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The Changing Face of Electric Power Systems: Teaching For a Challenging Future

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Abstract

When will the next big blackout be? How secure is our electric power system? Will we be re-regulating the electric power industry? Will we each have a fuel cell in our backyard to generate the power we consume?

The generation and delivery of electric power has changed significantly in the last decade, and will continue to change in the next decade. The deregulation of electric utilities, the continuing need for environmentally friendly systems, the increasing use of limited natural resources, the technical innovations in the design and simulation of power systems, the need for "quality" power, and the potential of very small generating plants (micro-turbines, fuel cells, etc.) in or near load centers have begun to effect the generation and delivery of electric power in ways previously not envisioned.

The California crisis of the last few years, the blackouts in the northeast in the summer of 2003 and the continuing blackouts across the world have brought the electric generation, transmission and distribution network back into world engineering and political thought and debate. This paper will summarize the yearlong study undertaken during a sabbatical leave for the purpose of determining the future of electric power systems and how this will impact the courses in electric power systems at the Rochester Institute of Technology.

Why all the changes?

The current backbone of the electric power system was constructed in the first 80 years of the twentieth century to provide power through vertically integrated regulated electric utilities. After many mergers and some bankruptcies, the federal government passed the Federal Power Act in the 1930's. This established the basic groundwork for investor owned utilities for many years. The United States federal government mandated a move to a deregulated environment in the late 1980's, followed soon after by specific laws to this effect by most states. This was a major change from the previous arrangement of vertically integrated electric utilities, with implementation frequently not well planned or executed. This is a classic example of competition by mandate, and not market driven competition.

The result of deregulation is a five tier system of electric power supply. The power is now generated mostly by a group of independent power producers, trying to maximize the return on their investments. The power is distributed to individual residences and businesses by a regulated distribution utility. Power is sold to the user either by the regulated utility or by a sales organization which purchases the power for the needs of a large group of customers. The coordination of daily electric power needs on the grid is done by an ISO (independent system operator). Lost in this shuffle is an approach to the means of transmitting the power from the generators to the regulated distribution utilities with real power and authority, which may soon be undertaken by an RTO (regional transmission organization).

De-regulation has come to an industry which is still growing. The national compound growth rate has gone down slightly from its pre-1974-energy-crisis rate of 7% per year, but is still growing even in uncertain economic times. At the same time, without traditional investment relief (rate cases, etc.), less capital has been invested in the system from the time when de-regulation was being enacted until now, with some segments spending more than others. Why invest when the rules of the game are still changing? Uncertainty of investment recovery is a very big issue.

At the same time, sensitivity to power quality has become a big item among customers, due to the proliferation of electronic equipment both within the home and throughout business.

The national agenda has called for “green” power, that which comes from renewable resources and / or does not pollute as much as many of the existing power plants. Development of wind power, tidal power, solar power, and enhancements in fossil fuel plants has been both encouraged and required.

A side effect of de-regulation has been the reliance on natural gas fired power plants. As independent power producers built merchant plants, they turned to the fuel that was plentiful and had the least environmental problems – natural gas. Gas turbine research has yielded units that are far more efficient than older ones had been, plus could be built near loads so that the exhaust heat could be used and further increase the thermal efficiency of the plants. Unfortunately domestic natural gas is no longer cheap, as the easy reserves have already been tapped. Now international supplies must be imported, raising environmental concerns and costs.

Is there long range planning and who does it?

Consumers and engineers desire a sure source of electric power, with a plan for anticipated growth and the flexibility to change the plans as needed for changes in the demand for electric service. Customers are frequently more concerned with continuity and quality of electric power than with a few cents difference in their electric bill.

A corresponding demand by the financiers is to have a quick return on investment (3-5 years as opposed to the traditional 30 year investor owned utility pay back period) and a continued anticipation of profits in the future, in that order. This is a mentality which decries the periodic need to forego a dividend so that a needed expansion or upgrading of the system can be undertaken.

The underlying laws of electrical engineering (ohm's and kirchoff's) still dictate where electric currents will flow. Planning for generation, transmission and distribution must use these electrical laws, in addition to the financial needs of a particular utility. During the era of regulated vertically integrated utilities, planning for the entire system was done by the utility, power pools and regional organizations. In the initial implementation of deregulation, the assumption was made that the system was robust enough to stand the several years necessary to sort out who would be responsible for the short- and long-range planning for growth. Recent blackouts have shown that this was probably not the case.

