Greening the Local Grid*

Smart solutions for distributed renewables.

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Suppose a utility's distribution management system detects a dangerous voltage fluctuation on a low-level feeder sometime around mid-day and opts to shed load to fix the problem, but then the operator discovers that the customer in question was operating banks of solar PV on warehouse roofs. You thought you were shedding load (and you were), but you also were shedding a fully dispatched generation supply. Now what?

Electric distribution networks, unlike interconnected transmission systems, were inherently designed to be radial systems — sending power out to loads along the feeders. Protection systems at their basic level can and do monitor the amount of power (current) being transmitted. When a sudden, unexpected surge occurs — as with a fault or equipment failure — the protective device operates, successfully clearing the problem and ensuring public and employee safety. While solutions have been applied to single-point generation, the interaction of multiple distributed generation sources makes the problem much more significant in aggregate than for any unit on its own. Solutions need to be developed to support distributed generation resources (DG) operating safely within the distribution power company's protection and control paradigms. Traditionally, when safety or system stability was a possible issue, transfer trip schemes were ordered, however these add a significant cost and might not be viable for small distributed resources.

This situation introduces a new problem for most electric distribution companies — having to forecast and then dispatch and perhaps curtail distributed generation. In order to maximize complementary distributed renewable resources, new innovative approaches must be developed. The problem would appear tailor-made for new smart grid solutions.

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The technical and operational challenges to fully realizing the potential of identified smart grid initiatives, and thereby facilitating significant penetration of renewable generation, are significant. And of equal challenge are the regulatory and policy implications. The market hasn't yet reached consensus on the optimal implementation scenarios, obtained technical maturity of solutions or derived a foundational financial modeling of smart grid investments.

Moreover, while there appears to be political will and public consensus that a smarter grid is good — if only because nobody wants a stupid grid — the financial implications of this vision haven't yet been vetted:

- Who will pay for all of the smart grid investment?
- How to ensure that distributed generation resources will provide power factor and voltage support.
- How to fairly treat all renewable generation that's connected to the distribution grid — the first one as well as the last unit.
- Will energy storage solutions serve as ancillary services, financed by special feed-in tariffs, funded by beneficiary renewable

*Published in the February 2011 issue of Public Utilities Fortnightly

and conventional generation producers, or other mechanisms?

- Technologies such as PV, wave power and others continue to require a premium over traditional fossil fuel sources. How will this be resolved?

Utilities won't invest in these enabling solutions unless cost recovery is assured. The independent market won't grow to its full potential unless it can receive the value that it brings to the grid. As the electric grid is managed, regulated and governed by many entities — including utilities (investor-owned, municipal and rural cooperatives); state, provincial and federal regulatory agencies; and independent system operators — all subject to legislative will, moving toward a high-penetration renewable future supported by a smarter grid won't be without obstacles.

AN INTERMITTENT FLOOD

Efforts are accelerating to replace fossil fuel as the primary fuel source for electricity generation with renewable generation options. While fossil sources will remain the dominant electric energy fuels for the foreseeable future, there is a steady worldwide trend towards renewable generation alternatives that requires that utilities act now to prepare for the future. Instead of being concentrated in a relatively small number of large generation sites, the renewable resources will be distributed on the transmission or distributed grid at whatever locations make the most sense for the particular technology.

The intermittency of renewable resources, such as wind and solar generation, leaves them as a viable source of energy, but constrained with respect to capacity value. The estimate commonly used in the policy and regulatory arena is that the capacity value of a wind generating plant to the grid is approximately the same as the plant's capacity multiplied by its anticipated capacity factor. A 100 MW wind plant with a capacity factor of 35 percent would provide a 35 MW capacity benefit to the electric grid, similar to a 35 MW conventional generator (see Figure 1).

Figure 1. Renewable Capacity Factors

Renewable Resource	Capacity Factor
Wind	28-40%
Small Hydro	35-75%
Solar Energy	27-42%
PV Electricity	14-20%
Biomass	75-85%

As the grid must balance generation and demand on a continual basis, and not just total energy production, the reduced capacity values for renewables have a significant impact on utility operation. Because the more abundant wind and solar renewable potential actually have the lowest capacity factors, proportionately higher amounts of renewable generation must therefore be brought online than fossil-fuel plants to compensate for the lower capacity.

In addition to the reduced capacity factor relative to overall facility power rating, the intermittency of these resources makes forecasting renewable resources difficult. Wind maps show the best locations in North America to develop wind resources, but these maps are based on long-term measurements and forecasts. They don't represent moment-to-moment variability. At one time or another, the wind does stop blowing. Developers of photovoltaic (PV) and solar thermal generation plants site their facilities in areas with the highest sun potential, but there will be days that storms, significant cloud cover or other factors will diminish production.

