Energy Storage Hubs

Also in this issue:

- *Solar Magnetic Storms*
- *Manufactured Gas Sites*
- *Cold Fusion Theory*

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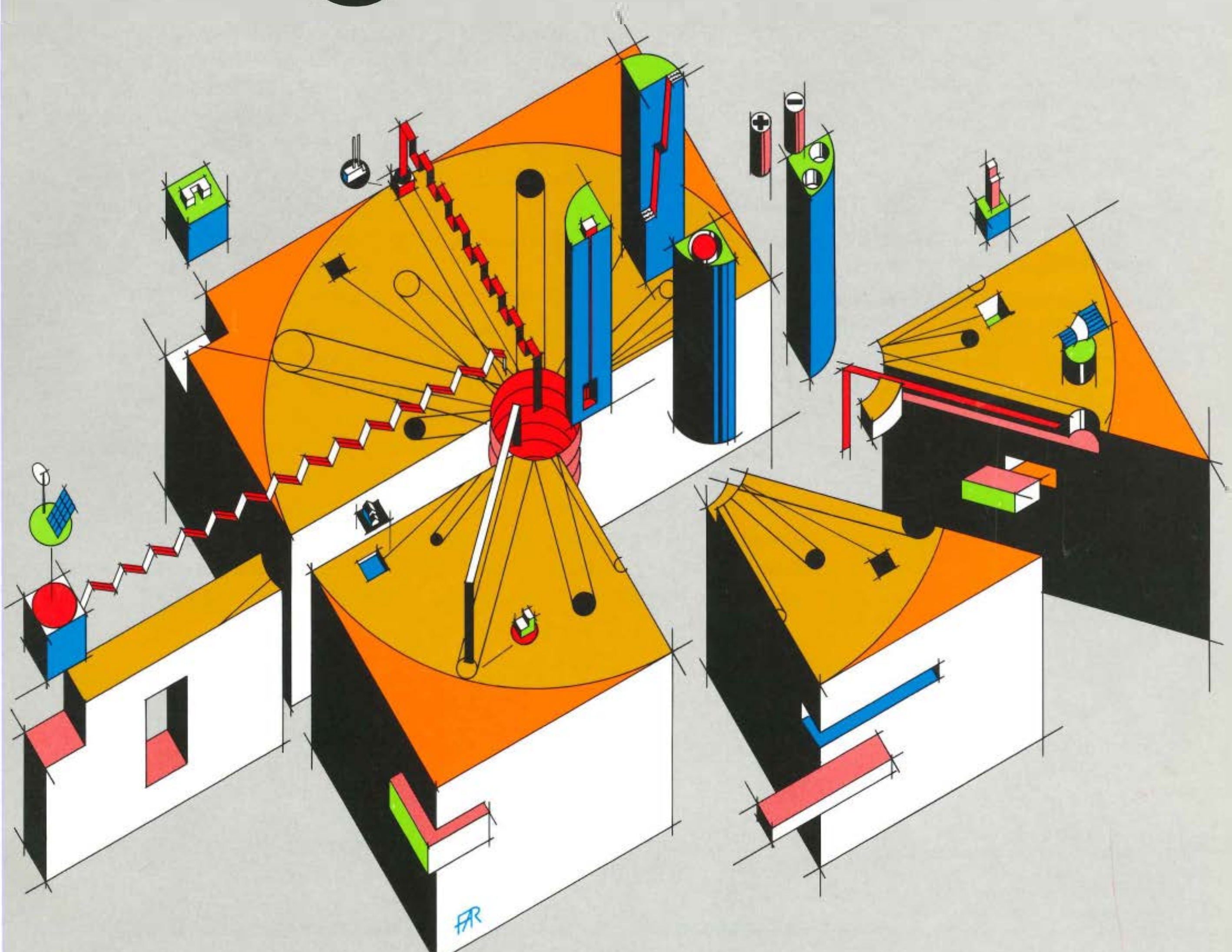

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Cover: The hub-and-spokes concept, which would allow a utility to store capacity from various generation sources and dispatch it in the most advantageous way, is the centerpiece of new strategic applications for energy storage technology.

EDITORIAL

Storage: The Competitive Edge

Historically, energy storage has proved to be an ideal supply-side resource, regardless of a utility's corporate strategy or generating mix. Not only has storage made it possible to level loads with the lowest-cost off-peak energy available, but it has been "a dispatcher's dream," according to PG&E's chief system dispatcher. These traditional benefits may be overshadowed in the 1990s, however, by the unique ability of storage to provide leverage over the supply system and open up new business opportunities.

Utilities have been thrust into an increasingly competitive business environment in power production and in customer service. In both of these areas of competition, the emphasis of utility corporate strategies has been on expense reduction—exactly the strategy followed by other industries that have entered the competitive arena, including many that have gone through deregulation. However, companies that relied entirely on lowering expenses have not fared well in the competitive environment over the long run: People's Express airline is a case in point.

