Getting Smart

Innovation and Trends for Future Electric Power Systems

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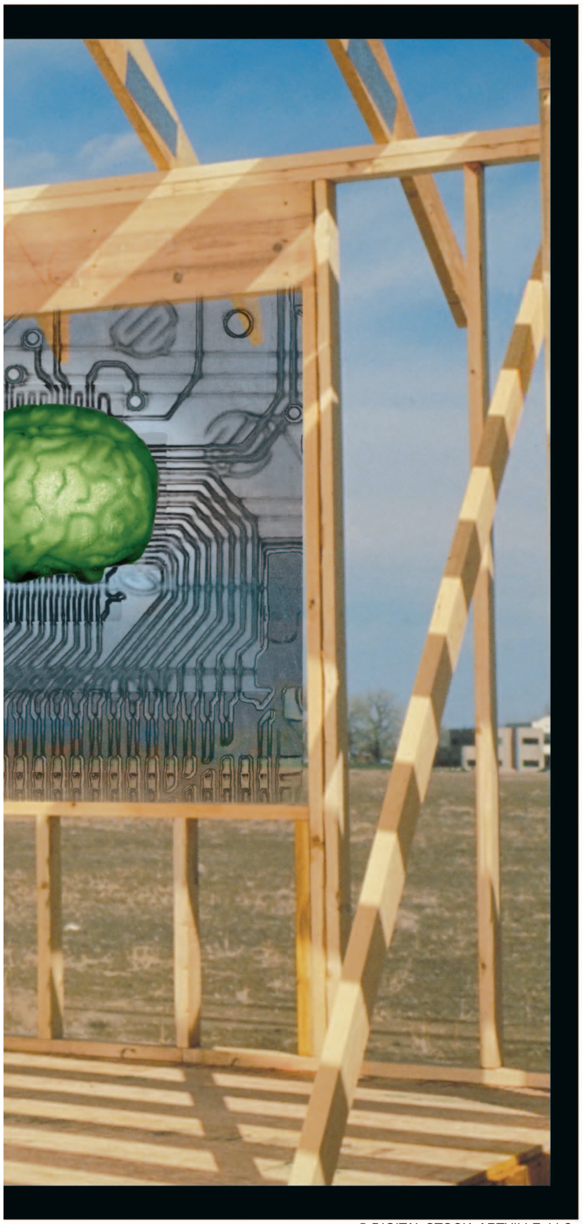

PRICES FOR CRUDE OIL ARE SKYROCKETING TOWARD US$100 per barrel. Global pressure is mounting to reduce green house gases produced by power plants. Major international financial institutions and banks are reeling with the sub-prime mortgage crisis. The U.S. Congress debates the merits of amending the Energy Policy Act of 2005 to require a mandatory national renewable portfolio standard. Much of the electric power transmission and distribution infrastructure is approaching its end of life. To paraphrase the vision of noted astrophysicist and rocket scientist Dr. Wernher von Braun: Do we dare to dream about the future?

Against this backdrop of increasingly negative headlines, today's power engineers seek to find innovative solutions to the burgeoning demand and growth of electric energy to serve societal needs for this century and beyond. Electric energy is the backbone of society, and its uses are pervasive in every aspect of daily living by serving the bulk of our energy needs in residential, commercial, industrial, transportation, and critical infrastructures.

By Thomas F. Garrity

The expanding demand for new electric energy supplies and the transmission and distribution networks that deliver the output of these power sources is fueled by the ever-increasing population. By 2020, the global population will reach 7.5 billion people, which represents an increase from 6.1 billion and 4.4 billion in 2000 and 1980, respectively. Electricity consumption projections for 2020 will exceed 27,000 terawatt-hours (TWh) compared to 15,400 TWh consumed in 2000, or a staggering 75% increase. Serving the growing appetite for electric energy will deplete further our ever-declining natural resources.

