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COMPETITION CAN ENHANCE BULK-POWER RELIABILITY

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Overview

The U.S. electricity industry is in the midst of a major restructuring. A combination of technical, economic, regulatory, and political forces is transforming the industry from its traditional vertically integrated, retail-monopoly franchise, heavily regulated status to an industry that is dominated by competitive forces at the generation and retail levels.

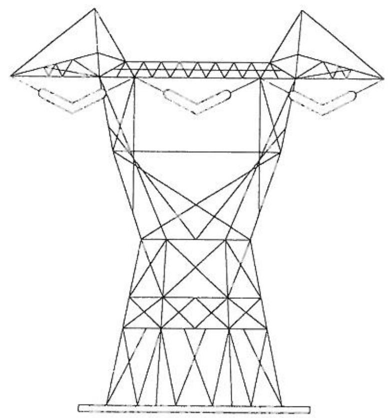
All participants in the efforts to restructure the industry agree that reliability must be maintained in the future. Some traditionalists fear that vertical deintegration and increased competition will degrade reliability. The purpose of this paper is to debunk that myth and show how competitive markets can strengthen reliability.

This *Profile* begins with a discussion of the unique characteristics of electric systems and the reliability implications of these characteristics. It then discusses today's systems for maintaining reliability. Finally, it explains how competition could improve reliability at lower cost in a future, competitive electricity industry.

PROFILES ON ELECTRICITY ISSUES are published to promote a better understanding of the economic and social impacts of policy proposals relating to electricity. ELCON members seek an adequate and reliable supply of electricity at competitive prices, not only for the benefit of industrial consumers and their labor force, but also for all consumers of industrial products and the U.S. economy.

Profiles on Electricity Issues

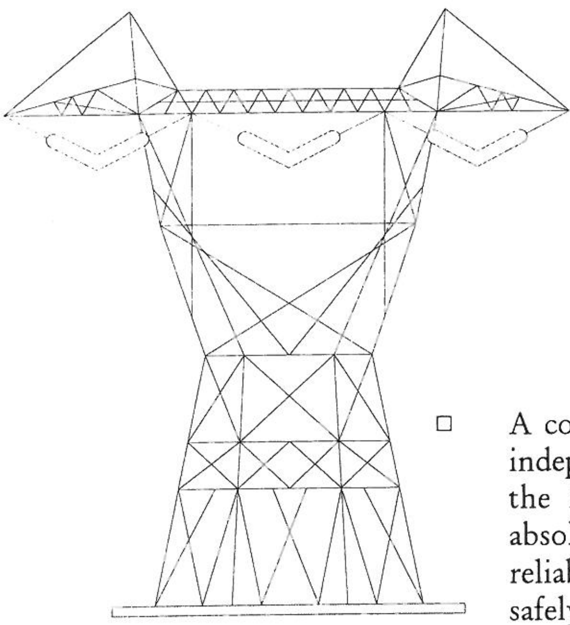
COMPETITION CAN ENHANCE BULK-POWER RELIABILITY



CONTENTS

ELCON

SUMMARY OF ELCON'S POSITION ON BULK-POWER RELIABILITY



- The restructuring of the electricity industry that is now underway throughout the United States need have no adverse effects on reliability. Indeed, greater use of markets to competitively buy and sell reliability-related services should enhance bulk-power reliability and reduce the costs of doing so.

- A competitive bulk-power system requires the formation of independent system operators to maintain the reliability of the interconnected regional grid. Such ISOs should have absolute authority to compel actions needed to maintain reliability in real-time and to restore the system quickly and safely after an outage occurs.

- The use of real-time (*e.g.*, hourly) pricing of spot-market electricity will create powerful economic incentives for end-use customers to more efficiently manage their loads, especially during times of impending emergencies. These prices provide similarly powerful incentives to suppliers to increase output during these critical periods.

- In competitive markets, the providers of reliability services (such as spinning reserves) should be paid for the service they actually provide. Similarly, those entities that use reliability services (such as generators with high forced outage rates) should pay for the costs they impose on the system.

- Competitive suppliers, including power marketers and the owners of generating units, can make money only if they can deliver their products to end-use customers. In addition, the unbundling in a competitive market of unregulated generation services from regulated transmission services will increase the economic incentive of transmission owners to properly maintain transmission facilities and right-of-ways. Thus, all the participants in competitive bulk-power markets—both suppliers and consumers—share a common and vital interest in protecting and enhancing system reliability.