Today, government authorities and utilities at every level are still trying to determine who is responsible for the planning of generation and transmission systems. Currently investment incentives are unclear or lacking. Since the distribution of electric power is still a regulated activity, distribution utilities are quickly coming to use the tools necessary to undertake distribution planning activity.

Deregulation - A new way of doing business.

The division of electric supply to regulated distribution utilities and unregulated merchant generation facilities has made the business of supplying power much more complicated. Adding the third layer of transmission and the fourth layer of control of the system to this division was slow in coming, although some areas of the country have made significant progress already.

Initially, deregulation resulted in a significant decrease in the capital expenditures for electric utilities at all levels. With few definitions of the responsibilities of each level, no one was sure who could recoup the investment in any addition to the system. Regulated utilities would be able to reclaim investment over a 30 or 40 year time period, merchant generators would need a payback in a few years.

A decade later, many definitions have been made. The distribution utilities are still regulated, with a defined payback. Merchant generators have been able to provide a payback in a reasonable time period. Little definition has been provided to suppliers of transmission or control systems, so investment in transmission is still lagging where it should be. The constrained transmission system typically represents a bottleneck to energy delivery.

An example of definition for the new, deregulated energy market system is a concept called Standard Market Design (SMD). SMD would provide a fixed definition for rates which could be charged for the generation and transmission of electric power, so that all who would consider investing in this area would be able to anticipate the expenses and reimbursements afforded to their investment. SMD has been slow in coming, with almost all parties arguing over the various aspects of the definition. One such argument is whether the states should have a final say in a particular transaction, or whether a federal or regional body would have the final say.

An example of the current difficulty in determining the need for updates in a system is in New York State. The New York Power Pool used to be composed of the 7 regulated utilities and the New York Power Authority representing themselves and all of the local municipal utilities and rural-electric-cooperatives. These 8 parties could decide the need for an addition to the system and who should pay for that need. The new body, the New York Independent System Operator (ISO) has 125 representatives of each of the 8 above bodies, plus individual representation from the municipal utilities and co-op's, plus representatives of each of the merchant generators or independent power producers, plus its own control-function personnel. Decisions by 8 parties are hard, decisions by125 parties seem almost impossible.

Changes in generator ownership and future generation planning

Most generators are now owned by a few large conglomerates of generation utilities or are owned by much smaller independent power producers. The regulated distribution utilities have been selling off their generators, as required by the deregulation legislation.

In this process, it has been interesting to note that many changes have occurred in the mixture of fuels, the efficiency of generating units, the development of co-generation and combined cycle plants, and those of green power. There are very few oil fired units left, several new coal fired units, many natural gas fired units and no new nuclear units in about 20 years. Medium-sized natural gas fired turbines have become much more efficient (especially with the base unit combined with combined-cycle and cogeneration units) and more reliable. Green power to date has meant primarily wind power, but fuel cells and solar power have also started to become economic for certain applications.

The United States will face its next big hurdle in the next 5 to 15 years, with the potential retirement of most of the large fossil fuel and nuclear units which have served us so well. What will be the replacement fuel? Who will be willing to pay the cost of the replacement units, especially if they are large base load units? Will the financial markets support any company which wants to construct a 1000 MW unit?

In order to answer the above questions, we will need to do some real analysis. One of the analyses will be to do a real cost/benefit analysis on the ecological and economic impact of nuclear v. fossil fuels. The inclusion of a significant amount of wind power and photo voltaic (which are not available at many peak times) in the system will require the same kind of analysis. Another analysis which will be useful will be one on the effect of many small to medium sized fuel cells or turbines used in distributed generation closer to the loads.

Notice that when the term green power is used, it frequently includes fuel cells. If the hydrogen for fuel cells were to be generated by electrolysis using energy from wind power, it then may become green power. Using hydrocarbons (fossil fuels) as the fuel for a fuel cell may generate power at a higher efficiency closer to the load than a central station generator, but it still produces harmful byproducts. Even hydrogen driven fuel cells will release a small amount of hydrogen into the air, which will interact with the air to produce harmful byproducts. Fuel cells are not absolutely green power.