Moreover, solar thermal generation requires a significant amount of land and will likely be sited outside of urban areas. Photovoltaic installations, however, are increasingly being integrated into the general fabric of community infrastructure. And while wind generation currently is predominantly limited to utility scale wind technology that can be applied at the community level.

Suppose a distribution substation transformer rating and loading indicates it can support 30 MW of DG. Rather than allowing just 30 MW of combined wind, PV or other renewable resource to be connected, given the diversity and variability of the resources, utilities need to look at new applications that will allow them to connect a greater amount of each—potentially up to 30 MW of each, so that during the night and windy conditions, it allows up to 30 MW of windmill DG to be generating and during the day it dispatches up to 30 MW of PV. Or it can be a mixture of the available resources. This implies that the distribution operating company must constantly monitor generation resources and exercise some control over DGs in order to ensure the grid isn't adversely affected on the rare event that generation from all available sources is operational and being maximized.

All of this means that producers will encounter difficulty if they seek to offer accurate generation forecasts to the utility grid system operators in order to support the 1-hour, 1-day, or 7-day and beyond forecasts. Since the grid operator (whether the utility or a regional independent agency) is responsible for matching anticipated demand with expected generation resources, any less-than-reliable forecasting of renewable energy production might result in the grid operator maintaining a higher reserve margin than ought to be needed — at least until better experience and tools are available.

PHYSICAL BACK-UP

There are physical mechanisms to address the impact that natural intermittency has on the value that renewable resources provide to the electric grid. These solutions also must offer immediate reactive response to sudden changes in generation capacity. A survey of the marketplace produces a variety of available solutions to this dilemma, from adding spinning reserve to demand response and the expansion of system interconnections.

> The potential value of demand response increases as the dependability of generation sources decreases.

Additional operational (or spinning) reserve can be added to the system to address the intermittency of renewables. While a technically acceptable solution, this comes with potentially high costs — both financial and environmental — because spinning reserve plants are often gas fired turbine engines. Their low use factor gives them a high per-MW and per MWh costs, and so they are designed primarily for fast ramp and dependability — not low emissions.

Demand response (DR) and energy storage both help to address intermittency. DR refers to the solutions that allow utilities to curtail load based on preset conditions and agreements with customers. This can be direct load control (DLC), advanced pricing programs, emerging enabling technologies or a combination. Energy storage technologies allow renewable energy to be captured during periods of low demand or high generation and fed back into the grid when demand is high or renewable output is low. Energy storage technologies also provide stability during ramping periods.

Another approach uses complementary power sources to combine the particular renewable facility with a resource that has opposing generation patterns. An example would be combining wind and solar resources, or wind and hydro. Ideally, these complementary resources would also be renewable, but the challenge is to overcome the inherent geographical distribution of different renewable energy supplies.

Expanding the existing system interconnections with adjacent power pools to take advantage of diverse generation mixes also offers a viable solution strategy. Greater diversity of resources, including geographic diversity of a single type of generation resource, increases the overall predictability and reliability of the system. But this may require adding significant transmission infrastructure with its associated financial and environmental costs.

A further example of mechanisms to address the impact of intermittency is the application of new technologies to allow more visibility into the operation of the power grid. This is especially applicable for the distribution system, and can also provide control over the system to ensure system stability, performance and reliability.

The broader interpretation of proposed smart grid solutions can support all of these potential solution themes, but currently available and emerging technologies can specifically assist with demand response, energy storage and grid operations based alternatives. These solutions include new devices (sensors, switches, controls) out on the electric system itself; equipment and applications that engage consumers; energy storage technologies that allow renewable energy to be produced when it's available and used when it's needed; as well as more integrated control and operations.

THE DEMAND RESPONSE SOLUTION

Energy usage isn't constant. Except for a very few number of users — such as 24x7 server farms, or constant industrial multi-shift processes, energy consumption goes through a well-understood pattern. The pattern changes according to customer type, geography, day of the week, or season. But by aggregating the profiles for various customer classes, an overall system profile can be obtained. Utilities have relied on all available generation, interconnection resources, and traditionally built peaking plants to meet the demand at peak conditions. Demand response offers a different solution to this problem; rather than increasing available generation capacity to meet peak, the utility can reduce the load and lower the peak to meet available generation capacity. This option provides a much more economic and environmentally low-impact solution to meet peak conditions, which tend to occur less than 5 percent of the days on average.

