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27. Development of a strongly constricted postpetiole has independently occurred within several ponerine genera including *Proceratium* (Ectatommini) and *Cerapachys* (Cerapachyini), and in the evolution from primitive ponerine or poneroid stock of Dorylinae, Ecitoninae, Leptanillinae, and Myrmicinae. The only ecitonine genus usually said to lack a worker postpetiole is *Cheliomyrmex* (Ecitoninae-Cheliomyrmecini); it has a tubulate but relatively unconstricted segment IV, resembling that of many ponerines (such as *Amblyopone australis*) (Fig. 3A) and exemplifying a condition presumably primitive for Ecitoninae [see figure 4-29 of (*7*), p. 70]. Similarly, in the Dorylinae, *Dorylus* has abdominal structure like *Cheliomyrmex*, while *Aenictus* workers have a strongly constructed postpetiole.
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Operating a Major Electric Utility Today

The power industry's development, its current problems, and possible future trends.

Theodore J. Nagel

The availability of a continuous and uninterrupted electric power supply is regarded by most people in our society as a necessity, if not, indeed, a fundamental right. The consumer's perception is based on the fact that he alone determines the use of electric power to meet some want.

Dependence on electric service permeates our daily lives. Electricity is vital not only to power much of our industrial equipment but also to automate its control. It is critical in the home, on the farm, in the store, in our transportation and communication systems, and indeed in all aspects of our complex, industrialized society. In many instances, other energy sources cannot be used without electricity. A prime example is the oil- or gas-fired furnace in our homes. Thus, any major interruption of electricity's supply will inevitably raise public concern regarding both the technological advance of the nation's power systems and the competence of their managers.

In any consideration of an electric utility's ability to provide a continuous and uninterrupted supply of electric power, it is necessary to keep in mind the unique nature of electricity, a uniqueness frequently lost in public discussions even within the scientific community and most often ignored in political debate concerning energy. This uniqueness is marked by the twin facts that electricity, by and large, cannot be stored and yet must be instantaneously available in the quantities demanded by the consumer whenever and wherever he needs it. Every other industry in our society can schedule its service and exert substantial control over the use of its product. This is true even for service industries such as transportation and communication. The transportation industry can limit the number of passengers on its conveyances, and the communications industry can prevent overloads by a busy signal. For electric power, however, the consumer controls the consumption of the product by a simple flip of the switch. Hence, the capability to serve—to make certain the switch turns on the light—must be planned years in advance. Overloading facilities has dire consequences for the quality of service to the consumer and threatens the very integrity of the power system itself. These stringent requirements are made increasingly difficult by the uncertainties now confronting the industry.

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Historical Overview

The electric power industry in the United States has evolved during the more than 90 years of its existence from small isolated generating plants supplying local communities over low-tension distribution systems to today's highly complex interconnected and interdependent groupings of power suppliers. Figure 1 traces this growth in terms of both the demand for electricity and the size or ratings of the principal power supply facilities.

It was during the latter half of this 90-year period that the benefits of availability and reduced cost of electric service became major factors in its use. Fifty years ago or so, electricity was still a luxury; it was not available in many of our rural areas; its cost was greater even than today's inflated level. It was only during the period when interconnection among separate power suppliers became practical that the objectives of increased availability and reduced price were realized.

The difficult technical problems of interconnected operation began to be solved in the decades of the 1920's and 1930's, with improvements made ever since. These early problems included confronting the need to develop equipment and procedures to assure accurate control of frequency—a vital aspect of stable interconnected operation—and to share load-regulating responsibility among all entities composing the network. Gradual expansion of interconnections has resulted in today's vast networks that extend over much of the United States and portions of Canada.

The growth in the size of power supply companies and their ability to interconnect permitted the industry to reduce the cost of electric service by exploiting inherent economies of scale as well as potential technological efficiencies in both generation and transmission. This trend continued until the 1970's, when unprecedented inflation in capital and fuel costs turned the cost curve upward (Fig. 2).

The Fundamental Framework

The fundamental framework of the power supply industry may be said to comprise financial, regulatory, technological, and institutional considerations.

Electric utilities are without doubt the most capital-intensive of all economic enterprises. The power industry today requires approximately $5 of investment per dollar of annual revenue. This is in sharp contrast to most manufacturing industries, which require $1 or less of investment per dollar of annual revenue. In addition to the high cost of facilities is the need to raise much of the investment in the marketplace. Thus, the power industry is inherently sensitive to the cost of money. It is also sensitive to the cost of the primary fuels used in the generation (conversion) process. Historically, the cost of operation—mainly that of fuel—represented approximately 50 percent of the annualized cost of electricity produced and delivered to the generating plant's terminals. The percentage is even higher today.

Another characteristic of the power industry is that it is among the most highly regulated activities in our economic system. By its very nature, it may be described as a natural monopoly; the cost of duplicate facilities by competing suppliers would be economically disastrous. Hence, regulation is a necessary substitute for competition. Regulation is largely state-oriented with respect to adequacy and cost of service to the retail consumer, with wholesale rates and interstate power transactions regulated by the federal government.

Supplying power is a highly technological process. A typical power system comprises a number of separate generating plants, each containing several generating units, with transformers stepping up to high-voltage buses. These generating plants, in turn, are tied together by a network of high-voltage transmission lines to substations where the power is stepped down to lower voltages for supply to local load areas through subtransmission and distribution networks.

