SMART TRANSMISSION: MODERNIZING THE NATION'S HIGH VOLTAGE ELECTRIC TRANSMISSION SYSTEM

WIRES

(Working group for Investment in Reliable and Economic electric Systems)

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WIRES PREFACE

WIRES presents this "primer" on the modernization of the nation's electric transmission system as part of its ongoing effort to inform policymakers about the technological, operational, and regulatory challenges and opportunities confronting the power industry. As it has long emphasized, WIRES contends that major new investment in a stronger high voltage transmission system is key to a clean energy future, to meeting the demands of increasing energy consumption, to reducing congestion and facilitating competitive markets, to increasing reliability, and to promoting resource diversity. A strong transmission system must also be an intelligent system that employs the best available technologies and materials. While, for example, the transmission system must be expanded and upgraded to reach major, heretofore untapped, wind and solar resources, it must also be animated by advanced digital technologies in order to integrate those resources into the electric system in an economically and operationally efficient way.

The industry's commitment to a "smart" transmission system is not new. Even during periods when investment in transmission lagged far behind investment in fossil generation, the transmission system was already becoming "smart." Across the high voltage transmission system, to quote one expert,

> the amounts of power controlled and traded are huge, handled by very large lines and system controllers who control hundreds of power plants. This part of the grid has already been using hourly pricing as well as direct control of plants and lines to balance the system and trade energy for many years. Moreover, the engineers who design and operate system controls have long used some of the

> most advanced computing and control tools available. (Fox-Penner, *Smart Power: Climate Change, the Smart Grid, and the Future of Electric Utilities*, at 34-35)

The transmission sector is nevertheless undergoing further "modernization." New communications technologies and advanced materials promise to optimize the capacity and efficiency of the electric system. These improvements are coming in the following technical areas, around which this report is organized:

- Integrated communications
- Sensing and measurement equipment
- Diagnostics and analytics
- Automation and controls
- Advanced materials and superconductors
- Energy storage
- Advanced components and power electronics
- Human interfaces and operator support

WIRES urges readers to approach this subject matter with an awareness of the cost and complexity of the modernization process. If anything, the report demonstrates that utilities and other transmission providers face difficult choices about when and where to invest in new technologies. Integrated communications and new control technologies represent off-the-shelf opportunities to improve day-to-day system operations in the near term. Sensing and metering equipment has advanced dramatically in the past two decades. Training operators to manage system controls in a new, more highly automated, and increasingly demanding and stressful environment is not optional. Nevertheless, these entail new investments in personnel and materiel that will, in many if not most cases, will ultimately require support from ratepayers.

In the intermediate term, the industry is using the revolutionary advances in computing technologies to diagnose system failures faster, analyze future electric system needs more thoroughly, and make more efficient planning decisions for the future upgrades and expansions of the transmission system. These capabilities will become even more essential to meeting the demands of public policies and regulatory decisions that may actually magnify the challenges of creating a truly 21st Century transmission system. Meeting those challenges will nevertheless entail financial commitments that can be difficult to make in an environment of financial and policy uncertainty.

Long term, there are potential technological game-changers which may only be attainable by significant investments in developing technologies now, or which may ultimately -- 40 or 50 years from today -- render today's grid obsolete or revolutionize its nature and operations. New materials offer tremendous promise for construction of transmission lines and towers that transfer much greater quantities of power with fewer losses. Superconductivity and industrial grade energy storage could attain these benefits to an even greater degree while virtually ending the significant aesthetic and land use difficulties faced by overhead conductors. The costs of commercializing these technologies are very large and it may be unrealistic, if not impossible, for electric customers, stakeholders, and regulators to insist on major private investment in deployment of these kinds of technologies in the foreseeable future, especially while there exist more immediate needs to invest in available technologies that can today ensure the reliability of the electric system, access to diverse generating resources, and the liquidity of wholesale power markets.

Making the transmission system smarter is only part of a larger solution to the challenges facing the wholesale electric system. The Brattle Group has estimated that the nation will need to invest up to $300 billion in its electric transmission system by 2030, an estimate that (while tempered by the flattening of demand during the current recession) probably represents a mainstream opinion about what it will take to meet rising demand, to access location-constrained generation, and to compensate for a quarter century when investment in the transmission system was in decline. In other words, the smart grid must also become stronger; it will need to reach new low-carbon resources; congestion issues must be addressed; its regulation can be further rationalized. Conventional transmission lines must be built and then be operated as a true interstate network. Emerging technologies will optimize the benefits of both existing and new transmission facilities. Smart technologies will therefore be an important component of the overall investment in the high-voltage electric system. Because the digital economy depends on reliable supplies of electricity, smart transmission is and will remain the first, and arguably the most important, "app" of the Smart Grid.