The businesses faring best are those that have creatively used their assets and new technologies to integrate supply and demand. Airlines, for example, deployed the hub-and-spokes service concept, which allowed them to transport more customers with fewer planes. Among the integrating technologies for utilities are storage systems. Storage gives utilities a competitive edge, whether in leveraging purchases of electricity; allowing an unbundling of services to meet a variety of customer needs cost-effectively; minimizing the risk of unexpected changes in fuel cost, load, or load shape; or increasing the productivity of costly baseload generating plants.

Conventional planning tools do not capture these strategic values of storage because they go no further than comparing the expenses of storage plants with those of generation systems. But storage is not generation; it is an energy management tool to be used in much the same way that hub airports help airlines manage passenger flow. And just as hub airports can't be evaluated on the basis of the number of passengers originating at the hub city itself, storage can't be evaluated solely on the basis of the expense of the electricity it "generates." Storage plants must be evaluated according to their strategic value as well.

The deployment of storage today is limited more by our imagination—by our ideas about how to use it in a competitive marketplace and how to quantify its strategic value—than by its cost. No doubt our business acumen will materialize new visions for storage applications, and our engineering skill will provide the tools to evaluate these visions properly. As this happens, storage may well become the technology of choice for new capacity, whether on the supply side or the customer side, in the 1990s.

James R Birk

Jim Birk, Director
Storage and Renewables Department
Generation and Storage Division

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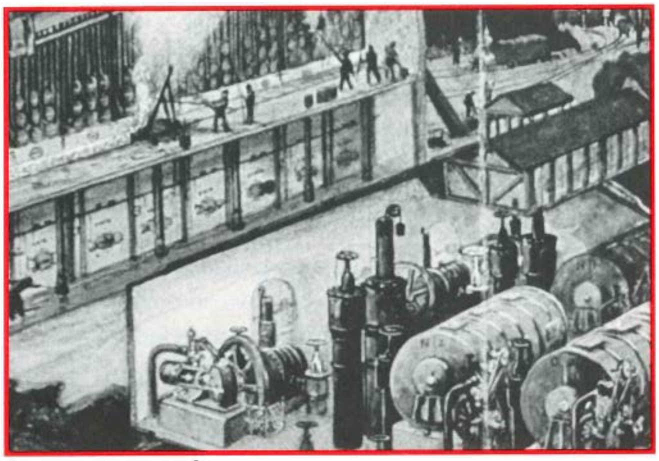

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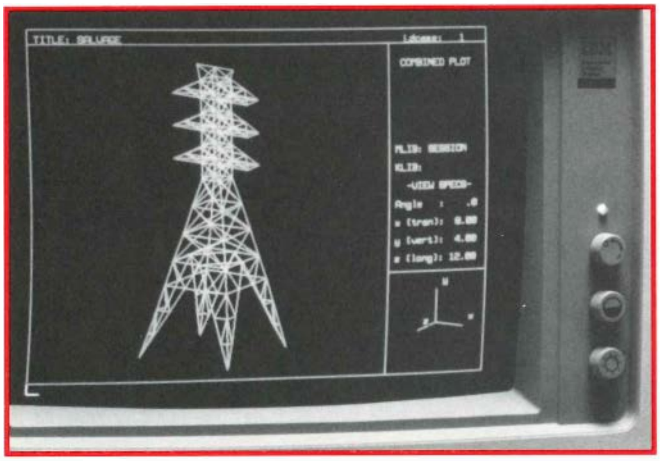

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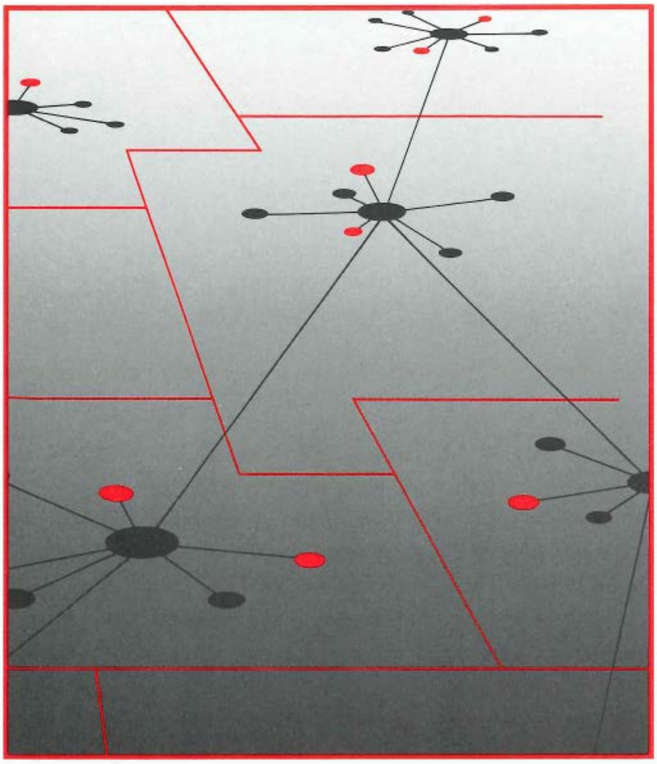

