishment and expansion by promoting the use of geospatial information for better decision-making. An ability to review any outages, overhaul or shutdown being planned, and the maintenance work planned to be performed during a particular period and planning of new infrastructure using Web GIS interface is one the prospective solution for development of smart grids.

Information on other aspects of the area like infrastructure settlement, road, canal, rail, administrative Village, Gram Panchayat, Soil Data, Natural resources like drainage and plot level information etc. can be integrated and accessed by utilities to obtain relevant spatial and feature information on electrical assets and power areas by different search options in a single window. As a result such facility could render utilization of human resources and emphasize skillful employees to manage and maintain during the disaster and catastrophic events.

Currently, Odisha transmission network is operated by a pyramid of 1 SLDC, and 2 Sub-LDCs monitoring round the clock with SCADA system enabled with fish as well as bird eye view, along with advance wideband speech and data communication infrastructure under ULDC scheme. Digitization with IEC 61850, development of Substation Automation System (SAS), deployment of advance communication links like *MPLS, VSAT and OPGW* and installation of AMI at nodal points shall bring in new opportunities and revolution in the field of monitoring, restoration and self-healing of the grids and the transmission lines in the network, when integrated with the SCADA and GIS [9][10].

III. GIS IN OPTCL TRANSMISSION NETWORK

OPTCL recognizes the importance of Information Technology and lays a strong emphasis on its use in functioning and management of EHT lines, to know the land use and land cover of the portion of the land under the power corridor (ROW) and area covering around the grids and substations, integration of existing MIS/ERP data with the spatial data, and to map in the GIS environment using Intergraph Geospatial Server (IGS). Thus OPTCL generated Web Atlas on pilot mode with the technical collaboration of Odisha Space Applications Centre (ORSAC) being a nodal agency of the State in the field of Remote Sensing (RS), Geographic Information System (GIS), Survey using Global Positioning System (GPS) & Differential Global Positioning System (DGPS) and Communication.

With the initiative for implementing the pilot project for Web Based Power Atlas system, ORSAC conducted survey of 5122 EHT towers and 32 numbers of substations covering 2328.69 ckm using Global Positioning System (GPS) and the geospatial database was generated with Universal Transverse Mercator Projection System (UTM) with WGS 84 spheroid and Datum. Natural Resource layers like Land use / Land cover, River & Water Body, etc., Infrastructure layers like Road, Railways, Canal Network, Settlement Spreads, other electrical lines etc. were generated in 1:10K scale using the resolution merged image (Cartosat-1+Resourcesat-2). The substations were mapped in 1:4K scale for generation of plot wise land use/cover using World View II Data of 0.5 m spatial resolution and the cadastral digital database. Administrative layers such as Village, Block, District, Assembly, Parliament and Survey of India Topo boundary were used to view the Power Atlas as per the administrative units desired by the user. Linking and integration of spatial layers with respective attributes were carried out using ERDAS APOLLO and ORACLE RDBMS to facilitate the querying, viewing and managing the electrical assets v/s natural resources like live and geographic crossing of electrical circuits. A Graphical User Interface created using ASP.NET for its customization. The project has facilitated unique integration of external e-shakti database of OPTCL in the GIS environment for accessing asset and Human Resource (HR) data to monitor the day to day decision making and disaster scenarios. OPTCL's Enterprise Resource Planning (ERP) initiative viz., e-shakti comprises of GIS relevant modules viz., Inventory, Enterprise Assets Management (EAM), HR and Projects. The Service Provider has integrated the Enterprise Asset data of e-shakti with GIS. On such addition, on demand, the GIS is equipped to visualize details of every assets included in the GIS survey in tabular text format retrieving from e-shakti data base, along with GIS coordinates, approach paths to the asset taking into consideration.

With the advent of such technology, implementation of crowd sourcing facility has developed an interaction with the Web Based GIS System of OPTCL at server by updating or messaging or sending up-to-date images with the help of an android based application installed in a mobile device specifically a cell phone, for the proper streamlining of field level data. Crowds take the images from their Android equipped mobile devices and write message by selecting proper department of OPTCL. The captured image will be geo-tagged by developed android app version Lollipop and above. All data, send by Crowds are saved in OPTCL server and marked as 'Received' Acknowledge. All the 'Received' messages with image can be viewed only by Approval Authority User of OPTCL Power Atlas Application followed by an Approval/Rejection process. In that case, the user may view the image, image captured location – latitude with longitude, message details, information regarding the department and, receiving date and receiving time [11].

IV. GIS IMPLEMENTATION IN OPTCL

OPTCL has taken initiative for GIS implementation with ERP database integration in its pilot phase with ORSAC as its implementation partner, which has been completed and hosted as Web Based for all field users. Further OPTCL has been rolling out GIS implementation for entire Odisha with seamless integration with the pilot project. The phases of implementation have been elaborated in the following.

- Surveying
- GIS Database Creation
- Satellite data
- Power Atlas Development
- Web customization
- Commissioning
- Hosting
- Training
- Non-Spatial Database organization and integration of ERP data with spatial Data

The undergoing project for rolling out of GIS throughout Odisha has however improved in its functionality like color satellite images, crowd sourcing facility, field level QC and verification works in each of its implementation module.

Survey:

Survey covers 88 EHT(400kV, 220kV &132kV) Sub Stations, 209 EHT Lines having 22,594 Towers (approx.) having 3-5 meter accuracy using GPS Instruments with Geographic Coordinate System (GCS) and WGS84 spheroid and datum setting. Every Tower is GIS-Surveyed as well as GIS Coordinates of Power Line projections are recorded.

The field survey data format is described in Table 1.1

The survey is conducted as per the Gantt chart comprising detailed activities along with resource requirements and time lines. Daily Progress of the Project is monitored using WhatsApp in android phones and issues, if any, are immediately resolved. The geo coordinates are immediately mapped on open source GIS images for verifications are carried out on daily basis jurisdiction wise. For substations,

Sl.No.	Tower No	Phase Sequence (T-M-B)		Long.	Lat.	Alt	Type of Tower		Jurisdiction	Dedicated Industrial feeder inf.	Live/ Geo Crossings inf.
		For Towers (T-M-B)	For Gantry (R-M-L) when looking towards S/S				Angle/ Suspension	SC/ DC			

Table 1.1 Field Survey Data Format.

the coordinates of boundary of all vertices along with the location of transformers, Switchyard, Main Gate, Gantry Tower, Control room and Colony within the polygon are recorded.

Feeder emanating (Gantry tower) points with its phase sequence(R-M-L) form part of the scope of GIS survey. Separate layer are identified with color coding for Angle type and Suspension type towers. Metering layers comprise of three types viz. Industrial, Generators & Inter State points. Angle towers are identified at the time of survey and the co-ordinate list is collected for display with a separate layer. Power Corridor 27m, 35m & 52m on either side of EHT lines of voltage level 132 kV, 220 kV & 400 kV is maintained respectively. All EHT Tower Images (Foundation Base, Insulator string, Total Tower View) are captured with proper naming convention for display as an album format.

GIS Database Creation:

Generation of GIS Data base based on survey coordinates of each EHT Tower, Grid and office.

Satellite Data:

Satellite data from NRSC (ISRO/DoS) colour merged have been collected for

(a) WV-II Multispectral (2mtr)

(b) WV-II Panchromatic for Sub-station Areas only (0.5mtr) for clear visualization of Electrical assets.

Power Atlas Development:

Power Atlas composed for all the EHT lines emanating from all the EHT S/S in the backdrop of satellite data with the option to see administrative boundary wise/ SOI Topo-map wise / division / section wise using web- GIS interface. Integration of HAL and SABIK plot level mapping data for whole of Odisha based on approval from Principal Secretary, R&B, Government of Odisha (GoO) which has not been covered in pilot project. The approach roads to each Tower and Substation are to be reflected in the GIS Displays. (Road Database shall be sourced from ORSAC, and there no need to generate the road database but to integrate in the GIS environment with point layers likes Tower and substations). The EHT Line relevant Administrative (Revenue) layout needs to be rendered in the User GIS Views, as per categorization by the State Government with appropriate color coding.

The thematic layers of importance for EHT lines-GIS-display include Railway Traction, Road Network, Rivers, Forest, Mines, Farming Fields, and Dwelling Areas etc. The layers are obtained from ORSAC. Details of Land type, ownership of adjoining areas of switch yard, details of objectionable objects like houses constructed under the lines or adjacent to lines within line corridor should be reflected. The information is to be obtained from ORSAC. Angle Towers and suspension tower will be marked in different layer with different color for monitoring the route of EHT Lines. All the other layers available with pilot project shall be optimized as per OPTCL's requirements. Soil, Land use, Roads and Railway lines will be incorporated for entire Odisha. Spatial query is to be incorporated to generate different view scenarios as per user queries. Few examples are given below. Live Line crossing will be recorded up to 11kV as separated layer Single feeder Line will be assigned different color code for different jurisdiction.

Necessary updating of spatial data entry format of feeders and substations will have to be filled up as per the formats enclosed where details of phase sequence and dedicated feeder details are incorporated. Those data will be populated as attribute. The Web-Atlas shall provide the facility to plan for the new feeder line taking the GIS layers into account following an easy workflow process and shall provide the facility to compose the map and shall be able to take the printout. The crowd sourcing facility shall be developed to take the digital snaps of the OPTCL infrastructures with its attribute information and the images shall be replaced with due validation mechanism. The web enabled Power Atlas shall be light weight in terms of response taking into consideration that High Resolution WV-II color Image would be there in the back ground and other GIS layers. There shall be options for the user to view the Power Atlas in the Google Satellite/Google Hybrid /Google Terrain /Google Road /Bhuvan/Wikimapia backdrop.

A. Web Customization / Commissioning:

Web Based customization will be done using Intergraph Geospatial Server 2015, Oracle 11g R2 and ASP.NET Technology. A user friendly GUI will be developed for easy access of Web Based Power Atlas and for Crowd sourcing facility. The figure 1 describes the work flow of Web Based Power Atlas.

B. Hosting:

The hosting of Web Based Power Atlas for Rest of circle integration with Cuttack circle will be hosted in ORSAC Server at OSDC, OCAC as well as at the OPTCL server at OPTCL office premise. The OPTCL premise shall be the permanent site, once the hardware/software and infrastructure are in place.

C. Non-Spatial Database organization and Linking of ERP data with Spatial Data:

OPTCL's Enterprise Resource Planning (ERP) initiative viz., e-shakti comprises of GIS relevant modules viz., Inventory, Enterprise Assets Management, HR and Projects. The Service Provider shall integrate the Enterprise Asset data of e-shakti with GIS.

On such integration, on demand, the GIS should be able to show details of every Asset element included in the GIS Survey in tabular text format retrieving from e-shakti data base, along with GIS coordinates, approach paths to the asset taking into consideration the hurdles reroute, such as river crossings, forest patches etc.

D. Migration of Cuttack Circle Pilot Project from ERDAS Apollo 2014 to IGS 2015:

The necessary Migration of the Pilot Project developed will be done from ERDAS Apollo 2014 to latest Intergraph IGS 2015 which will be used for Customization of Rest of Circles of Odisha.

E. Integration of Cuttack Circle Pilot Project with Rest of Circles:

The Cuttack circle pilot project will be integrated with Rest of circles to make the GIS mapping uniform for all EHT Towers in the Web GIS maps of Odisha.

F. Crowd Sourcing Facility:

It is proposed to develop android mobile interfaces for viewing the application, tagging objects to a point/line/polygon on a map that includes EHT tower images and any other documents. The mobile interface should allow OPTCL officials to log complaints, querying and uploading EHT tower images at the time of Break down or short circuits. Based on a weekly review or daily basis, the images will be uploaded into the Web GIS Portal by a designated GIS team. The solution should provide required features on spatial visualizations and analytical capabilities in terms of reports, charts and maps etc. over mobile phones. The mobile application should be compliant with Android Applications. Version 4.4 and above

G. Query Builder and a spatial decision support system:

The Web Based GIS System would be able to respond to user based queries. These queries can be based on spatial and non-spatial data. The queries can be generated on any of layers of the system. Standard Spatial queries should cover all spatial operators, including Proximity /Neighborhood analysis, Thematic Analysis, shortest and Optimal Routing, Multi-criteria and Multi-Objective Analysis.

The Analytics Module will cover user define expressions and use standard operators such as +,-<, < >, > including AND, OR, Between, Like etc. Along with, spatial operators - Entirely within, intersect, join etc. are also included. The solution is attributed with "Layer Search"; Allows user to search for features using a Layer's attributes or combination of layer's attributes and one or more joined tables (or views) which also enable to apply spatial filter to the queries from multiple layers. Query across multiple map services includes nearby search; find nearby places around a specific location. Location Search based on place is equipped. Charting; without any dependency on any other 3rd party charting s/w, the solution enables users to create dynamic charts from the map layer. The charts include pie, bar, line etc. as per selections by the user using features and attribute fields selected. The charts are displayed in a Chart Window. Dynamic Attribute Table; should enable users to identify features on the map and get more detailed information about those from disparate databases.

V. Challenges in the Project

Smart Transmission Grids are slowly but surely becoming a corner stone in the future power systems network configuration. They present a strong and valuable solution to today's energy market challenges. There is still a lot to be done to achieve an ideal smart transmission grid using GIS. Data up-to-date and analysis, augmentation works, system up gradation at both software and hardware level, visualization of sag and its calculations, static data are now to be matched based on the complete and reconfigured network. Power system engineers need to be trained have more deeply about the system variables and need to better access each and every configuration of the GIS enable transmission network.

The proliferation of sensors and communication devices and the emergence of embedded computing represent an opportunity to develop applications for connected environments in general, and especially management systems that address urgent challenges facing the smart grid infrastructure. Alignments behind technical standards are to be balanced with creating an environment that encourages innovation so that the overall GIS infrastructure may continue to evolve. Based on the above survey, we focus on those challenges to GIS infrastructures in both system design and operations to make it more efficient and secure. The challenges include the deployment of large-scale embedded computing, legacy power grids, intelligent appliances, and next generation communications and collaborations that will provide the foundation for a post-carbon society.

In addition, integration of SCADA with the system can render information about load flow study and more RT system; however reverse integration of data from GIS to ERP are some of the potential challenges that are being looked after. Support system for reactive compensation, islanding, load shedding, and other system monitoring techniques like generation status/availability, decision support system etc. are being reprogrammed in the GIS based module to bring out the versatility and compatibility at user end.

Metrics, cost and benefits analysis of GIS field projects has some major challenges. These challenges include; enabling a fair comparison of baseline performance and Smart Grid performance, collecting proper data at appropriate frequency and location, determining societal benefits, monetizing benefits, extrapolating results from a few circuits to larger control area, interpreting Smart Grid response to electrical disturbance, using appropriate assumptions and calculation methods.

VI. Conclusions

The paper presents a discussion on GIS along with its pitfalls in various technical and non-technical themes, with an organized approach to evolve the conceptualization of Smart Transmission Grid. An overview of Indian Power Scenario along with brief analysis about the power system units in Odisha is described. This paper shows how the implementation of GIS is a viable approach to cultivate the Smart Grid and its technologies along with a pioneer answer to the challenges to develop an intelligent grid network. Web Based Power Atlas System for pilot project facilitates for getting the geospatial information of electrical assets in decision making and planning process efficiently. It would also facilitate the administrators to take effective measures during disaster scenarios and other uncertain events. Further, various prospects of implementation of GIS and its possible challenges faced during the project commencements are also presented here. In this connection, the paper act as advocate to bring forth the significance and fortification of Smart Grid philosophy and implanting GIS based technology for power network mapping on the basis of proposed ideology in Indian subcontinent.

REFERENCES

[1] Bala, S.K.; Babu, B.C.; Bala, S., "A review on development of Smart Grid technology in India and its future perspectives," in *Engineering and Systems (SCES), 2012 Students Conference on* , vol., no., pp.1-6, 16-18 March 2012.

[2] Ministry of Power, Government of India Website. [Online] Available : http://powermin.nic.in, Jan. 2016

[3] Central Electricity Authority, 2016. [Online] Available: http://www.cea.nic.in, Jan. 2016.

[4] Odisha Power Transmission Corporation Limited Website. [Online] Available: http://optcl.co.in, Jan. 2016.

[5] P. Persai and S.K.Katiyar. Open source GIS and cloud computing technology for the power distribution system. Journal of Geomatics,Vol 9 No. 1 April 2015.

[6] Balijepalli, V.S.K.M.; Khaparde, S.A.; Gupta, R.P.; "Towards Indian Smart Grids" , Proc. Of T*ENCON 2009 - 2009 IEEE Region 10 Conference,* vol., no., pp.1-7, 23 26 Jan. 2009.

[7] Power Grid Corporation of Indian Limited, "Unified Load Dispatch & Communications Scheme", Nomination for CSI-TCS Best IT Usage *Award*, National IT Awards, 2003.

[8] González-Jaramillo, V.H., "Use of geographic information systems with open source solutions, an approach to access edemocracy & egovernment," in *eDemocracy & eGovernment (ICEDEG), 2015 Second International Conference on* , vol., no., pp.7-8, 8-10 April 2015

[9] [Online] State Load Dispatch Center (SLDC), Odisha. available: http://www.sldcorissa.org.in"

[10] Chaurasia, P. and T. Thakur, (2009). Consumer indexing - A GIS based approach, Power System, Third International Conference, Kharagpur, India, pp. 1-5.

[11] Pratap Sakhare "Development *of Web GIS Framework for Natural Resource Management Using ERDAS Apollo 2010*"Geospatial World Forum, PN-227.

[12] A.Alesheikh "*Web GIS: Technologies and Its Applications*"isprs2002/papers/422.

[13] Adnan, M., "Developing Efficient Web-based GIS Applications"ISSN 1467-1298, Feb 2010.

EXPERIENCES OF CESC IN SMART GRID INITIATIVES – LT NETWORK AUTOMATION

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1. Brief Overview of the Project

CESC Limited has an LT consumer base of around 30 lakhs spread over an area of 567 sq-km. Majority of LT Network in City Area is underground. Faults cannot be identified easily as in the case of overhead network – it takes more time. Special techniques are deployed to isolate faults in underground network and it is time consuming too. To reduce the no. of faults it becomes mandatory to monitor the LT Network in order to provide uninterrupted power supply to all consumers. This can be achieved by monitoring the plant and equipment in the LT distribution network for any outage with a final aim for reduction of restoration time in case of any failure. Automation has been done to monitor LT Load Current in Distributor, Voltage per Phase, LT Fuse Failure, Load Unbalance in 3 Phase and Fault Passage Indicator (FPI) Monitoring of the Ring Main Units (RMUs) in the HT Network. IEDs have been installed at different point in the network to process primary network parameters into transferable format to remote location for monitoring and corrective action. These IEDs have also been used in Power Fail Indication Systems for Important LT consumers in and around Kolkata. These devices collect the voltage parameters from each phase present in the LT service point at the consumer premises. On absence of voltage, it sends an alarm over SMS to a server present at LT Control Room of CESC. The data is decoded from the SMS to show the details of the outage. Proactive action can immediately be taken in case of any fault at consumer installation. All these implementations have been made a part of LT Network Automation, keeping Consumer Centricity of the Utility in mind and in order to make the LT Distribution Network more reliable. Till present date, 50 Power Fail Indicators at Consumer Premises, 25 LT Pillar Box Monitoring Devices, 19 LT Change-over Devices and 5 LT Fuse Failure Alarm devices have been introduced as a part of our LT Automation project.

LT Feeder Pillar Box with Junction Box containing Automation Unit

2. Challenges faced

Location and Space: LT Pillar Boxes are cubicles installed on roadside pavements in Kolkata. There is no additional space within the pillar boxes for automation equipment to be housed. Additionally, the Pillar Boxes enclose bare conductors inside it for LT AC Distribution. This poses as a Safety risk if Automation Units are installed inside them. As a result it is very difficult to find space for implementation of LT Automation in such equipment. This challenge was also present in Consumer Supply Installations, where there is no adequate space for housing the Automation Units. However, this challenge has been overcome effectively by use of innovative measures.

Consumer Concerns: The second major challenge was the participation of the Consumers themselves for installation of Power Fail indication devices at their Incoming Supply Points. It was difficult to convince and demonstrate to them the positives that can be yielded from this project.

Communications: In order to establish a secure connectivity over the internet through GPRS, a Virtual Private Network (VPN) tunnel was created. The net cost of establishment of the communication connectivity includes procurement of GPRS or CDMA modems, and VPN Gateway at Control Room end. Compared to the cost of installation, the performance of the Semi-Automation devices over GPRS or CDMA was very poor. The net availability at some places were between 50 to 60% and few places were 90% and above. This wide range of availability factor from any communication medium for this critical application is unwanted. As a result, the first challenge faced before deployment, was finding a suitable replacement to GPRS or CDMA as a reliable communication medium for Semi-Automation and Monitoring of RMUs.

SMS is comparatively reliable but still has major failure rates on particular days. In order to circumvent this challenge, redundancy was created in the SMS Gateways, which is, all the IEDs with SIM cards would send SMS to 2 different SMS gateways with SIM cards of 2 different service providers. These IEDs are programmed in such a way, that they can report the same instances to 5 different SIMs simultaneously. Hence, if one of the service providers had any network outage, the data would still reach the server. In order to make this process fail-safe, and independent on any particular device, the server itself was replicated by another backup server which is on hot standby in case the main data acquisition server fails to operate at any point of time.

3. Objectives

The main objectives of the implementation are as listed below:

a. Ensuring less outage duration in LT network
b. Constant monitoring of supply in important consumers
c. Energy Audit operations from LT Pillar Box Monitoring
d. Loss Control Measures in Theft Prone areas
e. Supply monitoring during important events and festivals

All the above objectives meet up to one single goal of the company, which is improve customer satisfaction. This can be achieved by creating an LT Distribution Network which will be both reliable and free from unnecessary outages. As the demand of electricity consumers increase day by day, CESC is responsible to meet and exceed such demand. CESC has always been lauded for reliable power supply in Kolkata and adjoining areas, but in order to be among the best in the business, it needs to keep improving its network and system. LT Power Fail Indication Systems will result in lesser outage duration in the LT Supply to the consumers as CESC will be in a position to attend to such outages swiftly. By constant monitoring of supply, CESC will be ready to act in case of any emergency at any of the consumer service points where IEDs have been installed. Loss Control measures can also be taken if Fuse failures are reporting faster than usual. This can result in enforcing upon theft prone areas and taking proper actions to prevent such occurrences. The entire project of LT Network Automation has met up with this challenge by providing a mechanism by which CESC is now able to proactively act on outages in the LT network, even before the consumer can complain. This has, as a result also lowered the outage duration and improved the network reliability and availability. LT Auto-change-over devices have been installed in Important Locations where upon sensing absence of power supply, the device changes over to it redundant supply path. This change is then alerted over SMS to the LT Control Room.

4. Technology

Various innovative measures have been included in order to initiate Smart Grid in CESC's LT Network. The major activities done in order to render the network Smart.

4.1. Smart Pillar Boxes

Pillar Boxes are the major method of LT Distribution from Distribution Transformers to Consumers. These contain Units with Fuses for each of the three phases. Each unit is then interconnected via. a Busbar for each of the phases. Every unit has provisions for Cable termination through which DTs are connected and service cables are provided to LT Consumers. Three types of Pillar Boxes are used in the network. Older pillar boxes were in use for a long time, but due to ageing, fusing posed a serious problem which led to unwanted outages in the network and to the consumers. These old pillar boxes contained re-wirable copper fuses which also led to frequent failures. These old pillar boxes were re-engineered keeping in mind the provisions for automation and the failure prone areas of the older design.

LT Pillar Box in older design

New Smart Pillar Box

The newer pillar boxes or Smart Pillar Boxes as they are presently known in CESC, contained HRC fuses in place of the older copper wire fuses, which significantly reduces the number of network outages due to fuse failure. These HRC fuses are also safe for operation. Overall, the Smart Pillar Boxes are compact in design and have provisions for CT wiring in each phase of each Distributor Cable, provisions for wiring up for Automation purposes. Presently, a total of 1120 Smart Pillar Boxes have replaced the older Pillar Boxes in CESC's LT Network.

4.2. Smart Pillar Box Automation

A pilot project of Smart Pillar Box Automation has been completed including 25 Pillar Boxes. CTs were installed on all cable cores in the Pillar Box for measuring the Electrical Parameters in each Distributor. The feed from the CTs were connected to Multi-Function Meters (MFM) further communicating the local FRTU over Modbus. The local FRTU has the feature to communicate and report to the LT Control Centre over Optical Fiber Network.

Automated Smart Pillar Box

4.3. LT Power Fail Indicator

LT Consumers have a Service Cutout before their Meters. These PFI (Power Fail Indicator) devices have been installed in 50 Consumers considered with high priority. This device is in-house developed and contains a Voltage sensor based on which an SMS is sent to a list of recipients and also to the LT Control Room using an SMS gateway server.

4.4. Smart LT Auto-Changeover Devices

Earlier, the scenario in case of LT Faults were very grave, where resumption of LT Supply to consumers due to faults, took a huge amount of time. This step has been aimed at reducing this time for changing over to a redundant LT source in case of any LT fault. Feeds from two sources are provided in these Auto-changeover devices, where one is the active source, the other is kept as the redundant source in case of the occurrence of any fault in the first source. The voltage comparator actuates the changeover switch on sensing absence of Voltage in the active source. Also, this changeover event is sent as an SMS to predefined list of mobile users.

LT Auto-changeover device at service point of Consumer

4.5. LT Compact Substations

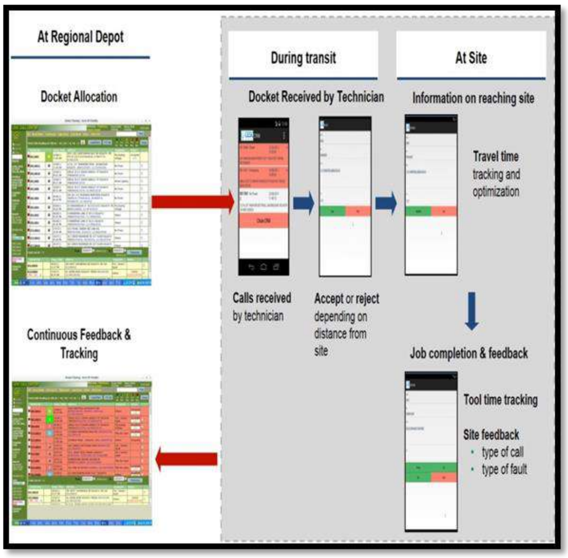
There are a lot of areas and pockets where there was a perennial problem of Low Voltage. These Low Voltage pockets have arisen due to Overloaded Distribution Transformers, Long Distributor Cables and High Concentration of Reactive Loads in small industrial areas.

The solution to the above problem has been catered to by the use of LTCSS. It is an Auto-transformer in conjugation with a Capacitor Bank to compensate reactive power and a voltage regulator.

LT Compact SubStation

4.6. Crew Management for LT Workforce

Apps have been developed integrating LT Fuse Failure Alarm system and the GIS developed by CESC. A Tab provided to the Field Workforce who move continuously based on Fuse Failure information. This information is received through the developed app available in the tabs provided. This system specifies to the Field Workforce about the Outage, and the Geographical Location of the Outage. This reduces the chances of prolonged outage due to LT Faults or Fuse Failures.



Dashboard view of the App for Workforce Management

5. Comparison of the pre-deployment scenario and post-deployment benefits

Before deployment, the difference from the network operations point of view was that in case of LT outage, CESC had no mechanism to proactively monitor and attend outages by itself. It was dependent of consumer complaints and distress calls before it would analyse and understand the situation and accordingly, act upon it. This mechanism leveraged a lot of time and hence, prolonged the outage duration unnecessarily. The entire project of LT Network Automation has met up with this challenge by providing a mechanism by which CESC is now able to proactively act on outages in the LT network, even before the consumer can complain. This has, as a result also lowered the outage duration and improved the network reliability and availability. This development has led to a change in the way CESC operates the LT network. The present focus is on strengthening the stability and reliability of the LT network. Hence, automation was thought to be an integral part of this process. Earlier, CESC would be dependent on fuse calls and complaints from consumers on Power Supply Outage. Teams were sent to check the extent of the Power Supply Outage and the source of the problem. This entire process would take out a valuable amount of time of the restoration process. After deployment of these IEDs to monitor the LT Network equipment, the difference can be felt in the total time taken to restore the supply. CESC can act ahead of a Consumer call. This not only improves the image of CESC among its customers, but also brings in a proactive approach to Breakdown Maintenance. Because of monitoring facilities, the time taken to find out the area of Supply Outage and the reason the outage can all be eradicated. Hence, the result is faster restoration of supply. This in turn meets the company's goal of improving Customer Centricity and better standard of Electricity Supply.

6. Road map of the Project

LT network automation is to spread in terms of Pillar Box Automation to all major Distribution Transformers existing in the LT network for monitoring of the network and also for Energy Audit operations.

The future roadmap includes Auto-changeover of LT Distributor Services, LT Volt-VAR Compensation techniques, and HT Consumer end Voltage monitoring.

Smart Metering of a large number of LT consumers is also a project in the immediate future which can improve quality of service to consumers even further.

Technologies adopted for successful deployment of AMR at Tata Power and use of AMR data for network planning.

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I *INTRODUCTION*

Tata Power is India's largest integrated power company with a significant international presence. The Company has an installed generation capacity of 8623 MW in India and has a presence in all the segments of power sector viz Generation (thermal, hydro, solar and wind), Transmission, Distribution and Trading. Tata Power supplies Electricity across Mumbai License area having a spread of 485 sq. Km and housing a population of approximately 1.45 crores. The customer base of Tata Power is around 6.5 lakh.

II *EXECUTIVE SUMMARY*

Tata Power has deployed Automatic Meter Reading (AMR) System and has covered varied segment of consumers viz. Commercial and Industrial, high value residential, slum dwellers and frequent payment defaulting consumers, under AMR. Meters on Distribution Transformers, and Boundary meters have also been covered under the AMR system. The prime objective of AMR system deployment are as follows:

- To fully automate the process of meter reading and billing without any human intervention.
- Faster detection of metering abnormalities, theft and network faults.
- Facilitate accurate Load forecasting.
- Facilitate Demand Response Initiatives.
- Achieve one milestone towards Smart Metering which is one of the drivers for Smart Grid.

This paper gives an overview about the different technologies strategically adopted and successfully implemented at Tata Power to induct its consumers under AMR.

III *Keywords—*

ABT	–	Availability based tariff
AMR	–	Automated Meter Reading
API	–	Application Programming Interface
CDF	–	Common Data Format
CRM	–	Customer Relationship Management
DAS	–	Distribution Automation System
DCU	–	Data Concentrator Unit
DR	–	Demand Response
DT	–	Distribution Transformer
DMS	–	Distribution Management System
GIS	–	Geographic Information System
LPR	–	Low Power Radio
MDAS	–	Meter Data Acquisition System
MDMS	–	Meter Data Management System
MIOS	–	Meter Interoperability Standard
OMS	–	Outage Management System
SMS	–	Short Messaging Service
MIS	–	Management Information system
GPRS	–	General Packet Radio Service
TOD	–	Time Of Day tariff structure
VEE	–	Validation, Editing and Estimation
WAN	–	Wide Area Network

IV *SMART METERING IMPLEMENTATIONS*

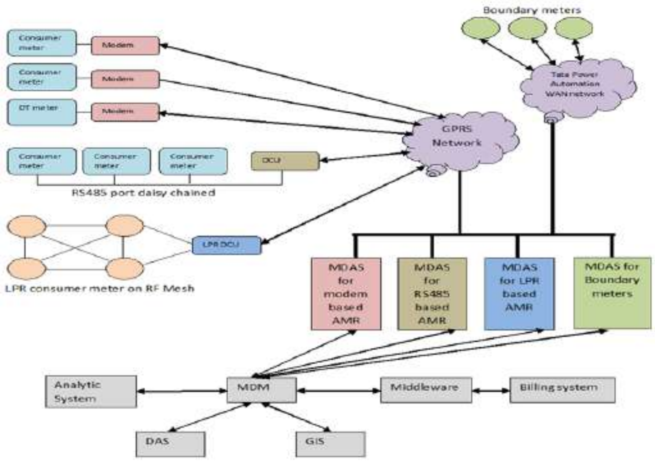

Fig 1 – AMR System Architecture

1. *GPRS modem based AMR – For Industrial and Commercial consumers and meters on Distribution Transformer.*

Electronic energy meters installed for Commercial and Industrial consumers were procured from different vendors and had different proprietary protocols for communication. It was decided to not replace the existing meters for the purpose of AMR. To cover these meters under AMR, GPRS modems are installed at each individual metering installation. These meters are read through optical port / RS232 port using API provided by meter manufactures as per MIOS standards. Legacy meters on Distribution Transformer were replaced with meters that can communicate using DLMS/COSEM protocol. The modem is preprogramed to acquire the meter data viz. billing, load profile, tamper and events at 30 minutes interval and push the same to MDAS through public cellular GPRS network. In addition, the firmware of the modems are customised and positioned such that the modem is not dependent on protocol and versions of the meters. A common Meter Data Acquisition System (MDAS) has been installed at the Data Centre that communicates with all makes of meter and converts the acquired metering data into a common data format.

2. *MODBUS protocol based AMR – For high value residential consumers in clusters.*

High value residential consumers and those in clusters have been covered under AMR through this technology. The RS485 communication port of 3 phase energy meters are daisy chained using shielded pilot cable and connected to a Data Concentrator Unit (DCU). Around 32 meters are covered in a loop and DCU polls every meter every 30 minutes and collects the register values over MODBUS. The load profile is generated internally in the DCU and a single file that contains the billing, load profile, tamper and events of every meter is pushed to a separate MDAS through public cellular GPRS network every midnight. The MDAS for such technology converts the acquired metering data into a common data format. This solution is deployed in areas which are safe and not tamper prone.

3. *Low Power Radio Frequency based AMR – Low cost AMR for mass residential consumers*

Mass residential consumers in housing societies and in slums have been covered under AMR through this technology. The meters are fitted with low power radio (LPR) communication modules that transmit data over radio wirelessly. The frequency of transmission is in the range of 856 – 867 MHz with a power output of less than 1 W. The 865 – 867 MHz band is available in India as a license – free band for low power radio applications. RF enabled Data Concentrator Unit (DCU) are installed in the vicinity of metering room and are used in conjunction for each set of 50 meters. Communication between RF MDAS and each DCU is implemented over public cellular GPRS network and data collection include kWh readings per 30 minute interval, tamper & event and billing. Instantaneous readings from each meter are polled by the DCU every 60 minutes and instantly pushed to the RF MDAS. The MDAS manages multiple DCU connections and provides up to date information on RF mesh formed among meters and the DCU.

4. *AMR for boundary meter*

ABT meters are installed at all the G <> T and T <> D interface points of Tata Power. The boundary meter data is used for calculation of distribution loss, AT&C loss, receiving station energy balance and feeder wise energy audit. The MDAS for ABT metering system acquires every 15 minutes consumption from all the meter through Tata Power's automation WAN fibre optic network.

V *METER DATA MANAGEMENT SYSTEM*

Meter Data Management System (MDMS) is tightly integrated with MDAS deployed for different technology. The ability of MDMS to store and manage meter data and its seamless integration with other operational systems like Analytics, GIS, DAS etc. offers many benefits to the utility.

a. Billing

Meter register data is validated with the load survey data and is sent to billing system only if it passes validation. This ensures the correctness and authenticity of billing data and helps improve consumer satisfaction. In cases where validation fails due to error in meter, the system facilitates estimation of the consumption based on the past trend. The VEE tool helps the utility to estimate meter readings and provide accurate and timely bills to consumers even if meter could not be read due to some site issue.

b. Asset management

The load survey data of Feeder and DT meters captured in MDMS provides trend of load pattern of Distribution Transformers and Feeders. This helps utility to transfer loads from over loaded to less loaded Transformers and Feeders. Alternately, DTs can be swapped as per their capacity to areas where they can be loaded optimally to reduce losses.

The coincident maximum demand report that can be obtained from MDMS for a group of meters under one distribution transformer/feeder and the load factor analysis report helps to understand the loading of distribution network. This facilitates utility to maximize asset utilization, improve outage planning & optimize network maintenance, reduce O&M cost and improve grid availability. This trend also enables the utility in acquiring customers in the vicinity of less loaded DT / Feeder.

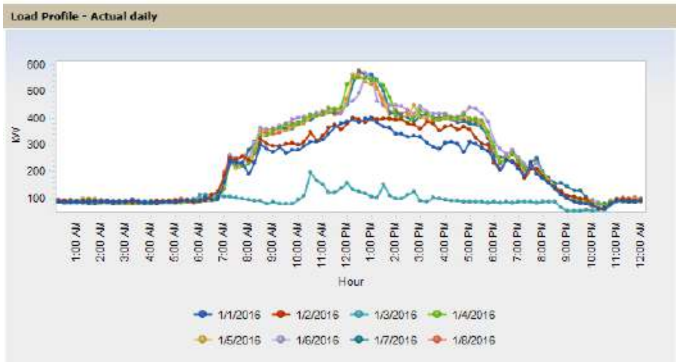

Fig 2 – Daily load profile of a typical DT meter

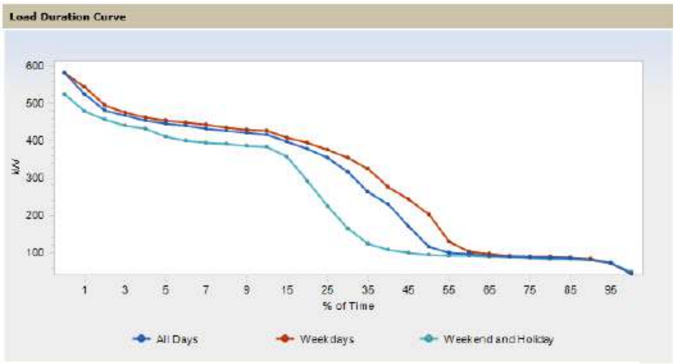

Fig 3 – Daily duration curve of a typical DT meter

c. Power Quality

AMR system captures instantaneous data viz voltages, currents, energies, power factor, frequency etc from meters every 30 minutes. These data are analysed through an in-house developed macro which throws the list of meter having abnormalities. These meters are then analysed on GIS to identify whether the abnormality is with respect to a single meter or a particular area fed from a Distribution Transformer. This helps the utility to identify power quality / network issues and manage the distribution network more efficiently.

Fig 4 – Voltage profile of a consumer meter

d. Meter event analysis

The MDMS captures events recorded in the meter and generates report that provides list of all the meters that have recorded a particular event (Event wise meter list). It also provides all the events registered by a particular meter (Meter wise event list). Such analysis helps in early detection of meter abnormalities and to identify tamper and theft.

e. Energy audit

MDMS provides consumption variation report for all consumer meters and Feeder / DT meters. Sudden change in consumption pattern of consumers in relation to the consumption pattern of concerned DT / Feeder helps utility to detect meter discrepancy / energy theft.

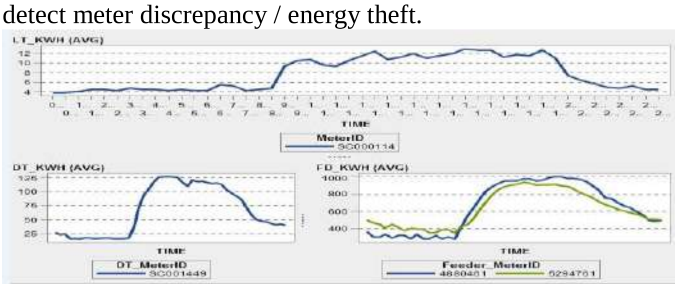

Fig 5 – Consumption pattern of a meter compared with associated DT and Feeder meter

f. Customer profiling

MDM system helps utility to group consumers as per category like industrial, commercial, residential etc and compare their load profiles for any period. This feature can be used to study the usage pattern of the customer participating in DR program and estimate extent of demand reduction /curtailment during the DR event.

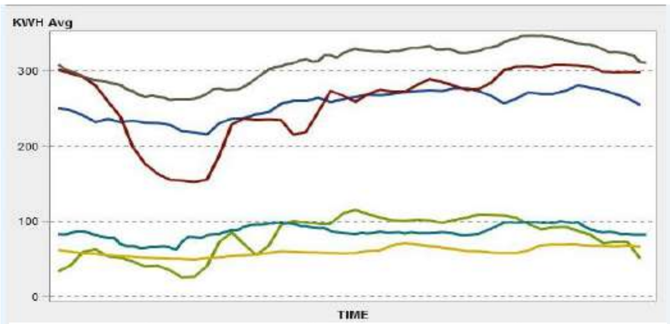

Fig 6 – Consumption trend for similar industry

g. Baseline consumption for DR

MDMS has been configured to include multiple algorithms as defined by the regulatory body to calculate baseline consumption for individual consumers participating in a DR event. This helps utility to determine the incentive to be offered to a consumer for curtailment in load during a DR event.

h. Benchmark

The MDMS enables utility to define a consumption benchmark for different category of consumers and compare consumption of individual consumers with the benchmark. This feature identifies the best and worst performing consumers vis-a-vis benchmark. This data can be shared with concerned consumers to improve their behaviour.

i. Customer Benefit

MDMS enables utility to provide detailed usage information to consumers through web page. This helps consumers to understand their consumption and relate it to energy costs. MDMS provides comprehensive information to consumers and facilitates them to take energy efficiency measures / demand shifting to manage their energy efficiently and reduce cost of energy.

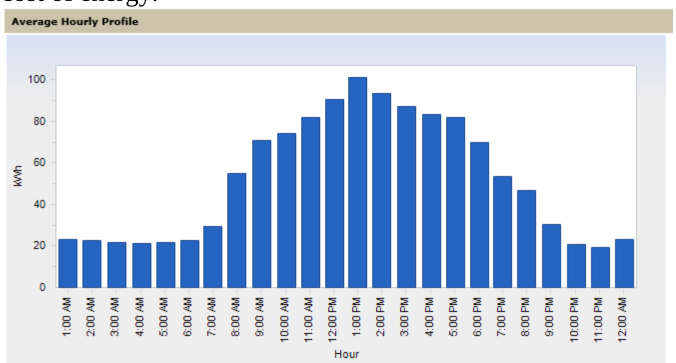

Fig 7 – Daily consumption data shared with consumer

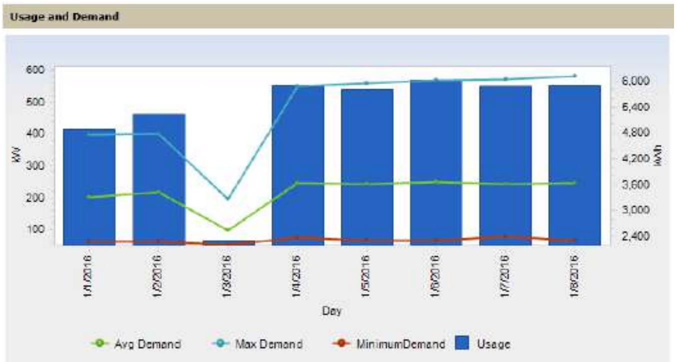

Fig 8 – Usage and demand data shared with consumer

A "bill-to-date" functionality in MDMS enables consumer to estimate the bill at any time in the month based on consumption trend till date. Rate Analysis feature allows the consumer to assess the impact of load shifting from one TOD slot to other through what – if analysis. E-mail alerts can be configured by the consumer as per self-defined logic for exceeding preset monthly usage, demand, power factor etc.

VI POWER FAILURE NOTIFICATION

Field devices like modem / DCU are configured to send message to the CRM system in the event of power outage to the consumer. On receipt of message from field devices, the CRM system automatically generates a call ticket and a service order is raised on the concerned O&M team for power restoration. This helps in speedy restoration of power supply and improved service to consumers. The CRM system also sends message to the GIS system for change of state during the event. The GIS system flashes consumer meters in red colour for the consumers having power outage on the GIS map. This helps Call centre executives to easily identify the affected area and consumers and to provide faster service to affected consumers.

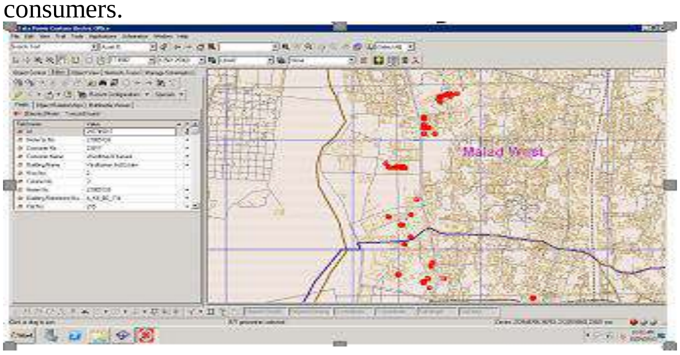

Fig 9 – Consumer having power outage highlighted in red on GIS

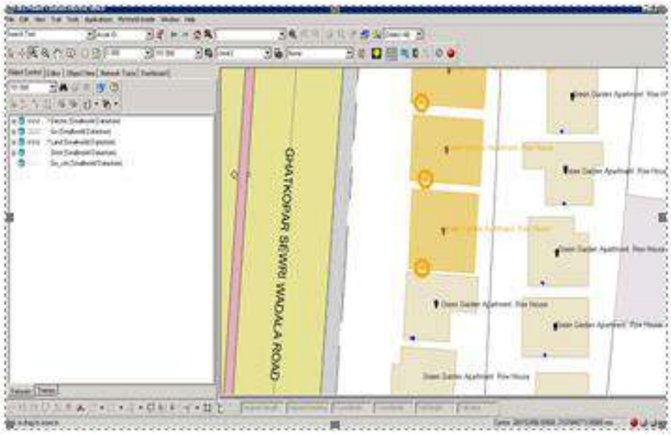

Fig 10 – Affected buildings highlighted on GIS in case of major power failure.

VII CONCLUSION

The solutions deployed by global utilities could not be implemented directly as it is in Tata Power due to constraints of consumer sites, meter specifications, meter installation practices etc. Therefore efforts were put to derive a customised solution by closely working with meter vendor and solution provider which enabled Tata Power to cover varied variety of consumer meters under AMR. Also the communication between field devices like modem and DCU with the MDAS are highly dependent on public cellular network operator, which was observed to be less reliable, due to variation in signal strength and throughput throughout the day. A mechanism has been developed to measure the signal strength every hour at every metering site and the same is analysed to take actions either by installing signal boosters or inducting alternate service provider. These initiatives have enhanced the overall success rate of Tata Power AMR system.

EXPERIENCES OF CESC IN SMART GRID INITIATIVES – RMU AUTOMATION

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Table of Contents

1. Brief Overview of the Project

CESC Limited has a vast HT Distribution Network operating at 6-11 kV level. This network comprises of a majority of underground cable sections aggregating 6259 ckt-km. As the majority of this network is underground, location and isolation of faults is time consuming. In CESC there are about 5100 Ring Main Units installed till date on the 6-11kV Distribution Network. Except for a few at Consumer Installations having circuit breaker, these SF6 Gas Insulated RMUs are generally fitted with Isolators. Non-extensible RMUs from ABB, Areva, Schneider, Siemens etc are used with either 3 or 4 Isolators per RMU. The Isolators are “Load Break” and “Fault Make” in nature but in the event of a downstream fault the upstream Circuit Breaker at the feeding Distribution Station trips and all the Fault Passage Indicators (“FPI”s - one fitted with each Isolator) through which fault current flows operate. The decision to deploy RMUs rapidly in CESC’s distribution system was taken just 6 years ago and with the number already commissioned, the restoration time in the event of faults on the 11 kV and 6 kV networks has already come down to one and a half hours compared to about four and a half hours before such RMUs were installed. With automation of the RMUs, it was expected to reduce the restoration time even further.

Automated RMUs adjacent to Writer’s Building, Kolkata

Automation of these RMUs involve incorporation of an FRTU (Field Remote Terminal Unit) for telemetering of Digital Status Inputs (Leg Isolator ON/OFF status, Fault Passage Indicator (FPI) status of each leg), Analog measurands (Leg Current, Batt. voltage), & Remote operation of isolators. Motors operating on 24V DC are retro-fitted with each Isolator assembly to enable remote operation of the Isolators. These FRTUs communicate with the Master Control Centre of CESC over IEC 60870-5-104 protocol. Such RMUs integrated with FRTUs make faster Fault Location, Isolation and Restoration (FLISR) possible. The Communication medium used in this project is primarily Optical Fiber. At present there are around 380 Automated RMUs in the Primary Distribution Network of CESC.

2. Challenges

There have been several challenges faced over the entire duration of the project.

Space constraints: As majority of the RMUs in the primary distribution network are located on roadside pavements (i.e pole mounted) or distribution transformer compounds, there are issues of space constraint for installation of additional Automation equipment CESC has tried housing the Automation equipment and accessories within the RMU itself. However, this has resulted in problems both during commissioning and maintenance, as there is paucity of space even within the RMU panels to accommodate such additional equipment. Presently, all the FRTUs are either wall mounted or installed on plinths within close proximity to the RMU, though this is not possible in all RMU sites – necessitating interfacing cables in excess of 15mts for such cases.

Motor retro-fitting of RMUs: RMUs have been installed in CESC's Distribution Network in the last 6 years. However, the RMUs generally do not come motorised from the manufacturers. This retrofitting of non-motorised RMUs has posed a major challenge as non-motorised RMUs are taken out of the network in batches & sent to the factory of the manufacturer for retrofitting of motors while the concerned network is restored by spare RMUs. This whole process involves multiple shutdown and isolation alterations to the primary network to enable extraction of non-motorised RMUs and subsequent installation of motorised RMUs with minimum supply outage.

Communication Medium: During PoC of the application on wireless medium, solutions from various Mobile Service Providers have been tried out, all yielding unsatisfactory link availability figures. Trials have been carried out over GPRS, CDMA and 3G. All these technologies have thrown up results which have not been consistent and reliable in nature. Considering the criticality of the application, a suitable and reliable communication medium was of utmost importance, which has been overcome by using Optical Fiber Communications.

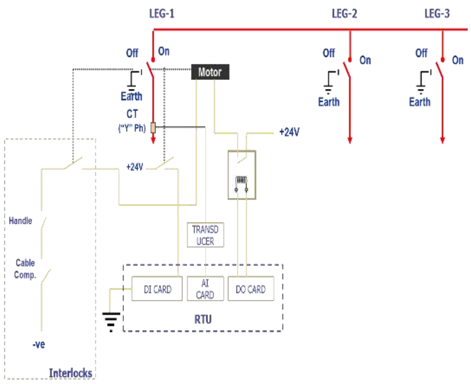
3. Objective

The primary objective of the implementation has been to ensure faster restoration of supply on occurrence of faults. There are several fault prone sections which have been identified and automated. The objective here is to provide facility for quick response to any network outage in such sections. This proactive measure will result in lesser revenue losses due to prolonged power supply outage. There are important consumers identified as well which have been automated in order to ensure fastest possible power restoration in case of outages. Government Super-speciality Hospitals, Important Pumping Stations, Government Office Buildings and Stadiums have all been committed swift restoration within 3 to 4 minutes. The objective of the implementation has also been to provide backup alternatives for power supply restoration in case of upstream faults in the 33 kV and 132 kV levels.

4. Description of the solution / technologies implemented

All the isolators are motorised for automated RMUs. For monitoring purpose, the isolator status signals are received as Digital Input (DI). This signal is retrieved through mechanical contact limit switches which make/break on mechanical movements. The ON/OFF signal from the Isolator legs are sent to the FRTU. The FRTU has DI channels which actuate micro-relays within it to send digital signals to its main processing unit. This processing unit will telemeter each Digital Signal in IEC 104 frame format and transmit it over Optical Fiber Communication network to the SCADA Server present at Control Room of CESC. Along with the Isolator indications, the Digital Input signals from FPIs and Earth Switches are also received by the FRTU. The motor operations are facilitated by Digital Output signals. The personnel in Control Room issue a command from the SCADA Server, which is sent to the FRTU at site. The Digital Output (DO) channel is turned ON, which actuates the DC Supply to the Motor on the specific isolator leg of the RMU. The motor operation render the Isolator to either turn ON or OFF as per the command issued from the control room.

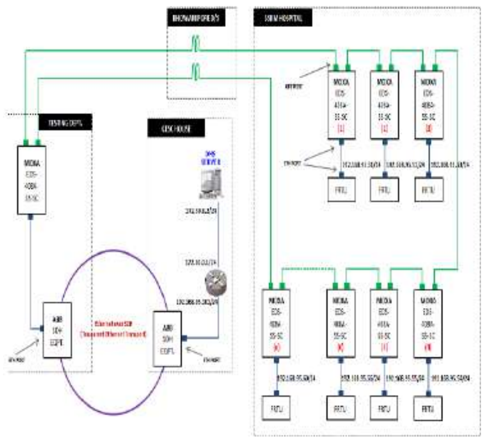
The Motor operation is done using 24 VDC Circuit, for which a Battery backup is also present to sustain motor operations for 5/6 hours in case of AC supply outage.



Input-output interfacing of RMU with FRTU

5. Implementation Process

Initially, factory-fitted RMUs were being used for Automation purposes. These factory-fitted RMUs had prefabricated motor assembly coupled to their isolators. This resulted in faster commissioning of the automated RMU and reduced cost on logistics. However, this process would result in foregoing a lot of non-motorised RMUs previously installed at various sites. In order to avoid this, the RMUs are now being retro-fitted in order to avoid procurement of new RMUs and rendering the older ones defunct. Retro-fitting procedures have now been standardised for all vendors of RMUs thereby saving on time. This is in itself a new technology or upgradation being employed in the implementation of the project.



RMU Automation over Optical Fiber network - Schematic

The Optical Fiber Network has been made in such a way that it has backup routes and redundancy in both physical level and data-link level. Network switches are configured in order to provide ring connectivity to major Automation sites. This will result in redundancy in the network, in case of Optical Fiber breakdown in any of the sections.

Fiber Optic Panel for RMU Automation

6. Comparison of the pre-deployment scenario and post-deployment benefits

Previously, in case of a primary network outage, normal restoration used to take about one and a half hour. This involved the movement of an engineer to the site of fault, isolation of the faulty section and finally restoration through normally isolated points in an RMU. As a result, major part of the network would remain de-energized for a long time, which can only be avoidable if automation is introduced.

After automation, there have been various instances where 100% load restoration on outage of a 33kV cable feeding a 20MVA transformer have been achieved within 12 minutes by operating automated RMUs in the downstream 6/11kV network – effectively shifting load to adjoining network from remote. This is a remarkable improvement in view of reduction in outage time.

On August 20, 2015, due to tripping of Ballygunge Distribution Station's 33 kV Power Transformer, 7 MW load was shed in the entire South Kolkata area. The entire load was restored within 11 minutes by the help of remote operations carried out through the Automated RMUs in the region.

7. Key Learning from the Project

Overcoming Communications issues effectively: Communication medium has been found stable in the project with use of Optical Fiber However, since, a majority of these OF sections are overhead in nature, it may not be reliable in the long run, considering the final number of RMUs to be automated within the network. This is due to the immense involvement associated with breakdown maintenance. Additionally, the installation & commissioning and operational maintenance cost associated with aerial OF sections can only be avoided by exploring latest wireless solutions such as RF Mesh, Wi-Max etc. that can provide the same reliability as that of the Optical Fiber Medium But within comparable cost margins.

Protection system for avoiding mal-operations: Since, the FRTUs are primarily electronic equipment, they are prone to maloperations to a certain degree. On a 6/11kV network such maloperations could lead to accidents and disruptions. This can be avoided by extra protection for isolator operation channels. During this project, we had faced few isolator maloperations leading to outages. This problem has been worked upon, and a DC Enabling Circuit has been implemented in order to avoid such mal-operations in future. It disconnects the DC supply to the motors in normal condition. Only when remote operation of isolators are required, DC ON command is to be executed followed by isolator operation commands.

Modifications in FRTUs for inter-operability: Another learning from the project was to include interoperability of FRTUs of different makes with RMUs of different makes. This will result in a standard process, which will be easy for operation, maintenance and breakdown.

8. Cost-effectiveness of Project

RMU Automation has had immense effect on the maintenance of the primary distribution network in CESC. CESC has even deployed automated RMUs for Durga Puja temporary supply points across Kolkata's important Puja Committees. This in itself explains that due to Automation support, consumers have also started relying on the quality of service of CESC. A total of Rs. 32 Cr has been invested on the RMU Automation project involving 300 RMUs in 1 year. The results Obtained from this exercise has been encouraging in all aspects. It has improved CESC's loss figures due to unwanted load shedding during faults and empowered control room staff to shift power from overloaded cables to adjacent networks at the click of a mouse. This could not have been achieved by any other way. Over the past year, numerous such operations have been done remotely from the Control Room, instead of deploying engineers at site. Majority of such restorations have been 100% and within 10-12 minutes only. Govt. Super-speciality Hospitals, Important Pumping Stations, Govt Office Buildings and Stadiums have all been committed swift restoration within 3 to 4 minutes. Such commitments have been met time and again over the last year. These proactive measures are also taken positively by Kolkata's Power Supply Consumers, who have a level satisfaction with CESC at present. Overall, this project has achieved the company's goal of providing quality uninterrupted power supply to its consumers thereby fostering an atmosphere of customer centricity throughout the power distribution ecosystem in Kolkata.

CESC has adopted a policy of Automating RMUs located in strategic points of operation in the Distribution Network for efficient load restoration instead of automating all RMUs in the network.

9. Roadmap of the Project

Presently, a total of around 380 RMUs have been automated mainly at important Govt. Office Buildings, Govt. Hospitals, Pumping Stations, Important Consumers and high consumption areas of Kolkata. The future roadmap includes automation of around 50% of the existing 5100 RMUs in the whole Distribution Network, spreading over other parts of Kolkata metropolitan area.

RMU Automation with respect to Smart Grid Initiatives: More cost-effective initiatives are being planned for the Communications Infrastructure with the introduction of wireless media such as, RF Mesh Communication Network, which can support not only RMU Automation as its only application but also other Smart Grid initiatives such as Advanced Metering Infrastructure (AMI), etc.

Intelligent Grid Operations: Self-healing RMUs are being planned for installation in strategic points of the Distribution Network which may improve the restoration time further from the order of minutes to probably even seconds. These self-healing RMUs will have intelligent devices programmed with PLC logic to take care of the outage situations occurring in the Primary HT Network without human intervention.

Ease of Commissioning: Plans are also under way for improving Installation and Commissioning time respectively by introduction of customized pre-fabricated connector-cables for interfacing between the RMU and the FRTU. This will reduce the time required for interfacing between the RMU and the FRTU. This plug-n-play method would result in faster commissioning of automated RMUs in the future, paving the way for rapid deployment of automation throughout CESC’s power distribution network.

Opportunities and Challenges for Deployment of CVR/VVO Methodology in Indian Smart Energy Distribution System

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***Abstract*—Due to emergence of Smart grid technologies, Conservation of Voltage Reduction (CVR) technique is widely accepted by utilities now a day. To reduce the system losses, peak load relief, reduction in load demand and energy consumption CVR technique provides considerable benefits. According to International Standards ANSI C84.1–2006 and IEEE std 1250-1995, the supply voltage level range from 0.9 to 1.05 per-unit (pu) of nominal voltage for customer appliances. CVR works on the principle that the acceptable voltage band can be easily and economically worked in the lower half of the voltage range, without creating any damage to load end customer devices. Electrical energy distribution losses and peak load demand are major concern of Indian energy distribution system. So challenges and issues related to deployment of CVR/VVO methodology in Indian smart energy distribution system has been discussed in this paper. Assessment of CVR technology using advance distribution management system (ADMS) based Voltage Var Optimization (VVO) controlling scheme also has been discussed in this paper. The main function of the VVO is to determine the operation setting of volt/var control devices, to minimize the active power loss of the distribution network and switching operation of the on-load tap changer (OLTC), automatic voltage regulator (AVR), and capacitor banks (CBs). VVO is an advanced method that optimizes voltage and/or reactive power (VAR) of a distribution network based on predetermined aggregated feeder load profile. For assessment of CVR effect, a modified IEEE 34 bus test system of radial distribution network has been considered and it is demonstrated that improved results have obtained.**

Keywords—**Volt- Var control &Optimization; Conservation of Voltage Reduction (CVR); Smart Grid; Distribution System**

I. INTRODUCTION

After approval of National Smart Grid Mission by Govt. of India, power utilities/business planners have large opportunities to invest and deploy the smart grid technologies in Indian power sectors. Recently govt. of India have started many smart grid activities and announced to develop the hundred smart cities in India after the successful implementation of Smart Grid Puducherry Pilot Project. Due to growth in GDP around 8% per year, India's Energy demand is expected to raise three times in the upcoming next decade and major portion of energy demand would be balanced by the grid supply [1]. In order to meet the expectations existing electric grid need to be renovated from transmission to distribution system. Conventional distribution system is required to upgrade within the concept of Smart Grid.

Main aspects of smart distribution system where more attention is required shown in fig.1 and discussed below [2]:

- Impact of integration of distributed energy source (DER) and electrical vehicles
- Use of more secure and reliable information communication technologies (ICTs)
- Optimization of distributed assets such as voltage, reactive power etc with the application VVO/ CVR techniques.
- Application of advanced tools such as OMS, DMS and VVO etc.
- Deployment of smart sensing & monitoring devices such SCADA, WAMS and micro PMUs
- Uses of Adaptive Protection schemes
- Deployment of AMI and encourage the consumers to use low power loss consumption devices.
- Distribution network should be self healing and secured.

In order to improve energy efficiency and reduction of load demand optimal use of distribution network assets is required. It can be achieved by deployment of CVR with coordination of VVO operation.VVO is a commercially accessible technology that includes the benefits of conservation voltage reduction (CVR) techniques and VAR optimization [3].

Organization of paper as fallows a brief description about CVR/VVO technology and discussion of CVR scheme with ADMS based VVO operation in Section II. Detail discussion about CVR in Indian distribution system with opportunities and challenges have presented in section III. Assessment of CVR effect with different load models is discussed in section IV. Conclusion and future work is presented in section V.

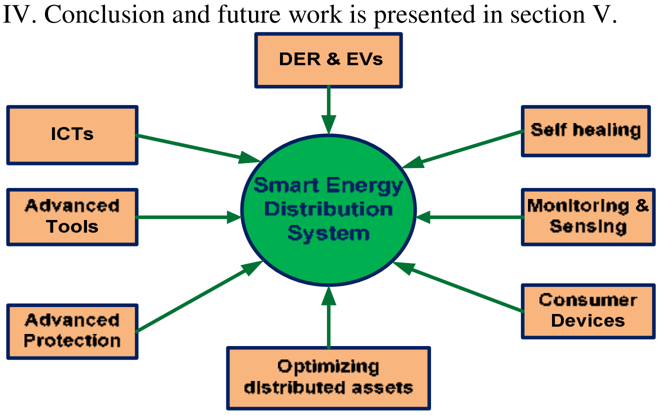

Figure 1 Functional block diagram of Smart Energy Distribution System.

II. BRIEF DESCRIPTION OF CVR/VVO TECHNOLOGY

CVR technology is getting fame rapidly due to successful operation of various pilot projects on CVR test performed by many smart Grid enabled power utilities worldwide. CVR is not a new concept to measure of conservation of voltage, late 1970's to 80's various tests had been performed by some utilities. Table I shows a brief literature survey on CVR test analyzed by many utilities from stating 1970's to 2015. The main goal of CVR is to save energy at low cost by lowering the delivery voltage into the lower half of the tolerance band without affecting the performance of the end user's devices. However, while reducing the voltage, CVR technology should fallow the international Standards ANSI C84.1–2006 and Canadian Standard Association (CAN-C235-83) on voltage regulation [4], [5]. According to ANSI C84.1–2006 customer appliances can works smoothly on lower half of the distributed voltage level without disturbing the device's performance. The impact of voltage reduction is calculated by fallowing ratios called CVR factors defined below [35]:

1. In term of energy savings, CVR factor (kWh) is measured as the ratio of percentage of energy consumption reduction (ΔE%) to percent voltage reduction (ΔV %)

$$CVR_f = \frac{\Delta E\%}{\Delta V\%}$$

2. In term of active power demand CVR factor (KW) is the ratio of percent of active power demand reduction (ΔP%) to percent voltage reduction

$$CVR_f = \frac{\Delta P\%}{\Delta V\%}$$

3. In term of reactive power demand CVR factor (KVAR) is the ratio of percent of reactive demand reduction (ΔQ%) to percent voltage reduction

$$CVR_f = \frac{\Delta Q\%}{\Delta V\%}$$

4. In term of economic or money saving CVR factor is then the ratio of percent of money savings(Δ$%) to percent voltage reduction

$$CVR_f = \frac{\Delta \$\%}{\Delta V\%}$$

A. Strategies for Implementing CVR Technology.

There are mainly two approaches for implementing of CVR:

a) Traditional Volt-Var Control (VVC) Schemes:

These schemes are also known as standalone or open loop VVC. These are mainly Load Tap Changer (LTC), Line Drop Compensation, Voltage Spread Reduction, and Home Voltage Reduction (HVR). Major drawbacks with these techniques are limited depth of voltage reduction, controlling of devices based on local data and poor dynamic adoptability [6].

b) Closed-Loop Close-Loop VVC Schemes:

In this approach feeder's efficiency have improved as compare to tradition approach. These techniques mainly based on SCADA control real time monitoring system defined below:

- SCADA Based Volt-Var Control or rule based VVC
- DMS model-based VVO
- Auto-Adaptive or Advance DMS based VVO

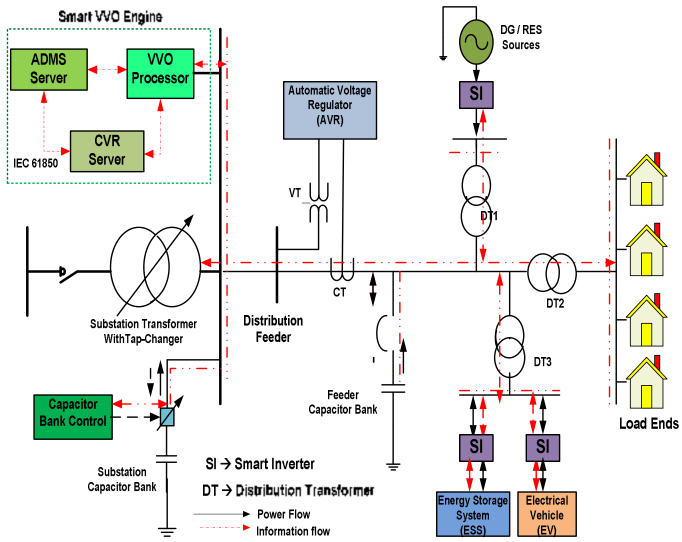

Figure.2 CVR Substation Based Smart Energy Distribution System.

B. Adavance DMS based VVO controlling scheme for CVR-

VVO is one of the most reliable and successful strategy for implementing CVR technology. Figure 2 shows the elemental block diagram representation of substation based energy management system with smart VVO engine. Smart VVO Engine is the combination of CVR server and VVO processor with advance DMS. Basically it controls the voltage and var regulatory devices such as AVR, OLTC, distribution transformer (DT) and CBs in an optimized manner so that objective of controlling of feeder voltage profile and reactive power flow must be in acceptable range [7], [8].

To deploy adaptive real-time VVO/CVO, centralized and decentralized control approaches are used. Figure 3 represents the schematic diagram of two approaches.

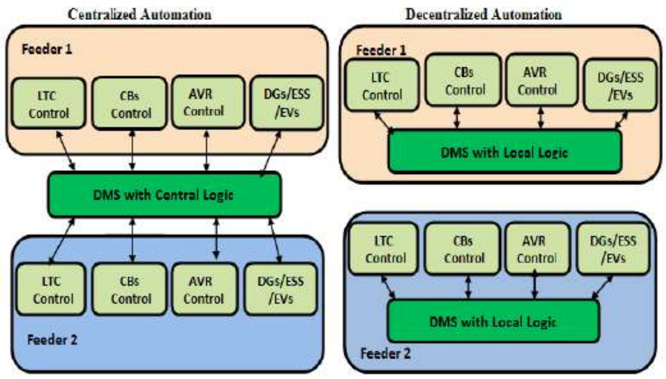

Figure.3. Centralized and Decentralized Controls Schemes for CVR/VVO

III. CVR IN INDIAN SMART DISTRIBUTION SYSTEM

Benefits such as peak demand reduction, energy saving, improved operation and reduction in green house gases achieved by utilities while operation of CVR in distribution system have encouraged to deploy CVR technology in Indian power sector. Due to enabling of various smart grid projects in India, there are many opportunities for testing of CVR technology in distribution power sector such as:

- Distribution power sector are in renovation phase so any new technologies like CVR/VVO can be adopted and implemented easily.
- To improve the operation of distribution system Ministry of Power has launched 14 Smart Grid pilot projects that will be executed by various distribution utilities in India.
- Most of the pilot projects are in initial stages or they have compiled their first or second stage so deployment of CVR in their project can be accumulated easily.
- Functionalities such as SCADA, DMS, Advance Metering Infrastructure (AMI) Peak Load Management (PLM), Outage Management System (OMS), and Power Quality Management (PQM) are used in project can also utilize for CVR analysis.
- Deployments of smart control and monitoring package such as wide area monitoring system (WAMS), Phase measurement units (PMUs) in Indian power sector.
- While operation of VVO Distribution system operator (DSO) can closely monitor and control of voltage and power factor of distribution grid.

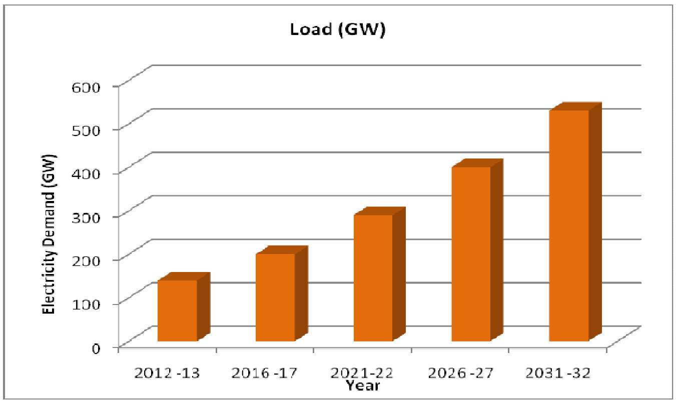

Figure 4 projected electricity demand growth of India [38]

Table I CVR Test Performed by Various Utilities

Utilities/Authors/ Ref.	CVR Factor (CVR_f)			Published Year
	(kW)	(kVAR)	(kWh)	
American Electric Power System (AEP) [9]			0.62	1973
San Diego Gas & Electric, CA[10]	0.548 -0.967		0.47-1.04	1982
Krishner & P.Giorsetto,[11]			0.409-0.991	1984
American Electric Power System (AEP)[12]			0.71	1986
Northeast Utilities (NU)[13]			0.57-1.35	1987
Bonneville Power Administration(BPA)[14]	0.90			1990
Commonwealth Edison, California [15]	1.0			
Snohomish PUD,WA Northwest Utilities[16]			0.336-1.103	1991
BC Hydro[17]	0.70			1995
Southern California Edison (SCE)[18]	1.0			
TiaPower[19]	0.57			
Snohomish PUD,WA Northwest Utilities[20]			0.336-1.103	2002
Avista utilities[21]	0.84			2005
Northwest Energy Efficiency Alliance [22]	Spring- 0.57,Summer-0.78 Fall-0.60, Winter-0.51			2007
Hydro Quebec (HQ) [23]	Summer (R, C, I) 0.67 ,0.97, 0.1 Winter (R, C, I)- 0.12, 0.8, 0.1			2008
Pacific Northwest National Laboratory (PNNL)(report), U.S.[24]	With All distribution feeders 3.04% reduction in the annual national energy consumption			2010
Idaho Power[25]	0.17-0.93	1.99-20.13	0.3-0.86	2010
R. Singh et. All [26]			0.67-1.33	2011
Electrical Power Research Institute (EPRI) [27]	0.6-0.95	50-6.0		
Dominion Virginia Power [28]			0.92	2012
Sunderman/Utility/ EPRI [29]	0.6-1.119	3.0		
Australian Experience [30]			0.4	
Ireland Experience [31]	0.58-0.98	6.0 - 6. 6		
Palmetto Elec. Coop, SC [32]			0.95	2013
Marc Diaz-Aguiló [33]	0.50-1.0	1.5-2.0		2013
Avista utilities [34]	0.881			2013
Consolidated Edison Company of NY[35]	0.54		0.55	2014
Zhaoyu Wang, et. All [36]	0.61 -1.32			2014
Sacramento Municipal Utility District [37]	0.61			2015

A) *Potential Benefits of deployment of CVR/VVO*

CVR technology has many potential benefits within the concept of smart grid. CVR/VVO has significant impact on energy efficiency and all conservation level without involvement of customers. Some of the potential benefits have discussed below:

- AT&C losses and energy consumption can be reduced up to significant level with the deployment of CVR technology. These reductions are directly associated with energy saving and it can be directly link to cost savings.
- Utilities can reduce their peak load demand with the enabling CVR effect for short or long time duration. This can reduce capacity payments and/or defer capacity additions/upgrades.
- Distribution efficiency of the system can be increased by the allowing the DSO to reduce losses through VVO operation.
- VVO technology offers a higher level of visibility into system operating parameters for utilities.
- Better integration & control of DERs, storage system and plug in EVs in to distribution system with the help of VVO system.
- Utilities and costumers can be benefited with reduction of operation and maintains losses with the closely watch of equipments.
- Customers can be benefited with lowering the dynamic prices due to reduction of load demand in deregulation environment.
- Reduction in Peak load demand, distribution losses through CVR operation results incremental reduction in electricity generation demand. So Utilities can lower their CO_2 emission and greenhouse gas emissions.