Shaping this debate is the realization that a significant portion of the rising global demand for electric energy will be met by our conventional resources (coal, oil, natural gas, and nuclear), but renewable energy sources will contribute an increasing share of the total energy supply. Further, our analysis suggests that the use of oil for power generation will decline with oil utilization largely allocated to the transportation sector. As stated, the contribution of renewable energy will grow in importance with supply increasing from 260 TWh in 2000, or less than 2%, to in excess of 5% in 2020 with a projected supply

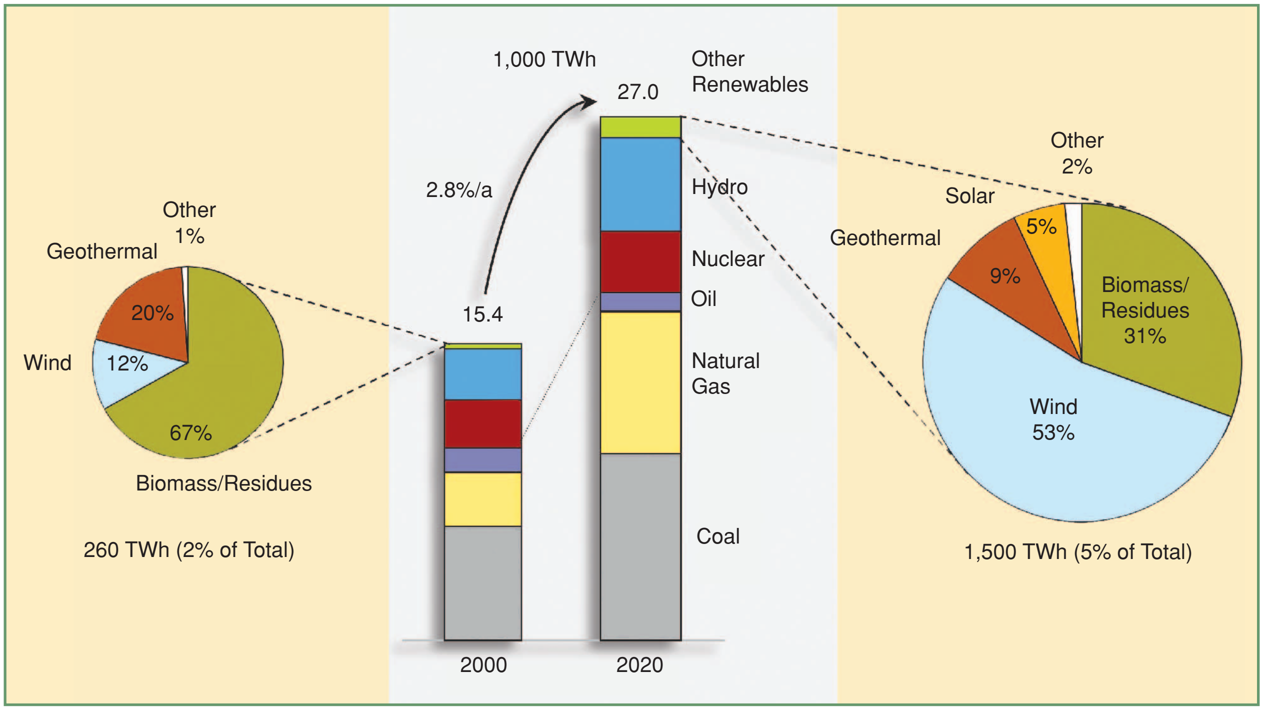

figure 1. Projected power generation additions: 2020.

contribution of 1,500 TWh. Wind generation will make up 53% of the total renewable power supply (Figure 1).

Technology to capture carbon dioxide (CO_2) emitted by coal-fired plants is early in its development, but it is generally acknowledged by some of the leading experts that carbon capture will become increasingly important to the successful deployment of next-generation coal plants. Coal represents a critical resource toward meeting the future electric energy demands. Technologies such as ultra-super critical steam turbines with thermal efficiencies of 44–46% and integrated combined-cycle coal gasification with efficiencies greater than 55% will reduce the total environmental emissions from these new plants, but some form of carbon capture will complement these high-efficiency fossil plants. The economics and efficiency of carbon capture technologies are yet to be fully understood, but there are small demonstration projects to prove the concepts that are in the early phases of testing.