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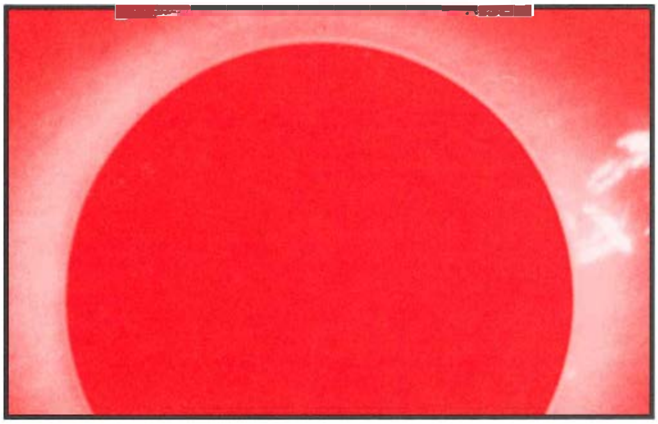

EDITORIAL

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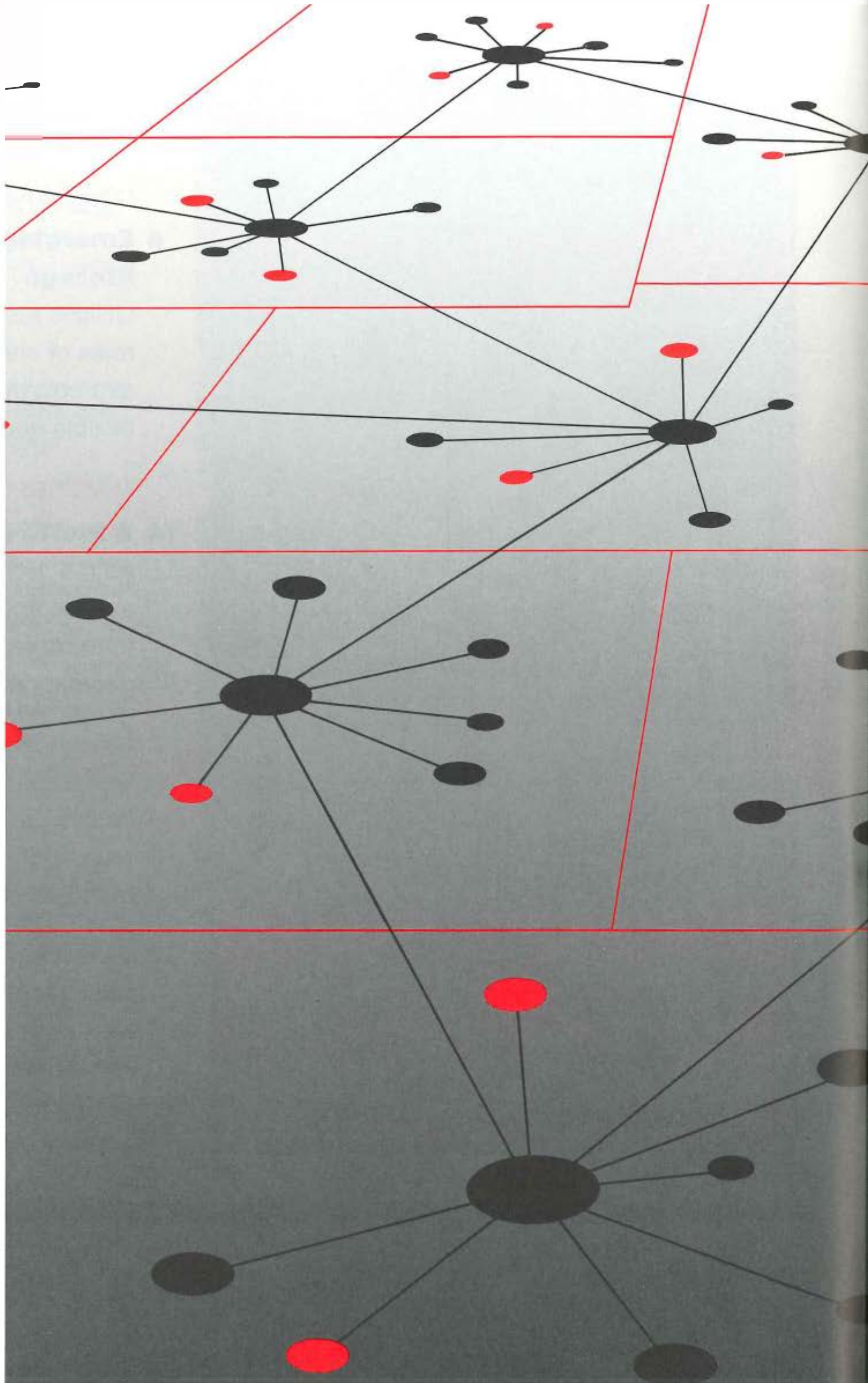
Emerging Strategies

