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BENEFITS OF SMART GRID FOR DISTRIBUTION SYSTEM IMPROVEMENTS

Robert RUSSO, E3 International, USA
Aaron F. SNYDER, EnerNex, USA

SUMMARY

Smart Grid is in part about data and transforming it into actionable information. The emplacement of ubiquitous, secure, two-way communications as a foundational element of Smart Grid leads to pervasive sensors providing timely data about the technical performance of the distribution system. Aligning this data with the actual system then gives the operator a tool to understand the health and performance of the system.

Using energy measurements at the circuit level can identify technical and non-technical losses, and lead to programs to mitigate those losses such as transformer balancing, circuit reconductoring, and targeted revenue protection activities (finding unmetered loads, potential theft, non-paying customers, etc.). This information can be used support the greater integration of variable renewable energy systems into a country's generating mix, and to develop time varying rates to encourage consumption during less expensive operating conditions (time-of-use rates). Demand management and energy efficiency programs can then be developed to encourage customers to use less energy to meet their needs, flowing all the way back to lessening the burden of procuring and managing primary energy sources.

Managing the voltage can improve system efficiency as well, keeping the need for reactive power exchanges minimized or localized to highly inductive points in the network (often large industrial customers, for example). Lessening the need for higher distribution voltage also reduces the needs all the way back to the primary power sources.

This paper will examine the use of energy, demand, and voltage in the Smart Grid context and the value of that data for distribution system improvements, including the need to integrate larger amounts of distributed renewable energy systems at the low and medium voltage level.

Key words: smart grid, grid modernization, distributed generation, renewable energy integration, demand management

rvrusso@eeeinternational.com, aaron@enernex.com

INTRODUCTION

Many changes have occurred in the industry over the past decade that will impact the next generation of grid evolution, often under the moniker "grid modernization," including (1) pervasive and massive penetration of distributed energy resources (generation and storage); (2) electrification in the transportation sector (electric vehicles of all types) and building sector; (3) grid edge computing possibilities; (4) cloud-based software becoming acceptable to the utility industry; (5) the addition of resilience as a core concept on top of reliability, leading to more microgrid installations; and (6), consideration of new business models, such as the distribution system operator or energy service company, that challenge the vertically-integrated, or even existing market, business environment of today. These trends will continue to evolve as country utilities and their regulators strive to reach their climate goals.[1]. The next generation of smart grid and the distribution system, as well as field area networks for metering and automation, must support these goals.

Serbia, and other Western Balkan countries, have a significant potential to improve electric gird reliability and allow a greater penetration of distributed generation sources, including distribution level solar PV systems, by implementing grid modernization technologies throughout their network. The urgency in Serbia to modernize its electric grid has become a major focus of the Serbian Government given the power system crisis in early 2022, when a breakdown in its two biggest coal plants caused widespread outages, requiring the import of unprecedented quantities of electricity. Serbia's electric distribution system has suffered from deferred maintenance and under investment, and now requires major investment over several years to improve system reliability. In addition, given its current high reliance on 2 major coal plants (Kostolac and Obrenovac) and its commitment to decarbonization, the growth of distributed energy assets in the country is critical. The very concept of Smart Grids is now a priority for the Serbian Government to [1]:

- Better facilitate the connection and operation of generators of all sizes and technologies.
- Allow consumers to play a part in optimizing the operation of the system through the prosumer concept
- Provide consumers with greater information and options for choice of supply.
- Significantly reduce the environmental impact of the whole electricity supply system by reducing reliance on coal
- Improve the system reliability, quality, and security of supply.
- Foster market integration towards a European integrated market.

Serbia has already taken the first steps to grid modernization with the commitment to invest €500 million ($566.9 million) in the country's low-voltage electric power distribution grid in the next couple of years, and the installation of about 205,000 smart meters in the cities of Kraljevo, Čačak, and Niš. But much more needs to be done in the area of grid modernization to maximize the benefits of these initial commitments.