What do the growing demand for new electric power generation sources and the diversity of resources mean for the transmission and distribution systems? Given the diversity of fuels and renewable technologies that will meet future electricity supply, new transmission lines will have to be constructed to deliver the electric power to load centers. The mix of central station power sources using fossil and nuclear fuels combined with distributed resources from hydro and other renewables will impose a set of unique challenges for power engineers. Transmission grids will require additional flexibility to match available resources with loads, to manage bottlenecks and congestion, to provide both technical and economic efficiency, to be built at a reasonable cost, and to maintain or improve reliability and security of supply.

Toward the end of the 20th century transmission development for high-voltage apparatus tended to saturate with a strong emphasis on cost reduction and improving equipment reliability. At the beginning of the 21st century, development trends for high-voltage apparatus and systems had more or less reached their technical and economical limits for cost reduction and improved reliability. Whereas innovation has been driven mainly by technology in the past, electric power efficiency and network intelligence have increased in importance. The shift in development focus to more intelligence in the transmission network has created new terminology known as "smart grid."

table 1. Evolution of the power system from a static to a dynamic infrastructure.

From	To
Central generation and control	Central and distributed generation with intelligence
Load flow following Kirchoff's Law	Load flow control by power electronics
Power generation according to load demand	Controllable generation, variable in feed and demand in equilibrium
Manual switching and trouble response	Automatic response and predictive avoidance
Deterministic response to power flow	Monitored overload of bottlenecks
Periodic maintenance	Prioritized condition-based predictive maintenance

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The smart grid entails a transformation to an information-enabled and a highly interconnected network between electricity consumers and electric suppliers embracing transmission, distribution, and generation. Simply stated, in this transformation the operation of power systems evolves from a static-as-designed infrastructure to a dynamic infrastructure using proactive supply and delivery management (see Table 1).

From Central to Distributed Power Generation

The mix of power generation resources will comprise central station power complemented by renewable energy sources, such as wind and solar technologies, and environmentally friendly distributed generation augmented by consumer demand-side response programs (Figure 2). All of these resources will contribute to an efficient and viable energy market where all participants will be compensated fairly. This mix of central and distributed generation capability will reduce greenhouse gas emissions as well since renewable energy can be effectively dispatched to serve load based on resource availability matched to consumer demand.

An important link to the consumer to enable demand-response functionality is the deployment of two-way communicating smart meters that will measure and quantify the load curtailment at the consumer premises. Advanced meter infrastructure programs are moving forward at a rapid pace with large numbers of pilot and full-scale deployments currently being implemented across the United States and Europe. The benefits of these various programs are still being evaluated, but the ability to establish connectivity to consumer loads