Energy storage has traditionally been seen as a way
generation. But as competition increases, utilities are
plant more strategically—as the hub of an extended



Electricity is produced instantly in response to customer demand. This is a fundamental principle guiding the production and supply of electric power—and one that sets electric utilities apart from other businesses. Unlike most other commodities, electrons aren't bottled or boxed, placed in a warehouse when demand is low, and then dispensed when demand increases. With no "inventory" to draw on, utilities have very little leeway in managing production and supply.

The ability to store electricity on a large scale would have a profound liberating effect on the utility industry. Supply and demand would not have to be balanced instantaneously, so utilities would have much greater flexibility in operating their systems and conducting power transactions. And stockpiling the excess electricity produced at night by baseload plants and using it during the daytime would enable utilities to more fully use this most efficient component of their generation mix; units that burn premium fuels during peak periods would be displaced.

These benefits provided the motivation to build the nation's 37 pumped-hydro storage plants, which account for about 3% of present U.S. generating capacity. Other storage technologies have been under development for decades. Compressed-air energy storage is soon to be demonstrated at Alabama Electric Cooperative, and large-scale battery storage—potentially one of the most flexible options of all—is now being demonstrated at Southern California Edison. The present economic situation offers growing incentives for the industry to put such technologies to work, as utilities facing an uncertain future strive to pare operating costs and use their existing capacity more effectively.

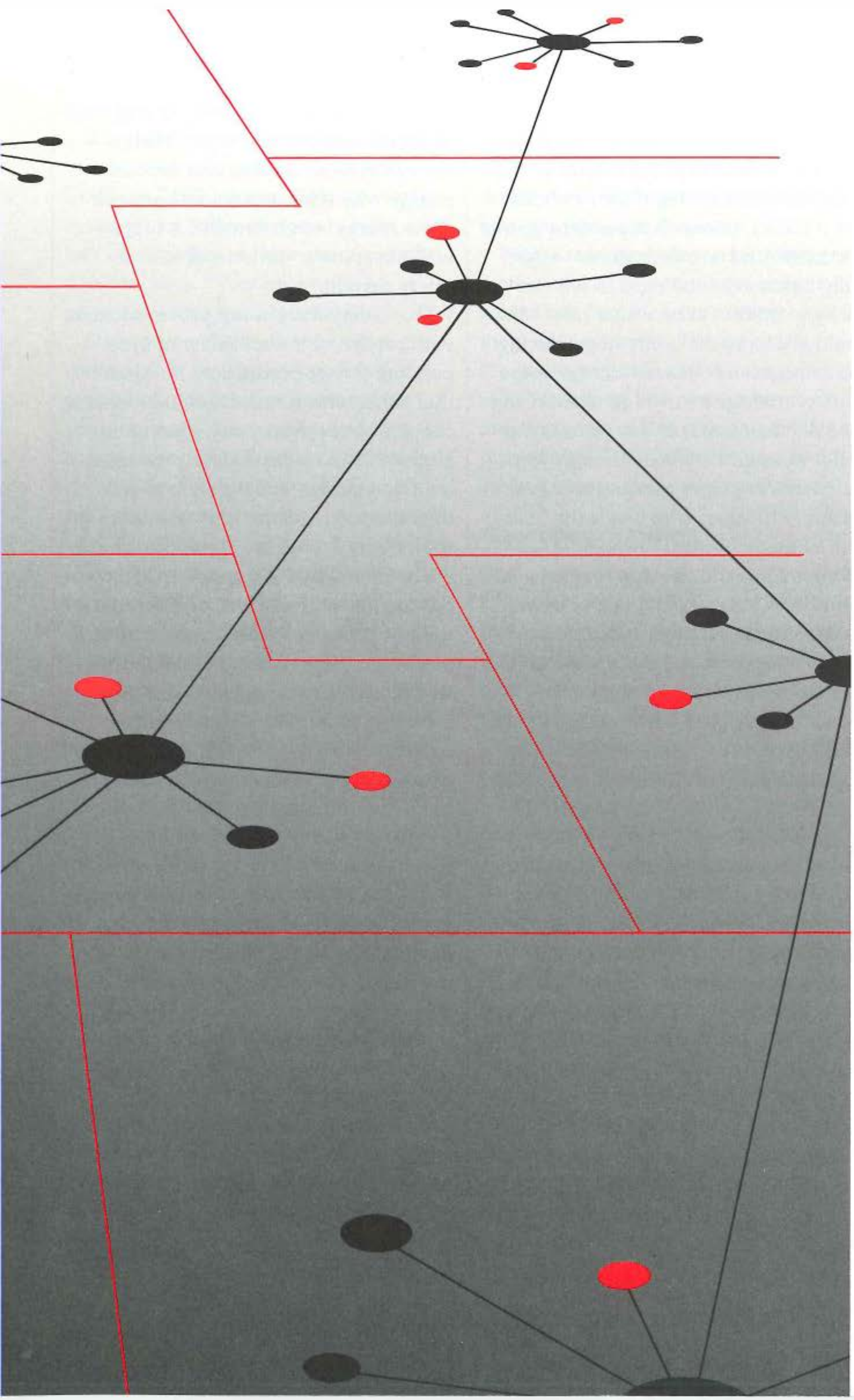
But James Birk, director of the Storage and Renewables Department in EPRI's Generation and Storage Division, sees

