Impact of Electricity Markets on Electric Power Systems

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Introduction

Electric power system is a complex network involving a range of energy sources including nuclear, fossil fuel, and renewable resources, with many operational levels and layers including control centers, power plants, and transmission, distribution, and corporate networks. Electricity is a cornerstone on which the economy and the daily lives of any industrialized nation's citizens depend. Many participants, including system operators, power producers, and consumers, can affect the operational state of the power system at any time. The interactions of these power system elements, including various physical components and human beings, also increase the complexity of the power grid. On the other hand, the diversity of the time scale at which the power system elements operate contributes to this complexity. The time scales for various control and operation tasks can be as short as several microseconds and as long as several years, which greatly complicates the modeling, analysis, simulation, control, and operation of a power grid.

At the beginning, individual power systems were designed to serve as self-sufficient islands. Each power system was planned to match local generation with load and reserve margins. The system planning criteria were based on the expected load growth, available generation sites, and adequate transmission and reactive power capabilities to provide an uninterrupted power supply to customers in the event of generation and transmission outages. However, it was soon realized that interconnections of power systems would have great advantages over isolated power systems.

The primary requirement for interconnections was the sharing of responsibilities among utility companies, which included using compatible control and protection systems, helping neighboring systems in emergencies, and coordinating maintenance outages for the entire interconnection. For instance, in an emergency, a system could draw upon the reserve generation from its neighboring systems. The burden of frequency regulation in individual systems would be greatly reduced by sharing the responsibility among all generators in the interconnection. In addition, if the marginal cost of generation in one system was less than that in some other systems, a transaction interchange could possibly be scheduled between the systems to minimize the total generation cost of the interconnection.

In the United States (U.S.) economy, the electric power industry represents approximately 4 percent of the gross domestic product (GDP). In terms of revenue, it surpasses industries such as telecommunications, airline, and gas. In addition to providing electricity to homes, businesses, and industry, electric power companies are major contributors to the growth and the stability of local communities across the nation in the form of billions of dollars in tax revenues, by employing nearly 400,000 workers in the U.S., and by providing a variety of public service programs that address the local needs of the areas they serve. This essential commodity has no substitute. Unlike most commodities, electricity cannot be stored easily, so it must be produced at the same instant it is consumed. The electricity system must accommodate any industrialized nation's ever increasing demand for electricity every second of the day and every day of the year.

Issues with Power System Planning and Operation

To some extent, power system restructuring has exacerbated the operations of interconnected grid. In a restructured environment, generators could be installed at any place in the system without much restriction; hence, transmission bottlenecks could become more common in restructured power systems. It is envisioned that new criteria for planning, design, simulation, and optimization at all levels of restructured power systems

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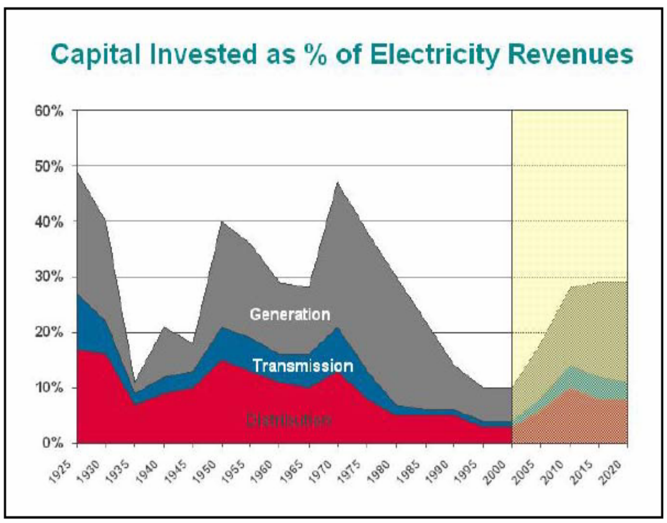
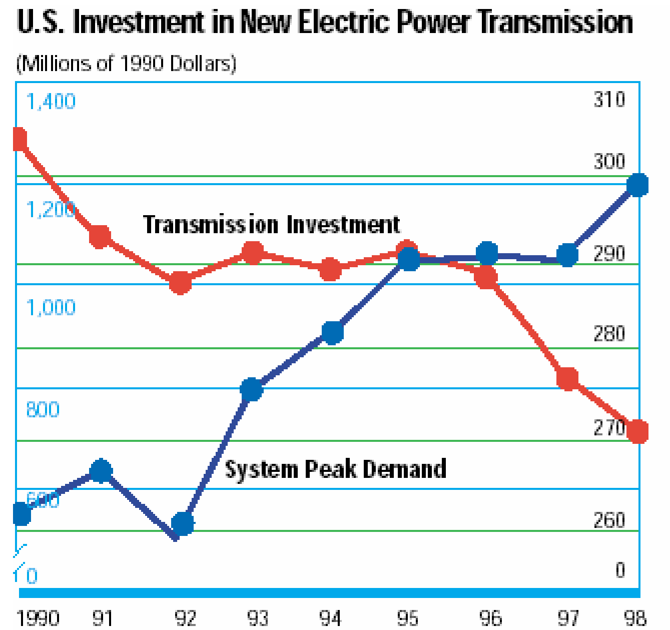
have to be coordinated by appropriate regulating authorities. The restructuring could also result in a slower coordination across the interconnected power network because some aspects of coordination might need to go through several intermediate procedures and be endorsed by different power market participants. However, the recent blackouts in the western and eastern regions of the U.S. provide a growing evidence that certain actions are urgently needed to ensure that the electricity sector will continue to meet the nation's needs for reliable and affordable energy. Much of the concern in this respect is due to the fact that the electricity infrastructure has made minute provisions to meet the changing needs of the economy. In fact, the investment needed to upgrade the infrastructure has reached new lows. As shown in Figure 1, capital expenditures by U.S. electricity providers were only about 12% of revenues during the 1990s which is even below the level reached briefly during the Depression.



