ANL/ESD-15/16

Foundational Report Series: Advanced Distribution Management Systems for Grid Modernization

Importance of DMS for Distribution Grid Modernization

Energy Systems Division

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Foundational Report Series: Advanced Distribution Management Systems for Grid Modernization

Importance of DMS for Distribution Grid Modernization

by
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FOUNDATIONAL REPORT SERIES

DISTRIBUTION MANAGEMENT SYSTEMS FOR GRID MODERNIZATION

This is one of seven reports on distribution management systems (DMS), their functions, implementation, and importance for grid modernization.

The reports on DMS in this numbered series of Argonne reports are as follows:

1. Importance of DMS for Distribution Grid Modernization (ANL/ESD-15/16)
2. DMS Functions (To Be Published)
3. High-Level Use Cases for DMS (To Be Published)
4. Business Case Calculations for DMS (To Be Published)
5. Implementation Strategy for DMS (To Be Published)
6. DMS Integration of Microgrids and DER (To Be Published)
7. DMS Industry Survey (To Be Published)

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LIST OF ACRONYMS AND ABBREVIATIONS

DER	Distributed Energy Resources
DG	Distributed Generation
DMS	Distributed Management System(s)
DR	Demand Response
EV	Electric Vehicle
FLISR	Fault Location Isolation and Service Restoration
PV	Photovoltaic
VVO	Volt-VAR Optimization

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IMPORTANCE OF DMS FOR DISTRIBUTION GRID MODERNIZATION

Grid modernization is transforming the operation and management of electric distribution systems from manual, paper-driven business processes to electronic, computer-assisted decision-making. At the center of this business transformation is the distribution management system (DMS), which provides a foundation from which optimal levels of performance can be achieved in an increasingly complex business and operating environment.

Electric distribution utilities are facing many new challenges that are dramatically increasing the complexity of operating and managing the electric distribution system: growing customer expectations for service reliability and power quality, pressure to achieve better efficiency and utilization of existing distribution system assets, and reduction of greenhouse gas emissions by accommodating high penetration levels of distributed generating resources powered by renewable energy sources (wind, solar, etc.). Recent "storm of the century" events in the northeastern United States and the lengthy power outages and customer hardships that followed have greatly elevated the need to make power delivery systems more resilient to major storm events and to provide a more effective electric utility response during such regional power grid emergencies.

Despite these newly emerging challenges for electric distribution system operators, only a small percentage of electric utilities have actually implemented a DMS. This paper discusses reasons why a DMS is needed and why the DMS may emerge as a mission-critical system that will soon be considered essential as electric utilities roll out their grid modernization strategies.

1 WHAT IS A DMS?

The IEEE Power and Energy Society (PES) Task Force on DMS has adopted the following definition:

> "A DMS is a decision support system that is intended to assist the distribution system operators, engineers, technicians, managers, and other personnel in monitoring, controlling, and optimizing the performance of the electric distribution system without jeopardizing the safety of the field workforce and the general public and without jeopardizing the protection of electric distribution assets."

Several key characteristics of the DMS can be derived from this definition:

- The DMS can be composed of multiple (one or more) systems working together to achieve the established business objectives for distribution grid modernization. That is, the DMS is not necessarily a single, monolithic solution from a single DMS vendor. Most DMS that are in operation today actually comprise separate solution platforms supplied by more than one vendor.

- Integration is a key characteristic of a DMS. Although a DMS may comprise solutions from different vendors, these systems must be interconnected through standards-based interfaces that permit well-coordinated operation of the electric distribution system.

- Considerable emphasis is placed on “optimizing” (improving) the overall performance of the electric distribution system. This terminology signals a significant change from well-established business practices that focus on maintaining “acceptable” electrical conditions on the distribution system.

- Safety and asset protection must never be sacrificed to achieve better efficiency, reliability, and overall performance of the electric distribution system.

Many electric distribution utilities have elected to address grid modernization by deploying individual stand-alone systems such as Distribution Supervisory Control and Data Acquisition (DSCADA), Fault Location Isolation and Service Restoration (FLISR), and Volt-VAR Optimization (VVO) to address specific operational issues. The utilities also use this approach for Distribution Automation (DA) proof-of-concept. In most cases, the level of integration and coordination between these individual solutions is limited, and the resulting operation may not be optimal under all expected operating conditions. For example, the VVO solution may not work effectively (and may have to be turned off) when the distribution feeder has been reconfigured by the FLISR application. The objective for a DMS is to ensure that new distribution system applications work in concert under all anticipated operating conditions.