for Energy Storage

shave peaks and improve the capacity factor of baseload

eginning to look at the advantages of operating a storage

nd flexible energy management network.



energy storage playing a broader role, one that is strikingly congruent with the institutional forces pressing on the industry: "Most utilities are aware that energy storage systems can help them meet peaks and increase the productivity of baseload power plants," says Birk. "But the vision of energy storage that's beginning to evolve here at EPRI, and at some utilities, shows us that storage can offer much, much more in a strategic environment. Many utilities have yet to recognize all the opportunities provided by storage—opportunities that can give them an edge in an era of increasing competition and possible deregulation."

The competitive edge

Storage certainly can reduce operating costs by allowing a utility to both maintain spinning reserve and satisfy peak demand with inexpensive off-peak power. And for capacity-constrained utilities, storage plants can defer or eliminate the need to build new generating capacity. But storage plants cost money too, often more than a new fleet of combustion turbines. Utilities are accustomed to evaluating technologies this way—on the basis of cost per kilowatthour generated. They tend to compare storage plants directly with other intermediate and peaking generators, although storage plants are not generating technologies per se.

So why turn to storage? According to Birk, it is a matter of looking beyond one's own system—a matter of buying and selling. Utilities routinely transfer power over the interconnected transmission network, which allows a utility short on capacity to purchase power, or one with a surplus to sell power to the highest bidder. "An energy storage system puts a utility in a position to buy electricity when it's cheapest instead of when customers need it," says Birk. "This strengthens the utility's bargaining position in the wholesale marketplace."

SUPPLY SIDE

Power from numerous generating sources flows into and is stored at the hub. This enables utilities to more effectively manage the flow of power in their system, from their own capacity as well as from third party generators. The hub acts as a buffer against reliability and power quality problems, so the utility's emphasis can shift to generating or buying power at the lowest cost.

Utility baseload capacity Storing off-peak baseload power allows utilities to operate coal and nuclear plants continuously at a higher, more efficient rating and to use that generation to displace units burning premium fuels during peak periods.

Intermittent generation Storage helps a utility to effectively manage the intermittent flow of power from cogeneration units and from photovoltaic and wind-turbine systems operated by independent power producers. The storage hub buffers customers from any lack of reliability or power quality from these sources.

Wheeled power Relatively inexpensive hydro power is often wheeled over long distances. The ability to park this power at a hub enhances a utility's bargaining position in the wholesale marketplace.

Hub and Spokes

The hub-and-spokes concept for organizing production is used in several industries, notably airlines, to manage supply and demand more effectively. For the electric utility industry, incorporating energy storage hubs in the transmission system could provide key offensive and defensive advantages in

And other utilities aren't the only players in the high-stakes game of electric power brokering. As a result of the 1978 Public Utility Regulatory Policies Act (PURPA), certain independent power producers and cogenerators are essentially guaranteed the right to sell electricity to utilities at premium rates—the avoided cost to the utility of producing the same power. "Just as storage helps a utility manage its own generation and load fluctuations, it enables a utility to better manage the flow of energy from independent power producers," says Robert Schainker, who heads the Institute's Energy Storage Program.

While some utilities may welcome an infusion of independent power during peak periods, the requirement to buy power when demand is slack forces them to reduce their generation in plants already paid for. "Storage allows a utility to put that independently produced off-peak power into inventory to meet coming peaks while keeping its own power plants running," Schainker points out. "Furthermore, in calculating the avoided costs paid to the independent, a utility can reason that the avoided cost is lower than it would be without the storage plant—the cost now being avoided is tied to off-peak generation costs, so the utility can negotiate that contract and not pay as much. As in any other marketplace, the guy who can store his product and sell it at his choosing has a competitive edge in buy-and-sell agreements."

Jim Birk offers another analogy. "The ability to store energy is like having cash in a bank account," he says. "With a storage system, a utility can deposit energy when demand is low and withdraw energy when demand is high—while keeping some in reserve as a safety margin."