Profiles on Electricity Issues

COMPETITION CAN ENHANCE BULK-POWER RELIABILITY

ERIC HIRST[1]

A. KEY FEATURES OF ELECTRIC SYSTEMS

Bulk-power systems include electrical generators, transmission networks, and control centers. These systems are fundamentally different from other large infrastructure systems, such as air-traffic control centers, natural-gas pipelines, and long-distance telephone networks. Electric systems have two unique characteristics:

- **Need for continuous and near instantaneous balancing of generation and load,** consistent with transmission-network constraints; this requires metering, computing, telecommunications, and control equipment to monitor loads, generation, and the transmission system, and to adjust generation output to match load.

- **Passive nature of the transmission network,** with very few "control valves" or "booster pumps" to regulate electrical flows on individual lines; control actions are limited primarily to adjusting generation output and to opening and closing switches to reconfigure the network.

These two unique characteristics lead to three reliability consequences that dominate nearly all aspects of power system design and operations:

- **Every action can affect all other activities on the grid.** The activities of all players must be coordinated to some degree.

- **Cascading problems that increase in severity are a real problem.** Failure of a single element can, if not managed properly, cause the subsequent rapid failure of many additional elements, disrupting the entire transmission system.

- **Contingency considerations dominate design and operation of bulk-power systems.** It is usually not the present flow through a line or transformer that limits allowable transfers of power, but rather the flow that would occur if another element fails.

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[1]This paper was prepared under contract with the Electricity Consumers Resource Council, Washington, D.C. The author is a Consultant in Electric-Industry Restructuring and a Corporate Fellow at Oak Ridge National Laboratory, Oak Ridge, Tennessee.

B. Maintaining Reliability in Today's Industry

Reliability is like beauty: it cannot be easily and unambiguously defined. But we know when the lights are off. A reliable electric system is one that allows for few interruptions of service to customers. Outages can be defined in terms of their number, frequency, duration, and amount of load (or number of customers) affected. Equally important, but much more difficult to quantify, is the value of loss of load.[2]

Although generation and transmission failures cause only a small fraction of the power outages, their economic and societal consequences can be much higher than those associated with distribution outages. Bulk-power outages generally affect many more customers and are much more difficult to recover from than is true for distribution outages.

To maintain reliability, system operators (today's utility control-area operators and tomorrow's independent system operators, ISOs[3]), undertake several activities. These activities include:

- **Observe the network** - Monitor real-time frequency, voltage, current, and power-flow conditions at each node and in each element to determine if failure of an element or voltage collapse is imminent.
- **Analyze and model the system** - Determine conditions in elements (individual pieces of equipment such as lines and transformers) that are not directly observed with the use of computer models based on observed current flows and voltages; estimate what will happen if an element fails; determine whether proposed transactions can be accommodated; and deal with normal uncertainties, such as load forecasts and the effects of temperature and wind speed on real-time thermal limits.
- **Communicate and coordinate** - Keep system operators in other control areas aware of the conditions within the control area that might affect operations in and reliability of the interconnected grid.
- **Take control actions** - Maintain the system in an acceptable state (primarily changes in generation output, transmission switching to a lesser extent, and load shedding as a last resort).
- **Monitor and enforce compliance** - Ensure that all market participants (generators, aggregators, marketers, transmission owners and operator, and end-use customers) are meeting their reliability responsibilities commensurate with the burden that each participant imposes on the grid.

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[2]A 10-minute power outage in a residence is an annoyance because someone has to reset the digital clocks but imposes only small economic costs. But a similar outage for a computer-chip manufacturer might entail the loss of millions of dollars of output.

[3]See ELCON's *Profile on Electricity Issues: Independent System Operators*, N° 18, March 1997.

NERC's Reliability Definition

The North American Electric Reliability Council (NERC), the primary guardian of bulk-power reliability, was established in 1968. NERC's creation was a direct consequence of the 1965 blackout that left almost 30 million people in the northeastern United States and Ontario, Canada without electricity.

NERC defines reliability as "the degree to which the performance of the elements of [the electrical] system results in power being delivered to consumers within accepted standards and in the amount desired." NERC's definition of reliability encompasses two concepts, adequacy and security. Adequacy is defined as "the ability of the system to supply the aggregate electric power and energy requirements of the consumers at all times." It defines security as "the ability of the system to withstand sudden disturbances."

