UNDERSTANDING THE U.S. POWER GRID:

>> Steps Toward a Stronger Electrical Power Network

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Recent power outages in North America have heightened everyone's interest, especially that of facilities and energy managers, about the condition of our electrical power system. While these blackouts have baffled many politicians, they have been no surprise to the technical community. In an effort to give the readers a better appreciation of the complexities relating to this topic, this article will briefly review these issues.

Unlike many other developed nations, the United States does not have a "national power grid." After the 1965 New York blackout affected more than 30 million people, the North American Electric Reliability Council (NERC) was formed in 1968. The NERC is an independent, self-regulating entity that seeks efficient ways to monitor the power grid and minimize major outages. The NERC divided the North American power systems into four regions, namely the Eastern, Western, Texas, and Quebec.

The Western Region includes New Mexico, Colorado, Wyoming, Montana, and other states west of these including the Canadian provinces of British Columbia and Alberta. The Texas Region only includes Texas. The Eastern Region includes all other continental U.S. states as well as Saskatchewan and Manitoba provinces. The balance of Canada's provinces is part of the Quebec Region.

In the beginning the primary role of NERC was promoting limited power exchanges among neighboring utilities and not necessarily developing a framework with a national outlook for power. Its role in addressing national power issues has evolved over the past four decades.

Overview of the Power Grid

Electricity is commonly generated at 20,000 volts. Using transformers, the voltage is raised to 230 kV, 345 kV, 500 kV, or 765 kV depending on the distance that the power needs to travel using transmission lines. Today the U.S. power grid system is a complex web of transmission networks that extend thousands of miles. In fact, the national power transmission network consists of more than 670,000 miles.

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The reason for converting the voltage to such high values for transmission is to reduce the physical size of the electrical conductors. For instance, when the voltage is doubled the power carrying capacity of the same conductor is quadrupled. The utilities substations reduce the voltage to 138kV, 69 kV, 13.8 kV, or 6.9kV and routes the power to commercial, industrial, and institutional consumers via distribution systems. At the customer site the power is reduced to 480/277 and 208/120 volts for use.

Normally in electric equipment the capacity is limited by thermal considerations. This means that at a steady-state condition the rate of rejecting heat from the device should be higher than the heat generated primarily due to the flow of electricity. For power transmission lines, other parameters such as power transfer and stability factors control the flow of electricity before approaching the thermal limits.

There are several underlying factors that make electricity unique among other major utilities. One of these factors is that given the current state of technology, we cannot store large amounts of electricity in a cost-effective manner. This implies that the generation supply and demand must be equal all the times. Second, unlike other regulated industries such as the telecommunication, natural gas, or transportation industries that are governed under federal laws, the electric utilities are regulated by every state's public utilities commission.

However, electricity flow is governed by laws of physics and not according to state rules or contractual arrangements. In fact, controlling power flow is not easy in most conditions, and given the current available technologies the operators can only exert limited control in directing the flow in every transmission line in the network.

One of the electrical concepts that is poorly understood by many non-technical people is the distinction between real and reactive power. As electricity flows along a conductor, it has two main components—namely real and reactive power. **Real power** is the power that is useful since it transfers actual energy. **Reactive power** is like a standing wave that travels back and forth similar to the ocean waves, but the net energy it carries is zero.

The flow of real power between two nodes in the power system is a function of their relative phase angle. In other words, the power flows from a node with the voltage wave leading the other nodes. Similarly, reactive power flows based on the voltage differences. The reactive power flows from the node that has a higher voltage to one that has lower voltage. Reactive power flow serves a critical role in the stability of the power system. According to one author, the need for reactive power is similar to the requirement to balance a bicycle while it is moving forward. When riding a bicycle, it not only moves forward, but it may move sideways and slightly up and down. Over time the net movements in the other directions except moving forward is zero.

Current Conditions

Over the past two decades the bulk power transfer among utilities has quadrupled. On the other hand the investment in new transmission lines has dropped significantly for over a decade by more than $100 million per year. For instance, in early 1990s, the amount of new transmission line added was over 13,000 miles annually, while in the past few years the number shrunk to less than half this number. There are two major reasons for this significant drop. First, the payback on a new gas-fired generation plant is less than five years, while it takes roughly 28 years to recover the investment cost of a transmission line. Second, in building transmission lines, the investors need to secure permission from a long list federal, state, and local agencies that could take many years, not to mention possible court challenges throughout the process. That is why, given the current tariffs, investing in transmission line is not a very attractive option in most cases. Finally, utilities deregulation has made the situation go from bad to worse.