That safety margin can prove valuable with respect to the reliability of independent power production, an issue that along with competition has raised concern about third-party generation. Under PURPA, independent producers are often guaranteed the right to put their electricity on the grid whenever they want to generate it, but they don't share the utilities' obligation to serve the customer. Therefore, it becomes the utility's problem to balance the bits and pieces of independent generation with its own capacity to maintain the level of reliability that utility customers have come to take for granted. Utility executives have expressed concern that a proliferation of independent power producers may erode the reliability of the grid system.

"It's really a matter of how independents respond to contractual arrangements," says Frank Young, director of the Electrical Systems Division. "A reliable power system needs spinning reserve and load-following capability, but cogenerators may not want to be assigned those functions. If a significant portion of generation is supplied by independents, the utility will have to provide spinning reserve and load following. Storage is an ideal way to do an era of increasing competition. With such a system, the hubs would consolidate supply from a diverse set of sources and distribute it to a diverse set of markets.

CUSTOMER SIDE

Different utility customers value different attributes of electric service. Coupled with fast-response storage technologies, the hub structure provides the coordination and flexibility to enable utilities to unbundle service, efficiently delivering different tiers of service to a spectrum of customers.

Hospitals Human care facilities require an uninterrupted supply of electricity to maintain life-support equipment. Contracts for high-reliability power could reduce the need for expensive on-site backup generators.

Computers Deviations in power quality can result in lost data or other damage. A guarantee of high-quality power may be highly desirable to computer-oriented businesses.

Residential customers Some homeowners may prefer to accept occasional interruptions in service in exchange for reduced rates.

Manufacturers Process flow can be of great concern in certain industries. Semiconductor manufacturers, for example, may want to be warned of impending outages so they can reschedule production to minimize losses.

that, because storage units can start up quickly and respond much more rapidly to load fluctuations than fossil-fired units can." Birk agrees: "Energy storage systems can buffer customers from any lack of reliability of third-party generation," he says. "That takes off a lot of pressure with regard to reliability."

Storage can also buffer the other great concern that has shown up with the growth of independent generation—power quality. The country operates on a very pure diet of 60-cycle alternating current, and computers and other high-tech end-use equipment are becoming increasingly finicky about what is fed them. By means of sophisticated control equipment and precise operating procedures, utilities ensure the quality of power as it is being generated. Third-party generators, however, are generally not equipped to fine-tune voltage and control frequencies to expected levels. Storage systems can buffer utilities and their customers from such glitches. "You don't have to worry about how the independents supply the power or even, within reason, about their reliability and power quality," Birk explains. "It's like modern steelmaking, where large amounts of scrap metal are used. All kinds of stuff is fed in—tin cans, auto bodies, machining wastes—but by the time it's melted down, refined, and out the door, you have uniform billets of a very precisely controlled composition." Power quality issues have resulted, for example, in the West Berliners procuring an 8.5-MW battery energy storage system in 1986 to maintain frequency. Although their problem was a result of their being an "island" utility rather than a result of unreliable independent power production, the benefit is the same.

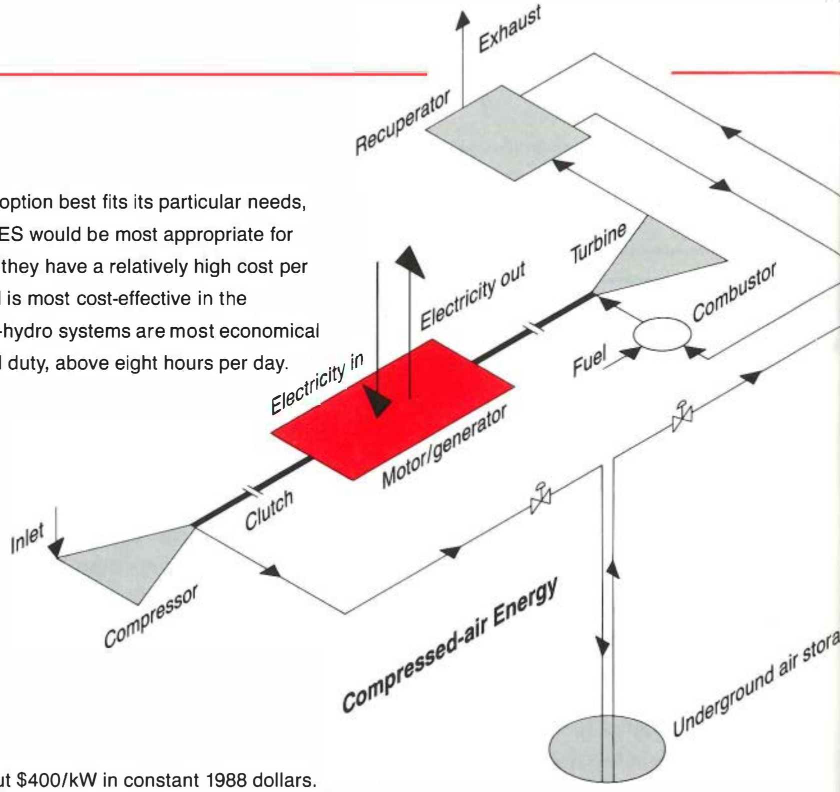
With a storage system separating generators and customers, independent generators become a more useful part of the power equation. The emphasis on the generation side can shift to providing electricity at low cost, rather than meeting goals of low cost plus reliability plus quality. The utility can now handle these concerns in a cost-effective way.