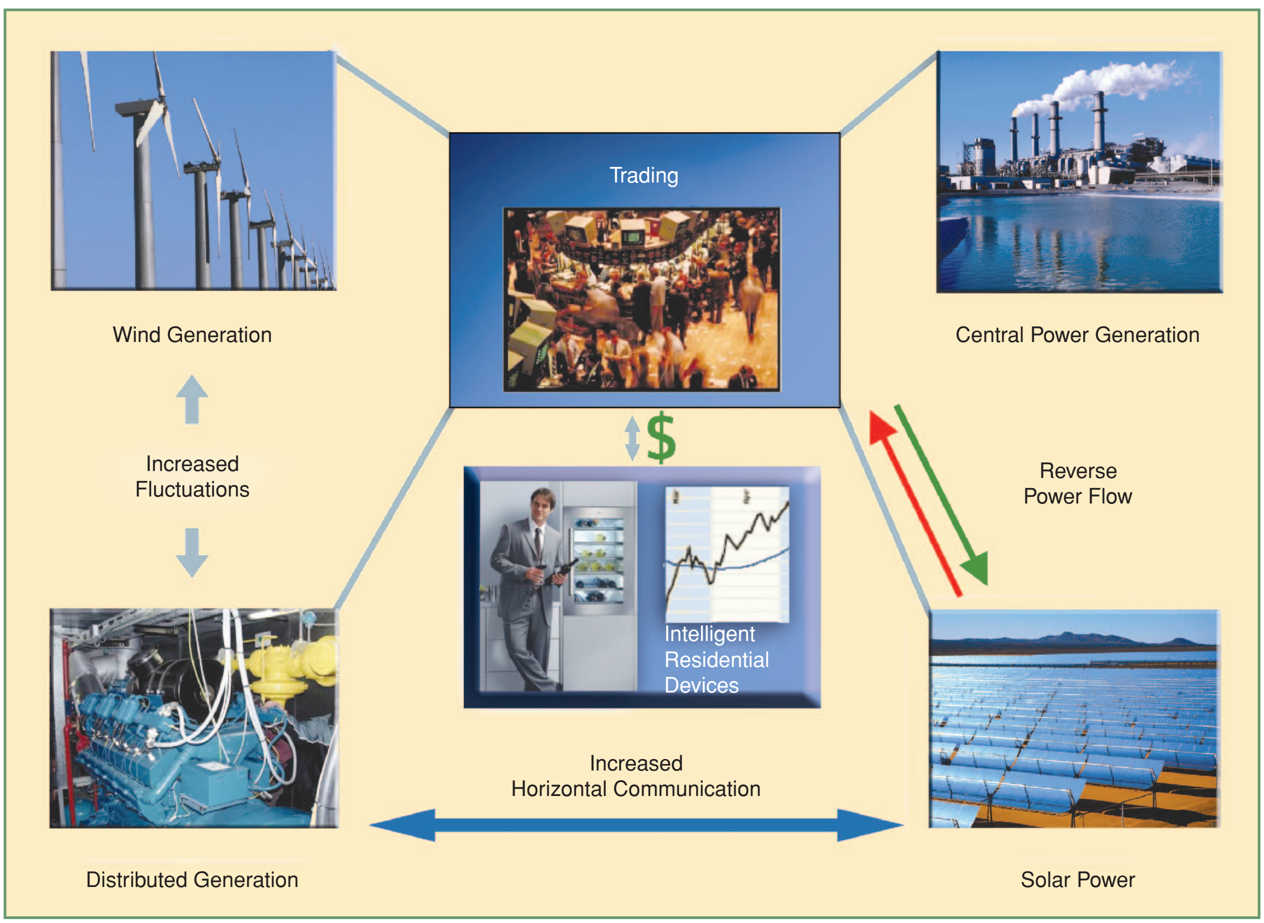

figure 2. Central and distributed generation.

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presents myriad opportunities to integrate demand-side load management into the total supply framework.

Power Electronics for Load Flow Control

Many new technology developments have occurred in the areas of high-voltage direct current (HVDC) and flexible ac transmission systems (FACTS). Some of these new innovations include:

- ✔ new measuring and sensing devices using optical transducers
- ✔ control systems for FACTS devices
- ✔ active filters
- ✔ ultra-high voltage (UHV) for bipolar 800 kV
- ✔ voltage source converters for HVDC.

The advantages of HVDC for long-distance transmission and asynchronous ties have long been known. HVDC interconnections have been deployed across large bodies of water using undersea cables to connect two separate power systems for economic exchange of power, principally in Europe, Africa, and Australia. Recently, a new project went into service in the United States with the completion of the Neptune project (Figure 3). A new HVDC transmission system linked Sayreville, New Jersey, and Long Island, New York. After commissioning, Neptune Regional Transmission System, LLC (owner) and Siemens (operator), placed the power link at the disposal of the local utility, Long Island Power Authority (LIPA). Thanks to this HVDC link, Long Island will be connected to the world's largest wholesale electricity market, PJM, enabling LIPA to access reliable, diverse (including renewable energy), and lower-cost energy sources. LIPA, with 1.1 million customers, will use the link to help cover the constantly growing power demand and strengthen the "backbone" of Long Island's transmission system.

