Integrating Smart Distributed Energy Resources with Distribution Management Systems

September 2012

An EPRI Overview on Managing Distributed Energy Resources

Introduction

No portion of the electric power grid has been impacted more by grid modernization (the "smart grid") than the electric distribution system. Grid modernization is transforming distribution operations from mostly manual paper-driven processes to automated computer-assisted decision making and control for distribution system optimization. A central part of this transformation is the Distribution Management System (DMS) which integrates numerous remote monitoring and central control facilities with enterprise level systems to optimize distribution system performance and accomplish a Variety of business goals.

At the same time, technology advancements in solar photovoltaics (PV) and battery storage have driven sharp increases in their employment by utilities, consumers, and third parties. These Distributed Energy Resources (DER) are often connected to the grid at the distribution level, and distribution operational requirements are being greatly impacted by their presence.

Inverters, the power converter circuits (DC-to-AC conversion), that integrate solar PV and battery resources to the grid are highly-capable devices with advanced message processing and fast power control with nearly instantaneous response to received commands and monitored conditions. Over the last few years, industry efforts have defined a wide range of standard grid-supportive functions[1] that inverters may provide and standard communication protocols[2,3] that allow these functions to be remotely managed.

Inverters' power electronic circuit capabilities, if properly exposed and integrated with DMS, can transform high penetration DER from problematic uncertainties to beneficial tools for distribution management. To achieve these potential benefits, DMS must account for the presence of DER in its models and advanced applications. Furthermore, the DMS should take advantage of the advanced DER control capabilities and opportunities for improving the reliability, efficiency, performance and overall quality of service for the electric distribution customers.

In the meantime, the current generation of Distribution Management Systems is not considering support from DER integration. In most cases, DER support within the DMS is limited to monitoring the output of "utility scale" DERs (> one megawatt). In addition, existing industry standards define advanced functions for DER only at the individual device level, and lack the more aggregated, feeder-level representations that are needed for enterprise integration. This white paper describes ongoing research at the Electric Power Research Institute that is exploring Various ways in which the DMS can utilize these distributed resources more effectively and help in accomplishing the 21st century objectives of electric distribution utilities.

Distribution Management Systems

What is a DMS?

A DMS is a decision support system to assist the control room and field operating personnel with the monitoring and control of the electric distribution system in an optimal manner while improving safety and asset protection. Traditionally, electric distribution utilities have relied primarily on manual, paper driven process for electric distribution operations. Managing the electric distribution system was handled in mostly manual fashion with voice communications between responsible parties supported by a collection of independent (standalone) computer systems, communication facilities, and device controllers. DMS is a concept that integrates these mostly independent facilities so that the distribution system can be operated in a well coordinated, highly efficient manner. Figure 1 depicts the DMS "integrated system" concept.

State of the Industry

Distribution grid modernization (the "smart grid") is producing

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This overview was prepared by EPRI

[1] Common Functions for Smart Inverters. EPRI, Palo Alto, CA: 2011. 1023059
[2] DNP3 Profile for Basic Photovoltaic Generation and Storage, AN2011-001, dnp3.org
[3] Advanced Power System Management Functions and Information Exchanges for Inverter-based DER Devices, Modelled in IEC 61850-90-7, International Electrotechnical Commission

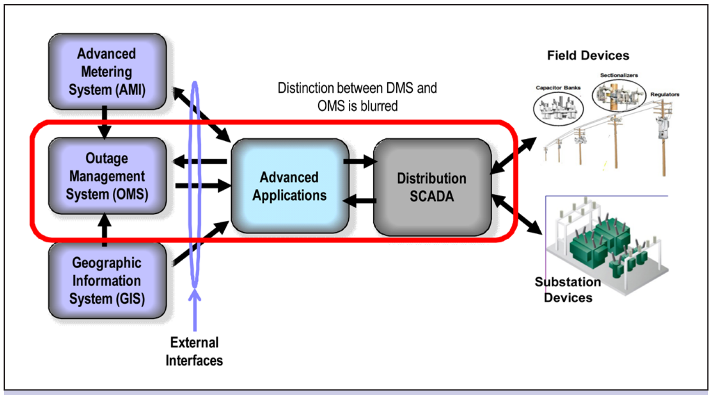

Figure 1: Integrated DMS Concept

considerable growth in the use of the DMS concept. Recent years have seen progress in the development of advanced distribution applications such as Volt-Var Optimization (VVO), implementation of communication systems that provide nearly system wide coverage, and the evolution of enterprise integration standards. In addition, the availability of government funding as part of the Smart Grid Investment Grant (SGIG) program has provided the financial boost needed by some utilities to move forward.

Three years ago, there were fewer than five major DMS projects underway in North America. Now, there are dozens of DMS projects that are currently being planned or implemented by small and large utilities alike. Some of these newer projects are using a "phased" approach in which basic functionality (monitor, display, alarm) are implemented first, followed in a few years by more advanced functionality (VVO, optimal network reconfiguration, etc.).

DMS technology is still at a level of infancy. Many utilities are currently conducting small scale field trials to obtain "proof of concept" for advanced application software for distribution system optimization. Key parts of system integration standards that are deemed necessary for effective enterprise system integration, such as the Common Information Model (CIM), are still being developed and demonstrated. While great progress is being made in bring these advanced systems to fruition, widespread acceptance and development of advanced DMS functionality using standard products and techniques is some years off.