WIRES intends this White Paper to highlight the aspects of the Smart Grid that few see or think about. It collects information from a variety of sources, as well as the experiences of WIRES members, in order to provide an introduction to some of the most widely applied, but least talked-about, technologies in the power industry. Our use of technical terms and concepts is more or less unavoidable but the general reader should find the basic themes and information herein to be quite accessible. In pursuit of its basic educational mission, WIRES previously published papers on transmission cost allocation, renewable energy integration, and other subject matters (which can be found at www.wiresgroup.com). WIRES always welcomes readers' comments.

We wish to acknowledge the special contributions to this report by Oncor Electric Delivery, Ms. Alison Silverstein, and our Smart Grid Committee.

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EXECUTIVE SUMMARY

North America's high-voltage electric transmission system, often referred to as the "grid," is today an aggregation of evolving networks of complex physical and information systems that enable the flow of electricity across and between regions. Transmission systems are already "smart" in the kind of sophisticated monitoring, market, and control technologies employed to manage the flow of power. However, the physical and public policy demands on that system are changing and transmission providers, both incumbent utilities and new market entrants that propose to build and own transmission facilities on a merchant basis, and grid operators are making new investments in physical transmission and information technology infrastructure to modernize the grid and make it stronger, smarter, and more efficient and secure.

For the high voltage transmission system, the modern smart grid exists at the intersection of four elements: (1) the physical infrastructure of the electric system; (2) advanced information technologies such as measurement, analytics, automation and controls; (3) high-speed bi-directional communication of data and control commands; and (4) advanced components such as power electronics, energy storage, and composite core transmission lines and superconductors. These technologies, deployed in a coordinated, strategic fashion, are making the transmission system more reliable, secure, flexible, efficient, economic, diverse, and environmentally sustainable.

This report reviews the elements of smart transmission and the investments that transmission providers are making to modernize and improve North America's high voltage grid. Although today's high voltage transmission system already contains high levels of sophisticated monitoring, analysis, automation, two-way communications, and power electronics, new investments are increasing the grid's digital management capabilities and efficiency as well as its throughput and reliability.

This report focuses on transmission-level technologies and the new investments being made to enhance the transmission system with those technologies. It does not examine the application of smart grid technologies at the distribution level, or behind the customer's electric meter – applications that are more typically associated with the term "smart grid." Last, this report seeks to place in perspective investment in smart technologies and in the physical transmission capacity that will be more fully utilized as part of the Smart Grid.

I. SMART TRANSMISSION: AN INTRODUCTION

Section 1301 of the Energy Independence & Security Act of 2007 ("Act") established a federal policy that the nation's electricity transmission and distribution system should be modernized to maintain a reliable and secure electricity infrastructure. The Act laid out the goals and characteristics of the smart grid. For purposes of the transmission system, those characteristics include:

- Increased use of digital information and controls technology to improve the reliability, security and efficiency of the electric system,
- The dynamic optimization of grid operations and resources, with full cyber-security,
- The development of standards for communication and interoperability of devices and equipment connected to the grid, including the infrastructure serving the grid.

The Act makes clear that the smart grid, including smart transmission, should also support the deployment and integration – actual or potential -- of demand-side resources, distributed generation, renewable generation, energy storage, and electric vehicles.

The modern transmission system is information-rich and complex. It must therefore be complemented by sophisticated processes and a workforce trained to understand, support, and exploit the capabilities of the system. Smart transmission, like the rest of the smart grid, is (or will be) characterized and built upon clear technical interoperability standards, open architectures that enable technological and process innovation, and extensive physical and cyber-security protections.

Even before the recent upswing in smart grid investments, the bulk power system was comprised of central station generation, transmission, and the dispatch and market systems that operate them. Together, it was the "smartest" component of the entire electric system. The system of communications-linked power plants, substations and control devices, informed by SCADA systems (Supervisory Control and Data Acquisition), and high-speed relays that collect grid and device information, make distributed control decisions and feed or respond to complex market or other dispatch phenomena. Smart grid investments today are building upon that foundation to provide an ever-increasing level of reliable and market-responsive service, as discussed below.