SMART GRID

One critical concept is to understand that smart grid is defined by a set of characteristics [2] for how the grid performs or reacts. This can mean "(1) Increased use of digital information and controls technology to improve reliability, security, and efficiency of the electric grid, (2) Dynamic optimization of grid operations and resources, with full cybersecurity, (3) Deployment and integration of distributed resources and generation, including renewable resources, (4) Development and incorporation of demand response, demand-side resources, and energy-efficiency resources, (5) Deployment of `smart' technologies (real-time, automated, interactive technologies that optimize the physical operation of appliances and consumer devices) for metering, communications concerning grid operations and status, and distribution automation, (6) Integration of `smart' appliances and consumer devices, (7) Deployment and integration of advanced electricity storage and peak-shaving technologies, including plug-in electric and hybrid electric vehicles, and thermal storage air conditioning, (8) Provision to consumers of timely information and control options, (9) Development of standards for communication and interoperability of appliances and equipment connected to the electric grid, including the infrastructure serving the grid, and (10) Identification and lowering of unreasonable or unnecessary barriers to adoption of smart grid technologies, practices, and services." Within these ten characteristics one can find a lot of technology, but also standards and policy to shape the future smart grid. In addition, many countries are pursing some level of decarbonization of their primary energy sources, like Serbia, digitalizing much of the energy sector with modern sensors, communications, and software applications using the data, and decentralizing both the energy supply and some of the command and control, further driving the trend to modernizing the electric grid.

Generally speaking, smart grid can be defined at a practical level as the sum of the transmission and distribution system, plus ubiquitous two-way communications, plus sensors and control devices exchanging data and information to monitor and control the grid under any operating condition. The continued migration to non-carbon-based primary energy sources, for example seen in a collection of European countries (2010-2020) to have increased from 151 to 491 Terawatt-hours for wind, 23 to 170 Terawatt-hours for solar, and 129 to 212 Terawatt-hours for other renewables, all while fossil fuel production decreased from 1727 to 1186 Terawatt-hours [3]. Related, the distribution of renewable sources throughout the grid, the so-called distributed energy resources (both generation and storage, fixed and mobile), has created the need for better sensor strategies to improve operational visibility and intelligence. Continuing in the vein of definition by attributes, some technologies, such as distributed energy resources, are not completely defined or may be defined by what they do rather than what they are. The original definition of those "distributed" generation devices (e.g., solar photovoltaics, reciprocating generators) that provided energy *TO* the grid, must now be expanded to "distributed energy resources" (see FIGURE 1) and include storage installed on the network and smart inverters on other generators that provide four-quadrant power and energy services. Similarly, other types of technology that help instantaneously balance generation and load by providing (or consuming) energy as a "resource" also fall under the umbrella definition. More recently, growth in electric vehicles, the non-fixed/mobile/multi-positional resources, further complicates the allocation of investments and resulting need to reconcile that resource as it serves as a both generator and a load. Utilities must fully model, monitor, control, and understand the many different resource offerings, now and in the future.

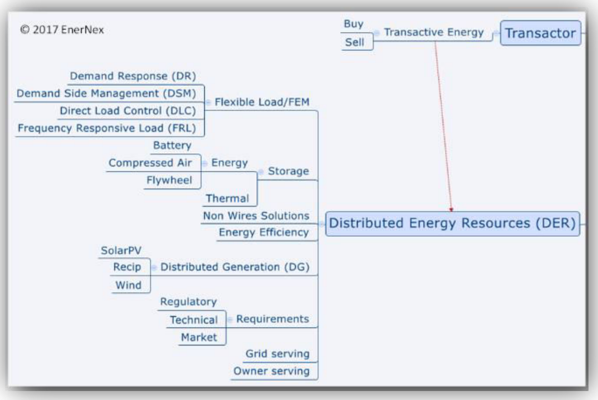

FIGURE 1 – DISTRIBUTED ENERGY RESOURCES

GRID MODERNIZATION

Wide-scale distributed energy resource integration, both fixed and mobile (i.e., electric vehicles of any type), create the need to measure the grid for delivered and received active and reactive power and energy, but also voltage, frequency, and a collection of advisory messages such as outage/restoration notifications, loss of voltage, reverse power, to name a few. As electricity consumers of all categories—residential, commercial, and industrial—become even tighter partners in the bi-directional or multi-directional power and energy exchanges on the grid, the key will be for utilities to fully leverage the power and energy capabilities of the circuits by upgrading the lines and transformers, installing better secure two-way communications, and ensure the right emplacement of sensors and metering to continue providing a reliable, self-healing, and reliant energy exchange platform. To achieve these benefits, the field area network [4] must also be adaptable to the new electric business paradigm, tailoring the speed and throughput for the application to move away from any limitations to delivering customer value.
Trying to have a server-client model for all grid applications places a heavy burden on quality of service of those networks. Recent developments in grid-edge computing and peer-to-peer networks for utility applications can obviate the "home run" nature of central hub-and-spoke utility networks for the millions of sensors and devices in the field. The next wave of field area networks for automation and metering should include grid edge capabilities in device communications and decision-making capabilities.