Incorporating DER Capabilities

The number of DERs that are installed on the electric distribution system has greatly increased in recent years. DERs range in size from utility scale generating units (1 megawatt or higher) to small consumer-owned units such as rooftop solar PV with a capacity of only a few kilowatts. The recent growth of DERs is due in part to the interest in reducing greenhouse gas emissions from fossil-fuel fired centralized generation resources. Another reason for increased DER deployment is growing consumer interest in reducing electricity costs and improving the reliability of service. Many customer owned generating units generate more power than is required by the customer at certain times of the day, and excess amounts can then be stored in local batteries or sold to the electricity distributor as an added financial incentive to install such resources.

The presence of high penetrations of such DG units on the distribution system is having a profound effect on electric distribution designs and operating practices that have existed for a century or more. On feeders with very high penetrations of customer-owned generating resources, the potential exists for having more power supply than demand on a given feeder, resulting in reverse power flow that can cause unacceptable voltage profiles and possible overloads along the distribution feeder. In addition, some renewable distributed generation units (solar PV and wind power) have highly Variable power output which can produce voltage fluctuations that reduce the overall quality of power supply on the feeder and, therefore, must be mitigated.

For these reasons, the distribution system operator and the distribution monitoring and control systems used by the operators must be aware of the current operating status of the DERs at all times and must be able to manage the output of these units. This is necessary to enable the operators to maintain quality of power on the circuits at all times, to guarantee the safety of the workforce and general public, and to protect existing utility-owned electrical assets.

At this time, utility capability to control customer-owned distributed generating units is limited to transfer-tripping larger generating plants during critical circuit conditions. However, DERs that are equipped with smart inverters and other intelligent controllers may be able to provide additional functionality, such as volt-Var support, to meet the changing feeder requirements on demand. For the purposes of this white paper, any control function that alters the normal operation of the DER (normal operation is, for example, to achieve maximum power output from generator at all times) is referred to in this paper as "Advanced DER Management".

Further development of DER connection standards (e.g. IEEE 1547) is needed to ensure that such control strategies can be

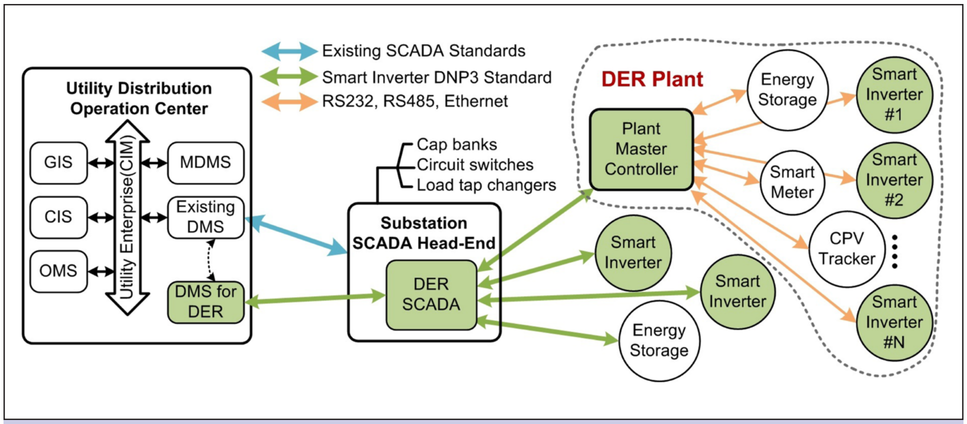

Figure 2: Example DMS-DERMS Architecture

executed without producing unacceptable electrical conditions out on the feeder. Suitable tariffs may also be developed for compensating owners of distributed generating resources for ancillary services (e.g. Var support) they provide. For example, in Germany when distribution system operators "spill" customer owned Variable generation, they still compensate the owners for the curtailments. When these technical and commercial issues are solved, it will be possible to use DERs to optimize the performance of the distribution system under normal and abnormal (emergency) operating conditions. The DMS is expected to interact with a Distributed Energy Resources Management System (DERMS) to be able to use the DERs in the most effective manner. Figure 2 depicts an overall DMS-DERMS architecture.

Defining DMS Functions

While there is considerable Variation in the DMS functionality from utility to utility, virtually all systems that are being implemented today include some or all of the following advanced applications. The function of each application is described and the field devices used by the applications are identified. Where applicable the future role of DERs is identified for each application.

Voltage Profile Management

One of the most fundamental objectives of distribution system management is to maintain the desired voltage profile along the feeder. Electric distribution utilities have used capacitor banks and voltage regulators (including substation transformer load tap changers (LTCs) to maintain acceptable voltage for all customers under all loading conditions.

In the past, distribution feeders exhibited a voltage profile with steadily decreasing voltage level with distance from the substation. The presence of high penetrations of distributed generating sources on the distribution feeders has made voltage profile management considerably more complicated. Reverse power flow caused by high DG contributions (especially during light load conditions) can produce voltage rise with increasing distance from the substation. Such conditions may also disrupt the operation of existing mid-line voltage regulators. The DMS must work in concert with the DERMS to ensure that such abnormal conditions do not reduce the overall quality of service.

Volt-Var Optimization

The objective of the Volt-Var Optimization (VVO) DMS application is to increase overall efficiency, reduce electrical demand, promote energy conservation, and improve power quality while maintaining an acceptable voltage profile.

The VVO application determines appropriate/necessary control actions for switched distribution capacitor banks and voltage regulators located in distribution substations and feeders to accomplish one or more of the utility-specified operating objectives (reduce losses, promote energy conservation, lower demand, etc.). In the future, the DMS VVO function may be able to control the output of DERs to help in achieving VVO objective functions. The following two functions – voltage reduction and power factor correction – are two Variations of the VVO function.