Each component of equipment and each facility of a power system are themselves complex. For example, a generating unit may have a capacity well in excess of 1 million kilowatts and be capable of supplying a moderate-sized city of as many as 1 million inhabitants. It consists of many elements: fuel handling facilities, a steam boiler operating at extremely high temperatures [1000°F (538°C)] and pressures [3500 pounds per square inch (238 atmospheres)], a turbine generator weighing in excess of 500,000 pounds (226,800 kilograms) and rotating at up to 3600 revolutions per minute, and numerous complex controls. Generating plants usually use computer dispatching and control. Power systems—assemblies of plants, transmission lines, substations, and distribution facilities—are largely automated, with heavy use of modern computer and informational technology.

From an institutional standpoint, the power industry is pluralistic, consisting of some 3400 investor-owned, cooperatively owned, municipally owned, state-owned, and federally owned entities. This composition largely reflects the in-

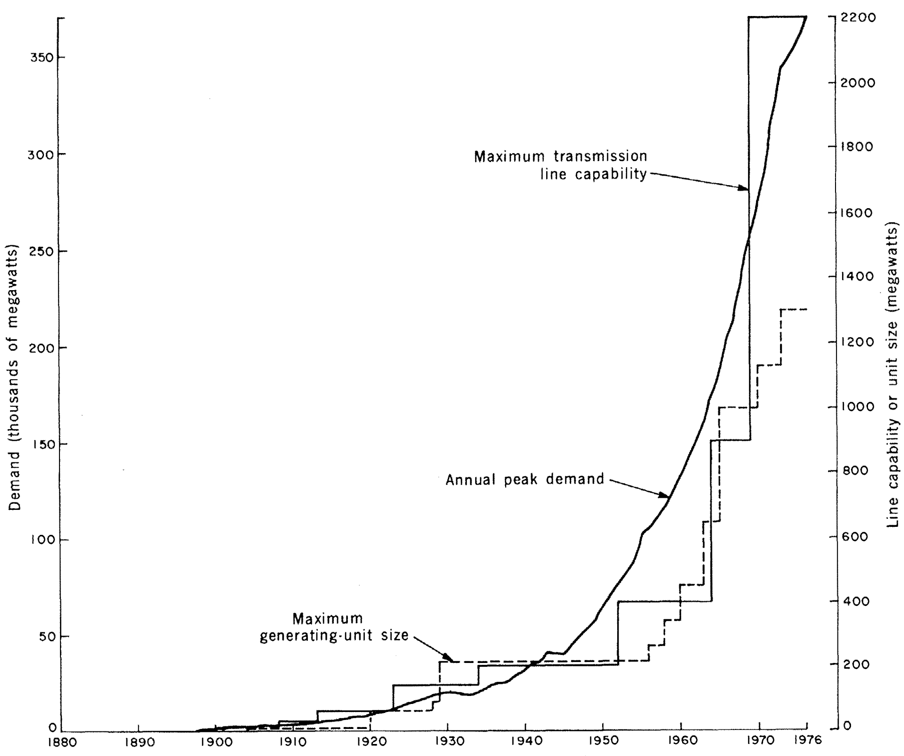

Fig. 1. Historical annual peak demand, maximum generating-unit size, and maximum transmission line capability of the electric utility industry of the contiguous United States.

dustry's historical origins, together with changes brought about by the need to meet specific national needs. The bulk of power generation and delivery (about 80 percent) is concentrated among the 100 largest systems. Approximately 75 percent of all electric energy produced in this country comes from the investor-owned segment of the industry, with certain large federal, state, and municipal entities accounting for much of the remainder.

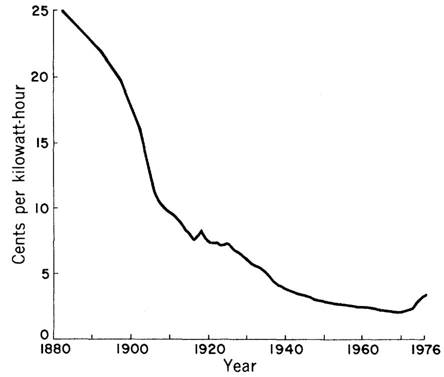

Fig. 2. Historical price of electricity sold in the United States to residential customers.

Electric Power Supply in the United States Today

The advent of interconnections has made power suppliers interdependent. This has resulted in the creation of three major networks in this country (Fig. 3). These networks cover (i) the combined eastern two-thirds of the country (including interconnected portions of the Canadian provinces) extending from the Atlantic Coast to the Rocky Mountains, (ii) the state of Texas, and (iii) the vast western section of the nation. By way of comparison, the combined generation of the eastern network alone, amounting to some 380,000 megawatts, is many times that of individual major European nations. The Texan and western networks are capable of generating about 35,000 and 92,000 MW, respectively. In all instances, the territorial spread of these networks is many times that of most other industrialized countries. Yet in each instance, the utilities of each of the three networks are continuously synchronized with each other. Power is dispatched among the various power systems composing each of the networks in order to achieve both economy and reliability.

The value of such large aggregations of utilities in networks is evident from the fact that at the instant a generating unit or plant is disconnected from the network, the great bulk of instantaneous support to carry the system's deficiency in generation comes from the inertial energy stored in the combined rotating masses of all generating plants in the network. While such an incident is accompanied by a slight temporary decline in the frequency of the network, the limiting factor in continued reliability of service is, generally, the capability of transmission facilities to sustain the resulting shift in power flows. Here it is important to recognize that the flows of power on individual elements of an interconnected network are generally uncontrolled and distributed in accordance with the physical characteristics (impedances) of the circuit elements. Trouble can of course arise when these elements become overloaded and are disconnected by protective relays. In such a case uncontrolled power failures (cascading and islanding) of certain portions of the network can occur.