II. SMART TRANSMISSION TECHNOLOGIES AND FUNCTIONS IN THE MODERN ERA

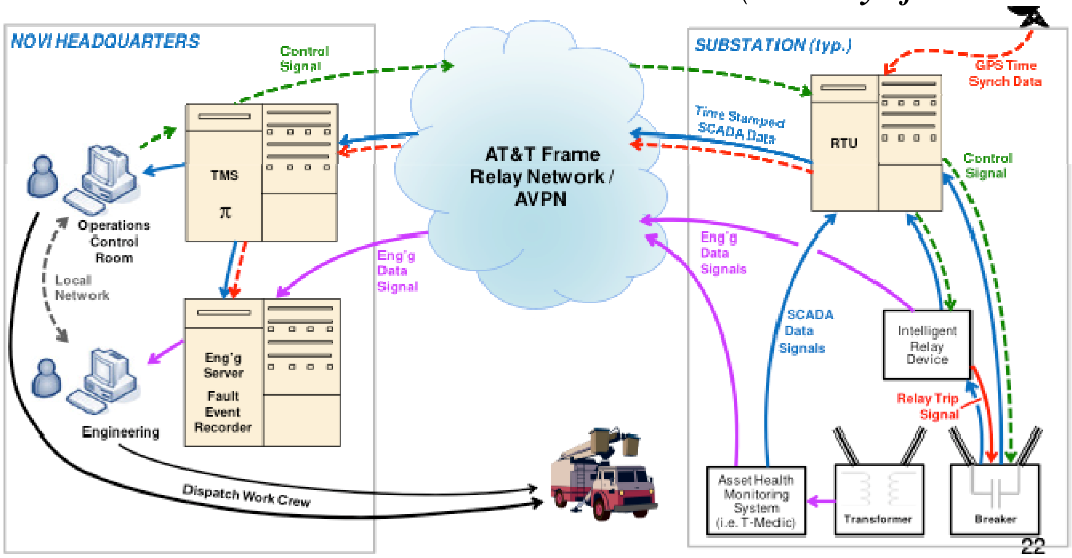
The principal elements of smart transmission technologies and grid modernization, including the integrated deployment of advanced materials, power electronics and energy storage, and examples demonstrating how North American transmission providers are deploying those technologies to improve the grid, are set forth below.

A. Integrated Communications

Many of the nation's utilities and regional grid operators are investing in high-speed fiber-optic communications systems to enhance their existing grid operations. These systems deliver two-way communications, collecting grid and device condition information from distributed monitoring devices and delivering control commands to and between control rooms, breakers, transformers, power plants, relays, and other equipment. Dedicated fiber optic systems are complemented with communications across the public and private networks, including fiber, wired, wireless and satellite technologies.

The communications systems that support smart transmission use advanced, standardized communications technologies and protocols including Local Area Networks and IP-based switches and routers at a substation, to connect all the sensors, SCADA systems, and other equipment within the substation, and provide a backhaul gateway to centralized control centers. The control centers link to external Wide Area Networks to exchange information and controls with other utility and regional networks. These communications technologies provide internal and wide-area operational security, expand both communications and substation functionality, simplify system upgrades and expansion, and expand the set of communications providers and technology options available to the transmission provider.

Illustrative utility internet-based broadband communications network (Courtesy of ITC Holdings)



B. Sensing and Measurement Equipment

Real-time monitoring and controls leverage high-speed communications and analytics – both centralized and distributed across the transmission system – to improve operators' observation and awareness of real-time system conditions, enhance their analysis and understanding of what is happening on the system, and enhance their ability to respond to system disturbances.

Synchrophasor technology, comprised of phasor measurement units or "PMUs" that collect time-synchronized data on frequency, voltage, electrical wave phase angles, and other system conditions at speeds of 30 samples per second (or faster), is rapidly changing how transmission systems are understood and operated. Current SCADA systems measure grid conditions every 4 to 6 seconds, which can miss important information about dynamic, high-speed changes in frequency, transmission line faults, and other grid stresses. Transmission owners are placing PMUs at key substations and power plant buses to gain wide-area observability and situational awareness across entire regions and interconnections.

Aggregated GPS-synchronized phasor data will change the transmission system from a data-poor to a information-rich network and transform both the understanding and operation of the entire system. The real-time, highly granular detail provided by phasor data allows operators to quickly identify developing grid problems, identify preemptive corrective actions, and implement faster automated and human control responses.

There were about 250 PMUs installed and networked across North America's transmission systems in early 2010; with the Department of Energy's Smart Grid Investment Grants and Demonstration Grants, another 850 PMUs will be installed across the nation by 2014. Those grants, matched by industry funds, are also supporting extensive work to develop new and improved phasor data applications to improve grid reliability and economics, including visualization tools, monitoring and integration tools for intermittent generation, in-substation automated device controls, and congestion management. Major synchrophasor technology projects are being implemented by the Midwest Independent System Operator, PJM Interconnection, Western Electric Coordinating Council, New York Independent System Operator, ISO-New England, Duke Energy, American Transmission Company, Dominion Virginia Power, Southern California Edison, and Entergy. These entities are building dedicated, high-speed communications networks to serve their expanded synchrophasor systems.

Protective relays and other intelligent electronic devices (IEDs) are used to monitor the condition of transmission lines and other equipment. IEDs can analyze and pass on the data they collect and can self-diagnose their condition and alert the control room to a problem. Relays, like many other IEDs, act without control room computer or operator intervention – when the relay detects a fault, it directs the breaker to trip, followed by a reclosing sequence until the fault clears or the circuit locks out.