B. *Challenges for deployment of CVR /VVO Technology*

Energy demand is increasing rapidly due to continuous rise in population and fast growth of Indian economy. To meet this energy demand with the electricity generations is not an easy task for Indian power sector. The projected electricity demand growth of India has shown in figure-4[38]. There are many challenging issues for implementation of smart grid enabled CVR technology in Indian distribution sector such as:

- Poorly or unplanned distribution network
- Edged and high lossy distribution assets such as transmission line conductor, transformers etc.
- Shortage of automatic control packages for smart distribution system
- Poor power factor due to lack of reactive power support and regulation services
- Shortage of power and large unauthorized power transaction
- Conventional metering and revenue collection procedure
- Political and social hindrances
- Lack of awareness of customers about their consumptions and incentive plans
- Distribution sector suffers from poor operational efficiencies with high AT&C losses, frequent and long outages etc.
- Measurement and verification of CVR factor.

IV. ASSESSMENT OF CVR EFFECT

This section discussed about analysis of CVR effect with different load models. The effect of CVR on energy consumption can be described by Joule's law, the power P, voltage V and current I in a resistive circuit satisfying P = VI with the assumption that there is no need of reactive power for consumer's devices. Lowering the voltage level reduces the power when the load consists of pure resistors with constant resistance R, followed by the ohm's low V=IR and $P = V^2 \backslash R$.

From various CVR tests it is observed that CVR effect is highly influenced by consumers load type. In this work fallowing types of load models have been used to analyze the CVR effect.

- Constant PQ Model
- Constant Impedance (Z) Model
- Constant Current (I) Model
- Constant ZIP Model
- Nominal Linear P, Quadratic Q Model

A. *Modeling of Distribution System*

For analysis of CVR effect IEEE 34-bus, 24.9 kV distribution feeder model has been considered in this study. Distribution model consist 34 nodes, two voltage regulators, capacitor banks and different load models [39].Modeling and power flow analysis of distribution system has been carried out in Open Distribution System Simulator (OpenDSS) platform developed by EPRI [40]. Similar load type has been considered at each node of the distribution feeder bus to analysis the CVR effect with individual load model. Load flow simulation has done in three mode discussed below:

- *Base Case:* Effect of voltage regulators (VR) and capacitors are not considered in this mode.
- *Non CVR mode:* In this mode effect of both voltage regulators (VR) and capacitors are considered in power flow analysis. Setting of regulators and capacitors are same as mentioned in ref. [40].VR1 &VR2 have secondary voltage level 122V, 124V respectively.
- *CVR mode:* In this mode effect of both voltage regulators and capacitors are considered in power flow analysis. Voltage level of regulators has been reduced. Modified voltage levels of regulators are 120V, 120V respectively.

B. *Simulation Results and Discussion*

This section presents CVR test simulation results with different load models. Power flow simulations have been done in SNAP mode with STATIC control mode in OpenDSS. Various simulation results are analyzed below:

1 Constant PQ Load-

This type load model increases the energy consumption with the reduction of voltage level because of increase in line losses due to more current is drawn by the loads. Constant PQ load is defined as model 1or constant P+jQ load in OpenDSS platform. Assuming all loads connected in test system is constant PQ type. From table II it is observed that power demand and losses are increased in CVR mode in compare to non CVR mode. From results it analyzed that CVR operation is not beneficial for constant power load models.

Table II- Simulation Results with Constant PQ load model

Constant PQ Load	Base Case	Non- CVR Mode	CVR Mode
Real Power Demand (MW)	2.01171	2.05156	**2.06452**
Reactive Power Demand (MVAR)	1.08286	0.288599	**0.351601**
Real Power Losses (KW)	346.734	282.418,	**295.426**
Reactive Power Losses (KVAR)	094.2187	028.8599	**058.1057**

2. Constant Impedance (Z) Load:

Assuming all loads connected in test system is constant impedance load type. Simulation results with Constant Z load have shown in table III. From simulation results, it is observed that there is reduction in power demand and losses with CVR mode operation. A significant energy savings can be achieved with CVR mode operation.

Table III- Simulation Results with Constant Z load model

Constant Z Load	Base Case	Non- CVR Mode	CVR Mode
Real Power Demand (MW)	1.87554	1.8409	**1.77326**
Reactive Power Demand (MVAR)	0.982843	0.247411	**0.234097**
Real Power Losses	272.048	216.278	**205.219**
Reactive Power Losses (KVAR)	032.0184	004.88726	**009.8391**

3. Constant Current (I) Load Model:

Assuming all loads connected in test system is constant current load type. Simulation results with Constant I load have shown in table IV. From simulation results, it is observed that energy saving is slightly improved with CVR mode. Reduction of energy consumption is less than in comparison to constant Z load model.

Table IV- Simulation Results with Constant I load model

Constant I Load	Base Case	Non- CVR Mode	CVR Mode
Real Power Demand (MW)	1.99679	2.00555	**2.00528**
Reactive Power Demand (MVAR)	0.916491	0.336811	**0.330613**
Real Power Losses (KW)	321.744	282.25	**279.515**
Reactive Power Losses (KVAR)	078.6221	049.6934	**048.4476**

4. Constant ZIP Load Model

Assuming all loads connected in test system is combination of constant impedance (Z), constant current (I) & constant power (P) or constant ZIP load type. Simulation results with constant ZIP load have shown in table IV. From simulation results, it is observed that real power demand is reduced but reactive power demand is increased with CVR effect. There is slightly reduction in real power losses. Energy saving achieved but reactive power support is required while operating with ZIP load for improvement of feeder voltage.

Table V- Simulation Results with Constant ZIP Load Model

Constant ZIP Load	Base Case	Non- CVR Mode	CVR Mode
Real Power Demand (MW)	2.08318	2.03856	**2.00864**
Reactive Power Demand (MVAR)	1.11941	0.35454	**0.395873**
Real Power Losses (KW)	359.134	283.919	**283.016**
Reactive Power Losses (KVAR)	100.403	048.2474	**050.652**

5. Nominal Linear P, Quadratic Q Load

Nominal Linear P, Quadratic Q Load is defined as model 4 in OpenDSS platform. While doing simulations with model 4 value of CVRwatts and CVRvars is 0.8 and 2 is considered respectively. Simulation results are shown in table VI. From results it can be observed that with operating in CVR mode power demand and power losses get reduced in comparison to non CVR mode operation. Considerable energy savings can be achieved with CVR operation.

Table VI Simulation Results of model 4

Load (Model 4)	Base Case	Non- CVR Mode	CVR Mode
Real Power Demand (MW)	1.98846	1.96813	**1.95263**
Reactive Power Demand (MVAR)	1.01161	0.289379	**0.253487**
Real Power Losses (KW)	312.588	268.66	**253.834**
Reactive Power Losses (KVAR)	064.6681	031.3621	**025.3487**

From analysis of all simulation results it can be conclude that a significant amount of energy savings can be obtained with CVR operation. Impact of different load models is highly influences the CVR effect. While operation of CVR violation of voltage limits is also a matter of concern.

IV. Conclusion and Future Work

This paper analyzed the benefits and challenges for deployment of CVR technology in Indian power distribution system. A structural diagram of smart energy distribution system also been discussed. A brief reviews of CVR technology shows that acceptance rate of technology is increasing globally. Study of CVR test on IEEE 34 bus feeder shows that energy consumption can be reduced with CVR effect. Impact of different types of load model on CVR factor also been discussed. A good amount of energy savings can be achieved with constant impedance loading in contest to others by using CVR techniques. Generally loads are mixed type such as ZIP model, in such cases a considerable energy savings also is achieved with CVR effect. Looking into other aspects of CVR such verification, controlling and implementation process has many challenges for utility planners. So to achieve more saving through CVR, better coordination of CVR and VVO is required. Advance DMS based volt- var optimization based approach for CVR analysis will be implemented in future work. Optimization of different distribution parameters will also be realized for better understanding of CVR effect will also realize in future.

REFERENCES

[1] http://www.indiasmartgrid.org/sgg4.php

[2] Brown, H. E., and S. Suryanarayanan. "A survey seeking a definition of a smart distribution system." IEEE Conf. North American Power Symposium (NAPS), 2009, pp. 1-7. 2009.

[3] Schneider, K.P.; Weaver, T.F., "A Method for Evaluating Volt-VAR Optimization Field Demonstrations," Smart Grid, IEEE Transactions on, vol.5, no.4, pp.1696, 1703, July 2014.

[4] ANSI C84.1-1995, American National Standards for Electric Power Systems and Equipment—Voltage Ratings (60 Hz), 1995

[5] CAN3-C235-83, Preferred Voltage Levels for AC Systems,0 to 50 000 V, 1983

[6] Zhaoyu Wang; Jianhui Wang, "Review on Implementation and Assessment of Conservation Voltage Reduction,"IEEE Trans on Power Systems,vol.29, no.3, pp.1306,1315, May 2014

[7] Dabic, Valentina, and D.Atanackovic. "Voltage VAR optimization real time closed loop deployment-BC Hydro challenges and opportunities." IEEE Power & Energy Society General Meeting, , pp. 1-5. 2015

[8] S.singh, S.P. Singh, " A smart Volt- Var Optimization Engine for electrical energy distribution system" IEEE Int. Conf. on Emerging Trends in Electrical, Electronics & Sustainable Energy Systems (ICETEESES-16) on March 11-12, 2016 (Accepted)

[9] R. Preiss and V.Warnock, "Impact of voltage reduction on energy and demand," IEEE Trans. Power App. Syst., pp. 1665–1671, 1978.

[10] J.C. Erickson and S.R. Gilligan, "The Effects of Voltage Reduction of Distribution Circuit Loads," IEEE Trans on Power Apparatus and Systems, Vol. PAS-101(7), pp. 2014-2018, July 1982.

[11] D. Kishner and P. Giorsetto, "Statistical Test of Energy Saving Due to Voltage Reduction," IEEE Transactions on Power Apparatus and Systems, Vol. PAS-103(6), pp. 1205-1210 1984.

[12] V. Warnock and T. Kirkpatrick, "Impact of Voltage Reduction on Energy and Demand: Phase II," IEEE Transactions on Power Apparatus and Systems, Vol. 1(2), 1986, pp.92-95.

[13] D.M. Lauria, "Conservation Voltage Reduction (CVR) at Northeast Utilities," IEEE Transactions on Power Delivery, Vol. PWRD-2(4),October 1987, pp. 1186-1191

[14] J. De Steese, Assessment of Conservation Voltage Reduction Applicable in the BPA Service Region, 1987

[15] D. Kirshner, "Implementation of conservation voltage reduction at Commonwealth Edison," IEEE Trans. Power Syst., vol. 5, pp. 1178–1182, 1990

[16] B. Kennedy and R. Fletcher, "Conservation Voltage Reduction (CVR) at Snohomish County PUD," IEEE Transactions on Power Systems, Vol. 6(3), August 1991, pp. 986-998.

[17] A. Dwyer, R. E. Nielsen, J. Stangl, and N. S.Markushevich, "Load to voltage dependency tests at BC hydro," IEEE Trans. Power Syst., vol. 10, pp. 709–715, 1995.

[18] B. Williams, "Distribution capacitor automation provides integrated control of customer voltage levels and distribution reactive power flow," in Proc. IEEE Power Industry Computer Application Conf., 1995, 1995, pp. 215–220.

[19] C.-S. Chen, T.-H. Wu, C.-C. Lee, and Y.-M. Tzeng, "The application of load models of electric appliances to distribution system analysis,"IEEE Trans. Power Syst., vol. 10, pp. 1376–1382, 1995.

[20] T.L Wilson, "Energy Conservation with Voltage Reduction- Fact orFantasy," IEEE 2002 Rural Electric Power Conference Record, 2002, pp. C3-1: C3-6.

[21] L. Global Energy Partners, 2005, Distribution Efficiency Initiative.[Online].Available:http://www.smartgridnews.com/artman/uploads/ 1/sgnr_2007_08011.pdf.

[22] R. W. Beck, Distribution Efficiency Initiative Final Report, 2007.[Online].Available:http://neea.org/docs/defaultsource/rfp's/longterm-monitoring-and-tracking-distribution-efficiency.pdf?sfvrsn=4.

[23] S. Lefebvre, G. Gaba, A.-O. Ba, and D. Asber, "Measuring the efficiency of voltage reduction at Hydro-Québec distribution," in Proc. 2008 IEEE Power and Energy Society General Meeting—Conversion and Delivery of Electrical Energy in the 21st Century, 2008, pp. 1–7.

[24] https://www.idahopower.com/pdfs/.../irp/.../presentation031215.pdf 2010 online[accessed, 15 January 2016]

[25] KP. Schneider, J. C. Fuller and D. Chassin, "Evaluating Conservation Voltage Reduction: An Application of GridLAB-D: An Open Source Software Package," Power and Energy Society General Meeting, 2011 IEEE, San Diego, CA, July 24-29, 20 11.

[26] R. Singh, F. Tuffner, J. Fuller and K Schneider, "Effects of Distributed Energy Resources on Conservation Voltage Reduction (CVR)," PES General Meeting, 2011 IEEE, San Diego, CA, July 24-29, 2011.

[27] Green Circuit: Distribution Efficiency Case Studies, EPRI, Technical Report, 2011. [Online] Available: [Accessed: January 15, 2016]

[28] M.A. Peskin, P.W. Powell and E. 1. Hall, "Conservation Voltage Reduction with Feedback from Advanced Metering Infrastructure," Transmission and Distribution Conference and Exposition (T&D), 2012 IEEE PES, Orlando, FL, May 7-10, 2012, pp. 1-8..

[29] W. G. Sunderman, "Conservation Voltage Reduction System Modeling, Measurement, and Verification," T& D Conference and Exposition (T&D), 2012 IEEE PES, Orlando, FL, May 7-10, 2012, pp. 1-4.

[30] W. Ellens, et aI. , "A Quantification of the Energy Savings by Conservation Voltage Reduction," Power System Technology (POWERCON), 2012 IEEE international Conference, Auckland, New Zealand, Oct. 30-Nov. 2, 2012, pp.I-6.

[31] E. Diskin, T. Fallon, G. O'mahony, and C. Power, "Conservation voltage reduction and voltage optimisation on Irish distribution networks," in Proc. CIRED 2012 Workshop Integration of Renewables into the Distribution Grid, 2012, pp. 1–4.

[32] R. l Casavant, Conservation Voltage Reduction: Improve Energy Efficiency and Lower Demand, PowerPoint Presentation Slides, IEEE 2013 REPC Conference, Stone Mountain, GA, April 30, 2013.

[33] M. Diaz Aguiló*, J. Sandraz*, R. Macwan*, F. de León, D. Czarkowski, C. Comack, and D. Wang, "Field Validated Load Model for the Analysis of CVR in Distribution Secondary Networks: Energy Conservation", IEEE Transactions on Power Delivery, Vol. 28, No. 4, October 2013, pp. 2428-2436.

[34] https://www.avistautilities.com/inside/resources/smartgrid/Pages/default.aspx [accesed Jan 15 2016]

[35] Sandraz, J.; Macwan, R.; Diaz-Aguilo, M.; McClelland, J.; De Leon, F.; Czarkowski, D.; Comack, C., "Energy and Economic Impacts of the Application of CVR in Heavily Meshed Secondary Distribution Networks," Power Delivery, IEEE Transactions on , vol.29, no.4, pp.1692,1700, Aug. 2014

[36] Z. Wang, M. Begovic, J. Wang, Analysis of Conservation Voltage Reduction Effect Based on Multistage SVR and Stochastic Process, IEEE Transactions on Smart Grid, Vol. 5, No. 1, pp. 431 – 439, January 2014

[37] http://www.epri.com/abstracts/Pages/ProductAbstract.aspx?ProductId=000000003002004930 [Accesed at 15,Jan 2016]

[38] Report on 18th Electric Power Survey of India" , Central Electricity Authority (CEA),MoP Govt of India, Dec. 2011

[39] R. C. Dugan, "An open source platform for collaborating on smart grid research," presented at the IEEE Power Energy Soc. Gen.Meeting, San Diego, CA, Jul. 2011.

[40] IEEE PES distribution test feeders. <http://www.ewh.ieee.org/soc/pes/dsacom/ testfeeders/>.

Outcome-driven Framework for Evaluating Power System Performance, Efficiency, Reliability, Resilience and Environmental Sustainability

Evolving Trends for Efficiency, Reliability, and Resiliency

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***Abstract* – Blackouts and brownouts have to be minimized for the growth and prosperity of businesses and citizens in India. The Government of India has announced the National Smart Grid Mission, Integrated Power Development Scheme and other programs for developing reliable, resilient, efficient, safe, environmentally sustainable and economically viable power and grid infrastructure. Performance Excellence in Electricity Renewal (PEER) is an effective framework that can support the Government's grid initiatives offering comprehensive, consumer-centric, outcome-driven system for evaluating power system performance and continuous improvement. It can help electric utilities assess investments and optimize their systems in ways that will support higher performance, reliability and resilience.**

This paper will highlight PEER's applicability to quantify the value of sustainable electric system and identify hidden value streams for various types of systems, including;

Campus – Privately owned or operated projects that have just one or few customers, includes distribution to multiple buildings & loads, for example College campuses, industrial parks and facilities.

City – Typically a public project with a large variety of customers, includes municipal utilities, citywide projects within an IOU territory.

Supply – Privately owned or operated projects that supply locally generated power to downstream customers or loads, with few customers or customer connection points & don't have control over the distribution system or the customer. Examples include CHP power plants for industrial facilities.

This paper will also highlight PEER's value addition with various implemented projects, including at the University of Texas at Austin and the city of Chattanooga in the state of Tennessee. For an example, UT Austin analysis quantified savings from reduced electricity and energy costs, distribution costs, and demand charges, as well as savings from improved operational efficiencies, reliability, and power quality. Additionally, processes for safety review of changes, risk mitigation, failure trending and analysis, and waste identification and elimination were reviewed against best practices.

Keywords – Reliability, Power quality, Safety, CHP Power plants, Distribution Costs, Demand Charges, UT Austin.

1. Introduction

In recent years, Power has become one of the most critical components of infrastructure and crucial for the economic growth and development of nation. The existence and improvement of adequate infrastructure in power sector is essential for continuous growth of Indian economy. With an installed capacity of 284 GW (198.4 GW in Thermal, 42.6 GW in Hydro, 5.7 GW in Nuclear and 37.4 GW in Renewables) [1], the country is targeting 175 GW only from renewables by 2022 [2] and the Indian power sector is expected to grow at a rate of 8 % per annum. While, power sector facing a significant challenge with Aggregate Technical & Commercial losses amounting to 26 % and other issues such as power quality, power theft contributing to a net loss in revenue of USD 11 bn (2012-13) [3] the growth is a question.

Also, comparing India with other growing economies such as Brazil & China which suffer 17 % & 6 % losses respectively. To overcome these challenges Government has come up with the National Smart Grid Mission (NSGM) and Integrated Power Development Scheme (IPDS). NSGM will focus on implementation and monitoring of smart grid projects and developing policy and standards under smart grid framework. IPDS is introduced with the objective of strengthening the sub-transmission and distribution network in urban areas, metering of distribution transformers/feeders/consumers and IT enablement of distribution sector. Key measures such as installing smart meters under NSGM and strengthening the grid infrastructure under IPDS can help in meeting the future demand and reduce T&D losses that will benefit the DISCOMs.

Looking at the environmental side, power generation in India is primarily dependent on burning coal & fossil fuels. About seventy percentage of power is generated from coal-fired thermal power plants. In a recent study conducted by Centre for Science & Environment (CSE), mentioned that the average carbon dioxide emissions were 14% higher than the average in China and also highlights that thermal power plants withdraw around 22 billion cubic meter of water every year – more than half of India's domestic water needs [4].

Hence it is clear that to provide quality power, prevent grid blackouts, and reduce GHG emission, to withstand natural calamities – a reliable, resilient, efficient, safe, environmentally sustainable and economically viable power and grid infrastructure is important. Performance Excellence in Electricity Renewal (PEER) is an effective framework that can support the Government's grid initiatives offering comprehensive, consumer-centric, outcome-driven system for evaluating power system performance and continuous improvement. PEER is designed to help industry stakeholders dramatically improve system performance by providing operators with a framework for continuous improvement and performance assessment. Modeled after the U.S. Green Building Council's LEED program for buildings, PEER provides energy professionals with a comprehensive understanding of how to define, specify, and assess sustainable power.

2. PEER SYSTEM

The system is developed considering the customer concerns, design requirements, and performance outcomes. PEER evaluates the facility and the power that goes into it from generation, to transmission, to distribution. The comprehensive credit based programme is classified under 4 key categories;

- Reliability, Power Quality & Safety
- Energy Efficiency and Environment
- Operational Effectiveness
- Customer Contribution

This paper describes in detail on the *Reliability, Power quality & Safety and Energy Efficiency & Environment category.* Each category includes a set of prerequisites – requirements that must be fulfilled in order to qualify for certification -- and credits with which project teams earn points. Projects that meet all prerequisites and achieve the required number of points are awarded PEER certification in recognition of outstanding performance. The rating system covers critical component such as Advanced meter for Operations, Emergency Response Plan, Safety review, Renewable Energy Portfolio Standard (similar to Renewable Energy Purchase Obligation in India), Improvement plan, Consumer Engagement Programme etc. as prerequisite to get qualified for certification process. While the system has Core & Bonus credits to evaluate and improve the performance of power system. These credits are inferred based on Standards and Codes developed by Institute of Electrical and Electronics Engineers (IEEE), National Fire Protection Association (NFPA) etc. PEER comprehensively address the reliability, power quality and environmental issues by setting up benchmarks and gaining a competitive advantage by differentiating their performance.

2. A. RELIABILITY, POWER QUALITY & SAFETY

The category broadly evaluates sustained and momentary interruptions, power quality measurements and practices for risk mitigation to improve the power quality and reliability. A communications backbone, advanced meters, and SCADA allow operators to locate and manage power interruptions and retrieve the data necessary to assess reliability. Additionally, an emergency response plan and review of design changes are foundational to establishing a safe and secure electric grid.

The sustained interruption criteria include all interruption events regardless of cause, including major events. This group of criteria includes interruptions to any conductor that normally provides power to the customer. Therefore, a loss of phase in power normally supplied as three-phase power to a customer would count as an interruption. The damage that power interruption events cause from a practical and economic standpoint is a key concern for customers. Measuring, reporting, trending, and benchmarking these metrics will assist with identifying poor performance and provide the justification for investment to reduce sustained interruptions and improve reliability. Based on the IEEE Guide for Electric Power Distribution Reliability Indices [5], the following credits are reported & documented; System Average Interruption Duration Index (SAIDI) – average outage duration in minutes experienced over one year, System Average Interruption Frequency Index (SAIFI) – average frequency of outages that a customer experiences over one year, Customer Experiencing Long Interruption Duration Index (CELID-5) – interruption duration longer than five hours in a year is considered & Average Service Availability Index (ASAI) – the fraction of time (often in percentage) that a customer has received power. These indices help in improving electricity performance based on reliability trends.

Interruptions lasting less than five minutes are categorized as momentary. Even momentary interruptions in power can cause significant loss and damage to sensitive electronic equipment. The increase in customer deployment of digital devices has created a need for information on short interruptions. Hence, measuring, monitoring & benchmarking would definitely improve reliability. According to IEEE 1366, following credits are reported & documented; Momentary Average Interruption Frequency Index (MAIFI) – the average number of times that a customer's power is momentarily interrupted each year. According Customer Experiencing Multiple Momentary Interruptions (CEMMI-5) – more than 5 momentary interruptions in a year are considered. Average Interruption Frequency Index (AIFI) - average number of times that a customer's power is interrupted each year, including both sustained and momentary interruptions. Through periodic measuring and constant monitoring of these data not only help in reducing the load shedding but also help in providing consistent power supply to its consumers.

To minimize risks, reduce injuries and improve reliability the rating system also consider Safety Review Process, Risk Mitigation and Failure Elimination. Safety – PEER recommends DISCOM to create a safety review process for new systems and all design and operational changes. The system should be able to track all injuries and deaths for staff and non-operator personnel for the purpose of ensuring that these events are incorporated into their safety review process. Failure Modes and Effects Analyses (FMEAs) - evaluated all systems and system components to identify and address both frequent and infrequent risks, including safety. The results are documented in a series of FMEA to prioritize risks based on controllability, severity, and probability. These FMEAs also identify improvements to mitigate risks and improve reliability.

For a growing number of customers with digital equipment or devices, variations in power quality can cause significant loss and damage and can increase electricity costs due to poor efficiency. The list of affected equipment includes motors, electronics, and other sensitive equipment. Hence tracking, monitoring and trending the Power Quality Measurements are essential. Acceptable power quality (PQ) event types such as Supply voltage variations, Voltage dips, Harmonics, Power Factor should be monitored based on nominal ranges mentioned in European Quality Standard EN 50160 [6]. The Reliability, Power Quality, and Safety category resolves all the above issues and provides a performance standard for assessing power system's qualities in the respective areas.

2. B. ENERGY EFFICIENCY AND ENVIRONMENT

This category broadly evaluates on the Local Air Permits, Renewable Energy Certificates (RECs), Renewable Energy Portfolio Standard (RPS), and Electricity Supply – Energy Efficiency, Air Emissions, Resource Use and capability for Energy Efficiency & Environment. These indicators would help to assess the environmental impact due to power generation and develop solutions to mitigate these challenges. To reduce carbon emission and increase the uptake of Renewable Energy – RPS (Programme similar to RPO – Renewable Energy Purchase Obligation, in India) is introduced, a regulation in US that requires a percentage of generation to come from renewable energy sources. Also obtaining Air Permit to reduce the impact on air quality due to local distributed generation are considered as a prerequisite. Improving electricity efficiency reduces emissions, water, and solid waste. Source Energy Intensity (SEI) [7] - measures the energy efficiency of gross electricity supplying the project — the amount of non-renewable energy required to deliver one unit of electricity (MMBtu/MWh). CO_2 intensity is the amount of emission in pounds released per unit of electricity (lbs/MWh). Nitrogen oxide intensity is the amount of emission in pounds released per unit of electricity (lb / MWh). Similarly, Sulfur dioxide intensity is the amount of emission in pounds released per unit of electricity. These three performance metrics, provide a means for estimating the overall emissions impact of generating electricity.

Electricity generation is a resource-intensive process that consumes and pollutes water and creates waste byproducts. Under Electricity Supply resource use to measure, track and monitor the amount of water consumed and waste produced in the electricity generation process. Water Consumption Intensity is the amount of consumed during generation (gallons) to the gross generation of power (MWh). Solid Waste Recycled is the measure of total solid waste recycled (tons) to the total solid waste generated (tons). These indices help in improving the system performance based on Environmental trends.

To increase the value of renewables, the industry created a program for renewable energy certificates (RECs) to enable customers to contribute additional value to renewable generation, the total generation represented by purchased RECs (MWh) to the project electric load (MWh) provides the percentage of RECs. Capabilities for Efficiency and Environment that improve energy efficiency and reduce environmental impacts of the electric grid. Credits such as District Energy, Cogeneration, Local RE generation & Environmental impact are demonstrations or design considerations that are proven to achieve improved grid performance and compliment the measurable performance outcomes. District Energy which distribute steam and hot or chilled water to multiple buildings eliminating the need for separate boilers, furnaces, and air conditioners at each building, which is considered if the project can meet thee cooling / heating loading of more than one building. Cogeneration is the practice of harnessing the heat byproduct of generating electricity and using that thermal energy for heating and other uses. Local RE Generation viz. Solar, Wind and Biomass are clean source of electricity. These credits are considered to recognize their importance in terms of energy savings and to encourage investments.

The electricity distribution system requires a large tracts of land to install delivery poles, wires, and substations. The process of installation and maintenance includes deforestations and tree trimming, negatively impacting local aesthetics and harming wildlife habitat – severely impacting the environment. Environmental impact credit helps address the above challenges by formulating a procedure or policy for underground cabling, tree trimming and animal protection etc. It is based on the ISO 14001 standard for environmental management systems [8]. The Energy Efficiency & Environmental category can be utilized to identify performance excellence and hidden waste. The system enables users to quantify hidden waste streams to improve the financial performance of proposed solutions. The combination of energy efficiency and environmental performance criteria favors renewable and high-efficiency/low emissions fossil fuel generation.

3. *PROJECT TYPES*

PEER provides a valuable framework that can be used to assess new designs and developments, long-term improvement plans, and existing project performance. PEER projects are of three types:

Campus – Privately owned or operated projects that have just one or few customers, includes distribution to multiple buildings & loads, for example College campuses, industrial parks and facilities.

City – Typically a public project with a large variety of customers, includes municipal utilities, citywide projects within an IOU territory.

Supply – Privately owned or operated projects that supply locally generated power to downstream customers or loads, with few customers or customer connection points & don't have control over the distribution system or the customer. Examples include Cogeneration / CHP power plants for industrial facilities.

4. *CASE STUDY*

The University of Texas at Austin is the first PEER certified campus. After undergoing a rigorous PEER review process the UT Austin was able to successfully achieve this milestone.

Since 1928, the campus generated 100 % of its own electric power and thermal energy. In the last decade the campus has doubled its size from 9 million to 17 million sq.ft. To support this growth the campus, the energy produced through District Energy system also doubled from 184 million kWh to 372 million kWh. Despite this growth in demand, UT Austin managed to keep fuel consumption remain flat by increasing their annual energy production efficiency by 30 %. In the last 10 years, UT Austin has invested close to $150 million in energy efficiency and capacity upgrades. This investment has supported in reduction of fuel costs and energy savings.

4. A. RELIABILITY PERFORMANCE

UT Austin has an Average Service Availability Index (ASAI) value of 99.998 % compared to Austin Energy's (Power supplier) ASAI value of 99.989 %, which is itself a far better value compared to the US average of 99.955 %. Translating these values in terms of System Average Interruption Duration Index (SAIDI) is 10, 58 & 240 outage minutes per year respectively. ASAI is the measure of amount of time that a customer has power over the course of a year. An ASAI of "four-nines" or 99.99 % reliability means the SAIDI value of 58 outage minutes / year. *Refer to figure [1].*

UT Austin's System Average Interruption Frequency Index (SAIFI) value is 0.11, which is also favorable compared to US average of 1.5 events per year. The UT Austin microgrid, which includes chilled water storage provides the campus with an uncommon degree of self-sufficiency and control: UT Austin's islanding capabilities would allow the campus's light to stay on even if the surrounding area were to experience an outage. Apart from this, the campus's excess power generation capacity and load shedding capability ensure that UT Austin's critical facilities will continue to get power even if one of the primary generators go offline.

4. B. ENVIRONMENTAL PERFORMANCE

UT Austin's combined heat & power (Cogeneration) system uses gas turbines with heat recovery steam generators and boilers to supply the campus's heating, cooling and electric needs. This system enables maximum heat recovery while minimizing fuel consumption; energy that might typically go to waste is instead used to heat buildings on campus. The campus district energy system eliminates the need for separate equipment at each building and enables the use of larger, more efficient equipment. At UT Austin, the chillers consume 0.7kW/ton, well below the industry rate of 1kW/ton.

Over & above, with the support of storage for any excess generation, UT Austin is able to continuously run its chiller at its maximum efficiency point. This results in an overall System Energy Efficiency (SEE) of 87 %. As it runs on natural gas, UT Austin has a Source Energy Intensity (SEI) of 7.4 MMBtu/MWh delivered – compared to state baseline of 9.2. *Refer to figure [2].* Lighting, water and steam projects save about $2.8 million per year in energy and water costs and reduce carbon footprint by 35 million pounds of carbon! [9].

5. *CONCLUSIONS*

This paper presents the ways in which Power systems need to be designed, developed and operated. Reliability, Safety and Environmental implications in the process of generation, transmission and distribution are described through a credit based approach. PEER is a readily available mechanism for the power sector who are willing to take up a structured process to measure, monitor, trend and set benchmark in the market. Also, projects can use PEER as a continuous improvement tool to maximize their returns and minimize risks and to provide responsible and cost-effective electricity to serve as a competitive advantage, attract new customers and help keep existing customers satisfied. One project a time, we can change the world. Building resilience into the power grid, generating clean source of power and delivering a reliable & quality power can transform our buildings, communities and cities in a bigger way and the value proposition generated due to this would be multi-fold. Going forward, the Government should look into creating favorable policy mechanisms and develop standards which would bring more transparency, creating a market transformation in the power sector.

5. FIGURES

Figure 1 – Key Performance Metrics: Reliability

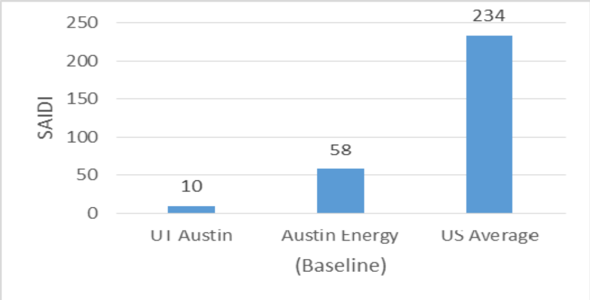
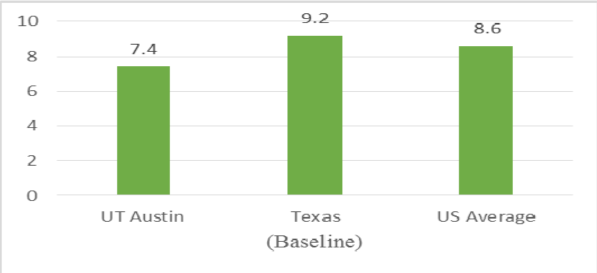


Figure 2 – Key Performance Metrics: Environment



6. REFERENCES

1. Central Electricity Authority website (http://www.cea.nic.in/reports/monthly/executivesummary/2015/exe_summary-12.pdf)
2. Ministry of New & Renewable Energy website (www.mnre.gov.in)
3. Institute for Energy Economics & Financial Analysis website (http://ieefa.org/wp-content/uploads/2015/08/IEEFA-Indian-Electricity-Sector-Transformation-August-2015.pdf)
4. India Climate Dialogue website (http://indiaclimatedialogue.net/2015/02/24/indian-coal-power-plants-worlds-most-polluting/)
5. IEEE Standards website https://standards.ieee.org/findstds/standard/1366-2012.html
6. European Committee for Electro technical Standardization (2010). EN 50160: Voltage Characteristics of Electricity Supplied by Public Electricity Networks.
7. Emissions and Generation Resource Integrated Database (eGRID) website. http://www.epa.gov/energy/egrid
8. International Organization for Standardization (2004). ISO 14001:2004
9. University of Texas website- https://www.utexas.edu/utakecharge/

Data Analytics

Operational Analytics can transform the Grid

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Abstract of your technical paper

The power of analytics can never be underestimated. Analytics within the smart grid, if used correctly, can enable utilities to respond more rapidly and effectively with issues regarding improved grid operations, performance customer engagement, and financial management. By utilizing the industrial internet of things (IIOT) and capturing the large amounts of data that is generated, analytics plays an integral part in staying ahead of the competition.
A large electricity transmission company owns and maintains the high voltage power transmission network within the UK, supplying 57 million people with electricity across a network of 4,500 miles of power lines and 340 substations.

Condition monitoring has traditionally been off-line or operated locally on-site, and the company recognized the power of moving to real time condition monitoring in terms of their short and long term asset management strategies. Bentley's AssetWise Amulet software was applied to interface to all forms of condition monitoring on site providing a single window into the assets on the substations. Analytics was applied to analyze the data in real time, generating alarms and notifications on asset health. This has allowed them to manage the operation of their assets by extending asset life and maintaining operation where previously they would have had to shut down the transformer. The solution has formed a major part of the submission to the Ofgem regulator for the 8 year regulatory review.

By using this level of analytics, the large electricity transmission company moved from "what happened?" to "what is happening now and what should I do about it?"

Keywords—data, performance, Internet of Things, Operational Analytics, condition monitoring, real-time, asset management, alarm management, notifications, extend life, strategies, condition, risk, dashboards, IT, modeling, predictive analytics, reliability,

INTRODUCTION

Data is at the heart of digital transformation. With the explosion data meaning that we are able to create, capture, access, monitor, and analyze more and more data every day, problems can arise in terms of what data to use, how we can use it properly and how can we turn the data into useful information that affects our decisions across the whole organization. This is where data analytics, and in particular operational analytics, answers those problems.

PRIORITIES IN THE ELECTRIC UTILITIES

There are many problematic areas within the electric utilities arena that are becoming major priorities. An ageing infrastructure is central to the inability to ensure a reliable, cost-effective, secure, and sustainable supply of energy. Temporary solutions can be put in place, such as monitoring asset health, structural integrity, condition monitoring and corrosion management, to stem the flow. Rising costs of generation and transmission, not to mention asset failure, loss of production with unplanned downtime, and operational expenditure. Transparency in environmental regulation and compliance is also a must when it comes down to emissions monitoring and reporting, while capturing, institutionalizing and retaining domain knowledge from an ageing workforce is also a must. Operational analytics is a solution that can bring all of these challenges together under one roof, bringing a wide variety of capabilities to bring visibility, increased performance and reduced costs.

WHAT IS OPERATIONAL ANALYTICS

Operational analytics is an industry-recognized emerging business process that focuses on improving day-to-day operational performance with the power of sophisticated analytics. It is a process that converges information technology, operational technology, and engineering technology by transforming historical and real-time data into actionable just-in-time data for improving operational efficiencies using predictive techniques. Data aggregation and analysis tools are used to provide clarity and context for decision making and business planning, as well as to provide a platform for organizational strategy. The software that enables the process is configurable and provides day-to-day visibility into the performance of existing assets. It also offers predictive analytical opportunities for utilities to improve their operations. This can be used in conjunction with an existing model to extrapolate relevant information as and when it is required, extending asset performance modeling capabilities for real-time operations.

OTHER FORMS OF ANALYTICS

There are many forms of analytics that perform well within their own right. Descriptive and diagnostic analytics provide insight into what happened and why it happened, but nothing about what will happen in the future. Predictive analytics takes that a step further. Traditional business intelligence provides users with conventional and dashboard reporting in near to real time. What is needed is a solution that combines the level of reporting for management, the data mining capability to look closely at what happened and what is currently happening in real time, and the predictive capacity offered to forecast events and opportunities. Operational analytics offers descriptive, diagnostic, and predictive analytics for a complete analytical solution (s*ee Figure 1*).

OPERATIONAL ANALYTICS AND THE GRID

T&D organizations generate a lot of data. This has been accelerated with the arrival of the Industrial Internet of Things and the explosion of big data, where the deployment of millions of smart meters and other grid devices is generating a huge amount of data. Managing, interpreting, and turning this data into actionable information is where operational analytics comes to prominence, giving utilities the ability to collect, analyze, and act on the information they receive. Gartner predicts that by 2021, 1 *million* IoT devices will be purchased and installed *every single hour** – so the need to start harnessing the IoT starts now. Not only will data grow in volume and size, but it will also vary in type due to the large variety of data sources. This is why aligning operational technology (OT) with information technology (IT) (and also engineering information technology, or ET) is so important (*refer to Figure 2*). Operational analytics benefits such as cost and risk reductions and enhanced performance and flexibility.

HOW IT AND OT CONVERGENCE CAN HELP THE GRID

Operational analytics can help utility companies drive operational efficiency by providing a broader view of their assets and how they are performing. With assets spread over a wide geographical area, it’s important to have all of the available information in one place to give you a clear and concise picture of health, condition, and performance right down to the component level. By monitoring a variety of parameters connected to health and condition, decisions can be made earlier via analytics that help to determine how likely it is that a failure or significant event will occur, so a contingency plan can be activated before it happens.

BRINGING VISIBILITY TO THE OPERATION

Amulet's operational analytics capability has been used to help users gain extra visibility into their assets' performance, effectiveness, and efficiency across transmission and distribution. Within substations, operational analytics has been used to monitor the condition of transformers using sensors to measure a variety of parameters, alerting engineers to any problem that may arise due to oil temperatures, dissolved gas anomalies, and more. In the field, the lifecycle of transmission towers can be extended by calculating and modeling the life span using corrosion, environmental, geospatial, and maintenance history data, to name but a few. Additionally, line inspections can be improved by using handheld devices to upload and download inspection data live from the field. Asset health indexing empowers utilities with the proof to make defensible asset investment decisions, formulating asset life extension strategies where possible to do so safely and reliably.

The risk of failure increases due to age and condition of T&D assets. It is essential to know how assets are performing at all times. For example, monitoring the level of dissolved gasses and the temperature of the cooling oil that circulates within transformers 24/7 identifies potential problems quickly (*see Figure 4*). This allows assets to be taken off line or operated on in a safe window, reducing costly failures and unplanned maintenance expenditure, ensuring the integrity and availability of the grid. Failures within the grid also incur costly clean ups and high-level investigations, even loss of reputation with its customers if affected.

CASE STUDY EXAMPLE

A large electricity transmission company in the UK had several hundred substation transformers situated in England and Wales of which approximately 100 were identified as being "at risk" from failure due to their age and/or condition. The determination of the failure risk is achieved through the monitoring of the dissolved gasses in the cooling oil, which circulates within each transformer. This gas is analyzed by using Hydran units of varying age and capability, where only a small percentage of the units had logging capabilities to enable the company to remotely gather readings for analysis. The company was therefore incapable of correctly identifying impending failures and trends to predict future problems.

Using remote devices throughout their substations to collect data from Hydran dissolved gas monitoring systems, data was transmitted by GPRS to a Web server for display and analysis with the Amulet platform. By taking data from assets within over 40 substations, and monitoring these levels using multiple techniques, engineers are warned of any potential failures in plenty of time in the form of SMS or email. These are sent in accordance to alarm levels that have be set for various measurable parameters within each transformer, such as Dralim Oil analysis, SF6 gas levels and DTS (the measurement of temperature along the length of a transmission line through use of optical fibers). Users have the ability to view any transformer via a treeview structure or layout by asset or route. They can also view assets on a geographic basis through the OS maps incorporated into the system.

Immediate benefits resulted in a reduction in OPEX, where the more data they received from their assets meant an increase in targeted risk management and enhanced business decision making; maintenance regimes were more informed and organized, and a reduction in the cost of retrofitting of condition monitoring could also be implemented. With the aid of analytics to monitor and analyze the condition ad performance, transformers that have been diagnosed with potential failure can be proactively taken off line, have no expensive cleanup costs, store the knowledge gained for 'family' failures, and obtain potential 'grey' spares for other units – with no loss to the grid. Further solutions included using the data for inspection records, as well as line surveys using handheld devices. Bringing in weather data has also been of significant benefit to help spot the relationship between current transformers and the environment.

Another strategy used was predicting the corrosion rate of the steel tower network to determine the life of a network through the degradation of the structures. The company required a strategy that would enable them to identify problem lines and individual towers based on their location and history, and use the data to determine the best intervention programs of painting, bar or tower replacement, as well as generate the best strategies for financial expenditure. This was created through a care and risk evaluation model. The model took into account all aspects of condition that affects the degradation of steel, zinc, and organic coatings on all above ground steelwork. This includes temperature, humidity, time of wetness; pollution in the form of air-borne sulfur dioxide; location in altitude, proximity to sea, lakes, reservoirs, rivers, minor and major roads; and history, including installation date, coating records, and maintenance history. The model is then used to calculate the long-term risk of the towers, and display them color coded individually on a map within the dashboard (*refer to Figure 5*). This marked the first time it was possible to predict the expected condition of transmission towers across a selection of the network. This allowed preventive and replacement strategies to be planned and costed across a long-term strategy.

A. Figures and Tables

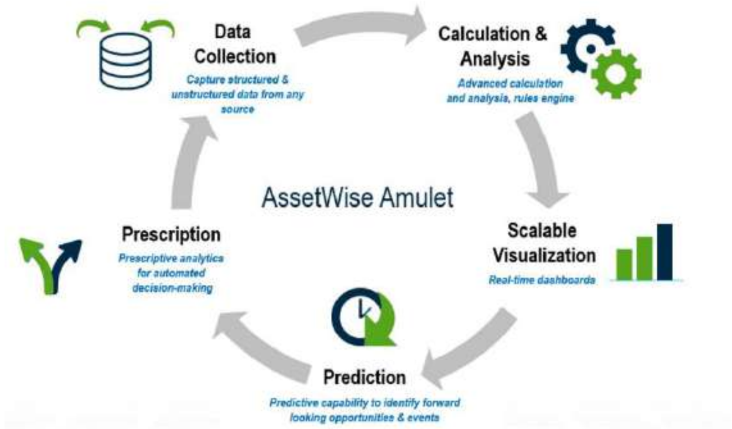

Figure 1. The complete operational analytics solution

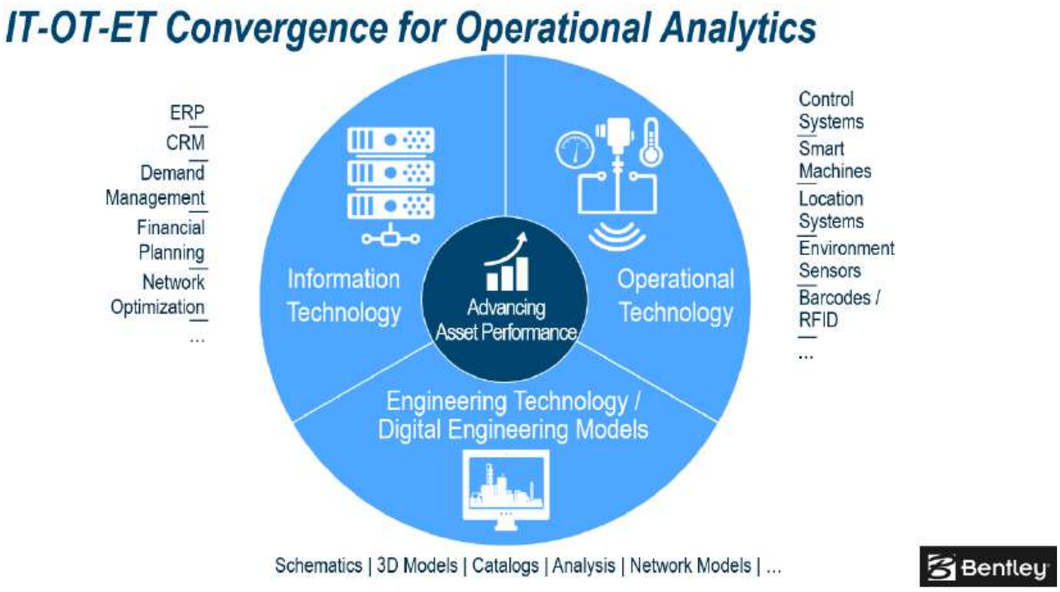

Figure 2. The data convergence of operational, IT and engineering data can bring many benefits, such as improved performance, reduced costs and risk, and greater flexibility.

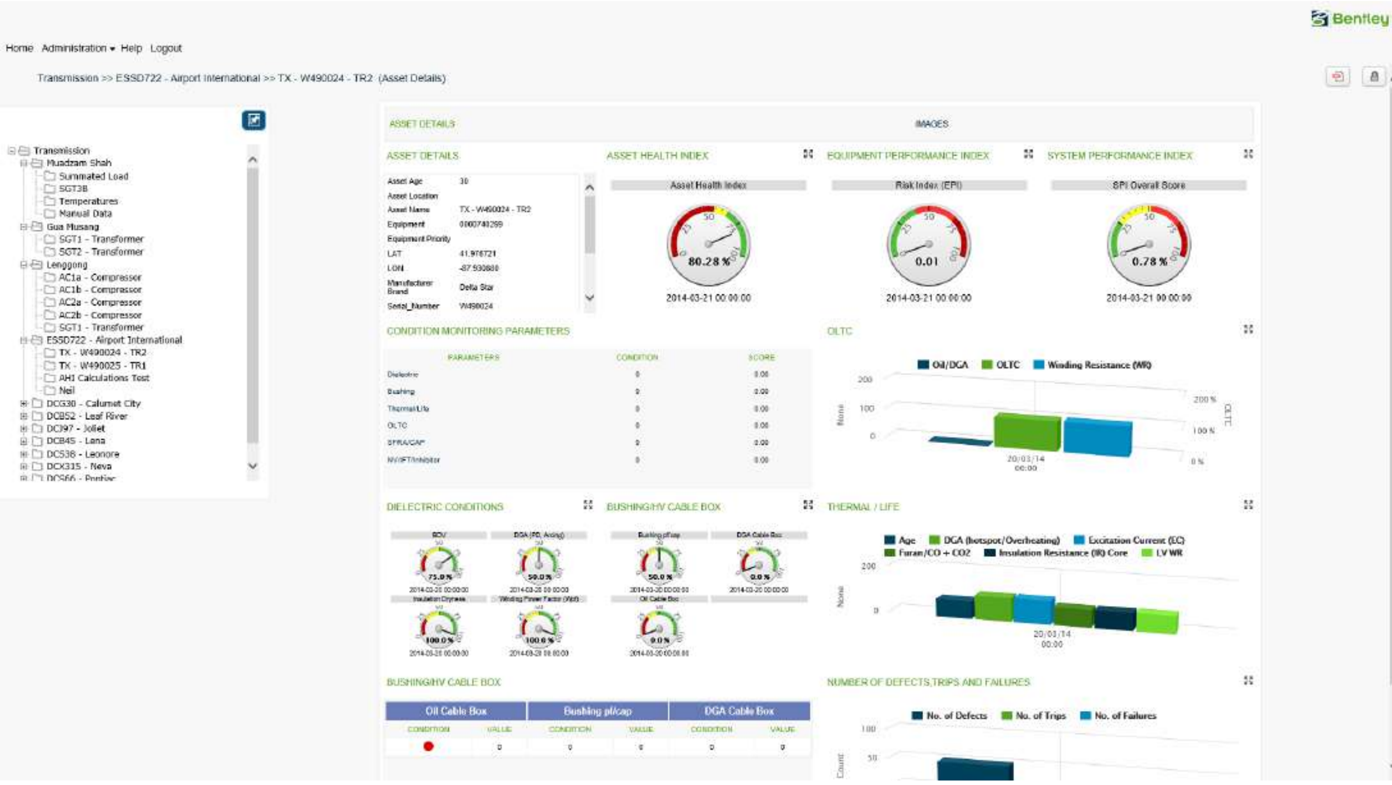

Figure 3. Typical power dashboard displaying transformer condition monitoring parameters and asset attribute details which can be used to calculate the overall Asset Health Index (AHI) score for transformer assets.

Figure 4. Typical power dashboard displaying transfix gas levels and alarm status.

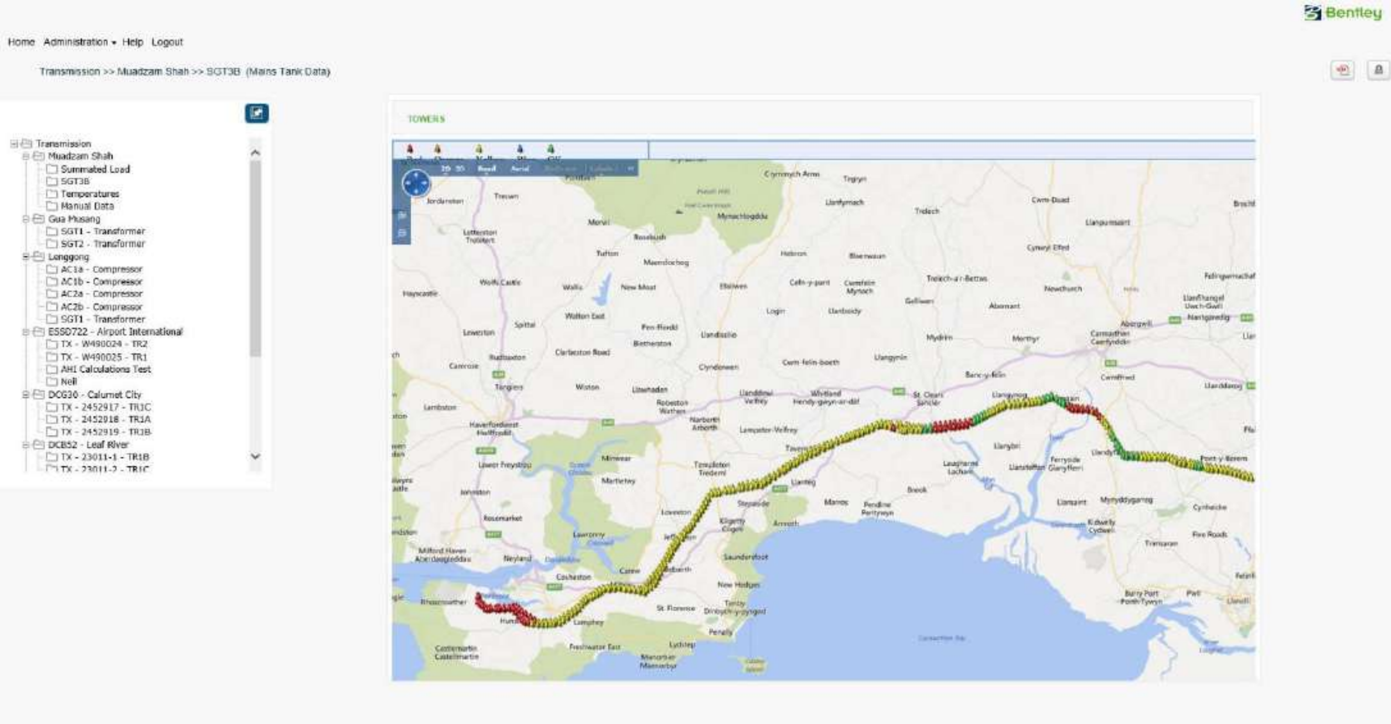

Figure 5. Example of the corrosion index showing the likelihood that towers will corrode due to emissions from nearby power station.

REFERENCE

** Top Strategic Predictions for 2016 and Beyond: The Future Is a Digital Thing, G00291252, 2 Oct 2015*

Long Range Radio for Smart Grid Communications

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Abstract
Selecting the right communications technology is critical for a successful rollout of any smart grid programme. This paper will illustrate the key considerations for the communications infrastructure for smart grid programmes and describe the characteristics of long range radio technology. Long range radio is an RF technology specifically designed for utility grade applications.

This paper describes the key considerations for the selection of a smart grid communication technology and the reason why the long range radio is one of the best suited communication technologies for smart grid applications.
Today's utility communications network are designed to accommodate a variety of smart grid applications. In addition to advanced metering infrastructure (AMI) deployments, utilities are searching for communications solutions for outage management, leak detection, remote shut-off, lighting control, distribution automation (DA), GIS, demand response (DR), and home area networks (HAN). Each of those applications requires communications and networking technology with suitable speed, reliability, and security that the utility requires for each of its business operations. While making decisions on an investment in a network technology, utilities must fully consider the broader impact that their choices will have on long-term utility operations

If a utility is on the verge of smart grid innovation, then let the lessons learnt by early adopters help you create a business case that moves your project forward.

Key considerations for smart grid communication technologies

In order to implement a reliable smart grid , the following key requirements should be considered for its communications infrastructure:

- **Support multiple applications**: Smart grid technologies are constantly evolving to include more solutions for utilities and their customers. A robust communications network has the bandwidth and interoperability to support multiple applications well into the future.

- **Collect, store and transmit secure data**: The best smart grids are resilient against intrusion and other malicious acts. When selecting a smart grid solution, be sure to ask about security certifications and what technologies and protocols ensure the solution is secure.

- **Prioritize and segment data**: Smart grids often come with significant amounts of data. Managed correctly, this data empowers utilities to answer customer questions and make strategic business plans. Select a smart grid that pairs with a data management system. This system should do it all- collect, store, validate, and manage data.

- **Expand to accommodate future technology**: Change is the only certainty, and a smart grid must be along for the ride. When looking at a smart grid check how it integrates into the present and future needs.

A resilient network is reliable, efficient and robust. After all, there is a lot riding on it such as metering and billing, distribution automation and demand response, among other applications. What's more, these workhorses require a communications network with speed, reliability and security.

Utilities need a network that enables them to prioritize the data collected from various applications on the network. Information regarding system integrity and outage management, for example, surely trumps billing reads.

Communication networks should also be standards-based, not proprietary. Furthermore, they must be designed for the future, that is, flexible enough to support the needs of the utility and its customers for decades.

These requirements predicate a dedicated radio solution, the Long Range Radio, typically at a frequency lower than GPRS for obstacle penetration and coverage reasons.

Long Range Radio

Long Range Radio (LRR) is a fixed base communication technology that can support smart metering, smart grid, smart street lighting and smart water networks. Operating on dedicated spectrum, it ensures security and provides utilities with a resilient and universal solution meaning there's no need for 'in-fill' technologies which add complexity and cost. LRR also has characteristics that are different from point-to-point or session-based radio communication networks.

Characteristics of Long Range Radio

- **Universal coverage**
  LRR is designed to provide 99%+ connectivity to meters in existing locations enabling country, region, or city-wide networks with a single technology.

- **Simple and efficient install process**
  Long range radio offers high connectivity performance to existing meter points, excellent building penetration, long range, and the necessary capacity to handle multiple utilities on a single network.

- **Direct to meter benefits**
  The ability to connect direct to meters is recognized as a benefit in almost every market. This maintains the independence in the meter supply market, improves the accountability of communications performance right through to the meters and offer clear lines of demarcation for installation and maintenance.

- **Long term resilience**
  This provides the flexibility of over-the-air updates and upgrades to modulation type. This feature facilitates innovation and changes to service requirements during its service life without needing to visit the endpoint.
  Even with an outage of a base station, endpoints still have the capability of being able to communicate with the neighboring one.

- **Dedicated communication network**
  Long range radio is designed to use dedicated, licensed spectrum. The spectrum used can be different in each country but should be chosen to be ideally suited for long range communications and have excellent building penetration characteristics, making it suitable for indoor connection performance.

- **Multi-utility network**
  The network can support electricity, gas and water utilities all operating on a single communications infrastructure.

- **Secure**
  Long range radio offers utilities a secure system on dedicated radio spectrum. Private key encryption at endpoint level is set at the point of manufacture with individual key encryption for each smart end point.

Some of the Long Range Radio implementations:

- In August 2013, long range radio was selected by the UK government as one of the communications technologies for the smart metering program where it will be operating on a 400MHz licensed band. The long range radio technology is provided by Sensus and is its FlexNet^{TM} product. Long range radio will be deployed across Northern England and Scotland, which is the most complex of the three regions with vast rural areas and has six of the ten largest urban cities in the UK. In the sparse, rural areas, meters are embedded within the cellar of centuries-old structures with difficult to penetrate building fabrics. Long range radio will be connecting 16 million electric and gas meters across 10 million homes and small businesses. The network will cover an area of 113,255 km^2 which represents approximately 50% of the UK coverage area.

- 280 MHz band long range radio communications trial test was performed successfully at dense urban is in Tokyo using Sensus' FlexNet LRR network technology. The purpose of this trial was to validate the connectivity and performance of Sensus' FlexNet LRR technology in several predefined tests environment, that are simulating smart metering devices. Very good results were observed from the 280MHz band in Tokyo urban area, especially for radio propagation, diffraction and building penetration performance. These 280MHz LRR connectivity advantages are slightly better than the other existing systems and are suitable for multiple applications of wireless sensor network including smart metering network.

- There are many diverse locations in the US where the long range radio technology has been in operation. These are rural, semi-urban, urban and dense urban type of locations. Some of them are in utilities in following states Alabama, State of Maryland, State of Georgia, State of Nevada. These utilities have the Sensus FlexNet LRR in operation for their smart grid applications for past few years.

Customer	Terrain	Area km^2	End Points	Actually Connected
Power Stream	Dense Urban	800	325,000	99.1%
NVE (Nevada Electric)	Dense Urban & Sparse rural	141,154	800,000	99.2%
PGE (Portland General)	Dense Urban & Mountainous Rural	10,360	800,000	99.2%
Southern Company	All terrains present	317,000	3,937,000	99.5%

Conclusion:

Technology selection of communications infrastructure is critical to successful rollout of smart grid projects. These smart grid communication networks need to be affordable, proven technology that can achieve 99%+ connectivity and operational performance over their long service life. The real-life performance of chosen communications technology needs to be demonstrated in each country where smart grid programs are deployed. The Long Range Radio has been found to meet or exceed the utility expectations for the smart grid communication infrastructure.

Reference

[1] David Ross-Scott, Scottish Power, *'Testing LongRange Technology for WAN Coverage'* presented by Scottish Power at Telecoms for Smart Grids, London, September 2013
[2] Andy Slater, CEng MIET and Alan Holloway PrEng BScEng MBL SMSAIE, *'A FlexNet Smart Grid Solution for South Africa'* (2013)

About the Author:

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As Principal Solution Architect , Deepak is responsible for pre-sales technical support of smart metering/ AMI projects in India for Sensus. Deepak has over 29 years experience in the energy and utilities sector. In particular, he has significant experience of implementing smart metering and AMI related solution.

SMART GRID KNOWLEDGE GRID

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WG 7 Chair, ISGF

Abstract— Implementation process of **Smart Grid** has been initiated in the country as a game changer in the energy management process under the umbrella of THE National Smart Grid Mission (**NSGM**), a framework for implementation of Smart Grids through participation of stakeholders e.g. utilities, regulators, industry organizations, testing agencies, Research institutes, consumer forums and media. During the course of this evolutionary journey, free flow of "**Idea**" and "**Access to Information**" could play vital role as two essential ingredients for the efficacy of "**Informed Decision Making**" and "**Innovative Problem Solving**" process.

The scenario of ever expanding distributed and diverse Information environment prevalent in the energy management arena calls for transition that would enable seamless flow of information and knowledge among stakeholders anytime, anywhere. This necessitates a state-of the-art collaborative platform based on BIG DATA architecture. Collaboration makes human smart, collaboration makes human innovative removing the veil of ignorance of one by the light of knowledge of other(s).

With the above objective, the idea of a collaborative, interactive, knowledge exchange platform called "**SMART GRID KNOWLEDGE GRID**" has been created as a single window for knowledge service delivery. The details of this concept have been presented in this paper.

In order to develop the SMART GRID KNOWLEDGE GRID with active involvement of all the participating organizations, a Smart Grid Knowledge Management policy and a Smart Grid Code of Practice have to put in place. Project Management and Change Management practices could help in making SMART GRID KNOWLEDGE GRID a reality.

<u>VISION: SMART WORKING FOR SMART GRID</u>

ROLES MANY GOAL ONE: SMARTGRIDS MANY KNOWLEDGEGRID ONE

'WHY" SMART GRID KNOWLEDGE GRID…………..

The National Smart Grid Mission (NSGM) has defined a broad framework for deploying Smart Grid technologies across the country. In order to fulfill the objective of the mission, Transparency, Accountability and Continuous Improvement are to be ensured along the course of this journey of transformation of India's power sector. As the days unfold, the NSGM stakeholders would appear as potential partners within the ever-evolving and complex power sector. This entails a mechanism of engagement through a seamless approach to integrate people, process and information for end-to-end visibility through active participation of hyper connected knowledge workers of NSGM team.

Smart Grid would make electrical grid smart, but the Human Grid would eventually build the Smart Grid. The much needed Knowledge Grid would make Human Grid smart and innovative.

OBJECTIVE: The objective of SMART GRID KNOWLEDGE GRID is to integrate all the stakeholders of smart grid mission and engage them in a holistic eco-system of smart working and establish a Unified knowledge space for Single Window Knowledge Service in the domain of smart grid.

OUTCOME: The outcome of SMART GRID KNOWLEDGE GRID is envisaged as a People centric, Process oriented, Knowledge driven, Technology enabled virtual working environment on a digital platform to bridge the gaps among islands of information in organizational SILOs, standardise processes across the smart grid domain and develop insight through collaborative knowledge sharing for efficient project/programme management.

'WHAT' is SMART GRID KNOWLEDGE GRID………

SMART GRID KNOWLEDGE GRID is envisaged as Human Machine Environment for problem solving and innovation through an interactive on-line platform with digitally enabled functionalities for a hyper connected workforce comprising of NSGM stakeholders. This would facilitate a collaborative knowledge exchange process in a managed cyberspace and act as single window for knowledge service delivery process with multiple knowledge resources for creation, use, update and reuse knowledge. This would also cater to the diverse concurrent queries in a BIG DATA environment.

FOUNDATION of KNOWLEDGE GRID: KNOWLEDGE MANAGEMENT POLICY

NSGM Knowledge Management Policy may be formulated and adopted by NSGM stakeholders. The Knowledge Management Policy document should comprise of the objectives, Strategies, Features, profile of Knowledge Bank Content, Roles & Responsibilities, Incentives & Recognitions and Compliance.

PROCESS

In order to fulfill the objective, a seamless approach to integrate people, process and information for End-to-End visibility through engagement and active participation of Hyper connected workforce of NSGM stakeholders in the role of knowledge workers.

The NSGM stakeholders have to function as an enterprise team so that the KNOWLEDGE GRID serves as the full-fledged interactive and dynamic resource base for a Technical, Educational, Administrative, Managerial 'Informed Decision Making' process. The big picture could continue to grow bigger and bigger as the canvas of NSGM expands with more and more participants entering into the arena. No team member would be left to work in isolation and NSGM would become the vehicle of progressively enriched actionable knowledge.

Processes, Sub-processes and activities of NSGM have common characteristics. A standardised approach with common code of Best Practices could be adopted throughout the life cycle.

CODE OF PRACTICE:

This document need to be developed to define the best practices and procedures required to be followed for SMART GRID KNOWLEDGE GRID.

PILLARS of KNOWLEDGE GRID:

INFORMATION ENVIRONMENT

The Data profile of NSGM would have the texture of BIG DATA in terms of Volume, Variety and Velocity.

The Volume is ever increasing exponentially from Mb to Gb to Tb to Pb to Exab to Zetab..and so on.

The Variety of Data spans from STATIC/Historic to PROGRESSIVE/Periodically updated to DYNAMIC/Near Real time and even Real time data. The velocity of Data flow could be in sync with the process, spanning from nanoseconds to mill seconds to seconds to minutes, hours, days, weeks, months etc.

Distributed information and diverse knowledge from wide variety of sources presently residing in silos with non standardised/individualized/proprietary formats need to be integrated to the KNOWLEDGE GRID. Wherever required, standard codification of data elements is to be done for seamless information exchange.

INFORMATION FLOW

The flow of Information would be through multiple channel – One to One, One to Many, Many to Many

INTEGRATION

In the prevalent scenario of multiple platform, appropriate Application Programme Interfaces, Data Integration Tools, Web interface, Web services would help integrate the information systems at various touch points of the multi-tier structure.

DOCUMENTS

A repository of Articles, Reports, Standards, Specifications, Diagrams, Schemes, White papers, Orders, Notifications, Guidelines, Regulations, Policies, Best practices, Case Studies, Disaster Recovery Measures/Contingency Plans, Strategic/Tactical/Operational Decisions, Minutes, Presentations, Course content etc. could be created and managed by a Document/System, Content Management System.

WORK FLOW

The process of Approvals/Sanctions/Disbursements/Debt Servicing, programme/project monitoring, Progress/Status/Exception reporting etc. could be automated and made on-line for efficient and secure processing. A.propriate authorization mechanisms with various levels of privileges would be put in place

DASHBOARDS

Advanced analytical tools could be used to create scheduled, Ad-hoc and On-demand Dashboards with appropriate mobility feature for High level reporting ANYTIME, ANYWHERE.

DATA DISCOVERY

The analytical eco system could ensure much sought after data discovery from "Known Known" to "Unknown Unknown" through predictive analytical tools and 'What if' analysis.

INFORMED DECISION MAKING

Problem database, Decision database, Lessons learnt and Shared experience/feedbacks coupled with sharing of experiential knowledge of decision makers in specific cases would ensure an effective decision making process for problem solving using data mining, text mining, and predictive tools.

MESSAGING and ALERTS

Automated messages could be generated and alerts could be prompted for target destinations with mobile facility based on predefined parameters and variable conditions so as to ensure adherence to schedules and compliance to standards besides timely tactical/operational measures.

EXPERT SYSTEMS

Project/Programme management tools and techniques, Document Management tools and techniques, Communication Management tools and techniques, Human Resource/Skill Management tools and techniques, Change Management tools and techniques, Risk Mitigation advisory/Tools & Techniques, Skill Inventory, Competency mapping/Analysis, Impact analysis, Idea Bank, Bulletin Board, discussion forums, web casting/webinars, e-classes, e-workshops, e-meetings, Social Media interface could be put in place.

COLLABORATION AND KNOWLEDGE SHARING

A multiuser collaboration tool would facilitate knowledge sharing by stakeholders/experts of diverse domains of various organizations.

PARTCIPANT COMMUNITY

The stakeholders of the KNOWLEDGE GRID would have multiple roles as custodians, contributors and consumers of knowledge. KNOWLEDGE GRID is functionally dependent on HUMAN GRID overlain on a digitally enabled platform with man machine interface. The participating members of KNOWLEDGE GRID could include, among others,

I. All enterprises/DISCOMs
II. Administrative Ministries - MoP, MoUD, MNRE, MHI, MoF, MoEF, NITI AYOG
III. Regulators - CERC, JERC, SERCs
IV. Equipment Manufacturers and Associations - IEEMA, Vendor community
V. System Integrators, Service providers, Industry partners
VI. Academic/Research Institutes – IITs, CPRI, TERI, VJTI
VII. Related Power Sector PSUs – POWERGRID, SECI, IREDA, PFC, PTC
VIII. Societies & Forums – FOR, ISGF
IX. Institutions and Autonomous Bodies – BEE, BIS, TEC, NCIIPC, CERT-In
X. Consumer Forums
XI. Citizens
XII. Media

The platform is primarily conceived as a large network of closed user community. However access can be selectively extended to specific guest users on request and registration, authorization and authentication.

SECURITY

Information Security Management System ISMS need to put in place at respective participating organisations to ensure security of the system. Cyber Security practices and measures have to be followed for risk mitigation.

CUSTODY OF DATA

Local archiving/updating/validation of source data of various organizations/institutions could be the responsibility of individual custodian of data and could be done at respective distributed data centres.

MAINTENANCE OF SYSTEM

The system could be maintained by a dedicated team of professionals/industry specialists /domain experts.

DISASTER RECOVERY/BUSINESS CONTINUITY

HOT standby with 100% redundancy for data archiving facility would be required at distant geographical location of different seismic zone.

WHERE" SMART GRID KNOWLEDGE GRID will reside………

The KNOWLEDGE GRID could have a distributed architecture with the central application hosted in a secured environment of cyberspace with remote access facility to users through MPLS VPN or Broadband internet/Leased line/WiFi connectivity.

AHosted/On-Premises/Private cloud environment is preferable for which one option is NPMC at MoP, where the basic infrastructure with broadband connectivity already exists.

"HOW" SMART GRID KNOWLEDGE GRID will be established………….

A time bound professional approach need to be taken for establishment of SMART GRID KNOWLEDGE GRID. This could be established progressively through project management technique and practice since inception to implementation.

Various activities of planning involve:

I. Formulation of policies
II. Determination of modus operandi
III. Standardisation of Process
IV. Definition of Responsibility Matrix
V. Preparation of detailed Activity Schedule
VI. Identification of Funding Mechanism – Assistance from NSGM outlay is one option

The SMART GRID KNOWLEDGE GRID may established through PPP model.

"HOW TO MAKE A QUICK START" FOR SMART GRID KNOWLEDGE GRID

To start with, a prototype/pilot Knowledge Grid can be undertaken with the help of the experience gathered and information collected from the ongoing Smart Grid Pilot project initiatives at various states.