The role of interconnections in network performance is often alluded to in assessing a disturbance or emergency. Unfortunately, misconception abounds. Narrowly defined, an interconnection constitutes a transmission tie between two corporately separate electric utility entities. Once established, however, such an interconnection often loses its special significance operationally. While constituting—for purposes of power transaction—one of perhaps several metering points between systems, an interconnection becomes, operationally, simply another transmission link in an already complex network. As for its usefulness in times of emergency, an interconnection is of benefit only if it ties into internal transmission facilities of commensurate capability.

The purpose of interconnections is to expand the scope of the individual power systems so as to enhance both reliability and economy of power supply. In terms of reliability, interconnections provide assistance during generation outages, assist in distributing excessive generation at times of major load outages, and provide support in times of transmission outages.

In economic terms, interconnections allow the full exploitation of economies of scale in both generation and transmission. Savings can thus be realized without compromising reliability, through the sharing of risk. Interconnections also allow the interchange of power to reduce generation costs among utilities to the benefit of the consumer.

During the past 15 years or so, the electric utility industry has recognized that still further coordination in the planning and operation of power systems was required. This need, which became evident with the vast spread of interconnections and the rapid growth of extra-high-voltage transmission (Fig. 3), was emphasized by the Northeast blackout of 1965. As a result, the electric utility industry formed voluntary regional reliability councils, of which there are now nine. These councils, in turn, make up the National Electric Reliability Council (NERC), covering the entire United States and portions of Canada (Fig. 4).

The reliability councils provide a mechanism to ensure the coordination of the system planning and operation of all bulk electric power supply facilities in North America. They provide a means for interchanging large amounts of vital utility data both within and among neighboring councils and, through simulation studies, determining the anticipated behavior of the entire interconnected network. Such computer simulations are carried out regionally, interregionally, and nationally. National simulations are carried out under NERC auspices. In addition, each of the reliability councils reports annually to the appropriate federal authorities its detailed plans and anticipated status over the succeeding 10-year period.

Power System Planning and Operation

The planning and operation of a major electric utility, while basically technological in nature, combine both engineering and art. Engineering aspects include the complex technology of its components, that is, its generating plants, transformers, transmission lines, circuit interrupters, relays, and controls. Mathematical techniques, supplemented by modern computational aids, provide the tools to design and analyze the behavior of such equipment, both separately and in combination.

The art in power system planning arises largely in the synthesis of equipment components into power systems. Although much theoretical work has been done toward the digital programming of system synthesis, the human mind—with its capabilities of imagination and creativity, bolstered by knowledge and judgment—remains the critical element in overall power system design. This is also true of system operation, wherein final decisions, especially in times of emergency, depend on human intervention despite all informational aids and computational assistance.

Economics is, of course, fundamental to the planning process. Costs enter into most, if not all, trade-off decisions in both planning and operating an electric utility.

Electric utility planning in the not-too-distant past (perhaps 10 years ago) was largely a matter of optimization among several alternatives. A utility first determined the probable future need for the supply of kilowatts of demand and kilowatt-hours of energy and then, through digital computer simulation, determined its ability to meet such demand throughout its service area under an array of assumed contingencies. Finally, it chose among several alternatives the program for additional facilities that optimally met the need. On the basis of such a program, it proceeded to build the requisite facilities with few, if any, constraints on its action. In system operation, there was always a reasonable expectation that facilities then under construction would be completed on schedule. One could thus reasonably foresee the system of the future and judge its adequacy to meet the expected demands.

Today, however, all this has changed. The planning and operating of electric utility systems must be carried out in an atmosphere of ever-increasing uncertainty: uncertainty as to the future demand for electricity; uncertainty that the necessary facilities to meet such demand will, in fact, be constructed; and uncertainty that, if constructed, such facilities could be operated. The challenge in managing a power system today lies, therefore, in retaining flexibility and options in order to meet an unknown future.

Day-to-Day Power System Operation

The day-to-day operation of a power system is directed and controlled from a dispatch and control center (Fig. 5). This figure shows at the far right a portion of a display board indicating in a dynamic or real-time mode the status of all high-voltage circuit breakers and transmission lines. The rest of the wall display includes meters showing the conditions of power flow on all interconnections and generating plants. The central console provides the man-machine interface permitting direct control of generating plants and, depending on the nature of the service area, certain power delivery facilities. The console also provides the central means of communication to all power plants and neighboring system control centers. The communication facilities in use for displaying system conditions and for controlling facilities are generally of three types: carrier communication over the system's own power delivery facilities, dedicated telephone circuits, and microwave channels. The latter are often part of the power system's own communication facilities.

In turn, each such dispatch and control center is linked to its contiguous neighbors through communication channels in order to ensure coordination in operation. Such coordination is carried out under an array of contractual arrangements, which include such conditions as emergency assistance in times of power deficiencies, economy trading to ensure the most economical supply of power at all times, coordinated maintenance of major facilities, as well as short-term and long-term power purchases and sales.

The coordination among contiguous power systems goes on continuously in that power system dispatchers remain in constant contact with each other. The fact that generating plants are subject to both preplanned maintenance outages as well as unexpected equipment failures is rarely known to the consumer of electric energy because such a deficiency on one system is made up by emergency support from other systems. It is only at times of an extreme disturbance, due to a series of unexpected events, that a major interruption to the consumer occurs.