One example might be smart outage notifications. Modern devices notify the utility of an outage in the field through multiple channels, but without verifying the outage. A new generation of devices could verify the outage locally between several devices in the mesh, settle on a conclusion, then communicate a validated outage to the utility with all the devices already listed in a group. Furthermore, a new generation of devices operating in a field area network with distribution automation devices could not only work together themselves but also could act upon validated outage and restoration messages from meters and other grid sensors without centralized utility action, automatically rerouting power flow around the outage.

Flexibility will require advancements in trust, security, and communications, on top of the device capabilities. In the utility space, the Open Field Message Bus [5] movement hopes to capitalize on existing standards familiar to the industry. The information models are derived from the IEC 61850 standard [6], the IEC 61968 [7] standard common information model, and MultiSpeak [8], while the communications are built on industrial Internet of Things standards such as data distribution service, message queue telemetry transport, and advanced message queue protocol. Core use cases for Open Field Message Bus were developed around microgrid operations and distributed energy resources segment management with layered coordination of the devices built upon grid architecture concepts from U.S. Department of Energy's Pacific Northwest National Laboratory. One concept is to quickly develop and deploy virtual or real nodes that communicate via Open Field Message Bus and have enough awareness and intelligence to operate without central control, offering more flexibility and autonomy of operations with quicker response time to grid outages for microgrid operation and optimization.

The future smart and modernized grid will be a platform for multi-party energy exchange that is transactional in nature, where neighbors can sell energy to neighbors, for example, without breaking the utility agreement or the law. This type of operating regime can improve not only reliability during normal operations, particularly during the peak with an excess of photovoltaic solar generation, but also resilience during grid outages by isolating circuits (i.e., a microgrid in island operation) from the main grid relying instead on local energy providers. Further, microgrids do not have to be privately owned. Transitioning the utility from a "poles and wires" company to an energy services company would permit an expansion of the utility portfolio and provide a contracted quality of service using any means permissible. This transition creates a freer marketplace for energy exchange, but this transition relies on investing in the grid, in sensors and telemetry, and smart metering as well as a more open future for field communications and sensors.

ENERGY, DEMAND, AND VOLTAGE APPLICATIONS

Energy (often measured in kilowatt hours or megawatt hours for real energy, and kilovolt-ampere-reactive hours or megavolt-ampere-reactive hours for reactive energy in distribution systems), demand (often measured in kilowatts or megawatts for real power and kilovolt-ampere-reactive or megavolt-amperes-reactive for reactive power) and voltage, along with frequency, power factor, and also amperes, are the core set of measurements and derived values used to monitor and control the grid. There is an inter-relation between energy, demand, and voltage as they relate to providing safe, secure, reliable electric service to all customers, and all grid technologies can use these values in different smart grid applications.

For distributed energy resources, it should be clear that a primary use is for energy (power) over time. Managing the energy flowing through the system is directly related to managing the current flowing in the system, which then has a number of applications for which smart grid technologies provides improvement: (1) ensuring the conductors and transformers are properly sized to minimize technical losses, or lower efficiency, (2) using smart switches, relays, and other devices to send energy in ways that do not follow Ohm's Law, and (3) using smart switches and relays to permit multi-directional energy flow rather than unidirectional energy flow, to name a few. For the first, adding smart meters at every load point, and also at the head and foot of the circuit permits, very tight reconciliation of energy input vs. energy output for each circuit. The output can be then divided into energy billed versus unbilled energy (sometimes called non-technical losses), and the current backwards derived to ensure that the transformers are balanced (another potential loss) and the circuits are not overloaded. This metering strategy would also provide a clear indication of revenue loss due to technical or non-technical losses. For the second, it is not always possible to introduce distributed energy resources where they might have the best benefit; in a similar fashion to using flexible alternating current transmission system devices on the transmission grid, smart switches, relays, and other devices can provide information to the distribution system operator to create specific pathways to solve energy and demand mismatches. For the third, the switching and relaying devices can be programmed to "talk amongst themselves" to solve grid problems and reconfigure the grid or give the distribution system operator information to then reconfigure the grid from the control center. All the above applications are enhanced by digital sensors with a measurement granularity (from a minute to an hour to a day) that meets the application needs and can be communicated over the secure, two-way field area network.

Managing the demand of the system with smarter sensors and smart meters helps the utility properly size the conductors to meet the peak demand, the value almost universally used for that sizing. Also expressed as power capacity, this is the real physical limit of the system for safe operation. The smart sensors and smart meters can work between themselves or with distribution operator applications to limit the demand in the system. One method is used both a "soft" and "hard" service switch, where the former has a programmable limit below the maximum permissible limit above which the switch opens, cutting the demand. This is also the function if the maximum current threshold is exceeded, for safety. A challenge for this technology is behind the meter generation from solar or battery storage, which creates a reverse current and can defeat certain programming in the meter switch logic. This is a continued area for research. However, the smart meters and smart inverters can also work together over a local area network or home area network to ensure proper operation and power delivery. Out on the grid, programmable fuse-type devices can work autonomously or through communications to limit the demand; clearly this has a wider grid impact than that of a single service. Both energy and demand management with smart devices, smart meters, and high penetration of distributed energy resources is a continuing area of research as these challenge legacy operating regimes.