Transformer monitoring is another example of how advanced sensors protect grid assets to improve grid reliability. ITC Holdings and other transmission operators have deployed a suite of sensors at key high-voltage transformers to monitor and analyze their condition and alert maintenance experts if the sensors reveal potentially problematic out-of-normal conditions. Transformer protection monitoring tools include dissolved gas in oil analysis, power factor bushing monitors, temperature monitoring, ground-induced current monitoring, and fan and pump monitoring to verify effective equipment cooling. ITC found that its transformer bushing monitoring system averted a potentially catastrophic failure when that system indicated that a key auto-transformer was failing at the interconnection between Michigan and Ontario; the warning alarm allowed ITC to carefully replace two critical bushings before they failed in service and caused a major outage.

Sensor-based condition monitoring can have a large impact on the reliability and utilization of the asset-intensive transmission system. It will afford transmission system managers an opportunity to replace or repair aging, vulnerable equipment before it fails, and to spot and remedy overloaded transmission lines and transformers before they can turn into reliability challenges or even unplanned outages. Extensive use of sensors on the transmission system will allow transmission system managers to provide more electricity through aging infrastructures, while spending funds on the transmission system more strategically and cost-effectively.

C. Diagnostics and Analytics

Transmission operations require a number of sophisticated diagnostic and analytical tools, including:

- Network topology processor makes sure that the on-line and real-time information seen in the control room are consistent with field conditions;
- The state estimator approximates system status, predicting power flows within a five-minute run cycle; although state estimators operate today using estimated data, several transmission system managers are planning to run their state estimators using real-time synchrophasor data;
- Contingency analysis is a tool that simulates the failure of individual grid components (i.e., the loss of various transmission or generation elements) to determine how each contingency would affect the grid, and how the grid should be repositioned or changed to restore safe operating conditions.

Dynamic line rating technology is a good example of how new smart grid analytics can relieve grid congestion and transmission constraints as well as protect reliability at limited cost. Oncor Electric Delivery utilizes daily regional weather forecasts to establish daily line ratings. Several utilities are demonstrating dynamic line rating technology that monitors the line sag and temperature, to calculate the line's capacity in real-time and provide that information to system operators; at lower temperatures, the line can carry more electricity, and at higher temperatures the operator can curtail the line with more precision for safe operations while protecting the life of the conductor. Thus dynamic transmission line ratings allow maximum safe flows on transmission lines to reduce congestion and related market costs.

The combination of geo-spatial information management with field force automation (an advanced form of workforce management) is another diagnostic and analytic tool that contributes to smart transmission and utility efficiency and productivity. Utilities use geographic information systems to track transmission assets and link those assets to maintenance management systems. Field tasks and workers are integrated with geospatial information, so managers can track field inspection, maintenance and repairs in real-time, plan and direct construction work, or re-dispatch field technicians as needed. The integration of asset, workforce, and geospatial information across multiple departments and functions improves system reliability, speeds emergency response, reduces operational costs, and improves worker productivity.

Event analysis is the marriage of enhanced monitoring with data analytics. Proactive event analysis uses synchrophasor and other data to quickly identify potential or emerging problems on the system, and identify corrective actions to prevent or mitigate those problems. Forensic event analysis uses phasor-generated data, security control and data acquisition ("SCADA"), and other data to understand why a "grid event" such as a rapid change in voltage support or a service interruption occurred, and thus how to prevent the next such event. All event analyses aggregate the GPS-based, time-synchronized data captured by PMUs and high-speed digital fault recorders in substations across the transmission system, and use automated procedures to analyze the transmission event, determine its cause, and find whether equipment operated incorrectly. Over time, examination of forensic analyses across multiple events can reveal important trends and operational issues.

Most grid analytics rely upon high-quality, high-resolution models of how the transmission and generation system and their component parts operate. These models are fundamental to modern transmission operational activities, including state estimation, network topology processors, security-constrained economic dispatch, contingency analysis, operator decision support tools, congestion management, and all of the automated protection and control strategies distributed across the system and built into many of the intelligent electronic devices. As more detailed synchrophasor data becomes available about real-time grid and device operations, those data are being used to check, calibrate and refine the various grid models. These improved models will produce more accurate analyses for operations and planning, which help to prevent outages, improve reliability, and improve asset utilization.

D. Automation and Controls

Most U.S. utilities have been investing in substation automation, with digital relays and major substation equipment linked by automated controls linked by an internal Local Area Network ("LAN"). Relay coordination for transmission system protection drives coordinated controls for circuit breakers within the substation. Substation automation can be based on one or more technical standards, including DNP3 and IEC 61850,[1] to ensure interoperability for substation commands and data exchanges.