2 WHY IS A DMS NEEDED?

At this time, much of the electric utility industry does not consider a DMS to be an essential part of distribution system operations. This view is still maintained primarily because current business processes for distribution system operations, which are primarily manual and paper driven, have served the electric distribution industry well for many decades. So a transition to electronic, computer-assisted decision-making for the electric distribution system is deemed unnecessary by some electric distribution utilities.

Electric distribution utilities have always focused on maintaining "acceptable" conditions on distribution feeders to:

- Maintain safe conditions for the electric utility workforce and the general public.
- Minimize electrical losses to the electric distribution system. This objective is especially important for electric distribution utilities, which experience high levels of electrical losses, including both technical (I^2R) and nontechnical (energy theft and unmetered loads).
- Protect electric distribution assets from potentially damaging short-circuit currents and voltage surges and sags.
- Maintain voltage within established limits (typically, nominal voltage plus or minus 5 percent) for all customers at all times under all loading conditions.
- Ensure that loading of all electrical equipment is well within established thermal ratings of the individual devices. Device loading has often been limited to half of what a device is physically able to carry.
- Ensure reliability of service in terms of interruptions and their severity.

Distribution system operators and other personnel who design, build, operate, and maintain the electric distribution system have done an admirable job in accomplishing the objectives listed above using manual, paper-driven business processes, without a high degree of monitoring and automation — and without a DMS.

The situation is rapidly changing, however. Today's electric distribution utilities are seeking to make distribution system operations even more efficient and reliable, with improved asset utilization and without compromising safety and the protection of distribution assets. Utility companies are also seeking to accommodate new distributed generators that are powered by clean and renewable energy resources (e.g., wind power, solar power) and to empower end-use customers to make informed decisions about their energy usage.

The criticality of DMS is likely to change thanks to many factors associated with grid modernization that are changing the way the electric distribution system is designed and

operated. Key factors that are expected to greatly increase the need for a DMS are described in the following sections.

2.1 Growing Complexity of the Electric Distribution System

Prior to the grid modernization era that began in the late1990s and early 2000s, electric distribution systems had not changed much in configuration and operational requirements. Figure 1 depicts a traditional distribution system of the time. Electric distribution utilities did not have to consider significant penetration of distributed generation, as all power flows were unidirectional (from the source substation to the feeder extremities), with a predictable voltage drop occurring along the feeders. Most electric utilities had very little or no automation and remote monitoring and control on their electric distribution systems. Distribution protection, control, and metering (including the end customers' revenue metering) were handled by electromechanical devices. Autonomous controllers (voltage regulators, switched capacitors, line reclosers, etc.) positioned in substations and at strategic locations along the feeder were sufficient to ensure that electrical conditions at all points on the feeder were acceptable under all expected loading conditions. Experienced distribution system operators were able to make informed decisions based on years of experience with distribution feeders that had not changed significantly over the years. In short, manual, paper-driven business processes worked well under these conditions.

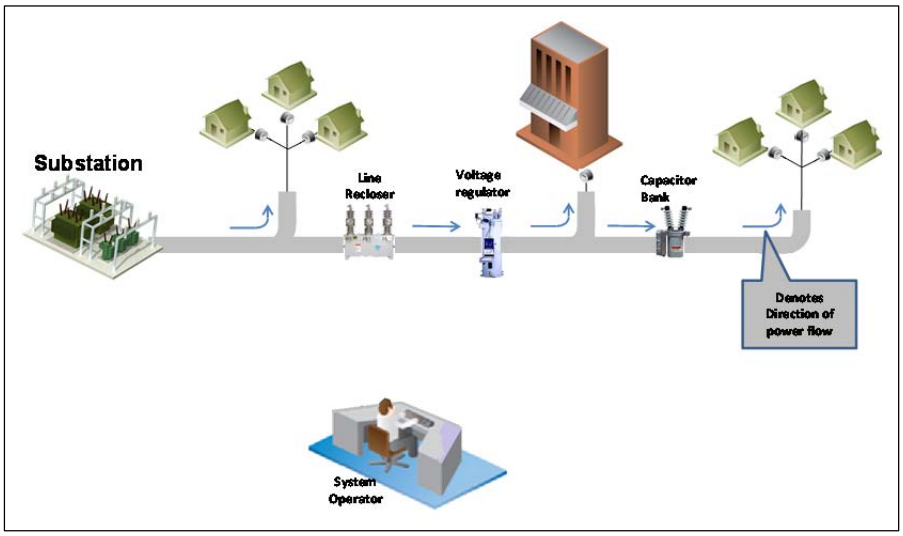

FIGURE 1 Traditional Distribution System

During the current period, referred to in this report as the "grid modernization" era, electric distribution utilities are experiencing many significant changes. Today's electric utilities are being challenged by regulators and customers alike to maximize the performance of the distribution system, with business objectives going well beyond the traditional objective of maintaining *acceptable* operating conditions at all times. One of the most significant changes