"WHEN" SMART GRID KNOWLEDGE GRID will be established………..

The time period for implementation of SMART GRID KNOWLEDGE GRID from zero date could be 10-12 months so that the platform is ready by the time one of the ongoing project is ready. The implementation process can start after tendering process is completed. However, preliminary activities e.g Idea sharing/opinion building, Survey of Data profile, Knowledge Management Policy Framework, Structure of Knowledge Bank etc. can be started

"WHO" will lead the initiative of SMART GRID KNOWLEDGE GRID………..

A dedicated team need to be formed for this purpose. ISGF may be assigned the role of nodal agency/Project Implementation Agency from concept to commissioning.

"WHAT WILL BE SOURCE OF FUNDING" of **SMART GRID KNOWLEDGE GRID**

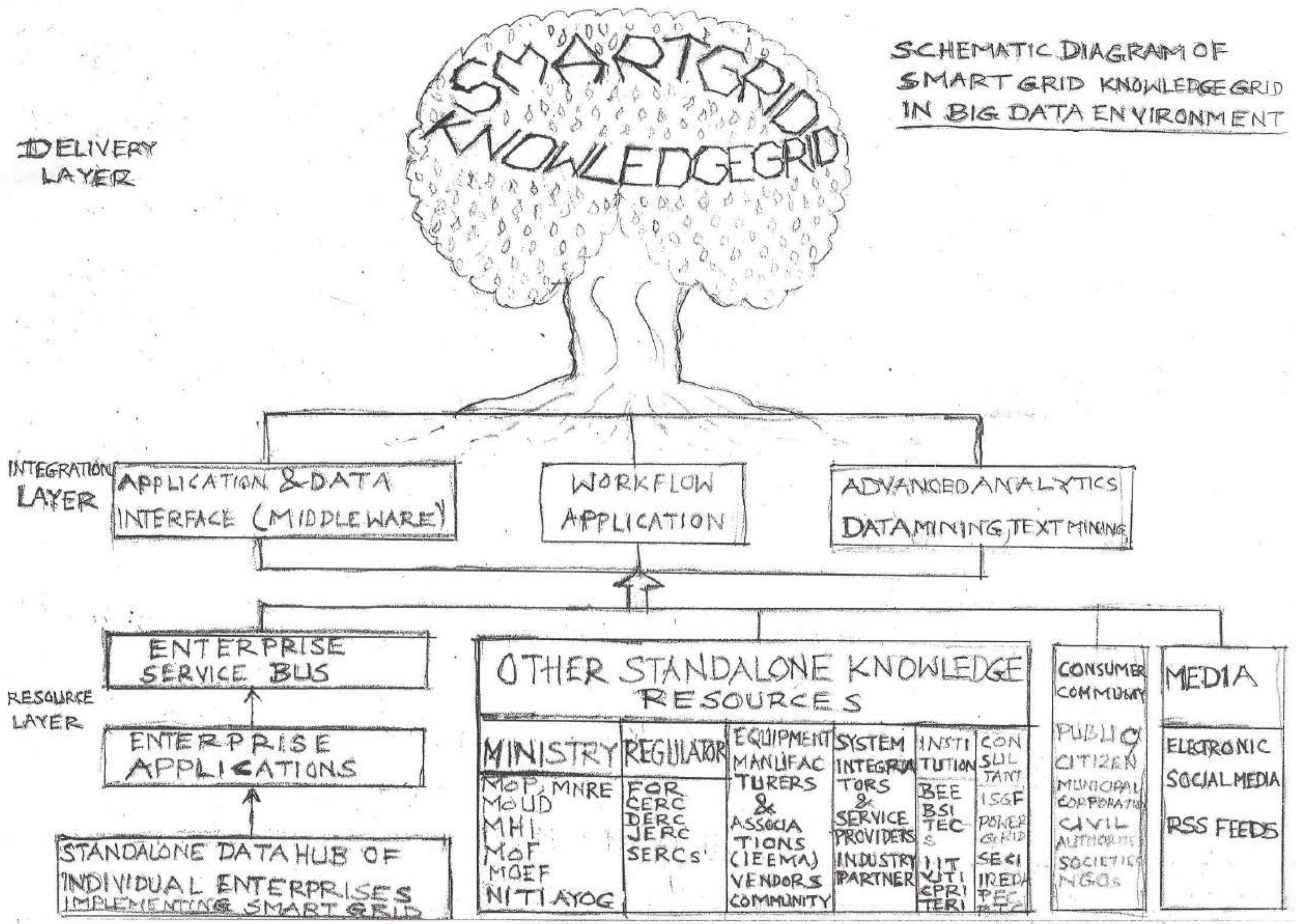
Once the In-principle approval is obtained to go ahead, the provision of outlay of NSGM may be utilized for this initiative.

RESOURCES

A designated team with members representing various stakeholders may be constituted and responsibilities assigned for tasks associated with SMART GRID KNOWLEDGE GRID.

CONCLUSION

The initiatives of R-APDRP and Smart Grid pilot projects has set the environment of transition from traditional predominantly manual process oriented system to modern ICT enabled process of managing the system of energy management by DISCOMs at the end user level. SMART GRID KNOWLEDGE GRID could go a long way to bridge the gap between present scenario of islands of information and future requirement of seamless flow of ideas and experiential knowledge through a collaborative digitally enabled and professionally managed platform for Smart Working and Innovation/Decision Making. This has to be collectively achieved through a well planned Change Management Process across the complete value chain and inter organizational/institutional framework.


SCHEMATIC DIAGRAM OF
SMART GRID KNOWLEDGE GRID
IN BIG DATA ENVIRONMENT
SMARTGRID
KNOWLEDGEGRID
DELIVERY
LAYER
INTEGRATION
LAYER
APPLICATION & DATA
INTERFACE (MIDDLEWARE)
WORKFLOW
APPLICATION
ADVANCED ANALYTICS
DATAMINING, TEXT MINING
RESOURCE
LAYER
ENTERPRISE
SERVICE BUS
ENTERPRISE
APPLICATIONS
STANDALONE DATA HUB OF
INDIVIDUAL ENTERPRISES
IMPLEMENTING SMART GRID
OTHER STANDALONE KNOWLEDGE
RESOURCES
MINISTRY
MoP, MNRE
MoUD
MHI
MoF
MOEF
NITI AYOG
REGULATOR
FOR
CERC
DERC
JERC
SERCs'
EQUIPMENT
MANUFAC
TURERS
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ASSOCIA
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VENDORS
COMMUNITY
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CITIZEN
MUNICIPAL
CORPORATION
CIVIL
AUTHORITIES
SOCIETIES
NGOs
MEDIA
ELECTRONIC
SOCIAL MEDIA
RSS FEEDS

Internet of Things Gateway Platform and Applications

A discussion of challenges in designing an IoT gateway and designing a generic Gateway platform

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***Abstract*— The promise of efficient and intelligent use of resources enabled by IoT has raised the expectations of the technical as well as the consumer community. Internet of Things (IoT) entails adding sensing capability and internet connectivity to everyday objects (Things) around us making them a network node. However it's not always possible to connect the IoT nodes directly to the public internet due to power or computational limitations. IoT Gateway help connect Things to broader internet by using connectivity technologies suitable for resource limited Things. There are a myriad of technologies which can be used for communication between Things and Gateway. Similarly there are multitudes of protocols to further connect IoT gateway to cloud application. There are many more challenges in designing an IoT Gateway like security, authentication and provisioning. It is not trivial to make the correct choices for a specific application. In this paper, we present a flexible architecture for Internet of Things Gateway Platform known as "Wireless Bridge" which supports different wireless technologies. We will also discuss various connectivity technologies and protocols that can be used to exchange the Things data with the Cloud Application with the help of IoT Gateway platform. The ideas presented here can help in building a secure, flexible and extendible IoT Gateway.**

Keywords— IoT, Wireless Bridge, RF Sensors Nodes, 6LoWPAN, Wi-Fi, BT, NFC, Sub GHz

INTRODUCTION

IoT is a network of connected objects (Things) with embedded electronics allowing them to sense, report and controlled remotely and sometimes take simple decisions. Other terms used to define similar concepts are M2M (machine to machine communication) and IoE (Internet of Everything). The concept of objects with electronics connected to a network has been in existence for quite a long time now. At a cursory glance IoT does not look like a new concept. There are however subtle differences between IoT and classical M2M. IoT seeks to connect every device (things) that we interact with including those which are generally not connected to the network. One more difference is that it intends to leverage existing IP based networks instead of creating dedicated network infrastructure as is the practice in current generation of M2M, thus creating a global network of things. While the premise of connection to the internet increases reach of IoT, it also poses unique challenges. One such challenge is that many IoT nodes have limited memory, storage and computation capabilities and are not able to connect to the IP based networks directly. An IoT Gateway fills in this gap by acting as bridge between IP based public network and local networks designed with specific needs of the IoT nodes in mind. It can also provide additional security, storage and processing services allowing the end nodes to be as cost effective and power efficient as possible. It also enables nodes using different communication technologies to talk to each other within the network. Unfortunately designing an IoT gateway for an application with future needs in mind is a herculean task because of so many variables affecting the design. The IoT space is very fragmented with thousands of vendors and almost no widely agreed standards. There too much literature available on the subject from technology vendors each promoting their own technologies. This paper aims to provide a holistic view of all available options to the implementers without going into vendor specific protocols.

CHALLENGES IN DESIGNING AN IOT GATEWAY

Node Connectivity: We need to select a short range Radio Frequency (RF) technology to connect to the IoT nodes. This selection is dependent on the various parameters like frequency band, modulation scheme, channel number, data-rate, latency, robustness etc. Additionally this decision is also dependent on local regulatory requirements. The selection is easier when we have a homogenous network having same types of nodes but become much more complicated when we have multiple types of nodes with different requirements.

Backend Connectivity: The IoT Gateway may use short range radio technology to connect to the IoT nodes but a long distance link is needed to connect to the internet. This selection is based on bandwidth requirements, available connectivity options in the area and criticality of the application. Since connectivity options vary from area to area, it's a good idea to have multiple backend connectivity options

Management Server: IoT nodes are not generally accessed (through the gateway) on the internet as standalone entities. It's more prevalent to have a central server manage the nodes, while IoT gateway facilitates this communication. We need to identify protocols for communication with the management server

Local intelligence: In a true cloud architecture, nodes send all the data to the cloud for processing and control. However this is not an ideal scenario to send useless data to the cloud because this results in wasted bandwidth, extra load on server and data loss in case of connectivity outage. The concept of edge computing solved this problem. If IoT Gateway can take most of the decisions locally and send only the filtered data to the cloud, it can make the system more efficient. The gateway decision logic may be programmed by the server for flexibility. The amount and type of local intelligence is application dependent and must be given deep thought as it would affect the gateway design decisions.

Power considerations: The power source of gateway and source also affects our decisions in related to the above points. As sensor networks become more prevalent and embedded in things they would need to be as unobtrusive as possible scavenging power from its environment.

Security: This is a factor that can make or break the success of large scale IoT networks. As these networks become part of more application (some of them critical in nature), security will assume paramount importance. Security should be a factor at every stage of design process, it's a mistake to add security after everything else has been designed.

Serviceability: This is an often ignored requirement. A look at history tells us that no system is perfect. Irrespective of the amount of pre deployment testing done, bugs and security loopholes would be found invariably after deployment. There must be a provision to service and update the IoT gateway (and nodes) in the field. There should not be sole dependence of remote serviceability, we should have additional connectivity options to service the installation.

Let's discuss some of these points in detail with available option. We would also discuss in what scenario each of these options may be used.

NODE CONNECTIVITY TECHNOLOGIES

In current landscape, many communication technologies are well known such as Bluetooth, Wi-Fi, NFC, ZigBee. There are also several new emerging networking options such as Sub GHz, Thread, ANT, Z-Wave that can be readily used for smart home, smart city, smart lighting, and smart metering applications.

Depending on the application, factors such as operating range, power consumption, data rate, operating frequency, battery life will dictate the choice of one or more from combination of the technologies. The table below draws a comparison of features of the major communication technologies on offer today. Comparison of these technologies in given in the table 1.

BACKEND CONNECTIVITY

Connectivity to the management server (backend) involves selection of backhaul connectivity technology as well as protocols for connecting to backend. Backhaul connectivity refers to the long range connection of the IoT Gateway to the ISP endpoint. Cellular technologies like 2G/3G/LTE are the most popular options. However we may use PLC (power line communication) for smart street lights or other applications involving power lines. Optical fibers can be used for applications requiring high bandwidth. For remote areas not covered by cellular connectivity options like satellite links or microwave point to point connections may be used.

Communication Protocol

There are many communication protocols which can be used by the IoT gateway to communicate with the cloud application. Here we discuss some of the more popular technologies along with their pros and cons.

Plain HTTP: This is by far the most ubiquitous protocol. It's widely accepted by servers and being backed by internet standards has least compatibility issues. It also maps naturally with the RESTful APIs. However it suffers from large overhead in form of HTTP headers and text based format. It is stateless despite being run on top of TCP. That makes it unsuitable for real-time usage. The client must send a request in order to get a response (command) from the server. Client has to keep polling for updates from the server.

CoAP: Constrained Application Protocol can be considered to be binary version of HTTP. It improves on some limitations on HTTP. It has very concise headers and supported binary data format thus reducing the overhead. It can be used on top of TCP or other transport as well even SMS. CoAP packets can be easily translated to a HTTP packet. However because of negligible internet infrastructure support it does not play well with firewalls, proxies and routers. Thus this protocol is only suitable for private networks typically inside the sensor network.

Web sockets: It is a new protocol also backed by web standards. It has the same addressing and handshake mechanism as used by HTTP. Thus making it compatible with existing network infrastructure. Once handshake is complete it switches to duplex communication on top of TCP. This makes it suitable for real time, two way communication. It's especially suited in shared hosting environments and gateways operating behind proxies.

MQTT: Is also a popular protocol running (optionally) on top of TCP. It has a topic subscriber model. Though more suited for broadcasting messages to interested gateways, it's also used for gateway to server communication. It has some features like last message persistence and will and testament message that make it useful for IoT application.

AMQP: This perhaps is the most suited protocol for gateway server communication. This protocol acts as a storing queue and ensures that packets are not lost, even in case of temporary outage.

XMPP: Extensible Messaging and Presence Protocol is a popular protocol used by chat clients for real time communication. It standardizes lot of things like user authentication and message IDs. However owing to its complex specification and exchange of data using verbose XML format makes it unsuitable for IoT application.

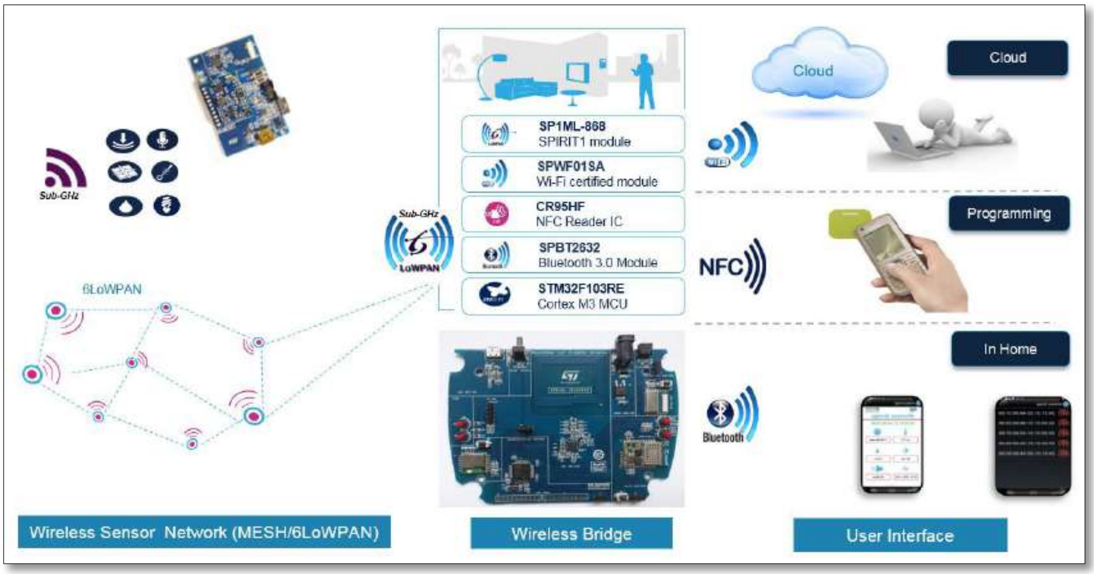

Figure 1 : STMicroelectronics Wireless Bridge Solution

IoT Gateway Platform Architecture

We here present a flexible design created by us for sensor data monitoring and control. The application is a generic one without special requirements for security or reliability.

Wireless Bridge IoT Gateway: Wireless Bridge is STM32 based IoT Gateway Platform solution as shown in figure 1 having different connectivity technologies. The system comprises of Bluetooth, Wi-Fi, Sub-GHz and Near Field Communication. Each of the communication technologies has its own benefits. Wi-Fi is used for exchanging Things or Node data on the Cloud Platform through Gateway Platform. Bluetooth is used for communicating the Things or Node data with the Android App through Gateway Platform and Sub-GHz is used for exchanging data between Gateway Platform and Things or Node. Bluetooth Wi-Fi and Sub-GHz modules are used in the Wireless Bridge platform which communicates with the STM32 on UART communication lines and NFC transceiver communicating with STM32 on SPI lines. The main challenge for STM32 microcontroller is to work with different communication devices without delay, serving all the request efficiently. The above architecture helps us to meet different use case requirements on different communication technologies. An Application layer is added on the Gateway solution that acts as bridge between the Cloud Application and Things. Contiki OS is used for the 6LoWPAN network. Smartphone application communicates with the Gateway board over the Bluetooth interface.

Key Communication Elements

Sub-GHz Module: The communication between the Gateway and Things is based on Sub-GHz using SPIRIT1 module on 6LoWPAN networks. SPIRIT1 module are ultra-low power & fully integrated RF modules operating respectively in the 868 MHz / 915 MHz ISM bands. These modules are based on the SPIRIT1 RF sub-GHz transceiver (with integrated SMPS), STM32L1 microcontroller, integrated filter/balun and chip antenna. The UART host interface allows simple connection to an external microcontroller with a standard firmware, allowing AT commands to facilitate RF configuration, data transmission and reception, using simple point-to-point communication.

Wi-Fi Module: The Wi-Fi module connects the Wireless Bridge Gateway with the Cloud Application. The SPWF01Sx intelligent Wi-Fi module is a standalone plug and play 802.11 b/g/n solution with integrated PA and an STM32 32-bit microcontroller. The modules also incorporate clock and voltage regulators.

Near Field Communication: The Gateway has CR95HF transceiver used as NFC reader/writer device to communicate with the NFC Passive Tag on the Things for configuration purpose. CR95HF is 13.56-MHz multi-protocol contactless transceiver device.

Bluetooth Module: The SPBT2632Cxx Bluetooth module provides complete RF platform in a small form factor. It is used in home automation applications for communicating with Bluetooth devices and smart phones.

Things Architecture

Things in this solution are based on Multi Sensors-RF platform which has 2 parts (STEVAL-IDI002V2 and STEVAL-IDI003V2). STEVAL-IDI002V2 is the master board consisting of a STM32L1 Cotex-M3 microcontroller, dual-EEPROM and Sub GHz Communication interface. STM32L1 runs Contiki3x based 6LoWPAN stack. It's selected because it has very low power requirements. Dual Interface EEPROM enables the Multi sensor RF platform to store the data from the sensors and gives an option to the user to access this data using a NFC enabled Smart Phone.

STEVAL-IDI003V2 consists of a multiple sensors like MEMS Accelerometer, MEMS Pressure sensor, MEMS Humidity sensor, MEMS Microphone and light sensor. The whole system can be powered by single cell Li-Ion battery.

Figure 2 : RF Sensor Node (Thing)

The Multi sensor-RF platform works as 'Thing' and the Sub-GHz module on the Wireless Bridge (Gateway) acts as a Root Node in the 6LoWPAN network. The sensor node reads the sensor data and transmit to the Root Node through the 6LoWPAN network. The node also has GPIOs which can be used to control actuators.

The IoT gateway has local and remote connectivity options to access sensor data and actuator on the nodes (Figure 4)

Web Access: A remote user can view sensor data and send command for the actuators using the web interface provided by the Management Server.

Android Application: A local user can access the nodes using the Bluetooth connectivity on smart phones. A mobile app can be used to pair the phone to Wireless Bridge platform and access the node functionality.

NFC Support: Wireless Bridge has NFC reader/writer support. This functionality can be used to configure the nodes (radio channel etc.) and Gateway (Wi-Fi and BT settings etc.)

Design of Management Server Application

We also designed a cloud application called ST CloudBridge that works as a bridge between sensor / actuator Things or Nodes and the end user. The block diagram of the Cloud Application is shown in figure 3. The Things or Nodes upload the data to the ST CloudBridge and fetch command and configuration information. The end user can monitor the sensor data stream. User can also set alarms for various situations. The platform also enables provisioning, control and configuration of the nodes. Cloud Bridge has two major parts: device module and web module. The device module interacts with the sensor / actuator nodes and the web module handles the web and mobile clients which are used by end users. The modules interact with each other using shared objects or cloud service bus. The solution runs on top of Azure websites platform. The Cloud Application has security features which allow to work with the registered nodes only so that data integrity is not compromised. The Cloud Application exposes standard REST based APIs that can be consumed by "Things" via the IoT Gateway.

It's important for an IoT management application to support multiple protocols. We must have modules for device management, monitoring, reporting and provisioning. IaaS is a preferred way of hosting cloud applications because of inherent load variability of IoT applications. Many cloud providers are now providing IoT specific services making the development and maintenance of IoT applications even more convenient.

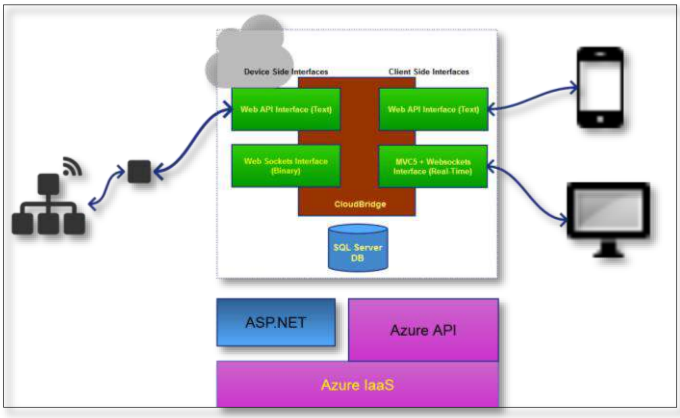

Figure 3 : Cloud Application for Node Management

APPLICATIONS OF INTERNET OF THINGS

Home Automation

Smart Home: These applications allow users to monitor and control security devices and home appliances remotely. It also allows for efficient energy usage by automatically shutting down appliances when the user is not home.

Smart City

Smart Street Lights: Monitoring of parameters like ambient light and traffic can allow us to control the brightness and timing of lighting providing substantial energy saving. Any failures light can be immediately reported and rectified to avoid accidents and crime incidents.

Smart Metering: Wirelessly connected meters enable remote meter reading along with applications like differential tariffs and two way metering. Such meters can also detect and report theft and other power leakage in circuits.

Smart Parking: Enabled by proximity sensors, this is yet another IoT application. Jams and bottlenecks can be avoided if users can get vacant parking information in advance. Users can also be charged more accurately on basis of parking time.

Smart Agriculture: Accurate moisture and nutrient monitoring can indicate when watering or fertilizers are needed. It can save water and fertilizer costs while also improving the production substantially. Coupled with weather forecast such systems can prove to be really helpful for farmers.

Healthcare

This is an upcoming area where IoT can bring revolutionary changes for the end users. Various wearable sensors collect patient's vital parameters such as temperature & blood pressure and transmit it to patient's online health profile via IoT Gateway. This allows for an accurate history of parameters to be maintained. This data correlated with patient's health history is a powerful tool in hands on healthcare professionals. The data can be analyzed in real time and in case of an emergency, swift action can be taken to provide immediate care to the patient.

Industrial

IoT can play an important role in monitoring and optimization of industrial processes. The availability of low power sensor nodes open new avenues in the Industrial automation which was earlier challenging. It's also useful in areas where human presence is hazardous and sometimes not possible.

CONCLUSION

We proposed a general-purpose IoT gateway working with Smartphone and Cloud Application connected to Things on 6LoWPAN network. The Things are connected to IoT Wireless Gateway on IPv6 network. The system solution can be customized for different application use cases. Availability of high quality open source mesh networking stacks like Contiki has helped the proliferation of IoT into consumer space. Security still remains a challenging subject implicit to all the IoT applications. The existing security techniques are holding well, but as IoT networks become more prevalent we would unearth more challenges. Communities are still working to find better low cost / low power solutions that will lead to a secure IoT network. Advances in the semiconductor manufacturing process, decreasing cost and better power management along with energy harvesting would be another gate opener in IoT space.

Technology	**Standard**	**Band**	**Range**	**Power**	**Data Rate**	**IoT Applications**
Bluetooth	Bluetooth 4.x specification	2.4 GHz	Medium 50-150m (Smart)	Medium Low (BLE)	Medium 1Mbps	Wearable devices Sensors Nodes IoT application
Wi-Fi	802.11b/g/n/ac	2.4 / 5 GHz	Medium 50m	High	High 500Mbps to 1Gbps	IP Camera Gate way devices
NFC	ISO/IEC 18000-3	13.56MHz	Low 10cm	Low	Low 100–420kbps	Access Management BT/Wi-Fi pairing e-Tickets Payment
Sub GHz	802.15.4 6LowPAN	868 MHz / 915MHz	High	Low	Low 500kbp	Smart Street light Energy meters Smart Building
Zigbee	802.15.4	2.4GHz	10-100m	Low	Low 250kbp	Smart street light Smart Building
Z-Wave	ITU-T G.9959	900MHz	30m	Low	9.6/40/100kbit/s	Home automation
Thread	802.15.4 and 6LowPAN	2.4GHz	N/A	Low	250kbp	Home automation

Table 1 : Comparison of Wireless Connectivity Technologies

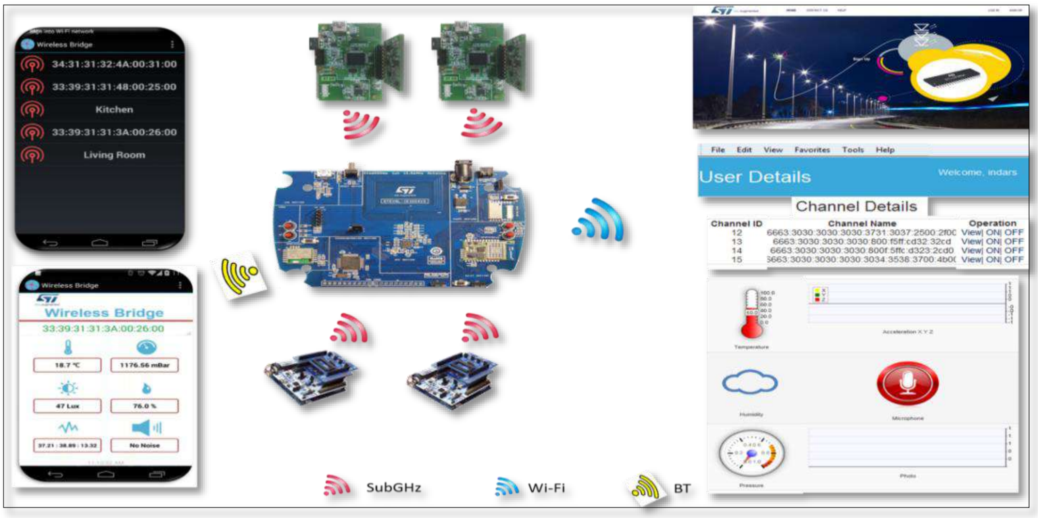

Figure 4: IoT Gateway Interfaces

Smart Grids and Cyber Security in India

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***Abstract*—Abstract of your technical paper**

In 2014 the Indian Government launched the Digital India scheme to empower citizens, boost the economy and improve delivery of services through e-governance initiatives by way of a pan-India programme. Also, in 2014 the government initiated the 100 Smart cities mission with the goal of making Indian cities 'smart' by using ICT driven solutions, along with big data analytics. The establishment of smart grids can be a key component for both digital India and the smart city schemes as the present grid losses are one of the highest in the world at up to 50%[1] and costing India up to 1.5%[2] of its GDP. At the same time the introduction of a smart grid brings with it certain security risks and concerns particularly to a nation's cyber security[3]. Though cyber security is being discussed in reference to these schemes - for example a National Cyber Coordination Centre[4] in place is being established under Digital India and the Smart City Concept note references the importance of secure smart grids - the conceptualization of these schemes and the existing regulatory framework in India do not seem to adequately take into consideration the cyber security implications of a smart grids network.

Through literature review and policy review this paper will look at the role of smart grids in these schemes, cyber security issues plaguing them and would recommend solutions to address cyber security needs and achieve the objectives of Digital India and Smart Cities.

Keywords—Keywords from your abstract

Smart Grids, Cyber Security, Policy, Digital India.

Introduction: Smart Grids in India

In 2014, the ambitious flagship programme, Digital India, of the Indian Government which paves way for a digital data avalanche in the country was announced. An integral component of the project is a well-designed digital infrastructure ensuring high connectivity and integration of services.[5] This aims to have a transformative impact on the economy and the industry, where the potential areas of developing good digital infrastructure are smart cities, smart homes, smart health, smart energy and smart grids, to list a few.[6] Likewise, the 100 Smart Cities Mission envisions changing the face of urbanization in India, to manage the exponential growth of population in the cities by creating smart cities with ICT driven solutions, along with big data analytics. Smart grid technologies are key for both Digital India and the Smart City schemes as "IT-enabled smart grids can have tremendous impact on the energy sector in India — right from power generation to power consumption", as quoted by Shri Piyush Goyal, Power and Coal Minister at the Digital India Conclave 2014.[7]

A Smart grid is a promising power delivery infrastructure integrated with communication and information technologies which enables monitoring, prediction and management of energy usages. It comprises digital communication, information technology and an automated system to advance energy and environmental sustainability through the

1 http://www.teriin.org/upfiles/pub/papers/ft33.pdf

2 http://economictimes.indiatimes.com/new-sections/energy/the-loss-of-power/lifenologyshow/44083310.cms

3 draft concept note on smart cities

4 http://economictimes.indiatimes.com/news/defence/government-clears-setting-up-of-national-cyber-coordination-centre/articleshow/46864939.cms

5 http://www.cmai.asia/digitalindia/

6 https://www.kpmg.com/IN/en/IssuesAndInsights/ArticlesPublications/Documents/CII-CONNECT-2014-final.pdf

7 http://www.newspatrolling.com/digital-india-conclave-2014-delivers-a-robust-framework-to-accomplish-the-revolutionary-dream-of-a-digital-nation/

integration of vast distributed energy resources.[8] Establishment of smart grids becomes highly important for the Indian economy as the present grid losses are one of the highest in the world at upto 50%[9] and costing India upto 1.5%[10] of its GDP. India operates one of the largest synchronous grids in the world – covering an area of over 3 million sq km, 260 GW capacity and over 200 million customers with the estimated demand of India increasing 4 times by the year 2032.[11]

In the year 2013, the Ministry of Power (MoP), in consultation with India Smart Grid Forum and India Smart Grid Task Force released a smart grid vision and roadmap for India[12], a key policy document aligned to MoP's overarching objectives of "Access, Availability and Affordability of Power for All".[13] It lays plans for a framework to address cyber security concerns in smart grids as well. To achieve goals envisaged in the roadmap, the Government of India established the National Smart Grid Mission[14] in the year 2015 for for planning, monitoring and implementation of policies and programs related to Smart Grid activities. [15]

A number of smart grid projects have been introduced, and are currently underway. KEPCO in Kerala has established smart meter/intelligent power transmission and distribution equipment system in the year 2011 and the smart grid operations focus on peak reduction, load standardization, reduction in power transmission/distribution loss, response to new/renewable energy and reduction in black-out time . Currently, it is working towards establishment of a real-time rating system and working on an integrated operation of electric power network.[16] Gujarat was introduced to India's first modernized electrical grid in the year 2014, to study consumer behaviour of electricity usage and propose a tariff structure based on usage and load on the power utility by installing new meters embedded with SIM card to monitor the data.[17] The BESCOM Project in Bangalore envisaged the Smart Grid Pilot Project for integration of renewable and distributed energy resources into the grid.[18]

Cyber Security challenges

At the same time, the introduction of a smart grid brings with it certain security risks and concerns particularly to a nation's cyber security.[19] Increased interconnection and integration may render the grids vulnerable to cyber threats, putting stored data and computers at great risk. With sufficient cyber security measures, policies and framework in place, a Smart Grid can be made more efficient, reliable and secure as failure to address these problems will hinder the modernization of the existing power system.[20] Smart Grids, comprising of numerous

8 http://ieeexplore.ieee.org/xpl/login.jsp?tp=&arnumber=6129371&url=http%3A%2F%2Fieeexplore.ieee.org%2Fxpls%2Fabs_all.jsp%3Farnumber%3D6129371

9 http://www.teriin.org/upfiles/pub/papers/ft33.pdf

10 http://economictimes.indiatimes.com/new-sections/energy/the-loss-of-power/lifenologyshow/44083310.cms

11 http://www.dot.gov.in/sites/default/files/u8/Reji%20Kumar%20Smart%20Grids%20DoT%20(3).pdf

12 http://www.engerati.com/sites/engerati/files/Smart%20Grid%20Vision%20and%20Roadmap%20for%20India.pdf

13 http://www.dot.gov.in/sites/default/files/u8/Reji%20Kumar%20Smart%20Grids%20DoT%20(3).pdf

14 http://powermin.nic.in/upload/pdf/National_Smart_Grid_Mission_OM.pdf

15 http://pib.nic.in/newsite/PrintRelease.aspx?relid=121331

16 https://home.kepco.co.kr/kepco/EN/B/htmlView/ENBEHP002.do?menuCd=EN020502

17 http://timesofindia.indiatimes.com/city/ahmedabad/Gujarat-to-get-countrys-first-smart-grid/articleshow/26930091.cms

18 http://www.greatlakes.edu.in/gurgaon/sites/default/files/SMAR_GRID_CHALLENGES.pdf

19 draft concept note on smart cities

20 http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.462.4054&rep=rep1&type=pdf

communication, intelligent, monitoring and electrical elements employed in power grid, have a greater exposure to cyber-attacks that can potentially disrupt power supply in a city.[21]

Cyber security and data privacy are some of the key challenges for smart grids in India, as establishment of digital electricity infrastructure entails the challenge of communication security and data management. Digital network and systems are highly prone to malicious attacks from hackers which can lead to misutilisation of consumers' data, making cyber security the key issue to be addressed.[22] Vulnerabilities allow an attacker to break a system, corrupt user privacy, acquire unauthorized access to control the software, and modify load conditions to destabilize the grid. Hackers or attackers, who compromise a smart meter can immediately alter their energy costs or change generated energy meter readings to monetize it by help of remote PCs. Also, inserting false information could mislead the electric utility into making incorrect decisions about the local usage and capacity.[23]

Initiatives in India:

As cyber security is critical for Digital India and the Smart City Concept note highlights a smart grid to be resilient to cyber attacks[24], a National Cyber Coordination Centre[25] is being established by the Indian Government. Also, National Cyber Safety and Security Standards has been started with a vision to safeguard the nation from the current threats in the cyberspace, undertaking research to understand the nature of cyber threats and Cyber Crimes by facilitating a common platform where experts shall provide an effective solution for the complex and alarming problems in the society towards cyber security domain. National Cyber Safety and Security Standards is also developing innovative strategies and compliance procedures to curb the increasing complexity of the Global Cyber Threats faced by countries at large.[26]

The National Cyber Security Policy 2013 was released with an umbrella framework for providing guidance for actions related to security of cyberspace[27], by the Department of Electronics and Information Technology (DeitY).

The Working Group on Information Technology established under the Planning Commission has also published a 12 year plan on IT development in India with a road map for cyber security, stating six key priority and focus areas for cyber security including :

- Enabling Legal Framework
- Security Policy, Compliance and Assurance,
- Security R&D,
- Security Incident – Early Warning and Response,
- Security awareness, skill development and training, and
- Collaboration.[28]

[21] http://ceng.usc.edu/~simmhan/pubs/simmhan-cloud-2011.pdf

[22] http://www.greatlakes.edu.in/gurgaon/sites/default/files/SMAR_GRID_CHALLENGES.pdf

[23] http://www.ijarcsse.com/docs/papers/Volume_4/1_January2014/V4I1-0244.pdf

[24] http://india.smartcitiescouncil.com/system/tdf/india/public_resources/Concept-Note-on-Smart-City-Scheme_0.pdf?file=1&type=node&id=2229

[25] http://economictimes.indiatimes.com/news/defence/government-clears-setting-up-of-national-cyber-coordination-centre/articleshow/46864939.cms

[26] http://ncdrc.res.in/organization-profile.php

[27] http://deity.gov.in/sites/upload_files/dit/files/National%20Cyber%20Security%20Policy%20(1).pdf

[28] http://deity.gov.in/sites/upload_files/dit/files/Plan_Report_on_Cyber_Security.pdf

Making Smart Grids Secure: Lessons from Bangalore

The Smart Grid project in Bangalore is piloted by Bangalore Electricity Supply Company Ltd. (BESCOM) as smart grid technologies are vital to meet growing electricity demands of the country, curb power losses, and enhance accessibility to quality power.[29] To ensure smooth implementation of BESCOM's vision, the company realised the need to put a cyber-security system in place to protect the smart grid installations in Bangalore city.

BESCOM has huge database of thousands of consumers' personal information like bank account details, payment and receipts details, financial transactions, SCADA system, power distribution and load data on systems in various servers currently located at multiple location.

All the functions will be performed and controlled through the IT system. BESCOM has come out with a separate IT security policy and dedicated trained IT cadre to safeguard its data and servers, becoming one of the few Discoms in India to take such measures for safeguarding the servers and data network from cyber crimes and threats. The organisation shall be undertaking recruitment process for hiring its IT specialist team. This would help put BESCOM's fears of unauthorized control over network leading to a complete blackout in the city, to rest.[30]

[29] http://bescom.org/en/smart-grid-vision-for-india/

[30] http://www.bangaloremirror.com/bangalore/cover-story/Bescom-braces-for-war-with-hackers/articleshow/49573782.cms

Recommendations:

As a Smart grid is a promising power delivery infrastructure integrated with communication and information technologies, advancing energy and environmental sustainability, deploying such an electric system has enormous and far-reaching economic and social benefits. Nevertheless, increased interconnection and integration tends to introduce cyber-vulnerabilities into the grid.[31]

With the evolution of cyber threats/attacks over time, it can be said that there are a lot of challenges for implementing cyber security in Indian smart grid. [32] Considering how important secure smart grids are for flagship projects in India, the existing regulatory framework does not seem to adequately take into consideration the cyber security implications of a smart grids network. Addressing the growing concerns, the government must aim to develop and adopt high level cybersecurity policy to withstand cyber-attacks. Also, India must focus on skills development in the domain of cybersecurity and have a capable workforce to achieve the targets set by Indian Government.[33] The country must look up to develop an overall intelligence framework that brings together industry, governments and individuals with specific capabilities for this purpose.[34]

The National Cyber Security Policy 2013, protecting public and private infrastructure from cyber attacks, along with all kinds of information, such as personal information of web users, banking and financial information, etc. is yet to be

[31] http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.462.4054&rep=rep1&type=pdf

[32] http://www.caeaccess.org/research/volume3/number4/shrivastava-2015-cae-651920.pdf

[33] http://perry4law.org/cecsrdi/

[34] http://www.ibnlive.com/blogs/india/saurav-jha/cyber-security-is-an-imperative-for-modis-smart-cities-10879-1130082.html

implemented by the Government properly.[35] In the Indian Power sector, the cyber security regulations or mandates are absent in the National Electricity Policy (NEP) as well as the Electricity Act 2003 and its amendment in 2007, with no reference to cyber security concerns. [36] These key legislations must be amended/ updated to take into account the growing challenges due to increased use of ICT in the power sector. The Cyber Security Policy would provide a basic framework for the institutions to make information secure and ways for adoption of the adequate safeguards.

As the concept of smart grids is still evolving in India, professional intervention various domains have pushed for adoption and development of standard process and products. Many international standard setting organisations like IEC, IEEE, NIST, CENELEC are engaged in standardization activities of Smart Grids and in India, the Bureau of Indian Standards (BIS) has been rolling out several varieties of standards targeting various technologies.[37] Therefore, BIS must develop standards taking into account the security challenges in the cyberspace as well.

Apart from policy and regulatory measure, the system on which the smart grids are built and networked must be made architecturally strong and secure. One of the areas where due attention is required is making the Supervisory Control and Data Acquisition secure. SCADA is a system that operates with coded signals to provide control of remote equipment and is entirely based on computer systems and network. Hacking this could create havoc by damaging, altering or misplacing the data.[38]

Numerous systems also employ the Public Key Infrastructure (PKI) to secure the Smart Grids and address the security challenges. [39] This can be leveraged for securing data integrity, revenue streams and service continuity. In a smart city, the smart grids that would be installed can be possible made secure at the communication layer by implementing PKI directly into meters, enabling identification, verification, validation and authentication of connected meters for network access.[40]

The key vulnerable areas prone to cyber attacks on information transmission are network information, data integrity and privacy of information. The information transmission networks must be well-designed as the network unavailability may result in the loss of real-time monitoring of critical smart grid infrastructures and power system disasters.[41]

Addressing these fast growing challenges and cyber security needs of the country by adopting suitable regulatory, policy and architectural steps would help achieve the objectives of Digital India and Smart Cities enabling “Access, Availability and Affordability for All”

[35] http://www.mapsofindia.com/my-india/government/encryption-policy-and-cyber-security-problems-in-india
[36] http://www.wipro.com/documents/facing-the-reality-of-cyber-threats-in-the-power-sector.pdf
[37] http://www.desismartgrid.com/2015/02/smart-meter-standards-in-india-new-release/
[38] http://www.bangaloremirror.com/bangalore/cover-story/Bescom-braces-for-war-with-hackers/articleshow/49573782.cms
[39] http://www.ijarcsse.com/docs/papers/Volume_4/1_January2014/V4I1-0244.pdf
[40] http://www.ibnlive.com/blogs/india/saurav-jha/cyber-security-is-an-imperative-for-modis-smart-cities-10879-1130082.html
[41] http://arxiv.org/pdf/1112.1158.pdf

IOT and M2M communications for smart Grids and Smart Cities

Subtitle: IOT smart Grids and Smart Cities- Overviews and way forward

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Abstract :

"Until recently most of the GOI policies have focused on the generation aspect of power. The focus slightly shifted to transmission and distribution under the APDRP/RAPDRP. IOT and M2M have a role to play in both but the most prolific application for these would be on the consumption aspect of power. It's not without reason that Energy efficiency is called the 5th fuel. If power policies are framed only with generation and distribution in focus, at the end of each review we will continue to say that India is a power deficit Country .The gap will always be there. The consumption aspects of power provides answers to the question – " *How are we really using the power that we are generating and distributing "?* ***Here is where there is a need for devices and systems to talk to each other and send actionable information back to the enterprise. IOT and M2M have been discussed for more than a decade now .Its only that with the advent of digitization, the usage and its value have become more relevant today. The technical paper aims to highlight the IOT/M2M concepts and its extreme importance in the consumption areas, typical solution architectures, interoperability and open source and the safety and security aspects of a fully connected environment."***

Keywords : IOT,M2M, architecture, distribution, consumption,security, open source, interoperability.

Introduction:

The Authors of the book "Trillions: Thriving in the emerging information ecology "say – "The Data are no longer in the computers. We have come to see that the computers are in the data". This sentence sums up the IOT/M2M concept perfectly.

Every new concept comes out with its own set of jargons so let's try defining some of them.

Things – Are any everyday devices which are capable of communicating with each other when connected to media or media independent networks.

M2M- Machine to machine is the exchange of the information between two or more "Things" which results in an actionable outcome.

IOT- With more "things" getting connected to each other, the information density increases so we would need much more than a local operating network to manage data and so IP takes over. The device data is now on an IP trunk and then this is displayed and controlled over an enterprise.

Smart Grids- A self-aware electrical network which responds to a given power situation in an electrical grid. A thing to remember here is that smart grids don't save power per se. They "**enable"**saving of power.

Sensors- Are "things" that gather and /or disseminate data. They could be anything from Things to monitor soil quality to blood sugar. They are cheap and can communicate directly over the internet or be tunneled over a local operating network. The key point here is that these "things" are event driven with their own processors, OS, protocols and language. All things may or may-not have the same configuration but they have the ability to exchange data over a common network.

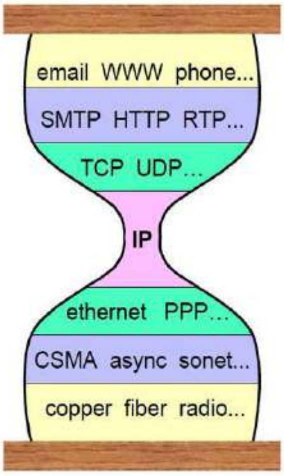
Communications – It has always been a dream for all "things "to come in over IP. The reality however is that the industry still prefers to work on two separate networks- One is a local operating network like ZigBee, RF,Z wave, wireless , M-Bus and media independent networks like home plug and Lon Works. For sending the local information over wider areas, we have GSM/GPRS/3G/ WiMAX and some really ultra –narrow band networks like SIGFOX . The narrow band networks for wide area information dissemination is particularly interesting since the sensor level networks tend to be narrow band and a narrow-narrow combination offers for an easier and cheaper integration. Why two networks? One –it still continues to be expensive to import an IP stack directly into a low cost everyday device. Two- sensor level networks tend to be more reliable than a pure IP network especially when critical data is to be transmitted. IP enables speed and volume. Device level networks enable reliability and determinism though the data size may be very small.

The IOT architecture- Every IOT /M2M architecture would ideally have three layers- the device layer (The Things part), the data aggregation layer (the point tunneling happens over IP) and the Enterprise layer (data visualization and analytics). There is no specific way to create an IOT architecture- One could start from the device layer and offer solutions till the aggregation layer. Others offer blocks of software in the enterprise layer and which allows multiple devices to get integrated into them. So it's either Bottom-Up or Top-down.

Typical applications: Sky is the limit. Homes, healthcare, buildings, automotive and transport, street lights, supply chain, manufacturing, smart grids and smart metering, environmental monitoring, agriculture, military, security and surveillance. Any place where we feel makes sense to exchange data, enable an actionable outcome and tag in a Business objective would qualify for an IOT application.

IOT Architecture

IOT architectures tend to be a bit more complex compared to other standard system architecture. The reason for that is that this domain would cover multiple applications, multiple types of devices and each of them varying in criticality and function. The other reason for that is based on the type of device in the architecture the data formats and data densities vary. For example RFID is a tag based architecture (tree configuration), the sensor tends to be peer to peer more like computers connected to the internet. So we have a mix and match of thing to a data server, thing to thing or the thing to internet. Whether a unified data addressing model will appear for IOT architecture looks difficult as of now because of the same reasons explained above. The advent of DNS allowed the device locations to be decoupled from the main services. A similar evolution is needed for the IOT architecture. With the basic challenge of getting multi-devices, multi-applications and multi-data formats into one IP back bone itself being a challenge, a unified data model for IOT would take time. So the question is how do we converge these diversities? I came across an interesting model here called the Steve Deering hourglass model for IOT.



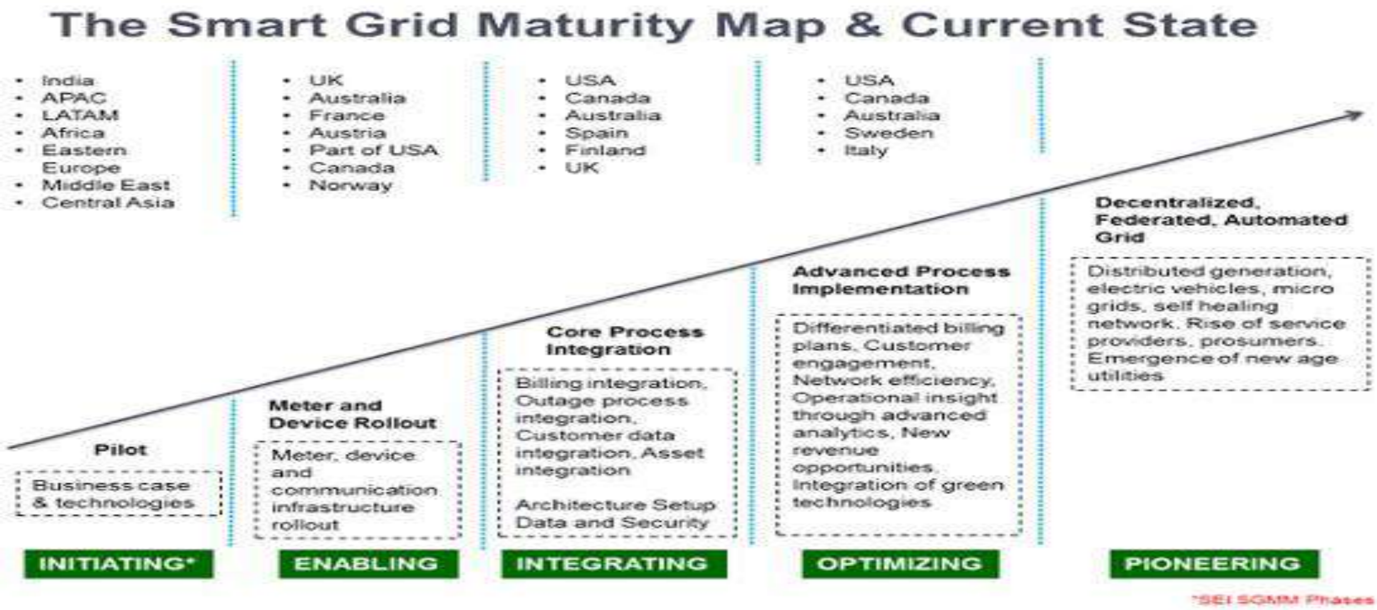
The Hourglass simply says "Everything over IP and IP over everything". In the model, we can see that it has a lower (device) layer, an upper (IP) layer and an IP "waist" where a middleware must reside. SOAP, XML and JSON still remain some common formats in which data is sent from the device layer irrespective of what protocols the devices communicate within themselves. Once we have data from the device layer on a common middleware, then tunneling over IP becomes easier.

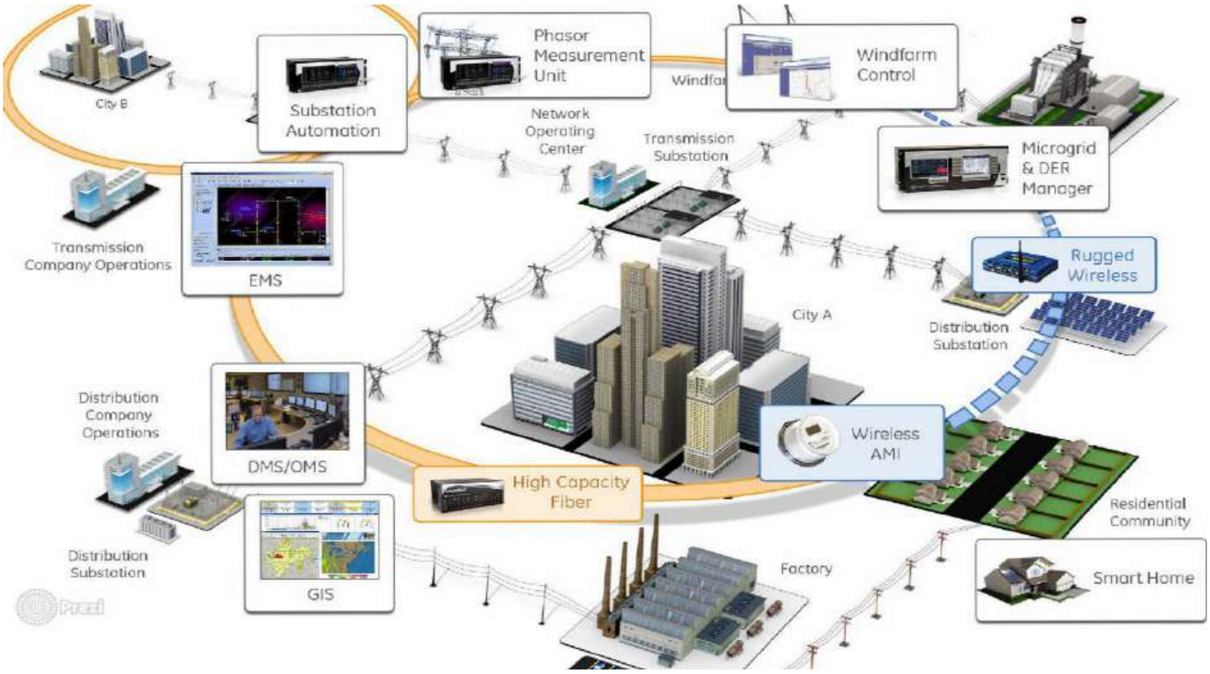
Interoperability/ Open Source and IOT

As the IOT industry evolves, we see a number of proprietary platforms emerge in the market. This is perfectly understandable since technologies tend to be disparate during early stage and then converge later. But by themselves, none of them would perhaps be able to envisage a holistic picture for a Grid or a city which is where the real value of IOT/M2M would be unleashed. However, it's important to think of neutrality from now on. DLMS and OSGP happened for smart metering and something similar needs to happen for an IOT ecosystem. DNS is again a good example here. DNS allows for distributed operation and its root servers are carried by different Organizations in different geographies. However the actual data formats in each root is agreed globally. Similarly, one may have multiple devices, multiple applications and multiple events running in an IOT application but within each device if the data point variable types are standardized, then interoperability happens. To elaborate further, we may have multiple temperature sensors, RFID etc. sold by various manufacturers, but as long as each one of those temperature sensors and RFID have a common name tag and a standard process variable type(read root as in DNS), interoperability is achieved . For this to happen there should be a lot of cooperation and understanding between the manufacturing communities. People often think that being proprietary is the best way to be profitable in business and if we open out, we run the risk of getting shut down. If that were true then how come the likes the IBM are growing their businesses year on year in-spite of the IP boom and computing being distributed? I feel interoperability is the best way to be in business.

IOT, M2M and Smart Grids

To me they are all the same. IOT and M2M applied around a Grid make it a smart grid. As the emphasis moves from power generation application to a power consumption application, the numbers of devices go on increasing. The other important aspect is linking of alternate sources of power generation to the Grid allows for a lot of interplay between devices. The Europeans and the US have had perhaps a head start for their IOT as applied to smart grids due to the deregulated power market and freedom of consumer choice. The Chinese in my opinion might not be too open to the classical idea of IOT for smart grid and may not appreciate terms like interoperability/open source etc. In India Until recently most of the GOI policies have focused on the generation aspect of power. The focus shifted to transmission and distribution under the APDRP/RAPDRP. The greatest value of IOT is realized when the consumption aspects of power are addressed. A lot of sensor networks are designed to perform optimally when more and more devices are connected to them. Buildings, Bank branches, ATMs, retail stores and food chains offer great opportunities for IOT technologies at play. The sheer volume and spread of these entities offer opportunities for energy benchmarking and other smart energy practices.

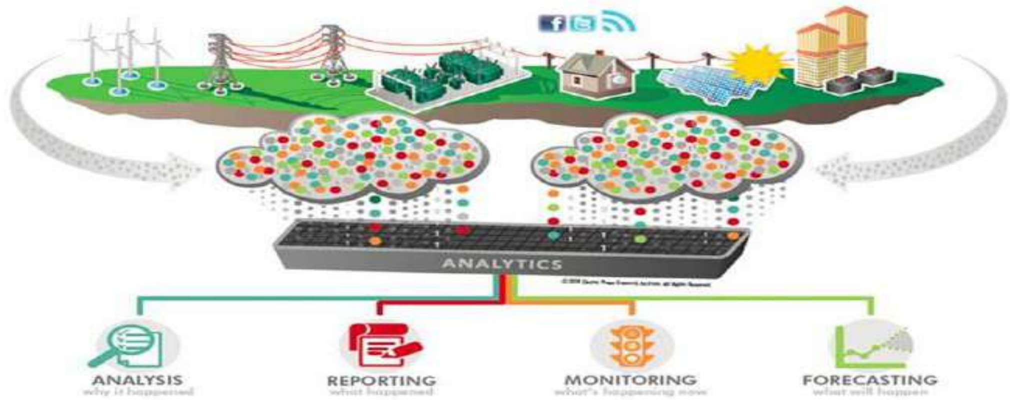




Typical smart grid architecture- Source- Axelta (www.axelta.com)

IOT/M2M , data Deluge and analytics :

It's now fairly well established on how real time data can enable grid efficiency and utilities can more quickly be responsive to the needs of the consumer. We also get to hear that although a lot of hype and noise has been created around smart grids and IOT, things have not really moved in the pace at which they should. The reason may be because the utilities understand the impact of a data deluge and are debating the preparedness of handling this deluge. Agreed there will be a lot of data coming up but are the utility IT systems geared up to handle the data? The challenge of upgrading the Utility IT systems is the main reason on why the rate of adoption is slow. The data that would perhaps be thrown out once these devices are in place would be a compound of what is there today. Now assuming that we have the infrastructure in place, how do we treat the data ie how do we see an IOT/smart grid application from an analytics point of view? Mathematically- Big data infrastructure + universal access (cloud) + data/information management + analytics equals smart grids



Apache Hadoop remains one of the most common analytics frame work because its open source The Apache Hadoop software library is a framework that allows for the distributed processing of large data sets across clusters of computers using simple programming models. It is designed to scale up from single servers to thousands of machines, each offering local computation and storage. Rather than rely on hardware to deliver high-availability, the library itself is designed to detect and handle failures at the application layer, so delivering a highly-available service on top of a cluster of computers, each of which may be prone to failures.

Security aspects of IOT

Now that we are talking about connecting everything from toasters to toilets and that too under an open environment, let's see what the security impact is and what can be done. Antivirus software helped PCs but not in this scenario. One reason why the security part took a back seat was because there was and still is no real humungous proliferation of IOT devices so while some one builds an IOT device he really doesn't worry much about security. But it's always good to be prepared. One simple way is to stop being geeks and go about blindly connecting everything to everything and analyze that towards nothing. The simplest way is to limit the number of devices that one connects to the internet. The problems with these everyday devices are that since they don't have visual displays, no one can make out even if they have been hacked into. For cities and businesses, there are a few IOT companies who have integrated security into their deliverables. Their platforms comply with leading security frameworks, employing bank-level SSL encryption on all sensitive interfaces of the platform. API end points communicate through secure socket layers (SSL/TLS) to prevent eavesdropping, tampering or message forgery. User interfaces and web applications use HTTPS-encrypted Communication to protect the privacy and integrity of data exchange.

Adopting IOT/ smart Grids in India

Let's perhaps look at the top 5 ways in which we could increase adoption of IOT in India.

1. With the current Government emphasis on smart Grids and smart cities, the major adopters of these technologies would be the Utilities and the Municipal bodies. A major challenge in working with these entities is the commercial terms. Unrealistic and Unviable commercials restrict participation of good players. Contracts get awarded to people who just say Yea to all just to get the contract .In the end we see a disaster and get to feel we were better off without all this!! The Government has acknowledged the failure of BOT and PPP models in infrastructure and has come out with a hybrid annuity model for speeding up Highway projects. We will need a similar approach for IOT/smart Grid initiatives. This way a lot of working capital issues are resolved.

2. While zero excise duty for start-ups for three years is welcome, it's also important that make in India takes off. A majority of IOT devices and platforms need to be imported. In the advent of local manufacture, the electronics have to be imported which attract import duty. How about a waiver of import duty for the parts for such projects?

3. Smart Grids and IOT tend to have complex eco systems of project management, vendor chain, engineering, device manufacturers and software. A pure IT or a pure hardware inclination or selection of implementing agencies whose basic focus is either of these may not do full justice to such projects. What we need are strong system integrators with strong project engineering and project management skills. They would need to be product and technology agnostic and have the ability to bring the best of breed technologies together.

4. While the device layer is fine, it's the GSM/GPRS/3G layer which has most data availability issues while implementation. I am sure most Utilities will agree with my point of view. There is a need to free more spectrum for those layers and "Our internet needs to be just fast enough "for the complete solution to be harnessed.

5. At a very high level, it's much more desirable and much more manageable to roll out such initiatives in Tier B and Tier C cities of India compared to the metros. The metros already have a head-start and might want to focus on making their roads wider and local transportation better. Digitization of smaller cities would result in parity of population distribution and ease burden on the tier A cities since they would be smarter and more habitable.

   With some of the best brains in Utilities and Municipalities in the Country, I don't see why all these initiatives may not take off and how !! ??

References :

1. “Trillions”: Thriving in the emerging information ecology
2. Znet.com
3. Axelta.com
4. Greentechmedia.com
5. Epri.com
6. Hadoop.apache.org
7. Exosite.com

Smart Microgrid Simulator

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***Abstract* - Localized grid, called microgrids, can help increase the resilience and mitigate grid disturbances and can thus transform a nation's existing electric grid. The challenges in the smart microgrids, because of the complexity and critical requirements of both power and communication systems demand extensive study not only in the field but more in a simulated environment, if useful solutions are targeted. This article presents the need, design challenges and methodology for developing a laboratory scale hardware simulator. The authors designed, developed and tested such a hardware simulator, which is used for active research at Amrita University, Coimbatore.**

Keywords – Microgrid Simulator, Smart Microgrid, Laboratory scale microgrid, hardware simulator.

INTRODUCTION

Large population and diminishing resources, in a country like India, demand the advent of technology to provide better life. One such scenario in electric power sector is the large supply-demand gap in electricity, that adversely affects the quality and availability of power delivered [1]. Smart grid suggests solutions to these problems through various measures like renewable resource based distributed generation (DG) and storage, dynamic load management, demand response, real time monitoring and control, etc., all made possible by integrating an intelligent information and communication technology (ICT) network [2]. This modernization of electric grid is a process that presents multitudes of challenges. Generation and transmission sectors of the power system network have already seen a large amount of ICT based intelligent techniques being applied for automation of various functionalities [3].

The distribution sector of the power system faces a wide variety of the challenges in distribution automation like distributed energy resource based electricity generation, demand management, etc. and customer integration to grid through concepts like smart meter, demand response, dynamic pricing scheme, etc [4]. These challenges are addressed in the concept of microgrids (MG) and it requires extensive studies in a laboratory environment as real field tests are not feasible due to the sheer complexity of challenges [5][6].

This article focuses on the necessity, challenges and guidelines for the design of such a laboratory scale hardware simulator for smart MG. The proposed MG simulator, a scaled down power system model, includes different generation and energy storage schemes like hydel, solar, wind, battery, pumped hydro storage etc., a bi-directional communication network with apt wired and wireless technologies like LAN, Wi-Fi, power line communication, RF, optical fibre cable etc., facility for grid connection and feeders to supply electricity to consumers.

Section 1 of the paper gives a brief introduction to the work described in the paper. The MG concept for distribution automation, its challenges and ways to tackle these are explained in section 2. Section 3 outlines the scope and design aspects of such a simulator and finally section 4 briefs out the methodology of design of such a system. Section 5 presents a laboratory scale MG hardware simulator developed at Amrita Vishwa Vidyapeetham University, Coimbatore and section 6 concludes the paper.

MICROGRID – RELEVANCE AND CHALLENGES

The ever-increasing rise in electrical energy demand and carbon emissions, related environmental impacts and diminishing natural resources have increased the relevance of grid connected renewable energy solutions. The distributed and intermittent nature of these resources demands distributed and efficient energy storages [7]. This distribution of generation and storage as well as already distributed loads (in the form of consumers) poses a great deal of challenge for real time control and management for the operation of the grid. This challenge is addressed by adopting the concept of MGs, treated as a smaller power system having scope for distributed generation, storage, transmission, loads, monitoring, protection and control devices, which can work in grid-connected or islanded mode [5][6]. There are two factors that make the MG different from a conventional distribution system. One of these is the close proximity of the generation to the loads. Second factor is the ability of MG to work in isolation from the main grid meeting all the local demand with local supply providing better reliability, self-control, power quality, and safe operation of the network [8]. With such diverse nature of operational capabilities and functionalities the MG concept presents a more complex level of monitoring, protection and control challenges in the real time operation of the grid [9].

The technical and non-technical challenges faced in the implementation of MG include islanding, operator safety, restoration and synchronization with scheduled and unscheduled shutdowns, distributed energy and storage management, protection coordination, reliability and power quality, standards, scheduling and decision priority, pricing, incentives, etc [9].

In the case of islanding or unscheduled shut down the safety of utility workers who are unaware of the presence of generation within the islanded MG is of utmost importance. Identifying the reason for islanding or shut down and taking appropriate action in real time to ensure smooth and reliable operation including synchronization, reconnection and even restoration of the grid are of prime importance [10].

Another important issue in MG's operation is the integration of renewable resources and distributed storage to the grid without affecting the stability, quality and operation of the grid. The differences in nature of integration of various renewable resources, the uncertainty and variability in the availability of these resources, limited flexibility of existing grid, status of the grid at the moment of integration, resource availability mismatch with load change pattern, etc. are major factors that challenge renewable energy integration on the grid [10].

Another major issue in the implementation of MG is the lack of established uniform standards. For the various concepts and technologies in MG well defined standards exist. But as the MG involves the use of a multitude of technologies and devices catering to various aspects of operation, the interoperability and co-existence must be ensured and for this some well-defined standards must be present [10].

The MG in the islanded mode of operation is expected to meet all its demand from the distributed generation and storages. But in the grid connected mode of operation a MG can import power from the main grid in case of deficiency in local generation or export power to the main grid in case of surplus generation. This demands efficient control schemes to allow bi-directional power flow between the main grid and the MG. This is a critical challenge that the MG control system has to deal with in real time, assisted by proper real time communication networks interconnecting the main grid control system and the MG control system [10].

An important factor on conventional grid that decides the reliability of electric power supply is scheduling, based on short term prediction of demand. In a MG scenario where the power generation depends on the intermittent schemes like solar and wind, accurate prediction is difficult. This challenge requires advanced and intelligent forecasting and dispatching environments [10].

Another important challenge that is present in MG implementation is the lack of intelligent network-wide sensing and real time communication system standards that can enhance the system performance [10].

These challenges clearly suggest the need of focused efforts leading to fruitful implementation of MG that can be achieved through intensive studies, simulations, and laboratory and field tests.

SURVEY ON LABORATORY SIMULATORS FOR MICROGRIDS

Various answers that are needed for an efficient MG implementation include penetration level of distributed generation schemes, clear operational and connection procedures during various operational scenarios of MG, reliable forecasting tool for renewable resources, strategies for handling surplus and deficit generation, integration of intelligent sensing and communication devices, etc. This invites the scope of using hardware or software based laboratory simulators for study and analysis to meet these requirements as they can provide fast, accurate, cost effective and reliable answers.

Jin-Hong Jeon et al. (2009) discussed a real time digital simulator (RTDS) based test system for MG management with a communication emulator. The test system models MG and distributed generation, controls the power flow, voltage and frequency at the point of common coupling and validates in grid connected and stand-alone modes [11].

Jacob Østergaard et al. (2012) presented RTDS based intelligent control laboratory which can be used as a platform to test and develop technologies for smart grid implementation. The system contains RTDS, a full scale SCADA system, a control room, IBM sever and phasor measurement unit lab [12].

Ji-Heon Lee et al. (2012) proposed a hardware simulator for a DC MG. The simulator has distributed sources like wind power, photovoltaic and fuel cell and storage options like super capacitor and battery. Each unit has a local controller and they communicate to the main controller, which does power management and state monitoring, using CAN or IEC 61850. The developed simulator could analyze the performance of a DC microgrid [13].

O. A. Mohammed et al. (2010) talked about a laboratory scale hardware test bed for studying connectivity issues in operational power systems. The test bed developed has capabilities to connect conventional as well as alternative power plant emulators, SCADA, communication network and control system. In addition to using the system as an analysis tool for interconnection issues it was also used as an educational tool for students for alternate energy integration and operational issues of power system [14].

Ram Mohan Reddi et al. (2010) developed a real time test bed for operation, control and cyber security related studies in power system. The work integrates RTDS, various controllers and power system devices to the test bed providing a human machine interface for monitoring and control along with server and data storage facilities for data analysis as well as cyber vulnerability studies. This setup provides an environment for testing various control algorithms in power system [15].

Chayanon Sontidpanya et al. (2011) presented an island detection demonstration on a laboratory sized power grid model, LabGrid. The system consists of computer controlled servo motors driven synchronous motors, discrete components with electrical properties as transmission line simulators, LABVIEW based grid control system and various measurements and logic to mimic the operation and controls in power system [16].

D.H. Moore et al. (2012) discussed the development of a laboratory system for smart grid demonstration. That included provision for integrating solar and wind generators, battery and compressed air storage elements, capacitor bank for power factor control and domestic, commercial and industrial loads. Sensors, controllers and protective devices for automatic protection and control are also incorporated in the system. The system is proposed as a platform for testing various algorithms, logics and strategies in sensing, communication and control of power system and also as an educational tool [17].

B. Chowdhury et al. (2013) developed an interactive power systems teaching lab where equipment can be configured to create experiments for various fields of study including power system operation and control. The various power system operations that can be modeled and studied includes fault, performance and protection of transmission system, grid tied and stand-alone PV and wind generation schemes, smart grid operation and control etc. [18].

S. Tellez et al. (2014) implemented National laboratory of smart grid (LAB+i) measurement of a process, local or remote communication, supervision and management system featuring information management, decision making, modeling of process and efficient application development. This lab serves as a test platform for technologies in smart grid in measurement, control and communication systems. The facility also allows control logic optimization, adaptive technology testing, evaluation of operational conditions and requirements [19].

Ceeman B. Vellaithurai et al. (2015) developed an end-to-end real time cyber physical test bed using RTDS and network simulator ns-3. The test bed has provisions for interfacing phasor measurement units (PMU) and phasor data concentrators (PDC) and also modeled communication network for power system. The test bed is used to demonstrate the impact of various cyber-attacks on power system and will also help in testing out mitigation algorithms [20].

LABORATORY SCALE SMART MICROGRID SIMULATOR – DESIGN

Microgrid is the distribution power system that has distributed generation schemes as well as loads having capability for grid connected and islanded mode of operation. The laboratory scale simulator for such a system will provide a facility for different measurements, operational and managerial schemes for real time monitoring and control of the operation of the MG. The hardware simulator provides a near field environment for testing of these strategies and algorithms for power systems event handling.

The following steps spell out the methodology for the design of a laboratory scale hardware simulator for a MG.

- For the design of a hardware simulator for a MG system, the first requirement is the decision on the number and type of generating stations and the loads. The rating of these generating units and loads will help in deciding the electrical system parameters for the MG implementation.
- The electrical machines that emulate the operation of these generating and storage units can be used to implement the hardware simulator.
- Another important factor is the geographical area that is covered by the MG under consideration. This would help in designing the transmission and distribution models interconnecting the distributed generation and storage units with the loads.
- The next requirement would be the position of individual elements like generation and storage units, loads etc. and the interconnection points to the MG which helps to finalize the topology of the MG.
- The actual electrical parameters of all the individual modules of the MG must be scaled down using the per unit concepts to

obtain a laboratory scale hardware simulator. This includes base voltage and power ratings of the entire system including the machines, transmission and distribution networks of the MG under consideration.

The next set of steps explains the methodology for converting the developed hardware simulator for MG into a smart microgrid (SMG) simulator.

- The electrical parameters that must be measured are to be identified and the point of measurement is also to be decided. This measurement is to be done in a distributed and synchronized manner throughout the MG so as to mimic a wide area measurement system behavior in an actual power grid.
- The data representation standards and rate at which the data is to be sensed, processed and communicated must be finalized.
- The computation that is to be performed in real time based on the measured data and the analysis that is to be done must be decided. This will help in finalizing the computing requirements of the smart modules in MG.
- The communication technology that must be used for the data transfer from point of measurement to the central control centre meeting the operational requirements must be decided.

The above steps help in finalizing the architecture of the smart measurement and control module, like a PMU, and the communication network for data transfer which makes the hardware simulator for MG a smart one.