Substation automation can reduce operational expenses and improve grid reliability by bringing multiple control and monitoring systems and data flows onto a single secure, high-speed IP network. Substation automation allows reliability actions and restoration of service (such as fault location or re-closures)

[1] Lebakken, Thomas & Dominc Orlando, "Substation Automation and Communication Standards: IEC 61850 and DNP3"; accessible at http://www.elp.com/index/display/article-display/302693/articles/utility-automation-engineering-td/volume-12/issue-8/features/substation-automation-and-communication-standards-iec-61850-and-dnp3.html

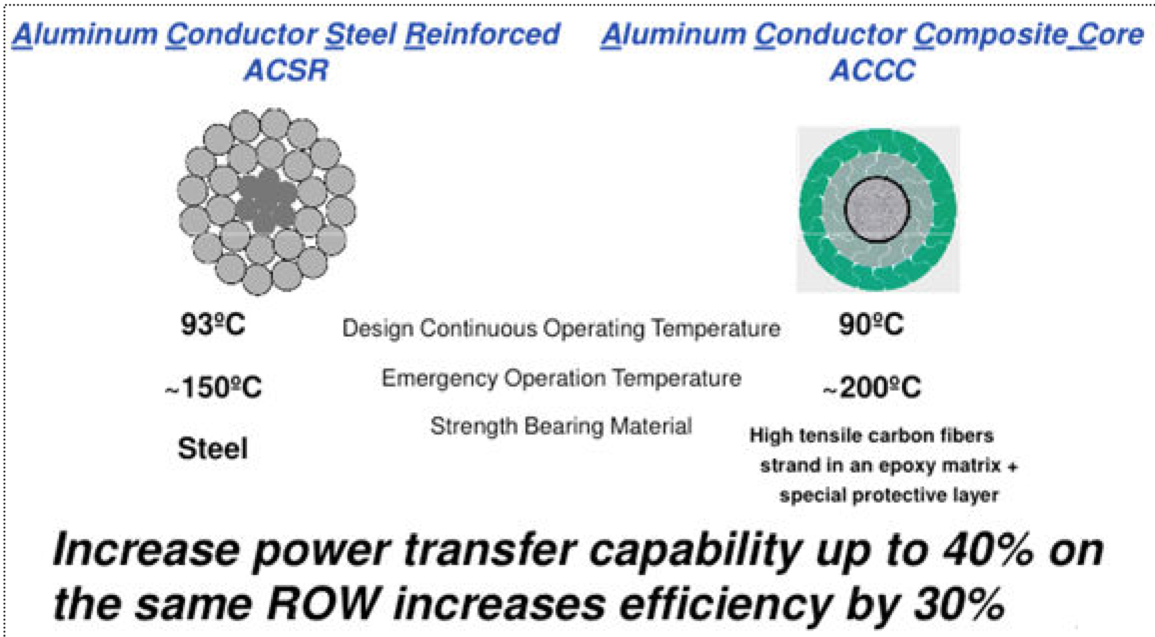
to occur faster with little or no human engagement. This lets utilities use their human workforce more efficiently, while automated applications such as condition-based maintenance reduce the need for service calls. Condition-based maintenance also allows utilities to reduce costs and improve reliability by moving away from time-based maintenance to maintenance triggered by changes in equipment condition and performance.

Energy Management Systems (EMS) have evolved from limited systems that provide remote control over distant transmission equipment, to incorporating SCADA that collect grid information and issue control directives. EMS is complemented by Load Frequency Control to balance load demand with power generation in real time, and Automatic Generation Control systems to manage generator operations for frequency and voltage provision.

E. Advanced Materials and Superconductor

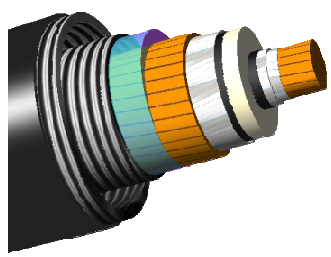
Transmission owners like Dominion Virginia Power and Centerpoint are using new types of conductors for transmission line upgrades in areas that cannot accommodate new transmission lines because of environmental sensitivity or urban density. Aluminum core conductors (Aluminum Core Steel Reinforced and Aluminum Conductor Composite Core) are high-temperature, low-sag wires that can replace traditional transmission lines to provide as much as 40% greater throughput without greater weight or sagging.

Advanced Conductors Increase Electric Transfer Capacity
(Courtesy of American Superconductor Corporation)



The first superconductors were developed in 1911, but it was the discovery of new, ceramic High Temperature Superconductor (HTS) material in 1986 that brought about a virtual revolution in the application to the field of electricity. HTS require less cooling, making superconductors more economical, opening vast new markets, and are being used in several ways in the modern transmission system. Superconductor cables have three to ten times the transfer capability of regular conductors, with very low impedance, so it can be placed in the transmission system to relieve congested or overloaded transmission lines or increase the capacity of a space-constrained substation. HTS is being applied in transformers, generators, motors, power cables, and stand-alone fault current limiters. Power cables carrying hundreds of megawatts have already been successfully demonstrated in the United States grid such as a 138kV installation in Long Island Power Authority (LIPA) and a 13.8kV installation in American Electric Power (AEP). Their ability to carry gigawatts of power through small rights of way can change high-voltage transmission system approaches in the years to come. Superconductor cables with fault current limiting capability allow increased power flows while managing fault current problems. Superconductor cable manufacturers also encourage the use of their HTS DC transmission cables in combination with HVDC converter technology to create "electricity pipelines" to carry high volumes of renewable electricity over long distances.