A classic example of day-to-day, hour-to-hour coordination among power sys-

Fig. 3. The extra-high-voltage transmission networks and their major transmission facilities in the contiguous United States.

tems making up the eastern network of the United States was demonstrated during the recent coal strike. In this instance during one 30-day period, more than 3 billion kilowatt-hours of electric power was imported into the east-central region of the United States from neighboring regions. This was done without overloading any of the major power supply facilities within the interconnected network and without an interruption to the overall power supply in the region.

Present Difficulties and Uncertainties

It is pertinent to examine the nature of the problems now facing the power industry, particularly with regard to those difficulties which have become pervasive during the past several years. Uncertainty is the very essence of the problems facing utility management today. Problem areas (*1*) can be categorized as (i) power needs, (ii) facility siting, (iii) regulatory delays and construction lead times, (iv) environmental constraints, (v) primary fuel supply, and (vi) financing.

Power needs. The need for power is basic to every utility judgment. Without an increase in demand for electricity in the future, there would be no need (other than for the long-term replacement of facilities) to construct new facilities. The question of the need for power gives rise to the bulk of the remaining issues; it is fundamental in every environmental im-

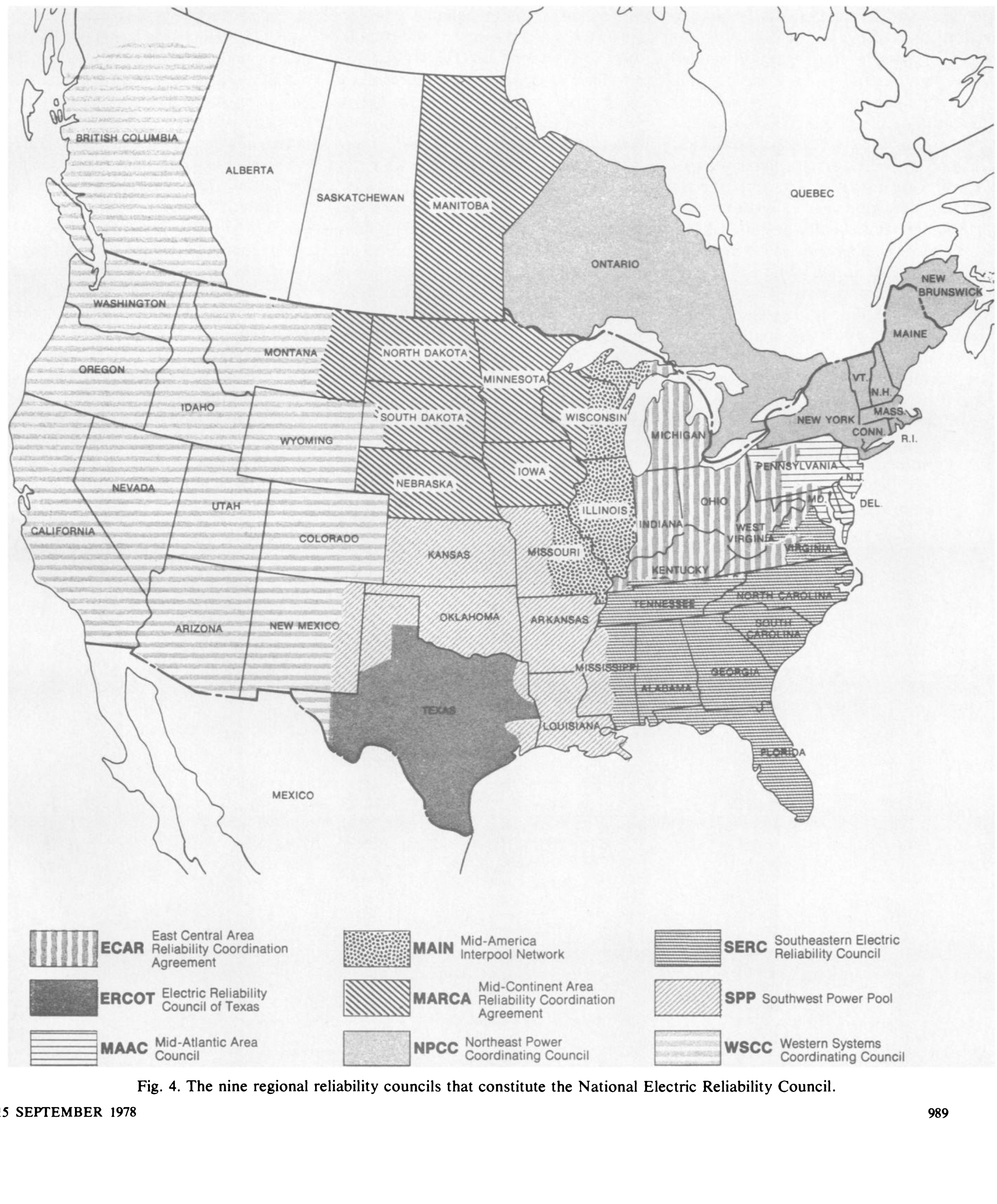

Fig. 4. The nine regional reliability councils that constitute the National Electric Reliability Council.

pact statement (EIS). In utility parlance it is called "load forecasting."