that is occurring is the growing presence of distributed energy resources (DER), especially DER that are powered by renewable resources (wind and solar power). This change has resulted in major growth in the monitoring, protection, and control systems that are needed to ensure optimal performance under all plausible operating conditions for DER. Figure 2 depicts a modern distribution system with a significant penetration of DER and many new monitoring and control facilities. Given the added complexities of managing the operation of distribution feeders containing some or all of the elements shown in Figure 2, manual, paper-driven business processes are, in some cases, proving to be ineffective, especially during widespread storm-related emergencies.

Even routine switching procedures are more complicated today, because feeders are loaded more heavily (up to 75% of rated capacity) to avoid capital expenditures for new capacity additions. System operators can no longer count on having plenty of spare capacity on adjacent feeders to accommodate load transfers from another feeder when equipment needs to be taken out of service to perform maintenance and repair work. Multiple load transfers requiring more complicated switching procedures are often needed in such circumstances.

This state of industry practice clearly dictates the need for a solution that is adaptable to changing field conditions and is intelligent enough to support computer-assisted decision-making. These emerging needs can be met using a DMS.

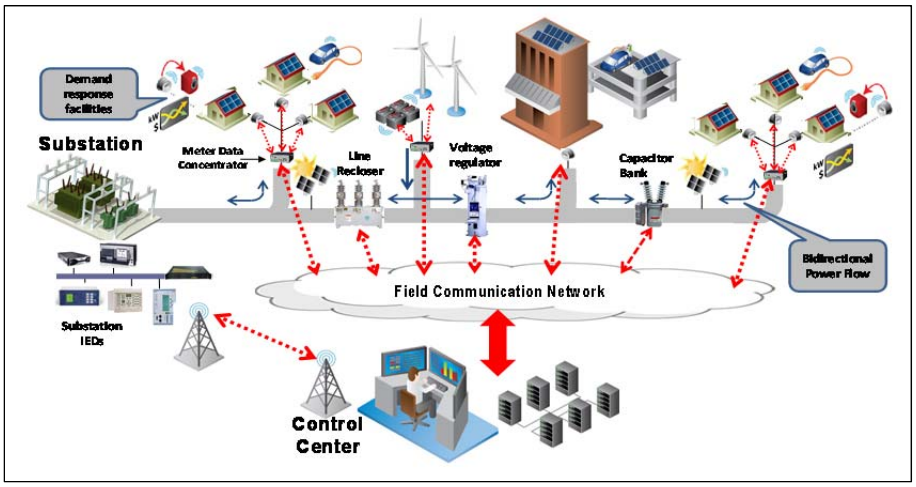

FIGURE 2 Distribution System of the Grid Modernization Era

2.2 New Operating Objectives for Electric Distribution Systems

Today's electric distribution utilities are seeking to accomplish much more than simply maintaining "acceptable" conditions at all times. Facing increased pressure from customers, regulating authorities, and shareholders, electric distribution utilities are seeking ways to achieve a whole new set of operating objectives geared at improving the overall performance of the

electric distribution system. The driving forces for these new business objectives include the following:

- **Growing customer expectations for service reliability and power quality.** Customer expectations for service reliability have grown over the years. This result is occurring primarily because of the expanded use of electronic and computer-driven electrical appliances that perform tasks deemed essential for daily living. Although most customers do not expect "perfect" power with no interruptions in service, customers do expect the utility company to:

    - Be immediately aware of all power outages before customers call in to report outages.

    - Initiate restoration activities, with field crews investigating and determining a course of action.

    - Provide an accurate Estimated Time of Restoration (ETOR).

    - Restore power as quickly as possible.