Transmission Level High Temperature Superconductor Cable (Courtesy of American Superconductor Corporation)



F. Advanced Components and Power Electronics

Advanced components and equipment are important elements of smart transmission and grid modernization. One such component is gas-insulated switchgear, which uses new cooling methods to make high-voltage substations more compact. For instance, a substation with gas-insulated switchgear can be shrunk to about one-fifth the size of a substation with conventional air-insulated switchgear.

Flexible Alternating Current Transmission Systems ("FACTS") devices use power electronics to improve the security, capacity and flexibility of high voltage transmission system. Static VAR Compensation ("SVC") is a robust, advanced electronics technology that uses high-speed controls to switch capacitors and reactors in response to electrical disturbances. Oncor Electric Delivery in Texas has installed two SVCs to provide grid voltage support while reducing the need to run costly local generation. Series compensation is a FACTS technology used to manage reactive power and reduce transfer reactance, which improves transmission system transient and voltage stability. Thyristor-controlled series capacitors are a form of series compensation used to damp inter-area low frequency oscillations. Static compensation (STATCOM) FACTS devices such as AMSC's D-VAR systems are being widely used at wind plants to detect voltage disturbances and inject reactive power as needed to stabilize and regulate voltage.

High voltage direct current ("HVDC") transmission uses power electronics to flow well-controlled, large volumes of power (400 kV and higher) across long distances (greater than 350 miles) without reactive power requirements and uncontrolled loop flows that affect alternating current transmission. In the U.S., HVDC lines are particularly useful for underwater cables; it is the likely technology to be used to deliver offshore wind generation to on-shore customers. HVDC systems can be installed back-to-back to interconnect independent power grids without synchronously interconnecting them; because HVDC systems cannot overload, they can block cascading line trips from flowing from one region or interconnection into another. Voltage Source Converter HVDC technology provides the security and benefits of high current and voltage controllability with multiple on- and off-ramps, and also offers "black-start" capability to power up networks and power plants that lack auxiliary generation.

G. Energy Storage

Diverse energy storage technologies have the potential to reshape and expand transmission system capabilities. Pumped storage hydroelectric facilities have proven to be highly economic in storing energy for release on peak. Bulk energy storage technologies such as pumped hydro and compressed air energy storage can be used to absorb large quantities of intermittent renewable generation (principally wind), and make that energy available when needed. This same time-shifting function can be performed by batteries matched to photovoltaic generation and distributed thermal energy storage that link off-peak wind to reduce on-peak air conditioning power requirements.

Batteries and flywheels can be used for back-up and supplemental power at utility substations, as well as for fast-acting voltage management and power quality protection buffers at wind and solar power plant busbars. Superconducting Magnetic Energy Storage ("SMES") devices and ultra-capacitors, units act like storage devices in that they provide fast-response, fast-recharge services that contribute to local grid voltage and frequency management. These storage technologies will be vital for integrating high levels of renewable generation into grid operations.

Electric vehicles are potentially a special form of power storage that could eventually play a large role in supporting the electric system. Electric vehicle batteries, if managed carefully, could be plugged in during off-peak hours to recharge the batteries, absorbing large amounts of renewable and minimum-load generation. During on-peak hours, vehicles could be re-connected to the grid to help meet peaking capacity or ancillary services demands. The storage area holds enormous potential for enhancing electrical system efficiency, if these prospective system additions prove economic.

H. Human Interfaces and Operator Support

The wealth of data and capabilities offered by the smart grid have little value if the grid's human managers cannot find and understand essential information about the grid in a timely, comprehensible, and prioritized way. Interface technologies convert information – whether from a weather forecast or a synchrophasor-based wide-area measurement system – into information that operators and managers can understand at a glance. A host of data-display techniques such as animation, color contouring, and virtual reality help give data relevant meaning for operators. Techniques are being developed to show the data behind particular displays, stacking and revealing additional levels of relevant detail. Behind the displays, sophisticated data mining, variance analysis, and other screening tools must sort through the incoming data to identify which data matter and when, distinguishing between normal and potentially problematic conditions in a context-sensitive fashion (for instance, weather and traffic conditions matter for storm outage restoration but less so for peak demand conditions). The industry is conducting extensive research and testing on how to use visualization, dashboards, and other measures to improve operators' understanding and response to grid conditions.

Operating companies of ITC Holdings and other utilities and grid operators use dynamic displays to help operators visualize grid conditions and enhance their situational awareness. ITC's EMS delivers a variety of displays at the desktop that allow operators to assess and drill down into key system integrity parameters, including equipment voltage thermal conditions relative to system operating limits, power flows, reactive reserves, and the status of neighboring transmission systems.