Since the Arab oil embargo of 1973 and the growing recognition of an energy crisis, there has been widespread discussion regarding growth versus no growth in energy demands. Both sides of the debate have held forth from positions of increasing polarization. The no-growth advocates see the societal costs of continued growth as outweighing the benefits. They see growth as limited by both resources and environmental problems. They regard continued growth as having an adverse effect on the quality of life. The advocates of growth see no reason for a decline in the quality of life because of rising levels of energy consumption. They see the benefits of growth, in terms of employment and improvements for the underprivileged in our society, as outweighing the costs. A moderate view realizes that much of the argument is one of value judgments, which, in a free society, should be made by each individual. Those who take this position believe that proper judgments can be made on what particular forms of growth should be encouraged or deterred. They believe that if our society is to endure, some measure of growth is essential.

The utility industry stands astride this growth–no-growth issue. It has been accused of lacking sophistication in load projection, of extrapolating past trends toward exponential growth in the demand for electricity, and of projecting a continued doubling in load every 10 years. In fact, many utilities today use well-articulated econometric models and other analytical tools in their load forecasting (with judgments of possible future trends without historical precedent). In their formulation, these models attempt to consider the rising costs of electricity and its price elasticity (*2*), the effect of conservation, and the availability and substitutability of primary fuels, such as oil and gas.

At present, the power industry has estimated an increase in the demand for electricity of about 5.2 percent per year, compounded annually over the next 10-year period. This compares to a projection of 4.4 percent, compounded cumulatively, in President Carter's National Energy Plan of April 1977. Regardless of the precise growth rate, both figures clearly indicate the need for additional power production and power supply facilities if the nation's demand for electric power is to be met.

Facility siting. Facility siting is a second major constraint facing utility managements today in their attempts to ensure a supply of electric power. Power plants have certain basic physical requirements in siting. Among these are sufficient land, with an accompanying buffer zone if possible; an adequate cooling-water supply for condensing the steam moved through the turbine; an adequate means of rail or water transportation for fuel in a fossil-fired plant and for equipment in all types of plants; and a location that can be integrated reasonably well into the transmission system moving the power from the production source to the consumption centers. These requisites greatly limit the availability of plant sites suitable for development.

All major generating plants are of the condensing type, with a closed cycle. That is, after the high-temperature, high-pressure steam is passed through the turbine, it is injected into a condenser where the remaining heat is removed and the steam converted to water. This not only provides the greatest overall conversion efficiency by recovering the maximum energy in the steam, but also retains the bulk of the highly purified and treated boiler feed-water for reuse. Purity of such water—freedom from contaminating minerals—is essential to limit chemical corrosion of the boiler tubes.

The power industry has striven over the past several decades to reach the theoretical maximum efficiency of the Carnot cycle, the thermal cycle used in all major thermal power plants. New methods of energy conversion, which may allow further increases in conversion efficiency, are being investigated. These include the fluidized bed and magnetohydrodynamics. The former depends for maximum efficiency on a combined-cycle concept in which the hot gases from the furnace drive a gas turbine directly and, in addition, create steam to operate a conventional turbine. The latter depends on the creation of an ionized plasma, which takes the place of a rotat-