LABORATORY SCALE SMART MICROGRID HARDWARE SIMULATOR

Following these design steps a laboratory scale hardware simulator for MG is developed at Amrita School of Engineering, Coimbatore. The MG under consideration delivers electricity over an area of nearly 25 km^2 with a peak power demand of 15 MW. The alternate energy based distribution generation schemes in the grid includes

i. 6.25 MVA Micro hydel Power Station – mimicked by 1kVA synchronous generator driven by DC motor,
ii. 7.5 MVA Wind farm – mimicked by 1 kVA Squirrel Cage Induction Generator (SCIG) driven by DC motor and 0.5 kVA Permanent Magnet Generator (PMG) driven by DC motor, and
iii. 0.78 MVA solar photo voltaic (SPV) farm – mimicked by 500 Wp SPV panel [21].

Figure1 shows the single line diagram of the 5 bus MG developed with real time data collection units (RTDCU) having measurement and communication capabilities [22].

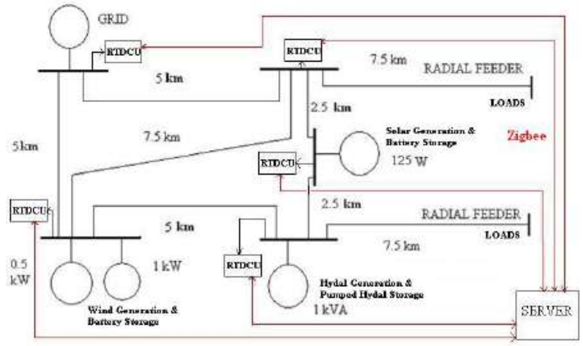

Figure 1: Single line diagram of 5 bus SMG

The MG developed has ability for grid tied operation by connecting to the main power grid enabling export or import of electricity based on local generation and demand in the MG. The different distributed generation schemes in this microgrid simulator include a synchronous generator acting as micro hydal plant, SCIG and PMG (each coupled with a DC motor emulated as a wind turbine) acting as wind generator, and SPV panel. The storage schemes in the microgrid simulator include battery with the SPV panel and pumped storage with the micro hydel plant. There are two radial feeders where consumer loads can be connected to consume the energy.

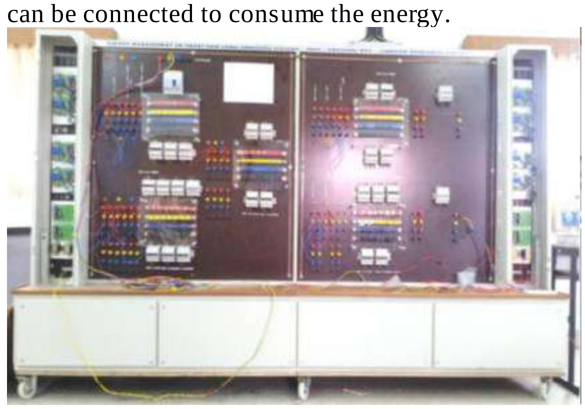

Figure 2: 5 bus SMG hardware simulator - front view [23]

Figures 2 and 3 show the actual laboratory scale smart microgrid hardware simulator developed at Amrita. The 11 kV transmission and distribution line is represented by lumped line sections representing 2.5 km of suitably interconnected transmission line. The transmission line parameters are calculated maintaining standard R/X ratio.

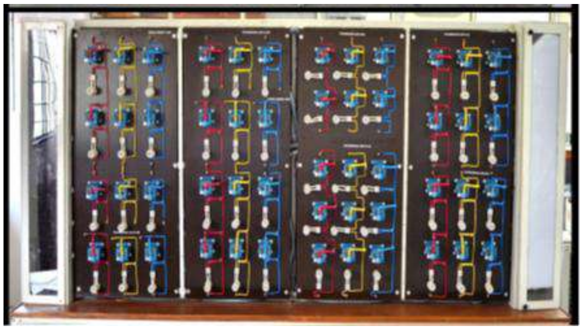

Figure 3: 5 bus SMG hardware simulator – back view - Transmission line models [23]

Eight RTDCU modules are distributed on five buses of the microgrid simulator for real time data collection. These devices sense voltage and current values and compute phasors and frequency and communicate these to a server at the main control centre through radio frequency based Zigbee modems. At the server side a LABVIEW based application is used to receive, process and store the data and generate any required control signal. Figure 4 shows the RTDCU modules interfaced to the hardware simulator.

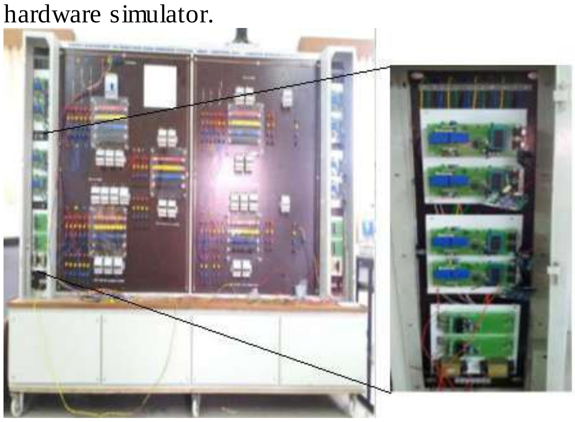

Figure 4: 5 bus SMG hardware simulator – with real time measurement modules [23]

The performance of the SMG hardware simulator and the RTDCU modules was validated for a direct load management application. In this application data collection, communication, decision making and control signal generation were done in real time to control the load according to the frequency deviation [23]. Figure 5 shows the schematic of the direct load control operation done in the 5 bus laboratory scale SMG hardware simulator to validate its performance.

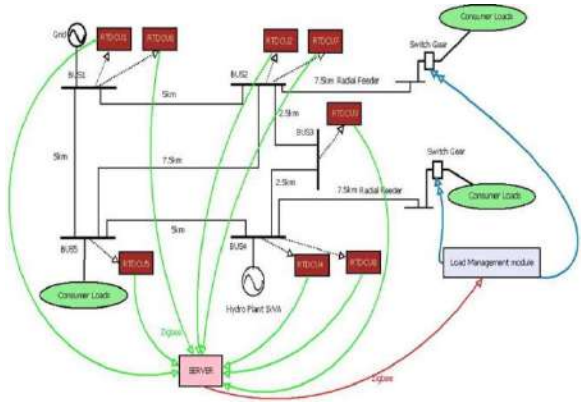

Figure 5: Schematic for direct load control in SMG simulator [23]

CONCLUSION

Various algorithms, strategies and operational procedures for fruitful operation of the MG in an efficient manner need extensive study and analysis. Achieving this job through field tests alone is going to be a costly, time consuming, and less efficient process. This problem can be easily solved by the usage of MG simulators. The design methodology for successful development of a laboratory scale SMG hardware simulator is brought out in this paper through extensive literature review, calculations, modelling and experimental procedures. The simulator developed and implemented at Amrita School of Engineering, Coimbatore, India following this procedure serves as a test bed for research and training on various smart grid technologies and solutions. A variety of challenges and issues can be modelled in the simulator and the solutions can be sought after.

The proposed methodology is expected to provide guidelines for further development, at national and international levels, of SMG simulators which can act as test beds for different power and communication system challenges in a smart SMG environment and also as a teaching tool for smart grid technologies and concepts.

REFERENCES

1. AF-Mercados EMI, Knowledge paper, Indian Smart grid Day 2013, Ministry of Power, Government of India, FICCI, and Indian Smart Grid Forum, January 2013.
2. Chun-Hao Lo, Nirwan Ansari, "The Progressive Smart Grid System from Both Power and Communications Aspects", *IEEE Communications Surveys & Tutorials*, vol. 14, no. 3,pp: 799-821, July 2012.
3. US Department of Energy, Smart Grid System Report, Report to Congress, August 2014.

4. Lahiri, R.N.; Sinha, A.; Chowdhury, S.; Chowdhury, S.P.; Gaunt, C.T., "Importance of distribution automation system for Indian power utility," in *Power & Energy Society General Meeting*, pp.1-7, 26-30 July 2009.
5. Hartono, B.S et al., "Review of microgrid technology," International Conference on QiR (Quality in Research), IEEE, pp: 127-132, June 2013.
6. Madani, V.; Das, R.; Aminifar, F.; McDonald, J.; Venkata, S.S.; Novosel, D.; Bose, A.; Shahidehpour, M., "Distribution Automation Strategies Challenges and Opportunities in a Changing Landscape," in *Smart Grid, IEEE Transactions on* , vol.6, no.4, pp.2157-2165, July 2015.
7. Ruud Kempener, Paul Komor and Anderson Hoke, Smart Grids and Renewables – A guide for effective deployment, International Renewable Energy Agency (IRNEA), November 2013.
8. Lasseter, R.H.; Paigi, P., "Microgrid: a conceptual solution," in *Power Electronics Specialists Conference, IEEE 35th Annual* , vol.6, pp.4285-4290, 20-25 June 2004.
9. Zhang Haiyang; Li ShanDe, "Research on microgrid," in *Advanced Power System Automation and Protection (APAP), International Conference on* , vol.1, pp.595-598, 16-20 Oct. 2011.
10. Nigim, K.A.; Wei-Jen Lee, "Micro Grid Integration Opportunities and Challenges," in *Power Engineering Society General Meeting, IEEE*, pp.1-6, 24-28 June 2007.
11. Jin-Hong Jeon; Jong-Yul Kim; Seul-Ki Kim; Chang-Hee Cho; Keo-Yamg Nam; Jang-Mok Kim, "Real time digital simulator based test system for microgrid management system," in *Transmission & Distribution Conference & Exposition: Asia and Pacific*, pp.1-4, 26-30 Oct. 2009.
12. Ostergaard, J.; Qiuwei Wu; Garcia-Valle, R., "Real time Intelligent Control Laboratory (RT-ICL) of PowerLabDK for smart grid technology development," in *Complexity in Engineering (COMPENG)*, pp.1-4, 11-13 June 2012.
13. Ji-Heon Lee; Hyun-Jun Kim; Byung-Moon Han, "Hardware simulator for dynamic performance analysis of DC microgrid system," in *Vehicle Power and Propulsion Conference (VPPC), IEEE*, pp.1491-1497, 9-12 Oct. 2012.
14. Mohammed, O.A.; Nayeem, M.A.; Kaviani, A.K., "A laboratory based microgrid and distributed generation infrastructure for studying connectivity issues to operational power systems," in *Power and Energy Society General Meeting, IEEE*, pp.1-6, 25-29 July 2010.
15. Reddi, R.M.; Srivastava, A.K., "Real time test bed development for power system operation, control and cyber security," in *North American Power Symposium (NAPS)*, pp.1-6, 26-28 Sept. 2010.
16. Sontidpanya, C.; Radman, G.; Craven, R., "An island detection demonstration on a laboratory sized power Grid (LabGrid)," in *Southeastcon, Proceedings of IEEE*, pp.158-163, 17-20 March 2011.
17. Moore, D.H.; Abdar, H.M.; Murray, J.M.; Chakraverty, A.; Loparo, K.A., "Grid of the future demonstration system," in *Energytech IEEE*, pp.1-6, 29-31 May 2012.
18. Chowdhury, B.; Parkhideh, B.; Martin, A.; Salami, Z.; Enslin, J.; Cecchi, V.; Kamalasadan, S.; Maciej, N., "Enhancing power and energy systems concepts with laboratory experience," in *Power and Energy Society General Meeting (PES), IEEE*, pp.1-5, 21-25 July 2013.
19. Tellez, S.; Alvarez, D.; Montano, W.; Vargas, C.; Cespedes, R.; Parra, E.; Rosero, J., "National Laboratory of Smart Grids (LAB+i) at the National University of Colombia-Bogotá Campus," in *Transmission & Distribution Conference and Exposition - Latin America (PES T&D-LA), IEEE PES*, pp.1-6, 10-13 Sept. 2014.
20. Vellaithurai, C.B.; Biswas, S.S.; Srivastava, A.K., "Development and Application of a Real-Time Test Bed for Cyber–Physical System," in *Systems Journal, IEEE*, no.99, pp.1-12, 2015.
21. S. Nithin, Sasi K. K., T. N. P. Nambiar, "Development of Smart Grid Simulator," Proceedings of National Conference on Power Distribution, CPRI, 2012.
22. S. Nithin, Sivraj P., Sasi K. K., Robert L., “"Development of a Real Time Data Collection Unit for distribution network in a smart grid environment," Power and Energy Systems Conference: Towards Sustainable Energy, pp: 1-5, March 2014.
23. S. Nithin, Sasi K. K., and Robert Lagerstöm, "Direct Load Control on Smart Micro Grid supported by Wireless Communication and Real Time Computation", in *Proceedings of the International Conference on Interdisciplinary Advances in Applied Computing* (ICONIAAC), vol no. 17, pp. 1-5, 2014.

Modeling and Analysis of a Hybrid Energy Storage for Solar PV System

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Abstract

Energy Storage technologies have existed since a long time and are becoming increasingly important due to the evolving smart grid of 21st century. These energy storage systems also help overcome some of the limitations of electricity generation from renewable energy sources, the major one being intermittent nature of generation. Integrating the Battery Energy Storage System with renewable energy sources can make the intermittent renewable energy sources more dispatchable. Besides, they also offer many other advantages like frequency regulation, transient stability, voltage support, flicker compensation, spinning reserve, uninterruptable power supply, load leveling, and peak shaving among others. However batteries pollute the environment. A hybrid energy storage system is distinguished by the advantageous coupling of two or more energy storage technologies with additional operating characteristics (such as energy and power density, self-discharge rate, efficiency, life-time, etc.) which is suitable for the application in decentralized PV-systems. The supercapacitors are high dynamic and high power density device to compensate the built-in limitations in embedded sources and shave transient power peaks. The batteries are a high energy density device, perform for supplying energy if limitations of the power and energy sources occur. The paper presents modelling and simulation of off- grid PV/battery -supercapacitor power generation system. The storage of photovoltaic energy by associating batteries with supercapacitors is investigated.

Keywords- Hybrid Energy Storage, Decentralized PV System, Supercapacitor, Battery.

I. Introduction

Environmentally-friendly and renewable energy resources are becoming increasingly important in, commercial , residential and industrial applications. Amongst renewable energy resources, solar PV systems and wind energy conversion systems are promising and generating a great deal of research focus [1-5]. However, electric power generation from these sources is intermittent, depending on the weather conditions as a result of which it becomes difficult to provide a stable power supply. Therefore, in small autonomous renewable energy systems, energy storage is required in order to increase the reliability and power capacity of the power supply. Batteries are one of most cost-effective energy storage technologies. However, the use of batteries as energy buffers is somehow problematic, since it is difficult to recover from rapid power fluctuations without reducing the batteries lifetime. In a supercapacitor, energy storage is by means of static charge rather than of an electrochemical process as in a battery, thus the supercapacitor has a higher power density than a battery. It is therefore advantageous to combine these two energy storage devices to accomplish better power and energy performances. Results of a literature review indicate quite a number of promising HESS-applications . viz, HESS in hybrid electric vehicles (supercapcitor/battery-HESS [6 -9], battery/fuel cell-HESS [10-11], HESS-applications in renewable autonomous energy supply systems mainly based on a battery/hydrogen combination [12-16] grid-connected HESS on a household [17],HESS for large scale wind- and PV-park power management [19-20], other specific HESS-configurations, like SMES/battery-

HESS [21], CAES/battery-HESS [22] and flywheel/battery-HESS [23]. Much work has not been done on batterys/supercapacitor energy storage systems integrated with solar PV . This paper presents a hybrid energy storage system that comprises a rechargeable battery, a supercapacitor bank integrated in a solar PV system.

II Modeling of Energy Storage Devices

Li - Ion Cell Model

Li-ion cell is modeled as a nonlinear voltage source and RC network element. Both, voltage and resistance values are generally functions of the battery State of Charge (SoC) and temperature. The mathematical model of the battery can be expressed as [18]:

Discharge Model (i* > 0)

$f_1 \; (it,i*,i)=E_0-\;[K\cdot Q/(Q-it\cdot i)]\;*-\;[K\cdot Q/(Q-it\cdot it)]\;+A\cdot \exp(-B\cdot it).$

Charge Model (i* < 0)

$F_2\;(it,i*,i)=E_0-\;[K\cdot Q/(\;it\;+0.1\;Q)]\;.I\;*-\;[K\cdot Q/(Q-it\cdot it)]\;+A\cdot \exp(-B\cdot it).$

Where,

E_{Batt} = Nonlinear voltage (V)

E_0 = Constant voltage (V)

Exp(s) = Exponential zone dynamics (V)

Sel(s) = Represents the battery mode. Sel(s) = 0 during battery discharge, Sel(s) = 1 during battery charging.

K = Polarization constant (Ah^{-1}) or Polarization resistance (Ohms)

i* = Low frequency current dynamics (A)

i = Battery current (A)

it = Extracted capacity (Ah)

Q = Maximum battery capacity (Ah)

A = Exponential voltage (V)

B = Exponential capacity $(Ah)^{-1}$

Supercapacitor model

The supercapacitor, basicly is the series combination of two double layer capacitances, back-to-back in the same package. One of the simplest ways of modelling supercapacitors is to model it as a generic capacitor, having a resistance in series Rs representing the charging and discharging resistance, a resistance in parallel RP representing resistance the self-discharge and a capacitor C. The supercapacitor output voltage is expressed using a Stern equation as [18]:

$$V_{sc} = [(N_sQ_Td)/(N_pN_eEE_oA_i)]+[(2N_eN_sRT)/F]\sinh^{-1}[Q_T/N_pNe^2A_iSQRT(8RTEE_oC)]-R_{sc}.i_{sc}$$

Where,

Ai	Interfacial area between electrodes and electrolyte (m^2)
c	Molar concentration (mol m^{-3}) equal to c = $1/(8NAr^3)$
F	Faraday constant
i_{sc}	Supercapacitor current (A)
V_{sc}	Supercapacitor voltage (V)
C_T	Total capacitance (F)
R_{sc}	Total resistance (ohms)
N_e	Number of layers of electrodes
N_A	Avogadro constant
N_p	Number of parallel supercapacitors
N_s	Number of series supercapacitors
Q_T	Electric charge (C)
R	Ideal gas constant
d	Molecular radius
T	Operating temperature (K)
ε	Permittivity of material
ε_0	Permittivity of free space

III HYBRID ENERGY STORAGE SYSTEM:

The HEES system architecture connects the EES elements through buses and power converters to enable charge transfer among the EES elements. Major advantages of a HESS are reduction of total investment costs compared to a single storage system due to a decoupling of power and energy , increase of total system efficiency, storage and system lifetime as the dynamic stresses are reduced high energy storage device. In this HESS, storage (A) (Fig 1) is dedicated to cover "high power" demand and transients and therefore is characterized by a fast response time, high efficiency and high cycle lifetime. The other storage (B) is "high energy" storage with a low self-discharge rate and lower energy.

Energy storage coupling architectures in HESS

There are different ways for the coupling of the energy storages in a HESS. A simple approach is the direct DC coupling of two storages. Main advantage is the simplicity and cost-effectiveness. Moreover, the DC-bus voltage experiences only small variations. Main disadvantage is the lack of possibilities for power flow control and energy management and a resulting ineffective utilization of the storages (e.g. in a supercap/battery-HESS with direct coupling only a small percentage of the supercapacitor capacity can be utilized when operated within the narrow voltage band of the battery). [23].The second energy storage coupling architecture in a HESS is via single bidirectional DC/DC converter. The bidirectional DC/DC converter controls the output current of the battery and allows the supercapacitor to supply the extra power requirement to the load. The most promising coupling architecture consists of dual DC/DC-converters. The parallel converter topology (Fig.1) is most often used by researchers.

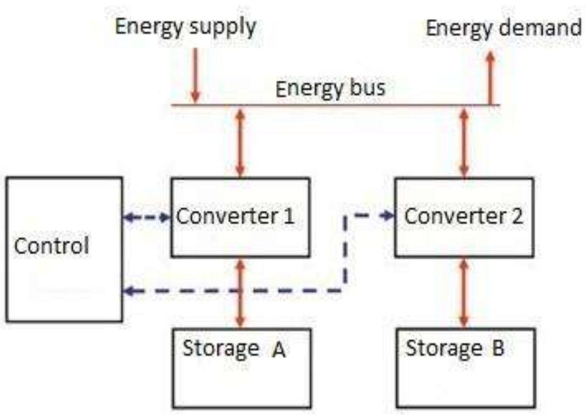

Figure 1 - Architecture of HESS System

The additional DC/DC-converter associated with the "high-power" storage is in charge of the voltage regulation of the DC-bus. It helps to operate the "high-power" storage in a broader voltage band, and hereby the available storage capacity is better utilized. Besides the parallel converter topology also a serial, cascade-type of converter topology is possible, which is generally more expensive and more difficult to be controlled. The dual input bi-directional DC/DC converter give rise to highest efficiency, reliability and flexibility. However, it involves the use of more costly DC/DC converters.

Therefore, the cost of power electronics and efficiency of the HESS the tradeoff between these topologies .

IV Methodology

For the proposed solution, the optimal use of the supercapacitors bank requires a power flow controller between the two energy storage subsystems (A - supercapacitors and B - batteries). With this solution, to limit the battery stress, the battery current should be maintained without big overshoots and so the current transitions should be also controlled. Consequently, the power flow of the supercapacitors can be controlled with a pulse-with-modulated (PWM) DC/DC converter being the semiconductors and commanded in complementary mode.

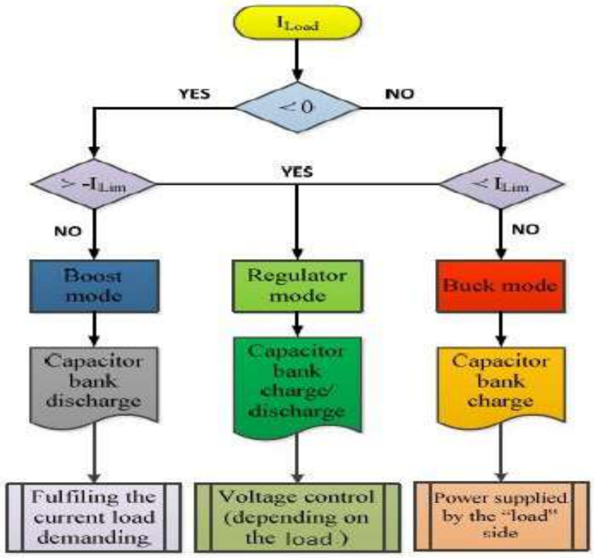

Figure 2 - Decision Flow Chart

Figure 2 gives the flow chart. During low load, the supercapacitors are charged at a rate controlled by modulating the switch (buck mode). The supercapacitor is discharged during high load at a rate controlled by modulating the switch. In this

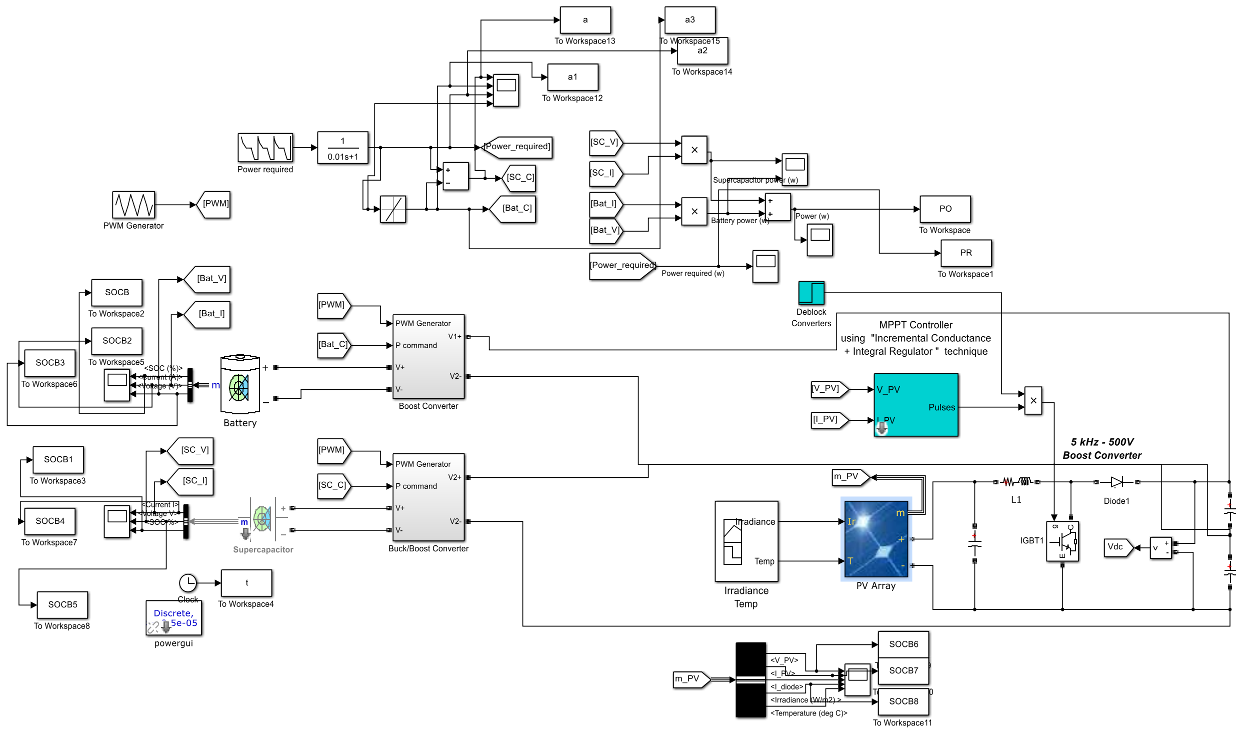

Figure 3: Simulink Model of a PV System with Hybrid (Battery and Supercapacitor) Storage

boost mode, the energy is delivered to the inductor *L* when is turned ON, and then transferred to the load through diode when switch is OFF Conversely to batteries, the supercapacitor ought to charge as fast as possible without exceeding the maximum current from regenerative braking, and to discharge most of its stored energy during acceleration.

V Simulation model

Hybrid energy storage system' (HESS) containing both a battery and a supercapacitor is implemented in Matlab/Simulink. The concept is generally successful because it exploits the strengths and compensates for the weaknesses of each storage device. To evaluate the behavior of such system, a simulation model based on the circuit as displayed in Fig 3. is developed in MATLAB based Simulink model.

For the stand alone PV system, the PV Block shown in Figure 3 is ideally considered. when the modules are connected in parallel. Input parameters for PV module are taken from the Solar Panel manufacturer with the following parameters.

- Maximum Power (Pmax) = 212.04W
- Nominal Voltage : 48V
- Open Circuit Voltage, Voc = 48Volts
- Voltage at maximum Power Point (Vmpp) = 38 V
- Current at maximum Power Point (Impp) = 5.58 amp

The Simulink model has the information of Irradiation Data. Generic Battery model used for Lithium Ion Battery and SuperCapacitor

VI Results and Discussion

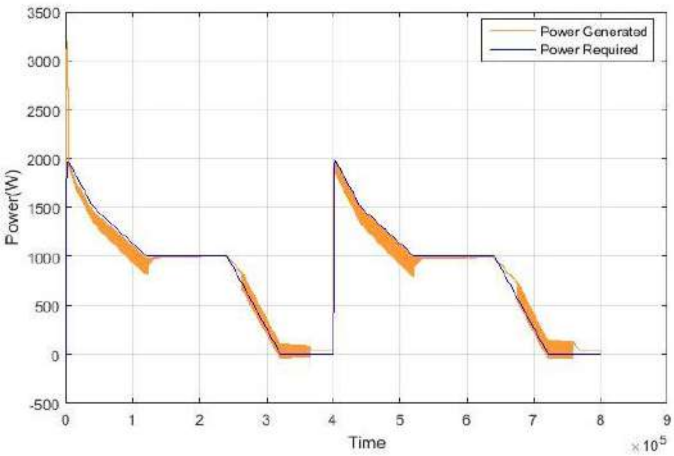

Figure4: Comparison of power

Figure 4 gives the difference between the Power required and Power Generated by the Standalone PV system with hybrid energy Storage using Battery and Supercapacitor together as energy storage devices. Initially the load is provided by SuperCapacitor as shown in Figure 5.

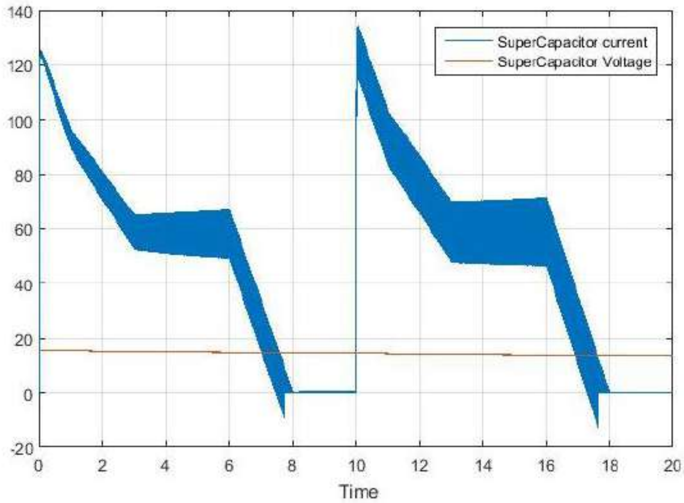

Figure5: SuperCapacitor Current and Voltage.

Power of the battery is limited by a rate limiter block, therefore the transient power is supplied to the DC bus by the supercapacitor. The Rate Limiter block is provided which limits the first derivative of the signal

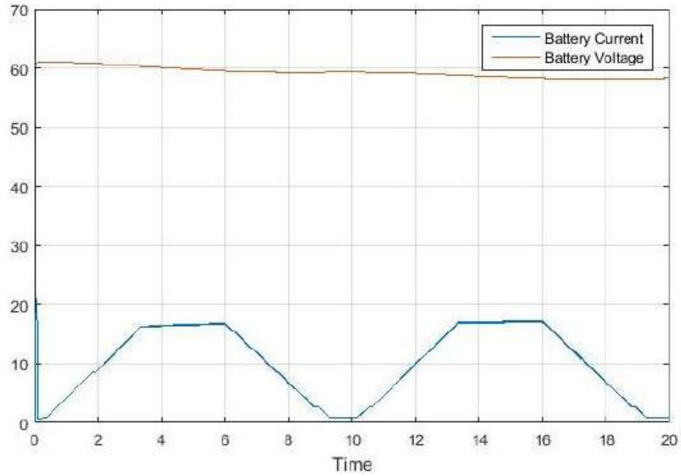

Figure 6: Battery Current and Voltage

passing through it. The output changes no faster than the specified limit i.e 300 ms. The Battery current and voltages are shown in Figure 6.

VII CONCLUSION

Solar, wind and other renewable energy sources are on their way to high level penetration in the electricity supply market. However, there are several challenges viz intermittency, high variability, limited predictability, limited dispatchability and non –storability. This increases the operation cost , reduces the stability and reliability of power system. To increase the reliability, electric energy storage systems are used. However no single type of EES device fulfils high power delivery capacity , high power density , long life and low cost of storage. Hybrid energy storage systems (HESS) are becoming an increasingly attractive option for energy management. This paper deals with integrating HESS system comprising of Supercapacitor and Li-ion battery for an off grid solar PV system user. Modeling and Simulation of the system is done using Matlab/Simulink software. The proposed system, comprising of PV panel, battery energy storage, DC/DC bidirectional buck and boost converter, Supercapacitor and Buck/Boost Converter and control methods, were simulated in MATLAB/Simulink Simulation results shows that the the supercapacitor supplies a major portion of burst power needed during transmission while the lithium-ion cell provides all reserve power and standby power. The combination results in improved Solar PV utilization and provides sustainable and reliable power for Users.

References

[1] G. Martin, “Renewable energy gets the "green" light in Chicago”, IEEE Power and Energy Magazine, Vol. 1, No. 6, pp: 34-39, Nov.-Dec. 2003.

[2] J. T. Bialasiewicz. “Renewable Energy Systems With Photovoltaic Power Generators: Operation and Modeling”, IEEE Transactions on Industrial Electronics, Vol. 55, No. 7, pp: 2752-2758, Jul. 2008.

[3] R. Karki, R. Billinton, “Reliability/cost implications of PV and wind energy utilization in small isolated power systems**”,** IEEE Transactions on Energy Conversion, Vol. 16, No. pp: 368-373, 4, Dec. 2001.

[4] C.L. Kana, M. Thamodharan, A. Wolf, “System management of a wind-energy converter”, IEEE Transactions on Power Electronics, Vol. 16, No. 3, pp. 375-381, May 2001.

[5] W. Chen et .al, “Super-Capacitors Based Hybrid Converter in Marine Elect ric Propulsion System,” Int ernat ional Conference on Elect rical Machines, pp.1-6, Rome, 2010.

[6] Yoo H et al. System Integration and Power-Flow Management for a Series Hybrid Electric Vehicle Using Supercapacitors and Batteries. IEEE Trans. Ind. Appl. vol.44. no.1; 2008. pp.108-114.

[7] Zheng JP. Hybrid power sources for pulsed current applications. IEEE Trans. Aerosp. Electron. Syst.; 2006.

[8] Camara MB, GualousH,Gustin F, BerthonA. Design and new control of DC/DC converters to share energy between supercapacitors and batteries in hybrid vehicles. IEEE Trans. Veh. Technol. vol.57.no.5; 2008. pp.2721-2735.

[9] HensonW.Optimal battery/ultracapacitor storage combination. J. Power Sources. vol.179; 2008. pp. 417-423.doi:10.1016/j.jpowsour.2007.12.083

[10] JiangZ, DougalR.A compact digitally controlled fuel cell/battery hybrid power source. IEEE Trans. Ind. Electron.vol.53.no.4;2006.pp.1094-1104.

[11] Ortúzar M, MorenoJ, DixonJ.Ultracapacitor-based auxiliary energy system for an electric vehicle: Implementation and evaluation.IEEE Trans. Ind. Electron.vol.54;2007.pp.2147-2156.

[12] Ulleberg Ø.Stand-alone power systems for the future: optimal design, operation & control of solar-hydrogen energy systems. PhD thesis. Trondheim; 1998.

[13] CarapellucciR, GiordanoL.Modeling and optimization of an energy generation island based on renewable technologies and hydrogen storage systems. Int. J. Hydrogen Energy. vol.37; 2012.

[14] KyriakarakosG, DounisAI, ArvanitisKG, PapadakisG.A fuzzy logic energy management system for poly generation microgridsRenew. Energy. vol.41; 2013. pp.315-327.

[15] BertheauP et al. Energy storage potential for solar based hybridization of off-grid diesel power plants in Tanzania. Energy Procedia.vol.46; 2014. pp.287-293. [16] Blechinger P et al. Assessment of the Global Potential for Renewable Energy Storage Systems on Small Islands. EnergyProcedia. vol.46; 2014. pp.294-300.doi:10.1016/j.egypro.2014.01.185

[17] Baoquan, L., Fang, Z., Xianwen, B., Control Method of the Transient Compensation Process of a Hybrid Energy Storage System Based on Battery and Ultra-Capacitor in Micro-grid, IEEE International Symposium on Industrial Electronics (ISIE), 28-31 May, 2012, Hagzhou, pp. 1325-1329

[18]www.mathworks

[19] GarusK. Stromspeicher Braderup nimmt Betrieb auf. Sonne, Wind und Wärme; 2014.

[20] WangG, CiobotaruM, AgelidisVG, MemberSS.Power Smoothing of Large Solar PV Plant Using Hybrid Energy Storage, IEEE Trans. Sustain. Energy. vol.5.no.3; 2014. pp.1-9.

[21] IseT, KitaM, TaguchiA.A hybrid energy storage with a SMES and secondary battery. IEEE Appl. Supercond.; 2005.doi:10.1109/TASC.2005.849333

[22] RuferA, LemofouetS.A Hybrid Energy Storage System Based on Compressed Air and Supercapacitors With Maximum Efficiency Point Tracking (MEPT). IEEE Trans. Ind. Electron. vol.53;2006.doi:10.1109/TIE.2006.878323

[23] Thilo Bocklisch, ‘Hybrid Energy Storage for Renewable Energy Apllications”, 9th International Renewable Energy Storage Conference, IRES 2015, Elsevier, pp. 103-111.

AMI data analytics

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Abstract

Tata Power has deployed Automatic Meter Reading System for Commercial & Industrial consumers. A Meter Data Management System (MDMS) is installed as a part of AMR system to store the meter data and act as a meter data repository. Many events & huge data is collected from the meters & manual analysis is a daunting task as every month additional meters are being covered in AMR. A Meter data analytics software was procured to analyze this high volume of meter data. The MDMS is integrated with Meter Data Analytics system. Every midnight the data from MDMS is pushed into analytics software thus avoiding any human interventions. The instantaneous data from MDAS is uploaded manually into the software. Various logics are developed into the software to analyse meters instantaneous data. This software tools shortlist the suspected meters & are further taken up for detailed analysis. The software is very fast and capable of processing all meter data quickly. With this tool we are able to analyze all HT & LT CT operated meters connected to AMR on a monthly basis.

Keywords

AMR – Automatic Meter Reading
MDMS – Meter Data Management System
MDAS – Meter Data Acquisition System

INTRODUCTION

Tata Power is India's largest integrated power company with a significant international presence. The Company has an installed generation capacity of 8623 MW in India and has a presence in all the segments of power sector viz Generation (thermal, hydro, solar and wind), Transmission, Distribution and Trading. Tata Power supplies Electricity across Mumbai License area having a Spread of 485 sq. Km and housing a population of approximately 1.45 crores. The customer base of Tata Power is around 6.5 lakh.

AMR SYSTEM ARCHITECTURE

Tata Power has installed AMR system covering high value industrial & commercial consumer meters. The AMR system is integrated with SAP billing system and the meter readings flow seamlessly from MDMS to SAP. The MDMS is also integrated with meter analytics system for carrying out mater data analysis.

Meter Data Analytics solution is used to analyse AMR data and Check
1) If there is any inconsistency in load profile patterns of consumer meter 2) Abnormal Events have been recorded by consumer meter 3) Instantaneous parameter data captured in AMR system on hourly basis.
The meter interval data is superimposed month over month to check for any drop in consumption pattern. Fig 1 shows monthly meter data superimposed over one another.

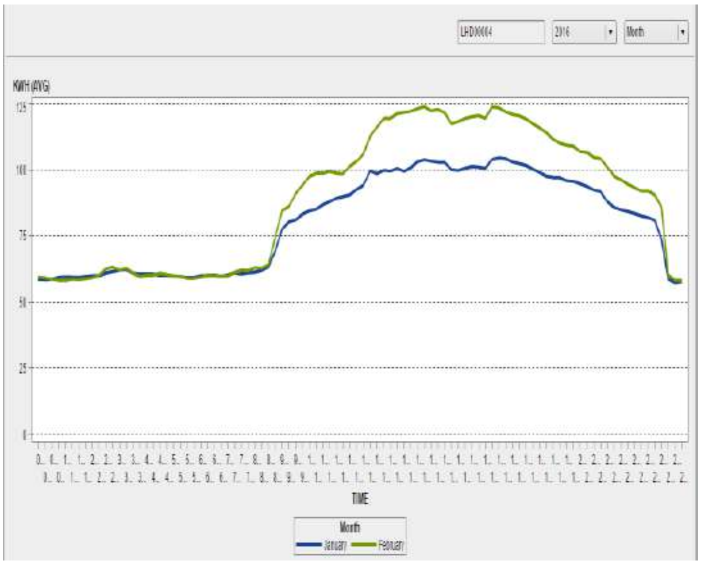


Fig. 1

The monthly data is further drilled down to check daily interval data superimposed over another. This helps in analysing the daily consumption pattern of the consumer. Fig 2 shows daily meter data superimposed over another.

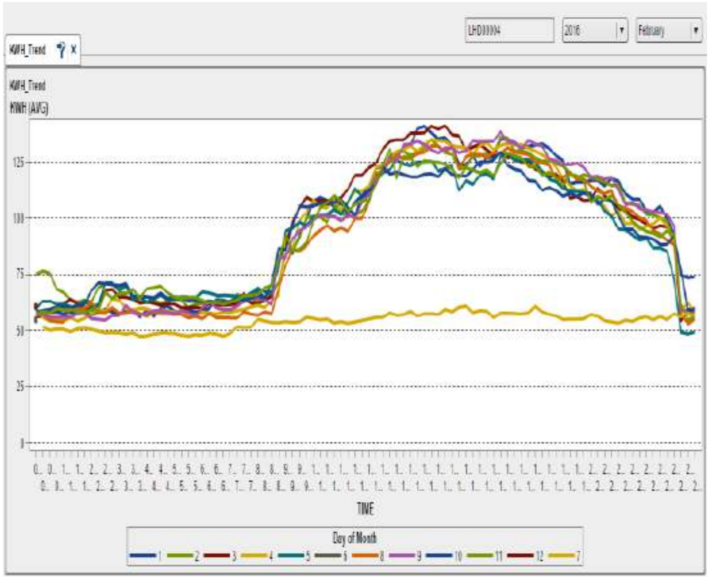


Fig. 2

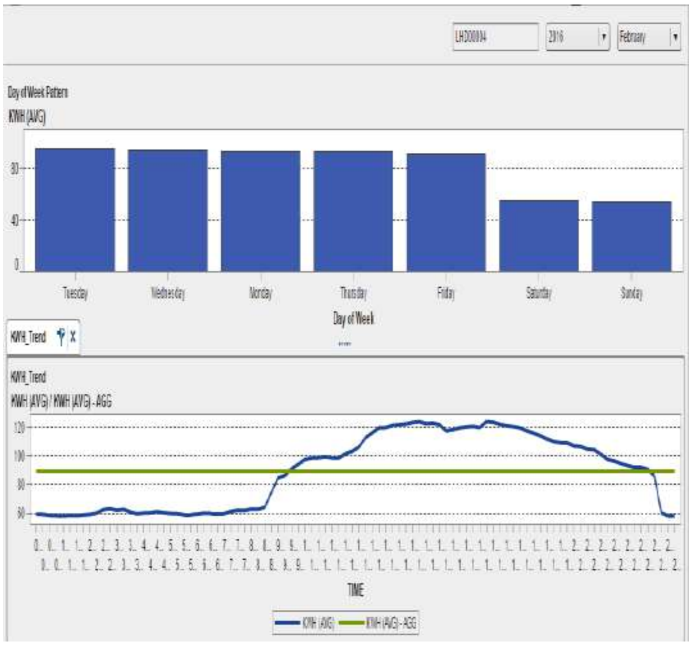


Fig. 3

The Fig 3 shows weekly consumption trend for the consumer.

Analysis of tamper events recorded by consumer meters helps to identify suspected defective meters. Fig 4 shows events recorded in the consumer meter captured using meter data analytics software.

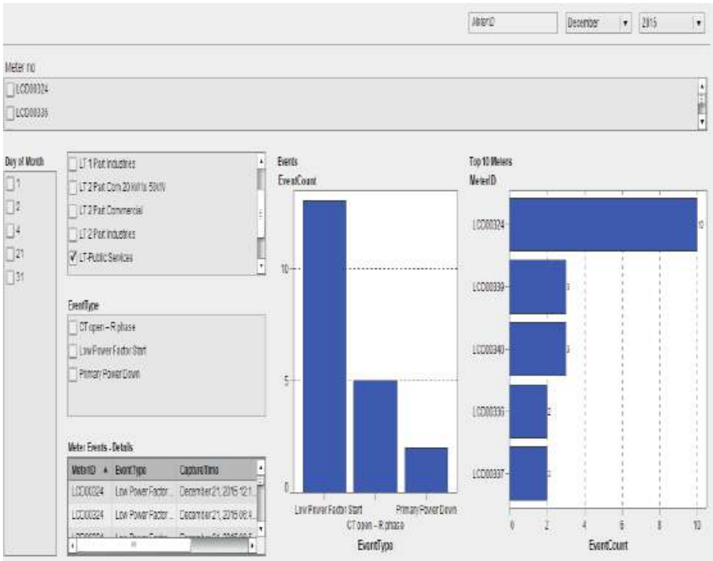


Fig.4

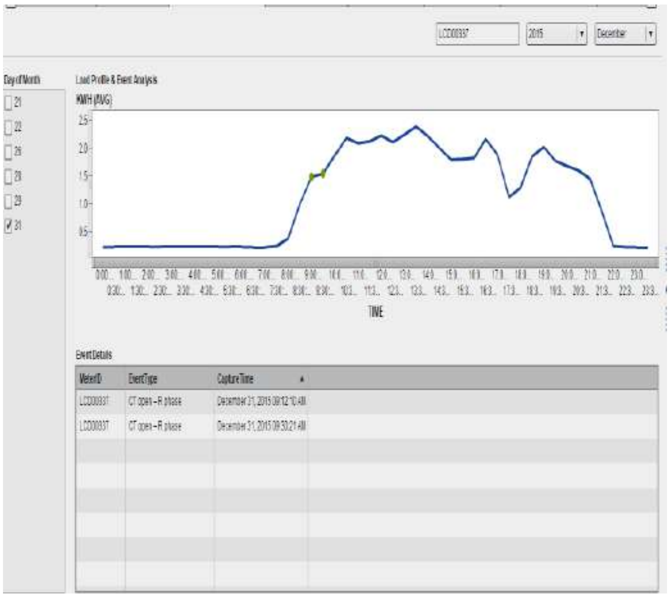
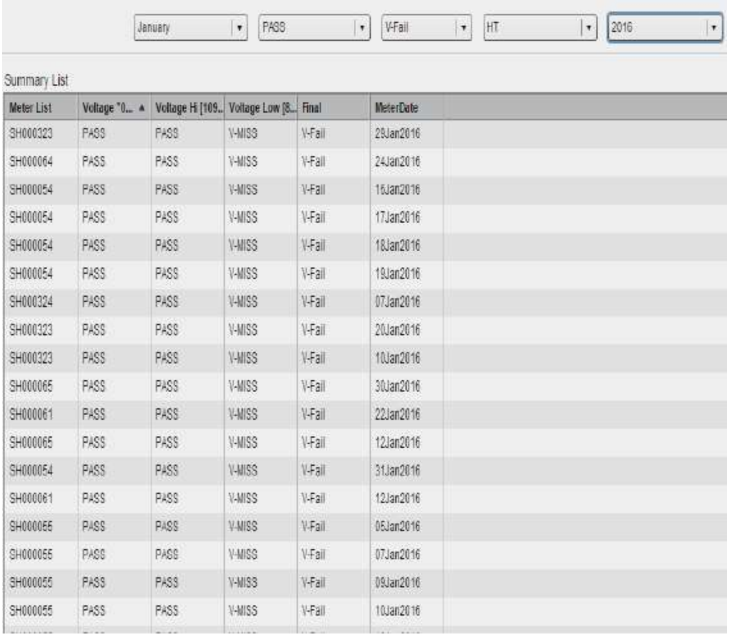


Fig. 5

The fig. 5 shows a graph with events superimposed over load profile of a consumer which helps to check if any drop in consumption is observed on account of event.

Analysis of Instantaneous Meter Data

The instantaneous data of meter is captured in Meter data acquisition system. The data is captured on hourly basis. This instantaneous meter data is available on the AMR web portal. The instantaneous meter data from web portal is exported into excel. The excel file is then uploaded manually in the meter data analytics system. Various logics are developed into the meter data analytics software to analyse meters instantaneous data. This software tools shortlist the suspected meters & are further taken up for detailed analysis. The fig. 6 shows list of suspected meters from instantaneous meter data.


January | PASS | V-Fail | HT | 2016

Summary List

Meter List	Voltage "0...	Voltage Hi [109...	Voltage Low [8...	Final	MeterDate
SH000323	PASS	PASS	V-MISS	V-Fail	29Jan2016
SH000064	PASS	PASS	V-MISS	V-Fail	24Jan2016
SH000054	PASS	PASS	V-MISS	V-Fail	16Jan2016
SH000054	PASS	PASS	V-MISS	V-Fail	17Jan2016
SH000054	PASS	PASS	V-MISS	V-Fail	18Jan2016
SH000054	PASS	PASS	V-MISS	V-Fail	19Jan2016
SH000324	PASS	PASS	V-MISS	V-Fail	07Jan2016
SH000323	PASS	PASS	V-MISS	V-Fail	20Jan2016
SH000323	PASS	PASS	V-MISS	V-Fail	10Jan2016
SH000065	PASS	PASS	V-MISS	V-Fail	30Jan2016
SH000061	PASS	PASS	V-MISS	V-Fail	22Jan2016
SH000065	PASS	PASS	V-MISS	V-Fail	12Jan2016
SH000054	PASS	PASS	V-MISS	V-Fail	31Jan2016
SH000061	PASS	PASS	V-MISS	V-Fail	12Jan2016
SH000055	PASS	PASS	V-MISS	V-Fail	05Jan2016
SH000055	PASS	PASS	V-MISS	V-Fail	07Jan2016
SH000055	PASS	PASS	V-MISS	V-Fail	09Jan2016
SH000055	PASS	PASS	V-MISS	V-Fail	10Jan2016

Fig. 6

Conclusion

The Meter Data management System acts as a meter data repository. This large volume of meter data is analysed using business analytics system. Standard load profiles for different consumer categories can be created and consumers showing deviation from standard profile can be pinpointed. AMR data analysis helps loss reduction opportunities through faster detection of metering abnormalities and meter tamper

Studies on applicable EMC standards for Smart Grid components and Environment

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Abstract*—A basic introduction to the possible Electromagnetic Interference (EMI) threats present in the Smart Grid environment and possible remedies for reliable operation of the Smart Grid is presented in this paper. The Smart Grid function involves transferring many digital information, control system, security, networking, interconnection of distributed resources inclusive of renewable energy sources to the grid, electric metering, sensors and broadband over power lines. These functions will have different reliability requirements. All existing power grid devices are immersed in an electromagnetic (EM) environment of natural and man-made EM sources that are either directly radiated into devices or are conducted via the power, signal and ground connections. The Smart Grid may be susceptible to factors due to EMI that can negatively impact the reliability of power delivery. The potential for EMI to other associated devices due to emissions from Smart Grid devices are also to be addressed.EMC have to be considered to ensure continuous dependable real time operation. So it is necessary to implement Electromagnetic compatibility as an integral process in the design of equipment and devices that are used in the operation of the Smart Grid. Detailed study on EMI sources present in the electromagnetic environments where Smart Grid devices may be installed has to be carried out to finalise the test level. The Scope of this paper is limited to defining the applicable EMC standards and facilities to address the issues due to EMI in electromagnetic environments where Smart Grid devices are installed.

Keywords—Smart Grid, Threats, Electromagnetic compatibility (EMC), Electromagnetic interference (EMI), EMC standards.

I. INTRODUCTION

India holds third position in the world in terms of largest power transmission and distribution network, Aiming to provide efficient, good quality and reliable power to the customers. Converting such a large grid system to a Smart Grid is a challenging task. In addition, considering Electromagnetic compatibility is essential for continuous and reliable real time operation of Smart Grid. So it is required to implement Electromagnetic compatibility (EMC) as an integral process in the design of devices and equipments that are used in the operation of the Smart Grid. This paper presents an overview of the electromagnetic interference and their impact on Smart Grid devices.

II. EXPECTED EMI PROBLMES IN SMART GRID LOCATIONS

Some of the possible Electromagnetic interference, which affects the Smart Grid components, are

- Power inverters and switched mode power supplies of user equipment are likely to cause conducted disturbances on the mains cord. These disturbances will affect the performance of other equipment connected to the same Smart Grid a.c. mains

- Smart Grid communications controls the Smart Grid meters that would be located at the power entrance to the structure and is used for registering the amount of electric energy passing through the meter. Such disturbances could degrade the performance of the meter. There is evidence that lightning equipment and household appliances can be switched from stand- by mode to active mode by these kinds of conducted disturbances when an unwanted event is triggered by these disturbances communicated falsely over the Smart Grid system.
- Coupling of RF disturbances from intentional (such as wireless transmitters) and unintentional radiators causing interference in equipment connected to the Smart Grid.
- Commonly occurring EM events like fast transients, electrostatic discharges and power line disturbances causing interference to equipment connected to the Smart Grid.
- High level EM disturbances from natural phenomena such as geomagnetic storms and lightning surges and even by intentional terrorist acts causing interference into equipment connected to the Smart Grid.

Power Quality degradation factors can disrupt the operation of a system that is powered by a mains power source. These mains degradation factors include:

- Voltage surges, dips, sages, spikes, and high and low voltage
- Power line faults
- Electrical Fast Transitions (EFT)
- Blackouts and Brownouts
- Electrical noise superimposed on the mains power line

These kind of power quality degradation factors may occur concurrently or independently, during any time interval.

III. SMART GRID AND ELECTROMAGNETIC ENVIRONMENT

The world is immersed in an electromagnetic environment of electromagnetic sources. Every part of the electromagnetic spectrum has many applications in everyday lives, and many of those applications involve technology. At the same time the same electromagnetic signals acts as an Electromagnetic interference (EMI), for other systems when they receive other spectrum signal which is not intended for that device usage. Electromagnetic interference, whether intentional or unintentional, leads to a wide spectrum of issues, including momentary failures or trivial inconveniences to equipment. EMI should be considered importantly in Smart Grid implementation because, the Smart Grid is a fully automated power delivery network, ensuring a two-way flow of information and electricity between appliance and the power plant and between all points in the Smart Grid. Its distributed intelligence, in addition with the automated control systems and broadband communications enables real-time transactions and seamless interface between people, industrial plants, buildings, generation facilities and the electric network. So it is required to implement EMC throughout every part of the Smart Grid location and devices. Figure 1 shows the actual scenario of the electromagnetic environment.

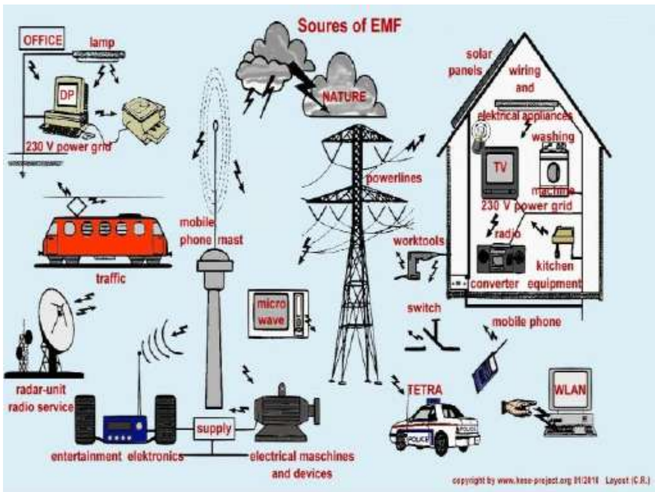

Fig.1. Electromagnetic environment.

A. *Ambient survey of the Electromagnetic environment*:

To achieve electromagnetic compatibility, environment in which the system is intended to operate is an important pre condition that should be carefully examined.RF spectrum in the Electromagnetic environment contributes the major role of EMI. The detailed study has to be carried out in the location where Smart Grid components are planned to be installed. Ambient survey helps to make analysis on the EMI strength existing in particular location. The suitable immunity specifications can be drawn based on the corresponding data of the electromagnetic environment

- Pre-ambient survey of the Electromagnetic environment
- Post- ambient survey of the Electromagnetic environment

Pre ambient survey of the Electromagnetic environment

Ambient level survey is necessary to establish the frequencies, timing, amplitude and spatial details of electromagnetic signals on a particular site. These EM signals are the elements of electromagnetic interference. This information is used to study the influence of EMI on equipment installed on this site and helps to draw immunity specification of the system.

Post- ambient survey of the Electromagnetic environment

After installation of Smart Grid components, again ambient survey should be performed to determine intentional radiation from wireless or radio systems or unintentional radiation from RF systems from Smart Grid devices may also couple and interfere with other nearby electronic devices or receivers. This information is used to reduce the EMI sources generated by the Smart Grid components itself.

B. *Reference standard for EM study.*

The document IEC 61000-2-5 provides a survey of all known electromagnetic phenomena and different types of location classes. It offers guide lines to identify immunity levels related to electromagnetic environment. IEC 61000-2-5 classifies the electromagnetic environments and to help in specifying immunity requirements of any electric and electronic equipment. However, the immunity requirements of equipment are not dependent only on its environment but also on the requirements of its applications.

C. *Classification of Smart Grid electromagnetic environments*

Smart Grid environment is classified as power delivery environment and customer EM environment. Fig 2 shows the classification of Smart Grid environment.

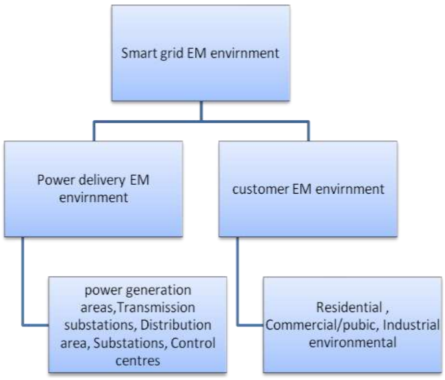

Fig.2. Smart Grid environment

IV. REVIEW OF SMART GRID EMC STANDARDS

EMC standards discussed in this paper for Smart Grid equipments are based on SGIP Electromagnetic Interoperability Issues Working Group Recommendations. Equipments should be designed to ensure electromagnetic compatibility to its intended operational environment and immunity to EM interface. List of EMC standard with respect to EMC testing of Smart Grid equipments is listed in Table I.

TABLE I.

EMC STANDARDS FOR SMART GRID EQUIPMENTS

TYPE OF TEST	STANDARD	EQUIPMENT TYPE
Immunity test	IEC 61000-2-5	For customer environment
Intentional electromagnetic interference	IEC61000-4-36, IEC 61000-2-9, 61000-2-10, 61000-2-13, 61000-4-25, 61000-6-6	Power delivery and the power customer equipments
Immunity test	CISPR 24/EN55024 IEC61326/EN61326	IT Equipment
ESD Immunity test	IEC 61000-4-2	Typical test methods for power customer devices
Radiated immunity test	IEC 61000-4-3	
Electrical fast transients/burst immunity test	IEC 61000-4-4	
Surge (lightning) test	IEC 61000-4-5	
Conducted CW immunity	IEC 61000-4-6	
Magnetic field immunity, power frequency	IEC 61000-4-8	
Voltage dips, interruptions immunity	IEC 61000-4-11	
Ring Wave immunity Low Frequency	IEC-61000-4-12	
Damped Oscillatory Wave Immunity	0.5 kV IEC-61000-4-18 61000-4-18	
Immunity	IEC 61850-3,IEC 61000-6-5, IEEE C37.90.1,2,3, IEEE 1613, IEC 60870-2-1, IEC 60255-26,IEC 60439-1	Equipment in Power Stations, medium-voltage and high-voltage Substations
Unintended conducted and radiated interference	FCC, Part- 15	power grid components

Additional EMC standards are necessary depending on the products and environment.

V. EMI SOURCES AND COUPLING MECHANISM

Since the density of the electromagnetic environment is continuously increasing, its consequences coming from the sources producing EMI also increases. Ambient EME can affect sensitive electronic equipments nearby EMI sources. The nearer the sensitive electronic system to the EMI source, the greater the source's radiated power level, and the higher is the probability that the EMI will cause an interference problem. Developments in technology as well as the number of products produced are having a substantial effect on the endeavours aimed at sustaining the necessary operation and interoperability of equipments and systems used in our society. These events had increased the challenges to maintain the required level of electromagnetic compatibility (EMC) in these products and systems.

EME consists of EMI sources that are both natural and man-made such as

- Lightning, solar Magnetic Storms
- Utility power grid transmission lines which have high voltage, Broadband over Power Lines (BPL) digital signals.
- Telecom transmissions, airport port radar,electrostatic discharge (ESD)
- High Powered Electromagnetic Pulse (HEMP) threats made to be utilized by military organizations and terrorist are designed to disable electrical and electronic equipment.
- Intentional Electromagnetic Interference source
- High Altitude Nuclear Electromagnetic Pulse (HNEMP)
- High Powered Microwave Weapon (HPM)

Coupling mechanism

Coupling is the mechanism by which emitted interference reaches the victim. The basic nature of EMI sources coupling between electrical and electronic equipment is shown in Fig 3

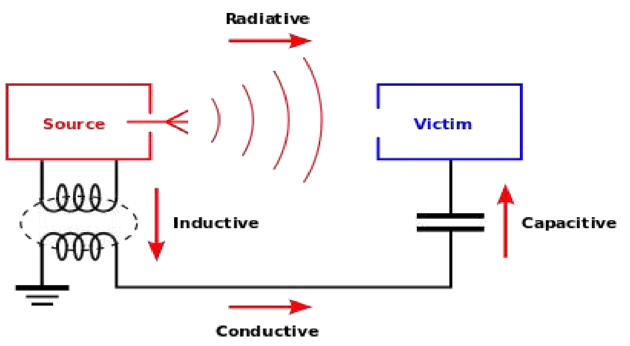

Fig.3. Conductive and radiative coupling paths

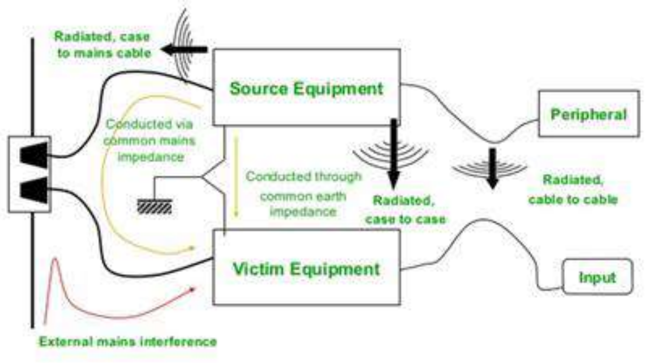

Fig.4. Natural occurance of coupling between the noise generators and Victims in EM enviroment.

TABLE II.

Types of coupling mechanisms, EMI sources and victims

EMI Source	Coupling mechanism	EMI victim
Transmitters	<u>Radiated</u> Antenna –Antenna	Receivers
	<u>Radiated</u> Antenna–Cable Antenna –Case	Electronic equipment
Other Smart Grid Electrical and electronic devices	<u>Radiated</u> Cable – Antenna Case – Antenna	Receivers
	<u>Radiated</u> Cable – Cable Cable – Case Case – Cable Case – Case <u>Conducted</u> Power lines Signal lines Ground	Other Smart Grid Electronic devices

The table shows types of Victim equipments, EMI generating equipments and mode of coupling elements.

There are two main EMC issues:

Emission is the release of electromagnetic energy, whether intended or unintended, through some source. EMC studies the unwanted emissions and the preventive measures which may be taken to minimise the undesirable emissions.

Susceptibility is the characteristic of any equipment, known as the victim, to break down or malfunction in the presence of undesirable emissions, which are known as Radio frequency interference (RFI).

Figure 4 shows the natural occurance of coupling between the noise generators and noise sinking equipments in electromagntic enviroment.

VI. SMART GRID COMPONENTS AND DESIGN GUIDE LINES

A Smart Grid uses digital technology to improve security, efficiency and reliability of the electric system from large generation, through the delivery systems to power consumers and a growing number of distributed-generation and storage resources. A Smart Grid uses embedded processing, sensing and digital communications to enable the Electric grid to be controllable, automated, observable and fully integrated with existing systems and with the capacity to incorporate a diverse set of energy. Figure 5 shows the two way communication between smart power grid systems.

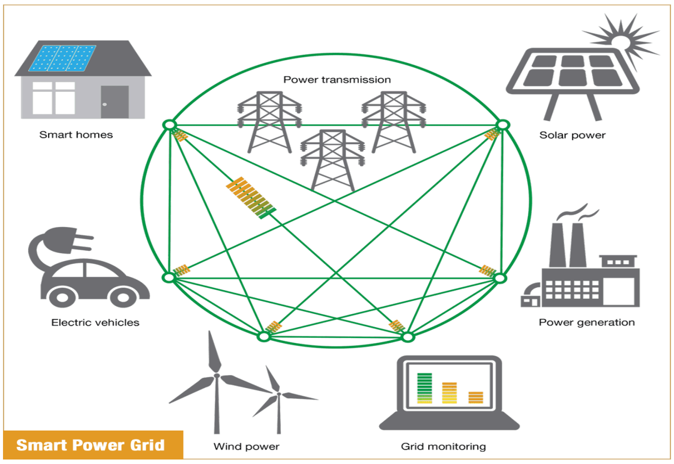

Fig .5. Interlinking of Smart grid sub systems

Design guide lines for Smart Grid Installation

The Smart Grid is composed many subsystems like Information/Data computing networks, existing power grid, telecommunication devices and links and Internet connections. The many components of Smart Grid system will perform well as integrated system in the environment in which it is intended to operate. Some of guidance is provided in this paper to ensure proper EMC performance of the Smart Grid. The Smart Grid components deployment is categorised into two locations. They are power delivery system location and power customer locations. It is required to carry out an ambient survey in these two places. The power delivery system consists of Bulk generation, Substations, Smart meters, Distributed energy resources, and Transmission Distribution and Advanced Metering Infrastructure. The following procedure will help to achieve good EMC performance for reliable operation of Smart Grid:

- Once the Smart Grid location is decided, carry out the ambient survey of electromagnetic environment in the selected location. This result will give the amount of possible interference exposed to and/or damage to electronic equipment that affects reliable operation Smart Grid
- Study of the Interference nature whether occasionally or permanent occurrence
- EMC Directive: The EMC directive applies to almost all electronic equipment. It covers the radiated and conducted emissions performance of electronic products as well as the radiated and conducted immunity performance. The R&TTE Directive applies to all radio equipments and telecommunication equipment intended to interface with public telecommunications networks. It covers the radio characteristics and frequency allocation of wireless transmitters. Select the suitable standard for Smart Grid components.
- Perform EMC test for the Smart Grid equipment's before installation
- If the Smart Grid equipments fail in the EMC performance test, the equipment should undergo EMC design loop.
- A good EMC design review should cover many aspects of an overall product design and integration of such a products.
- After installation of Smart Grid components, again ambient survey should be performed.
- Look for any new spurious components availability. That result gives the emission from the Smart Grid components. Identify and analyse the new spurious noise source and re design that particular device to reduce the emission from it.

VII. Design guide lines for EMC compliance of Smart Grid components

EMI cannot be prevented but protecting the equipment from EMI is possible. It has to be started from initial stage of designing of an electronic circuit. It is more difficult and expensive to fix the EMI problems after designing the circuit. Accordingly, there are a number of areas in the circuit which can be addressed during the design level to ensure the EMC performance.

- Circuit design for minimum radiation
- Circuit partitioning
- EMC filters
- Screened enclosure
- Screened lines and cables
- Grounding

By adopting these procedures, the EMC performance of the circuit can be greatly increased. However EMC testing has to be done to ensure that it meets the required performance. Some of the design review areas are listed in Table III.

TABLE III.

EMC design review areas of the circuit design

Emission Design review	**Immunity design review**
PCB Stack- up	ESD protection
Grounding	EFT protection
Power supplies	Surge protection
Return path	Radiated immunity protection
Decoupling	Net spacing
Power distribution network impedance	Voltage dips considerations
Stitching Vias	Shielding
Shielding	Conducted immunity protection
Enclosure Design	Magnetic field protection
Internal & External cabling	Sensitive pin protection
Impedance control	Analog consideration
High speed design strategy	Eye diagrams
PCB Zoning	Many emission design consideration also apply to immunity due to the concept of reciprocity.
Routing strategy	
Inter- board connections	
Guarding	

VIII. CONCLUSION

The necessity of EMC compliance for the smooth functioning of Smart Grid system and its components in the polluted electromagnetic environment has been presented in this paper. To ensure this, the Smart Grid systems and their components must be designed with consideration for conducting electromagnetic emissions injected into the grid and for immunity to various electromagnetic phenomena originating from the grid. Controlling emissions and ensuring an adequate level of immunity must both be taken care for assured, reliable and secured operation of the Smart Grid. If the manufacturers qualify their Smart Grid devices with EMC standards, the Smart Grid will function properly and have full interoperability, with other electrical and electronic systems. Several international organizations are underway to find an exclusive EMC standard for Smart Grid components and environment. In order to enable the system rugged to the EMI environment, it is necessary to follow the rules given in the standards and regulations.

Acknowledgment

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References

[1] IEC 61000-4-33, Electromagnetic compatibility (EMC) – Part 4-36: Testing and measurement techniques – IEMI immunity test methods for equipment and systems, Edition 1.0, 2014-11.

[2] William A. Radasky, Carl E. Baum, and ManuemW.Wik, "Introduction to the Special Issue on High-Power Electromagnetics (HPEM) and Intentional Electromagnetic Interference (IEMI)," in IEEE Transactions on electromagnetic compatibility, vol. 46, no. 3, August 2004.

[3] Electromagnetic Compatibility and Smart Grid Interoperability Issues, 2012-005, December 5, 2012.

[4] D.V.Giri and F.M.Tesche, "Classification of Intentional ElectromagneticEnvironments (IEMI)," *IEEE EMC Trans. Special issue Paper number B-1*

[5] Dr. Richard Hoad and B. Petit, "Protection of the infrastructure from HEMP and IEMI disturbances through the application of standards" A presentation to: The IET Seminar on The Triple Threat to Infrastructure 14th January.

[6] "White Paper on HPEM Technology" by Diehl BGT Defence.

[7] Engineering Electromagnetic Compatibility: Principles, Measurements, Technologies, by W. Prasad Kodali

[8] ZigBee Alliance, 2400 Camino Ramon, Suite 375, San Ramon, CA, +1 (925) 275-6607, http://www.zigbee.org (IEEE 802.15.4)

[9] Wi-Fi Alliance, http://www.wi-fi.org (IEEE 802.11a,b,g,n)

[10] WiMAX Forum, http://wimaxforum.org

[11] European Telecommunications Standards Institute (ETSI), http://www.etsi.org

Optimized Power Management of a Storage Enabled DC Grid Tied Solar PV Power System

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***Abstract*— The intermittency due to variable weather conditions and thus presents a major obstacle to the extensive penetration of Solar PV source into the utility grid. To mitigate this difficulty and power fluctuations at the load end, a possible solution could be the integration of battery energy storage with grid tied solar PV system. The Storage system can potentially improve power quality, reliability of power system by satisfying the required load demand under variable Solar PV output. Here we are proposing a battery energy storage named as Vanadium Redox Flow Battery (VRFB) [1-4] which is a promising energy storage technology to increase the supply reliability of large-scale PV applications. This paper also proposes an efficient power management scheme for VRFB storage enabled DC grid [5-7] connected PV power system. The integrated PV system will supply power to the required load and excess power will charge the battery via Bi-Directional DC-DC Converter. During PV Power generation deficiency, the battery will be in discharging mode to supply the required load power and thus smoothing the peak load [8-10] in that period. When the PV integrated storage system is not sufficient to supply the fixed load demand, then the DC grid will provide the remaining power to the load and charge the battery storage thus smoothening the transient. The entire proposed power management scheme has been designed with the real life technical specification of a 1 kW 6hr, 16 cells VRFB storage and the battery SOC (State of Charge) prediction algorithm [11] is also implemented in MATLAB/Simulink environment to lengthen storage lifetime also.**

***Keywords*— Solar PV,VRFB, Bi-directional DC/DC converter, MPPT, DC grid.**

I. Introduction

Utilization of renewable energy sources such as solar energy for electric power supply has received considerable attention in recent years due to global environmental concerns associated with conventional generation and potential worldwide energy shortages. The urgent need to reduce the use of conventional energy has led to the investigation of the use of renewable energy sources, such as the solar energy, to replace majority of the fossils fuel consumption. Solar PV energy systems have a fluctuating power output due to the variable weather condition and availability of the sunlight. Integrating an appropriate energy storage system in conjunction with solar PV array smoothens the Power fluctuation and improves the reliability of power supply at the load end. Vanadium Redox Flow Battery (VRFB) is a promising energy storage option for large stationary electricity storage systems with many potential applications in a deregulated and decentralized network. Considering the availability of PV power and Battery SOC the reliability of a standalone solar PV system undergoes difficulty. To mitigate this difficulty a DC grid [5] connected Solar PV system is introduced in this paper. DC grid works as an independent power source that is disconnected from the commercial AC grid at the instant of grid failure. A DC-DC bidirectional converter plays an important role to allow power to flow from and to the battery depending on battery SOC, PV power output and Load demand. In this paper a VRFB storage enabled DC grid connected PV system is designed and the power flow is optimized by a suitable algorithm to satisfy demand side requirement.