Decision support tools are becoming more powerful and useful now that those tools can be informed by phasor data and other real-time grid condition information. One valuable decision support tool builds on contingency analysis to create a set of options for an operator to respond to a new grid event, giving the operator several mitigation actions and predictions of the potential impacts of each. Fast optimization technologies, artificial intelligence, and advanced pattern recognition tools (based on mining historical data) combined with visualization tools, permit operators to better understand those options, share them with co-workers, implement chosen actions quickly, evaluate their impacts, and look for new options as needed.

Operator training is evolving along with smart grid technologies. Because today's electric system is more challenging to operate and subject to greater physical stress than ever before, operators today are being given far more technical electrical and operations training than their counterparts did only 20 years ago. Training methods have changed along with operators' tools. Today training includes virtual reality, replaying actual historic events and hypothetical events on a training simulator to make operators familiar with how the system responds in unexpected situations, and making operators more comfortable with their system understanding and response capabilities in emergency situations. Industry-wide operator certification programs are recognizing changing operator training needs and validating training programs as well as individual operators' training accomplishments.

I. Interoperability

A workable, cost-effective smart transmission system rests on a foundation of interoperability. Interoperability means the capability of two or more networks, systems, devices, applications or components to exchange and readily use information securely, effectively, and with little or no inconvenience to the user. Interoperability is achieved through development and use of a broad set of shared technical protocols and standards for physical, information, and communications management that ensure that all parts of the system can interface and interact effectively.

Smart grid technical standards are based on "open" architecture; that is, developed and maintained by a collaborative, consensus-driven process with wide participation by all relevant and affected parties, without domination by one organization or group. Most of the technical standards affecting transmission system operation and architecture are developed by standards development organizations that include the IEEE (the Institute of Electrical and Electronics Engineers) Power & Engineering Society, IEC (the International Electrotechnical Commission), NEMA (the National Electrical Manufacturers Association), and NERC (the North American Electric Reliability Corporation). Standards relevant to communications and information technology used for the smart grid (such as Ethernet and Internet Protocol-based communications) are imported from other industries, where they were developed by organizations such as the IEEE Computer Society, ISO (the International Organization for Standardization), and ANSI (the American National Standards Institute). In 2007, Congress tasked NIST (the National Institute of Standards and Technology) with coordinating interoperability standards for the smart grid. When NIST achieves consensus on such standards, they are submitted to the FERC for ratification through the rulemaking process. Thus far, FERC has received from NIST standards addressing transmission, cybersecurity, and substations.

Some of the most pressing standards governing smart transmission being employed today entail the harmonization between transmission standards IEEE 37.118 and IEC 61850 relating to substation equipment, transmission data, and time synchronization.[2] Another important standard is ICCP (Inter-Control Center Communications Protocol), an international industry standard used by transmission owners to exchange data between control rooms, local distribution

[2] National Institute of Standards & Technology, "NIST Framework and Roadmap for Smart Grid Interoperability Standards, Release 1.0," Special Publication 1108, at page 90, January 2010.

companies, RTOs, ISOs, and generators. The collected transmission-related protocols and standards will accelerate the development of interoperable smart transmission equipment and meaningful, actionable transmission data for wide-area situational awareness, equipment controls, and many other purposes.

III. THE BENEFITS OF SMART TRANSMISSION INVESTMENT

Smart transmission investment provides a range of benefits to power customers and to the markets that support the electricity trade. Although they vary according to the type and location of smart technologies, installation of new digital technologies materials and implementation of the functionalities identified above are aimed at achieving the following:

- Increased reliability
- Increased electricity throughput at lower delivered cost
- More efficient fuel use for generation, yielding lower air emissions
- Greater use of renewable and other clean generation resources, with lower operational integration costs
- More effective use of energy storage to lower the costs of peak electricity provision
- Facilitating third party participation in the power system
- Fostering wholesale and retail markets by improving information available to customers and market participants on grid conditions and electricity prices and usage

Advanced technologies are proving their worth on the grid every day. Although as widely deployed across the transmission system as on any other part of the electricity system, modern technologies themselves are not a panacea for what afflicts the system. Despite the installation of modern communications technology on the high-voltage network, a significant reduction in direct, real-time human control of all aspect of the system in favor of equally (if not more) reliable automation is just beginning. The smart transmission system of the future will be adjusted a myriad of FACTS devices over a wide area to maintain the grid in a steady state and it will do so faster than a human controller possibly could. In addition to improved relays, ubiquitous broadband, and common control platforms, the development and deployment of an information-enabled dynamic control infrastructure, operating like "autopilots" from a reduced number of proprietary control platforms, will be essential if we are to significantly reduce the potential for human error in the interest of maximizing efficiency and safety. Moreover, the ability of the grid control system to "heal" itself promptly when an interruption threatens or occurs will depend on use of EMS systems and state estimators that archive millions of past system "states" with which they can test current operations and make adjustments. The system will actually evolve.