In plain language, adequacy implies that there are sufficient generation and transmission resources available to meet projected needs plus reserves for contingencies. Security implies that the system will remain intact even after outages or other equipment failures occur.

- **Plan to expand and modify the system** - Construct capacity additions (new lines, transformers, and FACTS devices [4]) to improve reliability, to improve ability to observe and model the system, and to increase capacity.[5]

In addition to adequacy and security, power quality is a vital component of a reliable electric supply. Power quality is the delivery to customers of electricity in the form of a perfect 60-Hz sine wave, without surges, swells, sags, or harmonics. Maintaining appropriate levels of power quality is primarily a distribution, rather than a bulk-power, function.

Actions to maintain reliability occur over very different time frames, from cycles (fractions of a second) to minutes, to day ahead, to week ahead, to annual maintenance scheduling, and to several years for transmission and generation planning (Table 1).

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[4]FACTS refers to flexible AC transmission systems, the use of high-speed thyristor technologies to control transmission equipment, thereby improving reliability and increasing capacity.

[5]In theory, markets should determine whether and how to expand transmission capacity for commercial reasons and the ISO should be responsible for reliability-related expansions. In practice, such a split is likely to be unworkable.

TABLE 1

SERVICES THAT THE TRADITIONAL VERTICALLY INTEGRATED UTILITIES PERFORMED THAT CAN AFFECT BULK-POWER RELIABILITY

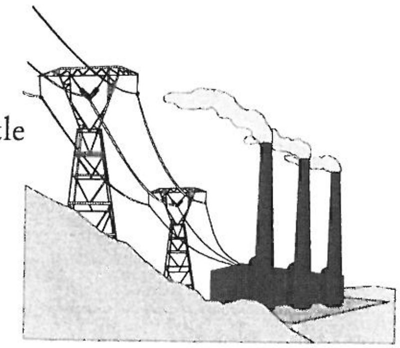
Service	Time scale	Description
Automatic protection	Instantaneous	Minimize damage to equipment and service interruptions caused by faults and equipment failures
Disturbance response	Instantaneous to minutes to hours	Adjust generation, breakers, and other transmission equipment to restore system to scheduled frequency and generation/load balance as quickly and safely as possible
Regulation and voltage control	Seconds to minutes	Adjust generation to match scheduled intertie flows and actual system load. Adjust generation and transmission resources to maintain system voltages
Economic dispatch	Minutes to hours	Adjust committed units to maintain frequency and the generation/load area-interchange balance at minimum cost subject to transmission, voltage, emissions, and reserve-margin constraints
Unit commitment	Hour ahead to week ahead	Decide when to start up and shut down generating units, respecting unit ramp-up and -down rates and minimum runtimes and loadings
Maintenance scheduling	1 to 3 years	Schedule and coordinate interutility sales and planned generating-unit and transmission-equipment maintenance to maintain reliability and to minimize cost
Fuel planning	1 to 5 years	Develop least-cost fuel supplies, contracts, and delivery schedules
Transmission planning	Several years	Design regional and local system additions to maintain reliability and to minimize cost
Generation planning	Several years	Develop a least-cost mix of new generating units, retirements, life extensions, and repowering based on long-term load forecasts

The response to faults (*e.g.*, a lightning strike) occurs automatically within a few cycles (*i.e.*, in less than a second).

A generator tripping offline causes an immediate imbalance between generation and load, which causes a decline in interconnection frequency. In response to this frequency decline, the generators under governor control automatically increase output to begin to restore frequency to its 60-Hz reference value. Generators under automatic generation control (those providing operating reserves) increase output to restore the generation/load balance within ten minutes.

System operators deal with the consequences of the above mentioned automatic actions to restore the system to a robust state in minutes to hours by redispatching generation, and perhaps transmission, resources. They also schedule transactions and ensure sufficient operating reserves for the following hour and day. System operators and planners also need information on future system loads for day-ahead and week-ahead planning for reserves and longer term for maintenance and resource planning. Regional coordination for operating and planning activities is necessary to optimize efficient and reliable service. Finally, the planning for new generators and transmission-system additions typically occurs from one to ten years ahead.