II. System Overview

The coordination between the major components of the proposed DC grid Connected solar PV system with VRFB energy storage is shown in the figure 1,

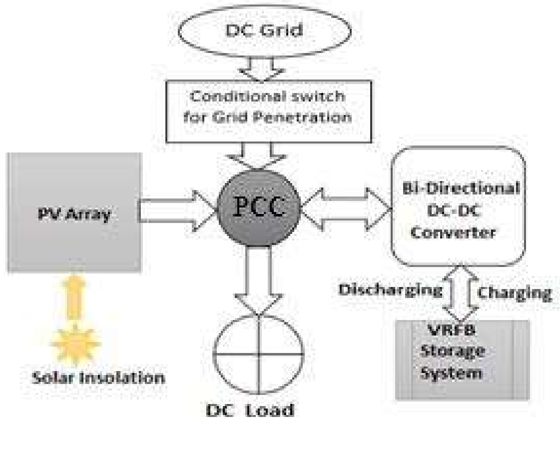

Fig1.Block diagram representation of the proposed system

Here in the figure 1, the Solar PV, VRFB, DC load and the DC Grid are connected together at the junction called Point of

Common Coupling (PCC). The control algorithm will decide optimized penetration of these sources to satisfy required load demand.
The technical specification of the system components for simulation purpose is shown in table I,

TABLE I. TECHNICAL SPECIFICATION USED FOR SIMULATION OF DC GRID CONNECTED SOLAR PV SYSTEM WITH VRFB ENERGY STORAGE

Parameters	**Technical specifications required to simulate the DC grid connected Solar PV system with VRFB Storage**		
	Solar PV Array	***VRFB Storage***	***DC load***
Power rating	1 kWp	1kW	350W
Voltage rating	36 Volts at MPP at NOCT	25.6 Volts for 16 cells	24 Volts
Current rating	27 Amperes at MPP at NOCT	50 Amperes Maximum allowable charging current	14.5 Amperes

III. SYSTEM LEVEL DESCRIPTION OF MAJOR COMPONENTS

A. *Solar PV Array*

Photovoltaic (PV) cells are made of light-sensitive semiconductor materials mostly silicon that use photons from sun light to dislodge excited electrons to generate DC electric power. The electrical power output of a single PV cell is very small hence multiple cells are connected in series or parallel to form a module. To satisfy large power demands these modules are further arranged in series-parallel combination to form an array. The power generation of the PV module varies significantly with variation of solar insolation that makes it intermittent in nature. An Electrical equivalent circuit of solar PV cell is shown in figure 2,

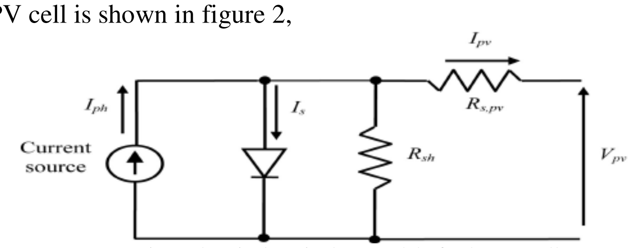

Fig.2 Electrical equivalent model of solar PV cell

From the equivalent circuit in figure 2 we can get the following mathematical equations of a solar cell,
The relation between the PV output current and the circuit components are described in equation (1),

$$I_{pv} = I_{ph} - I_0 \left[exp\left\{\frac{e(V_{pv}+IR_s)}{KT_c}\right\} - 1\right] - \frac{(V_{pv}+IR_s)}{R_{sh}} \quad (1)$$

Where,

I_{pv} = PV output current (A).
I_{ph} = Photo Current (A).
I_o = Reverse saturation current of the diode (A).
e = Charge of electron (1.6×10^{-19} C).
V_{pv} = Terminal output voltage of the PV cell (V).
R_s = Series resistance of PV cell (Ω).
R_{sh} =Shunt resistance of the PV cell (Ω).
K = Boltzman constant 1.38×10^{23} (J/K).
T_c = Cell temperature in ^oC.

A 1kWp Solar PV array is designed in MATLAB/Simulink environment and Perturb & Observed MPPT algorithm is implemented to extract maximum PV power under different insolation levels of the two individual case studies. This will enhance the efficiency of the Solar PV source.

B. *VRFB Energy Storage System*

VRFB stores chemical energy and generate electricity by a redox reaction between vanadium ions dissolved in the electrolytes. The relation between battery stack voltage and State of Charge (SOC) is established in this section based on electrical equivalent Nernst equation [2-4]. The relation between different electrical parameters of VRFB is given by;

$$V_{cell} = V_{eq} + \frac{2RT}{F}\ln\left(\frac{SOC}{1-SOC}\right)\ Volt \quad (2)$$

For stack voltage, $V_{stack} = n \times V_{cell}$ (3)

And battery terminal voltage is expressed as,

$$V_b = V_{stack} - I_{stack}(R_{Reactance} + R_{Resistive}) \quad (4)$$

For VRFB SOC [11] calculation,

$$SOC = \frac{P_{stack} \times T_{step}}{E_{capacity}} \quad (5)$$

The most significant feature of the VRFB is the modularity of their power (Watt) and energy (Watt-Hour) ratings which are independent of each other. VRFB are essentially comprised of two key elements; the cell stacks where chemical energy is converted to electrical energy in a reversible process, and the two electrolytic tanks where the energy is stored. The electrolyte flow to the stack is controlled by the two pumps.
The vanadium can exist in four oxidation states. A proton exchange membrane allows proton (H^+) crossing from anode side of the stack to the cathode and vice versa during charging and discharging. The scalability of energy capacity of VRFB can be made feasible by adding more electrolytes to the tanks. Hence unlike other conventional battery storage systems, complete renovation of the whole battery is not required in case of VRFB.
The physical model of VRFB is shown in Fig. 3,

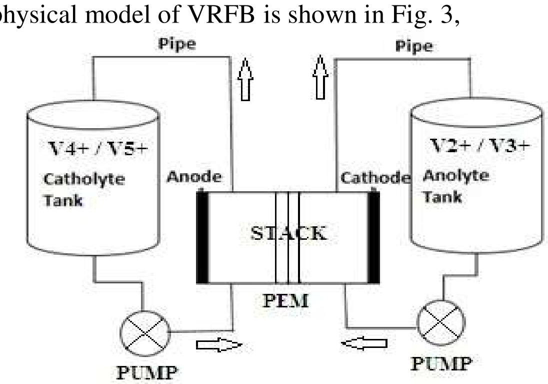

Fig.3 component level diagram of VRFB

The MATLAB/Simulink model of the 16 cell 1 kW 6hr VRFB based on the above equations (2-5) is shown in Fig.4,

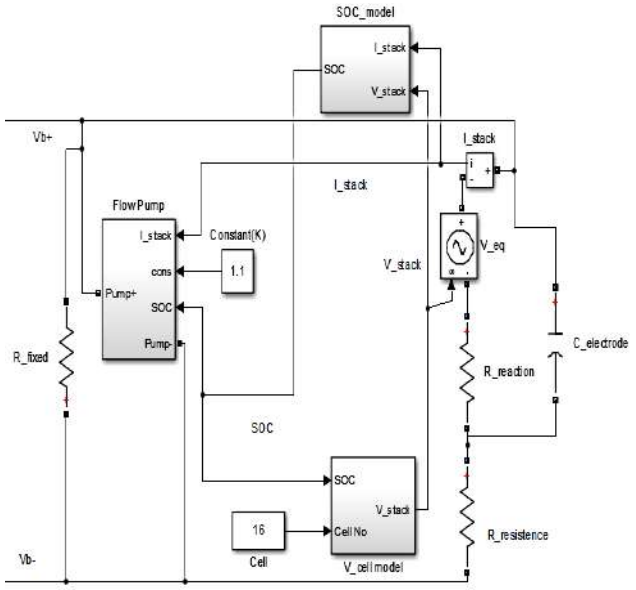

Fig.4 VRB electrical equivalent model for SOC estimation

The above electrical equivalent model of VRFB is capable of predicting the SOC online and very useful for designing the battery management system to lengthen the storage lifetime.

C. DC-DC Bi-directional Converter

The DC-DC half bridge bi-directional converter is designed to perform appropriate charging and discharging of the VRFB storage as and when required by the load depending on the solar PV generation and battery SOC.

In each switching cycle of the converter the battery is charged through source side active switch for the duration of T_{on}=DT, where T = ($1/f_{sw}$) is the switching time period and D is the duty cycle. This battery discharges power to load during T_{off} = [(1-D).T]. From the Fig.5 of bidirectional DC-DC converter simulation model, left to right power transfer mode involves Q1 and D2 as active switches while charging, while in the right to left power transfer the opposite switches Q2 and D1 are activated while discharging the VRFB. C1 and C2 are the filter capacitors used to smoothen the ripple content in power flow in both the direction.

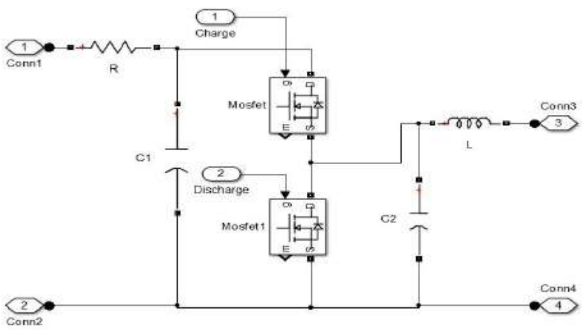

Fig.5 MATLAB/Simulink model of Half Bridge Bi-Directional DC-DC converter

D. DC Grid

Here the Solar PV DC grid [5] system constitutes of major components like solar PV connected through a DC-DC converter with Maximum Power Point Tracking Techniques (MPPT) to enhance the efficiency of Solar PV power system, a constant resistive DC load is used in this system and to take care of load and generation unbalance, a suitable VRFB energy storage system is used for power smoothing and load matching. The DC grid will supply power to the load in the worst case when there is neither adequate solar PV generation nor available battery SOC (Less than 10%) to maintain the required load demand.

IV. SIMULATION RESULTS

The performance of the overall DC grid connected solar PV power system with VRFB storage is simulated and analyzed with two practical case studies.

1. Simulation results of Case study 1:

In this case study 1, a practical set of 12 Hours solar insolation data is used to simulate the whole model and the results are shown in figure 6 – 10,

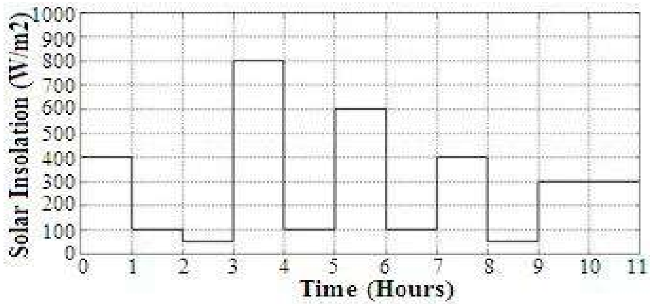

Fig.6 Twelve Hours Solar Insolation pattern for case study 1

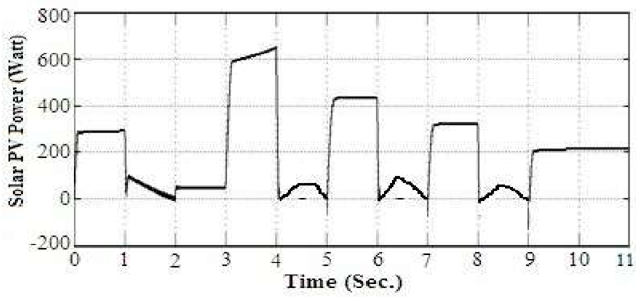

Fig.7 PV Power output (Watt) for case study 1

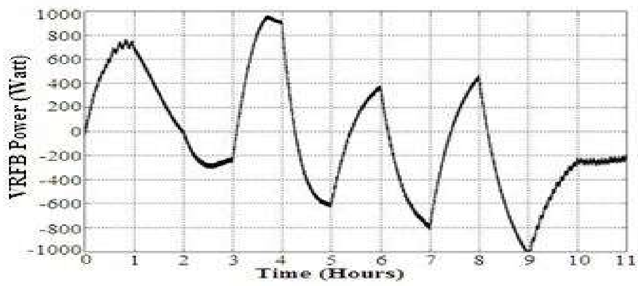

Fig.8 VRFB Power (Watt) for case study 1

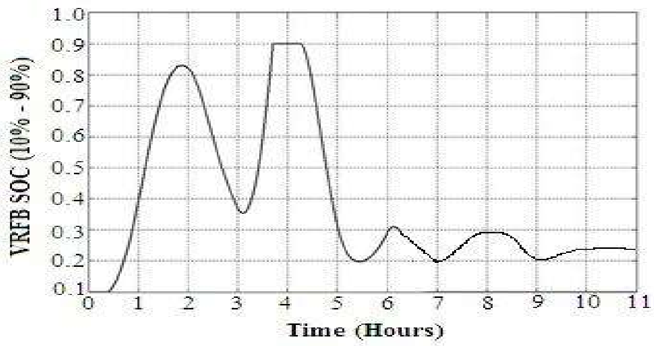

Fig.9 VRFB SOC (10% - 90%) for case study 1

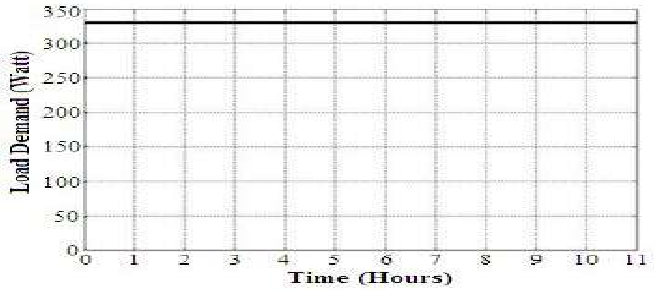

Fig.10 Load demand (Watt) for case study 1

2. Simulation results of Case study 2:
In this case study 2, another practical set of 12 Hours solar insolation data is used to simulate the whole model and the results are shown in figure 11– 15,

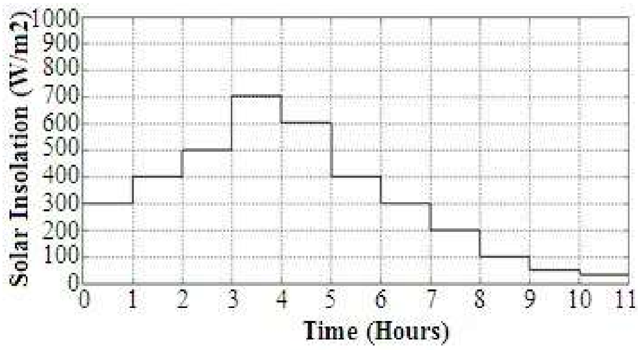

Fig.11 Twelve Hours Solar Insolation (W/m^2) pattern for case study 2

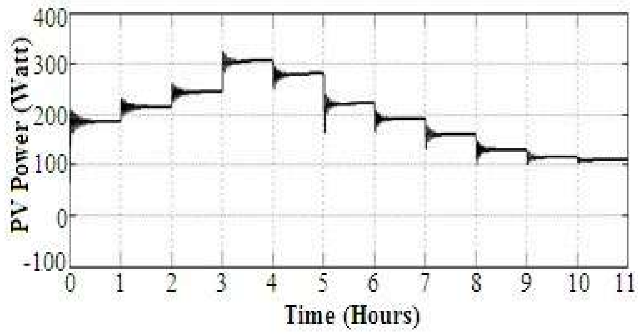

Fig.12 PV Power output (watt) for case study 2

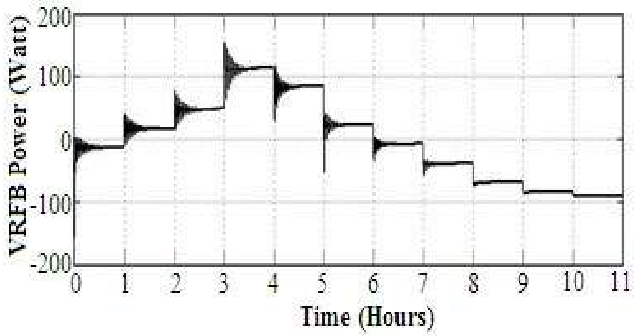

Fig. 13 VRFB Power (watt) for case study 2

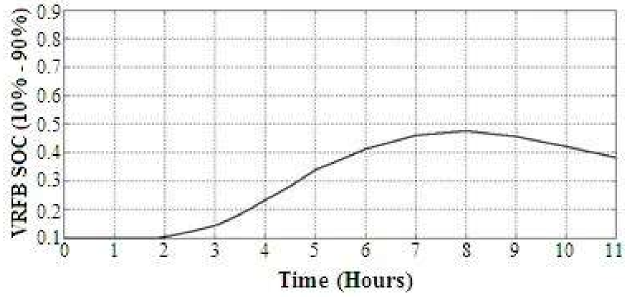

Fig. 14 VRFB SOC (10% - 90%) for case study 2

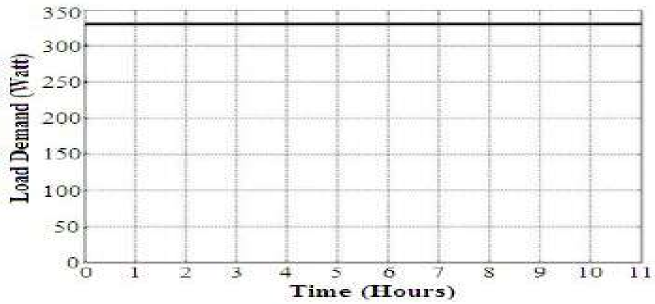

Fig. 15 Load demand (watt) for case study 2

A. Analysis

From the simulation results shown in figure 6–10 it is observed that in case study 1, during higher solar insolation (W/m^2) level the VRFB power is positive which means the battery is being charged as shown in figure 8 and the reverse happens in case of poor solar insolation. The charging and discharging modes of VRFB is executed by a suitable bi-directional DC-DC converter placed just after the Point of Common Coupling (PCC). The battery SOC online variation is observed while charging and discharging depending upon available solar PV power and fixed load demand of 350 Watt.

Another set of solar insolation is taken as case study 2 and the simulation results are observed as shown from figure 11-15. The cloudy weather is created in the second half of the twelve hours insolation data. It is observed that in this case study even during the first six hours of relatively higher insolation level, the PV source alone is not capable of supplying power to both the Load and battery. Hence the power management algorithm comes into act. Then the PV power partially charges the battery and the load is satisfied by both the PV power and major contribution of the DC grid. The second case study is basically performed to realize the worst condition when the high level penetration of DC grid along with VRFB storage is required to maintain the load requirement.

V. CONCLUSION

The simulation results for both the case studies show the online SOC prediction of VRFB storage and management of a fixed load demand of 350 Watt by the proposed power management algorithm. The control algorithm helps the VRFB storage neither to be overcharged (Greater than 90%) nor deeply discharged (Less than 10%) even after repetitive charging and discharging in order to match the required load demand. The high penetration of the DC grid is executed only in the worst situation of both very low solar insolation and very low available SOC of VRFB storage for power smoothing and load matching, thus making the overall PV power system cost effective and efficient by utilizing the PV power and VRFB storage for most of the time. The simulation results help in validation of the proposed power management scheme in practical field.

ACKNOWLEDGEMENT

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REFERENCES

[1] M. Skyllas-Kazacos, D. Kasherman, D. Hong, and M. Kazaco, “Characteristics and performance of 1 kW UNSW vanadium redox battery”, *Journal of Power Sources*, vol. 35, no. 4, pp. 399-404, 1991.

[2] J. Chahwan, C. Abbey, and G. Joos, “VRB modelling for the study of output terminal voltages, internal losses and performance”, *Proc. IEEE Can. Elect. Power Conf.*, pp. 387–392, Oct. 2007.

[3] C. Blanc, “Modeling of vanadium redox flow battery electricity storage system”, *Ph.D. dissertation*, *Echole Polytechnique Federale DeLausanne,* 2009.

[4] M. H. Li, T. Funaki, and T. Hikihara, “A Study on the Modelling of Output Terminal Voltage for Redox Flow Battery Based on Charge and Discharge Experiment”, *Industry Applications Society, IEE Japan,* pp. 585-586, 2006.

[5] L. Xu and D. Chen, “Control and operation of dc microgrid with variable generation and energy storage,” *IEEE Trans. Power Del.*, vol. 26, no. 4, pp. 2513–2521, 2011.

[6] L. Baumann, J. Grahn, E. Boggasch, and L. Khl, “Integration of a vanadium-redox-flow-battery into a hybrid energy system”, *7th International Renewable Energy Storage Conference, Berlin, Germany*, 2012.

[7] J. Guggenberger, A. C. Elmore, J. Tichenor, and M. L. Crow, “Performance prediction of a vanadium redox battery for use in portable, scalable microgrids,” *IEEE Trans. Smart Grid*, vol. 3, no. 4, pp. 2109– 2116, Dec. 2012.

[8] B. Turker, S. Arroyo Klein, E. Hammer, B. Lenz, and L. Komsiyska, “Modelling a vanadium redox flow battery system for large scale applications”, *Energy Convers. Manage.*, vol. 66, pp. 26–32, Feb. 2013.

[9] Guishi Wang, Mihai Ciobotaru, and Vassilios G. Agelidis, “Power Smoothing of Large Solar PV Plant Using Hybrid Energy Storage,” *IEEE Transactions On Sustainable Energy*, Vol. 5, No. 3, July 2014.

[10] Riccardo D‘Agostino, Lars Baumann, Alfonso Damiano and Ekkehard Boggasch, “A Vanadium-Redox-Flow-Battery Model for Evaluation of Distributed Storage Implementation in Residential Energy Systems,” *IEEE Transactions On Energy Conversion,* Vol. 30, No. 2, June 2015.

[11] A.Bhattacharjee, H.Saha, “A Generic Electro-Thermal Characteristic Model of Vanadium Redox Flow Battery under Different Charging Conditions”, *5th International Conference on Advances in Energy Research,* 15-17th Dec. 2015.

Transformation from Rigid to Smart & Agile Grid – Need and Reality of the 21st Century

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Abstract

Trend of transformation happening in the field of energy generation and energy consumption are amazing. A revolution is taking place in the area of energy management like the revolution in the telecommunication sector in the recent past, aided by wireless technologies. The transformation has begun and now there is no going back. Our effort should be to make this transformation smooth and making sure that all the stakeholder is ready to embrace it wholeheartedly. Smartness, easily available information for decision making and agility are what will make this disruptive change a pleasure. This paper will look at how trend in telecom revolution will help formulate vision, mission and policy initiatives in making the transition from the current state of electricity grid to future desired state of electricity grid. The paper will draw parallels between the two infrastructure sectors and the trend is amazingly similar. Based on the current trend, the paper will draw to be state of electricity grid wherein everyone has a stake. The paper will depict all the components and stakeholders of this to be grid.
Key takeaways from the paper will be:

1. Vision, mission and Strategic drivers of the future electricity grid
2. How would future grid look like
3. Enablers and Technological evolutions that is and would help development of this smart & agile grid
4. Socio-economic benefits of the future smart & agile grid
5. Policy initiatives that would make the transformation smooth, time bound and more value adding

Keywords

Electricity Grid, Smart Grid, Distributed Energy, Empowerment

Introduction

Access to energy, use of energy and infrastructure required for energy dispersion is going through disruptive change. The transformation happened in the way people communicated and used communication systems had also undergone a similar structural change. While I was doing my graduation (during 1992-1996), I used to stay in the college hostel. I went to college on Monday morning and retuned home for the weekend on Friday evening or sometime Saturday morning. On some occasions, while I had to compete some assignments I didn't go home for a weekend. Between this one week and sometime two weeks, there was no communication between me and my parents and they were never concerned about it. But on the other hand now a days if I do not call my parents one evening they are concerned. I am sure similar experience would be shared by a large number of my countrymen.

Today there are many villages in our country who does not have access to electricity. Even many more villages and many towns have highly irregular and unpredictable electricity supply. Large number of our population is still happy if they get about 8-12 hours electricity in a day. But this is going to be a history soon. Revolutionary change that happened in the telecom sector has just taken off in the electricity sector. Similar paradigm shift is happening in the way our general population views accessibility and availability of electricity. Like the customers do not tolerate call drops and other disturbances in a telephone call, consumer tolerance level against power disturbances becoming lesser and lesser. All the stakeholders including the policy makers, regulators, utilities, IPPs and other service providers have to be ready for such a scenario, which requires speedy and feedforward action.

Key factors / technologies that changeD telecom sector

Digitization, two-way communication and mobility were the key enablers for the telecommunication revolution that happened in our country. Key policy initiatives and

Government interventions at the right time have made sure that the fruits of the revolution are shared by all stakeholders.

Use of digital technology has enabled reach of telephone to large portion of our county in the form of STD booths and established quick communication link with large number of villages. Instant two-way communication provided a new aura in our daily interaction irrespective of the distance. This was a paradigm shift from the traditional one-way communication through letters, telegrams etc. Unidirectional communication has become a thing of the past at least when it comes to personal communications. Even pagers have been forgotten. And mobility has enabled us to communicate whenever there is need for it. We do not have to wait impatiently so that the person is at home or office or any other place where a telephone instrument is available. The wireless technology has enabled mobility and in addition it brought the cost of infrastructure substantially down making reach of the technology to every nook and corner of the country.

Today, access to these wireless and mobile technology has transformed the way individuals live or conduct themselves. Moreover, it has changed the way organizations do business and the way Government undertake administration of the public policy and social justice.

PARALLELS BETWEEN TELECOM SECTOR AND 21ST CENTURY GRID

ICT technology, Solar Energy and Advanced Battery technologies will be the enablers replicating telecom revolution in energy sector. ICT and smart metering will do to energy sector what digitization has done to telecom sector. Going forward, ICT and smart metering will allow connecting the rural masses to the mainstream grid and remain integral with it. Utilities will have to done away with the step motherly treatment to rural grid when it comes to demand side management.

Solar energy will replicate what two-way communication has done to telecommunication sector in the energy sector. Solar energy enables the citizens to generate their own electricity. They do not have to wait until utility is kind enough to switch on the distribution feeder supplying power to their area. This aspect will revolutionize the way citizens in general and rural population in particular will look at their electricity need and the services provided by the utilities.

Advanced Battery Technology (ABT) will the enabler for energy sector replicating mobility as enabler for telecom sector. ABT in combination with Solar and / or Grid and smart metering will provide mobility to energy use. The consumers will be able to decide when they must buy electricity (and probably sell electricity) irrespective of their actual consumption time. Traditional battery technologies have very low overall efficiency, relatively low life span and very high maintenance requirements making the over cost of using the technology prohibitive. Beside they are environment hazards and safety concerns. New ABTs now being made available and many other ABTs in prototype state or in lab development will find cost effective solution for all the disadvantages of current classical battery technologies. There is already more than 1000MW lithium ion batteries installed worldwide providing utility scale grid storage – making renewable energy dispatchable or providing ancillary services. Similar storage solutions will replace peaking power stations (using fissile fuel) sooner than later as it offers substantial cost advantages.

Per capita electricity consumption in India for the year 2012 was about 914kWh, while the world average was above 3000kWh and similar figures for China was about 3500kWh. GDP and standard of living have strong correlation with energy consumption. This shows an enormous potential for improvement. Tele density in India has increased from about 3.5% in 2000 to about 70% in 2012 and to about 80% in 2015, rural telephone density being about 48%. One crucial factor for this successful exponential growth was steep cost reduction in the telecom services, among others. Similar, trend is taking place (though in the early stages at present) in the solar energy and energy storage driven by learning curves and technological improvements / breakthroughs. The core technology supporting both the sectors is electronics.

21ST CENTURY GRID – HOW WILL IT BE DIFFERENT

Today's grid is supply driven or top down (Fig.1). Though the system operator tries to match the demand and supply, at least sometimes they end up reverting to power cut and load shedding (planned and / or unplanned) to manage the grid operations. Since the grid is supply driven, transmission and distribution losses are outside the system operators control. Large power generators and the large transmission line network are the backbone of the system. The resilience of the system depends on how well this backbone respond when needed. In this scenario black outs are a big concern and when it happens is a disaster.

The description of today's evolving grid is right opposite to what is described above (Fig.2). This new grid is demand driven or bottom up rather than the supply driven. Here the last mile consumer will be equally important to the centralized generator and the transmission network. He may not be only consumer anymore and therefore will be renamed as customer. While he will continue to consume power, he may produce commercial energy, he may store energy and he may also sell electricity to the grid. The economics will drive how the last mile customer will interact with the grid. He might sacrifice use of electricity in a particular period (say evening peak) to make a few bugs by selling his stored electricity to another customer who has a higher utility for electricity at that point in time. However, the key point is that the decision is within the customer's domain. The same economics will play a role in deciding whether to purchase a petrol car or an electric car or a hybrid car. Customers having hybrid car will further choose between charging their battery or filling gasoline based on the same economics.

Large number of energy customers will have factory producing energy on their roof or in their backyard. That in itself will become an economic activity. The grid stability this system can bring is fantastic provided it is integrated well. The grid will become two-way and interactive. The strain on the transmission and distribution system will become less and less. Going wireless may not be feasible for electricity transmission in the near future. However, distributed generation with distributed storage can make system optimally wired. Transmission and distribution infrastructure requirement will come down drastically while the reliability and efficiency will progress north if we are able to apply optimum use of ICT, Solar Energy and ABTs. Grid infrastructure backbone will shift from large power generators and the transmission lines to distributed generation and storage system. Black outs will become history. Once the customers have an independent energy factory and an independent energy storage, they are self-sustaining. The economics and reliability considerations will decide how much capacity of energy factory to install or how much energy should be stored.

Automobiles with its storage batteries (while in the garage) would become another big source of energy reserve. Today's automobiles are completely unused while in garage. With new age grid and technologies, the automobiles might help the owners earn a few bugs and / or contribute towards grid stability, while it is not on road.

Component of T&D cost in the delivered cost of electricity in India was about 40% in 2010. Distributed generation can substantially bring down this component of electricity price, making it another driver for distributed generation.

This scenario will force the utilities to respond. If the T&D losses continue to mountain, they will no longer be competitive and the customers might decide to move to stand alone micro / min grid instead of remaining connected with the utility grid. This in itself will become a compelling business case for utilities to tighten their belt and take decisive action. Utilities will also turn to storage technologies (distributed all though the grid infrastructure) to support grid stability and load management, synonymous to the telecom towers seen all over the country.

Possibilities are numerous and in this ever changing technological world it is practically impossible to visualize precisely what is coming.

21ST CENTURY GRID – THE RURAL STORY

Our Father of the Nation said soul of India lives in its villages. He also said "If we are able to adopt the charkha intelligently we can revive the entire economic life of our villages." The new electricity grid along with the communication technologies is providing us an opportunity to re-discovery this soul and it has the potential to make the rural India as big a center of economic activity as its towns and cities. Access to timely and accurate communication and reliable energy sources could provide the rural India a choice of selling processed or semi-processed products over selling raw produce. With access to energy, water, transport infrastructure and communication, our rural society could come close to a Utopian community.

Revolution in telecommunication technologies has brought the farmers closer to the market. Unlike earlier, today there is more transparency in pricing and the farmers are able to know the market price for their produce giving better bargaining power while dealing with the local traders. They have also become better informed about the government policies and procedure in getting what is due to them. Similarly, new age grid coupled with storage of energy driven by ABTs and other enabling technologies exploiting freely available energy sources, will extend mobility to the rural community's economic activities. Once energy is available to a customer when they need it, they will be more empowered to decide their economic activities wisely. Possibly they can have small cold storages to store perishable goods and this will lead to another revolutionary change in how we manage our food chain. The rural population will become less vulnerable to price variations and supply-demand mismatches. This will also lead to more stable agricultural commodities market helping both the producers and the consumers. With a reasonable empowerment, the farmers will be able to decide when to sell their produce irrespective of when they harvest. Once appropriate warehousing facilities are available within their reach, the banking system will also be able to better support the small and marginal farmers.

Electricity sector could be a perfect market place (as taught in the books), if production, consumption and storage are regulated well, with this objective. There will be infinite number of sellers and infinite number of purchasers in the market place. In such a scenario the Government's role will be limited to make the transmission and distribution infrastructure available at competitive cost without bottlenecks. Employment generation potential is immense, in the rural area in particular. Ideally the rural India has the potential to become energy factories (production & storage) to support the industrial and commercial activities elsewhere in the country, in addition to supporting their own economic activities. More importantly, these all can be achieved without degrading our environment further.

21ST CENTURY GRID – THE CHALLENGES

While the opportunities and hopes provided by the new evolving energy technologies are numerous, challenges are also plenty. A disruptive change is in the offering. Managing this disruptive change is challenging because it's a whole paradigm shift from top-down approach to bottom-up approach. Key players are changing and roles are getting mixed up. Here some conventional roles are getting challenged – like that of utilities. They need to anticipate what is coming and be agile to adapt to the ever changing technology and business environment.

Existing utilities are the most important enabling agency who can make the transformation smooth or rough or violent. Like happened recently in one of the US state's, the utilities can try to discourage the transformation by mounting resistance and creating artificial trade barriers. But the historical lesson is that they can only delay the inevitable and not prevent it. Like if a bridge is too rigid, it will not stand large storms and other natural calamities. Therefore, the designers incorporate flexibility in the bridge construction to withstand such conditions. The utilities will have to redefine their roles and adjust their business models to take advantage of the technology and the changes happening instead of resisting it.

In order to take full advantage of the technological advancement in a times and cost effective manner the legislative bodies and the regulatory bodies have to take appropriate and proactive action commensurate with the evolving technologies. These bodies have to make a masterplan looking at 20-25 years horizon at least and keep upgrading the plans periodically based on the technological evolution and the market development. Moreover, all the regulatory and enabling provisions and activities shall be in sync with this master plan. For example, timely adaptation of smart technologies is key to the adaptation of distributed generation and interconnected micro & mini grids. Regulatory intervention coupled with focused investments in the T&D infrastructure are un-avoidable & invaluable activities in this direction.

In this scenario, the proposed delinking of infrastructure and service components in the last mile distribution is key to adaptation of the new technological evolution. The infrastructure provider shall not have conflict of interest in the generation, sale and purchase transactions. Timely and gradual introduction of ancillary services like grid support and dynamic tariff based on supply and demand would make the system most efficient and will be key to the adoption of the new technologies.

Environmental wellbeing of economic activities cannot be neglected. Any factories including energy producing factories causing environmental degradation should not go scot free. Otherwise the market becomes distorted in addition to causing environmental degradation.

VISION, MISSION AND STRATEGIC DRIVERS OF FUTURE GRID

The telecom story has gone beyond "Connecting All" to giving identity to citizens and effective, efficient & timely administration of various statutory and other functions. Therefore, Vision for future electricity sector should change from the current slogan of "Energy for All" to "Empowerment and Opportunity for All". While Energy for All could be and should be a near term goal, it is too limiting on long term and is not capturing the full potential of the evolving technologies. Access to quality & affordable electricity brings forth numerous opportunities with it.

Mission should be to make smart, agile, efficient and bottleneck free grid infrastructure and a point of connection to every household. Next important mission should be to ensure appropriate regulatory regime in place on a timely manner.

Strategic drivers that should be focused on will be environmentally clean energy, 24x7 access to energy, rural economy development and employment generation. In short overall social well-being is the most important strategic driver that should shape future electricity grid.

CONCLUSION

Energy Industry is going through a revolutionary change unimaginable a decade ago. At least as it is played out, it is for good – economically, socially and environmentally. Lot of great minds are working to shape this change, around the world. The advantage it promises to brings to our nation is amazing in terms of energy security and overall wellbeing of it large rural population in particular. Last mile empowerment and agility in approach is the key for the success of a diverse and democratic society. Smart and agile electricity gird will greatly contribute to this empowerment.

Lessons learned from the telecom market development should make the progression to the new state of grid less disruptive. This should be a guidance to traditional market players as they are being challenged as telecommunication technological change has challenged the traditional companies in the telecom sector. They can ignore it only on their own peril. Mr. Shai Agassi's start-up "Better Place" has failed as a business, but the idea is still alive and will become a reality sooner than later.

A. *Figures and Tables*

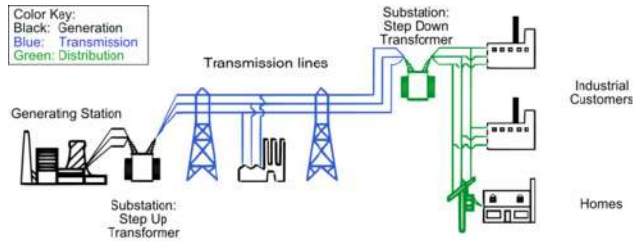

Fig 1 – Current Electricity Grid

Fig 2 – Future Electricity Grid

REFERENCE

http://www.mkgandhi.org/ebks/Gandhionvillages.pdf
http://www.worldenergyoutlook.org/media/weowebsite/2015/IndiaEnergyOutlook_WEO2015.pdf
http://www.livemint.com/Industry/jqvJpYRpSNyldcuUlZrqQM/Indias-per-capita-electricity-consumption-touches-1010-kWh.html
http://www.cea.nic.in/reports/annual/generalreview/general_review-2013.pdf
http://www.trai.gov.in/WriteReadData/Publication/Document/201304121052403536675NCAER--Report08june12.pdf
http://data.worldbank.org/indicator/EG.USE.ELEC.KH.PC/countries/1W-IN-CN?display=graph
http://www.trai.gov.in/WriteReadData/PIRReport/Documents/Performance_Indicator_Report_Jun_2015.pdf

A System level Framework for Evaluating High Share of Renewables in the Future Energy Mix

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***Abstract* - Keeping in view India's recent international commitment to expand the share of renewable electricity to 40% of total generation by 2030, this paper proposes a framework for planning and addressing the implications of high share of renewables in the energy portfolio. Of the planned capacity addition target of 175 Giga Watt (GW) for renewables, wind and solar energy sources form a predominant share of 160 GW. These sources are inherently intermittent in nature. For effective integration of these sources, a system-level framework is required to understand the impact – in terms of resource availability, land utilization, technology options, economics, evacuation infrastructure and the need for storage.**

There are multiple stakeholders involved in the planning and implementation of policies, both at the state and central levels. This framework will aid stakeholders to envision the impact of varying the share of renewables in the future energy mix over the medium to long-term period. Additionally, it can test specific policy levers to plan for a high share of renewables (up to 100%) in the energy mix. The framework is expected to facilitate the decision making process by incorporating inputs from multiple energy and power sector entities, thereby providing an integrated visual representation of the current and future energy situation in India. This framework is demonstrated for the state of Karnataka.

Keywords— Decision Support framework, Renewable Integration, Policy levers, Intermittency

INTRODUCTION

Recently, the Government set a national target for renewable energy as 175 GW by 2022, which is expected to include 160 GW of wind and solar capacity. The draft Karnataka Renewable Energy Policy 2014-20 [1] envisages a minimum non-solar renewable capacity addition of 3600 MW by 2020 in a phased manner.[1] Further, the Karnataka Solar Policy, 2014-21 [2] targets a minimum grid connected and rooftop solar capacity addition of 2000 MW by 2021.

In order to meet the ambitious national and state level targets for wind and solar capacity addition, there are several factors that need to be considered in the planning stage. These include land and resource availability, proximity to a robust grid framework, must-run status of plants, and available backup generating capacity to meet the hourly demand when wind and solar output is low.

Renewable sources are intermittent sources of generation and exhibit seasonal as well as diurnal variability. Fluctuations of high magnitude are observed in wind generation at sub-hourly levels. For an installed capacity of 1,800 MW in August, 2011 it was observed that there was loss in generation of the order of 100 – 150 MW (5 - 8% of installed capacity) within 15 minute time intervals [3]. This poses serious problems to grid operators and the utility to manage the intermittency.

In this context, power sector stakeholders are often faced with the challenge of identifying suitable strategies to mitigate the intermittency and supply-demand mismatch as a result of increasing penetration levels of renewables in the generation mix. The stakeholders typically include Karnataka Electricity Regulatory Commission (KERC), Karnataka Power Corporation Ltd. (KPCL), Karnataka Power Transmission Corporation Ltd. (KPTCL), State Load Dispatch Centre (SLDC), and Electricity Supply Companies (ESCOMs).

Going forward, there is a need to engage in dialogue with potential stakeholders to discuss the country's future energy situation (especially in the context of increasing penetration of renewables). To enable the same, this paper describes an analytical decision support framework to visualize the impact of different policy levers and energy strategies, particularly focusing on the state of Karnataka.

DECISION SUPPORT FRAMEWORK

The framework is designed to provide the capability for incorporating user-specific inputs to aid in decision making at multiple levels. This will be carried out via visualization of the impact of different policy levers on key decision criteria. The objective of the framework is to enable engagement with stakeholders through various stages of a planning process to incorporate their constraints, thereby factoring complexities which are representative of reality. Figure 1 shows a schematic representation of the analytical framework.

[1] Sources include wind, small hydro, biomass, co-generation, and municipal solid waste

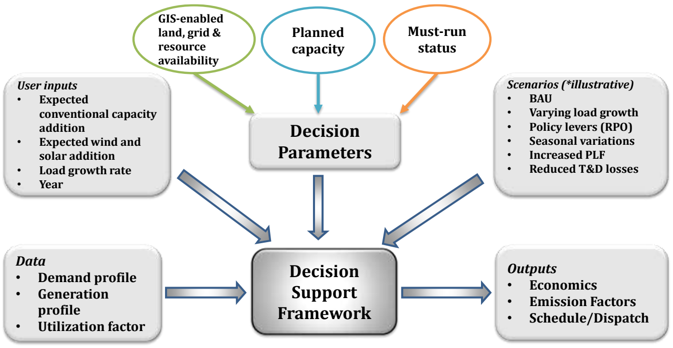

Figure 1: Schematic representation of the Decision Support Framework

Steps 1 through 6 below describe the various stages of the planning process as modeled in the framework:

Step 1-User Input Parameters: This step will allow a decision maker to input key parameters related to existing plans of capacity addition across different sources and the year for which multiple stakeholders would like to envision the impact of adding renewables. User inputs on annual load growth rate and year are used to project energy demand in that year. The load growth rate could be varied to project different demand scenarios.

Step 2-Location siting: The potential locations for installing wind and solar plants can be identified based on Geographical Information Systems (GIS) based assessment of resources and energy infrastructure planning. Selection of a good site for installation of renewable capacities is a crucial aspect and depends on a variety of decision parameters, such as, land availability, resource availability, proximity to road network and electric grid. For instance, as shown in Figure 2, the user can choose to distribute the wind capacities according to the land availability at different hub heights.

Step 3-Supply-demand curve: Based on the generation mix input in Step 1, the model will project a typical load curve for the user-defined year. This is done assuming that current variations in the load and wind/solar generation will apply to the projected load and wind/solar availability. The magnitude of load will increase based on the user-specified growth rate in Step 1. However, the framework will allow for flexibility to incorporate uncertainties in the projected load and generation with appropriate methodologies.

Wastelands suitable for wind power		Agricultural lands suitable for wind power	
Area (sq. km)	8,676	Area (sq. km)	87,362
Potential (MW)	34,133	Potential (MW)	12,900

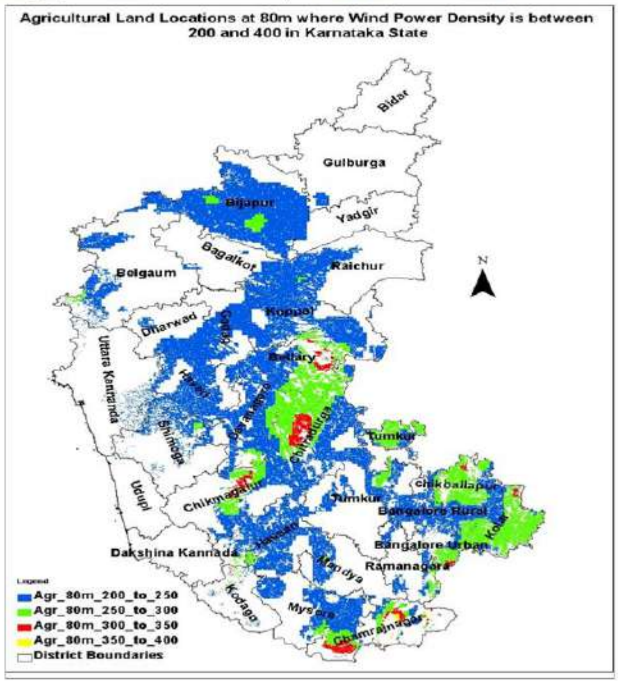

Figure 2: Wind Location Siting

For instance, the intermittency of wind generation for a planned installed capacity can be seen in parallel with the variation in load demand, as shown in Figure 3. Typical of seasonality associated with wind generation, the installed capacity may be adequate to meet anticipated demand more adequately in the monsoon months.

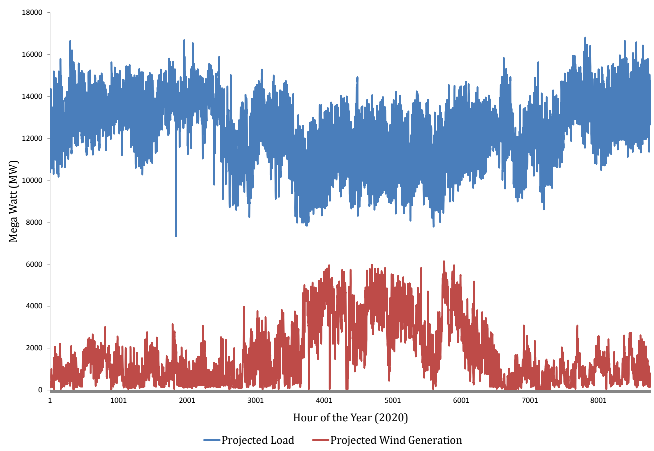

Figure 3: Projected Load vs. Projected Wind in 2020

Step 4-Daily Load Pattern: The user will be able to visualize the sub-hourly/diurnal variations in generation profiles based on trends of historic patterns, for a typical day, as illustrated in Figure 4. This information will also help decision makers to evaluate the complementarity of wind and solar resource profiles, as well as estimate the need for fast-ramping and flexible generation options in order to manage intermittency arising from wind and solar integration. Additionally, the framework will allow for flexibility to analyze the variations at user-specified (e.g. 15 minute intervals).

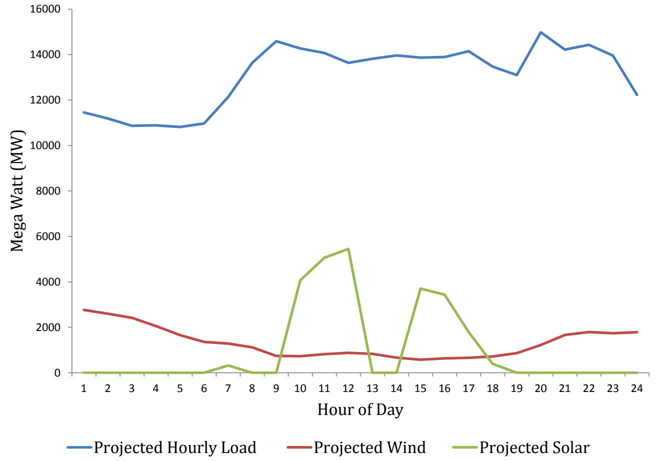

Figure 4: Projected Hourly Load vs. Projected Wind and Solar for a typical summer day in 2020

Step 5-Hourly demand vs supply schedules: The user will be able to visualize an hourly load schedule of sources for the planned generation mix in the year of interest at a preliminary level (Figure 5). The supply-demand mismatch can be evaluated for a best and worst-case scenario of days with good and poor resource (wind/solar) availability. The decision maker can foresee the possibility that, even if annual aggregate demand is met by an addition of wind or solar-based capacity in the generation mix, the sub-hourly variations in wind or solar power output may still result in shortfalls. The schedule can be modeled with real-world constraints of stakeholders, such as uncertainties in Central Generation Stations (CGS) imports, lack of flexibility in reducing base load from coal generation, and the impact of adding storage at the utility level.

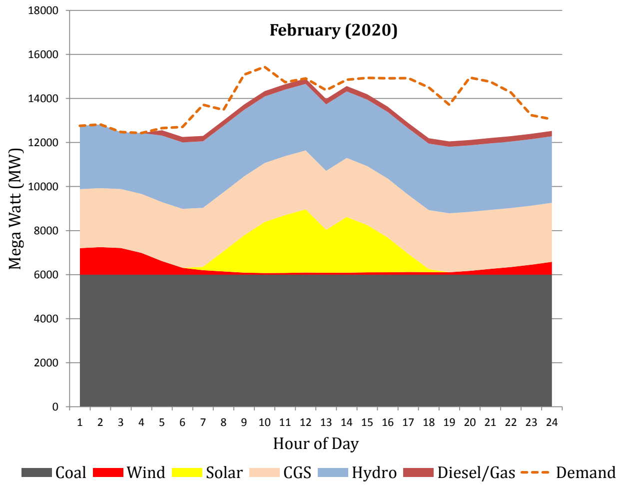

Figure 5: Projected Hourly Load Schedule for a typical day in February, 2020

Step 6–Output: Based on the input parameters and load schedule analysis, this step will quantify the impact of adding wind and solar based capacities to the generation mix on key decision criteria of availability, cost, and emissions.

DATA AND ASSUMPTIONS FOR BASE CASE

The following data and assumptions have been considered to set up the base case:

Demand

- 2011 is used as the base year for estimating hourly load projections
- Yearly rate of growth of demand is assumed to be a Compounded Annual Growth Rate (CAGR) of 7.9% based on Karnataka's actual growth of demand from 2012 to 2015 and estimated growth of demand from 2016 to 2020 [4].

Supply

- Conventional sources used for the analysis include coal, hydro, gas, diesel, and state's share in CGS
- Planned installed capacity for conventional sources is obtained from KERC. As a conservative estimate, it is assumed that plans would achieve partial completion based on historic trends. Hence, it is assumed that 70% of coal, gas and diesel each and 50% of CGS would be commissioned. It is assumed that 100% of planned hydro plants will be available for generation
- As intermittent sources are of primary interest for this analysis, only wind and solar capacity addition is considered from renewable sources
- Wind and solar capacity addition is based on capacity addition plans of KREDL/Government of Karnataka (GoK)

Table 1 below shows the current and planned capacities for sources used in the analysis:

Table 1: Current and Planned Capacity (MW)

Sources	Current (2015)	Planned (2020)[2]
Coal (State & Pvt)	5,380	2,390
Hydro	3,674	302
Gas	0	840
Diesel	226	0
CGS	2,258	2,181
Conventional (Total)	11,538	5,713
Wind	2,086	825
Solar	91	500

Source: PCKL, KERC

T&D Losses

T&D loss is assumed to be 21% based on current status as per KPTCL.

[2] Based on yearly plans for user-specified year of interest; illustrated here for 2020

Hourly demand vs supply schedule

- Annual average Capacity Utilization Factors (CUFs) have been considered for coal, hydro, gas, diesel and CGS.[3] Monthly CUFs have been used to estimate generation from hydro.[4] Hourly CUFs have been used to estimate generation from intermittent sources of wind and solar.[5]

- Load schedule is created as per the following order:
  1- Available coal, wind and solar
  2- CGS
  3- Must-run hydro
  4- Hydro and gas, to the extent available, have been used as levers to meet anticipated peak shortfalls as these sources can be dispatched flexibly.

- Coal is not backed down during monsoon months.

SCENARIO ANALYSIS AND DISCUSSIONS

In this section, the following policy scenarios are analyzed for 2020 using the decision support framework:

Scenario 1: Current Plans (BAU scenario)

As per the assumptions listed in the previous section, it is anticipated that there would be an energy requirement of 109 Billion Units (BU) with available generation/supply of 87 BU, resulting in an overall shortfall of 20% in the BAU scenario.

Maximum wind resource is available from July to September, while it is typically low from January to March. Hence, projected load schedules have been illustrated for 2 typical days in January and August (Figures 6 & 7). In the projected year, shortfalls observed are spread across nearly 6,600 hours. The maximum shortfall is observed to be 5,720 MW for January. Wind generation increases by nearly 45% during the monsoon months. Hence, the shortages are relatively lower in August.

If coal is backed down by 25% during the monsoon months due to increased hydro availability, a number of hours of shortfall across the year increases to 7,300 hours from 6,600 hours and the maximum amount of shortage is still observed in January.

[3] Coal (67%), Gas (30%), Diesel (30%), CGS (80%) (Source: CEA, KERC, and NITI Aayog)
[4] Monthly hydro CUFs are derived from daily generation data obtained from KPTCL for 2011
[5] Hourly CUFs for Wind and Solar are derived from daily generation data obtained from KPTCL for 2011

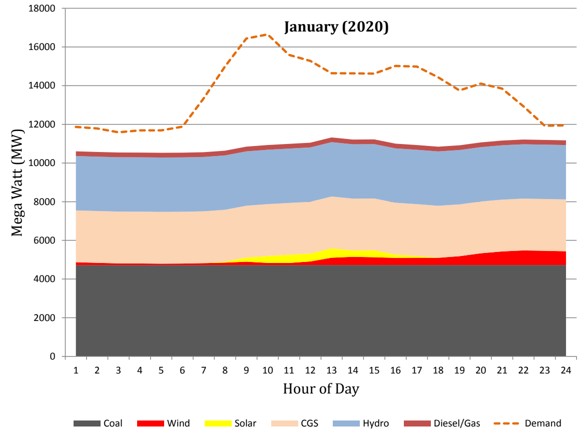

Figure 6: Projected Hourly Load Schedule for a typical day in January, 2020 (BAU)

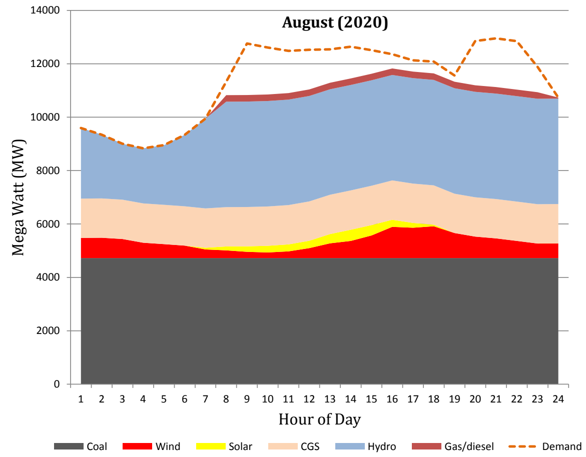

Figure 7: Projected Hourly Load Schedule for a typical day in August, 2020 (BAU)

Scenario 2: Increased Coal Plant Load Factor (PLF)

The PLFs of state-owned thermal power plants have remained low (around 63 – 66%) over the recent years in Karnataka. This may be due to a shift from the usage of washed coal to unwashed coal, frequent equipment failure and coal availability challenges. If appropriate measures to address the same are taken, PLF can be improved to about 85%.

An increase in PLF of state coal plants from current levels by 20% could reduce the number of hours of shortfalls by about 32% from the BAU case, and result in additional generation of nearly 11,100 MUs annually from the planned capacity.

Scenario 3: Reduced T&D losses

In Karnataka, the T&D losses have ranged from 16% to 25.5% across the five ESCOMs in 2014, which results in an average loss of nearly 21% for the state[6]. If appropriate measures are taken to reduce these losses to 12%[7], savings of up to 11,000 MUs will be achievable in terms of energy requirement.

In this scenario, the total number of hours of shortage reduces to 4,450 hours as compared to 6,600 hours in the BAU case. For a typical day in August, wind and hydro (as a lever) availability is adequate to meet the projected peak demand for most of the day, except during the morning and evening peak hours (9 am to 1 pm and 8 pm to 11 pm) (Figure 8).

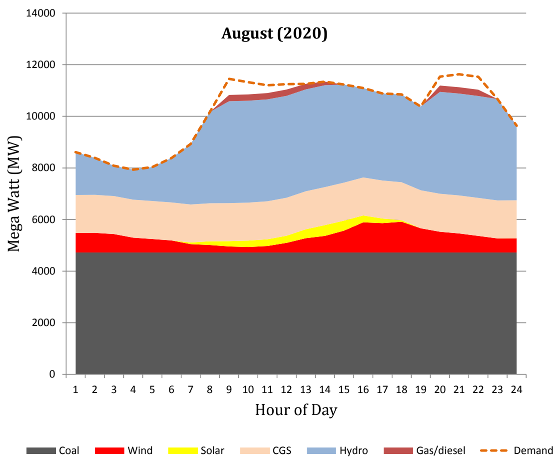

Figure 8: Projected Hourly Load Schedule for a typical day in August, 2020 (Reduced T&D losses)

Scenario 4: Renewable Purchase Obligations (RPO) trajectories

At present, ESCOMs are obligated to purchase 0.25% of their projected energy requirement from solar-based generation sources and 7 - 10% from non-solar based renewable generation sources of wind, biomass, and small hydro [8]. However, the Ministry of New and Renewable Energy (MNRE) plans to revise the RPO targets to achieve procurement of 10.5% of the demand in 2022 from solar-based generation [9]. Further, it is estimated that up to 30% of generation of the state can be met by renewable sources by 2030 [10]. Considering generation from a 10.5% solar-RPO target by 2022, we examine the possibility of meeting the remaining generation requirement for achieving a total of 30% generation from renewables by 2030 from wind sources, as the state has the wind potential necessary to meet the same. This translates to about 14.1 GW of wind and 16.7 GW of solar-based capacity to be added by 2020.

Based on the assumptions mentioned above, the total number of hours of shortage significantly reduces to about 790 hours as compared to 6,600 hours in the BAU case. Further, a surplus situation is observed for about 4,000 hours of the year. Since wind resource is concentrated in a few southern and western states, this opens up the possibility of exporting the surplus energy to neighbouring states through appropriate power purchase mechanisms.

As can be observed in Figures 9 and 10, for a typical day in the monsoon month of August, peak demand is fully met, with a potential surplus of nearly 9,280 MW. On the other hand, for a typical day in the month of February the evening peak demand may remain unmet even with a surplus generation from solar during the day. Hence, options for utilising surplus generation from ambitious wind and solar RPO targets, for powering storage and fast ramping sources (such as pumped hydro) could be explored in order to meet peak demand.

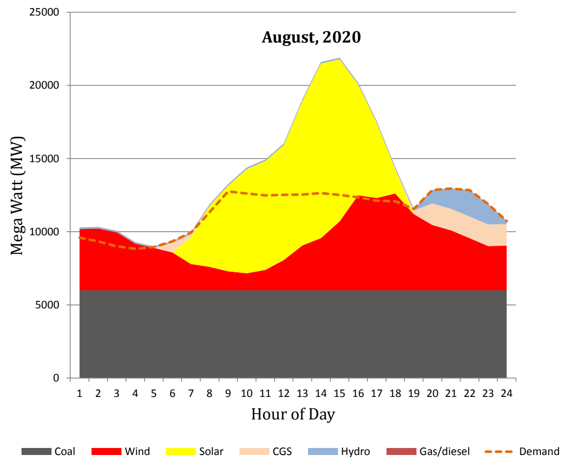

Figure 9: Projected Hourly Load Schedule for a typical day in August, 2020 (RPO trajectories)

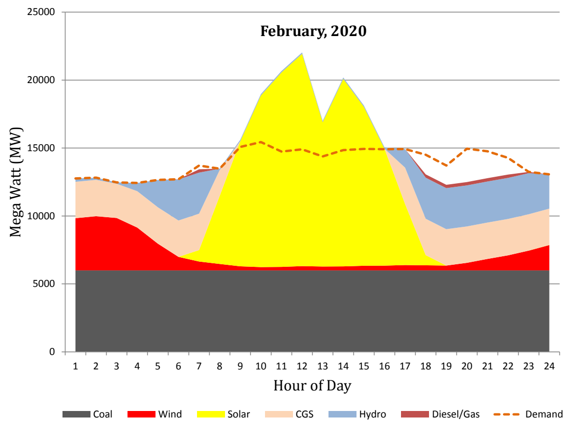

Figure 10: Projected Hourly Load Schedule for a typical day in February, 2020 (RPO trajectories)

Scenario 5: Maximum Wind Capacity Addition

In this scenario, we examine the impact of realizing the full wind potential in the state. As per MNRE's recent reassessment of wind power potential for a higher turbine hub height of 100

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[6] By adding 3.8% of Transmission loss [5] to ESCOM-wise distribution loss reported by KERC for 2014 [6]

[7] Based on lowest T&D losses in the state of Pondicherry for 2011 [7]

m, up to 55 GW of wind potential is available to be harnessed in waste and agricultural land in Karnataka. If this potential is assumed to be fully tapped, along with BAU plans for solar capacity addition, the number of hours of shortage during 2020 would reduce to nearly 680 hours.

However, as seen in Figure 11, during a typical day in the month of February (when wind availability is lower compared to the monsoon season), it would result in shortfalls during the day (8 am to 8 pm) while there is surplus power available during the night (1 am to 5 am). Hence, there is a need to optimally plan and schedule wind and solar generation, by taking into account any complementarity between the two resource profiles. This would enable their individual diurnal variations to be averaged out to a more manageable level, in order to meet the demand throughout the day.

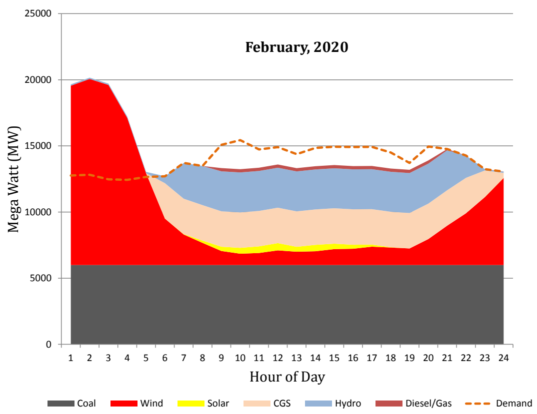

Figure 11: Projected Hourly Load Schedule for a typical day in February, 2020 (Max Wind)

KEY RESULTS

Table 2 presents the key results of evaluation of various scenarios, in terms of their impact on the decision criteria of average grid emission factor, average cost of generation, and number of hours of shortages. The current emission factor and cost of power of the grid is estimated to be 0.68 kg.CO_2/kWh and INR 3.06/kWh respectively.

Table 2: Key Results of Scenario Analysis

		Average Grid Emission factor [11] (kg.CO_2/kWh)	**Average Cost of Power (INR/kWh)[8]**	**No. of hours of shortage**
Scenarios	1	0.60	2.92	6,596
	2	0.67	3.03	4,482
	3	0.62	2.94	4,451
	4	0.47	4.27	789
	5	0.36	4.07	683

[8] KERC, [12], state reverse bids received for grid-connected solar projects

As can be seen from Table 2, high wind and solar capacity addition scenarios (4 and 5) results in the maximum reduction in emissions factor (up to 47%) and shortages.

The load demand in the previous section is determined based on a CAGR-based growth of demand. Table 3 below compares the supply availability resulting across multiple demand forecasts:

Table 3: Demand Forecast Methods and Supply Availability for 2020

Demand Forecast Basis (for 2020)	**Load Growth Rate (%)**	**No. of hours of shortage**	**Max. shortage (MW)**	**No. of hours of surplus**
18th EPS	7.0	7,371	7,420	0
Gross State Domestic Product (GSDP)	5.5	154	1,407	159
Employment Alignment (EA) Scenario II (a)	5.3	72	1,152	209

Note: In the GSDP-based estimate, the elasticity of electricity consumption with Karnataka's GSDP is used to project the future demand

In the EA scenario estimated by GoK [13], it is assumed that GSDP grows to 10.3% by 2022. This is based on net annual movement of 3, 20,000 workers out of agriculture sector, and a net annual movement of 2, 20,000 and 5, 00,000 workers into industry and services sectors respectively.

As can be seen above, the choice of demand methodology has a significant impact on the decision criteria. Uncertainties are inherent in demand forecasts depending on the choice of methodology. Hence, the framework can be used to inform planners of the range of outcomes possible from various demand estimation methodologies.

For increasing rates of growth of demand, it is observed that beyond 13%, a constant shortage situation could be anticipated throughout the year (Figure 12).

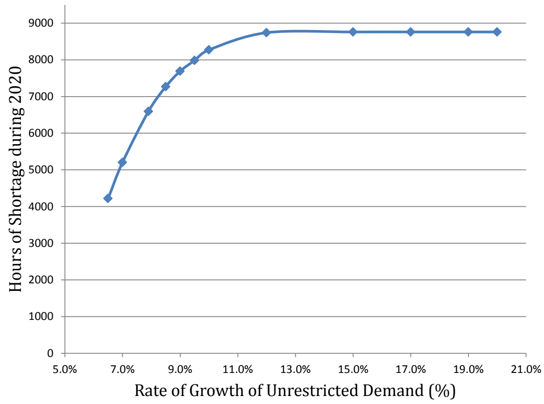

Figure 12: Sensitivity of Anticipated Shortages to Rate of Growth of Demand

CONCLUSION

The current installed capacity in Karnataka is predominantly from thermal and large-hydro sources (contributing to nearly two thirds of the capacity). These conventional sources form the base load for meeting energy demand. However, there are challenges associated with securing long-term fuel linkages for coal plants, uncertainties in price variability of fuels, and high emissions from thermal generation. Hence, it is expected that rapid capacity addition from renewable sources would be required to meet the growing demand, as reflected in state plans. Further, the large-hydro potential in the state is almost fully utilized, thus limiting its contribution to base load going forward.

In this context, a holistic framework would provide the decision makers with the ability to envision the impact of high penetration of renewables in the energy mix in the medium to long terms. This can be done taking into account real-world constraints in the planning process, such as uncertainties regarding the state's future share in CGS, and must-run regulations for some sources. It would help to engage individual stakeholders in constructive dialogue regarding key decision parameters as it enables them to jointly visualize the outcome of specific policy levers. The current analysis does not consider uncertainty in demand projections and generation profiles. However, for future use, the framework can include inputs from alternate methodologies of demand estimation, and stochastic generation profiles. This would aid in planning for optimal capacity in order to minimize mismatch between demand and supply. Considering that there is also a national commitment to provide 24x7 Power for All by 2019 [14], such a framework can help state level stakeholders to plan for reliable supply of power.

ACKNOWLEDGEMENTS

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REFERENCES

[1] KREDL. (2014). Draft Karnataka Renewable Energy Policy 2014-2020. GoK

[2] GoK. (2014). Karnataka Solar Policy 2014-2021

[3] Sudhakar et. al. (2013). Wind Power in Karnataka and Andhra Pradesh: Potential Assessment, Costs, and Grid Implications. CSTEP

[4] CEA. (2011). Report on 18th Electric Power Survey of India. New Delhi: MoP.

[5] KPTCL. (2015). KPTCL Statistics. Retrieved December 2015, from KPTCL official web page: http://218.248.45.135/Statistics/Tr.%20Loss.pdf

[6] KERC. (2014). 15th Annual Report 2013 - 14. Bengaluru: KERC

[7] NITIAayog. (2014). Annual Report on Working of State Power Utilities & Electricity Departments. New Delhi: NITI Aayog.

[8] KERC. (2015). Draft KERC Procurement of Energy of Renewable Sources (Third Amendment) Regulations, 2015.

[9] PTI. (2014, December 4). MNRE Plans Raising RPO Requirement to 10.5%. Newspaper article. Business Standard.Retreived from http://www.business-standard.com/article/pti-stories/mnre-plans-raising-rpo-requirement-to-10-5-114120400698_1.html

[10] Goyal et. al. (2014). Transitioning towards a Green Economy in Karnataka. CSTEP

[11] CEA. (2014). CO2 Baseline Database for the Indian Power Sector: User Guide Version 10.0. New Delhi: MoP

[12] MoP. (2015). Office Memorandum: Scheme for Utilisation of Gas Based Power Generation Capacity. New Delhi:GoI

[13] Karnataka State Planning Board. (2008). Karnataka - A Vision for Development. Bengaluru: GoK

[14] MoP. (2014, December 28). Landmark Initiatives towards Achieving 24x7 Power for All. Retrieved January 2015, from Press Information Bureau, GoI: http://pib.nic.in/newsite/PrintRelease.aspx?relid=114146

The Role of Smart Technologies in Making Smart Grid Smarter

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***Abstract*-- With the increase in energy needs, utilities are under significant pressure to distribute more power, reliably, systematically and sustainably, while at the same time reducing and managing demand. A common set of smart grid goals –or five pillars–which deliver returns against some of the industry's biggest challenges, are Economic, Environmental, Customer, Reliability and Innovation.**

And with the innovation in technologies like renewable energies like wind, solar, distributed generation, ultra-high voltage transmission and energy storage is starting to dramatically alter the technique the grid operates –transforming consumers into generators and active demand participants. This requires a major shift in customer's awareness of energy supply and distribution and how to take control of their service and costs i.e. smart customers.

To manage existing networks and new technology, complex forecasting, planning and control is required. The efficient incorporation of operational and information technology on a scale that has been difficult to achieve – until recently is equally important. To support an empowered energy world, utilities are beginning to look sincerely towards the role that smart technologies will play in transfiguring the grid.

The most successful smart grids of tomorrow will operate with unequalled agility – adopting highly collaborative, responsive and efficient business models that unlock human potential while protecting the environment.

In this paper we will study the impact of smart grid in the customer and different innovative technologies.

Keywords- Smart grid, smart technologies, and renewable energy.

I INTRODUCTION

As the complexity of the conventional grid is increasing due to population growth and advancement in technology and infrastructure has contributed exceptionally to instability, insecurity and inefficiency in power distribution. Along with the global resources crisis increasing seriously there is a need for more reliable, more robust and more efficient environment friendly power demand. In this context, the concept of smart grid has been determined and formed gradually, which is most efficient way to face future challenges as well as managing and reducing the demand.

The development of smart grid is essential if we want to achieve the shared goals for energy security, economic development and climate change mitigation. The smart grid enables several low carbon energy technologies, increased demand response, energy efficiency, and integration of various renewable energy resources while at the same time it also reduces the peak demand and stabilizes the electricity system.

In India , the potential energy demand [1-2] by 2032 is estimated to be as high as 900GW out of which renewable energy survivor that will be exploited till 2032 will be around 183GW[3-4]. With the deployment of the smart grid these peak demand can be reduced by 13% to 24% [5]. The use of smart grid will have a global impact in the near future [6] as it will affect not only the utilities but also the individual consumers [7]. With the help of smart grid the end users will become aware of their energy consumption patterns and thereby can actively manage their requirements as an active customer of the grid [8].

This paper provides a review of the different goals that can be met through smart grid, various technologies that are associated with the smart grid and applications that the smart grid is required to fulfill. This paper also explains the various implementation challenges that are encountered. Firstly the main features of the smart grid are outlined and the goals and technologies needed to realize the smart grid and mentioned. The visions of smart grid along with its implementation issues are further highlighted and conclusion is presented.

II WHAT IS SMART GRID?

There is no clear cut definition of the smart grid because nobody can exactly tell us how it looks like and how it will work in a given area. Literature review on [9-11], stated different definitions of the smart grid, but according to

European Commission Task Force on Smart Grid as “an electricity network that can integrate the actions of all users connected to it i.e. generators, consumers and those that do both in orders to ensure economical, efficient and sustainable

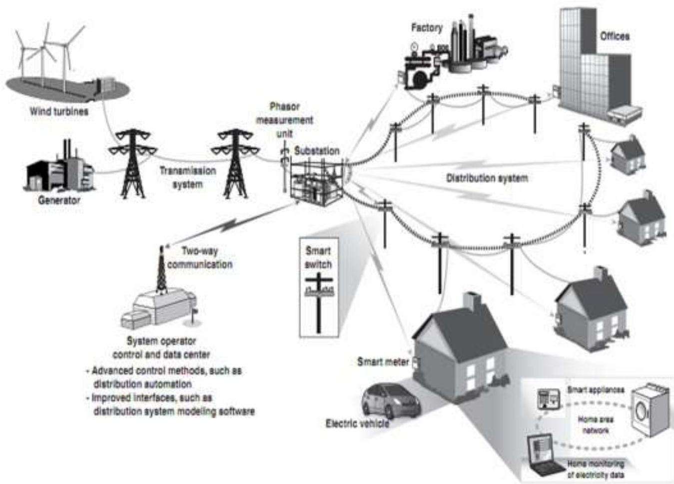

Fig.1 Smart Grid Conceptual Model

power system with low losses, and high level of quality, security of supply” [12]. Smart can be referred to as an electricity network that uses digital and other advanced technologies to monitor and manage the distribution of the electricity from all the generating stations to meet the varying needs of the customer. It has the capability to coordinate the needs of the utility and the consumers and to operate all parts of the system as efficiently and effectively as possible. The basic model of the smart grid is shown in Fig.1.

A smart gird enables real time communication between utility and consumers allowing the utilities to optimize the consumers usage based on environmental or price preferences. It operates with the help of software and hardware components. It also has the ability to integrated the renewable resources like wind and solar with the grid and thus providing reduction in carbon emissions [13].