    Outage management functionality that is included in state-of-the-art DMS is able to provide the functionalities listed above. The utilities, in turn, expect that outage management capabilities, coupled with automatic service restoration facilities (such as FLISR), will detect outages rapidly, isolate the damaged section of the feeder, and restore power to as many customers as possible that are served from the "healthy" feeder section within a few seconds. It is impractical to use manual, paper-driven business processes to meet all of these expectations and requirements even when a single power outage occurs. It is virtually impossible to manually manage service restoration within a few seconds when multiple outages occur.

- **Pressure to achieve better efficiency and equipment utilization of the existing distribution system by "squeezing" more capacity out of existing assets.** Electric distribution utilities are seeking ways to improve the overall efficiency of the electric distribution system through peak shaving, promotion of energy conservation, and reduction of electrical losses. These efficiency objectives are often connected to regional, statewide, and national objectives to reduce greenhouse gas emissions. Another objective for efficiency improvements is to lower capital expenditures for capacity additions. Conventional, stand-alone controllers associated with voltage regulators and switched capacitor banks do a reasonably good job of maintaining acceptable conditions, but are not able to provide optimal performance, especially when high penetrations of DER are present.

    The DMS will play a major role in helping to achieve these objectives by providing intelligent control of voltage regulators, capacitor banks, DER, and dynamic voltage controls under rapidly changing (and often difficult to predict) operating conditions (such as the on/off status of customer-owned generation). DMS applications that use an "as-

operated" model of the electric distribution system are well suited for performing voltage and VAR control under the dynamic circumstances that face today's electric utilities.

The DMS is also expected to play a significant role in increasing the utilization of existing assets. DMS application functions, such as the Dynamic Equipment rating for transformers and underground cables, will enable the electric distribution utilities to increase the loading on these assets without producing excess loss of life. This objective is met by basing equipment loading considerations on current conditions rather than conservative "worst-case" seasonal assumptions. This approach, in turn, will enable electric utilities to defer capital expenditures for replacing these assets or expanding the capacity.

- **Reduction of greenhouse gas emissions by accommodating high penetration levels of distributed generating resources powered by renewable energy sources.** Small amounts of distributed generation facilities having a capacity of less than 15% of the total demand usually will not have a significant impact on feeder operation and, therefore, do not require a significant amount of human intervention to manage these resources effectively or to implement changes to existing protection and voltage regulating facilities. However, as the penetration of distributed generation resources (including intermittent renewables) grows to 20% of the normal load and higher, there will be a need for active management of these resources. Some the stand-alone controllers ("bidirectional" voltage regulators with cogeneration facilities) are able to accommodate the reverse power flow associated with distributed generation in most cases. However, there are some circumstances in which a more intelligent formal voltage regulation, such as that provided by the DMS, is needed. Figure 3 depicts such a situation.

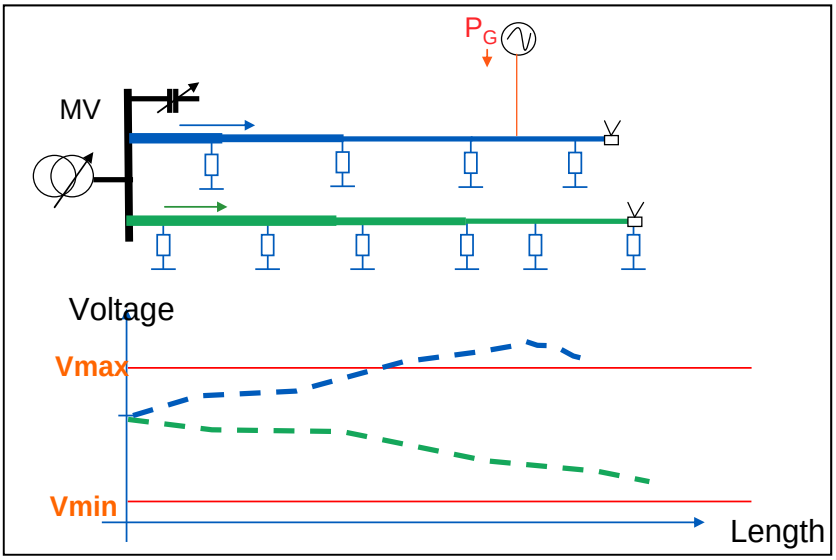

FIGURE 3 High and Low Voltage on the Same Substation Bus

As evident in Figure 3, high penetration of distributed generation with reverse power flow results in high voltage on one feeder (top, blue) ; however, a second feeder (green) that is fed off of the same substation bus and which does not have distributed generation is experiencing low voltage. Because the voltage regulation strategy for the substation manages the voltage on a common bus between these two feeders, the dilemma exists on how to eliminate both a high-voltage concern on one feeder and a low-voltage concern on the other feeder. Clearly, a more intelligent form of voltage regulation, such as that provided by a model-driven DMS solution, is needed in this case.