C. MAINTAINING RELIABILITY IN THE FUTURE



The restructuring of the U.S. electricity industry should have little effect on bulk-power reliability, but will greatly affect who does what to whom. Maintaining reliability involves two sets of operations: normal operations and emergency operations. Markets can do much to maintain reliability and prevent outages during normal operations. Markets may be much less effective during emergency conditions unless specific resources are contracted for ahead of time.

Time is the key factor that will determine whether competitive markets can provide the appropriate levels of reliability or whether engineering standards and direct control will be required. Roughly speaking, competition is likely to work well for actions that occur an hour or more in the future. Given this lead time, buyers and sellers can find the price level for each service that will balance supply and demand. For shorter time periods, however, system control may still be required. Even here, engineering standards may still be needed to specify the amount of each service that is required and to establish metrics for judging the adequacy of service delivery; markets can then determine the least-cost resources to provide the required services.

Disturbance response and generation planning provide useful examples of the two ends of the temporal spectrum. Almost all proposals for a restructured bulk-power system call for the creation of an *independent* system operator (ISO). Among its responsibilities, the ISO will have the ultimate authority to compel actions needed to maintain reliability in real time and to restore the system quickly and safely after an outage occurs. Although after-the-fact disputes may occur over who pays for what, there is no dispute about the ISO's responsibility, accountability, and authority to maintain reliability. For example, if the ISO deemed it necessary to reduce flows on a particular transmission line, to take a line out of service, to reduce output at a particular generator, or to increase output at another generator, the operators of those pieces of equipment would be required to comply with the ISO's order.

Generation planning, however, will be entirely different from its past practice. Historically, utilities planned for and built power plants to meet a predetermined reserve criterion, typically a one-day-in-ten-years loss-of-load-probability or a minimum reserve margin. The state regulator then allowed the utility to recover the costs of these generators through rates charged to the utility's retail customers (who, because of retail-monopoly franchises, had no choice about whether to pay for this "extra" generation). In addition, these costs were generally reflected in embedded-cost rates that had little or no temporal variation.

In the future, decisions on retirement or repowering of existing generators and the construction of new units will be made by investors with no regulatory involvement.[6] These decisions will be made on the basis of trends in market prices and projected revenues from the sale of electricity relative to the construction and operating costs of the unit in question. Generators will be built when the projected costs are low enough to yield a profit. And prices in the future are likely to vary from hour to hour throughout the year, based on the units in operation each hour and the balance between unconstrained demand and supply online. When demand begins to exceed supply, prices will rise, which in turn will suppress demand and increase the amount of supply available. Spot prices will stop rising only when constrained demand is brought down and supply is increased to restore the necessary generation/load balance. Although these spot prices are likely to be quite low for most hours (*e.g.*, around 2¢/kWh), they may exceed $1/kWh for a few hours each year (*e.g.*, during unusually hot spring days, when large generators are out for planned maintenance). It is the level, frequency, and duration of these high prices that will signal markets to build more generating capacity, rather than the decisions of electrical engineers in vertically integrated utilities. This price volatility will also signal customers on the benefits of managing their loads in real time.

In the approach outlined above, the economic paradigm of supply and demand elasticities replaces the engineering paradigm of planning reserve. A key concern with the use of pricing to equilibrate demand and supply is that governments will intervene and suppress prices in response to political pressures from consumers unhappy over the very high prices that will occasionally occur. Such political intervention would completely undercut the market and make it impossible for generators to decide whether and when to increase capacity.

D. Examples of How Competition Could Enhance Reliability

1. Pricing Reserves to Enhance Reliability

Operating reserves include two components, spinning and supplemental reserves. Spinning reserve includes generating equipment that is online, synchronized to the grid, that can begin to increase output immediately to changes in interconnection frequency, and that can be fully available within 10 minutes to correct for generation/load imbalances caused by generation and transmission outages. In principle, loads under the control of the system operator could help provide this service. This service can be provided by any generator that is connected to the grid and electrically close to the local control area that transmission limitations do not prevent the importation of this power.

Supplemental reserve includes generating equipment and interruptible load that can be fully available within 10 minutes to correct for generation/load imbalances caused by generation and transmission outages. This service can be provided by any generator that is connected to the grid and electrically close enough to the local control area that transmission limitations do not prevent the importation of this power.[7]

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[6]Of course, state governments will still oversee the siting and environmental consequences of these decisions. But states will not interfere with the economic aspects of these decisions.

