Grid Reliability Depends on Big Data

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Abstract - The US electric power grid is undergoing revolutionary change. On the one hand reliability, economy, profitability and sustainability are in decline. On the other new sources and uses of power and energy are proliferating. A hierarchical bulk power grid with a few hundred thousand nodes of interest is being supplanted by literally millions of new distributed ones. Immense quantities of new data are being generated requiring new approaches to information and communications technology and applications. Effectively managing and using this big data will be essential. The emerging energy network will be enabled by the Internet of Things

Keywords - smart grid, smart meters, distributed energy resources (DER), autonomous operations, Grid Edge, information and communications technology (ICT), Internet of Things (IoT), Enernet

The US electric utility grid has for decades been a patchwork of five weakly interconnected synchronous AC grids. About 20,000 generating units of 1 MW or more in some 7,000 power stations generate power and energy. Electricity moves one way from the generators through some 70,000 substations and 160,000 miles of high voltage transmission lines to remote load centers where it is distributed and delivered over 5.5 million miles of distribution lines to electric consumers through some 140 million meters.

Generation and transmission (i.e., the bulk power grid) has long been a smart grid with real-time monitoring and control to maximize reliability and minimize the cost of energy production. Central station generation units have been dispatched to supply customers' varying needs in aggregate at the substation level within the constraints of the transmission and distribution systems and subject to the vagaries of weather, equipment failures, operator error, energy markets and other variables. The distribution edges of the grid, while immense, have been largely passive, not extensively instrumented nor actively controlled in real time.

The generation and transmission grid is the largest and most complex machine ever created, a true wonder of the world. Yet, it pales in comparison to an entirely new kind of grid that is emerging for two reasons: First, the legacy bulk power system model is decreasingly adequate in terms of economy, reliability, sustainability, security and profitability. Second, even if the former were not the case, disruptive enabling technologies and new business models are revolutionizing the legacy grid from the edges inward. The new grid involves an unprecedented quantity and diversity of new endpoints and associated data, often referred to as "big data."

The electric utility industry had a relatively modest introduction to big data as it moved from monthly meter reading and billing to more frequent meter reading via "smart meters." The goal was to facilitate customer demand response programs that would relieve some of the reliability stresses on the electric utility grid and economic pressures on utilities' business model. The usual 12 monthly meter readings for each customer grew to 730 hourly readings or more each month. In addition, other data points were being created including power on/off status, blink counts, high/low voltage, power quality, meter base temperature, meter tampering, etc. So, the industry went from a dozen data points per customer per year to thousands. Over the course of a decade the scope of data is increasing by three orders of magnitude, from less than 2 billion data points per year to more than a trillion. And this is only the beginning.

The demand response programs gained some momentum, but it was clear that they were not going to be sufficient to rehabilitate the legacy grid model. In the meantime, disruptive enabling technologies were revolutionizing the electric grid and industry in other ways. This included an accelerating proliferation of small, distributed renewable energy sources, particularly solar PV, occasioned by exponential improvement in performance versus cost along with innovative, entrepreneurial business models. Other disruptive, enabling applications are emerging from wind generation to rapidly improving batteries to hyper efficient micro turbines to fuel cells.

There are already nearly a million rooftop solar PV systems in place today and the pace of market penetration is accelerating. Research suggests that by 2020 nearly one-third of all generation capacity will be customer owned and operated, about half renewable and half conventional backup/supplemental. Suppose that ten percent of all retail customers were to eventually deploy on-site generation, storage, or management systems that affect bulk power grid operations. The number of nodes of interest in the grid would grow by two orders of magnitude from less than the legacy grid's 200,000 centrally monitored and controlled assets to nearly 15 million independent assets at what has come to be known as the Grid Edge.

All these developments further stress the legacy electric grid. Wind and solar are not dispatchable and cannot automatically follow load. Customers may even choose to operate their own conventional generators in ways that are not optimum for their electric utilities. Grid generation must be reduced to accommodate their output, or load must be controlled to match their output, or energy storage must be utilized to time shift their output. This will require new kinds of data, analysis and control. Even customer load is not staying put! Imagine what the distribution grid will face if the accelerating trend towards electrification of transportation causes to be moving around on the electric grid the equivalent of millions of points of demand and energy consumption comparable to residential homes?

The longstanding centrally monitored and controlled power production and delivery model is sorely pressed by an increasingly complex, distributed system of energy production, storage, management and markets. Visibility and control will not be achieved by traditional, centralized data centers and control centers due to the mushrooming scope and stochastic nature of the endpoints involved. New approaches will be required for distributed data gathering and analysis, and for distributed, autonomous control.

How can a system with millions, ultimately billions of independent, autonomous, even stochastic inputs and outputs be monitored and optimized? Fortunately, before the DER revolution hit the electric utility industry, distributed communications and computing revolutionized the information and telecommunications industry. As the grid is experiencing orders of magnitude growth in complexity, information and communications technology (ICT) has already experienced far greater increase in capabilities.

What other network has grown from the number of connected customers to tens of billions of intelligent, independent endpoints? The Internet of Things has. Cisco has suggested that by 2030 there will be 50 billion things connected to it worldwide. It is, in fact, the ultimate smart grid: a powerful, reliable, resilient, efficient, and economical system of independent endpoints connected by real-time, two-way, digital communications. It is this truly smart grid that can supplement and maybe even eventually supplant the legacy bulk power grid.

Consider distribution fault anticipation, in microcosm an example of how the ICT revolution can improve grid reliability. New on-site monitoring devices can sample the AC waveform hundreds, even thousands of times per second. With on-board GPS and atomic clock as well as analytics and automation, they can provide a time-and-location-synched picture of grid performance. Advanced computer algorithms can detect patterns that suggest incipient problems with the grid. Or they can help monitor and optimize the grid edge more rapidly, accurately and flexibly in the face of increasing complexity and uncertainty. The traditional "run to fail then recover ASAP" mode for transmission and distribution can be "anticipate and avoid" interruptions of service. This can mean a dramatic improvement in the reliability, safety, security, and efficiency of the grid.

Robert Metcalfe, co-inventor of the Ethernet and smart grid guru recently said at a conference, "Like the Internet, energy will be distributed; there will be a layered architecture that provides flexibility and reliability . . . and the energy will be cheap and abundant like bandwidth." He has previously asserted that the electric grid will converge with the IoT in an information, communications and energy network, an EnerNet.

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