New opportunities

These ideas dovetail neatly with several EPRI efforts to help utilities expand into new markets through energy service options. The Customer Systems Division is developing a menu of end-use technologies to facilitate this expansion. Other EPRI research is focusing on differentiating the basic electrical service itself. "Utility service is traditionally measured in terms of kilowatthours," says Hung-Po Chao, scientific adviser in the Business Management Group. "But from a business planning standpoint that service is a bundle of characteristics or attributes. Reliability, power quality, price, and convenience—these and other attributes are part of the service that a utility offers its customers. And different customers value different attributes." EPRI is exploring ways utilities can unbundle service options to make electricity more competitive and to increase the value of utility service.

Energy Storage Technologies

In selecting a storage technology, a utility must consider which option best fits its particular needs, load shape, and budget. For example, battery systems and SMES would be most appropriate for providing peak power about five hours per day or less because they have a relatively high cost per hour of storage. CAES costs much less per hour of storage and is most cost-effective in the intermediate range, 5–12 hours per day of generation. Pumped-hydro systems are most economical in large sizes—over 1000 MW—and are best suited to baseload duty, above eight hours per day.



COMPRESSED-AIR ENERGY STORAGE

CAES plants use off-peak electricity to compress air into an underground reservoir. When electricity is needed the air is withdrawn, heated with gas or oil, and run through expansion turbines to drive a generator. Such plants burn about one-third the premium fuel of a conventional combustion turbine and produce one-third the pollutants. The compressed air can be stored in several types of underground structures, including caverns in salt or rock formations, aquifers, and depleted natural gas fields.

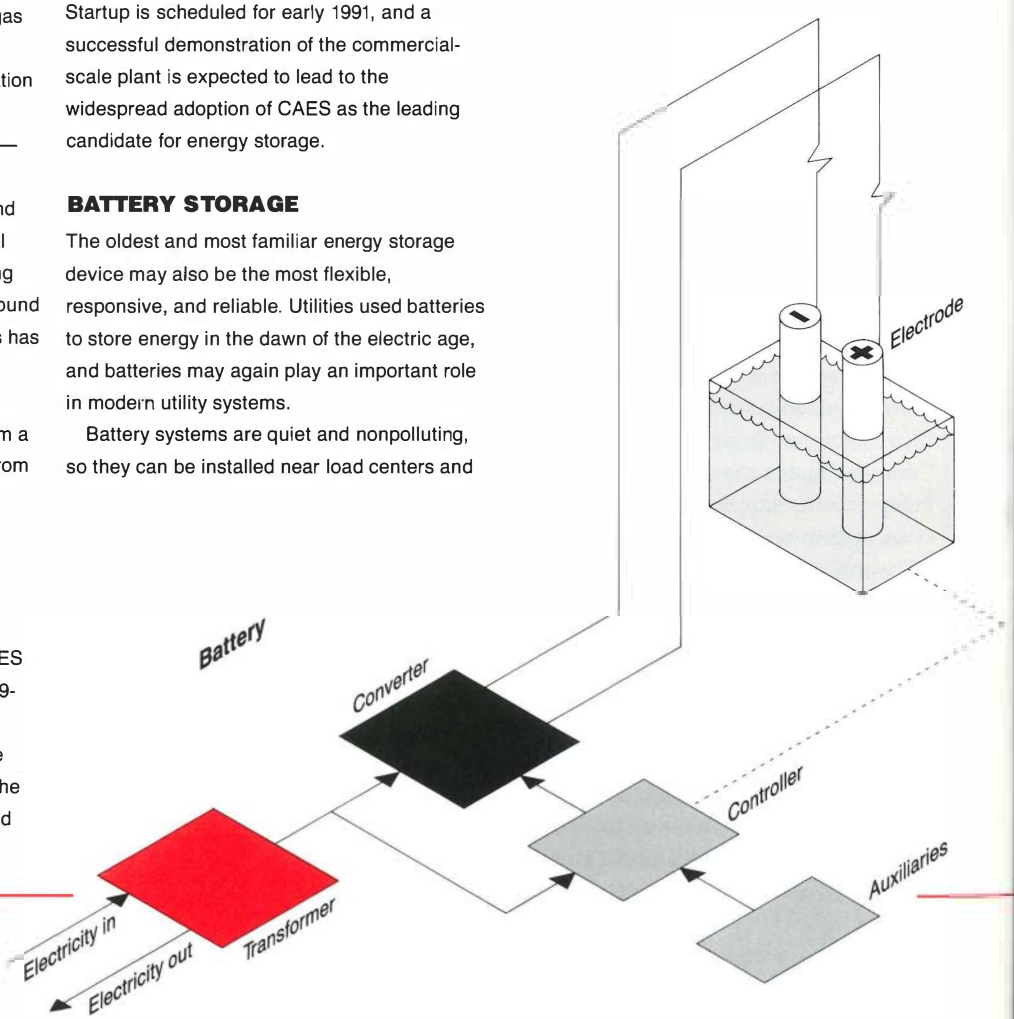
A 290-MW CAES plant has been in operation in Huntorf, West Germany, for more than a decade, demonstrating strong performance—90% availability and 99% starting reliability. EPRI has sponsored numerous technical and economic studies to determine the technical feasibility and economic viability of deploying CAES in the United States. These studies found that some three-fourths of the United States has geology potentially suited for reliable underground air storage and the required turbomachinery is available off the shelf from a number of vendors for plant sizes ranging from 25 to 220 MW.