- **Accommodation of significant new loads such as electric vehicle charging.** Even low levels of electric vehicle (EV) adoption may have a significant impact on utilities and the grid — a single EV plugged into a fast charger can double a home's peak electricity demand. EV charging must be optimized for grid load while guaranteeing that drivers' schedules and range requirements are met. Unmanaged EV charging can add to peak grid load. EV charging must be scheduled intelligently in order to avoid overloading during grid peak hours.

  Charging stations can be designed to respond to DMS signals to adjust or interrupt charging activity in response to localized or higher-level grid conditions. This capability is particularly relevant for public charging stations. Automated responses can include automated frequency response where the charging station monitors frequency against the norm and adjusts charging behavior when frequency excursions are detected. Smart charging in the home/work environment can be designed to respond in a similar manner to public charging, but with the added possibility of default charging behavior (e.g., an EV connected to a 7.2-kW charger may revert to 3.6-kW charging or vice versa as needs dictate). In addition, "algorithmic"-based home charging may be initiated to minimize load on local distribution network conditions.

  An EV management application function in the DMS provides the visibility and control needed to protect components of the distribution network, such as transformers, from being overloaded by EVs charging and to ensure that electricity generating capacity is used most efficiently. By providing intelligent monitoring and communications capabilities to an electricity network, a DMS provides a utility much greater control over all aspects of operations, from generation and distribution to metering and billing. As a result, the utility can carefully manage when and how EV charging occurs, collect EV-specific meter data, apply specific rates for EV charging, implement demand response (DR) programs, engage consumers with information on EV charging status and bill impacts, and collect data for greenhouse gas credits.

2.3 Growing Penetration of Distributed Energy Resources

Much of the activity in distribution grid modernization is centered on DER, which include distributed generators (DG), distributed renewables (wind and solar power), energy storage units, and controllable loads (i.e., DR). Small penetrations of DER (total capacity less than 15% of peak demand) have little or no effect on the operation of electric distribution feeders and, thus,

do not require any action from the electric distribution system operator. However, as the level of penetration grows to 20% of peak load and higher, the adverse consequences can be significant:

- High penetration of distributed generation on a feeder may produce reverse power flow (power flow back toward the main source of supply). This event, in turn, may produce a voltage rise effect on the feeder that is opposite from the normal voltage drop effect experienced by feeders without high penetration levels of distributed generation. Figure 4 shows a representative voltage profile for feeders with a high enough penetration of DER to produce reverse power flow. Such high-voltage conditions may be difficult to correct without active control of the distributed generator output voltage using an intelligent system such as a DMS.

- The sudden loss of a significant amount of distributed generation, such as loss of photovoltaic (PV) solar output because of passing clouds, can result in a significant drop in voltage on the feeder that will exist until voltage regulation facilities respond (after a short time delay) to the increased load from normal supply. Conversely, sudden restoration of distributed generation can produce high voltage on the feeder owing to the voltage rise effects produced by distributed generation. These high-voltage effects will exist until conventional voltage regulators respond after a short time delay to lower the voltage on the feeder. On partly cloudy days, the effect described above may repeat itself on a regular basis. The resultant impact is the fluctuation of feeder voltage, which may be perceived by customers in the form of flickering lights. Figure 5 depicts this situation.