Voltage Reduction

Recently, as electric utilities seek to address energy efficiency and conservation portfolios, many electric distribution utilities are turning to voltage reduction as a way to satisfy energy efficiency, demand reduction, and energy conservation objectives. Voltage reduction involves operating the distribution feeder at a voltage that is in the lower portion of the acceptable voltage range. Electric utility experience, backed by extensive laboratory testing, has shown that many electrical loads, especially electric motors, consume less real and reactive power and perform just as well (or better) when voltage is lowered slightly.

Power Factor Correction

Var control uses fixed and switched capacitor banks to manage reactive power flow in the electric distribution system. The objective of Var control is to maintain power factor (PF) on the distribution system as close to unity as possible to reduce electrical losses and to minimize the flow of reactive power from the central generators over the transmission and transmission networks to the distribution system.

Fault Location Isolation and Service Restoration

When a permanent fault occurs on the distribution system, numerous customers that are connected to "healthy" (non-faulted) sections of the feeder may experience a lengthy outage until repairs are made or switching is performed, as shown in the time line contained in Figure 3. The objective of Fault Location Isolation and Service Restoration (FLISR) DMS function is to restore power to customers served by healthy sections in less than one minute (before field crews arrive on the scene).

For heavily loaded feeders, some service restoration activities may be blocked due to lack of spare capacity on adjacent feeders. In such cases, FLISR may take steps to increase the load transfer capability of load between feeders by triggering demand response capabilities or voltage reduction, using energy storage to supply a portion of the load during such emergencies, and other such measures.

Load Balancing (Optimal Network Reconfiguration)

Usually, distribution systems are designed to be most efficient at peak load demand. Often, the network can be made more efficient

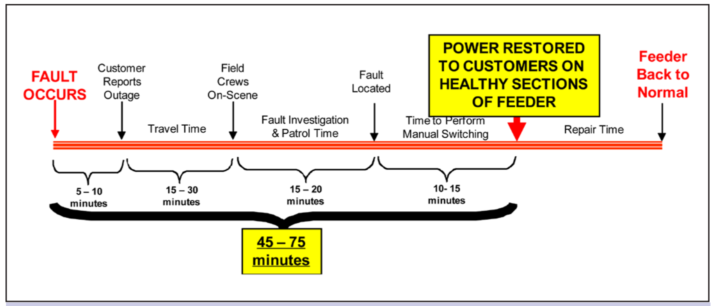

Figure 3: Time Line for Service Restoration (without FLISR)

and/or more reliable by reconfiguring it according to the Variation in load demand. The Circuit Load Balancing application enables the electric distribution utility to determine the best configuration of interconnected feeders to accomplish one or more "objective functions" without violating any of the established distribution feeder operating constraints.

Phase Balancing

Utilities strive to maintain a balanced three-phase distribution system. Unequal voltage levels and/or phase angles will affect three-phase-connected loads such as induction motors resulting in elevated current levels that produce abnormal heating within the motor coils. While utilities try to distribute single-phase loading such as residential and light commercial loads equally between phases, imbalance occurs as these loads switch on and off randomly. In the future, phase balancing capabilities may be enhanced by managing the amount of distributed generator output on each phase on a continual near real time basis to achieve better phase balance.

Contingency Analysis

Contingency Analysis (CA) is a "what if" scenario simulator that evaluates, provides and prioritizes the impacts on an electric power system when problems occur. Contingency analysis evaluates the effects of plausible contingencies, such as equipment overloads or unserved customers. This allows operators to be better prepared to react to outages by using pre-planned recovery scenarios.

Predictive Fault Location

The DMS predictive fault location application uses a short circuit analysis (SCA) program along with fault magnitude, protective relay targets, and other information from substation intelligent electronic devices (IEDs) to assist in locating the fault. The SCA tool identifies the possible range of locations for the fault given the distribution system model, the IED inputs, and utility-specified assumptions about fault impedance.

Emergency Load Shedding

Emergency Load Shedding (ELS) will rapidly reduce the amount of load on the electric distribution system in response to a power system-level emergency, such as the loss of a key generating facility or transmission line. ELS identifies specific large customers with curtailable loads, entire distribution circuits, and even entire distribution to be tripped to accomplish the load shedding requirement, taking into account current loading level and the desired amount of tripping.

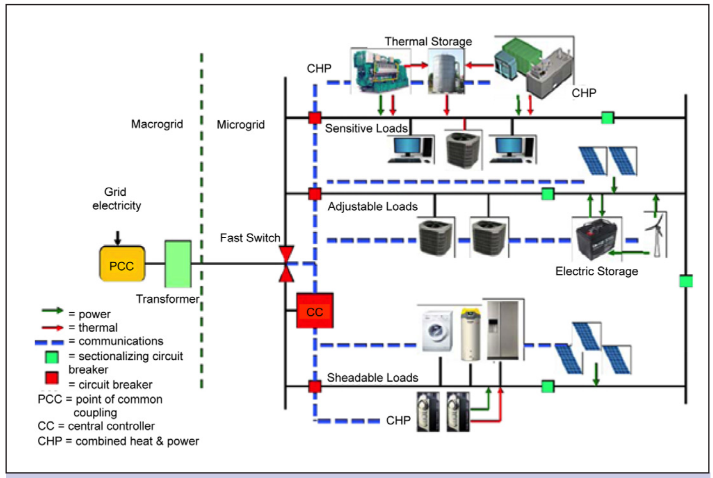

Figure 4: Microgrid Configuration

Switching Order Management

The Switch Order Management (SOM) function assist the dispatcher in preparing and executing switching procedures for Various elements of the power system, including both substation and field devices (outside the substation fence).