For industrial or commercial customers, demand management solutions are customer-specific and usually involve shutting down processes or production lines. In office buildings, it could be cycling the air handlers and lowering lighting. For residential consumers, traditional demand response solutions focus on direct load control where the utility uses a combination of a special purpose communication network and customer premise equipment to control appliances. Due to the preponderance of residential loads, most utilities peak in the early evening when people return home from work. Much of this is A/C in warmer climates and space heating in cooler zones, with cooking and general appliance use contributing the peak. Direct load control programs have proven effective, and this proven basic load control technology remains very viable today, and a key tool for utilities to manage peak energy consumption.

Recent advances in technology have also resulted in more customer-interactive and perhaps arguably friendlier solutions such as controllable programmable thermostats (PCT) which function in a manner similar to DLC in that they allow the utility to control the A/C units, but these allow the customer to override the remote control. The availability of these PCTs is tied directly to the explosion of smart meter programs throughout North America that use a standard wireless Zigbee radio chip to communicate from the utility-owned smart meter to customer premise devices. These home area network (HAN) solutions leverage the Zigbee radio and smart energy profile message standardization to enable communication with PCTs, in-home displays (IHDs) and customer energy management solutions. The incremental cost of the imbedded radio chip and the end-to-end solution is a relatively small part of the overall project cost, but has significant implications for enabling a truly system-wide and eventually continent-wide demand response solution.

While this demand response capability offers benefits for normal system operations, regardless of generating type, its potential value increases as the dependability of the generation sources decreases. DR can be thought of as a negative load or a pseudo-generation source, and depending on its cost and the rules under which it's called, the DR resource can be used to balance unexpected or sudden reduction in overall system supply, or can be scheduled when there's a high likelihood of forecasted shortages — for example in summer months in the Southwest, when conditions are easily identifiable for potential shortage conditions. Advance customer notification and preparations can contribute to the impact. Numerous studies of the results of DR programs have shown a pre-customer potential load reduction of up to 1.4 kW when the primary appliance is an A/C unit.

A challenge facing many of the demand response programs being deployed today is that they are operated as stand-alone solutions, dispatched as economics or reliability requirements are defined in the energy control centers of the utilities or the regional independent system operators (ISOs). For the modern distribution grid, the next step forward will likely entail integrating a distribution management system (DMS) with a demand response system. This will allow the DMS to do load forecasting, distribution generation forecasting, take inputs from the load control authority and decide when to invoke a given DR program on a specific area of the distribution grid. This integrated approach allows the DMS to measure instantaneously how effective the actively running DR programs are at shedding the anticipated amount of load, and allows the distribution operating company to safely operate the distribution grid during peak loading conditions without having to coarsely shed load at the substation or feeder level, which might contain valuable DG resources. The integrated DMS-DR-DG approach also allows the distribution company to optimally reconfigure systems to support short-term anomalies as well as anticipated longer duration changes in either load or generation, based on forecasts.

EMERGING DMS TECHNOLOGIES

State-of-the-art DMS, coupled with system-wide communication networks, are transforming how utilities operate their distribution networks. The DMS applications can aggregate load and status information, access current state electrical models, run real-time power flow studies, and remotely engage generators or call load shedding solutions. The goal of the DMS implementation is to migrate the operation of all aspects of the grid from isolated, highly interactive processes into an integrated, proactive and automated solution set (see Figure 2).