Biomass is a very attractive source of fuels. Using quick growing crops, drying them, and then burning them is free of most pollutants and uses the carbon dioxide in the growth process. Most crops do not grow that fast, and this would take a significant expenditure of land, but it is still a good path for investigation. Adding methane from landfills and wastewater treatment sites are a better first step and this is well underway. The subtitle of a very interesting article on this concept by Yan Kishinevsky and Shalom Zelingher (1) is "An Innovative Emission-Offset Project That Utilizes Anaerobic Digester Gas-Powered Fuel Cells to Produce Electricity."

Direct conversion of solar power to electric power has been a dream of people for over a century. New lightweight less-expensive materials are making this more feasible, at least for low power applications and remote sites. A few utilities and others have deployed this process over the last few years in limited applications. New materials used in the process may make it more economic in the future.

Wind is plentiful in many areas, and using the wind to produce power has been around much longer than electric power. Wind, however, in most locations is unpredictable and often not available during the peak electric demand times. Installation of wind farms continue to grow, but have created some control and demand problems. The control problems have solutions in modern power electronic applications. The solution to the timing of demand may have to wait for electrolysis of water to produce hydrogen or for more remote battery or other research to produce a better means of storing electric power.

Electric Light and Power (2) starts a lead article with "This spring Secretary of Energy Spencer Abraham declared that we were in the midst of a natural gas crisis." There is plenty of natural gas in the known resources of the world, but much of this gas is hard to transport to the US. The addition of more ships and loading docks will help, but it must still be tied to the gas grid to be useful. Each of these are able to be done, but will cost money and may not be popular with the "not in my back yard" (NIMBY) neighbors. This is a good short term solution, but natural gas is a fossil fuel and has limited long term availability in the same way as do coal and oil.

Nuclear (fission) generation of electricity has helped us meet our demand for the last half century, with no US accidents that have affected the general public and only one worldwide accident of significance. The state-of-the-art in the construction of nuclear power plants worldwide has changed significantly in the more than 20 years since a new reactor has been proposed for the US. The issue of long term storage has also been addressed by congress and the President recently, so this may give us a window of opportunity to start implementing this approach. Other ways of working on nuclear waste are also under development, as the lead sentence to an article in the November ASEE Prism states "Cleaning up toxic wastes is a huge job in the United States. Engineering researchers are putting microbes to work consuming toxic contaminants". We hope that such innovations will soon also help with nuclear waste as well. A new single permitting process should eliminate the problems that were caused with the reactor constructed but never operated on Long Island. Constructing a new nuclear reactor will have to be done quickly (so as to not tie up capital for an excessive time period), safely, and with significant government input. I do not believe that any private corporation can or should construct new reactors without the backing of the government. While there will be much consternation in this process, I expect that many of the existing nuclear generators will be replaced with new-generation nuclear generators.

The road to proper transmission and substation infrastructure

"Deregulation was supposed to create a free market for electricity that would drive prices down, but it hasn't exactly worked out that way – just ask anyone in California. The aging power transmission infrastructure, as it turns out, is simply too rigid and inefficient to meet the new demands." So states Robert Pool in Technology Review (4).

Transmission (including transmission substations) is that part of the system that is most required in a deregulated system, and which was least addressed by the legislation creating a deregulated environment. Legislators must have assumed that the system was robust enough to get us from the regulated environment to the deregulated environment and last the decade that it would take to determine process and responsibilities to get us from regulated to unregulated. Instead, much of the transmission system was barely able to properly supply power for the regulated system, having been stymied by improper regulation and by objections to particular sites by the NIMBY's.

The laws of electrical engineering, Ohm's and Kirchoff's, determine where electric real and reactive power will flow. There is no escape from providing for the proper flow of power from the source of generation to the loads on the system. Simulation (load flow, stability, probability studies, etc.) of the system can show where the weak spots are in the operation of the system and helping to determine where reinforcements are necessary.

Are there means of limiting the need for transmission expansion? Yes, several methods have been developed and are available or are in the testing mode at this time. Flexible AC Transmission Systems (FACTS) is the most promising from an immediate availability and low-cost standpoint. FACTS uses high-voltage power electronics components to control reactive power, short-circuit interrupt capacity, and many other operating capabilities of the system. FACTS is available now and can help get many parts of the system through the time necessary to implement other strategies.