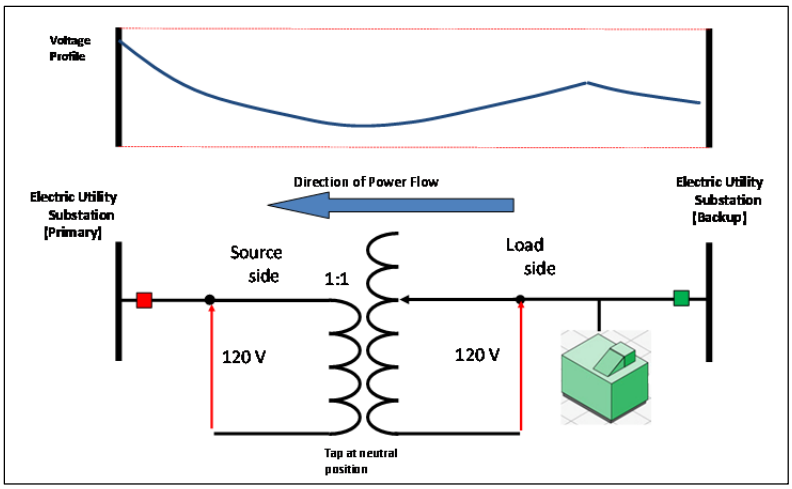

FIGURE 4 Reverse Power Flow due to High Penetration of Distributed Generation

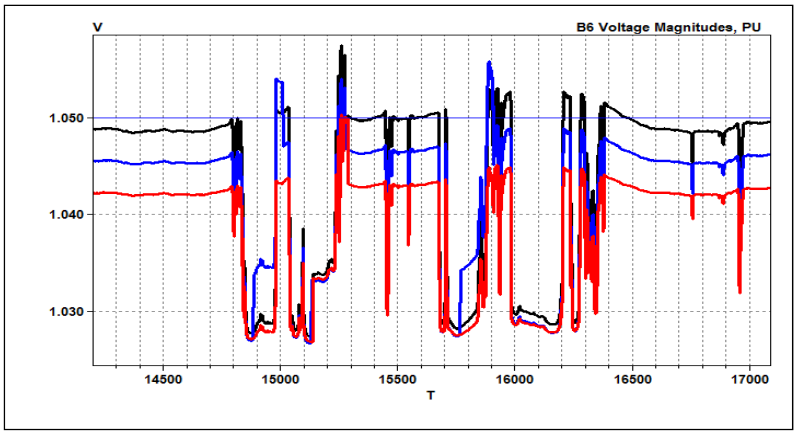

FIGURE 5 Voltage Fluctuations due to Intermittent Distributed Generation Resources

These voltage fluctuations may be mitigated by using a DMS to actively manage smart inverters and other power electronics–based devices that can supply or absorb reactive power rapidly and regulate fluctuating voltage to counteract the voltage rise or drop caused by the intermittent nature of distributed generating resources.

Growing DG penetration (especially renewables) can produce reverse power flow conditions, protection problems, and voltage variations that may affect overall power quality. The DMS can help mitigate these adverse consequences by deploying more intelligent voltage regulation, adaptive protection, load/generation balancing using energy storage, and dynamic voltage control. The DMS enables the system operator and the electric distribution utility to mitigate the undesirable consequences of intermittent generation output by managing smart inverters, solid-state power controllers, and other devices connected to the electric distribution system.

The DMS manages these resources to accomplish a wide variety of business objectives, such as peak shaving and coordination of DER for market and ancillary service purposes (the “virtual” power plant).

The DMS can include application software for predicting the output of renewables (solar PV and wind power) based on weather conditions and other factors, thus preparing distribution system operators for near-term operating challenges. Short-term forecasting of intermittent renewable output is essential for managing the ramp rates of these devices to ensure that they are within the requirements and guidelines established by the industry.

The DMS can also support the “microgrid” concept in both grid-connected mode and islanded modes. In grid-connected mode, the DMS maintains the proper balance between load, generation, and storage on the set of feeders and substations that comprise the microgrid. In “island” mode, the DMS manages the DER and control voltage and frequency to ensure acceptable operation of the microgrid when separated from the bulk power grid.

The DMS offers the electric distribution utilities a way to meet the requirements of independent system operators to participate in emerging markets, such as frequency regulation, by serving as an aggregator for distributed generating resources. The DMS can ensure that the required services are provided as requested within the necessary timeframe, and verify that these services have been delivered. Figure 6 depicts an industrial park containing numerous DER managed by a microgrid controller application that is included in a DMS.