Finally, managing voltage at every service location, in addition to that on the circuits and transformers, can add efficiency into the network by minimizing the exchanges of reactive power/energy, which is often unbilled for many residential and commercial customers. Power-electronics based devices can be part of the distribution voltage management strategy in one application where they inject, or consumer reactive power to manage the voltage within defined limits. When the voltage does not sag below a lower threshold, the current draw can remain at an acceptable level for most loads, leading to fewer technical losses and higher circuit efficiency. Another common program is conservation voltage reduction, where the smart sensors and smart meters voltage measurements are used to keep the higher voltage threshold from being exceeded where this may have been required to keep the most distant customers satisfied. The smart sensor and smart meter data can be used to more dynamically monitor the voltage and permit more frequent control, rather than using seasonal or type of day (i.e., weekend, holiday) adjustments which are very common. This can also lead away from using fixed capacitors toward more dynamic reactive devices which then can work with widespread/pervasive smart inverters to provide a dynamic voltage and volt-ampere reactive management scheme.

BENEFITS VALUATION

Today's customers are no longer satisfied with reliability-based investments. Both external extreme weather events and internal operating conditions with pervasive DER and multi-directional power flows will challenge the resilience of the future grid. Customers value grid resilience to keep as much energy flowing, to as many customers, at all times, no matter the circumstances. When perceiving poor reliability from the main grid, customers build resilient energy solutions for a campus, neighborhood, or even a single user. High distributed energy resource penetration in the future grid and the importance of grid resilience will permit a move away from the centralized, hub-and-spoke nature of most systems today and serve as a pre-distribution system market.

There are a variety of metrics to evaluate utility performance against their desired business case. One method is to evaluate how the trends for reliability or outage indices (SAIDI, SAIFI, CAIDI, CAIFI, etc. [9]) change under different investment scenarios. However, these do not have a direct valuation related to energy, demand, or voltage as they are based on interruption duration or frequency. Also, telling customer that they had fewer and shorter outages is not as important as a smaller bill due to less energy consumption.

One method to value the investments for the utility is diminishing technical losses, as those are directly related to operating expenses, and directly measurable either in whole terms, or as a percentage or efficiency calculation. Another method is to diminish the non-technical losses, whether due to direct action (such as theft) or indirect action (unmetered loads). Both these losses contribute to the high operating costs of the grid, which needs to be a managed part of the overall customer bill.

The addition of microgrids into the distribution system can complicate valuation calculations, particularly if they are privately owned. If the grid circuit is interrupted, for example, but the customers on the now islanded microgrid have electricity, does that count as an outage? How is the "loss" of energy sales related to valuing the microgrid installation from the utility perspective?

A different method to value the use of microgrids might be to develop metrics for resilience; that is, how many customers still have electricity based on their desire to have it at any given time, and a system's ability to meet that need. A simple assessment relative to other known utility practices can be the most effective, depending upon the utility practice under consideration. An example of this is shown in FIGURE 2, [10] where resiliency performance for a customer is calculated considering their demand, solar PV availability, battery demand, and utility service.

This example would require enough sensors, telemetry, and meters to permit the performance to be monitored with sub-15-minute granularity, and that collected information sent to the utility and customer for the metric calculation according to any contractual requirements on the service provision. This could be satisfied by a single smart meter with sub meters, a single multi-input smart meter, or a collection of smart meters (least desirable case) for that service point. This is an example of identifying a future business use case (i.e., there is a requirement of resilience as a service) then aligning that need with trends within the grid modernization space.

FIGURE 2 - RESILIENCY METRIC CASE EXAMPLE

Monetizing energy, demand, and voltage, as well frequency and power factor, has different approaches depending upon the particular regulatory environment. All stakeholders should work together to ensure that the overall cost is properly managed, yet flexible enough for new applications and services to be brought into the energy sector. The value of the communications network should not be understated, nor considered to be unreasonable. However, it is certain more work is needed to broaden the value streams for all stakeholders.

CONCLUSIONS

This paper explores the relationship between smart grid technologies and a future where more distributed energy resources, smarter sensors, smart meters, and secure, two-way communications are the norm in the energy sector.

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