A particular advantage of HVDC transmission technology when compared to constructing a new power plant or building a new conventional three-phase ac transmission line is the fact that the short-circuit power of the network does not

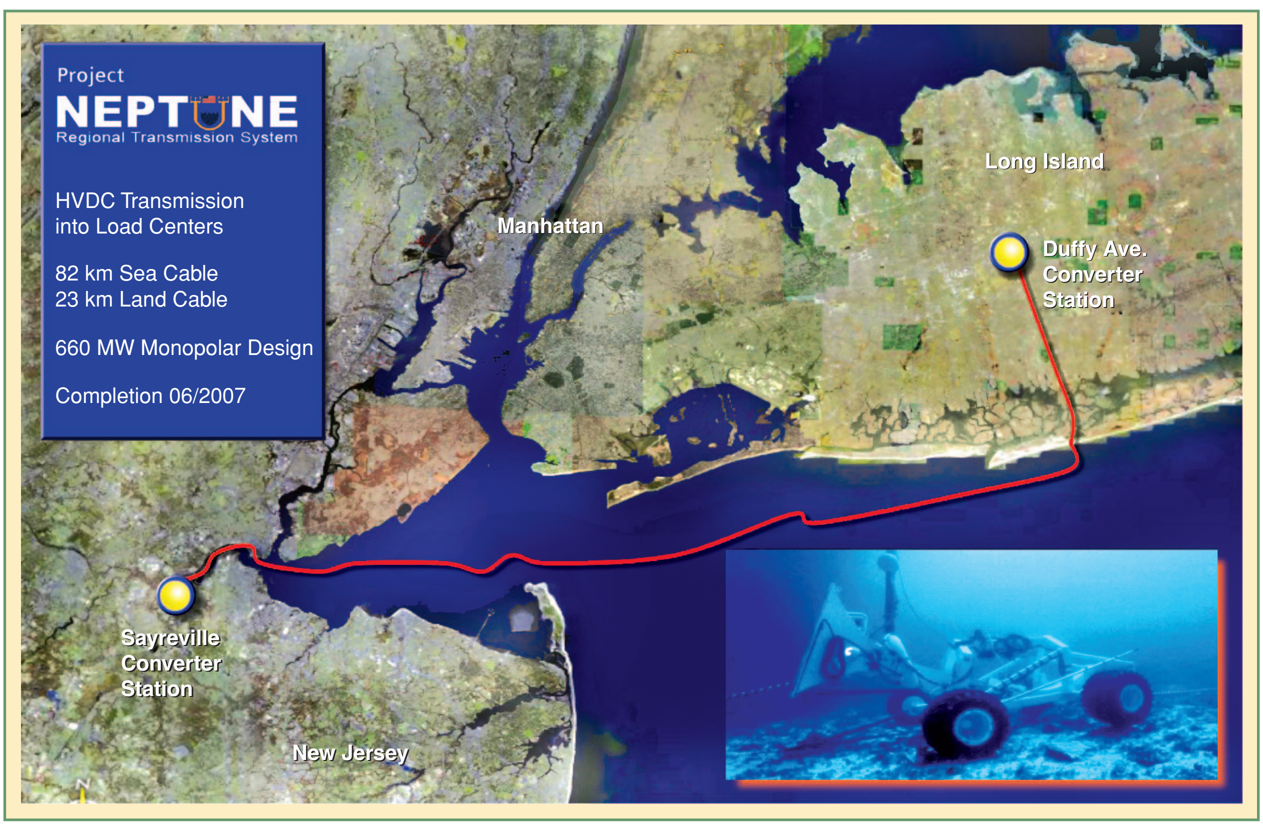

figure 3. The Neptune project.

The integration and deployment of distributed generation and renewable power will necessitate increased flexibility and operation of the grid.

increase; that is, no complex measures to upgrade the existing short-circuit capacity of the grid were required. In addition, fast-acting control functions enable HVDC systems to help stabilize the connected networks, which constitutes a decisive benefit of this technology in the event of outages and blackouts in the system. At the end of June 2007, 660 MW of power at a dc voltage of 500 kV began flowing through the HVDC submarine cable interconnection.

Power Generation According to Load Demand

The integration and deployment of distributed generation and renewable power will necessitate increased flexibility and operation of the grid. One can readily envision a plethora of different power sources that will be dispatched to serve load, with the load itself constituting a virtual generator through various local load control devices that will be called upon to switch off loads during peak periods. The increased use of decentralized energy management systems will facilitate these transactions and the balancing of distributed generation power sources with the load being served and controlled as part of the supply mix. A concept for a decentralized energy management system is depicted in Figure 4.