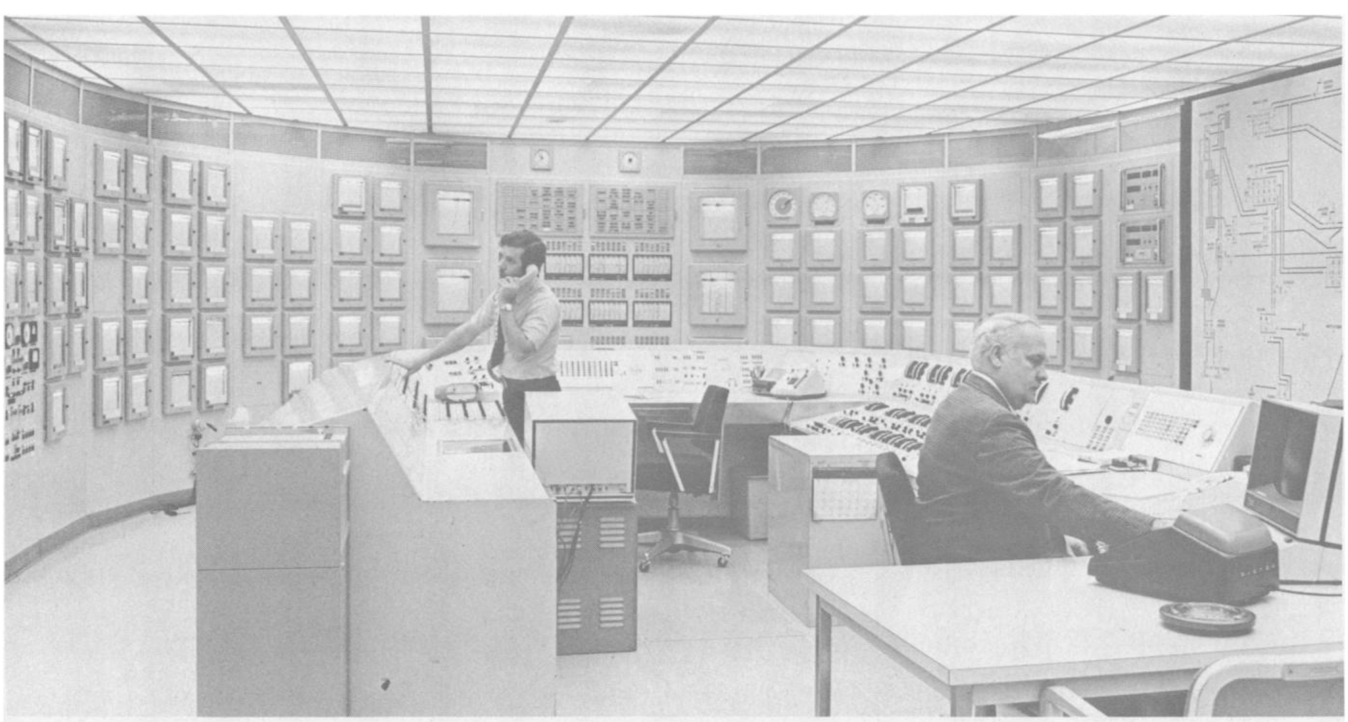

Fig. 5. The dispatch and control center of the American Electric Power System in Canton, Ohio.

ing electric field and produces direct-current electricity in the process. However, neither these nor any of the more exotic methods of producing electricity will be available as major sources during the next critical decade.

Public opposition—largely on environmental grounds—is another factor with which utilities must contend in siting plants.

The constraints on nuclear power plant siting are, of course, much more stringent and of a more complex nature than constraints on fossil-fired plants. The elaborate requirements of the Nuclear Regulatory Commission have changed and grown in complexity over the years. The crucial problem in this instance is not so much the need to meet a given set of requirements as the uncertainty regarding changing criteria and future standards for plant location and design. In addition, of course, there is a strong body of organized opposition to nuclear generation.

Opposition to facility siting also applies to transmission lines, an opposition based largely on esthetic grounds. Recently, however, in the case of extra-high-voltage lines, arguments have been raised regarding transmission's adverse health effects. Credible scientific data to support the arguments regarding the effects of ozone and electric fields on health are lacking. By contrast, considerable accumulated experience, international as well as national, supports the case that there are no adverse effects on health. Nevertheless, the industry has renewed its research effort in this area through the Electric Power Research Institute, an industry-sponsored research organization.

In the final analysis, whatever the motivations for opposing facility siting, it is the power industry that faces the problem of providing the facilities required to meet some measure of load growth.

Regulatory delays and construction lead times. Regulatory delays and resulting increased construction lead times are major threats to a reliable and adequate future power supply. The regulatory process, with its many opportunities for intervention and public hearings, has now made it necessary to commit fossil generating plants as long as 8 to 10 years in advance of need, with a minimum lead time of 6 years. Nuclear plant lead times for regulatory approvals and construction are now a minimum of 10 years and in several instances have reached as long as 14 years. Major transmission lines now require lead times of 6 to 8 years; in the past, such construction required only 2 to 4 years.

The introduction of the EIS adds a minimum of 2 years (not counting any time required for intervention and public hearings) to all construction lead times. In the case of nuclear plants this period is greatly extended, of course, by other regulatory requirements. Many states, in addition, have passed laws requiring certificates not only of public need but also of environmental compatibility for power plants and high-voltage transmission lines before construction can begin. These laws, in most instances, require public hearings. In my experience, there have been several instances of delays of 3 years or more in constructing needed 765,000-volt transmission facilities in the state of Virginia. In some instances, the need has been recognized and acknowledged by the regulatory body, but the delay has resulted from environmental opposition by several groups of protesters opposing each other. In one particular case, a badly needed transmission line has been delayed for more than 6 years.

The question of how the facility could be so badly needed if the public is still being served, even without the line, can be answered from a basic tenet in system planning: the planner must plan for an anticipated load level and a set of potential contingencies. Until the anticipated load level is reached and the set of potential contingencies occurs, the service to customers will not suffer even without the line. From this standpoint it is fortunate, perhaps, that load growth has been slowed during the recent past, largely as a consequence of a severe economic recession following an oil crisis. But what happens if load growth should once again accelerate? What would happen if the set of potential contingencies or facility outages were to occur? When this happens, the usual result is called a blackout, and a scapegoat is sought. Rarely is the past record of opposition to and constraint on the construction of facilities set forth.

Finally, the system operator, operating the system in an incomplete or abnormal state, is often able to avoid interruptions through expeditious measures and a reliance on interconnections. But what happens when the insufficiency becomes widespread and the operator's resources run out?

Public concern and involvement in the siting process is essential in a free society. In a complex, industrialized (but orderly) society, however, complex issues require the application of specialized knowledge by those trained and experienced. In other words, a specialized technical activity such as power system planning cannot be carried out in an open forum or in the atmosphere of a town hall. This means that the entire intervention process needs to be circumscribed by certain rules, so that its duration and scope are limited and the issues raised are relevant to the matter at hand. The alternative can be nothing less than confusion and chaos.

Environment. Few areas of constraint on the electric utility industry in providing the necessary power supply facilities have reached such levels of uncertainty and confusion as has the case of the environment. Here, the outstanding example is in air quality.

We all recognize the need to arrest continued degradation of the atmosphere and to improve its quality. The argument is not against establishing objectives for air-quality improvement but toward the lack of substantiating scientific evidence that goes into the current setting of standards; the absence of any cost-benefit analyses in the establishment of such standards; the indifference exhibited by the environmental regulators to the vastly rising financial investment to secure that last bit of incremental gain in air-quality improvement; and, perhaps most important, the continually changing standards for the emission of various effluents. Although some change in standards is inevitable during the development of a new and untried process, rapid and unanticipated change in such standards in an area of complex technology and high investment makes rational planning impossible. Certainly, establishing periods and levels of consolidation in air-quality achievement, with standards based on solid data supported by cost-benefit analyses and in line with technological development, is far more reasonable.