Although modern and smart grid investments will strengthen the transmission and generation system in many ways, smart grid investments complement and supplement but cannot replace conventional “wires in the air and steel on the ground” in terms of new or upgraded facilities. Computers, information technology, and communications alone cannot deliver generation from location-constrained renewable power plants to customers if physical transmission capacity either does not exist or is very limited. Congested transmission lines cannot deliver high volume of power between regions without construction of new high voltage AC or DC lines. Large metropolitan areas with growing loads will need new smart substations and other equipment to maintain even existing levels of reliability. Enhancing the physical backbone of the high voltage transmission system may be needed to improve system redundancy and resilience in response to the potential for terrorism and the threat to cyber-security.

On a per capita basis, Americans are consuming more electricity than ever before. Even with growing use of energy efficiency, demand response, and distributed generation, new challenges like demographic shifts and concentrations of energy users, urban sprawl, and changing patterns of energy use will drive the need for new transmission facilities. Economists that have studied various future scenarios predict that the nation will require as much as $300 billion in transmission investment by 2030, only about one-third of which will be a direct response to public policy directives that necessitate increased reliance on renewable energy resources. Much of this investment will be driven by the fact that most of the existing transmission system was built over 30 years ago, and many of those facilities have been over-utilized and insufficiently updated or maintained. Consider that 70% of America's transmission lines are 25 years or older; 70% of the large power transformers are 25 years old or older; and 60% of the circuit breakers are more than 30 years old. Consider further that most of those facilities were built before digital technologies were available. Failed or degraded transformers have caused restricted thermal ratings or rerouting that caused hundreds of millions of dollars in congestion costs and reduced the region's grid reliability over the past few years. Such failures have resulted in local brown-outs and outages and, on occasion, caused wide-area black-outs. According to the Department of Energy, major power outages and power quality problems cost the U.S. economy as much as $180 billion annually. With increased load on the system and transmission over greater distances come greater line losses and wasted energy. In the absence of major load reductions, only technology-driven efficiencies or significant transmission capacity improvements will be capable of maintaining system throughput efficiency.

Capacity constraints on existing transmission systems in some regions make more difficult any interconnection of new generation to the system. The challenge of integrating new capacity, especially where the demands of public policy are at stake, can be daunting. In the California ISO, for example, there are 375 power plants in the queue awaiting interconnection agreements, representing over 52,000 MW of capacity, and another 30 more with executed agreements. Approximately 70% of California's queued capacity represents renewable generation which is favored under the state's renewable energy standards. Regional transmission organizations and regulators continue to seek ways to streamline long and costly interconnection queues where new generators, excluding the majority of proposed plants that drop out for economic reasons, nevertheless await sufficient transmission capacity to enable delivery of their power to load.

The integration of new renewable wind energy resources will therefore require new and upgraded transmission. ITC's proposed Green Power Express project would entail transmission lines and related facilities through North and South Dakota, Minnesota, Iowa, Wisconsin, Illinois and Indiana, interconnecting approximately 12,000 MW of new wind generation to distant load centers. The Upper Midwest Transmission Development Initiative (a coordinated effort among five states – Wisconsin, Minnesota, Iowa, North Dakota and South Dakota) has, with the help of the Midwest ISO, developed plans to meet the existing RPS standards adopted by the five states. Those plans were developed by the Midwest ISO as part of the Regional Generator Outlet Study which looked at the transmission needed to move 15,000-25,000 incremental MWs of wind generation throughout the MISO footprint. MISO also developed, and FERC recently approved, the Multi-Value Project cost allocation proposal which would allocate the cost of regional MVPs to the entire Midwest ISO footprint. Currently, the

Midwest ISO is analyzing approximately $5 billion of new 345kV and 765kV transmission that would be eligible for MVP cost allocation status and that would be built between now and 2020. In Texas, Oncor Electric Delivery and other investors are building over 2300 miles[3] of new 345 kV transmission line and upgrading others dedicated principally to wind resource areas to allow more than 18,000 MW of wind power to reach consumers. Without these new transmission facilities, these wind generators would not be able to connect to the grid and customers would be denied access to renewable generation that they may prefer and state energy policy mandates. However, in all the cases cited, new communications and control technologies will be instrumental in optimizing the efficient use of those facilities.

CONCLUDING OBSERVATIONS

North America's transmission system is already smart, and new investments in technology will make it even smarter. Most of these smart grid technology elements are well-tested, mature and cost-effective, and their use will make the North American bulk power system more reliable, secure, efficient, economic, diverse, and environmentally sustainable. But while communications, computer analytical tools, sensors, and controls are critical smart grid elements, those technologies cannot themselves deliver electricity from a power plant to the consumer. That task requires a strong platform of wires, cables, and substations, and that in turn requires investment in existing transmission infrastructure and additional investment in new wires in the air and transformers on the ground. The combination of conventional transmission technologies with advanced smart grid elements will optimize the value of transmission investments and enhance transmission's value and service to the nation.

[3] http://www.puc.state.tx.us/about/commissioners/smitherman/present/pp/TREIA_110810.pdf

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