Sources: Electric Utility Industry Statistics, and
2001 Financial Review, Edison Electric Institute

Figure 1 Capital Investment

It is widely believed that the current transmission and distribution systems in the U.S. were designed primarily for the industrial era of the 1950s and 1960s, when mechanical switching and radial network design were adequate. Furthermore, annual investment in the transmission system in the U.S. has been cut in half since 1975 and capital expenditure plans announced by utility companies suggest that the under-funding trend is not going to be reversed soon. Figure 2 shows that the expansion of the transmission system in the U.S. is roughly one-quarter of the projected growth in demand. The construction of new transmission lines is projected to grow by only 6 percent over the next 10 years compared to an estimated 20 percent increase in load growth and installed generating capacity over the same time frame.



Growth in peak demand for electricity has far outstripped investment in transmission capacity. As a result, transmission constraints could aggravate already limited supplies of power and could result in high prices in some areas of the country.

Source: PA Consulting Group, based on data from the UDI data base.

Figure 2 Transmission Investment

The following factors have made it difficult to operate efficient and reliable restructured power systems:

- A large number of power system components are tightly interconnected and distributed in a vast area.
- Power system components are operated in multiple hierarchical layers.
- Power system components in different hierarchical layers have different spatial and temporal requirements for operation. For instance, the time frame of a protective device that is adaptive to lightning should be within several milliseconds, while the black start of a generating unit could span over several hours. The breakdown of a transformer at a user side could only affect a small area of the distribution system, but a short circuit fault on a backbone transmission line could affect a large part of the system.
- A variety of participants, including system operators, power producers, and energy customers, act on the system at different places simultaneously.
- The requirements for execution time are rigid and the requirements for reliability are extremely high.

- Random disturbances, including natural disasters such as lightning, unusually high power demands, and operational faults, can lead to widespread failure almost instantaneously.
- No single centralized entity can evaluate, monitor, and control all the interactions in real time.
- The relationships and interdependencies among various power components are so complex that conventional mathematical theories and control methods are hard to apply to many issues.

The under-investment in transmission facilities in the U.S. has also had negative consequences, including higher congestion costs and more frequent curtailment of economic transactions, increased energy losses, higher transmission system maintenance costs, more frequent transmission-related service interruptions, and increased opportunities for the exercise of horizontal market power, even in the absence of vertical market power. The recent events in the U.S. and Europe proved that the net social costs of under-investment in transmission could exceed the cost of over-investment due to a substantial increase in consumer costs incurred from even minute transmission capacity shortages. Among transmission planners, it is perceived that several factors have contributed to this under-investment in transmission infrastructure over the past decade, including:

- An extended period of uncertainty over energy policies and transmission ownership and operation has discouraged the planning for new transmission facilities,
- Market participants including transmission companies have focused primarily on business opportunities in merchant generation and transmission and energy marketing,
- Major investments on transmission are often difficult to justify to state regulators since much of the benefits are to accrue over a wide region while the customers of the local utility will be paying the major share of costs,
- The cap on retail energy rates in restructured power system has made it difficult for transmission companies to recover their investment costs,
- There has been no established constituency in the power industry for the planning of adequate and reliable transmission infrastructure.

The Case for Transmission System Planning

There are various obstacles for transmission planning in a competitive arena. At the outset, transmission costs only one tenth as much as generation, so the obvious question to ask is why don't they build enough transmission so that it would never constrain generation markets? This simple planning approach is mostly appealing to power engineers who prefer systems with excess capacity to meet unexpected needs and to market participants who intend to trade power over large regions. However, the reality is that the construction of new transmission lines is often opposed by local residents and landowners and is therefore politically difficult to achieve. In addition, regulatory rules may not permit utilities to recover fully the cost of such overbuilt systems. Furthermore, transmission plans based on market forces could neglect the public value of providing adequate reliability. Such plans could also ignore the need to link any transmission expansion proposals to local customer benefits. In principle, agreement among planners is growing that some form of market-based planning coupled with physical constraints, regulatory perspectives, and public interests is essential in the long term. Such market-based approaches will provide signals to investors on where to locate new generation and will help system planners, regulators, and local authorities decide and agree on transmission planning and siting.