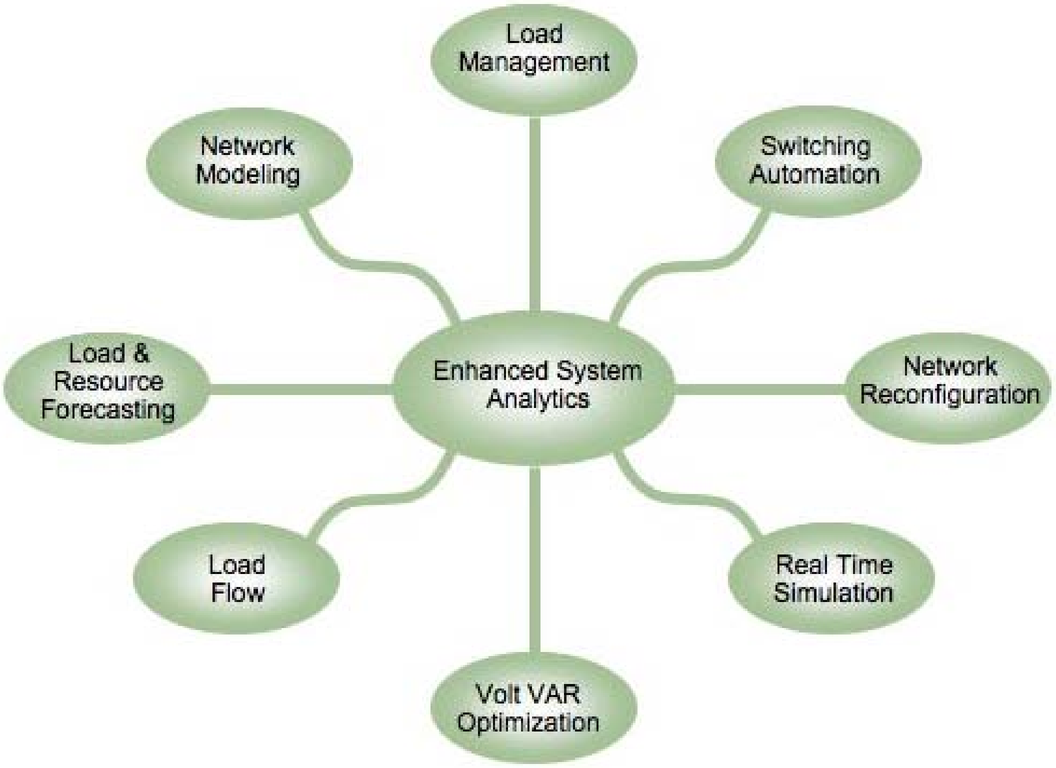

Figure 2. DMS-Centric Smart Grid Solutions

The ability to link the disparate applications to enhance performance and increase system optimization is extremely powerful. As an example, the integration of the load and DG forecasting capability (along with accuracy enhancing short- and long-term weather forecasting) with real-time power flow capability, a detailed network model and load management capabilities provides the foundation for a complete grid optimization solution. The new DMS solutions and remote monitoring devices are designed to bring the automated protection and control schemes out to the grid to automatically change settings to support relay reach and operation when feeders reconfigure themselves to allow DG to remain on-line.

The voltage-enhancing capabilities of the smart grid and DMS are an example of the future potential. The utility has traditionally been tasked with maintaining voltage within acceptable range at the end-customer delivery point. In a radial system, utilities developed a framework to accomplish this task. With a large volume of distributed generation, this becomes increasingly difficult. Older, traditional voltage regulators and capacitor banks that form the basis of current utility distribution system voltage management are inadequate for the future state. The response times of these devices are too slow to support the anticipated dynamic conditions. In addition, voltage regulators or booster controls traditionally operate in one direction while the future state system will be bidirectional due to the distributed sources.

As the utility portion of the power requirements is reduced, in favor of third-party or customer distributed sources, the complex interactions on the power grid can result in inadequate voltage support. As utilities still have ultimate responsibility for providing service within regulatory bounds, solutions need to be developed to manage voltage and reactive support in real time. It's a delicate balance of ensuring that distributed generators aren't harmed by power disturbances, as they can support the grid when most needed.

Supporting these DMS solutions are the communication networks that are evolving to support smart grid field devices, backhaul smart meter networks and enable direct-connect monitoring. There's no single network capable of meeting all the requirements of the smart grid, but a network of networks will combine to address bandwidth and latency requirements for the wide variation of unique applications, including system monitoring, distribution automation (DA), local control solutions and protection and control schemes. These include uWave, fiber and public and private WIMAX (and similar) networks, as well as smart meter networks.

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THE INEVITABLE REALITY

Notwithstanding all the market and regulatory issues, the increase in distribution connected renewable generation is a reality. The advancements in renewable technologies, coupled with design and manufacturing cost improvements, are resulting in large-scale wind being competitively priced to coal-fired generation sources. And while solar thermal and PV remain high-cost compared with fossil fuels, they continue on a downward trend. As the technology and cost efficiencies are translated down into the smaller scale installations, the widespread penetration of renewables on the distribution network is inevitable.

In parallel, utilities are increasingly exploring the evolving area of smart grid applications and integrated solutions, especially DMS. In addition to the well-publicized value of automated, self-healing network optimization benefits, specific applications such as improved volt-VAR optimization and integrated OMS capabilities provide significant financial, customer service and operational benefits. While the number of installed DMS installations is small, leading utilities across North America are aggressively pursuing their implementation. As the number of projects increases, the applications created, validated and deployed on these systems will also increase — further increasing their value. The challenge to utilities is to take advantage of the evolving technology opportunities for the sake of the benefits that these solutions offer as well as positioning the electric grid for a very different future.

About the author

Kevin Cornish is an Executive Consultant with 25 years of experience in the utility field, with particular expertise in Smart Metering and Advanced Metering Infrastructure (AMI) solutions, Demand Response and Energy Efficiency programs, and Smart Grid and related technologies. He has led strategy and business case development for utilities across North America examining the full breadth of AMI solutions: AMI technology, MDMS, demand response, distribution automation, and implementation requirements. Kevin holds an MBA in Marketing and Telecommunications Management; an MS in Electrical Engineering/Power Systems and a BSEE in Electrical Engineering & Computer Science.