Short Term Load Forecasting

The DMS includes a Short Term Load Forecast (STLF) function that is able to predict the load on a specified portion of the distribution system at a given time in the near future (7 to 10 days in the future). This information may be used to plan distribution line work and determine whether such work can be performed during normal working hours (when the load may be high) or during off-peak hours (when it may be necessary to pay workers for overtime hours.).

Management of Voltage Fluctuations

One of the main responsibilities of the distribution system operator (assisted by the DMS) is to maintain acceptable voltage for all customers under all loading conditions. Conventional voltage management functions are not suitable for managing more rapid fluctuations associated with Variable output from solar photovoltaic generating units and wind power units. The smart AC inverters associated with these DERs provide mechanisms such as rapid Var support for dealing with these fluctuations.

Management of Electric Vehicle Charging

The DMS is expected to play a role in management of electric vehicle charging, with the focus on demand management. That is, when the DMS needs to reduce demand on a given substation, feeder, or section of feeder, it may limit the amount of fast charging (Level 2 or above) that is allowed on that substation, feeder, or section of feeder. The DMS may also utilize the energy storage capabilities of electric vehicles via the vehicle-to-grid capabilities of vehicles that are current connected to a charging station. The energy storage capabilities of electric vehicles that are currently parked may be used for peak shaving, load balancing or other reasons.

Microgrid Management

With the growth of Distributed Energy Resources (including energy storage) on the electric distribution system, there is growing interest in supporting "microgrid" operation during system emergencies in which the normal supply to a portion of the distribution system (substation, feeder, section, or group of customers) is disconnected (disrupted). Microgrids use distributed energy resources (distributed generation and energy storage) to power a portion of the distribution system that has become disconnected from the main power grid. The role of the DMS is to monitor the load, voltage, and frequency on the microgrid to ensure that these are within acceptable limits. Figure 4 depicts a microgrid configuration.

The DMS will also work with DERs to ensure that a balance exists between the load and the generating capacity on the microgrid. If the load exceeds the generation amount (including power supplied from energy storage), the DMS may trigger demand response and other load shaving techniques to maintain the necessary balance.

Power Quality Monitoring

Electric distribution feeders are being subjected to higher levels of harmonic currents due to ever-increasing use of solid state electronics in electrical load devices, such as switching power supplies, Variable-speed drives and many types of office equipment. These short term transient conditions, often referred to as power quality issues, include momentary voltage sags and surges and voltage waveform distortions caused by non-linear customer loads.

One result of this trend is excessive internal heating in power distribution transformers that are loaded with harmonic-rich current. Utilities are often forced to derate transformers when they serve highly non-linear, harmonic-rich loads. The DMS monitors total harmonic distortion and other measures of harmonic content in feeder electrical content and determines what the transformer rating should be based on the harmonic content. Smart AC inverters provide a mechanism for mitigating the harmonics that would otherwise cause excessive heating, equipment derating, and possible loss of equipment life.

Manage Power Flow on Feeder

With 100% centralized generation and radial distribution feeders, there is only one possible path over which power can flow over the distribution system from the substation to the customer loads. The only available mechanism to control power flow is to reduce the demand through one of the several available demand reduction techniques (voltage reduction, direct load control, etc.).

With distributed energy resources present on the distribution feeders, the distribution operator is able to control the power flow to a greater extent. For example, it is possible to draw less power from the substation by requesting more output from distributed generators and energy storage devices. It is also possible to specify a limit to the power flow through any metered point by requesting more or less output from DERs.

Power Balancing and Generation Dispatch

As power resources become more distributed, systems more conducive to demand-response, and generation more intermittent, efficient and robust system operation will depend critically on the ability of new dispatch methods to provide a better predictive, forward-looking and holistic view of system conditions and generation patterns. A particular challenge connected with monitoring and controlling the demand-supply balance, when it comes to renewable resources, is that their outputs often do not follow traditional generation/load correlation but have strong dependencies on weather conditions. At the same time, a desire for transparency and market liquidity on the part of regulators and market participants naturally drives systems towards larger trading areas and towards creation of new incentives for end users to consume their energy smartly.

Demand Response/ Peak Shaving

Demand Response (DR)/Peak Shaving refers to mechanisms used to encourage consumers to reduce demand, thereby reducing the peak demand for electricity. Direct load control and demand response programs have been used for peak shaving to avoid the construction of new generating resources to accommodate peak loads that exist for only a short period of time. Much is being done in the Demand Response (DR) community today to leverage the use of demand resources that are located behind-the-meter. Customer-owned generation and storage and controllable loads that can be curtailed or increased upon request can change the load as seen by the utility. And, with the expected capability of new Smart Grid processes and technologies, the ability to create even more sophisticated DR programs should be possible. The DMS may use energy storage and other DERs to enable additional DR/peak shaving activities.

Adding Distributed Energy Resources

Over the past few years, the utility industry has made significant progress in defining common grid-supportive functions for distributed resources such as solar photovoltaics and battery storage, and also in defining the open standard communication protocols needed to connect these devices into utility networks. Figure 5 illustrates a utility enterprise, including a central office application environment (in blue) and field networks and equipment (in green).

Industry activities to create DER standards have thus far focused almost exclusively on the behaviors of individual DER units and the communication protocols over the field networks that connect directly to these devices (reference point 1 in Figure 5). The functional aspects of these standards are described informally in a publically available EPRI report entitled “Common Functions for Smart Inverters”[4], and formally in the IEC TR-61850-90-7. The functions include, for example:

- Intelligent Volt-Var control

[4] Common Functions for Smart Inverters. EPRI, Palo Alto, CA: 2011. 1023059.