Smart grid has different features besides demand side management and energy efficiency [14]:

- *Reliability:* The smart grid uses various technologies such as state estimation [15] that improves the fault detection and self healing of the grid without any manual intervention and thereby ensuring reliable supply of electricity and less vulnerability to attacks and disasters.
- *Flexibility in network topology:* the conventional grids are designed for one way communication only, but if a local sub network generates more power which can be supplied back then the reverse flow of this power will increase the reliability and safety issues. A smart grid is designed in such a way that it supports the bidirectional flow of energy, i.e. energy can flow from utility to consumers as well as from the consumers to the utilities.

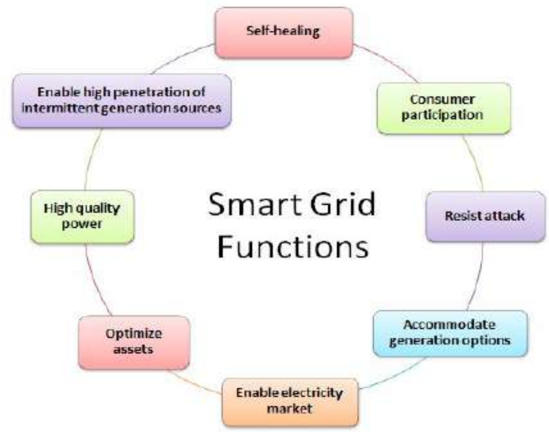

Fig.2 Features of Smart Grid

- *Strong/Security:* the smart grid is considered to be a secure grid as it has capability to mitigate the disturbances and contingencies very quickly [16]. It identifies the man made glitches and quickly responds to the cyber and physical attacks.
- *Interactive:* Smart grid is said to be interactive as it provides intelligent bi directional interaction between the utility and consumers regarding energy flow, data flow and capital flow.
- *Load adjustment/load balancing:* The total load connected to the power grid is not always constant, it varies accordingly. Traditionally to meet the demand some generators are kept in standby mode. With the help smart grid we can inform the consumers to reduced the load significantly during the peak times temporarily or continuously as per the available resources.
- *Sustainability:* The smart grid facilitates integration of renewable energy resources like wind and solar power even without the energy storage. Whereas the conventional grid doesn’t allow any such facility.
- *Peak Curtailment:* When the energy demand is high the smart devices track how much energy is used and when it is used and gives this information to the utilities to reduce demand during the high cost peak usage periods. It also gives the ability to directly communicate with the end users in order to reduce the load during peak hours and thus to prevent system overloading. For the same prices of the

electricity is increased during peak demand periods and decreased during the off peak periods [17].

Fig. 2 shows the different functions of smart grid.

III SMART GRID GOALS

The main goal of the smart grid is to improve the efficiency of the energy being transmitted as well as to maintain the stability of the existing electricity network. We can measure the success rate of the implementation of the smart grid with the help of following main goals [18].

- *Innovation*

Innovation is considered to be the core component of the smarter grid as both hardware and software technology advances rapidly and utilities also looks at different technologies to solve their existing problems more efficiently. The utilities understand that modernization of one area exposes other areas for improvement and development. Today the innovation is focused in collecting data, integrating system and data analytics to get a better view of smart grid. Once this work is done the more innovation is required to predict load forecasting and to optimize the load across the grid.

- *Customer*

The main parameter to measure the success of smart grid is whether it delivers customer satisfaction or not. The smart grid should focus consumer demand response. If the utilities are able to build the strong trust with minimal negative impact on consumers, this will enhance the deployment of technologies.

- *Reliability Impact*

Reliability is the major driver behind the smart grid investments as the utilities and operators wants to improve their performance. There are some reliability aspects that utilities address such as storm response, replacement of aging infrastructure, managing distribution feeder voltages, and maintaining grid capacity.

- *Environmental Impact*

Smart grid projects incorporate renewable energy resources making significant contribution in reducing the carbon emissions. Utilities may start to leverage the demand response to integrate the renewable, either to adjust the load to meet the excess demand, or to meet the short falls of supply. Consumer engagement and the environmental impact are partners. The majority of environmental is a result of customer's involvement and support.

- *Economic Impact*

All though the initial investment is quite but if overall things are done right, the smart grid can actually save money- customers can be benefited from a smart grid but only where a clear customer journey is identified.

IV SMART GRID TECHNOLOGIES

Smart grid technologies are collection of existing and emerging technologies that works together to increase efficiency in production, improve reliability and economic operation, and to integrate the renewable power into the grid. Some of the major technologies are explained in brief.

- *Sensing and Measurement*

The main duties if the smart grid is to evaluate congestion management, to prevent energy theft and to support control strategies. For the same purpose it uses different technologies namely advanced metering infrastructure (AMI), wide area monitoring systems, real time pricing, and digital protective relays. The smart meters record the real time usage of the electricity. This may provide communication path from power generation plants to end user in homes.

- *Internet of Things (IoT)*

Internet of things [19-20] is a large network of information sensing devices such as radio frequency devices, global positioning systems (GPS), infrared sensors, laser scanners and internet. With the help of smart devices IoT senses and indentifies the physical world. With the help of IoT we can achieve human-thing and thing-thing information exchange thereby establishing real time control, scientific decision making and accurate management of the real world. With the help of applications of IoT named as power internet of things (PIoT) reliable transmission of information through wired or wireless communication network and smart processing of the information can be achieved in the power grid. With the help of IoT technologies in online monitoring of power transmission lines can solve a number of problems like fault diagnosis, prevention, and research of power lines.

- *Energy Storage*

With the help of energy storage we can reduce the problem of congestion to a great extent. It also provides the connection with the smart grid thereby making islanding [21], load leveling and peak shaving [22] possible. It plays an important role to minimize the impact of sudden load changes and fluctuations. It can be stored in the form of batteries, superconducting magnetic energy storage (SMES) etc.

- *Power Electronics*

In the implementation of the smart grid power electronics plays an important role as it requires integration of renewable resources which is possible only with the help of developed power converter system. According to [21]-

[25], FACTS and HVDC provides voltage support, systematic power flow and it also controls stability of the grid. HVDC also provides system security by means firewall. The function of firewall is that it prevents the spreading of the disturbance which occurs in the system. As soon as the disturbance has been cleared, power transmission can be immediately resumed. Since power electronics devices are capable of accommodating fluctuations in frequency and/or voltages, improves the quality of the electricity, it can be safely interconnected with the power system.

- *Information and Communication Technology*

To ensure reliability a secure two way communication network is necessary so that the data coming from a number of nodes and sensors can be aggregated. Advanced communication technology not only provides real time control and monitoring but also supports the involvement of generating units to a new concerned group [26]. Also, using ICT facilitates the integration of the renewable energy into the grid. It also empowers the consumers with the tools using which they can optimize their energy consumption.

- *Transmission Enhancement Application*

There are a number of technologies available for the existing transmission system. FACTS are used to enhance the controllability of the transmission system and to maximize the power transfer capability. It this technology is deployed in the existing system it not only improves the efficiency but also defer the need of extra investment. Similarly high voltage Dc (HVDC) is used to connect the offshore wind and solar plants to the existing high power areas thereby reducing system losses and allowing efficient use of energy.

V VISION OF SMART GRID

The existing power grid has been industrialized and its modernization is accepted globally. Therefore there is a need for developing new plans and strategies to convert existing grid to a smart grid and to increase the number of existing smart girds.

The vision of smart grid tells us about the future grids, how it will operate, how it will looks like, and the approximate cost involved in it [27]. Smart grid has the capability to revolutionize the way the electricity is generated and distributed to different customers along with the ability to shift the peak and off peak demand to maintain the system balance. Smart grid is not just a flexible and efficient network; it will also create jobs, innovation and growth. It will force various customers to incentivize and empower their energy usage, to adopt new technologies and to minimize the cost of generation, transmission and distribution. Besides this, smart grid will provide power quality for digital economy. It will monitor as well as diagnose and respond to the deficiencies of the power quality so that there will be reduction in looses experienced by the consumers due to inefficient power quality.

Smart grid's role will be similar to that of a transitive agent. That is, it enables electrical, informational, and financial transactions among various customers and authorized users.

VI SMART GRID IMPLEMENTATION ISSUES

Smart grid a technological innovation that will ensure better electricity delivery infrastructure. India is a country where there are several areas which do not have electricity or which suffers several outages. Therefore such a system is essential for a country like India. Even though this would be a great system for this country, it has some implementation issues which are listed following in brief.

- *Access to Capital*

Funds are the major concern in implementation of smart grid. Further, the risk associated with the smart grid is more, so the policy makers and regulators should make such policies so as to attract more and more investors despite knowing the risk associated with it, as the risk to return ration of smart grid will be more in a long run.

- *Lack of Awareness*

Customer's level of understanding about the smart grid and its associated functions is quite low [28]. So before implementing the smart grid concepts, the concerned authorities should make the consumers well aware about what the smart grids are? How smart grid can contribute to lower the carbon economy? What are the benefits associated with the smart grids?

- *Technology Maturity and Delivery Risk*

This is the main constituents of the smart grid which includes hardware, software and communication technologies. In some part s of India, technology is developed whereas in some parts it is in initial stages and yet to be developed till a significant level. As the technology will advance the delivery risk will reduce automatically.

- *Skills and Knowledge*

As we will move towards the smart grid, we will require developing new skill set in data analytics, data management. This transition will require support from both, government and the private owners to support education programs that will help in building managers and engineers for tomorrow.

- *Cyber Security and Data Privacy*

Due to transition from analog to digital infrastructure, there comes a challenge of communication security and data management as the digital infrastructure is more prone to malicious attacks by hackers. In addition to this, the privacy of individual customers about their consumption pattern should also be maintained. If these two aspects are not considered transparently it will create a negative impact on consumers' perception about the whole system.

- *Policy and Regulation*

The current policies and the regulations are designed according to the existing grids. As we will move towards the smart grid there should be some amendments in the existing policies, standards, regulations and guidelines to support smart grid, to protect the consumers and to avoid market exploitation.

VII CONCLUSION

Smart grids are the foundational investment that will provide efficient use of the information in the electrical system to at considerable cost saving to the consumers and the utilities. It will also change how the power system planning is done, and how the wholesale and retail electricity markets are coordinated. It is improvement of the conventional grid to make the grid more efficient, reliable and stable. The paper has discussed various emerging technologies that will contribute in the development of smart grid to meet the future requirements. Additionally the paper also discusses the features and goals that are met with the help of the smart grid. It also discusses the vision and implementation issues of the smart grid.

This paper focuses on the main goals i.e. innovation, economic, environment, customer, and reliability. These are considered to be the main pillars and with the help of these pillars the success of smart gird can be explained for a particular region.

REFERENCES

[1] Country statistical profile, OECD Factbook statistics: India 2013 [Online]. Available: (http://dx.doi.org/10.1787/csp-ind-table- 2013-1 en).

[2] Government of India, Central Electricity Authority [Online]. Available: (http://www.cea.nic.in/reports/monthly/executive_rep/mar13/mar 13.pdf).

[3] Government of India, Central Electricity Authority [Online]. Available: (http://www.cea.nic.in/reports/monthly/gm_div_rep/power_supply_position_rep/energy/Energy_2013_03.pdf).

[4] Government of India, Central Electricity Authority [Online]. Available: (http://www.cea.nic.in/reports/monthly/gm_div_rep/power_suppl y_position_rep/peak/Peak_2013_03.pdf).

[5] Smart Grid Roadmap, International Energy Agency [Online] Available: (https://www.iea.org/publications/freepublications/publication/smartgrids_roadmap.pdf}

[6] M. G. Simoes, R. Roche, E. Kyriakides, A. Miraoui, K. McBee, S. Suryanarayanan, P. Nguyen and P. Ribeiro, "Smart grid technologies and progress in Europe and the USA," *IEEE Energy Conversion Congress and Exposition (ECCE)*, Phoenix, Arizona, Sept 2011, pp. 383-390.

[7] A. Molderink, V. Bakker, M. G. C. Bosman, J. L. Hurink, G. J. M. Smit, "Management and control of domestic smart grid technology," *IEEE Trans. Smart Grid*, vol.1, no.2, pp. 109-119, Sept. 2010.

[8] D. J. Dolezilek, and S. Schweitzer, "Practical applications of smart grid," *Schweitzer Engineering Laboratories*, Feb. 2009, pp 1-7.

[9]R. Hassan, and G. Radman, "Survey on smart grid," *Proc. of IEEE Southeast Conf.*, March 2010, pp. 210-213.

[10] T. Baumeister, "Literature review on smart grid cyber security," Dec. 2010. *[online]* Available http://csdl.ics.hawaii.edu/techreports/10-11/10-11.pdf (Sept. 29, 2012).

[11] M. H. J. Bollen, J. Zhong, F. Zavoda, J. Meyer, A. McEachen and F. C. Lopez, "Power quality aspects of smart grids," *Int. Conf. on Renewable Energies and Power Quality (ICREPQ)*, Granada, Spain, March 2010.

[12] European Commission, "European smart Grid technology platform," Luxemburg, Dec. 2006.

[13] K M Valsamma "Smart Grid as a desideratum in the energy landscape: key aspects and challenges".

[14] Z. Xue-Song, C. Li-Qiang and M. You-jie, "Research on smart grid technology," *Int. Conf. on Computer Application and System modeling (ICCASM)*, San Diego, CA,vol. 3, Oct. 2010.

[15] Yih-Fang Huang; Werner, S.; Jing Huang; Kashyap, N.; Gupta, V., "State Estimation in Electric Power Grids: Meeting New Challenges Presented by the Requirements of the Future Grid," Signal Processing Magazine, IEEE , vol.29, no.5, pp.33,43, Sept. 2012.

[16] F. F. Wu, K. Moslehi, and A. Bose, "Power system control centers: past, present and future," *Proceedings of the IEEE*, vol. 93, no. 11, pp. 1890-1908, Nov 2005.

[17] Berger, Lars T. and Iniewski, Krzysztof, ed. (April 2012). *Smart Grid - Applicacions, Communications and Security*. John Wiley and Sons. ISBN 978-1-1180-0439-5.

[18] Global Smart Grid Impact Report: [Online]. Available: (https://www.smartgrid.gov/files/global_smart_grid_impact_report_2013.pdf).

[19] He Ke. The Key Technologies of IOT with Development & Applications[J]. Radio Frequency Ubiquitous Journal. 1. 2010.

[20] Zhen Yan, Li Xiangzhen, Wang Hongyu, Zeng Lingkang, Chen Xi, Overview of Internet of Things, 12th China association for science and technology annual meeting, p542-547, 2010.
[21] V. Hamidi, K. S. Smith, and R. S. Wilson, "Smart grid technology review within the transmission and distribution sector," *IEEE PES Conf. Innovative Smart Grid Technologies,* Gothenburg, Sweden, Oct. 2010, pp. 1-8.
[22] R. Kumar, "Assuring voltage stability in the smart grid," *IEEE PES Conf. Innovative Smart Grid Technologies (ISGT)*, Anaheim, CA, Jan. 2011, pp. 1-4.
[23] A.R Phadke, Manoj Fozdar, and K.E. Niazi, "A new multi-objective formulation for optimal placement of shunt flexible AC transmission system controller," *Electric Power Components and system*, vol. 37, no.12, pp. 1386-1402, 2009.
[24] W. Zhang, F. Lee, and L. M. Tolbert, "Optimal allocation of shunt dynamic VR source SVC and STATCOM: a survey," *Int. Conf. on Advances in Power System Control, Operation and Management (APSCOM), Hong* Kong, Oct/Nov. 2006.
[25] A. Sode-Yome, N. Mithulananthan, and K. Y. Lee, "A comprehensive comparison of FACTS devices for enhancing static voltage stability," *IEEE PES General Meeting*, Tampa, FL, June 2007, pp. 1-8.
[26] M. Saravanan, S. M. Raja Slochanal, P. Venkatesh, and J. P. S. Abraham, "Application of particle swarm optimization technique for optimal location of FACTS devices considering cost of installation and system load ability," *Electrical Power System Research*, vol. 77, pp. 276-283, March 2007.
[27] X. P. Zhang, "A framework for operation and control of smart grids with distributed generation," *IEEE PES General Meeting,* July 2008, pp. 1-5.
[28] M. C. Peterson, and B. N. Singh, "Smart grid technologies for reactive power compensation in motor start applications," *IEEE Transmission and Distribution Conf. and Exposition*, New Orleans, Louisiana, April 2010, pp. 1-6.
[29] R. Krebs, B. M. Buchholz, Z. A. Styczynski, K. Rudion, C. Heyde, and Y. Sassnick, "Vision 2020—Security of the network operation today and in the future: German experiences," *IEEE PES General Meeting*, July 2008, pp. 1–6.
[30] B. Ablondi, "Bringing the smart grid to the smart home: it's not only about the meter," *SmartGridNews.Com*, Jan. 2010. *[online]* Available: http://www.smartgridnews.com (Sept. 29, 2012).

Optimization of RE Generation Forecasting

Perspective from mature renewable energy markets

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Abstract **—** The renewable energy market in India has historically thrived on policy incentives, focused on providing privileges to renewable energy generation. However, as the penetration of renewable energy has now taken a sizeable share in India's energy-mix pie, mainstreaming of renewable energy has become inevitable. The recent Central Electricity Regulatory Commission (CERC) directive mandating generation forecasting and scheduling for RE developers, albeit to a limited extent, is the frontrunner of this trend: a definitive step towards maturing of the Indian renewable energy market. Transitioning from the current status to a 'mature market' status has its consequences that have to be accounted for both technically and commercially by the Indian power system. This paper explores the experiences of other developed energy markets for tell-tale symptoms that link RE generation forecasting with progressive maturing of their respective renewable energy sectors. It delves into the optimum scale/nature of forecasting vis-à-vis renewable energy penetration levels in terms of the following parameters-accuracy, frequency, geographical smoothing and forecasting-risk apportionment. This paper would also enable understanding the impact that progressive operative regulations would have on renewable energy capacity addition dynamics and achievement of India's 175 giga-watt (GW) target.

Keywords—*renewable energy, forecasting, CERC, accuracy, geographical smoothing*

1. Introduction

Renewable energy (RE) is abundant and environmentally-friendly. However, the cost of using RE is still high because it is difficult to be integrated into the power grid either temporally or spatially. Among various RE sources, wind and solar are two most commonly used variable sources. This paper focuses on these two types of renewable energy sources only.

Electricity has a unique feature: consume it while producing with little or no storage. Conventional power is generated according to the demand from customers. The primary problem of introducing RE into the power grid is the unpredictability of RE such as intermittent nature of wind speed, and furthermore for a wind farm, different wind turbines generating different amount of power based on the wind direction and location with in the wind farm [1]. Solar irradiance is affected by cloud cover, haze effect and solar elevation angle. Although the solar elevation angle is analytically determinant, the cloud cover and haze effect are stochastic [2].

As on 31 December 2015, out of the total 38.8 GW of grid connected renewable generation capacity in India, close to 30 GW comes from wind and solar energy [3]. Power generation from solar and wind systems is highly variable due to its dependence on meteorological conditions which poses significant challenge for system operators to manage the frequency and voltage profile of transmission grid within the permissible limits. An efficient use of this fluctuating energy source requires reliable power generation forecast information for grid management and operation strategies. Solar and wind power forecasting systems provide the information on how much power can be expected at which point of time in the next few hours and days.

The objective of this paper is to find answers to the questions of best-fit geographical and spatial scale of forecasting, in view of the system requirements of accuracy and commercial implications, by studying the international experience in global energy markets that have a history of successful implementation of RE forecasting systems.

2. Wind and Solar Power Forecast Models

Wind and solar power forecast models can broadly be classified according to the data input they require. The two main types are time-series models and Numerical Weather Prediction (NWP) based models.

Time-series models use only the online (or most recent) weather and power measurements and time-series analysis methods to predict renewable power generation up to a few hours ahead. Time-series models are the simplest and therefore least expensive type of RE power forecasting models. The simplest time-series model is the Persistence model, in which the future power generation is always predicted to remain the same as it is now. Persistence is the model that all other renewable power prediction models must improve upon in order to justify the extra effort they require for forecasting. These models use time-series analysis techniques such as recursive least-squares algorithms, auto-regressive models, or artificial neural networks to find trends in the wind speed or solar irradiation measurements and then extrapolate these trends a few hours into the future.

Numerical weather prediction models are computer simulations of the atmosphere of the Earth used to make weather forecasts. The most advanced NWP models are run on dedicated supercomputers at national weather centers. NWP-based models outperform time series models for forecasts longer than 4 to 6 hours, and can be physical or statistical in nature. Physical NWP-based models estimate the local meteorological data for a RE farm using only the output of a NWP model and then convert it to local renewable power production. Some past measurements of NWP output and renewable power are required, however, to calculate the Model Output Statistics (MOS) parameters used to reduce systematic errors. Most renewable power forecasting models use a combination of all three types of models to make the most accurate power forecasts possible [4]. Figure 1 illustrate the steps that physical NWP-based models use to create wind power forecasts.

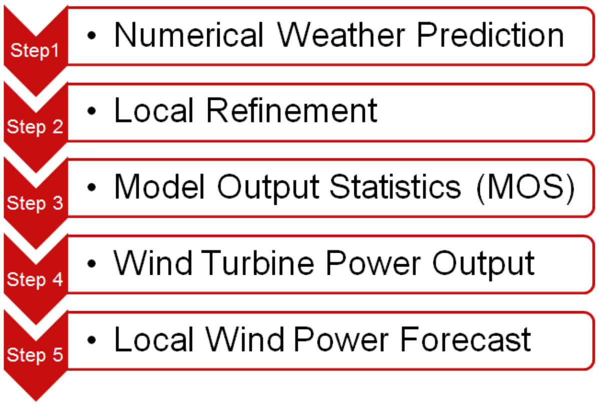

Figure 1: Steps to create a wind power forecast using a NWP-based physical model.

Step 1 in the process uses the information about the current state of the atmosphere and attempts to predict the future state based on known physical laws. These physical laws describe how the state variables such as temperature, pressure, humidity, and wind speed will change from their values. The accuracy of NWP models is limited due to imperfect measurement of the initial state variables and the variable nature of the weather.

In the second step, Local Refinement, the wind speed and directions output by the NWP model are translated to the local wind speed and direction of the wind farm whose power generation is to be forecasted, at the hub height of the wind turbines. The simplest method involves using the wind speed and direction at the nearest NWP model grid point nearest to the wind farm. The wind speed and direction can also be interpolated from the four NWP model grid points that circumscribe the wind farm. Ideally, to reduce systematic errors, the orography, roughness, and presence of obstacles (trees, buildings, etc.) should be taken into account [5].

The third step in physical modelling is Model Output Statistics (MOS), which is used to reduce systematic errors. They can be caused by incorrect roughness parameters, ignoring the effects of complex terrain, or too low resolution of the NWP model. The most accurate forecasting systems use real time measurements and auto-adaptive algorithms to continuously recalculate the parameters. MOS could be applied before the conversion of wind speed to wind power, after the mentioned conversion, or even both.

The next step involves translating the wind speed forecast into a wind power forecast. This can be done using the wind turbine power curve provided by the manufacturer, or by using the actual power curve derived with past wind speed and wind power measurements. A wake model could be used to estimate the drop in power generation due to wake effects [5].

The other type of NWP models, Statistical models attempt to calculate the power generation directly (ignoring physical considerations) using the NWP output and past measurements of both NWP output and power generation. The statistical approach is based on training of model with measurement data. The idea is to derive a statistical relation between the given input from the weather prediction and the measured power output of RE farms. The clear advantage of statistical models over physical models is that all physical considerations are considered implicitly. The complicating effects of orography, roughness, and wind turbine wakes are automatically considered in the model. The forecasts are inherently adapted to the location of the RE farm such that systematical errors are automatically reduced. The disadvantage of statistical models lies in the need for long-term measurement data and an additional effort for training the model.

The combination of different NWP and/or time series models is becoming common. It takes advantage of the fact that different forecast models have different strengths and weaknesses in different weather situations. This is due to the broad variety of physical and numerical implementations of the dynamics of the atmosphere inside the models.

Ensemble Forecast: Reliance on a single forecasting methodology for centralized forecasts can increase the risk of systematic bias. A common way to improve centralized forecasts is through ensemble forecasting. An ensemble method is popular in statistics and machine learning. It uses multiple predictors to obtain an aggregated decision which is better than any of the base predictors [6]. According to Opitz and Maclin [6], there are two kinds of ensemble methods: competitive and cooperative for ensemble classification. Similar to classification, ensemble forecasting can be categorized into competitive and cooperative ensemble forecasting. Competitive ensemble forecast is to train different predictors individually with different data sets or the same dataset but with different parameters and then the prediction is obtained by averaging (or other equivalence) the decision so fall individual predictors (base predictors). On the other hand, cooperative ensemble forecast is to divide the prediction task into several sub-tasks and select appropriate predictors for each sub- task based on the characteristics of the sub-tasks, and the final decision is a sum of all the outputs of the base predictors. [7]

In nut-shell; for operating the most state of the art forecasting models majorly (not limited to) four data inputs are essential: a) robust NWP data including the solar irradiance data for solar power forecasting, b) real (near real) time generation data, c) static data on wind and solar plant location and their machine/equipment characteristics, and d) historical weather and RE power generation data. It is to be noted that RE generation forecast can be carried out with and without the mentioned data using different techniques. Accuracy of forecast will always depend on the quality and completeness of the input data provided to the forecasting models.

3. Requirement of RE Generation Forecast

Globally, renewable energy forecasts are mainly used by generators for maximizing productivity of power plants: on long-term basis for scheduling plant maintenance down-time, on day-ahead basis for ensuring optimum scheduling of electricity on the spot market, and on real-time basis (1-2 hours ahead) for mitigating commercial grid-imbalance implications. In contrast, precise energy forecasting is done by the system operators on long term basis for arranging alternate power sources, and on short-time basis for ensuring system stability via allocation of balancing power to cover up intermittencies.

Various types of forecasts have different time horizons, methods, and applications in the power system operations. Table 1 below briefly mention various types of forecasts, their time horizon, key applications and methods [8].

Table 1: Forecasting methods and applications

Type of Forecast	Time Horizon	Key Application	Methods
Intra-hour	5-60 minutes	Real-time dispatch, market clearing	Statistical, persistence
Short term	1-6 hours ahead	Scheduling, load-following, congestion management	Mix of statistical and NWP models
Medium term	Day(s) ahead	Scheduling, reserve requirement, market trading, congestion management	NWP with corrections for systematic biases
Long term	Weeks or month ahead	Resource planning, contingency analysis, maintenance planning, operation management	Climatological forecasts, NWP

4. EFFECT OF GEOGRAPHIC SMOOTHENING

Though wind generation is variable over time, due to the fluctuations of wind speed, however, the output variability of a single wind plant is different from the variability of many wind plants dispersed over a geographic area. The variability of wind decreases as the number of turbines and wind power plants distributed over a larger geographical area. Figure 2 shows an example of the variability of wind for a single wind turbine, several wind turbines and all wind turbines in a country. The variability of wind generation decreases with spatial aggregation. This is because normally, the correlation between wind speeds at two different locations decreases with increase in their distance. As wind speeds with varied correlations feed wind farms, their overall wind output generation will have much less variability. Thus, the geographical dispersion of wind farms has a beneficial smoothing effect on wind power variations. Wind energy output over larger geographic areas has less variability than the output of a single wind power plant.

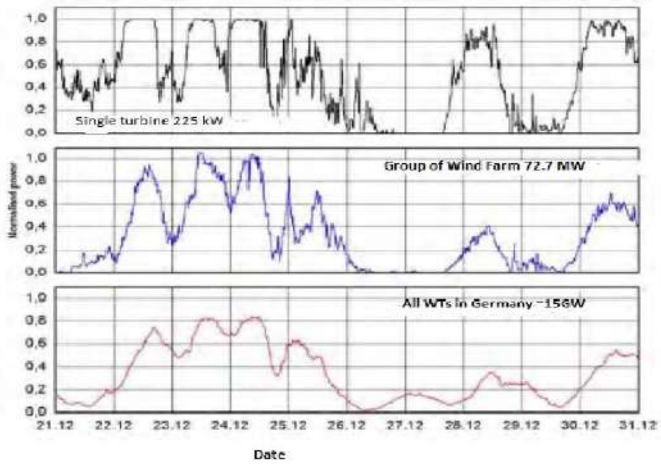

Figure 2: Sample of wind power output from a single turbine and for a group of wind farms in Germany [9].

Spatial diversity, as with wind, can mitigate some of this variability by significantly reducing the magnitude of extreme changes in aggregated PV output, as well as the resources and costs required to accommodate the variability. Either the aggregation of the output of separate PV panels within a plant, or the aggregation of the output of several separate PV plants at different locations helps to smooth the variability of the overall solar energy output. Figure 3 illustrates this effect.

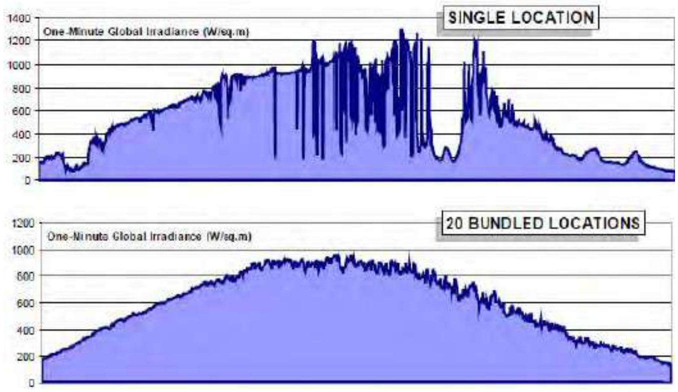

Figure 3: One minute irradiance and variability at one single location in the network & from bundled stations [10].

Although the ramping characteristics are fast for PV plants, the time it takes for a passing cloud to shade an entire PV system depends on factors such as the PV system size, cloud speed, and cloud height, among others. Therefore, for large PV systems with a rated capacity of 100 MW, the time it takes to shade the entire system will be on the order of minutes, not seconds [11].

5. ACCURACY OF REAL TIME FORECASTS

Experience shows that deviations in forecasts of wind output decrease with proximity to real time and spatial aggregation. Globally, load forecasts made many hours ahead are fairly accurate. This is not true for wind forecasts. Generally, only very near term wind predictions are highly accurate [12]. In particular, the error for 1 to 2 hour ahead single plant forecasts can be about 5-7%; for day ahead forecasts, the error increases up to 20% [13]. This trend can be seen in Figure 4 from the Spanish transmission system operator REE [EURELECTRIC, 2010].

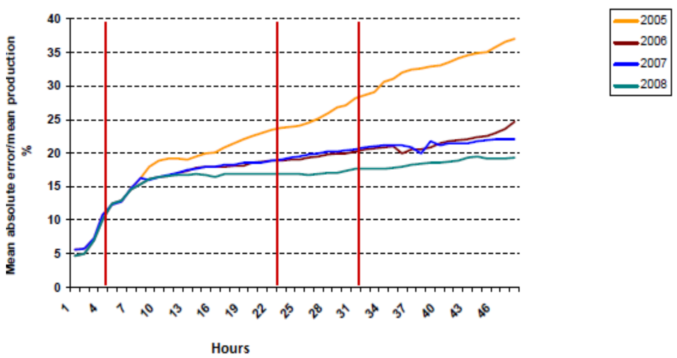

Figure 4: Evolution of the wind forecast error, as a percentage of wind production, as a function to the distance to real time.

It can be observed from the Spanish experience that for forecasts very near to the actual event (1-2 hours) the mean absolute error was the least. At the same time the system improved over the years for longer duration (>24 hours) forecasts, however, improvement in very short term forecast was not significant.

6. Status of RE Forecasting in India

The concept of forecasting and scheduling of renewable energy generators and commercial settlement thereof was first introduced in India in 2010 under the Indian Electricity Grid Code (IEGC), 2010. Subsequently, the Renewable Regulatory Fund (RRF) mechanism was envisaged to be implemented from January 1, 2011. However, due to several implementation issues, the commercial aspect of the mechanism was suspended and later in 2015 CERC came out with a new regulation on forecasting and scheduling of RE generation [14]. National Load Despatch Centre (NLDC) issued the Procedure for implementation of the framework on Forecasting, Scheduling and Imbalance Handling for Renewable Energy (RE) Generating Stations based on wind and solar at Inter-State level in October 2015 [15]. The regulation is applicable from November 2015 on regional / inter-state RE generators. However, it is interesting to note that by November 2015, the time the regulation came in force, no significant wind capacity was connected at inter-state level. However, more than 25 GW wind capacity is installed and operating in different states where the intra-state regulation, to be notified by the respective State Electricity Regulatory Commissions (SERCs), on forecasting and scheduling of RE is applicable. Recently three Indian states, namely Madhya Pradesh, Karnataka and Tamil Nadu, also issued draft regulations on forecasting, scheduling and deviation settlement of wind and solar generating stations at the state level. These regulations would be applicable on majority of the existing wind and solar projects operating in these states.

In some developed European electricity market e.g., Germany and Denmark, research and ground work on forecasting of wind power generation started more than 20 years ago. Solar forecasting started a little later. Hence, the forecasting accuracy in these markets is quite high. E.g., in Germany the wind power forecasting accuracy at the control area of whole Germany is as high as 96% (only approx. 4% RMSE) [16]. The United States also initiated activities on RE generation forecasting in a big way during the last decade. Table 2 compares the development of forecasting framework in major markets in the United States vis-s-vis developments in India [17].

Table 2: Development of Wind power forecasting framework in major US markets and in India

	PJM	**ERCOT**	**India (Inter-state)**
Wind forecasting since	2009	2008	2015
Installed capacity then	165 GW	80 GW	282 GW
Wind capacity then	2.5 GW	8 GW	25 GW
Wind energy penetration then (% installed wind/total installed)	1.5%	10%	9%
Forecasting level (developer/ operator/both)	Both	Both	Both*
Description of Forecast	**Long Term**: Provided hourly, from 48 hours ahead to 168 hours ahead. **Medium Term**: Updated from 6 hours ahead to 48 hours ahead. **Short Term**: Updated with frequency of every 10 min, forecast interval of 5 min for next 6 hours. Forecast on 5 aggregation levels. Statistical power curve for each wind project.	Wind power forecasts are updated hourly and cover 1-48 hours ahead. Forecast delivered by 15 minutes past each hour.	Based on the RE forecast, developer (or aggregator) will provide day ahead and intra-day schedule. Max 16 revisions are allowed per day. The revisions may be effective from 4th time block; there may be one revision for each time slot of one and half hours starting from 00:00 hours of a particular day.
Forecast Performance Metrics	For all of PJM monthly averaged mean absolute error (MAE) for the May 2009 - July 2009 period ranged from 4.9% to 5.1% for intra-day; 5.9% to 7.9% for day-ahead; and 5.2% to 5.6% for the evening forecast at 4:00 PM, which covers 8 to 32 hours ahead.	For all of ERCOT, monthly averaged MAE for the day-ahead forecast, for May 2009 to August 2009, ranged from 8.28% to 10.73% of capacity for all hours.	**Data not available**. **Tolerance band:** Errors within ±15%, no penalty. For errors from 15% to <25%, penalty at 10% of PPA rate. For errors from 25% to <35%, penalty at 20% of PPA rate. For errors >35%, penalty at 30% of PPA rate.

***PJM**: Pennsylvania - New Jersey - Maryland Interconnection*
***ERCOT**: Electric Reliability Council of Texas*
** Regulation mentions that generator will have the option of choosing between its own forecast and site level forecasting as done by the respective RLDC*

Though data on forecast performance is not available for inter-state projects, however, it is expected that RE project developers and forecasters will learn from global best practices since a lot of research has already been done in this subject in many countries.

At present, in India, the focus is on RE developer level generation forecast which will enable the developer to schedule its generation. However, all over the developed RE markets, system operators also independently forecast the RE generation within their control area to ascertain requirement of balancing reserves on a day ahead basis. In India as well, proposal for Renewable Energy Management Centers (REMC) is at advanced stage. REMC's major functions would be to engage in RE generation forecasting from primarily the grid security perspective, online geospatial monitoring of RE Generation, and work as central repository for RE generation data within the control area of REMC's parent load dispatch centre [18].

7. Conclusion

The regulatory framework in India has imbibed several aspects of a state-of-the-art RE generation forecasting framework. For instance since the forecasts are always accurate closer to the actual event, CERC has allowed 16 wind and solar power schedule (forecast) revisions per day effective from 4th time block of revision. Hence, the forecaster may make use of forecasting models receiving high quality real time data to train their models for very short forecasts. It is also an established globally that variability of renewable energy generation decreases with spatial aggregation. In the CERC regulation there is a proposal to either schedule (forecast) at plant level (RE projects having capacity of 50 MW or more only are allowed to connect at inter-state network) or through Qualified Scheduling Entity (QSE) which can undertake the forecasting and scheduling activity on behalf of more than one RE developer. These QSE are aggregators and can benefit from the regional smoothing effect if they can create a portfolio which is big and geographically diverse. However, CERC/SERC regulations should provide further clarity on the role of these QSEs and allow them to provide a combined RE generation schedule of as large an area as possible. Moreover, forecasting-risk apportionment mechanism through QSE is still ambiguous and need further detailing.

Currently, National Institute of Wind Energy (NIWE) in association with Indian Wind Power Association (IWPA) is carrying out the combined wind generation forecast of more than 7.2GW of installed capacity in the state of Tamil Nadu. Initial results are encouraging and the accuracy is expected to improve with human experience and training of forecasting model. Such arrangements can significantly reduce the cost (penalty) of forecasting errors for the RE developers. The central regulator has also provided a generous permissible error range of ±15% with respect to available capacity within which no penalty is levied on the developers. This is expected that this range will decrease once the forecasting framework matures and RE generators & forecasting service providers attain sufficient forecasting experience in local Indian conditions.

References

[1] Bremnes JB. *A comparison of a few statistical models for making quantile wind power forecasts.* Wind Energy 2006;9:3–11.
[2] Mellit A, Kalogirou SA. *Artificial intelligence techniques for photovoltaic applications: a review.* Prog Energy Combust Sci 2008;34:574–632.
[3] Ministry of New and Renewable Energy: http://mnre.gov.in/mission-and-vision-2/achievements/
[4] Dr. Matthias Lange, Dr. Ulrich Focken. *State-of-the-Art in Wind Power Prediction in Germany and International Developments.* Energy & meteo systems GmbH
[5] Andrew Boone. *Simulation of Short-term Wind Speed Forecast Errors using a Multi-variate ARMA(1,1) Time-series Model.* Master's Thesis for Master of Science Degree in Sustainable Energy Engineering. Royal Institute of Technology, Sweden.
[6] Opitz D, Maclin R. *Popular ensemble methods: an empirical study*. J Artif Intell Res 1999;11:169–96.
[7] Ye Ren, P.N. Suganthan, N. Srikanth. *Ensemble methods for wind and solar power forecasting—A state-of-the-art review 2015.*
[8] Monteiro, C., K. Keko, R. Bessa, et al. (2009). *Quick Guide to Wind Power Forecasting: State-of-the-Art 2009*. Argonne National Laboratory. ANL/DIS-10-2.
[9] Holttinen, H., Meibom, P., Orths, A., van Hulle, F., Lange, B., O' Malley, M., et al. (2009). *Design and operation of power systems with large amounts of wind power.* Final report, IEA WIND Task 25, Phase one 2006-2008. Retrieved from http://www.vtt.fi/inf/pdf/tiedotteet/2009/T2493.pdf
[10] Hoff, T., Perez, R., Ross, J., & Taylor, M. (2008) *Photovoltaic Capacity Valuation Methods.*
[11] Mills, A., & Wiser, R. (2010, September). *Implications of Wide Area Geographic Diversity for Short Term Variability of Solar Power.* Lawrence Berkeley National Laboratory, Environmental Energy Technologies Division.
[12] Xie, L., Carvalho, P., Ferreira, L., Liu, J., Krogh, B., Popli, N., et al. (2011, January). *Wind Integration in Power Systems: Operational Challenges and Possible Solutions.* Proceedings of the IEEE, 99(1).
[13] Milligan, M., Porter, K., De Meo, E., Denholm, P., Holttinen, H., Kirby, B., et al. (2009). *Wind Power Myths Debunked: Common Questions and Misconceptions.* IEEE Power & Energy Magazine.
[14] CERC, *Forecasting, scheduling & imbalance handling for Renewable Energy (RE) generating stations based on wind and solar at inter-state level*. 07.08.2015.
[15] National Load Despatch Centre (NLDC). *Procedure for implementation of the framework on forecasting, scheduling and imbalance handling for renewable energy generating stations based on wind and solar at inter-state level.* October 2015.
[16] Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH. Report on Forecasting, Concept of Renewable Energy Management Centres and Grid Balancing. May 2015
[17] Jennifer Rogers, Kevin Porter, Exeter Associates, Inc. *Central Wind Power Forecasting Programs in North America by Regional Transmission Organizations and Electric Utilities* December 2009
[18] Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH. *Detailed Project Report for Establishment of Renewable Energy Management Centres (REMC*). May 2015.

Enhancement of fault ride-through grid code of a vector-controlled doubly-fed induction generator for different types of fault

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Abstract*- This paper describes the challenges arised by the integration of a doubly-fed induction generator (DFIG) based variable speed wind turbine with an ac network during different fault conditions. A vector controlled model has been implemented in PSCAD/EMTDC software. Grid disturbances such as severe voltage dips caused by short-circuit faults can lead to disconnection of wind farm from the grid, which may cause instability in the grid. To avoid this situation, the grid code requires wind farms to remain connected and continuously operated even if the voltage dips reaches very low values. The depth and duration of the voltage dips are usually defined by a voltage-time diagram. Low-voltage ride-through (LVRT) requirements during grid faults has been represented in this paper. The system is allowed to be disconnected from the grid only when the voltage dips are in the area below the limit line of LVRT. The grid codes also require the system to supply a certain amount of reactive power to support the grid voltage during the fault. The limits and ranges for the LVRT requirements vary with the grid operators in different countries. The dynamic response of different parameters during different types of fault conditions and improvement of the wind farm fault ride through capability by reactive power compensation has been analyzed in this paper.

Keywords- Grid code, Doubly-fed induction generator (DFIG), Fault-ride-through, Stability, Protection.

I. INTRODUCTION

Interconnection of wind power generation in power system is increasing abruptly all over the world. Wind Turbine (WT) interconnection standards have been developed in many countries to ensure stable system operation. These standards are called grid code. Some requirements are specified in grid code for interconnection of large capacity wind farm. Fault ride through (FRT) which indicates the protections required for wind generator during a fault, is the most important criteria of a grid code.

Literature [1] describes how to keep DFIG connected with grid during abnormal condition. Dynamic responses of different parameters by adding active diode crowbar has been investigated. Fault-ride-through (FRT) capability of crowbar with different FACTS controllers like STATCOM, UPFC has been compared for a DFIG. The effect on the voltage at point of common coupling (PCC) and FRT has been studied for different dynamic controller [2].

In literature [3], the responses of the pitch controller, DC-link voltage and current of stator and rotor for various types of fault conditions have been analyzed. The results from simulations have been compared with and without crowbar to validate modelling. Fuzzy controller is used for improvement of FRT of variable speed wind turbine. This controller compensates the voltage at PCC by regulating active and reactive power of wind turbines. Different case studies for multiple numbers of WTs in different locations of 37 bus weak distribution network have been investigated to check performance of controller [4].

In the literature [5], a rotor current limiter (RCL) has been inserted to the rotor circuit instead of crowbar depending upon fault conditions. The rotor side converter can stay connected as well as DFIG can maintain its normal condition after faults in proposed method. The improvements of rotor current, electromagnetic torque pulsation, DC voltage fluctuations and reactive power absorption have been implemented in the simulation. FRT performance of DFIG can be improved by two voltage booster techniques such as, dynamic voltage restorer (DVR) and high temperature superconducting fault current limiter (HTS-FCL). These two schemes require grid code for reactive current support at balanced and unbalanced fault conditions [6].

In literature [7], a proper control strategy has been designed for parallel capacitors to enhance FRT capability of DFIG WT. The function of these switching capacitors is to protect dc-link overvoltage during imbalance power condition which has been presented in an experimental study. In recent time, super capacitors are one the suitable solutions to compensate the problems of power fluctuations caused by massive penetration of wind energy in the power grid. Super capacitor has been proposed to connect at the dc link of DFIG in the PSCAD/EMTDC simulation model. The performances of grid voltage, stator current, real and reactive power have been evaluated in this model [8].

For the improvement of fault ride through criteria of DFIG an algorithm has been proposed to switch capacitor banks for reactive power compensation. Rotor crowbar protection scheme for overcurrent has also been implemented.

The whole paper is divided into six sections. Section-II describes grid code and low voltage fault ride (LVRT) through capability. Vector controlled DFIG modeling in PSCAD/EMTDC software has been described in section-III. Section IV describes simulation results and analysis for different types of faults. Section V describes the enhancement methodologies of FRT. Conclusion part has been described in section VI.

II. GRID CODE AND FAULT RIDE THROUGH CAPABILITY

In various countries, grid codes have been developed and enforced since long back. They ensure applications of uniform standards for power systems and provide a framework for manufacturers to develop their equipment. Grid codes are usually based on the experience acquired through the operation of power systems and may vary from one utility to another. Differences in various grid codes also depend on regional and geographical conditions. However, the key elements in the different grid codes remain similar across the globe since their ultimate goal is to ensure safe, reliable and economic operation of the power system.

With the rapid development of renewable energy sources throughout the world and their integration into the grid, the grid codes in many countries have been updated to address issues related to renewable energy power generation. According to the updated grid codes, wind farms tend to be considered as power generation plants, which should perform in a similar manner as conventional power-generation plants. The main elements in the grid codes include fault ride-through requirements, active/reactive power control, frequency/voltage regulation, power quality, and system protection.

The FRT shall be applicable to all new wind farms planned or commissioned after date specified by concerned authority with due consideration of penetration level, cost and tariff. During fault ride through, the WTs shall have the capability to meet the following requirements:

(a) Minimize the reactive power requirement from the grid.
(b) The wind turbine generators shall provide active power in proportion, to retain grid voltages as soon as the fault is cleared.

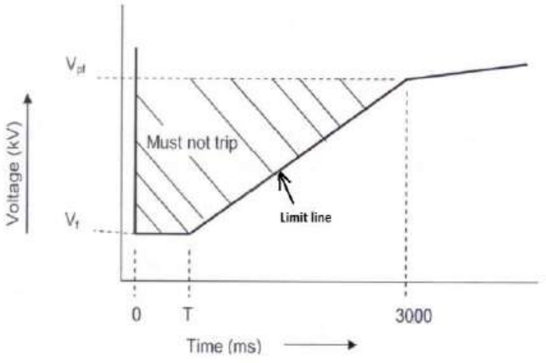


Fig.1 Fault ride through characteristics in Indian grid code

In Fig.1 V_f indicates 15% of nominal system voltage and V_{pf} is the minimum Voltages (80% of nominal system voltage)

According to Indian Electricity Grid Code for interconnection of WT, the operating region during system faults is shown in Fig.1. Wind farms can be disconnected if the operating point falls below the limit line. Most wind energy conversion systems with full capacity-converter are capable of meeting the requirement.

Table I shows FRT requirements in many countries. It is noted that the limits and ranges for the LVRT requirements vary with the grid operators in different countries, but they all share a common background and purpose.

TABLE I. LVRT REQUIREMENTS IN DIFFERENT COUNTRIES

Country	Connection Voltage	Fault Last(ms)	Drop Voltage (%)	Recovery time (sec)
Germany	D/T	150	0	1.5
Denmark	D/T	100	25	1.0
England	D/T	140	15	1.2
Ireland	D/T	625	15	3.0
Spain	T	500	20	1.0
Italy	35 kV or more	500	20	0.3
USA	T	625	15	2.3

III. VECTOR CONTROLLED DFIG MODELING IN PSCAD/EMTDC

The DFIG consists of wound rotor induction generator in which the rotor circuit can be controlled by external devices to achieve variable speed operation. The stator of the generator delivers power to the grid from the wind turbine in unidirectional way. The power can be delivered to the grid from the rotor and vice versa through generator/rotor-side converter (RSC) and grid-side converters (GSC).The vector controlled simulation model of grid connected DFIG has been implemented in PSCAD/EMTDC software illustrated in the Fig.2. A 2 MW, 4 pole, 690 V DFIG model has been chosen where power coefficient C_p is 0.28. DFIG is connected with 33 kV grid through a 0.69/33 kV step-up transformer. The control schemes of generator and grid side converter have been described in subsection (a) and (b).

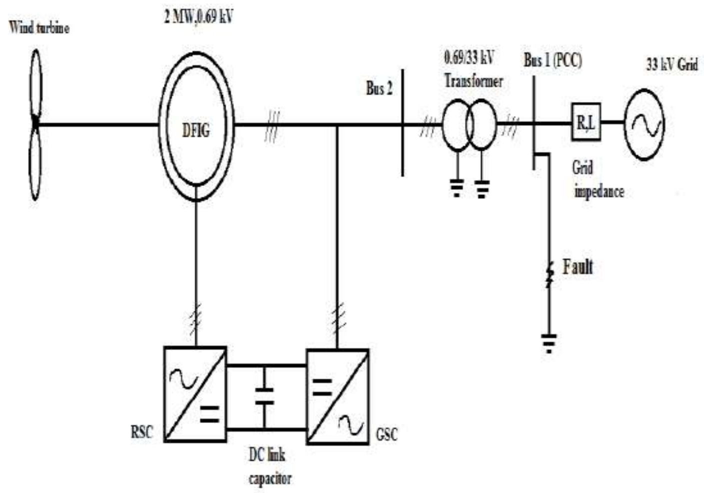


Fig.2 Schematic of DFIG-based Wind turbine for FRT enhancement

a. Generator side converter and control

A stator flux oriented vector controlled scheme has been implemented in this converter model. The active power and torque of machine are controlled by quadrature axis component of rotor current I_{rq} and direct axis component I_{rd} controls the reactive power and voltage. So, decoupled control of active and reactive power can be obtained from this scheme. Present location of rotating stator flux has been determined by integrating stator voltage after removal of resistive drop which is shown in equation (1).

$$\psi_{\alpha s} = \int (V_{\alpha s} - I_{s\alpha} r_s) dt$$

$$\psi_{\beta s} = \int (V_{\beta s} - I_{s\beta} r_s) dt \qquad (1)$$

$$\varphi_s = \tan^{-1} \frac{\psi_{\alpha s}}{\psi_{\beta s}}$$

Where,

$\psi_{\alpha s}$ and $\psi_{\beta s}$ are stator flux linkages, $I_{s\alpha} r_s$ and $I_{s\beta} r_s$ are resistive voltage drop, $V_{\alpha s}$ and $V_{\beta s}$ are stator terminal voltages, *α, β* indicates stationary reference frame and φ_s represents stator flux position in equation (1). A pulse width modulation (PWM) based hysteresis-band current control topology has been used to control rotor current and make it approaching the reference value.

b. Grid side converter and control

This is a sinusoidal PWM (SPWM) based converter. The function of this converter is to keep dc link voltage constant and control reactive power flow into the grid. These two parameters are described in equation (2) and (3)

$$C \frac{dV_{dc-link}}{dt} = \frac{3}{2\sqrt{2}} m i_d - i_{dc-link} \qquad (2)$$

$$Q_{grid} = 3 V_d i_q \qquad (3)$$

Where,

C is dc-link capacitance, *m* is modulation index of converter, i_d and i_q are direct and quadrature axis components of current respectively which are flowing between grid side converter and grid, $V_{dc-link}$, $i_{dc-link}$ are the dc-link voltage and current, Q_{grid} is reactive power flow through grid and V_d is phase voltage of grid in equation (2) and (3). From these two equations it has been observed that voltage across capacitor and reactive power through grid can be controlled by i_d and i_q respectively. Reference values of grid voltage has been obtained in the control strategy mentioned in Fig.3.

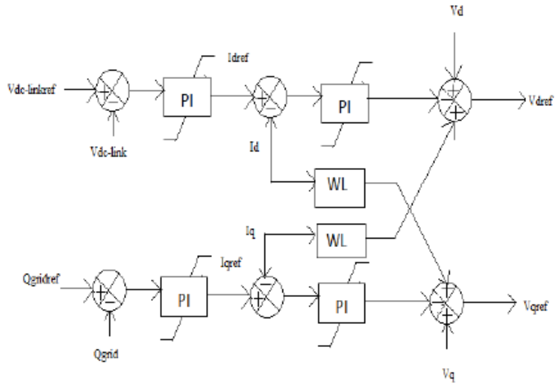


Fig.3 Grid side converter control scheme

$V_{dc-linkref}$ is the reference value of DC link capacitor voltage, $Q_{gridref}$ is the reference value of reactive power on the grid side, i_{dref} and i_{qref} are the reference values of grid current in d-axis and q-axis respectively, v_{dref} and v_{qref} are the reference values of the grid ac voltage in d-axis and q-axis shown in the Fig.3. The reference voltages of SPWM converter can be generated after Park's transformation.

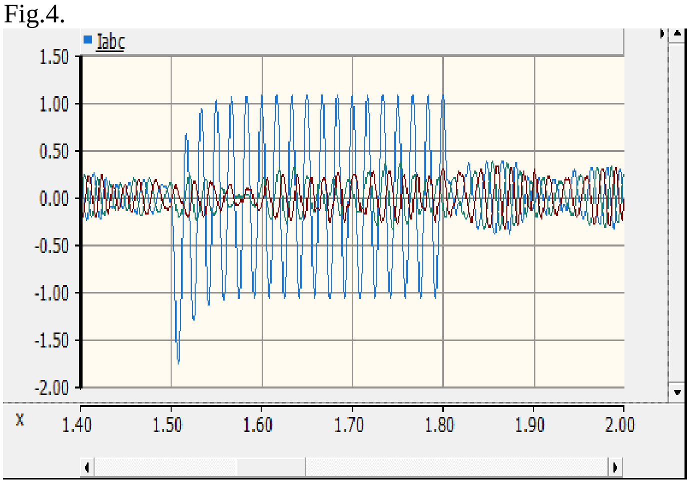
IV.SIMULATION RESULT AND ANALYSIS FOR DIFFERENT TYPES OF FAULT

PSCAD/EMTDC simulation has been done to investigate the asymmetrical fault characteristics of DFIG. Dynamic performances of different parameters like grid voltage, current, active and reactive power have been studied for different types of fault. These faults are created at PCC.

(a) Single-phase to ground fault

DFIG becomes steady after 0.5 sec when it is switched from speed control mode to torque control mode. A single-phase to ground fault has been simulated at 1.5 sec and fault duration is 0.30 sec. The responses have been represented in Fig.4.

As phase A has been short circuited, the current of that phase increases from 0.25 p.u. to 1.0 p.u. and other phase currents remain unchanged. The r.m.s value of grid voltage declines from 1 p.u. to 0.80 p.u. during this fault which is indicated in Fig.4.



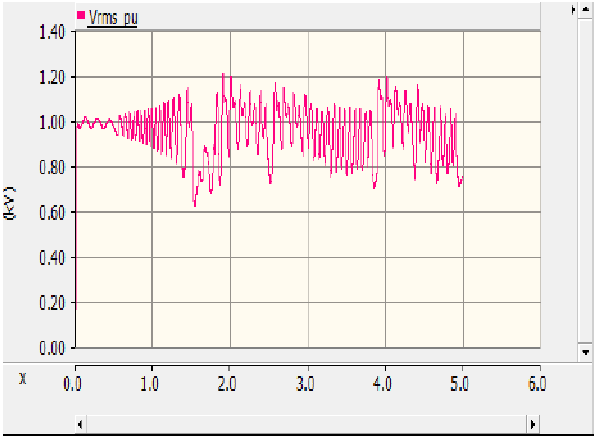


Fig.4 Grid Current, voltage responses during single-phase to ground fault

(b) Two-phase to ground fault

A two-phase to ground fault has been simulated at 1.5 sec and fault duration is 0.30 sec. Here, Phase A and B are connected to ground. Current of these two phases increases about 4 times during fault condition. Voltage at PCC has decreased from 1.0 p.u. to 0.5 p.u. due to this fault which is shown in Fig.5.

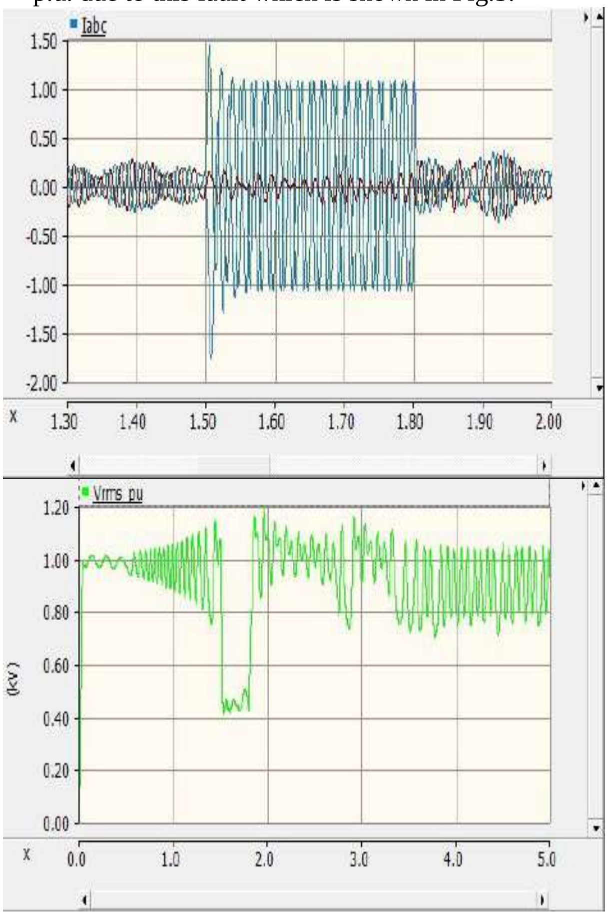


Fig.5 Grid Current, voltage responses during two-phase to ground fault

(c)Three-phase to ground fault

Here all three phases are connected to ground. Fault time and duration remain unchanged. The inrush current has been obtained in all three phases from PSCAD/EMTDC simulation. Due to this abrupt increase of current in all phases, voltage at grid end falls to zero. Active power transfer from DFIG reaches near zero and reactive power increases during this fault which is represented in Fig.6.It is the most severe case among all.

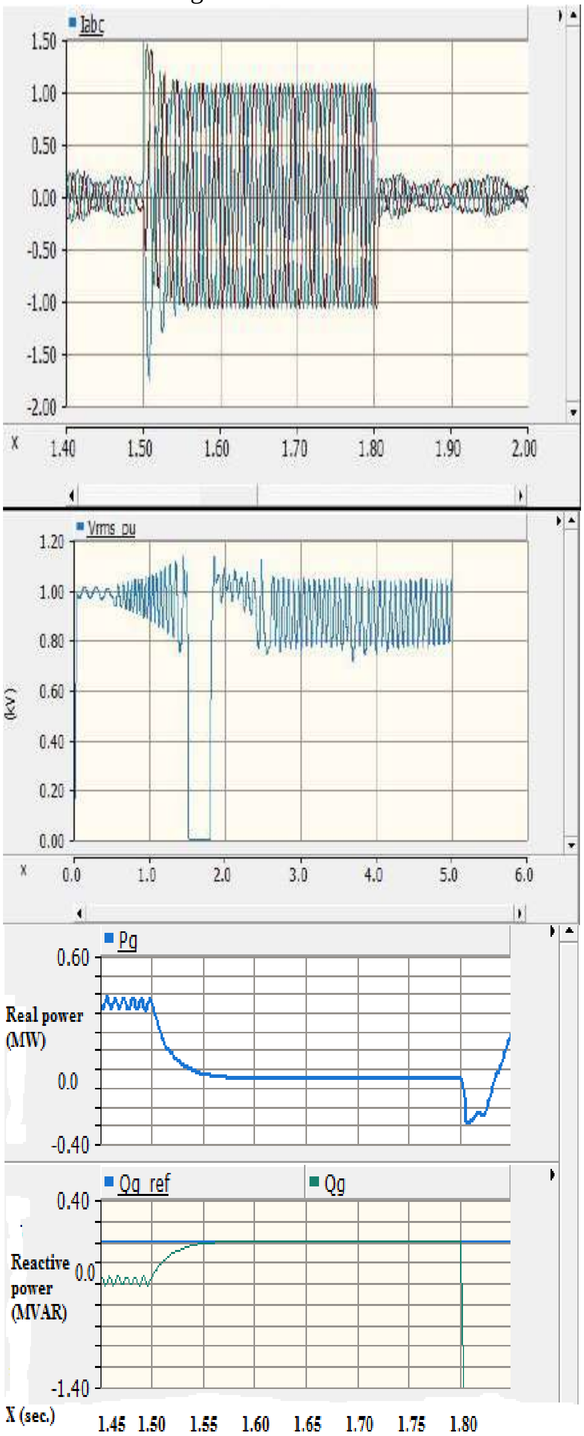


Fig.6 Grid current, voltage, active and reactive responses during three-phase to ground fault

V. FAULT RIDE THROUGH ENHANCEMENT TECHNIQUES

Due to unbalanced faults, voltage at PCC varies significantly which needs LVRT options. An algorithm has been proposed to enhance fault ride through capability by reactive power compensation, which is shown in Fig.7. In this strategy the voltage sag during fault has been checked. The deepest voltage allowed on the generator terminal due to fault is 0.3 p.u. If sag more than 0.3 p.u., capacitor banks should be connected for reactive power compensation to enhance the wind farm fault ride through requirement. But, the wind farm must be disconnected from grid when sag exceeds 0.75 p.u..

In the proposed algorithm, the voltage at PCC during single line to ground fault is maintained within allowable limit. So, LVRT is not necessary for this fault. The voltage sag exceeds 0.30 p.u. during two phase to ground fault obtained from PSCAD/EMTDC simulation. The circuit breaker attached with capacitor bank (0.6 MVar) should be closed for VAR injection, represented in Fig.8. During the three phase to ground fault the voltage sag exceeds 0.75 p.u.. The main breaker should be tripped and generator must be disconnected from the grid during fault period.

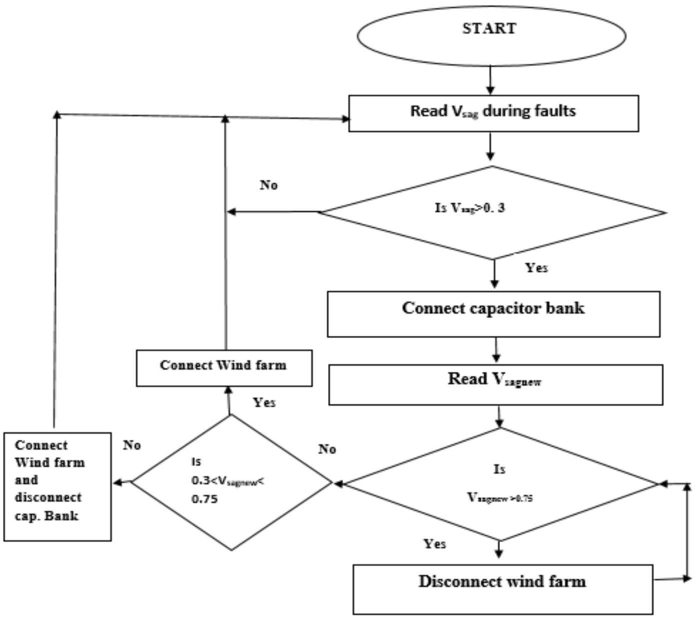


Fig.7 Proposed algorithm for FRT enhancement

Besides the proposed algorithm, a rotor crowbar protection must be well coordinated for over-current protection. It had been positioned between rotor winding of induction generator and rotor side converter. Crowbar protection includes a three phase full bridge circuit with a switch. It should be triggered due to rotor inrush current as a result the rotor side inverter gets blocked. Over-voltage problem has been faced by dc link capacitor during faults. For overvoltage protection crowbar is also necessary. DC link voltage falls below a certain limit and crowbar connection becomes deactivated. The rotor current of generator with and without crowbar protection has been represented in Fig.9.

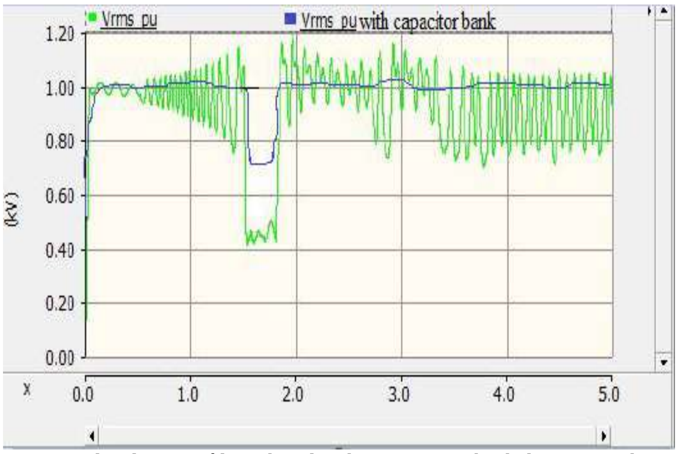


Fig.8 Grid Voltage profile with and without capacitor bank during two phase to ground fault

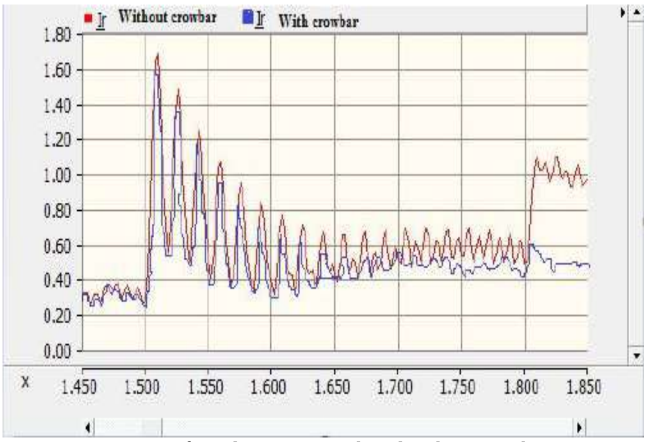


Fig.9 Rotor current of wind generator with and without crowbar protection

VI. CONCLUSION

In this paper an efficient algorithm and rotor crowbar protection scheme have been implemented for enhancing fault ride through of a DFIG based wind turbine. The responses of grid voltage, current, active and reactive power have been simulated and analysed during different types of asymmetrical fault in PSCAD/EMTDC software. LVRT options of grid code must be required to maintain wind farm interconnection during faults. For improvement of LVRT with VAR compensation has been described by applying the proposed algorithm. The voltage at PCC has been improved by incorporating capacitor banks. Besides, rotor crowbar protection has been included to protect rotor inrush current and dc link overvoltage. The simulation result shows that rotor heavy current has reduced. Both schemes are capable of fulfilling fault ride through grid code requirements at different operating conditions of DFIG.

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REFERENCES

[1] H.Karimi-Davijani, A.Sheikholeslami, H.Livani and N.Norouzi,”Fault ride-through capability improvement of wind farms using doubly fed induction generator”, in *Proc. IEEE Universities Power Engineering Conference (UPEC)* ,1-4 Sept.,2008.

[2] Kazi Ahsanullah and Jayashri Ravishankar,” Fault ride-through of doubly-fed induction generators”, in *Proc. IEEE Power, Signals, Controls and Computation (EPSCICON) International Conference*, 3-6 Jan.,2012.

[3] Chang-Doo Cho, Soon-Ryul Nam, Sang-Hee Kang and Seon-Ju Ahn,” Modeling of DFIG wind turbines considering fault-ride-through grid code”, in *Proc. IEEE Advanced Power System Automation and Protection (APAP) International Conference*,vol. 2, pp.1024-1028,16-20 oct.,2011.

[4] Geev Mokryani, Pierluigi Siano, Antonio Piccolo and Zhe Chen,” Improving fault ride-through capability of variable speed wind turbines in distribution networks”, *IEEE Systems Journal*,vol. 7,no. 4, pp.713-722,Dec 2013.

[5] Maher A. Azzouz and Ehab F. Elsaadany,” An enhanced fault-ride-through capability of doubly-fed induction generators during grid Faults”,in *Proc. IEEE Power and Energy Society General Meeting*,22-26 July,2012.

[6] Surour Alaraifi, Ahmed Moawwad, Mohamed Shawky El Moursi and Vinod Khadkikar,” Voltage booster schemes for fault ride-through enhancement of variable speed wind turbines”, *IEEE Trans. Sustainable Energy*,vol. 4,no. 4, pp.1071-1081,oct. 2013.

[7] L. Huchel, Mohamed Shawky El Moursi and H. H. Zeineldin,” A parallel capacitor control strategy for enhanced FRT capability of DFIG”, *IEEE Trans. Sustainable Energy*,vol. 6,pp. 303-312,Jan. 2012.

[8] Doaa M. Yehia,” Fault ride-through capability enhancement of DFIG-based wind turbine with supercapacitor energy storage”, in *Proc. IEEE International Conference on Power & Energy (PECON)*,pp. 187-190,2014.

Enhancing TPDDL distribution network operation & customer outage performance.

PSC-OMS Merger

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Abstract

TPDDL adopted smart technologies like SCADA-DMS and OMS to improve reliability and customer outages. These were implemented at different times, from different vendors and operated in different environments resulting in inefficient and non-optimal outage durations, costs, and customer satisfaction. The flow of information from DMS to OMS happens through ICCP, but no reverse flow of information from OMS to DMS happens. Consequently the DMS dispatchers have no clue as to the impact of outages on customers and OMS dispatchers have little clue as to the cause of outages. This means often delayed and to some extent inaccurate information conveyed to the customers, and no benefit accruing to reliability from customer calls.

For better efficiency in network and outage management & accurate reporting integration of the two systems was required. However technological integration was beyond question due to incompatibilities in technologies, vendors and data systems. So physical integration done by placing the user interfaces side by side and operated by the same dispatchers. Work processes re-designed and interfaces tightened to enable cohesion among crews and dispatchers. This had the desired improvements on reliability and customer outage services.

Keywords— SCADA, DMS & OMS

INTRODUCTION

TPDDL adopted smart technologies GIS/SCADA/DMS/OMS operationalized in different phases during 2006 to 2012. Though these technologies by design had interface with each other, they were giving sub optimal performance due to such implementation. Integration was therefore need of the hour. However due to difference in operating platforms,
Data systems, vendors, and with no benchmark or such implemented system to follow, it was explicitly difficult for a seamless integration to be possible. Through a series of innovations involving multiple applications development, aligning work practices, extensive trainings, relentless monitoring dashboard, integration achieved. It provided seamless experience and vastly improved performance.
The analysis of reports from the two systems revealed major gaps in reporting, safety, customer feedback and nonalignment between teams like –i) Details of Outages reported in the two system varied widely in terms of counts, duration, cause, customers affected ii) Dual reporting separately in DMS/OMS caused dissatisfaction in operation teams and delays iii) These variations caused inaccurate feedbacks to customers. iv) Lack of clarity in linking cause (event)/impact (outage) v) Bottlenecks in interface process. vi) Inaccurate reliability estimations. vii) Duplicities in reports and data systems. viii) Offline manual reports. Specific feedbacks from users and customers were triggers.

The innovation was the creation of an integrated system and process of quality network operation, efficient management of customer outages through 24X7 monitoring of the distribution network, and online reporting through SCADA/DMS/OMS integrated platform.
In the existing system, the two systems – DMS/OMS sourced from different vendors, implemented at different timeframes, were operated in isolation at two different locations with different set of operators. But their operating data and customers were the same or mostly overlapping. Often events reported in one system was missed in another, duration or customer affected varied in both system. Result was inaccurate reliability estimations, complaints closed with irrelevant causes, and dissatisfaction. The reports of the two systems differed widely on same parameters and linking the two seemed futile. Maintaining duplicate set of data for the same parameters was redundant and incurred unnecessary costs.
Integration through direct technological merger of the two systems was not feasible due to difference in operating platforms, data systems, vendors, and with no benchmark of such implemented system to follow. So through a series of specific developments like – 1.Development of multiple applications in the two systems to enable operators to do the operation and

create online report simultaneously 2. Extensive trainings and remote assistance to field crews to map accurately complaints and network operations and provide accurate & quality data in each complaint 3. Designing & development of a robust monitoring system through multiple customizations to enable continuous monitoring of the network status and critical performance parameters, and 4. Sustained focus on continuously enhancing and expanding the skill and knowledge of the operators and operation teams, the desired integration achieved. In the next step the complaint closing process was decentralized and field crews enabled through 24X7 assistance from the control room to close the complaints with correct information. The focus of control center shifted from closing complaints to proactively monitor network status and minimizing customer outages. Similarly field crew focused on accurate mapping, quality input and timely closing of complaints.