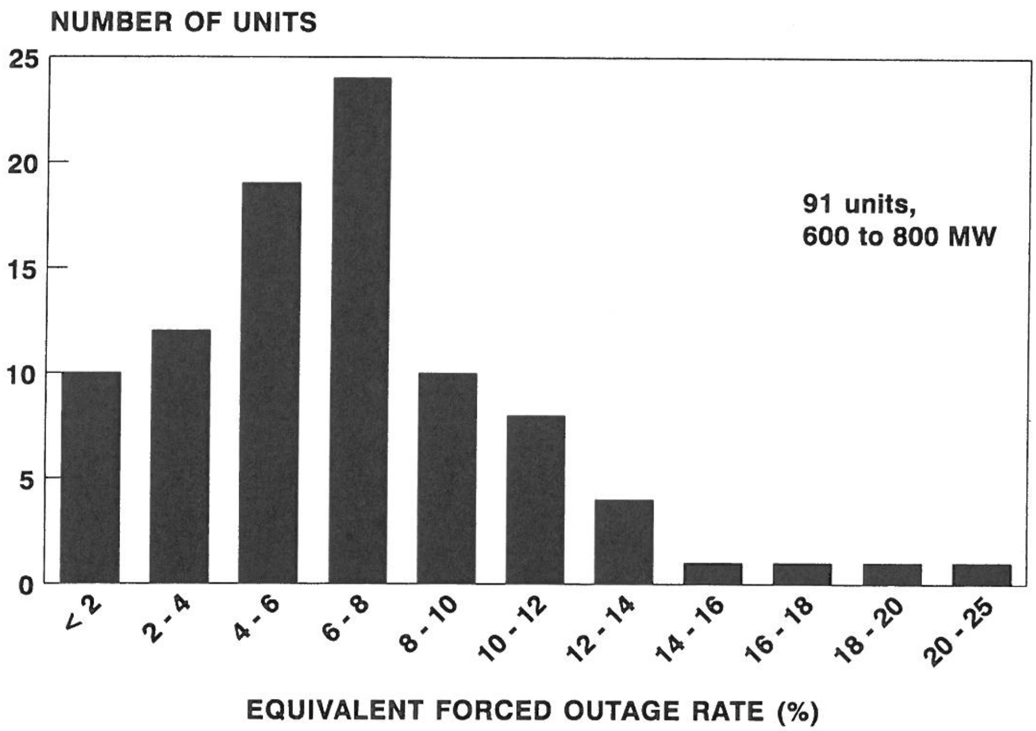
[7]This service might also include the provision of generating capacity that must be fully available within 30 or 60 minutes (the exact time depends on the rules of the regional reliability council) and can then be maintained

Each of the regional reliability councils establishes minimum amounts of capacity that must be set aside for operating reserves, usually expressed as a percentage of the hourly or daily peak demand. Typical levels are 3% for spinning plus 3% for supplemental reserves.[8] In principle, these levels are based on the reliability of the generating units in the region. However, nowhere is the assignment of reserves based on the performance of specific generating units. Figure 1 shows the equivalent forced outage rates for 91 coal-fired units (with capacities between 600 and 800 MW) for the 5-year period 1991 through 1995. The average for these 91 units is 6.6%, but the performance of individual units ranges from excellent (less than 2% forced outage rate) to terrible (more than 20%).

In a competitive market, the responsibility of each unit to provide operating reserves should depend directly on its forced outage rate. In other words, the units with low outage rates would be required to provide or pay for much less operating reserves than would the units that have very

FIGURE 1

EQUIVALENT FORCED OUTAGE RATES FOR 91 LARGE COAL-FIRED UNITS
(Based on data from NERC)



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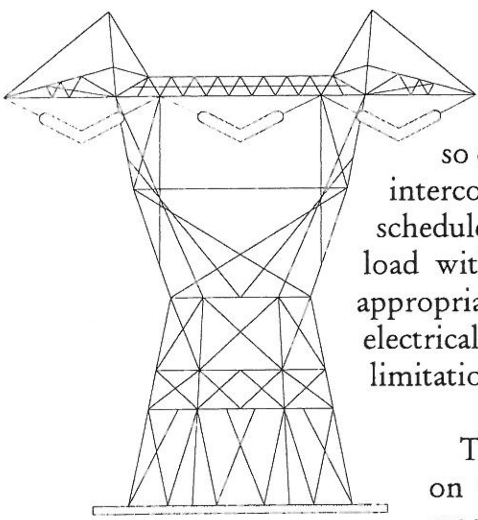
until commercial arrangements can be made (*e.g.*, for two hours) to "backup" the normal supply for the load.