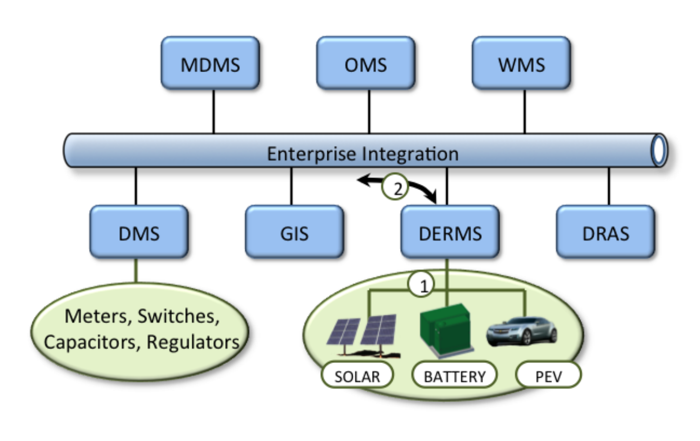

Figure 5: Utility Enterprise Diagram

- Intelligent Volt-Watt control
- Reactive power /power factor
- Low-voltage ride through
- Load & generation following
- Storage systems charge/discharge management
- Connect/disconnect
- Dynamic reactive current injection (responding to changes in voltage dV/dt)
- Max generation limiting
- Intelligent frequency-Watt control
- Peak limiting function for remote points of reference

These standardized functions have been mapped into Various communication protocols, so that it is possible to support the same set of functions in different environments, including:

- Natural support in the IEC MMS protocol due to the information model being established in 61850-90-7
- Support in field SCADA systems using the DNP3 protocol.[5]
- Support in residential home area networks using SEP2.0.[6]
- Support in industrial, plant, and other environments using the ModBUS protocol.[7]

Although these standards focus on the field connection to the individual DER, they were developed with a view toward the present activity - making it possible for many DER, including different types, sizes, and brands, to be managed uniformly and collectively.

In Figure 5, the function of managing the DER devices is shown as an enterprise application called a Distributed Energy Resources Management System, or DERMS. In actual implementations, DERMS functionality may or may not be a dedicated software. Stand alone DERMS products could be developed and deployed, or DERMS functionality could be integrated into DMS, EMS, SCADA, or other applications. Nevertheless, it is beneficial at this early stage of industry consideration to think of a DERMS as a separate logical entity so that the interactions between DER and other utility systems can be identified and supporting information standards developed.

The Need for Standard DERMS Enterprise Functions

Before information and communication standards can be developed to support DERMS integration with DMS and other enterprise applications, the functions that a DERMS presents to the utility enterprise must be identified and could also be standardized (reference point 2 in Figure 5).

To explain what is meant by a "function that a DERMS presents", consider the case of the reactive power generation capabilities of inverters, and the challenge of exposing of these capabilities to a DMS in a useful and manageable way.

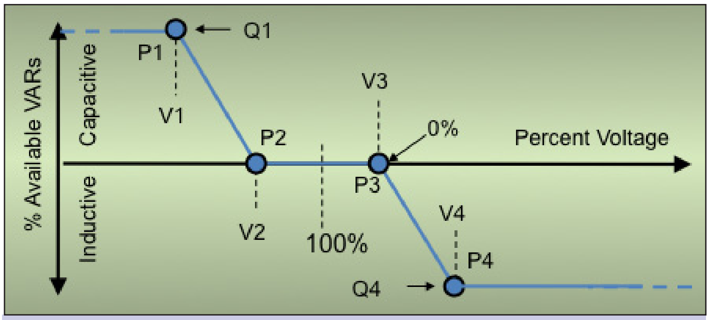

Figure 6: Volt-Var Curve Configuration via Array of Points

[5]DNP3.org, Application Note AN2011-001
[6]ZigBee Alliance, Smart Energy Profile Version 2.0.
[7]SunSpec Alliance, http://www.sunspec.org/specifications/

Per the existing industry standards identified previously, each inverter might be configurable to follow Volt-Var curves. As illustrated in Figure 6, these curves are user-defined in the form of an array of points that define a piece-wise-linear shape.

The curve identifies the level and sign of Var output as a function of the AC voltage observed at the inverter's point of electrical connection. When many DER devices with this capability are connected on a single distribution circuit, the curve settings could be different for each device for a Variety of reasons, such as:

1. It may be more effective to have Var generation at points where the circuit impedance is higher, such as points further from the substation
2. Because of present Watt levels, some DER may have more or less present capacity for Var generation
3. Agreements with DER owners may affect Var availability, maximum Var levels, or cumulative Varh utilization
4. Limitations of local assets, such as transformers or protection equipment may limit Var availability
5. Local voltage Variability (e.g. Variable load induced) may result in different dead-band or hysteresis settings in the Volt Var configuration

If the Volt-Var settings Vary from one DER to another, and a large number of devices are connected to a distribution circuit, then managing overall Var behavior of all DER becomes very complex. If the DERMS application shown in Figure 5 performed no function, then the complexities of managing the many DER would be directly exposed to other applications on the utility enterprise. This is undesirable, and does not result in DER services at the enterprise level that are useful tools to support DMS functions such as those described previously.

Identifying Example Enterprise Functions

The conceptual purpose of a DERMS is to manage many diverse DER, to understand the unique status and capabilities of each, and to present these capabilities to DMS and other applications in a more useful and manageable way. This could mean aggregating the capabilities of individual devices, and transforming their settings and effects so that they become attributes at the circuit, feeder, or segment level. The following sub-sections provide examples of DER-related services that a DERMS could provide.