These series of small innovations geared towards creating an integrated platform for network operations, managing customer outages & creating online reports and empowering the operation teams was achieved in multiple stages , and built upon the learning's and corrections from preceding stages. The end product is an integrated platform in DMS/OMS where a single operator working through both the system monitors the network for Load & network change, operates the network in DMS in order to minimize the resultant customer outages in OMS, thus linking both the cause & event accurately. Simultaneously the field operation has an integrated view of the customer outages resulting from network operations and proactively monitors the two for quality information about each other. The system so created is unique that the features are not available in any standard DMS /OMS Software. It is a right step towards Advanced DMS.

CHALLENGES

The first challenge involved operating the two systems together. Initially both systems placed side by side. Operators from both system sat together and exchanged information. Yet it had limited impact. Next each set of operators trained in other system and operated individually both the systems together. This resolved information exchange issue but created complexities for operators as each operator handled two systems, two keyboards, two phones and two reporting systems. As expected, the stress level increased and despatchers complained. Monitoring of vital parameters slipped. Interaction between despatchers and crews delayed and reporting suffered. Three major applications developed helped tide over the problem-1. An online reporting tool 2.An application developed to enable field crews to plan and avail LV outages. 3. Enabling complaint closing through PORD. 4. Monitoring through dashboard. These measures significantly reduced the burden on operators and made joint operation possible.

When these two systems were merged the biggest challenge was to devise a mechanism that could incorporate all functionalities available in existing report with the ease in operations at the same time. Both system worked on different databases, hence a common database was supposed to be created which could link the operations done in DMS and OMS on real-time basis. Above it an operation mechanism was required which could enable operator to key in the desired information. Two report capturing technologies were developed one after the other to cope up the challenges. Finally after a lot of brain storming sessions and meetings a common consent was developed for the reporting mechanism and process was finalized.

Change management from existing to new system proved a big challenge. First the despatchers needed a lot of convincing to allay apprehensions and confusions. A sustained effort to upgrade and enhance the skill for authorization in both systems undertaken for each despatcher through multiple trainings and assessments. Next the operations team managers convinced for the proposed change through multiple meetings and presentations. In the third stage all the field crew supervisors trained in the new system by the despatchers themselves, and certificates awarded after successful training. In this way both set of stakeholders prepared each other. In the final stage, the field crews got remote assistance through advanced communication tool like communicator, videos & slides, and also through mobile. Parallel awareness and training to zonal Breakdown supervisors carried through District level meeting for all 12 districts separately. This was a massive drive in enhancement of skill and knowledge.

CONCLUSION

Financial Impact: Reducing the costs through man-hour reduction by improving the process and systems through this project has been the dominant benefit of this project. Around 18% reduction in PSC group strength from pre-integration to post integration or a reduction of 13 employees that translates to a cost saving of around Rs 1, 14, 55800. Also the employees transferred to other group were trained and experienced staff at Manager / Asst Manager / executives who were utilized in experienced positions in Business development and other groups.

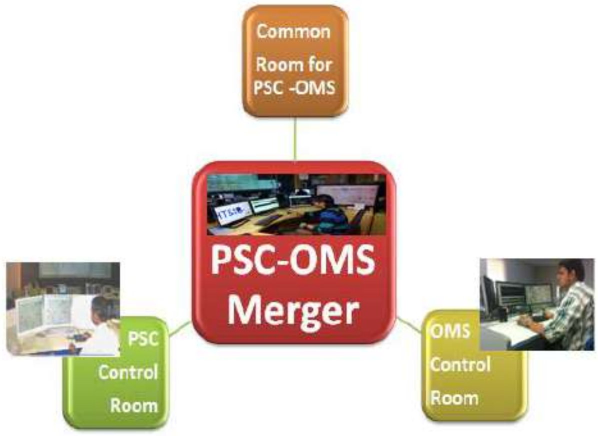
Environmental benefit: Integrated operations created process and reporting tools that captured operation sequence into automatic records saving requirement of paper entry and outside reporting tool. Around 40% of paper saving due to online report creation leading to a major environmental Impact (a saving of 1800 A3 size papers per annum). Employee Engagement through Skill Enhancement & Customer satisfaction: Pre integration the two set of operators were competent in the system operated by him till that time. DMS dispatcher was proficient in Load management and OMS dispatchers' proficient in complaint management. Now both set of operators trained in alternate skill set.

Employee Engagement through Skill Enhancement & Customer satisfaction: Pre integration the two set of operators were competent in the system operated by him till that time. DMS dispatchers were proficient in Load management and OMS dispatchers' proficient in complaint management. Now both set of operators trained in alternate skill set. This has improved engagement and value addition to employees. Similarly Complaint closing delegated to zonal crew supervisors (TOs) after training and authorization. Planned outage at LV Level also delegated with regular monitoring. This eliminated delay in complaint closing and unwanted complaint merging leading to customer satisfaction.

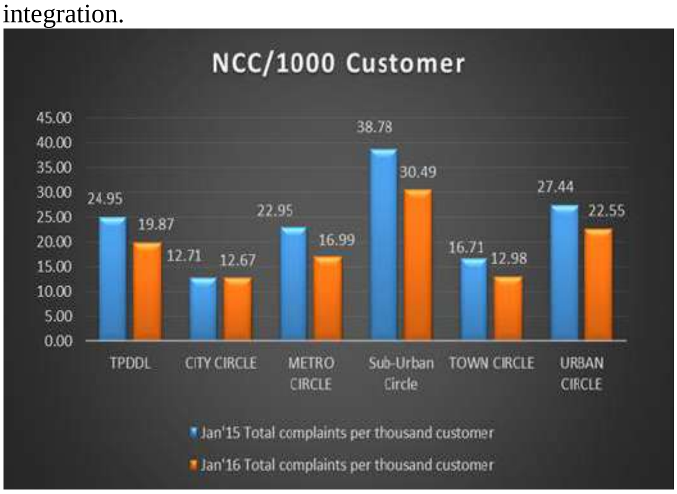
Accuracy in reporting and Safety in operation: The online capturing of operation sequence into records and reports and accurate mapping of complaints into each interruption events in the network has eliminated manual editing and modifications, taking consumer and duration figures directly from system making the reports accurate and independent, though impacting key figures negatively. The figures are expected to improve in next FY. Also network upkeep, SLD maintenance & PTW compliance improved as each operation done online in the system improving safety culture.

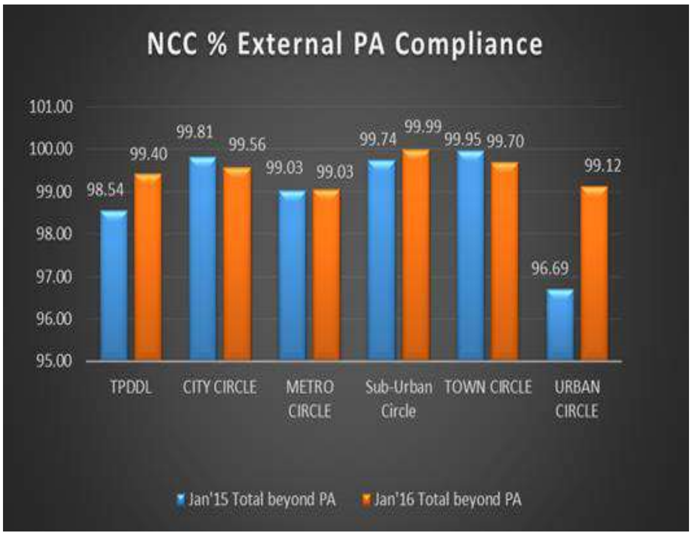
Quality in operation: Before this project, the zonal HV breakdown supervisor was generally unaware of the complaint management process and seldom took into account the impact of network operation on customers or reliability figures. After integration each ZSO was asked to furnish / link complaints with the events. This increased their awareness of customers impacted and brought sensitivity to correct reporting and minimizing outage duration. Operations are done and reported in real time improving quality. As a result avoidable complaints % is falling. Similar awareness in PSC has brought down avoidable complaints from 16% to less than 5%.

A. Figures and Tables



Improvement was observed in reliability parameter like per thousand customer call and PA compliance after PSC- OMS integration.





The PMU-based system observability for fault detection and isolation for a distribution network model

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Abstract*—The aim of this paper is to provide an algorithm which gives a complete system observability by optimally placing the PMUs in a distribution network. A 15-node rural distribution network has been chosen for case study. Based on the algorithm, PMUs are placed at about one-third of the total number of the buses that are present in the distribution network model for obtaining complete observability and also for fault detection. Necessary parameters such as voltage and current phasors, frequency, rate of change of frequency, total vector error, sequence components of voltages and currents, and circuit breaker status that are required for the system observability are computed from the PMU measurements to make the distribution network completely observable. Fault detection is done using PMU measurements and sectional isolation shall be performed. This paper analyses the benefits of using PMUs for fault detection and isolation and this algorithm can provide a significant situational awareness tool for the system operators and a suitable associate tool for the topology processor which is required for the linear state estimator at the distribution management system. Optimal placement of PMU is necessary to improve the state estimation accuracy and to reduce the monitoring costs. The Linear State Estimation and Fault Detection techniques which are given in this paper have a very low computational burden because it avoids iterative computations and provides an analytical solution. The implementation of this paper is performed by using LabVIEW, Matlab/Simulink and MiPower.

Keywords—Phasor Measurement Unit (PMU), Recursive Technique, Non-Recursive Technique, Linear State Estimation, Fault Observability, Distribution Network Model.

I. INTRODUCTION

Electrical quantities like voltages, currents, active and reactive power are to be monitored continuously by the system operators ultimately to use them for the grid state estimation. The accurate measurement data that are coming from the PMUs can considerably enhance the grid state estimation and its corresponding applications. Traditionally, the state estimation problem has been focused on transmission networks, currently, and even more in the mere future, the state estimation for distribution network will become a primary aspect for accurate grid operation.

One of the disadvantages of a traditional state estimators in order to obtain a state estimate is that at a very minimum a complete tree of the network must be monitored. The advantage that phasor-based estimators give is, that each measurement can stand on its own and, if the application requirements could be met then a relatively small number of measurements can be used directly. For example, if we consider the issue of controlling oscillations between the two systems which are separated by a large distance, then only two measurements would be sufficient in order to provide a useful feedback signal.

The conventional state estimators have a particular bus as a reference. The phasor measurements have a universal time as a reference, that is, the sampling instants determine the reference for the PMU data. PMUs can measure the currents in the lines connected to the bus, in addition to the bus voltages. A linear, rectangular, estimate will be formulated by only using these linear PMU measurements. Integrating the line current measurements into a conventional state estimator with the system state which is expressed in polar coordinates, this means expressing the line currents as a non-linear functions of the magnitude and the angle of the bus voltages. Anyway the magnitude and the angle can be computed from the rectangular parts, but the problem is the covariance of the measurement errors and the resulting covariance of the errors are the estimates.

In the distributed generation, safe and secure operation of the power system seriously rely on the level of power system operating condition monitoring. The potential and the current applications of the PMUs can enhance the normal observability and fault observability in the power system. When the voltage at the two ends of each line and the current at any end of the line is known then the system becomes fault observable [1]. Observability is necessary for the linear state estimation monitored system. PMUs are placed at about one-third of the total number of the buses that are present in the distribution network model for complete system observability and fault detection.

The fault that was found has to be cleared immediately, otherwise it may cause serious damage to the line components and may eventually cause the system to collapse. During a fault, by observing the voltage drops at the necessary buses, an approximate fault region can be detected by sparse PMU measurements. Usually, the large voltage deviation is observed if the fault is closer to the bus. The appropriate locations for PMUs can minimize the multi-estimation in the network when fault occurs. In general, the system may not be observable for the fault condition even though if it is observable in the normal condition. In this paper, the applications of PMUs for the fault detection has been investigated and this method can effectively reduce the number of PMUs while retaining the accuracy of the fault location, and the problem of multi-estimation for the distribution network has been addressed. Unlike the normal observability [2] – [7], the optimal and the minimum number of PMUs have been extensively studied for the fault observability in the power system. The work of [8] – [9], gave a detailed account of one-bus-spaced strategy for the PMU placement as well as the fault location by measuring the fault current and the voltage phasors at the two ends of the faulted line. The results show that the PMUs should be installed atleast at one-third of the total number of buses.

In the modern control centers, linear state estimators are likely to become the main option for system monitoring as the increase of PMUs and advancement in communication channels are emerging rapidly. This Paper helps to provide an important situational awareness tool for the system operators and a suitable associate tool for the topology processor which is required for the linear state estimator at the distribution management system.

II. PMU DESIGN USING RECURSIVE AND NON-RECURSIVE TECHNIQUES

The analog sinusoidal signal and the GPS signal are provided as an input to the PMU. The synchronizing signal of 1 pulse per second from the GPS is provided as the input to the phase lock oscillator and it gives the sampling signal whose phase is same as the GPS signal, but the sampling frequency is different. The sampling frequency is then given to the sample and hold element which is placed inside the A/D converter in order to obtain the samples $x_0, x_{1,} x_2 \dots x_{k-1}$. A sequence $n = 0,1,2,3 \dots (k-1)$ is evaluated inside the CPU module from the sampling signal using the time stamped subsystem which is needed to calculate the another $k \times 1$ sequence $e^{-jn\theta}$. The next $e^{-jn\theta}$ is multiplied with the corresponding x_n and added up to $k-1$ samples in order to get the phasor X^{k-1} for the first window and X^{k-1} is same for both Recursive and Non-Recursive techniques. By calculating X^{k-1}, we get the magnitude and the phase angle as the final output [10].

Phasor technology can contribute for the improvement in the state estimation by providing the time synchronized sub-second data. For the Non-Recursive algorithm, the phasor calculations are performed newly each time for the successive window, but for the Recursive algorithm, instead of new phasor estimation, by adding the phasor update to the old phasor to get the new phasor for the new window. Discrete fourier transform based recursive and non-recursive algorithm is considered, and the samples from the analog signals are given by (1),

$$x_n = x_m \cos(n\theta + \varphi) \tag{1}$$

Where, $n = 0,1,2,3 \dots (k-1)$

The phasor can be calculated as given in (2) and (3),

$$X^{k-1} = \tfrac{\sqrt{2}}{k} \textstyle\sum_{n=0}^{k-1} x_n (\cos(n\theta) + j\sin(n\theta)) \tag{2}$$

$$X^{k-1} = \frac{\sqrt{2}}{k} \sum_{n=0}^{k-1} x_m \cos(n\theta + \varphi) \{\cos(n\theta) + j\sin(n\theta)\} \tag{3}$$

The calculations are performed separately for both real and imaginary components. The real and imaginary components can be written as in (4) and (5),

$$X_r^{k-1} = \frac{x_m}{\sqrt{2}} \cos(\varphi) \tag{4}$$

$$X_i^{k-1} = -\frac{x_m}{\sqrt{2}} \sin(\varphi) \tag{5}$$

Thus, $X^{k-1} = X_r^{k-1} - jX_i^{k-1}$

$$= \tfrac{x_m}{\sqrt{2}} e^{j\varphi}$$

Here $k-1$ is the last sample of the phasor for calculation. Recursive and Non-Recursive algorithms are described after the calculation of the first phasor in-order to update the phasor for the successive windows. Non-Recursive algorithm is the easy way to calculate the phasor for every window. The equation for the Non-Recursive phasor calculation can be represented as (6),

$$X^{k+a} = \frac{\sqrt{2}}{k} \sum_{n=0}^{k-1} x_{(n+1)+a}\, e^{-jn\theta} \tag{6}$$

Where, $a = -1,1,2,3 \dots$

The CPU module for the Non-Recursive phasor calculation technique is shown in *Fig. 1*,

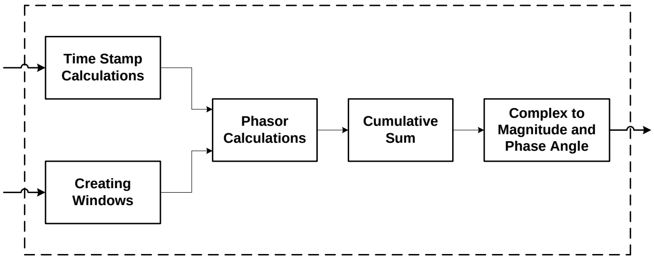


Fig. 1. CPU Module for Non-Recursive algorithm

For the Recursive phasor estimation, the phasor is first calculated for X^{K-1} and then X^K is calculated by adding the phasor update to it. The equation for the Recursive phasor calculation can be represented as (7),

$$X^{k+a} = X^{k+(a-1)} + \frac{\sqrt{2}}{k} (x_{k+a} - x_a) e^{-jr\theta} \tag{7}$$

Where, $a = 0,1,2,3 \dots$

The CPU module for the Recursive phasor calculation technique is shown in *Fig. 2*,

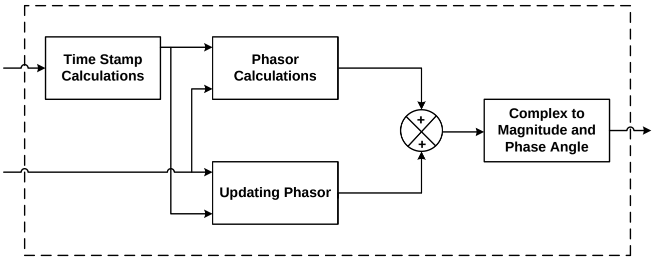


Fig. 2. CPU Module for Recursive algorithm

Here a and $a-1$ represents the present and the past state. By comparing (6) and (7), it is obvious that for the Non-Recursive phasor estimation as there is no $a-1$ phasor present in the equation, so the present output depends only on the present input. For the Recursive phasor estimation the present output X^{k+a} depends on the past output $X^{k+(a-1)}$ and the present input. So, compared to Non-Recursive phasor estimation, the Recursive phasor estimation is faster because the phasor estimation is not performed in every step.

The error keeps on increasing in the Recursive phasor estimation if there is any small error in the phasor updating part, that means the sine wave is not continuous. There is no such error in the Non-Recursive phasor estimation because the phasor rotates counter clockwise with sampling angle $\theta = \frac{2\pi}{N}$, but the sinusoidal remains stationary for the recursive phasor estimation. The phasors that are obtained for a Recursive and Non-Recursive phasor estimation can be represented in a compass plot as shown in *Fig. 3*.

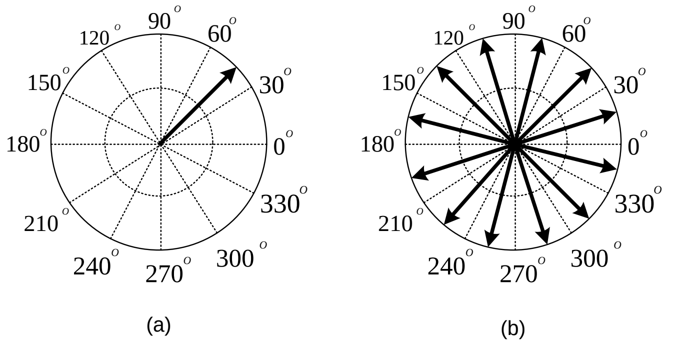


Fig. 3. (a) Recursive and (b) Non-Recursive Phasor Estimation

Global Positioning system (GPS) can provide time tracable to Coordinated Universal Time (UTC) with accuracy adequate to keep the Total Vector Error (TVE), Frequency Error (FE), Rate of Change of Frequency Error (RFE) within the required limits. A time error of $1\mu s$ corresponds to a synchrophasor phase error of $0.018°$ for a $50\ Hz$ system. The phase error of $0.57°$ will by itself cause 1% TVE as given in (8),

$$TVE(n) = \sqrt{\frac{\left(\hat{X}_r(n) - X_r(n)\right)^2 + \left(\hat{X}_i(n) - X_i(n)\right)^2}{\left(X_r(n)\right)^2 + \left(X_i(n)\right)^2}} \quad (8)$$

Where, $\hat{X}_r(n)$, $\hat{X}_i(n)$ and $X_r(n)$, $X_i(n)$ are the sequences of estimates given by the unit under test and the theoretical values of the input signal at the instant of time (n) assigned by the units to those values. The synchrophasor measurements shall be evaluated under the total vector error criterion as in (8). Frequency measurement and ROCOF measurement errors are the absolute values of the difference between the theoretical and the estimated values respectively as given in (9) and (10),

$$FE = |f_{true} - f_{measured}| \quad (9)$$

$$RFE = \left|\left(\frac{df}{dt}\right)_{true} - \left(\frac{df}{dt}\right)_{measured}\right| \quad (10)$$

Where, the true and measured values are for the same instant of time.

III. LINEAR STATE ESTIMATION

The issues of data scan and time skew could be eliminated if the estimates could be formed with only the PMU data. The static assumptions could be removed if the PMU data would be time tagged. So, at any instant in time we could obtain an estimate of a dynamic system. Due to the communication delays the estimate might be obtained a small time after the measurements were made, but it would be an estimate of the state of the system at the instant the measurements were made. There are several issues that must be addressed, one is the need for redundancy to eliminate the bad data and the other thing is to know the required number of PMUs for the designed system. At one extreme, we would be measuring the state but not estimating it if the PMUs are installed at every bus. The loss of a measurement would only mean the loss of the information about the bus in question but the knowledge of all the other buses are available.

A PMU in a substation could easily have an access to the line currents in addition to the bus voltages. All phasors at the same reference would mean that the voltages and currents are sampled at the same sampling instances. The knowledge of the line current can be used to compute the voltage at the other end of the line. So, by measuring the line currents we can extend the voltage measurements to the buses where no PMU is installed. The redundancy issue is addressed with the large number of PMUs in the system, but on the other hand, the small number of PMUs are required to measure all the bus voltages indirectly and to achieve the optimum PMU location $[11] - [13]$.

To begin the linear formulation, similar to the element bus incidence matrix, a current measurement bus incidence matrix is defined where it has as many rows as the measurements of currents and as many columns as there are buses (excluding ground). The equation for the linear formulation is given as in (11),

$$\begin{bmatrix} V_a \\ V_b \\ \vdots \\ \vdots \\ V_p \\ I_1 \\ I_2 \\ \vdots \\ \vdots \\ I_{m-1} \\ I_m \end{bmatrix} = \begin{bmatrix} I_{p\times q} \\ Y_{m\times m}\ A_{m\times q} \end{bmatrix} \begin{bmatrix} V_1 \\ V_2 \\ \vdots \\ \vdots \\ V_{q-1} \\ V_q \end{bmatrix} \quad (11)$$

Where, m is the number of current measurements, n is the number of lines, p is the number of buses with the voltage measurements, q is the number of buses in the system, $A_{m\times q}$ is the incidence matrix, $Y_{m\times m}$ is the diagonal matrix of admittances. $I_{p\times q}$ is the unit matrix from which the rows corresponding to the missing bus voltages are removed.

The equations are linear and the (11) is in the form of $Z = BV$, and to find the estimates, the equation can be written as (12) and (13),

$$\hat{x} = (B^T W^{-1} B)^{-1} B^T W^{-1} Z \quad (12)$$

$$\hat{x} = MZ \quad (13)$$

Where, $M = (B^T W^{-1} B)^{-1} B^T W^{-1}$

Unlike some estimators, this equation is linear and hence no iterations are needed. The estimates are obtained by matrix multiplication as soon as the measurements are obtained. As long as there is no change in the bus structure, there will not be any change in the matrix M which converts the measurements to the state estimate. It can be computed offline and stored for real time use. The matrix M becomes real under certain conditions of measurement configuration, simplifying the computations even further [14] – [16]. So, for the distribution network model as shown in *Fig. 4*, the linear formulation with 28 current measurements on 14 lines, 5 voltage measurements for the 15 bus distribution network are given as (14) and (15),

$$\begin{bmatrix} V_2 \\ V_4 \\ V_6 \\ V_{10} \\ V_{12} \\ I_1 \\ I_2 \\ \vdots \\ \vdots \\ \vdots \\ I_{27} \\ I_{28} \end{bmatrix}_{33\times1} = \begin{bmatrix} I_{5\times15} \\ Y_{28\times28} \;\; A_{28\times15} \end{bmatrix}_{33\times15} \begin{bmatrix} V_1 \\ V_2 \\ V_3 \\ V_4 \\ \vdots \\ \vdots \\ \vdots \\ \vdots \\ V_{12} \\ V_{13} \\ V_{14} \\ V_{15} \end{bmatrix}_{15\times1} \tag{14}$$

or

$$[Z]_{33\times1} = \begin{bmatrix} I_{5\times15} \\ Y_{28\times28} \;\; A_{28\times15} \end{bmatrix}_{33\times15} [V]_{15\times1} \tag{15}$$

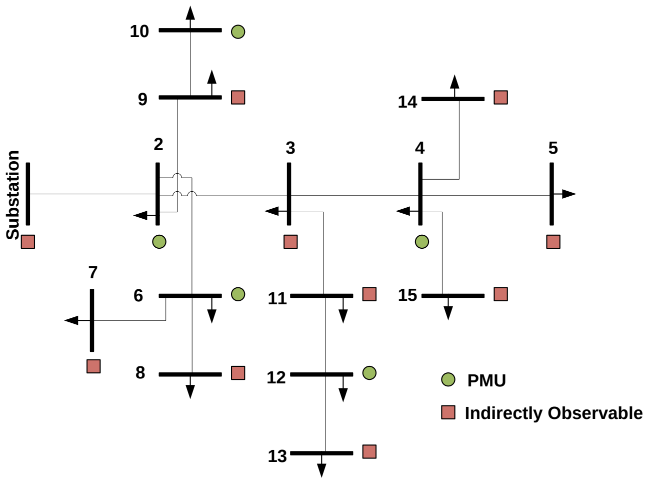


Fig. 4. Distribution Network Model with PMUs

IV. Fault Observability using PMUs for a Distribution Network Model

The precise fault location on the lines can expedite the repair of the faulted components, speed-up the restoration and reduce the outage time, thus, power system reliability can be improved [17]. Faults and device failures affects the power quality in the power systems and also cause the losses for the electric utilities and the customers. In this paper, with the minimum number of measurements, the fault location and the impedance can be uniquely determined from the entire network for full fault observability, and helps to design an appropriate solver to find the fault location and impedance from the measured data.

The dual circuit of the network is obtained followed by its impedance matrix by employing the concept of duality. The voltage changes in the dual circuit represents the current changes in the actual network, by using the impedance matrix as a powerful tool for the fault analysis. These matrices change according to the place and impedance of the fault, whenever the fault occurs in the system. Therefore, the impedance elements of these matrices are obtained, which are a function of the fault location and impedance. These functions of the network and its dual circuit can be used to calculate the effect of each fault on the voltage and current phasors that are recorded by the PMUs at the measurement points.

The mesh impedance matrix Z' is developed and the mesh equations of the network are obtained as (16),

$$V_s = Z' I_m \tag{16}$$

Then the network mesh currents I_m are obtained from the mesh admittance matrix $Y' = (Z')^{-1}$ using the line and load impedances and the voltages feeding the network. The pair $m_{pa} = (\Delta V_{pa}, \Delta I_{pa})$ are the measured changes in the voltage and current at the PMU bus p. $a = (x, y, D, R_f)$ contains the location and the impedance of the fault, where, x and y are the sending and receiving end buses of the faulted line respectively, D is the distance from the sending end bus and R_f is the fault impedance. $\sigma = \{m_{pa} | \, 1 \le a, x, y \le N, 0 \le D \le 1, R_f \in R^+\}$ is the set of all possible pairs, where, N being the total number of network buses. m_l is a subset of σ, with integer $l \ge 1$, that can uniquely identify all the faults (location and impedance) in the network. So, for any two different faults a_1 and a_2, where, m_{pa1} & $m_{pa2} \in m_l$ and $m_{pa1} \neq m_{pa2}$ for same p. The trivial solution occurs when $m_l = \sigma$ for most of the networks. So once the subset m_l, when exists, is identified, then the fault location and the impedance can be found using m_l with the available methods, making no possibility of multi-estimation.

The impedance matrix can be obtained by inverting the admittance matrix, the direct development of the impedance matrix is preferable because for a distributed power systems with large number of nodes it exert a significant computational burden and errors [18]. The impedance matrix after the fault can be calculated, by having the impedance matrix before the fault, to avoid the matrix inversion.

Single line diagram of the of the part of a network, before and after the fault are shown in *Fig. 5* and *Fig. 6* respectively.

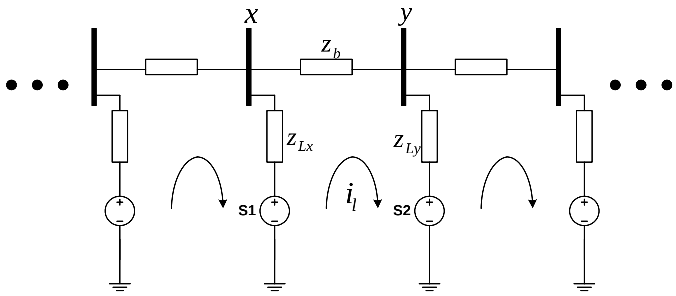


Fig. 5. Before the fault

The point of fault can be assigned to a new bus when the fault occurs on the line section x and y. Pre-fault condition of Z can be modified to accommodate the new bus. By adding the line impedance $-Z_b$ between the two lines x and y, it can be formulated [18] as in (17),

$$Z_{ij}(1) = Z_{ij}(0) - \frac{\left(Z_{ix}(0) - Z_{iy}(0)\right)\left(Z_{xj}(0) - Z_{yj}(0)\right)}{Z_{xx}(0) + Z_{yy}(0) - 2Z_{xy}(0) - Z_b} \tag{17}$$

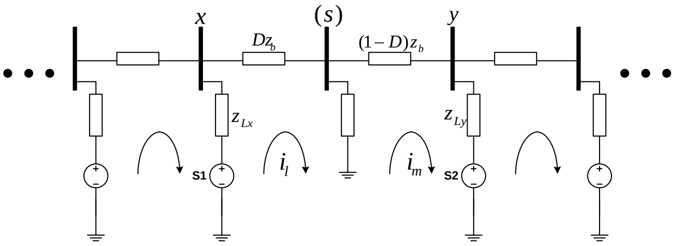


Fig. 6. After the fault on point s

Where, $Z_{ij}(1)$ is the element of i^{th} row and j^{th} column of the modified impedance matrix Z, index (1) shows the first step of the level of modification, index (0) is the element before modification. By adding DZ_b between the new bus s and x, it can be formulated as (18), (19) and (20),

$$Z_{sy}(2) = Z_{xj}(1) \tag{18}$$

$$Z_{is}(2) = Z_{ix}(1) \tag{19}$$

$$Z_{ss}(2) = Z_{xx}(1) + DZ_b \tag{20}$$

By adding $(1-D)Z_b$ between the new bus s and y, it can be formulated as in (21),

$$Z_{ij}(3) = Z_{ij}(2) - \frac{\left(Z_{is}(2) - Z_{iy}(2)\right)\left(Z_{sj}(2) - Z_{yj}(2)\right)}{Z_{ss}(2) + Z_{yy}(2) - 2Z_{sy}(2) + (1-D)Z_b} \tag{21}$$

By knowing the elements of the modified impedance matrix, the change of voltage in i^{th} bus due to the fault current at bus s can be given as (22),

$$\Delta V_{is} = Z_{is}(new) \times I_f \tag{22}$$

Where, $Z_{is}(new)$ is the element of i^{th} row and s^{th} column of the modified matrix $Z(Z_{ij}(3))$.

$$I_f = \frac{V_{s\,(prefault)}}{Z_{ss}(new) + R_f} \tag{23}$$

Where, I_f is the fault current (23), $Z_{ss}(new)$ is the diagonal element of s^{th} row and s^{th} column of the modified matrix $Z(Z_{ss}(3))$, which is the thevenin's impedance at bus s. It is appropriate to assume that along the line the voltage drop is linear and especially for the small and medium size distributed generation networks the capacitive effects of the power lines can be ignored. So, the pre-fault voltage at point s between the lines x and y can be calculated as (24),

$$V_{s\,(prefault)} = V_y + (1-D)\left(V_x - V_y\right) \tag{24}$$

By substituting all the equations in $\Delta V_{is} = Z_{is}(new) \times I_f$, the voltage change measured is obtained at the i^{th} bus due to the fault located at point s. Therefore, the relationship for voltage change based on fault location and fault impedance can be given as (25),

$$\Delta V_{is} = Z_{is}(new) \times \frac{V_{s\,(prefault)}}{Z_{ss}(new) + R_f} \tag{25}$$

Where,

$$Z_{is}(new) = Z_{is}(3) = Z_{is}(2) - \frac{(Z_{is}(2) - Z_{iy}(2))(Z_{ss}(2) - Z_{ys}(2))}{Z_{ss}(2) + Z_{yy}(2) - 2Z_{sy}(2) + (1-D)Z_b}$$

$$Z_{ss}(new) = Z_{ss}(3) = Z_{ss}(2) - \frac{(Z_{Ss}(2) - Z_{Sy}(2))(Z_{ss}(2) - Z_{ys}(2))}{Z_{ss}(2) + Z_{yy}(2) - 2Z_{sy}(2) + (1-D)Z_b}$$

Further simplifying the above Eq., it can be represented as (26),

$$\Delta V_{is} = \frac{\delta_1 D^2 + \delta_2 D + \delta_3}{\gamma_1 D^2 + \gamma_2 D + \gamma_3 + \gamma_4 R_f} \tag{26}$$

Where, $\delta_1, \delta_2, \delta_3, \gamma_1, \gamma_2, \gamma_3, \gamma_4$ are the coefficients which are calculated from each line and are the functions of pre-fault impedance matrix elements and the two end voltages of that line.

The method based on mesh current analysis is used for line current measurements to find the changes in the line current using network dual circuit. Nodal impedance matrix $\hat{Z}$ can be modified by using the comparison of dual circuit before and after the fault. Since, the nodal voltages in the dual circuit are same as the mesh currents in the original circuit. So, the mesh current equation can be given as (27),

$$I_m = Y' V_s \tag{27}$$

Where, $I_m = [I_1, I_2 \cdots I_n]^T$ is the vector of mesh currents, $V_s = [V_1, V_2 \cdots V_n]^T$ is the vector of mesh voltage sources, $Y' = \hat{Z}$, and n is the number of mesh currents in the original circuit. The new loop is added to the original network if fault occurs. The voltage source for both loops are affected since the branch is common between the two loops, can be represented as (28),

$$\begin{bmatrix} I_1 \\ \vdots \\ I_i \\ \vdots \\ I_n \end{bmatrix} = \begin{bmatrix} Y'_{11} & \cdots & Y'_{1m} & \cdots & Y'_{1i} & \cdots & Y'_{1l} & \cdots & Y'_{1n} \\ \vdots & \ddots & \vdots & \ddots & \vdots & \ddots & \vdots & \ddots & \vdots \\ Y'_{i1} & \cdots & Y'_{im} & \cdots & Y'_{ip} & \cdots & Y'_{il} & \cdots & Y'_{in} \\ \vdots & \ddots & \vdots & \ddots & \vdots & \ddots & \vdots & \ddots & \vdots \\ Y'_{n1} & \cdots & Y'_{nm} & \cdots & Y'_{ni} & \cdots & Y'_{nl} & \cdots & Y'_{nn} \end{bmatrix} \begin{bmatrix} V_1 \\ \vdots \\ V_m - \Delta V_f \\ \vdots \\ V_i \\ \vdots \\ V_l + \Delta V_f \\ \vdots \\ V_n \end{bmatrix} \tag{28}$$

From (28), the change in the respective mesh current measured by PMUs at i^{th} bus due to the fault at point s between the loops l and m is calculated as (29),

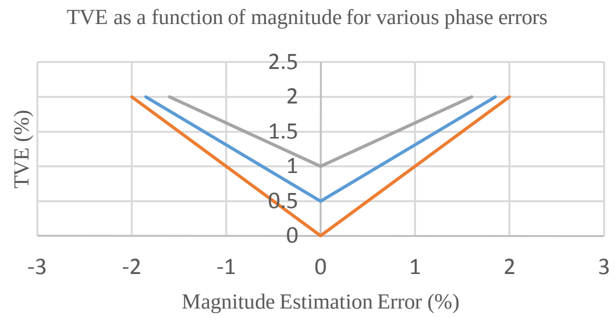
$$\Delta I_{is} = [Y'_{il}(new) - Y'_{im}(new)] \times \Delta V_f \tag{29}$$

Where, $\Delta V_f = I_f R_f = \frac{V_{s\,(prefault)}}{Z_{ss}(new) + R_f} \times R_f$

Therefore, the changes in the voltage and current that are measured at i^{th} bus due to the fault at point s are obtained.

V. CONCLUSION

This paper gives the detailed analysis for implementation of the linear state estimator for the PMUs placed optimally in the distribution network along with fault observability. This paper helps to provide a significant situational awareness tool for the system operators and a suitable associate tool for the topology processor which is required for the linear state estimator at the distribution management system. The results shown below gives the advantage of using PMU data at 10 frames per second for the frequency deviation at bus 6. Furthermore, the analysis in this paper shows that the computational burden for Linear State Estimation and Fault detection techniques are very low because it avoids iterative computations and provides an analytical solution to reduce the monitoring costs.



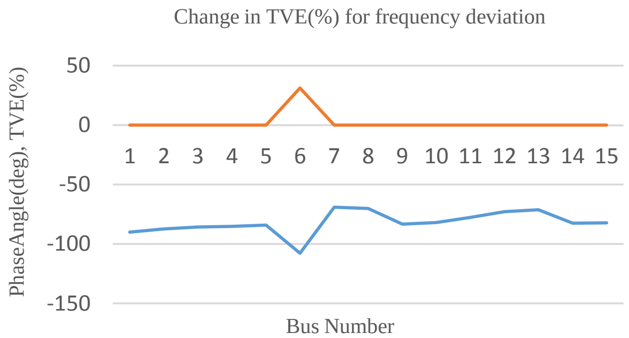


Table I

Grid Network Parameters							
Bus Data					***Nominal Real and Reactive load***		
Branh No.	From Bus	To Bus	$R\ (\Omega)$	$X\ (\Omega)$	Bus No.	$P_L(kw)$	$Q_L(kvar)$
1	1	2	1.3531	1.3235	1	0.0	0.0
2	2	3	1.1702	1.1446	2	44.1	44.7
3	3	4	0.8411	0.8227	3	70.0	71.0
4	4	5	1.5235	1.0276	4	140.0	142.0
5	2	9	2.0132	1.3579	5	44.1	44.7
6	9	10	1.6867	1.1377	6	140.0	142.0
7	2	6	2.5573	1.7249	7	140.0	142.0
8	6	7	1.0882	0.7340	8	70.0	71.0
9	6	8	1.2514	0.8441	9	70.0	71.0
10	3	11	1.7955	1.2111	10	44.1	44.7
11	11	12	2.4485	1.6515	11	140.0	142.0
12	12	13	2.0132	1.3579	12	70.0	71.0
13	4	14	2.2308	1.5047	13	44.1	44.7
14	4	15	1.1970	0.8074	14	70.0	71.0
-	-	-	-	-	15	140.0	142.0

APPENDIX

See Table I.

REFERENCES

[1] R. Kavasseri S.K. Srinivasan "Joint placement of phasor and conventional power flow measurements for fault observability of power Systems" Published in IET Generation, Transmission & Distribution Received on 3rd December 2010.

[2] Baldwin, T.L., Mili, L., Boisen, M.B., Adapa, R. "Power system observability with minimal phasor measurement placement," IEEE Trans. Power Syst., 1993, 8, (2), pp. 707–715 M. B. de Rossiter Corrêa, C. B.

[3] Xu, B., Abur, A. "Observability analysis and measurement placement for systems with PMUs," IEEE Power Systems Conf. Expo. 2004, 2, pp. 943–946.

[4] Gou, B.: "Generalized integer linear programming formulation for optimal PMU placement", IEEE Trans. Power Syst., 2008, 23, (3), pp. 1099–1104.

[5] Chakrabarti, S., Kyriakides, E.: "Optimal placement of phasor measurement units for power system observability", IEEE Trans. Power Syst., 2008, 23, (3), pp. 1433–1440.

[6] Chakrabarti, S., Kyriakides, E., Eliades, D.G.: "Placement of synchronized measurements for power system observability", IEEE Trans. Power Deliv., 2009, 24, (1), pp. 12–19.

[7] Chawasak, R., Suttichai, P., Sermsak, U., Watson, N.R.: "An optimal PMU placement against measurement loss and branch outage", IEEE Trans. Power Deliv., 2007, 22, (1), pp. 101–107.

[8] S. Geramian, H. Askarian and K. Mazlumi, "Determination of Optimal PMU Placement for Fault Location Using Genetic Algorithm," 13th International Conference on Harmonics and Quality of Power, 28 Sep. to 01 Oct. 2008, page 1-5.

[9] K. Mazlumi, H. Askarian and others, "Determination of Optimal PMU Placement for Fault-Location Observability," DRPT2008 6-9 April 2008 Nanjing China,page 1938-1942T.

[10] A. G. Phadke and J. S. Throp "Synchronised Phasor Measurement and their application", *Springer, 2008*.

[11] Nuki, R.F. and Phadke, A.G., "Phasor measurement placement techniques for complete and incomplete observability", IEEE Transactions on Power Delivery, Vol. 20, No. 4, October 2005, pp 2381–2388.

[12] Gou, B. and Abur, A., "An improved measurement placement algorithm for network observability", IEEE Transactions on Power Systems, Vol. 16, No. 4, November 2001, pp 819–824.

[13] Abur, A. "Optimal placement of phasor measurements units for state estimation", PSERC Publication 06-58, October 2005.

[14] Phadke, A.G. and Thorp, J.S., "Computer Relaying for Power Systems", Research Studies Press, Somerset, England, 1988.

[15] Thorp, J.S., Phadke, A.G., and Karimi, K.J., "Real-time voltage phasor measurements for static state estimation", IEEE Transactions on PAS, Vol. 104, No. 11, November 1985, pp 3098–3107.

[16] Phadke, A.G., Thorp, J.S., and Karimi, K.J., "State estimation with phasor measurements", IEEE Transactions on PWRS, Vol. 1, No. 1, February 1986, pp 233–241.

[17] Y. Liao, "Fault location utilizing unsynchronized voltage measurements during fault," *Elect. Power Compon. Syst.*, vol. 34, no. 12, pp. 1283–1293, Dec. 2006.

[18] J. J. Grainger and W. D. Stevenson, Power System Analysis , New York, McGraw-Hill, 1994.

Unification of Electric Vehicle with Smart Grid

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Abstract-- **Electrification is a potentially significant route towards decarbonizing road transportation. Economic, security, and environmental pressures are driving countries around the world to electrify transportation. Plug in Electric vehicles (PEVs) could play a central role in minimizing CO_2 emission.**

The Smart Grid will have the infrastructure needed to permit the efficient use of this new generation of PEVs. PEVs can remarkably lessen our dependence on oil, and they emit no air pollutants when running in all-electric modes. However, they do depend on power plants to charge their batteries, and conventional fossil-fueled power plants emit pollution.

To run a PEV as precisely as possible, it needs to be charged in the wee hours of the morning, when power demand is at its lowest. Smart Grid technologies will help to meet this goal by interacting with the PEV to charge it at the most optimal time. PEVs may play an important part in balancing the energy on the grid by serving as distributed sources of stored energy. By drawing on a multitude of batteries plugged into the Smart Grid throughout its service territory, a utility can potentially introduce extra power into the grid during critical peak times, avoiding brownouts and rolling blackouts.

In this paper, Integration of Smart Grid with Plug in Electrical Vehicle will be studied.

Keywords- Smart grid, electric vehicle, renewable energy.

I INTRODUCTION

Due to the rising awareness about the impact of CO_2 emissions along with the combination of technological advances, the electric vehicles (EV) can play an important role in decarbonising road transport. To slow down the changes in climate and to reduce the dependence in fossil fuels, the combustion based engines can be replaced by electric vehicles. Although the electricity demand for the electric vehicle will remain small as compare to overload load, but they could have a much bigger impact on peak loads, as many motorists will seek to charge the vehicles during the evening. Therefore electricity suppliers will need to anticipate the long term investments that will needed to respond to this emerging trend. The possible solution for this is to facilitate the gird integration of EV. The smart grid that uses information and communication technologies for electricity distribution and load management can enable the integration of EVs into electricity load and can lower costs. Smart grid technology that enable the EV charging can shift the load to off peak periods, thus flattening the daily load curve and reducing generation and network investment needs. For this purpose, advanced metering infrastructure is an essential component as it enables two way flow of information between consumers and utilities with real time data. It also facilitates consumers to schedule charging intelligently.

In this paper, firstly a brief introduction of smart grid and electric vehicle is carried out. This paper focuses on the cost-efficient integration of electric vehicles with the grid using different charging strategies and integrated on-board charges. State of art charging mechanisms are not considered appropriate solutions for charging.

EVs as these strategies assume that availability of electricity is same during the entire day. Hence, EVs try to charge immediately when they arrive somewhere, trying to fully recharge their batteries [1]. Several research groups [2-4] have shown that these charging mechanism casus peak load demands such as morning and evening. Therefore there is a need for smart charging. All EVs are equipped with an on board charger [5]. This charger enables vehicle to grid capability. This paper also discusses different approaches for the implementation of chargers in EVs.

II SMART GRID AND ELECTRIC VEHICLE

A smart grid is referred to an electricity network that incorporates variety of information, communication [6] and other advanced technologies that monitors and manages the transport of the electricity from the generating stations to the different end users in real time. Smart grids allows better co ordination of the needs of all operators , end users and utilities as efficiently as possible, minimizing environmental effects and maximizing system reliability, and stability. Now a day's smart grid technologies are at varying levels of maturity, some of the technologies have developed and have been already being deployed, and some are in their development stages. EV charging infrastructure could play an important role in future. It is still in developing stage and it is said to be well suited for the smart grid as they have ample energy storage, geographically dispersed, and are easy access for control signal. The ability to store energy is quite useful for smart grid. When too much energy is being produced it can be stored and can be pulled off the grid and reserved for the later use at peak times. When there is too little energy to meet the required demand the energy can be flow out of the storage onto the grid. The flow of the energy from the storage to the grid maintains the stability of the system by maintaining the system frequency. The smart grid has the infrastructure needed to enable the efficient integration with EVs. EVs can drastically reduce the dependence on oil, and also they don't emit any air pollutants as the run in all electric modes. However they do rely on conventional power plant for their charging which in turn emits pollution.

To run an EV as cleanly as possible, it should charged in wee hours in morning, when the peak load is at its lowest, and wind and solar power are in its peak. Smart grid technologies will help to meet this goal by interacting with the EV to charge it at most optimal time. Further, some sophisticated software will ensure whether the EVs are fully charged or not, in addition to this we'll be able to demand the immediate recharge as and when we'll need it.

In the future, EVs will play an important role in balancing the energy requirement on the grid by serving as distributed sources of stored energy, named as "vehicle to grid". It can inject extra power into the grid during peak times when there is a shortage of power, thus avoiding rolling blackouts and brownouts.

III SMART CHARGING STRATEGIES

The impact that EVs will have on the grid will depend on the number of EVs in vehicle fleet and charging scheme used. The most conventional way to charge an EV is to plug in the vehicle and get it charged like any other load. The charging starts automatically as soon as EV is plugged in. This is known as dumb charging. Whereas in smart charging, the vehicle is charged when the grid allows it or the EV actually need the charging. To make this type of charging possible two types of communications have to be made possible between grid and vehicle. For this purpose advanced metering infrastructure is used. Due to this approach there is an active management system, a hierarchical control structure. As it monitors all the elements connected to the grid and its state [7-8]. This type of control provides the most efficient usage of the available resources. Another way is vehicle to grid concept. It is the most complicated charging scheme and is considered to be the extension of the smart charging. It also allows the energy stored in EVs to be delivered back to the grid for grid support. The smart grid which uses advanced metering infrastructure supports this kind if feature.

Smart charging of the EVs can be implemented to avoid distributed level congestion. EVs can be instructed to avoid charging if there is congestion in the transmission line. Further if vehicle to grid technology is also implemented, EVs can supply energy to the grid as and when needed during grid congestion. Further with the help of smart charging, integration of renewable energy is also facilitated. It can also help in reducing the peak demands. It the demand is high EVs can be instructed to stop charging or can be asked to discharge if vehicle to grid technology is available. Smart charging also avoids the voltage to fall below a specific value by active power control and by reactive power control by reducing the power factor of the charging vehicles at that time.

In addition to controlling the active power charging, it is possible to use the EV battery for reactive power regulation. As we know that the reactive power injected in the transmission lines by the transmitted and distributed generations, causes energy losses and increased system instability. With on-site injection of reactive power from the EV batteries, the amount of reactive power needed to be transmitted is reduced.

IV CHARGER TOPOLOGIES

- *Unidirectional Chargers*

  Two types of power flow are possible between EVs and the grid. In unidirectional flow, the electric vehicle can charge from the grid but they cannot inject the power in the grid. These chargers typically use a diode bridge in conjunction with a filter and dc-dc converter. These converters are implemented in single stage and it also limits weight, cost, losses and volume [15]. It is quite simple to control this kind of charger and hence it is easy for the utility to manage the heavily loaded feeders due to multiple EVs [16].

- *Bidirectional Charger*

  A bidirectional charger has two stages. Firstly an active grid connected bidirectional ac-dc converter that enforces power factor and bidirectional dc-dc converter to regulate the battery current [17-18]. When operating in charging mode, they draw a sinusoidal current with a defined phase angle to control active and reactive power. Whereas in discharge mode the charger should return the sinusoidal current in a similar fashion [18-20]. A bidirectional charger supports charging from the grid, battery energy injection back to the grid, typically known as vehicle to grid concept. Although bidirectional have many advantages but there are many serious challenges for the adoption of this technology [21]. Due to frequent cycling the battery degrades rapidly, metering issues, and cost associated with these chargers should be overcome [22].

- *Off- board Charger*

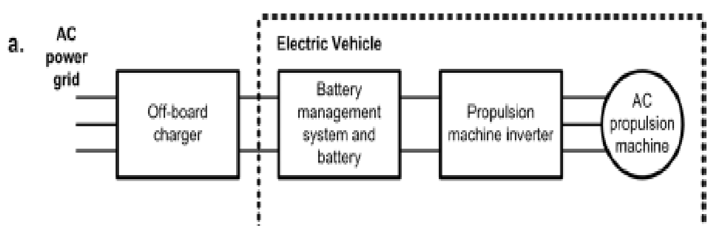
In off board charger the charger is an external unit, rather a component of the EV. It involves redundant power electronics as it produces a high DC voltage. Its associated cost is extra and it has higher risk of damage and also adds clutter in the environment [9]. Figure 1.a shows an off- board charger.

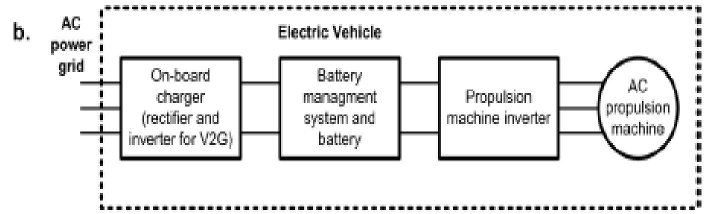
- *On-board Charger*

In this case the charger is the component of the EV and it allows the users to charge the EV wherever a suitable power source is available. These on board chargers limit level of power due to weight, space and cost constraints [10-11]. The drawback of this topology is that it requires an additional AC/DC inverter. One inverter enables the vehicle to grid capability and the other one drives the AC propulsion machine. Figure 1.b shows an on board charger.

- *Integrated On-board Charger*

The concept of integrated on board charger has been proposed to minimize weight, volume, and cost [12-14]. In the integrated charger, the motor drives serves as a bidirectional as-dc converter. Though it has complex control circuitry and extra hardware, it offers low cost and high power bidirectional fast charging with unity power factor. Figure 1.c shows an integrated on board charger topology.





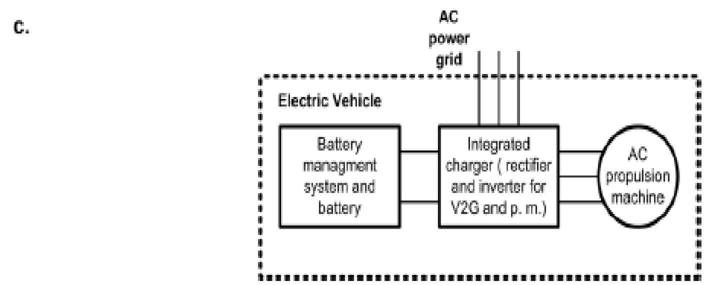


Figure1. Block Diagrams of (a) an off board charger topology, (b) an on board charger topology, and (c) an integrated on board charger topology.

V BENEFITS OF ELECTRIC VEHICLE

1. *Energy Efficiency*

As the number of EVs will increase the need for investment in electricity network capacity and smart grid technologies will increase. Depending upon how the EVs are being used, they can account for a substantial share of total electricity consumption mainly peak loads. With the help of smart grid technologies the electricity utilities will be able to manage load outside the peak hours to schedule charging. This will mitigate the need to build additional power stations and to reinforce the capacity of transmission system to meet a higher peak demand. In doing so it also helps to minimize CO_2 emission from the electricity network.

2. *Stabilization of Grid*

With the concept of vehicle to grid (V2G) connection electricity can be fed back to the grid from the EVs during peak used periods (such as mid afternoon in summers). This concept reduces the need for new power plants, with a tradeoff of life of batteries of the EVs. For this purpose EVs can be charged mostly at night, when there is unused generating capacity [23]. Although V2G is technically possible, but it remains uncertain whether it will prove to be economical or not due to following reasons [24]:

- The availability of potential capacity for V2G supply for a given number of EVs within a region will vary according to the time of day, i.e. available V2G will be lowest during the peak driving times and will be maximum during the night. This implies that the effective capacity of the V2G will lowest when its requirement is highest as peak driving times will coincide with peak periods of electricity.
- As the increase in charge/discharge rate will require significant improvement in battery technologies as the batteries will be used for load following purposes. Further significant amount electricity will be lost in charging and discharging of the EVs. The losses involved in charging an efficient battery from the grid are at least 20%. Returning this energy to the grid by "inverting" the direct current involves losses of about 10%. Therefore the value of V2G supplies should be at least 40% higher than that of grid to vehicle (G2V).
- Although smart grid technology is able to manage V2G supply, it is not able to manage it on a large scale. A large number of EVs that would need to be managed may make it expensive. The complexity will increase if the vehicles are parked away from the home, which will require installing additional metering and billing system.

3. Environmental

According to the Department of Energy (DOE) transportation is the largest emitter of carbon dioxide. Electric vehicles do not release any air pollutants. They also generate less noise pollution as compared to the conventional internal combustion engine vehicle in motion as well as in rest [25]. There are some special kind if electric vehicles that also help the pollution created by the other vehicles [26].

4. Renewable based Electricity Supply

EV batteries could support more deployment of renewable based electricity generating technologies. The storing capacity of EVs can compensate the unpredictable and sudden fluctuations in wind and solar power capacity, by storing excessive energy produced during sunny and windy days. And after that feeding it back to the grid during peak load periods or when the wind and solar power generation is low (V2G). With the help of this concept, the value of power fed into the grid during off-peak periods can be increased.

5. Utility Business Models

EV batteries provide energy independence and security to the utilities. With the growing worldwide competition for the oil created economic risks. So if utilities will have EV battery they will not rely on only conventional source of electricity.

6. Energy Demand Management System

Energy demand management is the modification of the consumer demand for the energy by giving them financial assistance or through changing their behavior through education. It will be able to forecast the demands of EVs and to fulfill them with best quality of service. The following figure shows the concept of energy demand management system used in electric vehicles.

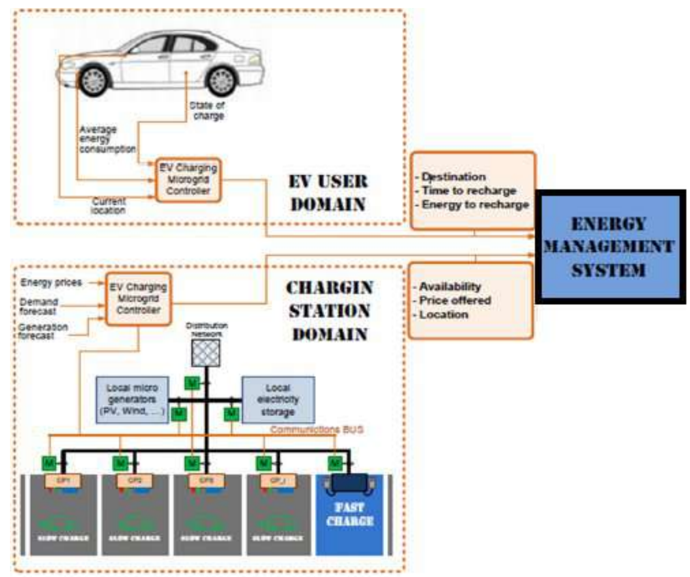


Figure2. Energy Management System used in Electric Vehicle

Its main purpose is to obtain the consumption data based on current and the user profile. Depending upon the current availability and future forecast of energy the demand management module will update the prices of stations in order to influence on users and to prevent jam situations on recharging stations.

Further with coordinate charging plays a vital role in reducing the impact of EVs charging. We can also reduce losses with less computation time and can improve power factor of the electricity supply. Coordinate charging refers to controlled charging.

VI CONCLUSION

Electrification is a potentially main route towards decarbonising road transportation, though it will require huge investments, both in developing such vehicles, the electricity network, and associated charging infrastructure. As the use of electric vehicles will increase, smart grid technologies can be deployed to manage commercial and household load in a better way, using intelligent metering infrastructure and communication networks. Moreover the charging can be scheduled intelligently. In other words the utilities can suggest the consumers to charge the EVs during off peak loads in order to save energy, and cut emissions. Also the storage capacity of the batteries in EVs can be used as a supplementary source of power during peak load periods. The stored energy in EVs can be fed back to grid during afternoon, known as vehicle to grid concept. In this way smart grid and EVs both can be mutually beneficial.

This paper gives a brief introduction of electric vehicle and smart grids. Different smart charging technologies are outlined first. Different charging topologies like unidirectional charger, bidirectional charger, on –board charger, off-board charger and integrated on-board charger are further articulated. Benefits of the electric vehicle are spelled out and the conclusions are presented.

REFERENCES

[1] R. A. Waraich, M. D. Galus, M. Balmer, G. Andersson, K. W.Axhausen, "Plug-in Hybrid Electric Vehicles and Smart Grid: Investigations Based on a Micro-Simulation," http://www.eeh.ee.ethz.ch/uploads/tx_ethpublications/galus_iatbr2009_PHEVs.pdf.
[2] S. Shao, T. Zhang, M. Pipattanasomporn, S. Rahman, "Impact of TOU rates on distribution load shapes in a smart grid with PHEV penetration," IEEE PES Transmission and Distribution Conference and Exposition, April 2010, pp. 1-6.
[3] A. Karnama, V. Knazkins, "Scenario-based investigation of the effects of Plug-in Hybrid Electric Vehicles (PHEVs) in 11 kV substations in Stockholm," 7th International Conference on the European Energy Market (EEM), June 2010.
[4] K. Mets, T. Verschueren, W. Haerick, C. Develder, F. De Turck,"Optimizing smart energy control strategies for plug-in hybrid electric vehicle charging," IEEE/IFIP Network Operations and Management Symposium Workshops (NOMSWksps), April 2010, pp. 293.
[5] H. Makkonen, J. Partanen, P. Silventoinen, "Concept of battery charging and discharging in automotive applications," International Symposium on Power Electronics Electrical Drives Automation and Motion (SPEEDAM), June 2010.
[6] McKinstry, G.; Galloway, S.; Kockar, I., *An initial assessment of the potential impact of smart metering on a decentralized energy network*, Universities Power Engineering Conference (UPEC), 2010 45th International, pp.1,4, Aug. 31 2010-Sept. 3 2010.
[7] J. A. Peças Lopes, C. L. Moreira, A. G. Madureira, "Defining Control Strategies for MicroGrids Islanded Operation", IEEE PWRS - IEEE Transactions on Power Systems, vol.21, no.2, pp.916-924, June 2006.
[8] N. J. Gil, J. A. Peças Lopes, "Hierarchical Frequency Control Scheme for Islanded Multi-Microgrids Operation", Proceedings of IEEE Lausanne Power Tech 2007, Lausanne, Switzerland, July 2007.
[9] S. Lacroix, E. Laboure, and M. Hilairet, "An integrated fast battery charger for electric vehicle," in Proc. IEEE Veh. Power Propulsion Conf., Sep. 2010, pp. 1–6.
[10] S. Haghbin, K. Khan, S. Lundmark, M. Alakula, O. Carlson, M. Leksell, ¨ and O. Wallmark, "Integrated chargers for EV's and PHEV's: Examples and new solutions," in Proc. Int. Conf. Electrical Machines, 2010, pp. 1–6.
[11] M. Grenier, M. H. Aghdam, and T. Thiringer, "Design of on-board charger for plug-in hybrid electric vehicle," in Proc. Power Electronics, Machine and Drives, 2010, pp. 1–6.
[12] S. Lacroix, E. Laboure, and M. Hilairet, "An integrated fast battery charger for electric vehicle," in Proc. IEEE Veh. Power Propulsion Conf., Sep. 2010, pp. 1–6.
[13] L. Solero, "Nonconventional on-board charger for electric vehicle propulsion batteries," IEEE Trans. Veh. Technol., vol. 50, no. 1, pp. 144– 149, Jan. 2001.
[14] L. De-Sousa and B. Bouchez, "Combined electric device for powering and charging," Int. Patent WO 2010/057892 A1, 2010.
[15] B. Singh, B. N. Singh, A. Chandra, K. Al-Haddad, A. Pandey, and D. P. Kothari, "A review of three-phase improved power quality ac–dc converters," IEEE Trans. Ind. Electron., vol. 51, no. 3, pp. 641–660, Jun. 2004.
[16] M. A. Fasugba and P. T. Krein, "Gaining vehicle-to-grid benefits with unidirectional electric and plug-in hybrid vehicle chargers," in Proc. IEEE Veh. Power and Propulsion Conf., Sep. 2011, pp. 1–6.
[17] G. Y. Choe, J. S. Kim, B. K. Lee, C. Y. Won, and T. W. Lee, "A bidirectional battery charger for electric vehicles using photovoltaic PCS systems," in Proc. IEEE Veh. Power Propulsion Conf., Sep. 2010, pp. 1– 6.
[18] J. G. Lozano, M. I. Milanes-Montero, M. A. Guerrero-Mart ´ ´ınez, and E. Romero-Cadaval, "Three-phase bidirectional battery charger for smart electric vehicles," in Proc. Int. Conf.-Workshop Compatibility Power Electron., 2011, pp. 371–376.
[19] H. Chen, X. Wang, and A. Khaligh, "A single stage integrated bidirectional AC/DC and DC/DC converter for plug-in hybrid electric vehicles," in Proc. IEEE Veh. Power Propulsion Conf., Sep. 2011, pp. 1–6.

[20] N. Tan, T. Abe, and H. Akagi, “Design and performance of a bidirectional isolated DC–DC converter for a battery energy storage system,” IEEE Trans. Power Electron., vol. 27, no. 3, pp. 1237–1248, Mar. 2012.
[21] J. Tomic and W. Kempton, “Using fleets of electric-drive vehicles for grid support,” Power Sources, vol. 168, no. 2, pp. 459–468, Jun. 2007.
[22] S. B. Peterson, J. F. Whitacre, and J. Apt, “The economics of using plug-in hybrid electric vehicle battery packs for grid storage,” J. Power Sources, vol. 195, no. 8, pp. 2377–2384, 2010.
[23] First vehicle-to-grid demonstration (By Pacific Gas and Electric Company).
[24] IEA (2011c), *Impact of Smart Grid Technologies on Peak Load to 2050*, IEA/OECD, Paris, France. Available at: http://www.iea.org/publications/free_new_Desc.asp?PUBS_ID=2435.
[25] "Transport: Electric vehicles - European commission". *Ec.europa.eu*. Retrieved2009-09-19.
[26] "SAFA Tempos: Electric Vehicles to Save Pollution(Electric Vehicle in Nepal)". *Paranjaya Paudel. August 4, 2012*. Retrieved December 13, 2014.

Amendments to the Indian Electricity Act – Separation of Carriage and Content / Preparation for Retail Competition

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Abstract:- Before entering into the retail supply of electricity, one has to analyze the targeted area of supply which subsequently affects the targeted consumers and other factors. Supply license is required to be obtained from the appropriate state commission for the desired area of supply.

Tariff charged by the licensee from its consumers shall be determined by market but on the basis of normative cost and standard of performance, the State Commission may fix a ceiling price for the respective category of consumers. Supply licensee is required to sell power not more the ceiling tariff prescribed the appropriate Commission. Adequate arrangement of power would be the foremost priority of the supply licensee for maintaining the reliable and uninterrupted power supply. If the power supply is uninterrupted and reliable this may attract other consumers for availing the supply connection from the supply licensee. Further, In order to survive and beat the competition from other supply licensees, it is required to maintain the power purchase mix in such a manner, the aggregate power purchase cost and other operational costs which falls below the ceiling price approved by the State Commission and other retail competitors. Consumer Satisfaction shall be primary motive of the supply licensee and all the grievances of the consumers related to supply licensee may be resolved in the time bound manner. This will help the supply licensee in making a strong and positive perception amongst the consumers which will help the supply licensee in new consumer acquisition and beat the competition.

Keywords: Electricity amendment act (2014) , Opportunities for supply licensee, Preparation for supply licensee.

Introduction:-

For promoting the competition and efficiency in the electricity distribution system, Government of India has proposed the Amendment in Electricity Act (2014) herein after referred as “the Act”. One of the key features of the Act is the separation of carriage and content. In near future, the Act may be placed for approval before the parliament.

Present scenario of the electricity distribution business comprises of monopoly or monopolistic competition resulting in average level of performance by the distribution licensee leaving no option to consumers for opting services of other efficient distribution licensee.

Proposed amendment in the Act provides for perfect competition in distribution business which promotes the efficiency in performance of distribution licensees. It works on the principle of “survival of the fittest” as the consumers will be having choice for opting supply licensee on the basis of Tariff offered, reliability and quality of power.

Preparation for retail competition by a supply licensee:-

With the changing environment in the electricity distribution system and in order to survive the competition, following preparation may be required by the existing and/or the new business entrants:

- **Selection of Area of supply** – the area of supply subsequently affects the targeted consumer mix and various other factors like distribution loss, technical losses, distribution network etc. There will be universal supply obligation due to which the new connections cannot be denied by any supply licensee to any consumer falling in its area of supply. Hence proper balance of high end and low end consumers in combination with strong and robust distribution network with low distribution and technical loss will be much beneficial for the supply licensee in terms of cash flow and revenue generation.

- **Obtain a Supply license** – after the targeted area of supply has been analyzed, the next step is to apply for a supply license. The supply license may be obtained from the State Electricity Regulatory Commission (SERC’s) after qualifying all the eligibility criteria which may be determined by the respective SERC.

- **Entering the Power Purchase Agreements** – a supply licensee may have to enter in various long term and short term power purchase agreements in order to ensure adequate and reliability of power to its consumers. This shall be the mandatory requirement of the one of the eligibility criteria of the SERC's while obtaining a supply license. In the present scenario the power purchase cost forms part of about 80% to 90% of the Aggregate Revenue Requirement (ARR) of all the distribution licensees.

  The supply licensee shall be very cautious while entering into the Long term Power purchase agreements. The Power Procurement Portfolio of supply licensee shall be designed in such a manner which on one hand ensures the adequate and reliable availability of power to all of its consumers and on the other hand lower the average power purchase cost of the supply licensee.

- **Tariff for the consumer** – Tariff charged by the supply licensee shall be govern by various controllable and uncontrollable factors like the power purchase cost, O&M cost, and other operational cost. However, the State Electricity Regulatory Commission may fix a ceiling tariff beyond which the power could not be offered to the consumers for sale. The power purchase cost shall be treated as uncontrollable cost and would be fully passed on while determining the ceiling tariff but the O&M Cost and other operational cost may be determined on normative basis beyond which it may not be allowed in the ceiling tariff.

- **Cost Efficiency** – Cost efficiency ensures the lower tariff which can only be achieved by lower cost of supply. The cost of supply includes Power Purchase cost, O&M Cost and Other operational cost.

  The power purchase cost can be reduced by arrangement of majority of power from the generating companies offering the low tariff. This may help the supply licensee keeping its power purchase mix.

  O&M Cost includes Employee Expense, Administrative and general (A&G) Expenses and Repairs and Maintenance (R&M expenses). Other Operational cost comprises Depreciation, Interest on loans, ROCE etc.

  However, the O&M cost and other operational costs are approved by SERC on normative basis, but the supply licensee can save its cost by managing its business lower than the cost approved by the SERC on normative basis.

- **Operational Efficiency** - Operational efficiency ensures the quality and reliability of power and also a robust consumer care system for timely resolution of consumer complaints related to various commercial aspects. There may be on flaw as in case the consumer complaint pertain to the wire business utility (carriage business), the consumer may not know where to register complaint whether to go to supply licensee or to go to the wire business utility for resolution of complaints. The supply licensee shall have to guide the consumers for resolution of such cases if possible supply licensee shall have to coordinate with the wire business utility for timely resolution of complaints.

The abovementioned preparation may help the existing supply licensee as well as the new supply licensee to beat the proposed competition in electricity distribution system. Consumer satisfaction shall be the primary motive of the supply licensee and the consumer can only be satisfied by enjoying the Quality and reliable power at a low tariff with timely resolution of their complaints (if any). The supply licensee offering such level of services at low cost would be able to retain its consumers and also attracts the prospective new consumers which make them a market leader.

Benefits of retail competition in electricity Distribution :-

Society may enjoy several benefits of retail competition in electricity distribution sector. Some of them are as follows:-

a) Focused approach on consumer satisfaction.
b) Focused approach on electricity distribution business by Segregation of wheeling and retail business
c) It will promote efficiency among the electricity distribution business.
d) Consumer may have choice in selecting the supply licensee.
e) Investment in the electricity distribution sector may be invited which further contributes in the GDP of India.
f) More employment opportunities may be offered in the electricity distribution sector.
g) Quality and reliable power to consumers.

The Electricity Amendment bill (2014) may be placed for approval in the lok sabha in FY 2016-17 and may be put up for approval in Raj Sabha. After the finalization of the Electricity Amendment bill (2014), it may be implemented in the phased manner. In other developed and some developing countries the separation of carriage and content business was a great success. We hope this may be implemented successfully in India.

References:-

- The Electricity act 2003.
- Proposed Electricity Amendment Act (2014).
- Tariff orders for DERC.
- DERC Supply code and Performance Standards regulations 2007

Smart Grid Initiatives and Experiences in India: Updates and Review

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Abstract- In Indian electricity sector with peculiar characteristics of an energy-deficit, populous and geographically diverse and spread out country, Smart Grid lie solutions for energy poverty and universal energy access .The paper discusses the present Indian power sector scenario and the relevance of smart grid in India. The main objective of this technical paper is to underline the present scenario of those selected Smart Grid pilots in India, including proposed state- of-the-art Technology Integration, Consumer Coverage (Base), and status.

Keywords- Smart Grid, EV, OMS, RE, AMI, MNRE,PLM, PMU, WAM.

I. INDIAN POWER SYSTEM SCENARIO

With the growth of 8 to 10% per year in its power sector, India has become third largest electricity producer and consumer in the world [1] .The country has achieved generation capacity upto 284.303 GW with addition of 37GW of Renewable Energy capacity per year [2]. Peak Demand met as on 31-12-2015 is148.46GW which is 3.2% less than the required demand during the year [1].

Estimated potential energy demand by 2032 will rise up to 900GW out of which renewable energy contribution will be approximately 183 GW[4-5].Targeted increase in Renewable energy is 175GW by 2022[2].

The contributions of various Renewable energy are shown in Table 1 as on 31-12-2015.