[8]In ECAR, the spinning and supplemental reserve requirements are both 3% of the daily peak load. In MAAC, the spinning reserve must be the greater of 700 MW or the capacity of the largest unit on line; its supplemental reserve requirement is 1700 MW. In FRCC, the spinning reserve must equal 25% of the largest unit online and the supplemental reserve must equal 75% of the largest unit.

high outage rates. This economic signal would provide the appropriate incentives to generation owners, encouraging them to undertake the amount of maintenance that would just balance the higher cost of providing more reserves. In addition, in the event of an outage, the generator responsible for the outage should pay for the operating costs of the units that responded to the outage (*i.e.*, the incremental fuel plus O&M costs beyond those associated with the spot-market price for that hour). This pricing approach would provide further incentives for maintaining high availability levels at all generating units.

2. PAYING FOR REGULATION PERFORMANCE



Regulation includes online generating equipment that is equipped with governors and automatic generation control (AGC) to track the moment-to-moment fluctuations in customer loads and unintended fluctuations in generation. In so doing, regulation (along with spinning reserve) helps to maintain interconnection frequency, minimize differences between actual and scheduled power flows between control areas, and match generation to load within the control area. This service can be provided by any appropriately equipped generator that is connected to the grid and electrically close enough to the local control area that transmission limitations do not prevent the importation of this power.

The tariffs filed by most utilities with FERC charge for regulation on the basis of a customer's average hourly load, although the amount of regulating burden a customer imposes on the system is a function primarily of the load's *volatility* (minute-to-minute variation) rather than its level. Similarly, the payment to generators that provide this service should reflect the accuracy with which they respond to the AGC signals from the control center. As Figures 2a and 2b show, generator performance can be quite variable. Again, a pricing system that paid generators for their actual, rather than assumed or average, performance would encourage improved regulation performance and a more reliable system.

3. CUSTOMERS RESPOND TO REAL-TIME PRICES

Real-time prices that vary from hour to hour provide important economic signals to both suppliers and consumers. High prices will encourage the construction of new generating units and the prompt restoration to service of existing units that are offline. Similarly, high prices will encourage customers to reduce their usage at those times. Together, these supply and demand responses to price will reduce the need to maintain expensive generating capacity that is only rarely used. Thus, economics can substitute for engineering to maintain real-time reliability when demand would otherwise exceed supply.

Figure 3 shows the real-time response of an industrial customer to the real-time price signaled it received one day in July 1995. As the price jumped from 2¢/kWh at 11 am to 29¢/kWh at 3 pm, this customer reduced its load from 23 MW to 13 MW.

Figures 2 A & B

Minute-to-Minute Output from Two Generators Providing Regulation Service

The Top Figure Shows Excellent Performance, and the Bottom Figure Shows Poor Performance. The Two Units Are Owned and Operated by the Same Utility.