Identify Installed DER Capability: A function to identify the total capability of installed DER. This could include Watt ratings, Var capabilities, energy storage capability, etc. These capabilities could be provided at the level of a complete distribution circuit, a single feeder, line segment, etc.

Report Present DER Status: A function to report the present activity/state of DER devices. This could report real-time Watt generation, Var generation, battery state of charge and rate of charge/discharge, on/offline status, etc. As possible, these would be aggregated and reported as an attribute of the particular circuit, feeder, line segment, phase, etc.

Provide Forecast/Prediction of DER Opportunity: A function, based on weather, status, historical and other information, by which a DERMS may provide a forecast (minutes, hours, day) of DER output, range of adjustability, Var availability, etc.

Connect / Disconnect DER: A control function by which all DER on a specified part of the distribution system may be disconnected-from or reconnected-to the grid.

Provide Voltage Regulation Support: A control function by which Varying degrees of Var support may be requested on a circuit, feeder, or line-segment basis.

Provide Phase Balancing: A function by which total load may be balanced across the A-B-C phases at a given point of reference.

Coordinate DER with Circuit Reconfigurations: A function by which all DER in an affected circuit section may be informed of a change in the circuit configuration. For example, if a section is switched to an alternative substation, the characteristics of the DER may be modified to work in harmony with the new circuit configuration.

Provide Maximum Capacitive Var Support: A function by which a DERMS provides maximum capacitive Var support for conditions such as transmission system Var contingencies. The maximum capacitive Var level that all DER on a feeder is able to provide may be dependent on many factors, including the voltage at each device, present Watt levels, etc.

Provide Support for Conservation Voltage Reduction Mode: A function by which a DERMS manages the DER on a feeder to optimally support a Voltage Reduction Mode when it is active.

	Standard Functions for Individual Smart Inverters														
DERMS Enterprise Services (Circuit, Feeder, or Segment Level Functions)	Status Monitoring	Event Logging	Nameplate Values	Volt-VAR Curves	Volt-Watt Curves	Reactive Power / PF	Low Voltage Ride Through	Load & Gen Following	Chg/ Disch of Storage	Connect/ Disconnect	Dynamic Reactive Current	Max Generation Limiting	Frequency-Watt Curves	Peak Limiting Function	Circuit Config and Islanding
Identify DER Resources by Circuit/Segment			X												
Retrieve DER Capabilities by Circuit/Segment			X												
Retrieve DER Abnormal Condition Characteristics	X	X													
Retrieve Forecasted DER Capabilities	X	X							X						
Retrieve Present DER Status	X														
Connect/Disconnect DER										X					
Stay Off After Trip															
Limit DER Maximum Generation												X			
Peak Limiting														X	
Provide Requested Var Support				X		X									
Request Future Watt Support									X						
Provide Requested Watt Support					X				X			X	X		
Provide Requested Power Factor						X									
Provide Maximum Capacitive VAR Support				X											
Provide Voltage Regulation Support				X	X						X				
Inform DER of Alternate Circuit Configuration															X
Phase Balancing												X			

Table 1: Example Utilization of Standard Inverter Functions to Provide DERMS Enterprise Services

In order to provide services like these, a DERMS could utilize many existing standard smart inverter functions. Table 1 indicates some examples of how standard smart inverter functions (horizontal axis) might be utilized by a DERMS to produce more aggregated, feeder or segment-level services (vertical axis) that would be useful to a DMS or other enterprise applications.

The actual method that a provider of DERMS functionality might employ to produce a given high-level service would likely be up to the DERMS provider. Industry standards are appropriate and beneficial for the upstream (enterprise) and downstream (DER) interfaces, but the internal behavior of a DERMS is a place for innovation, competition and product differentiation.

Coordinating DERMS with DMS

If a set of useful DER-related services were made available as suggested herein, and exposed using standardized interfaces and protocols, then it would be increasingly practical for a DMS to have capabilities to make use of these services. And not just a DMS and/or a DERMS, but many enterprise applications may be involved. DER-related services may be provided by a GIS, weather system, markets, metering, and other applications. Likewise, DER-related services may be consumed by billing systems, forecasting systems, work management systems, and others.

The specific ways in which a DMS might utilize DER capabilities to support distribution management is best left to DMS providers and utilities to determine. It is their domain of expertise, and need not be standardized as long as there are supporting standards for the functions and information at the interfaces between applications.

Given the broad range of functions that a DMS may perform, and the broad set of DER-related services that could be provided, there

Example DMS Functions	Example DERMS Enterprise Services: Identify DER Resources	Retrieve DER Capabilities	Retrieve DER Abnormal Conditions	Retrieve Forecasted DER Capabilities	Retrieve Present DER Status	Connect/Disconnect DER	If Trip Stay Off	Limit DER Maximum Generation	Peak Limiting	Provide Requested Var Support	Request Future Watt Support	Provide Requested Watt Support	Provide Requested Power Factor	Provide Maximum Var Support	Provide Voltage Regulation Support	Inform DER of Alt Ckt Config	Phase Balancing
Maintain Voltage Profile	X	X						X							X		
Voltage Reduction	X	X													X		
Volt-Var Optimization	X	X			X					X		X	X				
Power factor correction	X	X								X			X				
Fault Location Isolation and Restoration	X	X			X					X		X			X	X	
Load balancing (optimal network reconfiguration)	X	X			X					X		X				X	
Phase Balancing	X	X															X
Maintain V & F of Microgrids	X	X								X		X	X		X	X	X
Contingency Analysis	X	X		X	X												
Predictive Fault Location	X	X															
DER Dispatch								X									
Emergency Load shedding												X					
Switching Order Management				X		X	X										
Short Term Load Forecasting				X													
Hot Line Tagging							X										
Management of EV Smart Charging				X							X	X					
Management of V2G Capabilities				X							X	X					
Demand response/ peak shaving									X								

Table 2: Example Utilization of DERMS Enterprise Services to Support DMS

are an essentially unlimited number of ways that a DMS might leverage DER-related services. Table 2 continues the example started in the previous section, providing example mappings of DER services on into DMS utilization. In the following section, a couple of more detailed examples are provided.