TABLE I [1]

SMALL HYDRO POWER	WIND POWER	BIO POWER	SOLAR POWER	TOTAL CAPACITY
41.46GW	24.3 GW	44.18GW	43.46 GW	37.41GW

Fig.1 shows country's total installed capacity and the amount contributed by different energy sources.[1,5]

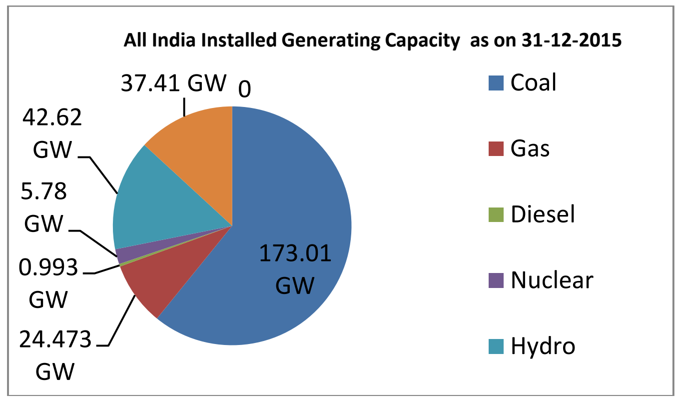

Fig. 1 All India Installed Capacity from different energy sources

Indian Transmission Sector has achieved highest transmission level of 1200kV. 220kV & above Transmission line length achieved is 336460CKM till 31-12-2015[1]. Substation transformation capacity has reached upto 633056MVA.Inter-regional transmission Capacity in MW has reached upto 47450[1].

With such a growing scenario electricity sector is still facing huge demand and supply gap,poor power quality and high AT&C losses.

Distribution sector is the weakest link. Aggregate Technical and Commercial losses (AT&C) losses in the country are about 25.30% [1]. Distribution sector is characterized by inefficiency, low productivity, frequent interruption in supply and poor voltage .

Inspite of launching of various ambitious programmes to provide 24x7 electricity to all of per capita power consumption in the country is 1010 kilowatt-hour (kWh) in 2014-15 [1] which is among the lowest in the world.

One-fourth of the households in the country still have no access to electricity.

Rural part and is facing frequent blackouts. Only 84.9% of Indian villages are having at least an electricity line, out of them only 46 percent of rural households have access to electricity[5] .

The losses due to India's state utilities, over the past five years, were as high as 30%.[4]

About one-third of that loss is technical, but the rest is either given away for free or at subsidized rates to farmers, or lost to pilferage. High technical losses in our country takes place due to overloading, sub transmission and distribution growth without forecasting.

The commercial losses are caused by pilferage, meter tampering, defective meters and errors in meter reading.

II SMART GRID CONCEPT

The twentieth century concept of power flow business model consisted of unidirectional flow of power starting from the generation to consumer end due to limited numbers of generators and energy providers in the market.This structure has changed with restructuring and deregulation around the world, including India. The new Electricity Act (EA), 2003 (with amendments in 2004 and 2007) and downstream policies have brought out a fundamental change in the Indian power sector with the last decade by various outcomes in the form of competition, accountability and private sector participation.Concept of power market and power trading and active participation of consumers created an interactive atmosphere in the power sector. Also, due to distributed energy sources the power flow has become multidirectional . Smart grid concept can bring better load forecasting, load dispatch capability and integration of renewable generation to manage peak demand and supply ratio. Advanced technologies like Distribution Automation(DA),Substation Automation, Advanced Metering Infrastructure (AMI) with two way communication and Meter Data Management System(MDMS),Electronic Billing System and Customer Care Centers will definitely help in increasing proper metering and reduction in energy theft.

Smart grid is an integration of new technologies like SCADA, Outage Management System (OMS), Geographic Information System(GIS),Renewable Energy Integration(RE), Advanced Metering Infrastructure(AMI), Peak Load Management System(PLM) comprising of entire generation ,transmissi on,distribution and consumers. The aim of smart grid is to make existing grid more reliable,robustand efficient by using intelligent devices and IT technologies.

A traditional electric grid with automation and advanced layers of IT and communication technologies can manage the multidirectional flow of power from generation point to end consumer or a step ahead up to appliances and can control the load on real time basis to minimize the demand supply gap.

TABLE II. shows some basic differences between traditional grid and smart grid.

TABLE II

TRADITIONAL GRID	SMART GRID
Electromechanical,Solid State	Fully Digital/Microprocessor Based
One way and local two way communication	Global Integrated two way communication
Centralized Generation	Distributed Generation
Limited monitoring ,protection and control system	Adaptive protection
Blind	Self monitoring
Manual Restoration	Automated Restoration
Check equipment manually	Monitor equipment remotely
Consumers are uninformed and nonparticipative	Motivates & includes the consumer
Minimum Optimization	Optimizes assets and operates efficiently

Increase in the efficiency of power delivery, reduction in power losses with optimal power quality, self healing, smart and active participation of consumer by empowering them to manage their electricity uses and reduction in carbon emission are the main advantages of smart grid.

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TABLE III. contains some basic advantages of smart grid technology.

TABLE III

Benefits of Smart Grid	
To Utilities	To Consumers
Stablized Grid	Improved quality of power supply
Better Peak Load Management	Producer and consumer enabled.
Strong Renewable Integration	Reduced electricity bills
Reduced AT&C Losses	User Friendly Interaction with the utility
Revenue Increment	Opportunities to enter and interact with the electricity marketinto the ne
Better Asset Utilization	Better load management through smart meters.
Self Healing	Opportunitiesto purchase electricity from clean energy sourses.use re
Reduction in capital and operational cost	Reduction in load curtailments

III. BUILDING BLOCKS of SMART GRID TECHNOLOGY

Smart grid technologies consists of set of new technologies spread over from generation to transmission, distribution and upto consumers.
Major intelligent technologies are listed below:

1. Advanced Sensing and Measurement Technologies like PMU's ,Demand Side Management, Remote measurement and Time of Use. Smart Meters ,Intelligent Electronic Device, Fault Pass Indicators.
2. Advanced Metering Infrastructure(AMI)
3. Demand Side Management and Demand Response.
4. Power Quality Management.
5. Outage Management System.
6. Advanced Power Electronics
7. Renewable Integration
8. Micro grid
9. Wide Area Measurements
10. Energy Storage Systems
11. Plug- in Electric Vehicles
12. Integrated Communications Technologies
13. Cyber Security.

IV. FACTORS FOR ADOPTION OF SMART GRID IN INDIA

Electric Grid in the developing countries like India is facing new challenges of providing secure, reliable, quality and sustained energy to all. Optimal use of present bulk power generation in combination with distributed resources are the main challenges.

For different stakeholders like utilities, customers , regulators and government the main driving factors for adoption of smart grid technology are :

1. Reduction in AT&C losses and improvement in system efficiency.
2. Management of supply short fall and Peak Load.
3. Integration of renewable energy into the grid with the concept of green power.
4. Load Forecasting.
5. Customer satisfaction and financially sound utilities .
6. Grid Improvement .
7. Energy Advancement .
8. Managing Human Element .
9. Maintaining Security, Reliability and Resilience of Large Interconnected System .
10. Maintaining Quality of Supply and IT Enabled Services in Distribution Sector .
11. Regulatory Changes in the Electricity Sector .

V. POLICY REFORMS AND SMART GRID INITIATIVES TAKEN BY GOVERNMENT OF INDIA

India Smart Grid Forum and India Smart Grid Task Force launched by the Hon'ble Minister of Power in May, 2010.To accelerate implementation of Smart Grids in India in alignment with the Ministry of Power's overarching policy objectives of "Access, Availability and Affordability of power for all**".**Five Working groups have been constituted to take up the different task related to SMART GRID activities i.e. WG1 – Trials/Pilot on new technologies, WG2 – Loss reduction and theft, data gathering and analysis,WG3 – Power to rural areas and reliability & quality of power to urban areas,WG4 – Dist Generation & renewable,WG5 –Physical cyber security, Standards and Spectrum**.**Ten Working Groups dealing with the following were constituted:

1. Advanced transmission
2. Advanced distribution
3. Communications for Smart Grid
4. Metering including Interoperability standards
5. Consumption & load control
6. Policy and regulations
7. Architecture & design incl. interoperability
8. Pilots and business models
9. Renewables and Microgrids
10. Cyber Security

Launch of the India Smart Grid Knowledge Portal in Jan 2013 [7-8].

Release of the IPv6 Roadmap version 2 on 26th March 2013. Approval of 14 smart grid pilot projects by the India Smart Grid Task Force in 14 States in June 2013..A committee was constituted by Ministry of Power, under Chairperson, CEA to review Functional Specifications of Low Cost Single Phase Smart Meters and its report was released on 12th June 2013.

Launch of Roadmap for the country at the Power Ministers Conclave on Sep 10th 2013 are the major steps taken by GoI.

National Action Plan on Climate Change (NAPCC) has fixed fifteen percent of total generation of the nation from Renewable Sources by 2020.National Mission for Electric Mobility (NMEM) launched by Ministry of Heavy Industries and Public Enterprises (MHIPE), has put a target of around forty million electric vehicles(27 million two-wheelers and 5-13 million four–wheelers) in the country by 2020 [6].

National Smart Grid Mission (NSGM) has been launched by Ministry of Power in May 2015 to promote smart grid development activities in the country. Power Grid Corporation of India Limited (PGCIL) will work as a resource centre for providing support to NSGM.

In June 2015 the Forum of Regulators has approved the Model Smart Grid Regulations (MSGR) to help in acceleration of smart grid initiatives in the country.

Central Electricity Regulatory Commission (CERC) is implementing Renewable Purchase Obligation (RPO) on Distribution Utilities to purchase at least ten percent of their power mix by the year 2015.

Thus in India the smart electric grid network will provide better way to control the technological advancements and electrical infrastructure up gradations on real time basis. Introduction of Electric Vehicle (EV) will again put a burden on the complexity of today's grid.

VI. Smart Grid Technology Implementation steps in Distribution

Following are the major proposed targets and programmes of Government of India (GoI) :

1. Access to uninterrupted electricity to all minimum for 8 hours per day.
2. Hundred percent electrification for all households by 2017.
3. Reduction in AT&C losses upto below 10% by 2017 [10].
4. Roll out of AMI for all customers in a phased manner based on connection size and business scopes for utility by 2017.
5. Formation of National Optical Fiber Network (NOFN), with a target to connect 2,25,000 village panchayats through optical fiber cable.[10]
6. Microgrid, storage technologies, solar photovoltaic to grid (PV2G), building to grid (B2G) technologies are being appreciated to manage peak load demand.
7. Adoption of standard for smart grid.
8. Active participation of experts from different utilities.

Restructured Accelerated Power Development Programme (R-APDRP) in 2008 was launched with the aim of reducing AT&C losses and making the utilities IT enabled. It is divided into two parts: part A and part B.

Under part A installation of meters at distribution transformers and feeders and IT enabled billing system for efficiency improvement are being established.

Work has been completed in 953 out of 1412 towns sanctioned across 31 states of the country under part A [11].

Part B aims to upgradation and strengthening of distribution network.

Work has been completed in 265 out of 1259 towns sectioned across 27 states under part B [11].

R-APDRP is now merged with recently launched Integrated Power Development Scheme (IPDS) in November 2014 to strengthen the sub transmission and distribution network in urban areas [9-10].

IPDS comprises three components:

1. Strengthening of the subtransmission and distribution network in urban and semi-urban areas.
2. Improving metering in urban and semi urban areas.
3. Enabling IT in the distribution segment.

Deendayal Upadhyaya Gram Jyoti Yojana(DDUGJY) aims to undertake regulated power supply to agricultureal consomers and continuous power supply to non agricultural consumer in rural atreas through feeder separation for agricultutral and non agricultural consumers.

DDUGJY consists of three parts:

1. Separation of agricultural and non agricultural feeders.
2. Strengthing and augmentation of sub-transmissin and distribution system in rural areas.
3. Rural Electrification.

Ujwal Discom Assurance Yojana (UDAY) is launched by GoI to make majority of discoms profitable..The major initiatives under this scheme are:

a. Improvement in operational efficiency of Discoms.
b. Reduction in their power cost
c. Reduction in interest cost.
d. Enforcing financial discipline through alignment with state finances.

VII. Smart Grid Technology Initiatives in Transmission

Development of a reliable, secure and resilient grid supported by a strong communication infrastructure that enables greater visibility and control of efficient power flow between all sources of production and consumption by 2027 [3].

1. 11 nos. of High Capacity Power Transmission Corridors (HCPTCs) have been finalized to meet bulk power evacuation requirement of various Independent Power Producers (IPPs) mainly coming up in resource rich and coastal States such as Chhattisgarh, Odisha, Madhya Pradesh, Sikkim, Jharkhand, Tamil Nadu and Andhra Pradesh .
2. About 2,000km long -+800kV, 6000 MW HVDC Bi-pole connecting Biswanath Chariali in Assam to Agra in Uttar Pradesh is under implementation, and shall be amongst the longest such lines in the world.
3. Highest voltage level in the world, 1200 kV UHVAC Single Circuit (S/c) and Double Circuit (D/c) test lines were successfully test charged along with one 1200 kV Bay at 1200kV UHVAC National Test Station at Bina, Madhya Pradesh and field tests are currently undergoing.

4. MNRE and CERC have entrusted POWERGRID identify transmission infrastructure for Renewable capacity addition in 12th Plan. Studies include: – Identification of transmission infrastructure for Renewable Capacity addition in 7 states: Tamil Nadu, Karnataka, A.P, Maharashtra, Gujarat, Himachal Pradesh and Rajasthan – Estimation of capex requirement – Strategy framework for funding and speedy renewable power development .

VIII. Smart Grid Technologies in Transmission Sector

Implementation of Wide Area Measurement System WAMS) is going on through out the country. At the first instance 62 such units have been deployed (Northern: 14, Western: 16, Southern: 12, eastern: 12, & North-Eastern: 08) [3].

Dynamic line rating (DLR) which uses sensors to identify the current carrying capability of a section of network in real time, can optimise utilisation of existing transmission assets, without the risk of causing overloads

High-temperature superconductors (HTS) can significantly reduce transmission losses and enable economical fault-current limiting with higher performance, though there is a debate over the market readiness of the technology.

Implementation of FACT,,STATCOM,SCADA,,Remote Communication,Substation Automation at different transmission and distribution substations are the majoe initiatives towards smart grid implementation in the country.

IX. IS 16444:2015 National Standard for Smart Meters

On the basis of technical specifications and functional requirements published in report by CEA in June 2013,Bearue of Indian Standard (BIS) has released the national standard for Smart Meters, IS 16444:2015, in August 2015.This standard is applicable for a.c. Static Direct Connected Watthour Smart Meter of Class 1 and 2.It specifies requirements of smart meters only.Requirements of DCU,HES,HHU and IHD are not being covered in this standard.

As Smart Meter is a composite unit consists of metrology elements,control,elements,module and two way communications features,it works as measurement and computational unit in addition of controlling,event capturing,storing and communicating entity with HES. Real time data obtained from Smart Meter is useful in various smart grid applications.

Standard IS 15959:2011covres the requirements of Data Exchange from Smart Meter.

The standard is revised in two parts:

1. IS15959(Part 1):2011

'Data Exchange for electricity meter reading ,tariff and load control:Part1 Comparision Specification"

2. IS15959(Part 2):2011

'Data Exchange for lectricity meter reading ,tariff and load control:Part1 Comparision Specification for Smart Meters".

The standard considers smart meter as single unit consisting of metering ,load switching,metering protocol,and communication modules as four different functional zones. On the basis of communication modules used to communicate with DCU or HES the standard proposes two different variants :

1. Variant 1 provides communication connectivity with DCU using NAN module.
2. Variant 2 provides communication connectivity with HES using WAN module.

Standard defines metering,general constructional ,mechanical,electrical ,load switching and communication requirements for smart meters.

Tests for Metrology,Tests for Load Switching,Test for Data Exchange Protocol,Test for smart meter communicability, and smart meter functional requirements like smart meter disconnection mechanism, Reconnection mechanisms and Communications and recording of each tampering data, instantaneous parameters and first power ON and first power OFF detection and communication are also included in the standard to check.

The formation of this most awaited standard is an important step towards the smart grid initiation programme.It will definitely work as a guideline for the meter manufactures and utilities to improve there technology and infrastructure.

Jharkhand Bijali Vitaran Nigam Limited Ranchi has opened tender for procurement of Two Lacs A.C. Single phase Two Wire Smart Energy Meters of class 1.0 with two way communications facilities suitable for Advanced Metering Infrastructure(AMI),Peak Load Management (PLM), and Demand Response.The same board has also opened another tender for procurement of fifteen thousand Three Phase Four Wire Whole Current Static Smart Meters of class 1.0 with with two way communications facilities suitable for Advanced Metering Infrastructure(AMI),Peak Load Management (PLM), and Demand Response.

X. SMART GRID PILOT UPDATES ACROSS INDIA

On the recommendation of India Smart Grid Task Force (ISGTF), Ministry of Power had approved 14 pilot smart grid projects in India in October 2012 [15].

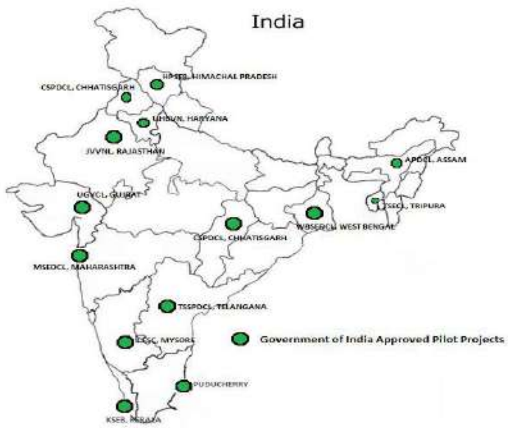

Fig. 2 Smart Grid Pilot Projects Spread All over India

These projects deployed advanced technologies like: AMI for residential, commercial and industrial consumers along with Peak Load Management and Outage Management System. Estimated cost of these projects is around Rs 4 billion, out of which half of the money will be funded by MoP and the remaining amount is to be arranged by the state utilities.Of the 14 projects initiated, only seven are in various stages of execution and three have been cancelled, while there are four in tendering stage. State wise smart grid pilot projects and their current status as upto December 2015 are discussed below [11]:

1. Utility: Assam Power Distribution Company Limited
Project area:Guwahati Distribution Region.Consultant-MEDHAJ
Consumer base:15,000Nos.
Functinalities :AMI R,AMI I,PLM,OMS,PQM,DG.
Project Status:Project awarded to M/s Phoenix IT Solutios Work has been approved and preparation of design and documents has been sent to MoP.Smart meters prototype testing is under progress.

2 Utility:Uttar Gujrat Vij Company Limited Gujrat
Project Area:Naroda of Sabarmati circle and Deesa-II of Palanpur circle. Consultant-GERMI
Consumer Base-39,442Nos.
Functionalities :AMI I,AMI R,OMS,PLM,PQ
Project Status-UGVCL vide letter dtd 5th Nov.2015 stated that scope of pilot area confined to Naroda only.

3 Utility:Uttar Haryana Bijli Vitran Nigam Limited Haryana.
Project area: Panipat City Sub Division.
Consumer Nos.:31,914reviced to 11,000.
Functionalities: AMI I,AMI R,OMS,SCADA/DMS
Project Status:The project is funded by Japan's New Energy and Industrial Technology Development Organization(NEDO).
On December 4,2014 contract of detailed engineering and work implementation was awarded to Japan's Fuji Electric Works.

4. Utility:Himachal Pradesh State Electricity BoardLtd, Himachal Pradesh. Consultant-POWERGRID
Project Area:KalaAmb Industrial Area
Consumer Nos.:1500
Functioalities: AMI I,PLM,OMS,PQM
Project Status: Project awarded to Alstom T&D India for a total cost of 31.41 crores on Feburary 28 2015.Work has been started.
1100 Smart Meters installed,data from 300 meters being monitored.

5. Utility:Chamundeshwari Electricity Supply Corporation Limited, Mysore. Consultant-POWERGRID
Project Area-Additional City Area Division Mysore.
Consumer Base-21,824.
Functionalities:AMI I,AMI R ,PLM,OMS,PQM,DG/MG.
Project Status-On April 30,2014 the project was awarded to a consortium led by Enzen Global Solutions Pvt Ltd.Cyan Technology,UK.
Installation of 500 single phase meters has been completed,14DCU and 81 Modems installed.Softwares in Smart Grid Control Centre also installed SCADA application.

6. Utility:Kerala State Electricity Board,Kerala
Project Area:Restructured to 8 nos. of the R-APDRP towns.
Consumer Base-25,078
Functionalities –AMI I,AMI R,OMS
Project Status-Documentation on retendering is completed.Pre bid meeting was scheduled on 18.12.2015.

7. Utility:Maharashtra State Electricity Distribution Company Limited.
Project Area: Baramati Town
Consumer Base:29,997
Functionalities:AMI I,AMI R,OMS
Project Status:Project has been cancelled.

8. Utility: Electricity Department Of Government Of Puducherry.

Project Area:Division 1 of Puducherry, Consultant-POWERGRID
Consumer Base:34,000
Functinalities:AMI I,AMI R
Project Status:Tender notice issued.Bid(5 nos.) opened on 29.10.2015.

9. Utility : Punjab State Power Corporation Limited Punjab.
Project Area: Industrial Division of City Circle Amritsar. Consultant-POWERGRID
Consumer Base:2734.
Functinalities:AMI I AMI R,PLM
Project Status:Contract awarded to M/s Kalkitech. Site survey and design documents are in progress.

10. Utility:Jaipur Vidhyut Vitaran Nigam Ltd.Rajasthan
Project Area: Vishwakarma Industrial Area Jaipur
Consumer Base:34,752.
Functinalities: AMI I,AMI R,PLM,OMS
Project Status: Regulatory commission’s update is still awaited.

11. Utility: Telangana Southern Power Disturibution Company Limited (Tspdcl)
Project Area:Jeedimetla Industrial Area, Consultant-CPRI
Consumer Base:11,904
Functinalities: AMI I,AMI R,PLM,OMS,PQM
Project Status: Lol was issued to M/s ECIL,Hyderabad on 28.10.2015.

12 Utility: Tripura State Electricity Corporation,Tripura
Project Area:Electrical Division No. 1 of Agartala town
Consultant-POWERGRID
Consumer Base:42,676.
Functinalities: AMI I,AMI R,PLM.
Project Status:Project was awarded to M/s Wipro and the cost is under revision.

13. Utility:West Bengal State Electricity Distribution Company Limited
Project Area: Siliguri Town in Darjeeling District. Consultant-POWERGRID
Consumer Base:5275
Functinalities: AMI I,AMI R,PLM.
Project Status:Contract awarded to M/s Chemtrols Engineering Ltd.in June 2015 and work is expected to begin soon.

14. Utility: CSPDCL Chhattisgarh
Project Area: Siltara-DDU Nagar of Raipur District. Consultant-POWERGRID
Consumer Base:1987
Functinalities: AMI I, PLM.
Project Status: Project is cancelled.

XI. Other Smart GRID Projects in India

1. Smart Grid Testing Laboratory,CPRI Bangalore

Apart from the 14 sectioned smart grid pilot projects Ministry of Power has also approved the “Smart Grid Research Laboratory” project at CPRI Bangalore with the outlay of 11.05 Crores. Purpose behind the establishment of this laboratory is to develop it as a Smart Grid Technology Centre (SGTC) and Interoperability LaboratoryCPRI also providing consultancy in building smart grid systems and testing of subsystems of Smart Grid components. SCADA consultancy services for seven towns of Andhra Pradesh DISCOM,Project Mangement Servisec for Bangalore City DAS project for BESCOM are some important consultancy services provided by CPRI. Other Smart Grid Laboratories are under developmental condition and soon will start working,the main projects are:

- Itron Inc at Noida, has establishedt The Smart Metering Lab and Knowledge Center
- Smart Grid Research Laboratory at Indian Institute of Technology, Jodhpur Rajasthan and Indian Institute of Technology, Guwahati .
- TERI’s Smart Controller Laboratory (SCLab) in New Delhi, India..
- HCL’s Center of Excellence (CoE) Smart Grid Lab in Noida, India.

2. TATA Powers Mumbai, AMI Project

The project consists of deployment of Advanced Metering Infrastructure. The first phase of the project covers 5,000 smart meters. The technology partners of the project are Cyan, L&T and Neosilica. Cyan is providing Wireless technology and Neosilica is providing Meter Data Acquisition System interface from Cyan's Head End Server into Tata's Meter Data Management System for billing and fault management.

3. BESCOM, Bangalore Indiranagar Smart Grid Pilot Project

BESCOM Bangalore is conducting a smart grid pilot project at its Indiranagar area with the consumer coverage of 63,058.Major functionalities used are

Advance Metering Infrastructure; Peak Load Management and Solar Rooftop PV Systems (RTPV).

4. ODISHA SMART GRID PROJECT

Disaster Resilient Power Strengthening System has been announced by Odisha government by using a Smart Grid power network, for the cyclone prone Ganjam district in Orissa. Implementation of latest Power System technologies which can withstand very high-speed cyclones through underground and overground cables and gas insulated sub-stations with full automation and control. Cosumers will be informed about the power cuts through SMS.

5.CHHATRAPUR SMART GRID PILOT PROJECT

Odisha. Government has also taken up a small Smart Grid pilot project covering 5800+ consumers and installing one MW solar power plant .

6. CALCUTTA ELECTRIC SUPPLY CORPORATION LIMITED (CESC)

Under USTDA grant Tetra Tech and ESTA International, Inc are preparing Smart Grid Roadmap for the Calcutta Electric Supply Corporation Limited (CESC). The planned functionalities are is being prepared by under a USTDA grant. SCADA/DMS/EMS The CESC made recommendations for are the functionalites being planned to use.Smart metering, AMI, Improved power qualities,improved communication infrastructures are the majoe technologies planned to implement.

XII. A. PUDDUCHERRY SMART GRID PILOT PROJECT

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 technology implementations in collaboration with 60 service providers [14]. 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 & micro grid.

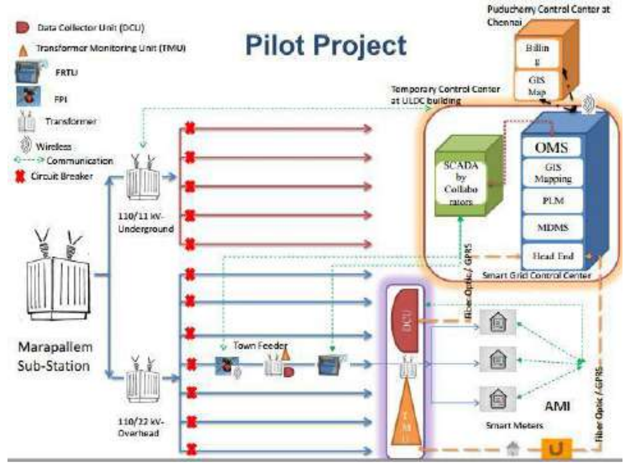

Fig. 3. Pudducherry Smart Grid Pilot Project

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. Up to 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.

XII. B. JEEDIMETLA SMART GRID PILOT PROJECT

Jeedimetla Smart Grid Pilot Project is proposed to implement power management in power distribution sector by using intelligent smart grid technologies.The plan under this project is to deploy about 12000 smart meters among 43000 domestic and industrial consumer contributing in higher power consumption [12-13] . Focus is on HT and LT network automation, strengthening the distribution network and introducing the IT and Communication technologies in distribution. Project Manager designated by TSSPDCL will coordinate all project activities in association with CPRI will lead the Smart Grid effort. Functionalities used in the project include AMI for residential, AMI for Industrial, Peak Management ,Outage Management and Power Quality.

XIII. CONCLUSION

Smart Grid technology needs better electricity delivery infrastructure. Unfortunately in our country still there are several regions without access to electricity or facing frequent electricity outages. Smart grid implementation needs strong computer software and hardware network, sensor and high speed communication technology network and customer supporting services to help them to communicate directly with the utilities. In other word it is a information exchanging network with combination of electrical infrastructure and information technology. Adoption of smart grid technology is helpful in reduction in electricity theft, AT&C losses and improvement in distribution reliability.Integration of renewable energy sourses needs new standards for interconnection. Installation of PMU, interconnection of Energy storage devices, ,HVDC interconnection in transmission has greatly increased the way of making existing grid smart.Apart from all these efforts discussed in the paper still there is a need of strong and dedicated institutional framework to implement the targeted goals as mentioned in India Smart Grid Vision and Roadmap reports.

REFERENCES

[1] Government of India, Central Electricity Authority[Online]. Available:http://www.cea.nic.in/new website/annual reports2015.html.

[2] Ministry of New and Renewable Energy-Physical Progress[Online]. Available:http://www.mnre.gov.in/mission-and-vision-/achivements.html

[3] Government of IndiaMinistry of Power[Online]. Available:http://www.powermin.nic.in/power-sector-glance-all-india.html

[4] Country Statistical Profile,OECDFactbookStatistics:India 2013[Online]. Available:http://dx.doi.org/10.1787/csp-ind-table-2013-1-en..

[5] SheoliPargal and SudeshnaGhoshBanerjee,"More Power to India:The Challenges of Electricity Distribution "World Bank Report,June- 2014.

[6] Government of India,National Electric Mobility MissionPlan 2020,Department of Heavy Industries[Online]. Available:http://dhi.nic.in/writeraddata/content/NEMMP2020.pdf.

[7] "The Smart Grid Vision for India's Power Sector-A White Paper,"PA Consulting Group,March 2010[Online]. Available:http://www.sari-energy.org/Page Files/what_We_Do/activities/smart_grid_vision_for_india_power_sector_june_2010/white_paper-Th_%20Smart_Grid_Vision_for_India/White_Paper_on_the_Smart_Grid_Vision_for_India_final.pdf

[8] Draft Smart Grid Roadmap for India[Online]. Available:http://re.indiaenvironmentportal.org.in/Draft%20Smart%20Grid%20Roadmap%20for%20india.pdf

[9] Power Line Magazine:August,2015 Issue.

[10] Government of India, Ministry of Power,Integrated Power DevelopmenScheme[Online].Available:http://powermin.nic.in/upload/pdf/Integrated_Power_Development_Scheme.pdf.

[11] ISGF Smart Grid Bulletin, Volume 2,Issue 12,December 2015.

[12] Detailed Project Report (DPR) of Jeedimetla, Hyderabad Smart Grid Pilot Project.

[13] Telangana State Sourthern Power Distribution Company Ltd. [ONLINE] https://www.tssouthernpower.com.

[14] Partnership to Advanced Clean Energy – Deployment (PACE-D) http://www.paced.com/wpcontent/uploads/2014/04/Puducherry-Smart-Grid-Pilot-Project-PowerGrid.pdf

[15] India Smart Grid Forum [ONLINE] Available: http://www.indiasmartgrid.com .

BIOGRAPHIES

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Multi Agent Systems in Renewable Hybrid Power System: A Critical Review

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Abstract- **Reform in utility grid for controlling purpose from centralized to decentralize control has been accelerated due to more contribution of renewable energy sources in electric grid. Consequently these changes or modifications generate new and advanced concepts or methods in control system of smart grid. Remedy for these requirements are the multiagent systems. Multiagent systems have ability to tackle disturbances due to penetration of renewable energy sources, ability to run in islanding mode for safe mode operations. Basically multiagent systems are one step ahead from Artificial Intelligence (AI). Here agents are acting as bridge to eliminate gap between men and machines through intellectual interactions. Prime aim of this review is to up-to-date with application of multiagent systems in renewable hybrid power system so that it may appears as reference for basics of multiagent systems architectures with its merits and demerits. Here many aspects related to step by step development of multiagent systems applied in renewable hybrid systems have been considered. They are: system power control, optimization techniques with more emphasis on agent communication, agent platform, service restoration and MAS architectures because agent platform and agent communication mode are the basis for any multiagent system design. Service restoration of power system plays an important role for stable operation also. For simple and easy design of multiagent system decision on proper selection of agent platform and agent communication is very important. This review helps for the same. Many aspects of multiagent systems and its behaviors are compared for providing global perspective of the state of art.**

Keywords: Multi-Agent, Smart Grid, Hybrid Power System, Renewables

I. Introduction:

Incorporation of renewable energy sources in electrical grid in a smart way is known as smart grid, in which carbon free energy sources with modernized grid will interact together via communication and control networks. Main point to the operation and working of any smart grid system is system controller structure which consists of hardware and software protocols for exchanging system status and control signals [1]. Recent trends for controlling and monitoring of any smart grid's operation are moving towards application of automated agent technology usually called multi agent structures. The Multi-Agent system (MAS) theory in distributed artificial intelligence (DAI) provides feasible technical support for modeling and realization of Smart Grid.

Operation of hybrid power system in Smart Grid is a typical Multi-Agent questions solution process, and every section (or segment) in Smart Grid system is equal to an Agent in the process. Every sub-mission or unit equipment in power system could be acted and realized by single Agent or well-organized Agent group, and complete the power distribution tasks together through their interaction and mutual coordination and cooperation. The hybrid power system shall be stimulated as the MAS, which makes the system easier to design, reduces the complexity of the system, intensifies the recombination, expandability and reliability of the system, and improves the flexibility, adaptability and dexterity of the system. Inclusion of artificial intelligence and expert system in multi-agent structure (MAS) are the additional merits in designing of hybrid controllers in the hybrid system [2].

The lack of awareness of MAS leads to poor and in-efficient operation of the hybrid system. Moreover the end user remains ignorant of the usefulness of such an intelligent tool which not only solves the complexity but also saves time by real time operation. The work presented in the paper throw light on the operation, coordination and communication of MAS along with application of MAS in hybrid power system by introducing the audience with its suitability. In the following paper section II deals with the architecture of MAS explaining agents in detail while section III describes the application of MAS in renewable hybrid power system and section IV concluding the work.

II. MAS Architecture

2.1 Agent

An agent is a real or virtual entity able to act on itself and on surrounding world, generally populated by other agents. Its behavior is based on its observation, knowledge and interaction with the world of other agents. An agent has capabilities of perception and partial representation of the environment, can communicate with other agents, can reproduce child agents, and have own objectives and autonomous behavior.

According to Jennings and Wooldridge's [3] ''An agent is a computer system situated in some environment, and that is capable of autonomous action in this environment in order to meet its design objectives.''

We can define an agent as a software system that communicates and cooperates with other software systems to solve a complex problem that is beyond of the capability of each individual software system. An autonomous agent should be able to act without the direct intervention of human beings or other agents, and should have control over its own actions and internal states.

An agent operates in an environment from which it is clearly separated (Figure 1). Hence, an agent (1) makes observations about its environment, (2) has its own knowledge and beliefs about its environment, (3) has preferences regarding the states of the environment, and finally, (4) initiates and executes actions to change the environment. Agents operate typically in environments that are only partly known, observable and predictable.

Autonomous agents have the opportunity and ability to make decisions of their own. Rational agents act in the manner most appropriate for the situation at hand and do the best they can do for themselves. Hence, they maximize their expected utility given their own local goals and knowledge. The most important common properties of computational agents are as follows [4]:

(a) Autonomy/flexibility: an agent should have the ability to operate independently without intervention of any, but with basic control on its actions and decisions.

(b) Reactivity: an agent should have capability of accesses in the environmental changes and react timely.

(c) Pro-activeness: an agent should have initiation for goal oriented execution without being dependent on reaction to inputs.

(d) Social ability: an agent should communicate with human and other agents on the basis of agent communication language.

(e) Collection of data: an agent should have sufficient data through its knowledge about environment. It would assist them for taking decision towards its goals.

(f) Protocols: An agent should have a list of well-defined protocols which suggest proper mode of communication with either other agents or humans which belong to the system.

(g) Continuous learning capacity: An agent should possess continuous learning capacity, i.e., by updating its data collection as per the performance of its commutating component, variation in the environment and position of college agents.

(h) Computational component: An agent should possess at least one computational component which would assist in calculation of required results.

(i) Helping agent: An agent should possess an agent, who provide help, sharing of his location and has capabilities with other agents.

3.2 Multi-agent systems

A multi-agent system (MAS) means a system in which the key abstraction used is that of an agent. It is a loosely coupled network of problem solvers that work together to solve problems that are beyond their individual capabilities. The agents may have only a partial model of their environment and may possess a limited set of means for the acquisition and integration of new knowledge into their models and for pushing the system's state towards their own goals.

Figure 1. The agent and its environment [5]

The knowledge of two agents, referring to the same things, is not necessarily commensurate and may have different representations.

In a community an agent has to coordinate its actions with those of the other agents; i.e., to take the effects of other agents' actions into account when deciding what to do. Coordination requires some regulated flow of information between the agent and its surrounding environment, in other words, communication. Note that in a MAS coordination is possible both by indirect communication via the environment, or by direct information exchange between specific agents. In any case, communication needs some languages with syntax and semantics, at least partially known for each communicating agent [6].

In general, meeting high-level objectives and satisfying system-wide constraints need cooperation in a multi agent system where agents are self-interested and autonomous. The overall operation of MAS is affected by an organization that is imposed on the individual agents.

The basic idea for any multi agent structured system is to break down a complex problem handled by centralized system, i.e., single entity into simple small sub problems taken care by decentralized system, i.e., various entities as shown in Figure 2.

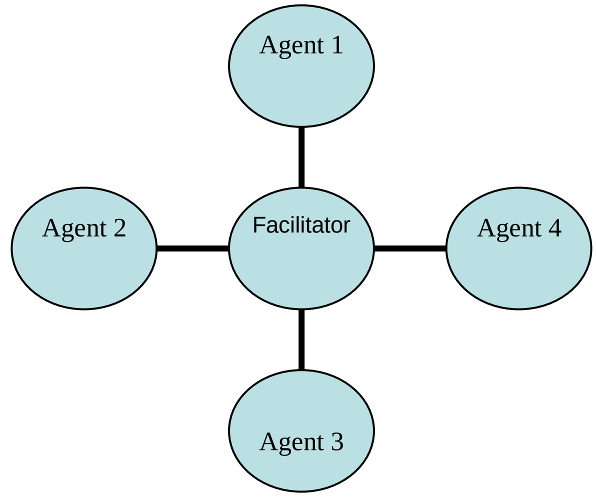

Figure 2. Basic architecture of MAS

III. Applications of MAS in Hybrid Power System

MAS can have applications in microgrid with islanding mode or with standalone hybrid system. It is known that in microgrid central controller can be designed for proper dispatching of power flow from DGs and energy storage systems with multiple time scales; [7-12]. However with the increase in time scale, longer prediction errors from renewable energy generations and more complications in solving optimization problems may occur. Therefore, MAS has been suggested for power dispatch management on the basis of local information and actions and is also suitable for real time controller [13-15].

MAS based techniques are applied to facilitate the smooth microgrid operation by performing central framework agent based modeling and energy management system as in [16] or as in [17] by frequency control to improve stability of the system or as in [18] for integration of microgrid with utility grid.

Here proper power sharing scheme by using MAS for hybrid power sources has been discussed in [19]. Authors in [20] suggested MAS for dispatching of DGs with voltage support on distribution feeder, whereas various aspects of DGs were not taken into consideration. MAS based state flow diagram described the DC voltage control of microgrid in [21] but no discussion on energy management method was held. MAS based

Strategy for switch over of energy storage system among four statuses was explained in [22].

Application of MAS for controlling of small microgrid consists of solar energy source, energy storage banks like batteries and controllable loads were presented in [23]. Authors discussed in [24] MAS technique for Intelligent Distributed Autonomous Power Systems (IDAPS) in which message exchange was compatible with IP based network on the basis of IEEE standard on the Foundation for Intelligent Physical Agent (FIPA). Here MAS capability was seemed as software alternative for traditional hardware based zonal protection while microgrid was on islanding mode. It was also explained that MAS made available flexible path for redefinition of zonal boundary on the fly and has capability to isolate and stabilize microgrid. The authors of [25] proposed an MAS-based algorithm to balance the generation and demand by adjusting the generation of DGs in real time. However, algorithm only targeted the dispatch of DGs according to their capabilities and did not consider the differences in their dynamic responses. Hybrid MAS has been proposed by authors in [26] for renewable energy management system of eco-building unit. For optimization of microgrid operation with optimal production of used DGs, an artificial immune system based algorithm is used with MAS in [27]. Authors in [28] have used ANN based power generation forecast for smart grid energy management with consideration of critical and ordinary load demand.

Nowadays, execution of MAS in power system is more popular as it is compatible for operation in off line as well as on line simulation. A Multi-Agent (MA) has been deployed in [29] within the grid-agent framework for controlling hardware at various locations in Australia. For real time operation of Micro-Grid (MG) using SG Test Bed, authors of [30] have developed simulated model in Real Simulator Computer Aided Design (RSCAD)/real time digital simulator (RTDS) along with MAS developed in JADE platform.

Properties of hybrid MAS based controller are explored by authors in [31] wherein they have capacity of monitoring real time data, intelligence to opt operation model, ability to have self-control optimization of microgrid operation and provide independent local protection.

Authors in [32] describes the decentralized technique of multiagents, distributed and coupled networks of intelligent hardware and software agents that work together to achieve the goal of finding a suitable solution for restoration of the system under study.

Nagata et al. [33–35] have presented multiagents for restoration of distribution systems. Their work does not include load shedding, islanding or the presence of distributed generation.

IV. Conclusion

As the technical community works toward a smart power grid, advanced control strategies and tools provide an excellent platform for new applications. For some applications of renewable hybrid power system it is necessary to develop distributed control algorithms such as multiagent systems. This paper introduced the theory and concepts that make Multi-Agent systems (MAS) well suited for the operation and control of smart grid. Agent interaction, coordination and cooperation was discussed in the context of MAS design architectures. A step-by-step conceptual framework and platforms for building MAS were introduced. The application of MAS in microgrids for market operations, controlling of hybrid system, fault location and service restoration was reviewed.

Reference:

[1]. R. Khare and Y. Kumar, Multiagent structures in hybrid renewable power system: A review, Journal of Renewable and Sustainable Energy 7, 063101 2015

[2]. Y. Shoham and K. Leyton-Brown, Multiagent Systems: Algorithmic, Game-Theoretic, and Logical Foundations (Cambridge University Press, 2008).

[3]. N.R. Jennings, M.J. Wooldridge, Applications of intelligent agents, in: N.R. Jennings, M.J. Wooldridge (Eds.), Agent Technology: Foundations, Applications, and Markets, Springer, 1998, pp. 3–28.

[4]. H. Feroze, “Multi-agent systems in microgrids: Design and implementation,” M.S. thesis, Virginia Polytechnic Institute and State University, 2009

[5].Russel, S., Norvig, P., 1995, Artificial Intelligence: A Modern Approach, Prentice Hall.
[6]. H. S. Nwana, “Software agents: An overview,” Knowl. Eng. Rev. 11(3), 205–244 (1996).
[7]. R. Palma-Behnke, C. Benavides, F. Lanas, B. Severino, L. Reyes, J. Llanos et al., “A microgrid energy management system
based on the rolling horizon strategy,” IEEE Trans. Smart Grid 4(2), 996–1006 (2013).
[8]. Q. Jiang, M. Xue, and G. Geng, “Energy management of microgrid in grid- connected and stand-alone modes,” IEEE Trans. Power Syst. 28(3), 3380–3389 (2013).
[9] S. Y. Derakhshandeh, A. S. Masoum, S. Deilami, M. A. S. Masoum, and M. E. H. Golshan, “Coordination of generation scheduling with PEVs charging in industrial microgrids,” IEEE Trans. Power Syst. 28(3), 3451–3461 (2013).
[10] A. J. del Real, A. Arce, and C. Bordons, “Combined environmental and economic dispatch of smart grids using distributed model predictive control,” Int. J. Electr. Power Energy Syst. 54, 65–76 (2014).
[11]. S. Mohammadi, S. Soleymani, and B. Mozafari, “Scenario-based stochastic operation management of micro grid including wind, photovoltaic, micro-turbine, fuel cell and energy storage devices,” Int. J. Electr. Power Energy Syst. 54, 525–535 (2014).
[12]. J. Zhao, C. Wang, B. Zhao, F. Lin, Q. Zhou, and Y. Wang, “A review of active management for distribution networks: Current status and future development trends,” Electr. Power Compon. Syst. 42(3–4), 280–293 (2014).
[13]. A. Dimeas and N. Hatziargyriou, “Operation of a multiagent system for microgrid control,” IEEE Trans. Power Syst. 20(3), 1447–1455 (2005).
[14]. J. Jimeno, J. Anduaga, J. Oyarzabal, and A. G. de Muro, “Architecture of a microgrid energy management system,” Eur. Trans. Electr. Power 21(2), 1142–1158 (2011).
[15]. B. Ramachandran, S. K. Srivastava, and D. A. Cartes, “Intelligent power management in micro grids with EV penetration,” Expert Syst. Appl. 40(16), 6631–6640 (2013).
[16]. E. Kuznetsova, Y. Li, C. Ruiz, and E. Rio, “An integrated framework of agent-based modelling and robust optimization for microgrid energy management,” Appl. Energy 129, 70–88 (2014).
[17]. Z. Wu and W. Gu, “Active power and frequency control of islanded microgrid based on multi-agent technology,” Electr. Power Automob. Equip. 11, 57–61 (2009).
[18] R. Velik and P. Nicolay, “A cognitive decision agent architecture for optimal energy management of microgrids,” Energy Convers. Manage. 86, 831–847 (2014).
[19]. Z. Jiang, “A multi-agent based power sharing scheme for hybrid power sources,” in Vehicle Power and Propulsion Conference (VPPC), IEEE, 9–12 September 2007, pp. 7, 11.
[20]. M. E. Baran and I. M. El-Markabi, “A multiagent-based dispatching scheme for distributed generators for voltage support on distribution feeders,” IEEE Trans. Power Syst. 22(1), 52–59 (2007).
[21]. J. Lagorse, D. Paire, and A. Miraoui, “Multi-agent system for energy management of distributed power sources,” Renewable Energy 35(1), 174–182 (2010).
[22]. J. Zeng, J. Liu, J. Wang, and H W. Ngan, “A multi-agent solution to energy management in hybrid renewable energy generation system,” Renewable Energy 36(5), 1352–1363 (2011).
[23]. A. Dimeas and N. D. Hatziargyriou, “A multi-agent system for microgrids,” in Proceedings of the IEEE Power Engineering Society General Meeting, Vol. l, pp. 55–58.
[24]. M. Pipattanasomporn, H. Feroze, and S. Rahman, “Multi-agent systems in a distributed smart grid: Design and implementation,” in IEEE/PES Power Systems Conference and Exposition, Seattle, WA, USA, 2009, pp. 1–8.
[25]. A. Kantamneni et al., “Survey of multi-agent systems for microgrid control,” Eng. Appl. Artif. Intell. 45, 192–203 (2015).
[26]. Z. Jun, W. Jie, L. Jun-feng, G. La-mei, and L. Min, “An agent-based approach to renewable energy management in ecobuilding,” IEEE International Conference on Sustainable Energy Technologies (ICSET), 24–27 November 2008, pp. 46, 50.
[27] R. Bhuvaneswari, S. K. Srivastava, C. S. Edrington, D. A. Cartes, and S. Subramanian, “Intelligent agent based auction by economic generation scheduling for microgrid operation,” in Innovative Smart Grid Technologies (ISGT), Gaithersburg, MD, USA, 2010, pp. 1–6.
[28]. L. J. Ricalde, E. Ordonez, M. Gamez, and E. N. Sanchez, “Design of a smart grid management system with renewable energy generation,” in IEEE Symposium on Computational Intelligence Applications in Smart Grid (CIASG), 11–15 April 2011, pp. 1, 4.
[29]. G. James, D. Cohen, R. Dodier, G. Platt, and D. Palmer, “A deployed multi-agent framework for distributed energy applications,” in Proceedings of the Fifth International Joint Conference on Autonomous Agents and Multiagent Systems, ACM, New York, NY, USA, 2006, pp. 676–678.
[30]. F. Ibarra Hernandez, C. A. Canesin, R. Zamora, F. Martina, and A. K. Srivastava, “Energy management and control for islanded microgrid using multi-agents,” in North American Power Symposium (NAPS), 22–24 September 2013, pp. 1, 6.
[31]. X. Zhou, Y. Gu, Y. Ma, L. Cui, and S. Liu, “Hybrid operation control method for micro-grid based on MAS,” in IEEE International Conference on Progress in Informatics and Computing, Shanghai, China, 2010, pp. 72–75.
[32]. Jignesh M. Solankia, Sarika Khushalani Solanki ,Noel Schulz; “Multiagentbased reconfiguration for restoration of distribution systems with distributed generators”, Integrated ComputerAided Engineering 17 (2010) pp 1–16
[33]. T. Nagata, Y. Tao, H. Sasaki and H. Fujita, A MultiAgent approach to Distribution System Restoration, *Proceedings of 2003 IEEE/PES General Meeting*, Toronto, Canada, July 2003.
[34] T. Nagata, Y. Tao, Y. Tahara, T. Aoyama, H. Fujita and M. Koaizawa, Development of Bulk Power System Restoration Simulator by Means of MultiAgent Approach, *Proceedings of 47th IEEE International Midwest Symposium on Circuits and Systems* **2**, 337–340, IEEE 2004.
[35] T. Nagata, H. Nakayama, M. Utatani and H. Sasaki, A MultiAgent Approach to Power System Normal State Operation, *Proceeding of 2002 IEEE/PESGeneralMeeting* **3** (July 2002), 1582–1586, Chicago.

Smart Grid Project Outcomes: MAHATRANSCO Experience and Lessons Learned.

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***Abstract*—** This paper discus in brief various aspects related to SMARTGRID technology development highlighting global trends. It covers major challenges faced by Indian Transmission Utilities while developing smartgrid technologies. The paper further focuses on various technological aspects needing attention to address some of these challenges. It highlights the importance of Communication system adequacy in developing Information and Communication Technologies (ICT) based SMARTGRID technologies with case study on the same. It also presents in brief MAHATRANSCO experience in adopting, implementing and utilisation of some of the SMARTGRID technologies alongwith the lessons learned and tentative proposed way forward for future development of SMARTGRID technologies in Indian context.

Keywords—Smartgrid,WAMS,Renewable energy management system, bandwidth, ICT, Substation Automation.

I. INTRODUCTION

Government of India has launched ambitious developmental programmes like “Make In India”, “Digital India”, “Smart-City Developmental Plan”, “Power to all”, “Start Up India” etc. All these alongwith growing energy demand of the country puts tremendous pressure in developing energy sector infrastructure in Distribution, Transmission, Generation, Renewables, Nuclear etc. Considering this scenario there is a need to adopt smarter technologies to address these challenges faced and to develop the energy sector to further transform developing India into “A Developed India”. Following are some of the important smartgrid technologies those can be adopted to take up these challenges and assist in seamless development of Energy sector and to further boost the economical growth of the country.

a) Wide Area Masurement/Monitoring System (WAMS)
b) Renewable Integration and Renewable Energy Management system
c) Extensive Use of Flexible AC Transmission system
d) Adoption to Dynamic Compensation
e) Adoption to High Tension Low Sag (HTLS) conductor technology
f) Adoption to Dynamic Line Rating (DLRs) technique
g) Utilisation of Energy Storage Systems
h) Utilisation of Automated Fault Analysis System
i) Adoption to UHV technologies
j) Development of Microgrids
k) Smart Metering
l) Development and Utilisation of Off-shore Wind Energy in Indian scenario
m) Development and Adoption of VSC based HVDC systems
n) Development of Smart Asset Management schemes
o) Seamless integration of Electrical Vehicles (EVs) into the grid for grid management in near future.

Any transmission expansion, development and grid management plan in Indian scenario must consider various smartgrid technology options available while proposing it with due relevant studies done in this regard.
This paper discuses in brief some of the challenges faced by MAHATRANSCO while developing some of the SMARTGRID applications alongwith case study for the same.

II. IMPORTANCE OF COMMUNICATION SYSTEM AND SMARTGRID DEVELOPMENT IN INDIAN SCENARIO

New smart grid technologies and concepts, such as Wide Area Monitoring, Protection, and Control (WAMPAC), Dynamic

State Estimation, Dynamic Pricing, Demand Response, Demand Side Management (DSM),Renewable Energy Management System(REMS) etc are expected to require considerable communication resources. Considering the cost of retrofit as well as establishing of new communication infrastructure being costly and time consuming, detail communication system study becomes important aspect before adopting new smartgrid applications requiring data transfer and its usage. Thus future power grids will require the integration of high-speed, secure connections with legacy communication systems, while still providing adequate communication system reliability, control and security.

The state of Maharashtra has the largest power system in State sector in India with a peak demand of over 20,000 MW. Maharashtra State Electricity Transmission Company (MAHATRANSCO/ MSETCL) as a State Transmission Utility has 638 EHV substations with 1,18,450 MVA of transformation capacity and total line length of 45,531 Circuit Kilometers. Current MAHATRANSCO system is having state of the art SCADA system for fetching the substation data to the State Load Despatch Centre (SLDC/LDC). The RTU installed in each substation fetches the digital status and analog measurements and reports it to the SLDC as per IEC 60870-5-104. MAHATRANSCO has established Availability Based Tariff (ABT) metering system for efficient energy accounting purpose in its substations. This meter data from various locations is sent to SLDC. MAHATRANSCO has implemented Enterprise Resource Planning (ERP) system handling data from various sections of organisation like Projects, Operation and Maintenance (O&M), Finance, Human Resource Department (HRD) etc. All these applications alongwith VOIP system has considerable communication requirements. In addition to these above mentioned applications, MAHATRANSCO has started implementing smartgrid technology like Wide Area Measurement Systems (WAMS) [1] in its grid. All these applications depend on communication system for proper data transfer / communication of data from remote sites to central location in proper manner. It also highlights that, co-simulation of communication system and power systems will become more important in days to come as the two systems become more inter-related.

A. *COMMUNICATION SYSTEM ARCHITECTURE IN MAHATRANSCO*

Fig.1 shows communication system architecture in MSETCL. Currently MSETCL uses leased lines as well as optical fibres at selected locations for communication purpose.As shown in fig.1, substation data for the different applications in transmission utility like MAHATRANSCO in Indian context like RTU-SCADA, Availability Based Tariff (ABT) Metering System, Enterprise Resource Planning(ERP) and Voice Over Internet Protocol (VOIP) are connected to local LAN. The LAN switch is connected to MPLS router for communicating with the external world. There are different types of last mile connectivity in use like RF, VSAT and Optic Fibre at different locations in MSETCL. Newer smartgrid application like WAMS also utilizes the same network for data transfer.

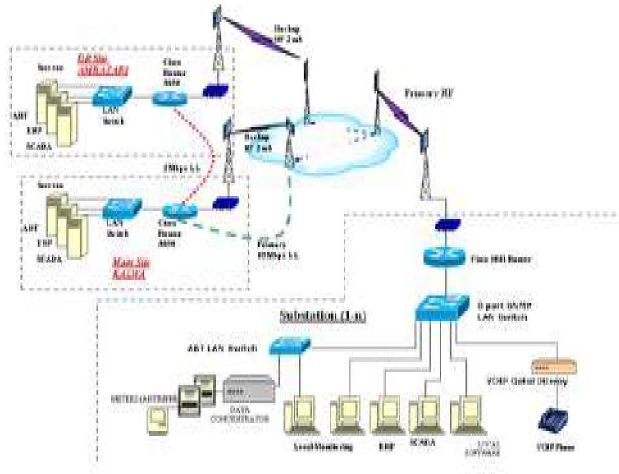

Fig.1: Communication architecture in MSETCL

B. *SMARTGRID APPLICATIONS AND BANDWIDTH ADEQUACY*

Smartgrid developments for its effective utilization depend on proper data receipt and its usage, so it is important to have robust communication system for this purpose. In order to understand bandwidth adequacy while developing smartgrid technology like Wide Area Measurement Systems(WAMS) alongwith existing applications in transmission utility like MAHATRANSCO study was conducted. This subsection describes in brief important aspects of it. Table-I shows the actual parameters considered as per IEEE C37.118 standard for understanding WAMS bandwidth requirement in MSETCL.

TABLE-I: Actual parameters considered as per IEEE C37.118

Item name	
Number of Phasors	6
Number of Analog channels	3
Number of Digital points	7
Communication traffic type (UDP or TCP)	TCP
Number of frames/sec	25
Phasor data type	Float
Df/Dt data type	Float

The PMU configuration considered above is same as the PMU configuration at MSETCL substations. With above configuration, as per IEEE C-37.118 standard total bits/PMU data comes out to be 695. Considering overheads for TCP communication, total bits per overheads comes out to be 560, so total bits/frame becomes 1255 (WAMS data + overheads), so total bit/second comes out to be 31.37 Kbps, thus total bandwidth required for PMU data transfer from substation location to PDC approximately comes out to be 32 kbps. Similarly bandwidth requirement for other existing offline and real time applications in MSETCL was also considered in order to know about total bandwidth requirement for all applications, so that the newly added smartgrid application like WAMS can be developed properly. Eg.: At 400kV Dhule substation in MAHATRANSCO system Supervisory Control and Data Acquisition(SCADA) application requires 414.46 kbps, Availability Base Tariff (ABT) Metering system requires 80kbps,Enterprsie Resource Planning(ERP) requires 824 kbps, Voice Over Internet Protocol (VOIP) requires 80kbps,whereas WAMS requires 32kbps ,thus total bandwidth requirement comes out to be approximately 1438 kbps considering all current applications in MAHATRANSCO.

III. ARCHITECTURE OF WIDE AREA MEASUREMENT SYSTEMS (WAMS) IN MAHATRANSCO

Figure-2 shows architecture of WAMS infrastructure in MAHATRANSCO/MSETCL system. Present MSETCL's Wide Area Measurement Systems (WAMS) infrastructure includes Phasor Measurement Units (PMUs), GPS-Clock and antenna installed at various locations at twelve 400kV and three 220kV level substations. Central Phasor Data Concentrator (PDC), Visualization software and Historian software is installed at State Load Despatch Centre (SLDC) of Maharashtra located at Kalwa.

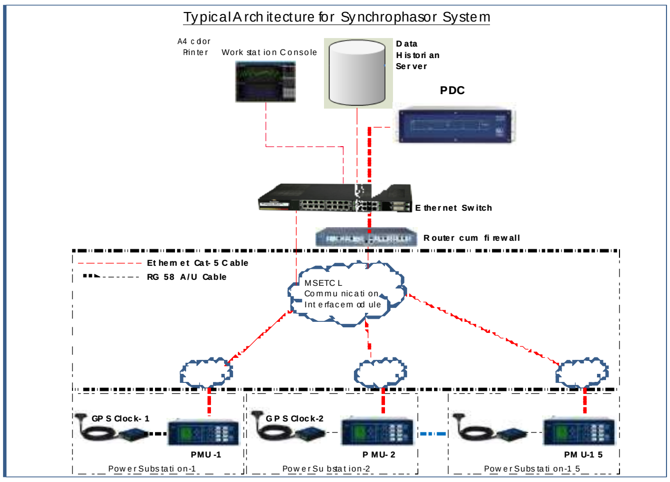

Fig.2: Architecture of WAMS infrastructure in MAHATRANSCO.

The Real time data transfer of parameters like V, I, P, Q, F, DF/DT and Delta is done from PMUs to PDC located at SLDC-Kalwa.

Fig. 3 shows three layer architecture showing how the data flows from physical WAMS infrastructure spread across MAHATRANSCO system in Maharashtra state in India to data storage/ archiving system comprising of Phasor Data Concentrator(PDC),Historian etc and further to application softwares.

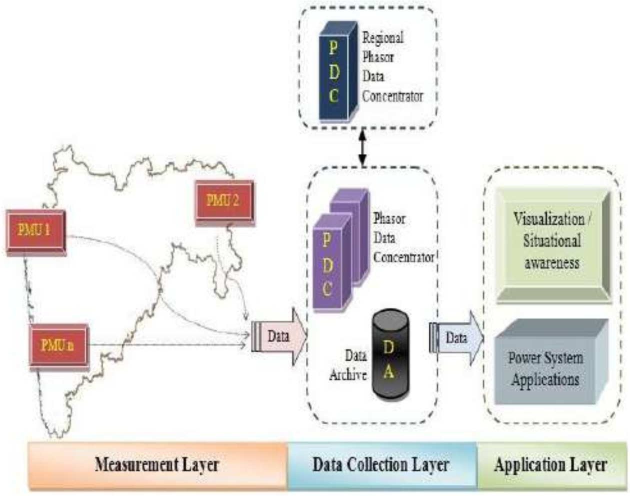

Fig.3 : Three layer Architecture of WAMS infrastructure in MAHATRANSCO.

B. CHALLENGES FACED DURING WAMS DEVELOPMENT IN MAHATRANSCO

Today's power system functioning has become complex and interdisciplinary in nature that requires working in integrated manner with due considerations to telecommunication and Information and Technology (IT).

In initial stages of development of synchrophasor system in MSETCL, various communication system related problems were experienced as follows some of them are discussed below. Fig.4 indicates Communication status of data transfer from 400kV Lonikand substation to central Phasor Data Concentrator (PDC) located at SLDC-Kalwa. Request timed out indicates break in communication from this location.

Fig.5 indicates Communication status of data transfer from 400kV Lonikand substation to central Phasor Data Concentrator (PDC) located at SLDC-Kalwa. Request timed out indicates break in communication from this location. Table-I, indicates typical preview of status of communication healthiness and data transfer from PMUs located at different locations in MSETCL system to central Phasor Data Concentrator (PDC) located at State Load Despatch Centre (SLDC)-Kalwa. Table- I also indicates synchronization status of various PMUs with GPS clock. PMUs found 'OK' indicates PMUs are properly synchronized with GPS clock and data is being sent satisfactorily to central PDC. From the table it can be found out that, 400kV Padghe and 400kV New

Koyana [With PMU ID No. 2 and 5 respectively in Table-I] are the two substations whose status is indicated as 'Not Found'. In this case after analysis it was found that, at 400kV Padghe optical fibre which is a communication media was having problem, resulting in non-transfer of data. Whereas at 400kV New Koyana due to adverse atmospheric conditions communication was affected further resulting in non-transfer of data.

```
Reply from 172.16.29.140: bytes=32 time=54ms TTL=250
Reply from 172.16.29.140: bytes=32 time=17ms TTL=250
Reply from 172.16.29.140: bytes=32 time=11ms TTL=250
Reply from 172.16.29.140: bytes=32 time=54ms TTL=250
Reply from 172.16.29.140: bytes=32 time=30ms TTL=250
Reply from 172.16.29.140: bytes=32 time=26ms TTL=250
Reply from 172.16.29.140: bytes=32 time=485ms TTL=250
Request timed out.
Reply from 172.16.29.140: bytes=32 time=13ms TTL=250
Reply from 172.16.29.140: bytes=32 time=11ms TTL=250
Reply from 172.16.29.140: bytes=32 time=14ms TTL=250
Reply from 172.16.29.140: bytes=32 time=171ms TTL=250
Reply from 172.16.29.140: bytes=32 time=14ms TTL=250
Reply from 172.16.29.140: bytes=32 time=12ms TTL=250
Reply from 172.16.29.140: bytes=32 time=12ms TTL=250
Reply from 172.16.29.140: bytes=32 time=97ms TTL=250
Reply from 172.16.29.140: bytes=32 time=34ms TTL=250
Reply from 172.16.29.140: bytes=32 time=13ms TTL=250
Reply from 172.16.29.140: bytes=32 time=13ms TTL=250
Reply from 172.16.29.140: bytes=32 time=10ms TTL=250
Reply from 172.16.29.140: bytes=32 time=14ms TTL=250
Reply from 172.16.29.140: bytes=32 time=12ms TTL=250
```

Fig.4: Communication status of data transfer from 400kVLonikand substation to central Phasor Data Concentrator (PDC).

TABLE-II: Real time PMU status and PMU synchronisation status in MSETCL synchrophasor system

Real-time Status

Input Connections

Input PMUs

PMU Name	PMU ID	Input Connection	PMU State	PMU Status	Unlock Time
CHANDRAPUR	3	MSETCL	Found	OK	Locked
BOISAR	15	MSETCL	Found	OK	Locked
KALWA	1	MSETCL	Found	OK	Locked
AURANGABAD	9	MSETCL	Found	OK	Locked
EKLAHRE	14	MSETCL	Found	OK	Locked
BHUSAWAL	4	MSETCL	Found	Out Of Sync	Unlocked for 100 s
LAMBOTI	10	MSETCL	Found	Out Of Sync	Unlocked for 100 s
KORADI	7	MSETCL	Found	OK	Locked
DHULE	6	MSETCL	Found	OK	Locked
TROMBAY	13	MSETCL	Found	OK	Locked
KOLHAPUR	8	KOLHAPUR	Found	PMU Error, Out Of Sync	Unlocked for over 1000 s
NEW KOYANA	5	NEW KOYANA	Not Found		
PADGHE	2	PADGHE	Not Found		
LONIKAND	11	LONIKAND	Found	OK	Locked
GIRWALI	12	GIRWALI	Found	OK	Locked

PMUs status 'Out of sync' indicates that, PMUs are not synchronized with GPS clock and data cannot be sent satisfactorily to central PDC in proper synchronised manner.

In case of 400kV Talandage (Kolhapur) [PMU ID No. 8 in Table-I] status is shown as 'PMU error, out of sync'. After carrying out troubleshooting activities at this place it was found that, antenna at this place was having problem which has resulted in error and PMU not in synchronization with GPS, after replacement of faulty antenna with proper one issue was sorted out.

IV. UTILISATION OF WIDE AREA MEASUREMENT SYSTEM IN MAHATRANSCO GRID

This section discusses in brief utilization of Wide area Measurement Systems (WAMS) for analysis of events in the grid. 220kV Uran GTPS is one of the important substation in MAHATRANSCO network attached to Uran Gas Turbine Power plant (GTPS). On 31st October 2015 around 13:55 Hrs. disturbance occurred at 220 kV Uran GTPS. This resulted into tripping of220kV feeders/equipments connected to the 220KV Bus –I & II through bus bar protection. Fig. 5 shows single line diagram of 220kV Uran GTPS GCR alongwith tripped, Non-tripped and under outage elements in the system [2].

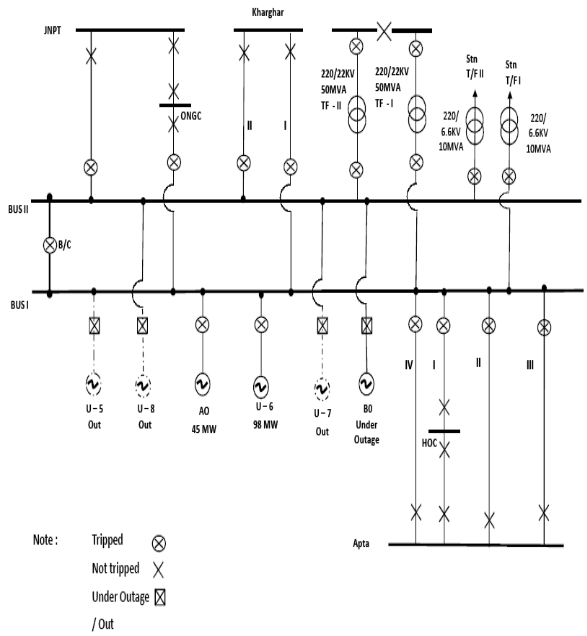

Fig.5: Single Line diagram of 220kV Uran GCR.

Fig.6 shows variations in active power as shown by PMU located at 400 kV Kalwa substation in Maharashtra during this event. Fig.7 shows rise in current as shown by PMU at 400 kV Kalwa substation during this incidence. Fig. 8 shows rate of Change of frequency df/dt during this event as captured by synchrophasor system established in MAHATRANSCO grid. The df/dt plot shows that, event initiation around 13:55:34:920Hrs.

Fig.6: Variations in Active power P at 400kV Kalwa.

Fig.7: Rise in Current at 400kV Kalwa.

Thus this section gives brief information about utilization of WAMS in Indian context for grid monitoring.

Fig.8: df/dt variations as sensed by synchrophasor system

A. *OTHER SMERTGRID PILOT INITIATIVES IN MAHATRANSCO*

I. Remote Operation of Substations in MSETCL

MAHATRANSCO has also taken initiatives in development of other SMARTGRID technologies. It includes substation automation covering remote operation of multiple substations from single location. This includes remote operation of 100kV 100 kV FGIL,100kV BOC and 100kV Taloja substations in MAHATRANSCO system from 220 kV Taloja substation as shown in fig.9.

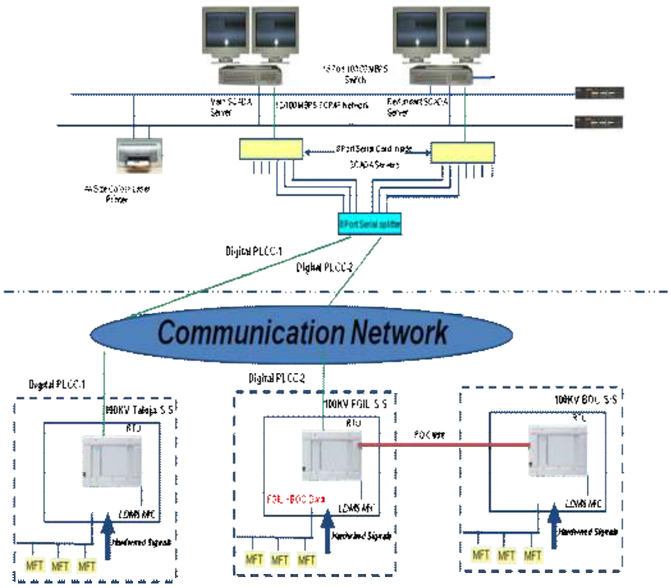

Fig.9: Architecture of Remote operation of substations in MSETCL system.

The major challenge faced by MAHATRANSCO while implementing this Substation Automation project was integrating different make numerical relays with local SCADA system alongwith data transfer related issues. But lateron these challenges were overcome.

MAHATRANSCO has also adopted HTLS technology in some locations. Apart from this, it is planning for development of Renewable energy Management systems (REMS),Automated Fault Analysis System(AFAS),Utilisation of DLR, Adoption of Dynamic Compensation etc in near future.

V. CHALLENGES IN IMPLEMENTING SMARTGRID TECHNOLOGIES IN INDIAN SCENARIO.

As most of the smartgrid technologies are designed and developed in advanced countries considering their needs, there is no tailor-made solution considering Indian power sector requirements, so efforts should be made towards development of the same. Following are some of the important challenges in implementing smartgrid technologies gridwise India.

A) WAMS Implementation

1) Communication challenges in integration of PMUs with PDC.
2) Evolving consensus amongst stakeholders at Central and State level regarding architecture for synchrophasor system implementation and requisite data transfer.
3) Integration of different make PMUs and PDCs.
4) Integration of PMUs with Situational Awareness system
5) Meaningful utilization of synchrophasor data for operation, monitoring of grid in real time. Real time and Offline application development based on this data for use of Indian utilities in cost effective way.
6) Developing closed loop Wide Area Monitoring, Protection and Control (WAMPAC) systems.
7)Synchrophasor data storage, preserving useful data, Cyber-security
8)Integration of WAMS with SCADA and improving state estimation
9) Non-availability of human resource to take up the challenges in implementation of WAMS technology understanding the practical challenges and advancement in upcoming technology.
10)Non-availability of standard test set up for testing synchrophasor technology components in isolated and integrated manner.

B) Development of Renewable Energy Management Systems (REMS)

1) Non-availability of Real time data from renewable sources of energy as expected.
2) Seamless utilization of wheather data and renewable energy data for real time scheduling and dispatch.
3)Lack of requisite infrastructure as desired for communication system to transfer real time data from remotely located renewable sources of energy to central location.
4) Indian utilities are yet to start regularly utilizing wheather forecasting tools for predicting renewable sources of energy in grid operations.
5)Inadequate manufacturing, Design and Development support to meet the requirements of Indian renewable energy sector development.
6)Utilising untapped Off-shore Wind Energy potential in India.

Following important aspects also need immediate attention while developing SMARTGRID technologies in Indian context.

1) Systematic efforts towards Smart Planning and related Studies at Central and State level in coordinated manner.
2) Development of Smart Pricing Mechanism, making it easy for green energy to be more affordable.
3)Effective and efficient regulatory mechanism making it easy for adoption of advanced SMARTGRID technologies.
4)Institutional framework for provision of funds for development of SMARTGRID technologies.
5)Developing manufacturing facilities promoting smartgrid technologies.
6) Development of National and State level groups under the leadership of engineers from Power sector with field experience accommodating engineers from Information and Technology and Communication sector to undertake smartgrid pilots in different areas and further developing these pilots into fully developed projects with adequate funding.
7) Effective utilization of qualified human resource within and outside country towards development of smartgrid technologies.

VI. CONCLUSION

This paper covers various aspects in development of SMARTGRID technologies in Indian context. It presents in brief MAHTRANSCO initiatives in taking up these pilots. It also discusses SMARTGRID technology options and related challenges towards development of these technologies in Indian context.

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References

[1] A. G. Phadke, Synchronized phasor measurements in power systems," IEEE Computer Applications in Power, vol. 6, pp. 10-15.
[2] MAHATRANSCO internal report.