Automatic Response and Predictive Avoidance

The evolution to smart grids will bring about significant changes to the functionality of energy management and control systems. In addition to the normal functions of supervisory control and data acquisition, generation dispatch, frequency control, network management, monitoring grid performance, and power flow analysis, the control center functions will expand to include static and dynamic security assessment capabilities along with self checking of relay settings on critical transmission facilities. With the eventual deployment of phasor measurement units to monitor grid performance across heavily loaded regional

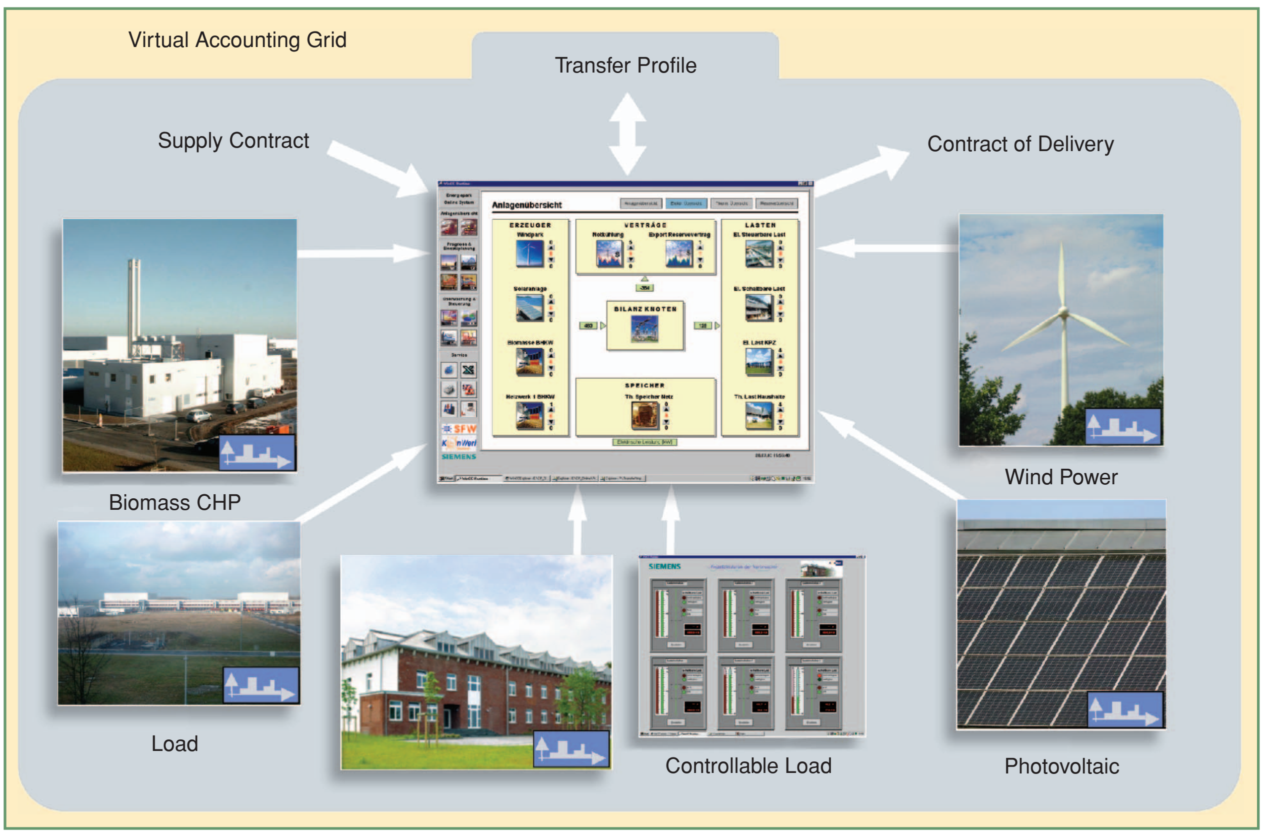

figure 4. Decentralized energy management.

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interconnections, there will be advances in state estimators that are capable of real-time simulations for large networks. All these advanced techniques will be further enhanced with the evolution of new power system simulators with high-resolution visualization capabilities that can determine vulnerabilities in the power system in advance of the next major system event or outage. Collectively, these innovations in state-of-the-art energy management systems will assist operators in avoiding major blackouts in the future (Figure 5).