Enterprise Integration Standards

Interoperability of systems requires open standards. In the areas discussed in this document, those standards include both functional behaviors (i.e. standardizing the DER-related use cases and services on the enterprise) and the communication standards (information models) needed to support these functions.

Communication standards in the enterprise integration environment include the IEC 61968/61970 CIM and MultiSpeak and are different from standards that cover field network protocols (e.g. IEC 681850, DNP3) both in terms of design and purpose. As research continues in the DER/DMS area, EPRI intends to contribute and coordinate it with the CIM and MultiSpeak standards development groups, and with the NIST groups that are helping to coordinate overall activities, with the vision of making standards-based end-to-end DER integration possible.

Examples Aligning DER Services with Advanced Distribution Controls

Volt-Var Optimization with Smart DER

Numerous electric distribution utilities have implemented or are planning to implement an advanced Volt-Var Control and

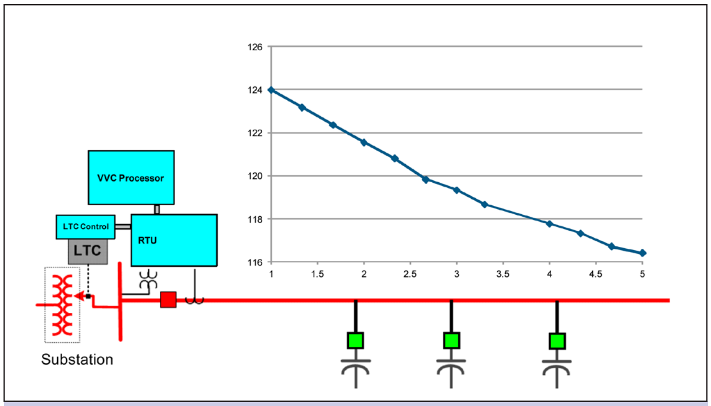

Figure 7(a): Original voltage profile

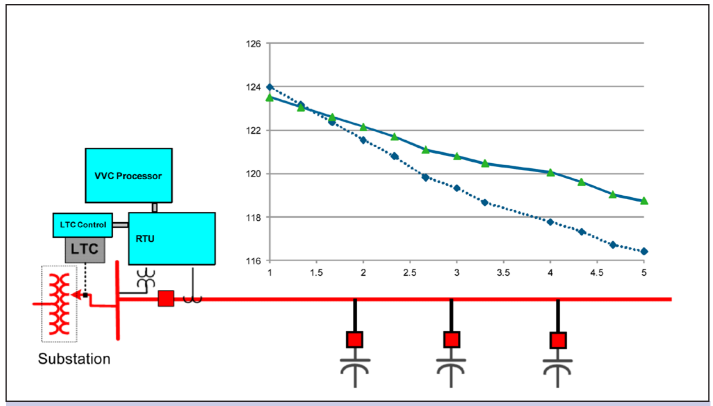

Figure 7(b): Capacitor Switching

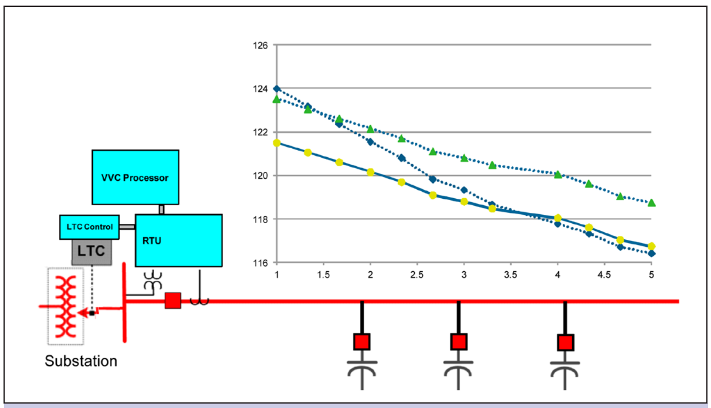

Figure 7(c): Volt regulator Operation

Figure 7: Conventional VVO

Optimization (VVO) function as part of their DMS to improve voltage profiles and increase overall efficiency of the electric distribution system. Recent DMS implementations of VVO utilize switched capacitor banks and voltage regulators (including LTCs) to accomplish the VVO application. Additional benefits beyond what can be achieved using these conventional devices are possible by using the smart inverter functions. This improved version of VVO could be referred to as “DER Enhanced” VVO.