The following issues are discussed further for enhancing power systems in a competitive era:

Regional Power System Planning. Historically, generation and transmission were planned on an integrated basis by a vertically integrated utility under state regulatory oversight. Models, data, analyses, and transmission plans were accordingly coordinated on a regional basis for reliability purposes. This process met the primary objective of balancing generation with load but did not address the secondary objective of facilitating competitive electricity markets. It is well noted that transmission operation is regional in nature, so the planning process should be regional as well. Just as highways and airports respond to regional needs, power transmission planning should through the regional transmission operator (RTO). This premise does not ban local input, however, states, local governments, regional industries, and the public can and should collaborate on the expansion and planning of transmission facilities.

Role of the U.S. Federal Government. Under current law, siting of power transmission facilities is a responsibility of state governments, even though the transmission system is not only interstate but also international, extending into both Canada and Mexico. Federal law governing the responsibility for siting transmission facilities was written in 1935, nearly 80 years ago. At the time, transmission facilities were not interstate, and there was virtually no interstate commerce in electricity. In general, state decisions on where to locate transmission lines often do not recognize the importance of proposed transmission facilities to the interstate grid. Hence, the U.S. FERC's role could have a major impact on siting and construction of interstate electric transmission lines. For instance, a current bottleneck in transmission siting is the limited access to right-of-way. The federal government is the largest landowner in the United States and owns most of the land in some western states. Improved access to federal land can help remove some of the transmission planning constraints.

Also, a limiting transmission planning issue is the lack of enforceable reliability standards. Since 1968, the reliability of the U.S. transmission grid has depended entirely on voluntary compliance with reliability standards. There is a broad recognition that voluntary adherence with reliability standards is no longer a viable approach in an increasingly competitive electricity market. Accordingly, the 2003 contingencies in the Northeastern part of U.S. have emerged broad support for the development of these standards by self-regulating organizations overseen by FERC.

Recent electricity industry efforts to obtain government approval to construct major new transmission facilities or upgrade existing facilities have frequently been controversial. At the same time, the need for transmission system improvements grows urgently. State and federal governments and transmission owners need to work more closely for making significant changes to improve the process of reviewing and approving proposed transmission projects while continuing to respect and protect the legitimate interests of all parties affected by transmission projects.

Cost of Power System Infrastructure. Indirect costs of not building transmission lines, such as the price consumers pay for not having access to many sources of electricity and the economic cost of blackouts, can be just as important as the direct construction and operation costs of a transmission line. The indirect costs must be factored in when determining whether to build a transmission line. The financial losses due to U.S. power system disturbances are much higher than expected and have become significant to the U.S. economy. The loss represents an additional cost of about 50 cents for every dollar spent for electricity. In addition to the direct costs of disturbances, many high-tech companies need perfect power and increasingly they are installing on-site equipment to meet their specialized needs. In a growing number of cases, the cost of installing power conditioning equipment in buildings has begun to dominate the cost of power delivery.

It is due to the regulatory ambiguity surrounding transmission and distribution planning that most companies have limited their investments until the market structure is established more clearly. Investments are almost completely limited to completing the projects that are under construction or to paying penalties for canceled orders. Environmental investments are being limited in general to only the absolute minimum that current laws require.

There are about 157,810 miles of transmission lines in the U.S. while transmission grid expansions are expected to be slow over the next ten years, totaling only 7,000 miles. The key concern is that the large gap is getting larger between the economy and the electricity infrastructure that is supposed to support the economy. Expanding the transmission system will benefit consumers by reducing the possibility of outages, promoting affordable and stable power prices, and encouraging the construction of cleaner, more efficient power plants. Although the electric transmission cost on average represents a small portion of the total cost of delivering the electricity, any transmission investment has the potential of yielding benefits far outweighing costs.

A more intensive transmission planning and the implementation of technologies over the next two decades that can reduce the frequency of disturbances and possible damages should conservatively reduce outage costs by about half. Failure to take action to reduce power disturbances could result in further degradation of the electricity infrastructure, leading to an increase in costs, perhaps by as much as an additional $100 billion per year over a twenty-year period in the United States.