Monitored Overload of Bottlenecks

High-speed protection, substation automation, and deployment of advanced sensor technology to monitor critical apparatus in the network will provide more intelligence to system operators. Mobilizing grid capacity reserves through monitoring of overloads will enable the operators to relieve bottlenecks and redeploy necessary generation and transmission assets to eliminate congestion points in the grid. These capabilities are available in today's control centers, but the enhanced functionality of high-speed digital protection and monitoring devices will provide more timely and accurate information to the control centers (Figure 6).

Asset Management

The aging transmission and distribution infrastructure is a global concern. Much of the installed T&D equipment has experienced service duty in excess of 30 years. This equipment has performed well over the years and arguably still has useful life remaining in spite of its service life being approached or exceeded in certain cases. The industry has aggressively pursued various asset management strategies to extend the service life of T&D assets. Accumulating and analyzing the volumes of operational data present opportunities to systematically determine the remaining life of the installed equipment and allow electric power company personnel to prioritize maintenance activities to address the most critical equipment.

A well-executed asset management plan, formulated around a solid business strategy, can enhance the performance of the installed T&D infrastructure. Extending maintenance intervals with condition monitoring

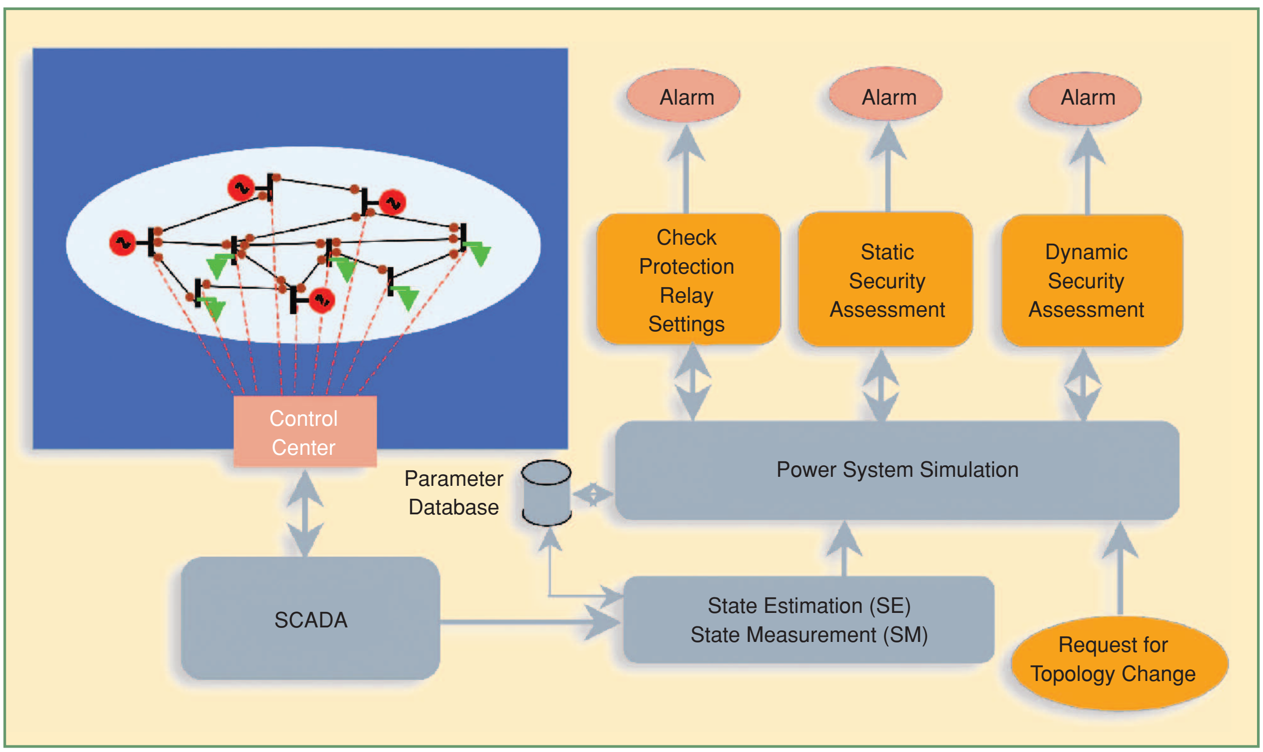

figure 5. How energy management systems can help to avoid blackouts.