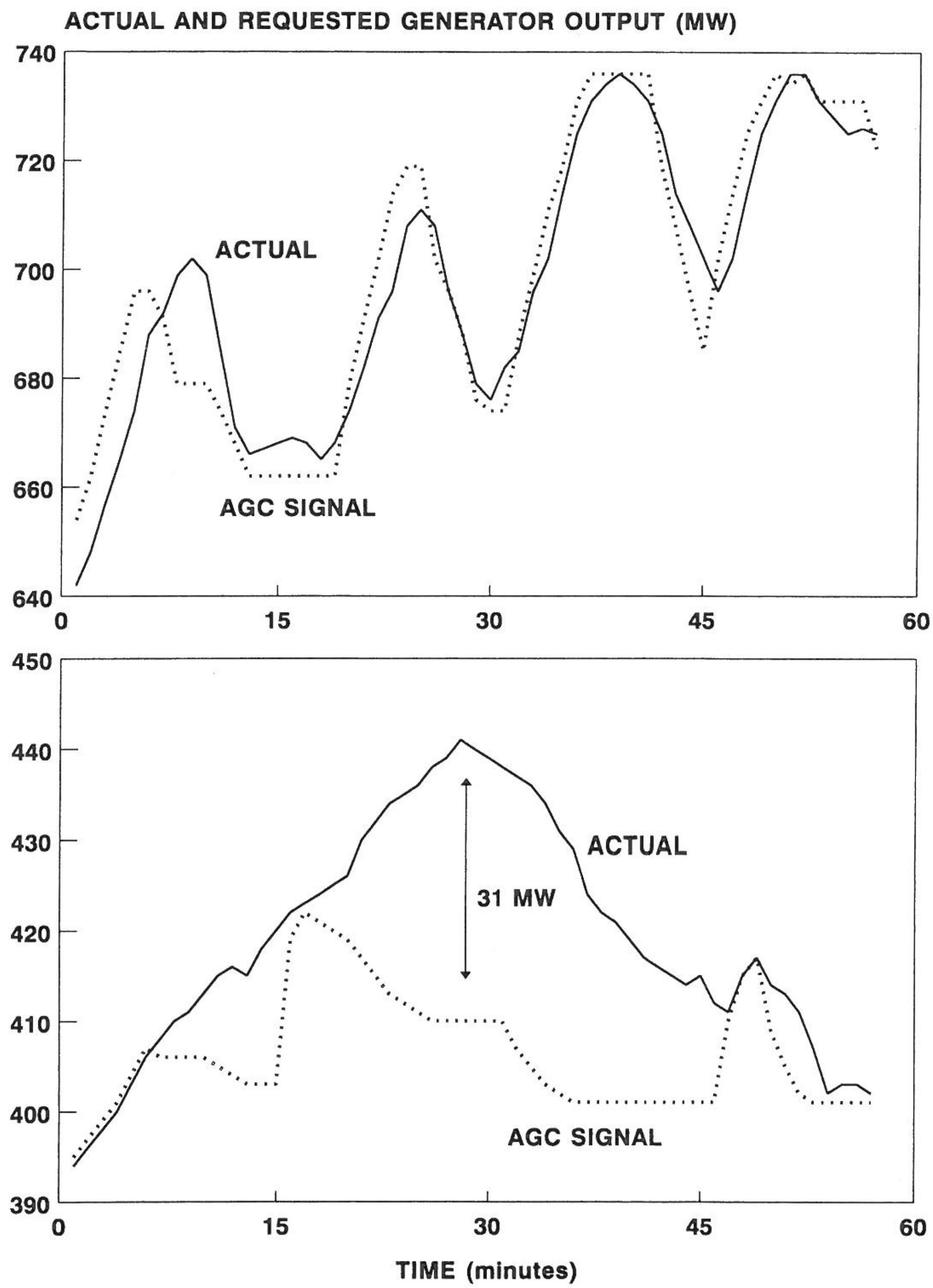
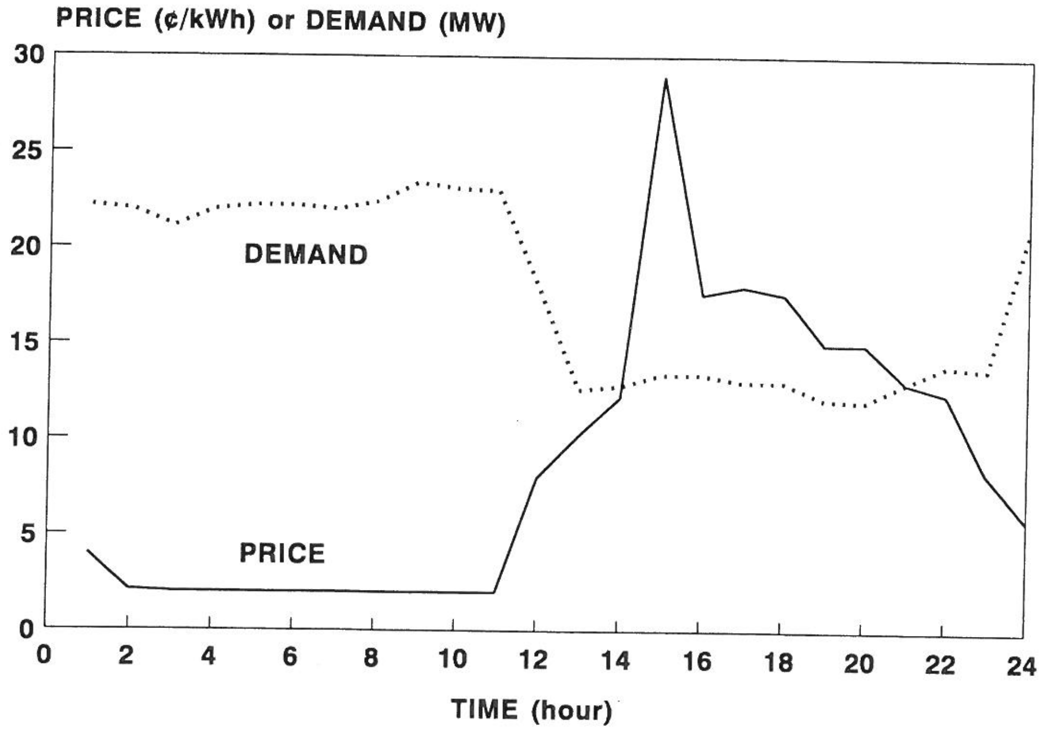