Conventional VVO is accomplished by performing two main steps:

1. Use switched capacitor banks to “flatten” the voltage profile
2. Use voltage regulators to lower the voltage as much as possible

Figure 7(a) shows the feeder voltage profile before performing any VVO control actions. The voltage at the substation end of the

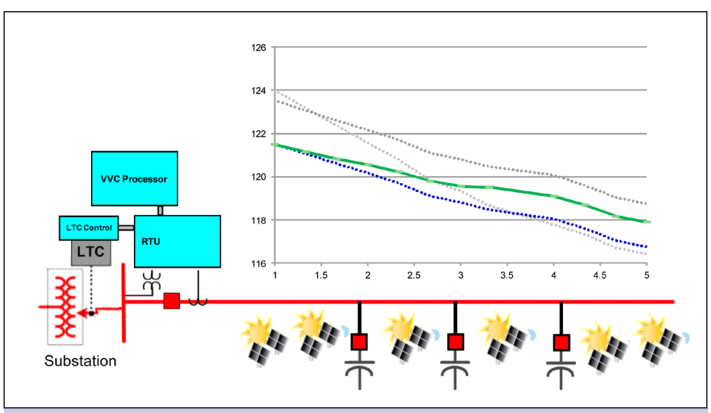

Figure 7(d): Smart inverter Impact on voltage

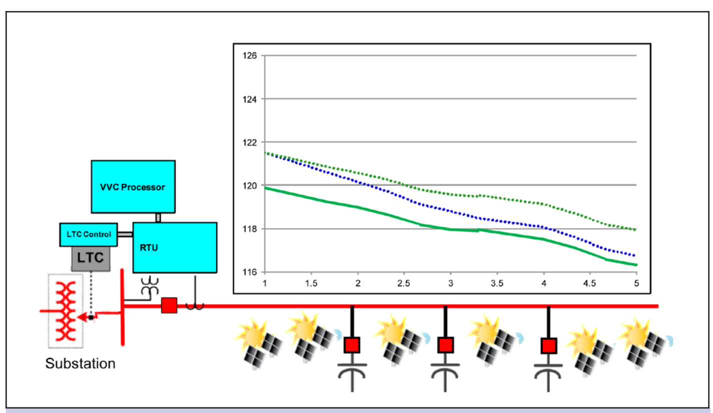

Figure 7(e): Final voltage reduction

feeder is at the upper end of the acceptable voltage range, while the voltage at the end of the feeder is near the low limit, thus preventing any voltage reduction. Figure 7(b) shows the effect of performing step 1 of VVO which has the effect of raising the minimum voltage on the feeder and "flattening" the voltage profile. This enables VVO to perform step 2, which uses voltage regulators to lower the feeder voltage, thus accomplishing the overall VVO objective.

DER Enhanced VVO uses the Volt-Var function of smart inverters to elevate the voltage level (flatten the voltage profile) more than conventional capacitor banks. This enables the voltage regulator(s) to lower the voltage along the feeder even more, resulting in lower average voltage for all customers, and improved overall efficiency. Figure 7(d and e) depict the DER-Enhanced VVO results.

Fault Location, Isolation, and Service Restoration (FLISR) with DER

For heavily loaded feeders, some service restoration activities may be blocked due to lack of spare capacity on adjacent feeders. One solution is to install additional automated switches that are able to split the feeder into smaller parts that can be transferred between heavily load feeders. Another solution is to provide more ties to adjacent feeders and thereby split the load transfer between several backup sources. Both of these approaches are expensive solutions.

Another possible solution is to trigger demand response capabilities or use DERs (energy storage, distributed generators, etc) to supply a portion of the load during such emergencies, thus reducing the amount of load that must be transferred following the fault. Figure 8 depicts this proposed solution.

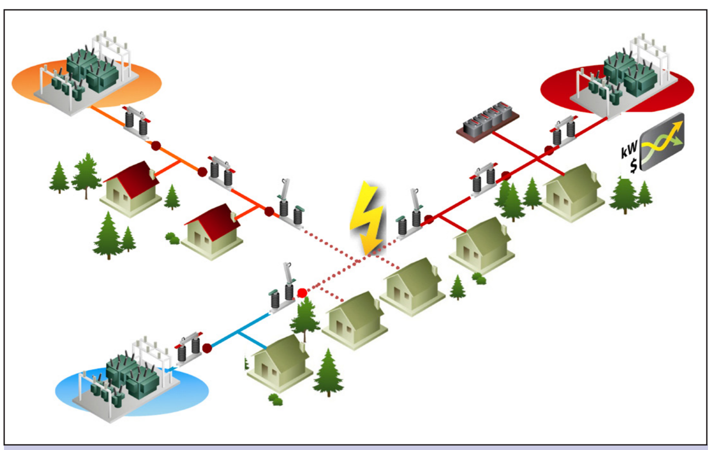

Figure 8: Using DERs for Enhanced FLISR

Conclusions & Recommendations

Distributed Energy Resources of Various types are becoming increasingly common in utility distribution systems. Technology improvements continue to add new capabilities and drive down cost, raising the likelihood that higher penetrations of these devices will come. Fortunately, the present DER penetration levels are low in most circuits, and the utility industry has time and opportunity to develop a framework of standards for multi-vendor interoperability to guide the arrival of these devices and their integration. A proactive approach is much preferred, rather than waiting until penetrations are high, and reacting to the cost and maintenance complexity associated with incompatible devices and applications.

The collaborative work performed by the power industry over the last few years in the area of smart inverter standards and field network protocols was a good first step toward preparing for higher penetration of distributed energy resources. But standards do not yet exist to support the enterprise integration of these device capabilities in a useful and manageable way.

EPRI is launching a new collaborative activity specifically to address the need for enterprise integration of distributed energy resources. The activity is being coordinated with the Department of Energy, through the DOE SunShot Smart Inverter initiative, and with the National Institute of Standards and Technology (NIST), through the Smart Grid Interoperability Panel's (SGIP) Distributed Renewables, Generators, and Storage Domain Expert Working Group. The activity includes a face-to-face workshop that brings together a group of utility distribution management experts, DMS software, and DER specialists, to identify a starting list (core set) of practical, useful, DER / DMS interactions. The output from this workshop will provide the industry with an initial point of reference for DER integration and will provide guidance to ongoing research and standards development organizations. Those interested in participating in this activity may contact EPRI by email at askepri@epri.com.

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Integration of Distributed Renewables

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