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complements the asset management strategy and provides valuable information about the equipment operational performance, which is an important benchmark to determine necessary maintenance.

Looking ahead, power systems engineers will focus their attention on new equipment purchases that can yield long service life with minimal maintenance intervention. More sensors will be installed to monitor critical service parameters so that maintenance personnel can perform just-in-time maintenance versus historic interval-based inspections and servicing. Extended maintenance intervals will inherently increase the initial cost of new equipment, so life-cycle cost evaluations will be essential to understand the value of reduced or very low maintenance expenses over the equipment lifetime.

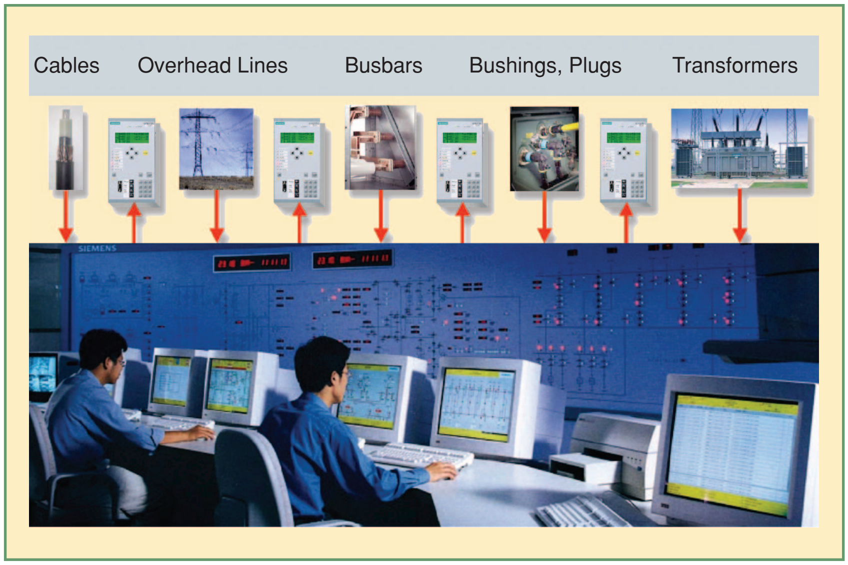

figure 6. Monitoring bottlenecks.

Summary

The electric power industry is experiencing a period of sustained growth to meet the growing energy needs of the planet. Innovations such as deployment of smart grid solutions will facilitate the pending growth of the infrastructure as new facilities are added to the network and embedded with the installed base. Grid intelligence will assist planners and operators dealing with the increasing complexity of secure and reliable power supply and delivery. Renewable power generation technologies will expand in both the total gigawatts to be installed and percentage of contribution to the total energy consumed, but renewables alone will not displace the need for new base load generation. Cleaner and lower-emission fossil generation sources will continue to be the backbone of power generation additions. Nuclear power will grow in importance as the industry looks toward the future, but siting and permitting these plants will create formidable challenges in the industrialized countries. Conservation and efficiency improvements will contribute to demand reduction and parenthetically reduce the need for new generation additions.

While not specifically mentioned in this article, innovations and technology developments to increase continuous current ratings and fault-interrupting capabilities for high-voltage equipment will continue as urban centers grow and expand. Compact designs with reduced footprints are necessary to install new substations in densely populated urban areas with very high load densities. UHV ac and dc will become increasingly important as transmission distances increase between power supply resources and urban load centers. Distribution automation, not discussed in this article, will help to optimize the reliability and performance of distribution systems. Major investments in new distribution automation and distribution management systems will occur in the not-too-distant future as the industry seeks to capitalize on the deployment of advanced meter infrastructure systems.

Looking forward, we face exciting and challenging times in our industry. There has never been a better time to be a power systems engineer leading this industry transformation.

For Further Reading

J. Makansi, *Lights Out: The Electricity Crisis, the Global Economy, and What It Means to You*. Hoboken, NJ: Wiley, 2007.

Biography

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