Current air-quality requirements have created not only great uncertainty in the planning of new electrical generation but have also created the need for huge capital investments in a difficult time of inflating costs. This is particularly serious in an industry which is the most capital-intensive in our economy.

Heat released in water during the electric energy conversion process has been defined by law as a pollutant. Hence, the industry has resorted increasingly to constructing cooling towers, within which the heat extracted from the exhaust steam by the condenser is dissipated to the atmosphere. This is in contrast to once-through cooling, in which the heat from the exhaust steam is extracted within the condenser by passing through water from a natural cooling body, such as a river or lake. Although cooling towers provide an alternative approach to once-through cooling and avoid the emission of heat directly into the cooling-water body, they are not without their own environmental impacts. These take the form of an esthetic intrusion on the landscape and, in certain instances, an icing hazard created by the drift of their plumes of moisture. The ultimate development of dry cooling towers (large radiators), from which the heat is released directly to the atmosphere, is fraught with greatly increased inefficiencies, huge physical size, and very high costs.

Primary fuel supply (3). Electricity depends for its production on the use of primary energy sources, such as coal, oil, gas, uranium, and the kinetic energy of falling water. Electricity is a secondary source of energy that currently consumes about 29 percent of the nation's overall energy production. A dependable and assured primary fuel supply is therefore vital to the future production of electricity.

The fuel supply to generating plants is one of the greatest uncertainties confronting utility management today. Coal-fired generation during 1976 supplied about 47 percent of the nation's electricity and is expected to maintain this commanding lead for the next decade. Coal's absolute contribution is expected to rise from 481 million tons (4.4×10^{11} kg) in 1977 (65 percent of all coal used in the United States) to 879 million tons (8.0×10^{11} kg) by 1986. While seemingly in line with the Carter Administration's energy objectives for the use of coal, the near doubling of coal requirements within this 10-year span creates an insoluble problem of coal supply without immediate and extensive action to expand the western coal fields. In light of the issues confronting the development of western coal, this expansion seems to be impossible at this time. Hence, a great uncertainty arises as to the future coal supply for utility needs, which is further escalated by air-quality considerations.

The role of oil in generating electricity is expected to decrease slightly from a 1977 figure of 17 percent to 15 percent by 1986. In absolute quantities, however, utility consumption of oil is expected to rise from 631 million barrels in 1977 (about 9 percent of overall petroleum product use) to 878 million barrels in 1987. The bulk of this increase will occur by 1982 as a result of the replacement of natural gas by oil as a boiler fuel. The power industry is well aware, however, of the need to reduce its dependence on oil as a primary fuel. (The last base-load oil-burning unit, previously committed on the basis of air-quality needs, is scheduled for service in 1983.)

Air-quality regulations during the past several years have resulted in the compulsory conversion of certain existing generating units from coal to oil. At present, there are federal attempts to convert many of these same units back to coal (*4*). However, the same air-quality regulations that made them convert to oil in the first instance, together with the unavailability of suitable coal supplies, the absence of coal handling and storage facilities at the plant sites, and excessively high costs, prevent the reconversion of many of these units. This is a further example of the uncertain, chaotic situation created by changing goals on the part of governmental authorities.

The use of natural gas as a boiler fuel is expected to diminish from 12 percent of overall power generation in 1976 to 3 percent by 1986. President Carter's 1977 National Energy Plan calls for the complete phasing out of gas as a boiler fuel by 1990. The power industry is aware of the need to cease using natural gas as a boiler fuel. In fact, the last gas-fired unit came into service in 1977. Some conversion to oil, the only feasible alternative fuel for gas-fired units, has already occurred at substantial cost, at a loss in unit capability, and at decreased unit availability due to the fouling of restricted boiler surfaces.

A fourth source of primary energy supply for power generation is nuclear power. Nuclear generating plants supplied 13 percent of all electricity produced in 1977. This figure is projected by industry sources to grow to 28 percent by 1986—a difficult, if not unrealistic, goal in light of the issues facing nuclear generation. The projected growth in nuclear generation would be equal to a fourfold increase in absolute quantities during the 10-year period and is premised on having about 164,000 MW of nuclear generating capacity by 1986. This contrasts with some 39,000 MW at the end of 1976. The vastly extended lead times resulting from lengthy licensing procedures, the Administration's ambivalence toward nuclear power, and the hiatus in commitment toward the breeder reactor for longer-term needs and for reprocessing spent fuel have added immeasurably to the power industry's uncertainty as to the type, degree, and source of its future primary energy needs.

Water power, the only remaining primary energy source for electric power generation, provided 11 percent of electricity production in 1976 and is expected to decline to about 7 percent in 1986. This is primarily the result of a general lack of suitable sites and of the rising opposition to the environmental consequences of hydroelectric installations.

Financing. A final but substantial problem facing utility managements today is financial. This involves both the capital and operating aspects of utilities.

Ten years ago, the investment per kilowatt in conventional power plant capacity dropped to as low as \$100 to \$110. For such a plant committed today and to be brought into service in the early to mid-1980's, the investment is well in excess of \$500 to \$600 per kilowatt. The reasons for this severe increase in the capital cost of facilities are the substantial increases in labor rates, the escalated costs of equipment and construction materials, and the accumulation of capital charges during the construction period because of increased delays. The financial problem is additionally aggravated by the need for high current investment in pollution-control facilities.