For short lines, usually urban, the technology is already here to use super-conductors and gas-insulated lines and substations. High-voltage DC (HVDC) has been in operation in the US and other countries for several years. The use of HVDC is a power electronics application with the ability to limit short-circuit capacity and to isolate the frequencies of two separate systems.

Today, transformers are being overloaded more than most engineers recommend. A transformer can withstand a very temporary overload (a few minutes) occasionally without loss of transformer life or for a slightly longer period with a defined loss of life. The practice of overloading transformers for several hours several days in a row will, and is, shortening the life of many transformers from the norm of about 40 years to perhaps less than 20 years. Many currently installed transformers are already over 30 years of age, and could last several more years without the practice of overloads. This is a part of the same practice which looks at quick profits without looking at the long term implications of decisions currently made.

The same can be said of transmission lines. Very-short overloads are anticipated, as it takes time to increase the temperature of the conductor to cause significant damage. For longer overloads, significant damage can be done to the conductors (causing them to loose shape or eventually melt) and cause inappropriate droop. If a line has too much droop, it comes too close to vegetation, roadways, or buildings. Such may have been the case with the trees which had also not been properly trimmed during the August 14 blackout in the Ohio. Vegetation should be trimmed on a regular basis, but lines should also be operated within their emergency limits.

How about this long term problem of the EMF caused by transmission and primary distribution lines? Recent studies have been able to show only a statistical link to possible damage to humans. Utilities must be able to show how EMF will be limited in any new site for a high or medium voltage transmission line or substation.

Will distributed generation limit the need for additional transmission systems in the future? While the future is a long time, current indications are that the transmission grid will need to grow significantly in the next decade and beyond.

Lines will need to be built, but who will pay for them? This is a tricky question, as those currently building generating stations which require additional transmission will plan for perhaps a 15 year operating window while the lines will need to operate for many more years. Current legislation calls for an open transmission system, but does not provide a means to determine who will pay for the additional lines necessary. Regional Transmission Organizations (RTO's) are being formed to be both an ISO and an organization to determine who will construct, maintain and pay for the transmission facilities and the system control function. Some areas are well on their way to developing solid RTO's, and others have not really started. Determination of whether the states or the federal government have a final say on the creation and operation of RTO's will help in forcing this process to its ultimate end. RTO's must be created and have the teeth to force the process in order for deregulation to work.

Distribution – the regulated business and its possible growth.

Customers are fortunate that distribution utilities still exist and operate the local system. They provide a safe and reliable system, with good customer interfaces. Now that deregulation is here and is defined to be mostly at the transmission, control and generation levels, distribution utilities can get back to the business of providing their normal function. Many such utilities have sold most of their generators and turned over control of the higher voltage lines to an ISO or RTO.

Like the transmission network, the distribution network is getting old. The network must be maintained with the traditional anticipation of 30 to 40 years on most of the more expensive components. Routine maintenance of substations, sub-transmission lines, transformers, distribution and utilization lines must continue and be enhanced. The regulators must assure that the utilities are providing a reliable system as well as an economic one. Decisions based on quick profits must not be allowed.

What is missing from the current mix? Tree trimming (Vegetation Management) is an important part of operating overhead lines. Periodic maintenance of transformers, breakers, communication systems, and relays is important. An enhanced customer interface tied to better SCADA systems would help to alleviate customer issues many times before they arise. A continued emphasis on power quality and the education of customers for their own power quality is important.

Broadband communications over power lines is a very realistic promise for the future. Customers now obtain broadband by means of DSL through telephone lines or directly from cable companies. Many rural customers do not have cable or DSL capability available. Distribution utilities are hoping that they can be cost-competitive with other providers and also provide automated meter reading and system control functions on the same network. Functions such as time-of-day pricing and demand –side-management would become more feasible.

Distribution utilities, both in the regulated and unregulated parts of their business, are also providing the direct sale and billing of power to their end users. Customers have been accustomed to a single provider, and enjoy this service.