New Devices for Enhancing Power Transmission and Generation Capacity. Advanced energy management systems offer the hope for controlling transmission flows and voltages and will allow for expanded capability on the system without requiring new construction in short-term. Among the new hardware facilities for managing transmission flows are superconducting and low-cost DC connections as well as Flexible AC Transmission System (FACTS) devices, which refer to a variety of power electronic devices for improving the control and stability of transmission grid. Planning tools could seamlessly integrate an array of locally installed distributed and distributed generation (DG) such as fuel cells, photovoltaic, wind, small hydro units, microturbines which could reduce the need for transmission and distribution. DG encompasses any small-scale electricity generation technology that provides electric power at a site close to consumers. The size of DG could range from a few kilowatts to hundreds of megawatts. DG units, which are scattered throughout the distribution system, will be connected to a consumer's facility, the utility's distribution system, the power transmission grid, or a combination of these options. New generation technology ranging from coal refining, combined cycle units to advanced nuclear power plants could also form the core of clean and affordable energy portfolio of the future.

Innovative Technologies for Managing Power System Operation. In contrast to the current investment climate for transmission planning, the prospects for the application of new technologies to transmission infrastructure have never been brighter. New policies, however, are urgently needed for unleashing innovative technologies which could transform electric power systems to an enterprise that could better serve growing demands of our society. A prominent application of technology is to create a dynamic and interactive power system that is merged with communication networks to form a real-time information and power exchange infrastructure for managing severe cases. Figure 3 shows an example of such systems. This new infrastructure will be needed to empower retail energy markets, support the interaction among control centers, manage the security of susceptible components of the power system, and fundamentally raise the value proposition for electricity. Promote the load management at the customer level and transform the power system into a consumer gateway that allows price signals, decisions, and communications to flow through the two-way energy information portal. Public support for transforming the functionality and the value of electricity services could be justified because the societal savings achieved from more efficient energy use will considerably outweigh additional costs of new technologies.

Outreach and Public Education. It has become considerably more difficult to construct a new transmission line than a new generating plant. New generation has a small geographic footprint and can be sited in areas of minimal opposition, whereas transmission planners are limited in their choice of rights of way by the existing system configuration, prior development, and environmental and land use issues. When it comes to transmission additions, virtually any one of the multiple political jurisdictions along the planned route can delay or even veto the plan which would effectively block the planning initiative. In such incidents, political entities at the federal or state level have often refused to take a broader public interest perspective by pre-empting local oppositions. A key to the public support of a transmission planning project is the public understanding of a transmission line project, which can affect many people who may not see any direct benefits from the transmission line. Open and frank discussion of the project, its benefits and drawbacks, and the owner's responsibilities in building and operating the transmission line, will further help that understanding.

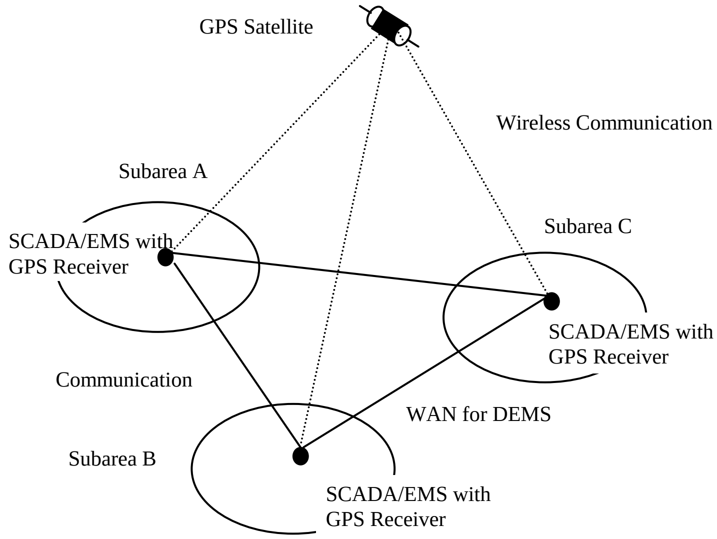


Figure 3 Power System Communication

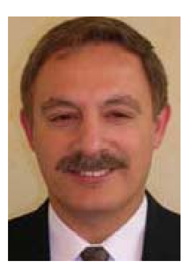
Final Note

Below are a few recommendations for enhancing the electric power system in the restructuring era:

- Establishment of a comprehensive and competitive electric market structure
- Establishment of a all-inclusive generation and transmission planning criterion to assert reliability needs of the power grid.
- Integration of distributed technologies for generation and storage to support customer micro-grids.
- Deployment of new devices such as FACTS and superconductors for mitigating power flow congestions in stressed power systems.
- Deployment of new technologies to transform the static grid to an intelligent and automatically switched network.
- Participation of customers in demand side management and market price signals.

Further Reading

[1] M. Shahidehpour and Y. Wang, Communication and Control of Electric Power Systems, John Wiley and Sons, June 2003
[2] M. Shahidehpour, H. Yamin and Z. Li, Market Operations in Electric Power Systems, John Wiley and Sons, March 2002



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