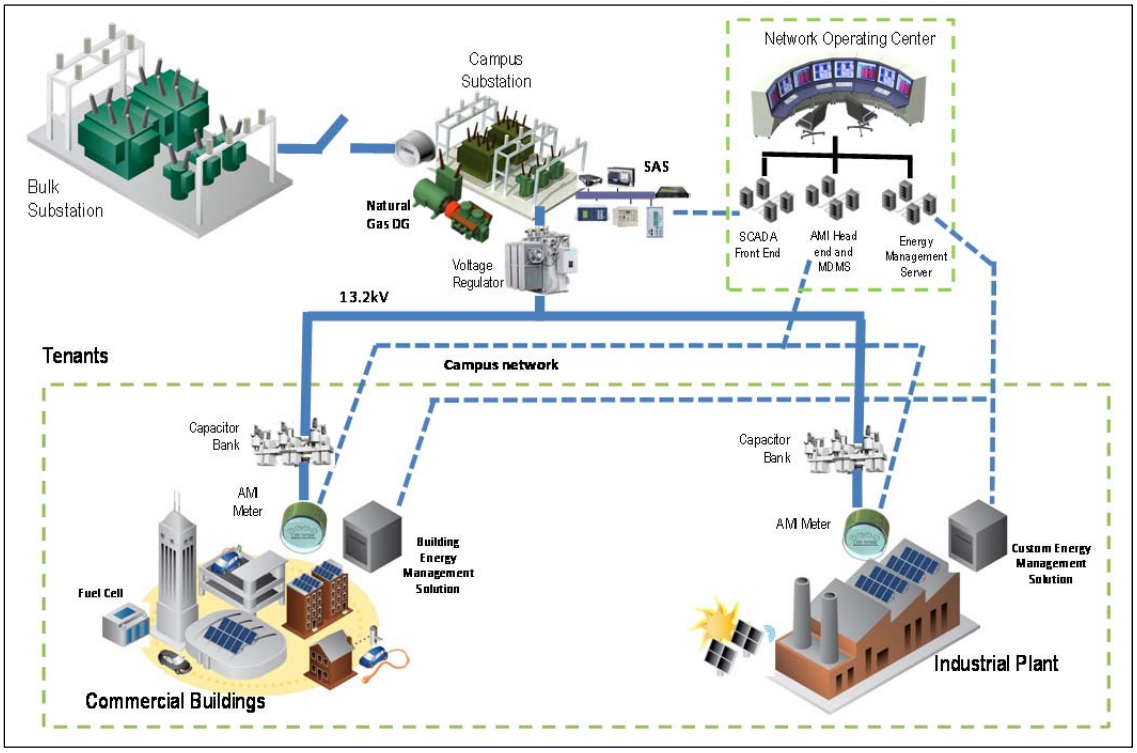

FIGURE 6 Distributed Energy Resource Management System Big Data — Avoiding the Data Tsunami

2.4 Big Data — Avoiding the Data Tsunami

One of the significant characteristics of the traditional electric distribution system is the lack of continuous monitoring facilities (e.g., distributed sensors) that provide visibility of electric distribution system performance to the system operator. Grid modernization has increased the amount of information about the performance of the electric distribution system that is delivered to the operator by several orders of magnitude. New sources of information include advanced metering infrastructure (AMI) and new field-mounted sensors, including stand-alone sensors and sensors that are embedded in line switches and other automated gear.

This wealth of new information has great potential to improve decision-making by personnel responsible for the operation and maintenance of the electric distribution system. However, the large amounts of information that need to be collected and managed will place strains on all but

the most carefully built systems. These systems will require DMS solutions that are designed from the ground up with high performance and scalability in mind. The massive growth in communication capabilities, low-cost sensors, and integration will generate large amounts of data that exceed the capacity of many operational systems in place today. The DMS must take advantage of modern and emerging database technologies to manage this data. Then, utility engineers and analysts can use the DMS to study low-reliability areas, identify problematic designs and equipment, and better account for aging infrastructure and forecasted load growth and load profile changes in new construction designs. The resulting analysis will bring benefits of improved reliability at lower costs.

The DMS is expected to play a key role in preprocessing, filtering, and routing actionable data to responsible parties. Best-of-breed computer platform designs will allow operators to scale the DMS platform across multiple processors nearly linearly using technology similar to what is used in large data centers.

Added value and benefit are gained from integrating the DMS with other backend systems, such as customer information systems, work management systems, asset management systems, and system engineering and design tools. To enable this integration, the architecture of the DMS system should allow for the use of standard message-based integration so that interfaces with other backend systems can be created in a manner consistent with common information technology (IT) practices and at a low cost of ownership.

2.5 Aging Infrastructure

One of the most significant problems that is facing electric distribution utilities is the aging of the electric distribution infrastructure (e.g., lines, electromechanical equipment, underground cables). Many of the components that comprise the electric distribution system have been in service for 20 to 30 years and longer. As a result, many electric power devices (switches, transformers, capacitor banks, voltage regulators, etc.) are reaching the end of their useful lives. Increasing failure rates are therefore expected for this equipment, which will ultimately result in declining reliability. It is not practical from a resourcing standpoint (i.e., monetary and human resources) to replace every piece of equipment that is reaching the end of its original predicted life (approximately 40 years). Although selected equipment replacement needs to take place to eliminate poor-performing and unreliable equipment, a more prudent approach is to closely monitor the performance and control of the aging assets in question.