System control needs to service the entire system

Writing before the August 14 blackout, S. H. Horowitz and A. G. Phadke (5) said "New protection, monitoring, and control techniques will offer the opportunity to reduce power system catastrophic failures."

The control of the system is important both for the immediate operations and for the planning of the future system. Such control is done by ISO's and RTO's, who also coordinate with regional reliability councils and the North American Electric Reliability Council (NERC). NERC and the reliability councils have established general operating guidelines for their regions and do some daily checks of the system. More immediate actions are taken by ISO's and RTO's.

To properly control a system, simulations of the system have been developed to model power flows, system stability, economic operations, probability of outages, and several other functions. After the August 14 blackout, the use of existing and proposed simulation programs for the sensing and control of areas with depressed voltages will be required and implemented in all areas. Full communications between RTO's and ISO's is essential and will be required.

Systems, however, must be controlled to minimize overloads as well as faults and system collapses. Many relays today are set only for faults, and do not force operator action for significant line or transformer overloads. Staging of relays to determine immediate actions, notification of operators for longer term actions, coordination with system control to prevent cascading events, and final control for significant overloads is an excellent goal for the ISO's and RTO's. This is something that can be implemented only with much planning and expense.

ISO's and RTO's must also control the generation to meet each day's demand. Techniques such as time of day pricing and demand side management are tools which should be available to them.

Simulations do not tell the entire story. Automatic control of the system by appropriate relays is an important tool, but cannot anticipate every possible occurrence. The human interface is still important, and the human operator must not only have the authority to control the system but must also be charged with doing so.

James R. Dukart (6) writes "A perplexing and still unresolved question is whether the blackout could have been contained in Ohio, particularly if the right alarms would have been sounded on FirstEnergy's system."

We have been too slow to implement RTO's. We must speed up this process and give them the power to implement proper control and system expansion.

Manufacturers – where have you gone?

There are no US manufacturers of large transformers (500KV and up) and UHV circuit breakers. This is a serious quality control issue for US electric utilities. There are several good manufacturers worldwide, and some of them have subsidiaries in the US, but this does not give us a good domestic base.

Education – where will our engineers and workers come from?

Three of my four engineering contacts from industry started their interviews with that question. Each of them was more concerned with the education of engineers, but a couple of them were also concerned with appropriate educated technicians and craftsmen. One was particularly concerned that with the breakup of the vertically integrated utilities, too much of the history of the utilities was lost to retirement rather than to the independent power producers and merchant generators.

One concern was expressed a couple of times, and that was that the engineers should at least be familiar with the broad sense of power systems, including an understanding of insulation and an understanding of super conductors. No one was concerned with the current sense of analog or digital electronics, but they were concerned that we maintain a good understanding of digital control and of telecommunications.

My rebuttal to them was that the division to which this paper is being submitted is healthy and growing. ASEE's Energy Conversion and Conservation Division is one of the best in ASEE and represents many engineering and engineering technology programs which will be happy to provide graduates at many levels to meet the needs of the electric utility industry.

Two of them felt that we should build consortiums which would better support those institutions willing to provide good support for power engineering and technology. There was a 1960's model at RPI which lasted almost 40 years and a recent TVA model which shows promise.

Answers – answers – answer awaited

Kathleen Davis in her article about title BLACKOUT says: "I've heard enough reports about the blackout to write a book. We all have." The question is not whether we could write a book, but what will that book us teach us so that we can enter the next decade.

This next decade will be an exciting time for electric power systems.

Will we see a possible re-regulation and vertically integrated utilities? Probably not, but we may see a change in the charge to each of the participants in the process. Certainly, RTO's or their equivalent must be created and given the authority and responsibility to assure that the systems operate properly. The cost of replacement and addition of transmission facilities will be shared by the appropriate participants.

Plans will be made to replace many of the central system generating plants. A mix of fuels and the addition of more green power must happen. A serious look at the mix of hydrocarbons and nuclear plants should be undertaken.

Distribution utilities should thrive, as their charge is already determined, and they may undertake other initiatives like broadband communications.

System control strategies will undergo many changes, as they did after the 1965 blackout. The system should become more robust, but may get less so until the appropriate funding mechanisms are determined, funded, and implemented.

It would be wonderful if the education of engineers, technologists, technicians and craftsmen were to be better supported by the utility industry.

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