To ameliorate the situation, NERC for the past five years has been asking for legislation to make its rules mandatory. Similarly, the Federal Energy Regulatory Commission (FERC) has been asking without much success for more oversight over the operation of the power grid. In the meantime the number of power transactions across the power grid has increased, outstripping any spare capacity that existed only a few years ago. One of the Department of Energy transmission experts stated to *IEEE Spectrum* magazine in 1999: “We were all just waiting for the big one.” Similarly, a former EPRI (Electric Power Research Institute) expert had recently stated, “Everybody in the business knew something like this was going to happen. It wasn’t a question of whether, but when.”

Similarly, when New Mexico Governor Bill Richardson was the U.S. Secretary of Energy during the Clinton Administration and had referred to the United States as “the superpower with a Third World power transmission system,” he was stating a harsh reality. Unfortunately, the policy makers did not take this warning to heart. According to Ilya Roytelman, a power engineer for Siemens AG who is familiar with the European power networks, “The U.S. grid system is 30 years behind the state of art” and “every system in Europe works better.”

New Technologies

Given the speed of electricity, power outages usually cascade so quickly in just a few seconds from inception leaving little time for a human operator to respond in a well-coordinated fashion. In other words, they cannot balance the supply and demand across the system without overloading transmission lines. Therefore, unless possible conditions are identified ahead of time and preprogrammed in a real-time computer system, it will be impossible to manually respond to abnormal power conditions adequately. To improve the power network in the U.S., new products and technologies must be used widely across the system. A brief summary of these technologies follows.

New SCADA Systems

Supervisory control and data acquisition (SCADA) systems in use today are able to assemble real-time information for the operators. However, recent breakthroughs in SCADA technology can enable these systems to effectively protect the power grid and prevent actions that may worsen the network conditions in an emergency.

WAMS

Wide area measurement systems (WAMS) collect a large amount of information about the system condition. The data can be extremely helpful in determining what actually happened during a failure. Although WAMS cannot protect the system per se, it provides valuable insights that can prevent future outages.

Transmission Line Monitors

The major problem of transmission lines is the thermal expansion under an overload. As the line expands, its capability to carry the electric flow further, while the losses continue to increase, make the conditions worse. New materials with lower thermal expansion have been developed for transmission lines, thus limiting the power carrying capacity in an overload condition. In addition, new technologies have been developed where fiber-optic strands are embedded inside transmission lines. This will enable the system to continuously monitor if the line is sagging and if so, the operator can take appropriate action prior to a failure.

FACTS

Flexible alternating current transmission systems (FACTS) are solid-state devices that enable power systems to control voltage and other parameters continually. Unlike the electromechanical controllers that are too slow to govern the flow of current quickly and prevent bottlenecks, these devices can act very fast and can provide real-time control. This level of control makes it possible to channel power to particular grid branches and enhance voltage regulation. More importantly, during peak demand conditions, with 50 percent additional power going through existing lines, the need to expand many transmission paths is reduced.

HTS

The recent breakthroughs in high temperature superconductor (HTS) technologies create excellent opportunities for transmission lines. First, the cables can carry more than 100 times the current than a copper cable of similar size when cooled around ten degrees absolute temperature. Second, during a short circuit as the line temperature increases, it loses its superconducting characteristics and thus can limit the current flow.

SMES

Superconducting magnetic energy storage (SMES) devices are energy storage devices that consist of a superconducting coil in a magnetic field. Such devices in the future could be utilized across the power grid to eliminate momentary voltage dips, thus stabilizing power networks and preventing costly power interruptions.

Concluding Remarks

The principal challenge of transferring large quantities of power from a generation site to a distant load through the transmission system is a difficult task. There are not enough mechanisms to control routing of power in the network to the degree that the operators desire. In reality, the route is indirect and is a function of the impedance of individual lines, the point where power enters and leaves the system, and other factors.

Under normal conditions and true competition, the marginal cost and marginal revenues can be equal where any power provider can bid to supply the system with power. However, under an overload condition, markets diverge quite rapidly. Power congestion in only a few lines can result in huge price variations in a localized area. Therefore, the salient features of the power grid, legal constraints, and line congestion can impede transfer of power between two areas. Consequently, transmission line companies can exercise quasi-monopolistic practices over local markets by exploiting bottlenecks, operational idiosyncrasies, and legal loopholes. That is why the general public gets baffled when they hear about localized price volatilities and power shortages.

Given what is stated above and the lack of a plan to address this as a national issue, it is safe to assume that things will get worse before they will get better. The role of electricity in the institutional mission of our colleges, universities, and other educational facilities is more critical than ever before. Given the complexity of the electrical network, it behooves power engineers and facilities officers to communicate the critical issues pertaining to the system more frequently and effectively with policy and decision makers.

Reference

http://www.spectrum.ieee.org/WEBONLY/special/aug03/black03.html.