FIGURE 3

GEORGIA POWER COMPANY'S REAL-TIME PRICES AND ONE INDUSTRIAL CUSTOMER'S RESPONSE TO THOSE PRICES ONE DAY IN JULY 1995



E. KEY INGREDIENTS FOR RELIABILITY

Increasingly, proposals to restructure the electricity industry call for the creation of an ISO to manage many of the operations of the bulk-power system, as discussed in the ELCON *Profile* on *Independent System Operators*. These proposals all call for the ISO to have the ultimate responsibility and authority on all matters related to the maintenance of real-time reliability. This authority includes those actions taken during normal operation to protect the system from contingencies as well as those actions taken during emergencies.

- ☐ The ISO must be completely independent of and have no financial ties to generation and no commercial ties to either retail or wholesale electricity customers. This independence is essential to the integrity and perceived honesty of the system operator in maintaining reliability. Absent such independence, market participants will always worry that ISO decisions on transactions and generation levels favor its generation and customer-service interests, rather than those of the system as a whole. Such worries are likely to lead to lawsuits.

- ☐ Wherever feasible, the ISO should use markets for the provision and purchase of reliability-related services rather than use command-and-control decisions. Such markets can readily be established for regulation, spinning and supplemental operating reserves, backup supply, energy imbalance, and losses. Such markets might even be possible for some location-specific services such as voltage support, black-start capability, and network-stability services. Although markets can probably not be used to determine the amounts of each service required, markets can determine the hour-to-hour prices for each service.

- Over time, the centralized definition and requirement of a planning reserve margin should be replaced with the use of real-time pricing. A positive reserve margin is used to ensure that sufficient generating capacity will be available in the event that demand is high and some generating units are experiencing forced or planned outages. Typically, the reserve margin is determined on the basis of a one-day-in-ten-year loss-of-load probability. Today's LOLP criterion is equivalent to a $3/kWh value of unserved energy on a fully embedded basis. Rather than have a centralized entity predetermine the required amount of generation, real-time pricing could accomplish the same goal in a more economical fashion.

- The designers of tomorrow's bulk-power systems must recognize differences in time scales. For short times (*e.g.*, less than an hour), markets may not be able to respond fast enough and control should be vested in the ISO. For longer periods (*e.g.*, an hour or more), markets can and should be allowed to operate. As metering, telecommunications, and computing technologies improve and come down in cost, the breakpoint will shift to shorter times and competitive markets may be able to assume more responsibility for determining appropriate levels and costs of reliability.

F. Conclusions

The U.S. bulk-power systems are the envy of the world. Our systems have operated at high levels of reliability for decades. The changes underway and contemplated for bulk-power structures and operations need have no adverse effects on reliability. Indeed, greater use of markets to competitively buy and sell reliability-related services should enhance system reliability and reduce the costs of doing so.

Bulk-power reliability is primarily a commons issue. Individual customers generally cannot select their desired level of bulk-power reliability. However, individual customers can sell certain services (*e.g.*, interruption rights with "call options") to the ISO that help maintain reliability at appropriate levels. More generally, customer responses to real-time prices can enhance reliability and reduce the need to build generation.

Competitive suppliers, including power marketers and the owners of generating units, can make money only if they can deliver their products to end-use customers. In a competitive industry, the unbundling of unregulated generation services from regulated transmission services will also increase the economic incentive of transmission owners to properly maintain transmission facilities and right-of-ways. Thus, all the participants in bulk-power markets—both suppliers and consumers—share a common and vital interest in protecting and enhancing system reliability.