The DMS is able to track the operating duty imposed on all electrical assets and use that information to determine whether maintenance activities or device replacement are needed. The DMS can also bias its control actions to avoid, where possible, operating power apparatus that is showing signs of wear and the possible need for replacement.

The DMS may also play a significant role in maximizing the utilization of existing energized assets (especially substation transformers and underground cables) by closely monitoring the operating condition of these assets. The DMS can continuously monitor this critical equipment and inform the distribution system operator when operating limits are being approached. This

capability enables utilities to operate these assets with smaller operating margins without jeopardizing equipment reliability or causing excessive loss of life. In addition, the DMS can support dynamic equipment ratings that are based on actual real–time conditions rather than worst-case seasonal assumptions. The DMS can provide the information and algorithms to support condition-based maintenance strategies.

2.6 Aging Workforce

The distribution systems offering community has always relied on the availability of very experienced, senior operators who are extremely knowledgeable about the operation of the electric distribution system, especially potential week spots. As these experienced distribution system operators retire or move on to other opportunities, a new generation of distribution system operators with considerably less experience takes over the responsibility of operating the electric distribution system. The computer-assisted decision-making characteristics provided by a DMS are ideal for this operating environment.

Preparing new operators to take over from very experienced counterparts requires a significant amount of on-the-job training. For the most part, this training is provided by the very senior operators themselves. At the same time, even the most senior distribution system operators require a significant amount of training on new technologies and operating requirements.

DMS-based training simulators provide interactive simulation of power system operations under normal circumstances and emergencies. They can be used to prepare operations personnel to meet these challenges. The training simulator shortens the time needed to bring candidate operators “up to speed” and reduces the time spent by senior operators to support training activities. DMS-based training simulators can be used to design and conduct exercises to prepare operators to meet the complex challenges of managing and balancing distribution system operations. In addition, the training simulator can enable utilities to conduct realistic emergency preparedness drills so that the total workforce can be prepared to meet “storm of the century” types of events. Figure 7 depicts a training simulator that is included in the DMS.

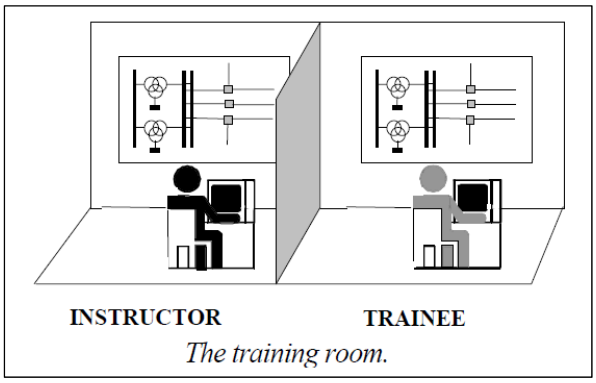

FIGURE 7 DMS-Based Training Simulator

In addition to facilitating the training of new operators, the DMS will eliminate many of the manual paper-driven business processes (such as hand-drawn map updates) that consume a significant amount of time for existing control center personnel. Productivity improvements made possible by the DMS will enable the electric distribution utility to make the most effective use of its limited personnel resources.

3 SUMMARY

As we proceed in the grid modernization era, many significant changes are expected to occur in the ways that electric utilities operate the electric distribution system. Distributed energy resources and two-way power flows impose many new challenges for the distribution system operator. Although the distribution system of the past was fairly predictable in terms of load voltage profile and other operating conditions, the distribution system of the future will be characterized by a high degree of uncertainty caused by customer-owned intermittent generating resources, nonlinear loads, microgrids, and other such factors. Many of these uncertainties require very fast responses from system operations in near-real time, which cannot be accomplished using manual, paper-driven business processes. Electronic, computer-assisted decision-making is clearly needed to mitigate these consequences.

Grid modernization offers many new capabilities to meet these challenges to operators of distribution systems. Some of these capabilities are provided by the technology, such as smart inverters and power electronics-based devices; other capabilities are from sensors and communications; and still others are from data analytics. For distribution system operations, the capabilities are brought together in the distribution management system.

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