The annual fixed costs to the utility are affected by both the rising capital cost of facilities and the recent increase in the cost of capital itself. The latter is particularly important in view of the fact that more of the utility's capital funds are now raised in the capital markets than in the recent past. Interest rates have experienced significant increases in recent years. These effects have had a compounding impact on the annual fixed costs of facilities.

In addition to the sharp rise in capital and interest costs, the power industry has been plagued by major increases in fuel costs. For example, coal, which for many years cost the American Electric Power Service Corporation 18 to 20 cents per million British thermal units of heat value, has more than sextupled in price, all in the brief span of 7 to 8 years.

Hence, an industry that, for many years, was able to reduce the price of its product through technological improvement and thus counter the effects of past inflation has recently experienced the need for rapid and successive increases in rates for its service. Technological improvement is no longer sufficient to counter inflationary effects, certainly not in an industry so highly dependent on capital investment.

These steep increases in the cost of electric service have inevitably caused concern and opposition on the part of the consumer and have created difficulties for the regulatory commissions, which must approve all requests for changes in electric rates. Unfortunately, many regulatory bodies have yielded to political expediency and have delayed, substantially reduced, or denied utility requests for rate relief.

The net result of insufficient and tardy rate relief has led to the delay of facilities and will lead to a gradual degradation in the quality of service to the consumer. It is perhaps unfortunate that this degradation in quality of service has a relatively long "time constant." While we may warn of impending disaster in power supply, the outward evidence is slow in materializing. However, when it comes, it will be a long time—at least equivalent to construction lead times of 10 years and more—before substantial improvements in power supply can be effected.

Dangers of the Future

The array of problems and uncertainties confronting the power industry, although possibly relatively short term in scope, will have long-term effects. These effects will reveal themselves as a gradual attrition in generation reserve levels and a reduction in transmission capabilities.

Generation reserve levels are that portion of installed capacity in power plants over and above the aggregate demands of all consumers. It is not excess capacity but, rather, capacity that is needed and used to provide for scheduled maintenance outages and overhauls of the highly complex equipment of power plants. It is also required to provide against the emergency outages and partial curtailments resulting from temporary equipment failure or malfunction. Similarly, transmission reserves are needed to provide against the inevitable occasional outages, either preventive or forced, of transmission facilities.

The lack of generation reserves sufficient to meet the needs of the power system and its consumers will inevitably lead to the need to curtail service to the consumer during peak-load periods. Initially such curtailments will be infrequent and dependent on the availability of generating capacity; such curtailments will increase in frequency and duration with time.

The lack of sufficient transmission capability to meet all foreseeable contingencies, in the first instance, will lead to temporary blackouts as transmission lines are removed by their protective devices to guard against overload damage. As the problem deepens, however, programmed interruptions will be necessary to avoid the risk of widespread uncontrolled power failures.

With this in the offing, it behooves all power systems to prepare curtailment programs and strategies. Such programs will require state regulatory approval since they involve both voluntary and compulsory steps for reduction in electric energy consumption, to be followed ultimately by actual consumer interruption.

In light of the inevitable impact of these uncertainties on service to the consumer, the question can be asked whether the utilities have the technology and managerial will to cope with future large-scale deficiencies in generation and transmission facilities. On a day-to-day basis the answer is yes.

Telecommunications, computer hardware and software developments, and information processing have reached the point at which the technology for determining system status on a continuous basis ("state estimation" in utility parlance) has been or is being installed at numerous control centers. System simulation techniques likewise permit off-line and on-line assessments to be made. Automatic load-shedding, triggered by the declining frequency of an overloaded system, has been universally installed to cope with sudden emergencies.

The design and control of power systems in the past have been predicated on the existence of adequate generation and transmission. As a result, system operation has been highly automated, and manual load-shedding on power systems as a means of balancing load and generation is often impossible. This problem does not require large-scale new technology but, rather, the expenditure of large sums of money for supervisory control facilities to give the operator of the system the ability to disconnect consumer load.

Grappling with the social issues of interrupted service to the consumer, which has been anathema to past utility managements, whose prime objective was satisfactory service, will perhaps be even more difficult. However, the preservation of the power system to ensure service to the most consumers is of overriding concern. Hence, after everything possible is done to provide the necessary facilities to meet consumer demands, utility managements need to face the ultimate decision of controlled interruption of load.

Conclusions

Electric power deficiencies can only result in interrupted service to the consumer. Curtailing electric service is the only technological response available to the power industry. Such curtailment will have serious impacts on the socioeconomic structure of this nation. As such, they should be regarded as only short-term responses to a long-term problem.

The long-term solution to power deficiencies requires the building of the requisite power supply facilities. If a prolonged period of an energy-limited economy with all its adverse consequences is to be avoided, action must be taken immediately by the government, with full power-industry cooperation, to alleviate the severe constraints to the construction of required facilities.

References and Notes

1. *Seventh Annual Review of Overall Reliability and Adequacy of the North American Bulk Power Systems* (National Electric Reliability Council, Princeton, 1977).
2. In economics, price elasticity defines the change in demand for a product as the result of an incremental change in price.
3. *Fossil and Nuclear Fuel for Electric Generation—Requirements and Constraints* (National Electric Reliability Council, Princeton, 1977).
4. Only generating plants originally designed for oil or coal as alternative fuels can be converted.