As a direct result of this work, CAES technology is now gaining a foothold in the United States. With funding and technical assistance from EPRI, Alabama Electric Cooperative is building the nation's first CAES plant, a 110-MW unit that will store air in a 19-million-cubic-foot cavern mined from a salt dome. This voluminous cavern will allow the plant to generate at 110 MW for 26 hours. The fixed-price, turnkey cost for this first-of-a-kind plant is about $400/kW in constant 1988 dollars. Startup is scheduled for early 1991, and a successful demonstration of the commercial-scale plant is expected to lead to the widespread adoption of CAES as the leading candidate for energy storage.

BATTERY STORAGE

The oldest and most familiar energy storage device may also be the most flexible, responsive, and reliable. Utilities used batteries to store energy in the dawn of the electric age, and batteries may again play an important role in modern utility systems.

Battery systems are quiet and nonpolluting, so they can be installed near load centers and



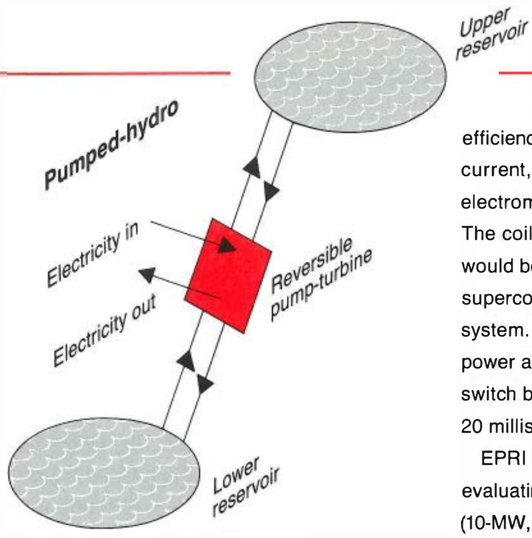
in existing suburban substations. Factory-built modules reduce construction lead time and allow utilities to accurately match load growth without overbuilding new capacity. Quick response is one of the technology's strong points: batteries can respond to load changes in about 20 milliseconds.

Southern California Edison is demonstrating the technical and economic feasibility of lead-acid-battery storage in a 10-MW, four-hour-capacity plant recently built at SCE's 12-kV Chino substation. During a two-year test and evaluation program, the Chino facility will be used to demonstrate the cost and benefits of battery storage for load leveling; voltage, VAR, and frequency control; and spinning reserve.

EPRI and the Department of Energy are developing advanced batteries that pack more energy into a smaller package, last longer, and cost less than lead-acid devices. Sodium-sulfur batteries may achieve a 15–30-year life and 75% efficiency and may cost about $425/kW for a 10-MW, three-hour plant. One drawback of sodium-sulfur devices is that they have to be kept at 330°C (626°F) to operate. Zinc-bromine batteries operate at ambient temperatures; they are expected to cost about $425–$600/kW for a 10-MW, three-hour plant and to be capable of 65% efficiency, and they are expected to have at least a 15-year life.

PUMPED-HYDROELECTRIC STORAGE

In operation worldwide for more than 50 years, pumped-hydro plants are still the only energy storage technology in widespread use. Such plants use off-peak power to pump water uphill to an elevated reservoir. When electricity is needed, the water is released to flow to a lower reservoir, and its potential energy is used to drive turbines. There are now 37 pumped-storage plants in the United States, but several factors may limit further deployment of this storage option. Pumped-storage plants require a large area with suitable topography for the upper and lower reservoirs. Many of the best sites are already taken, and proposed plants



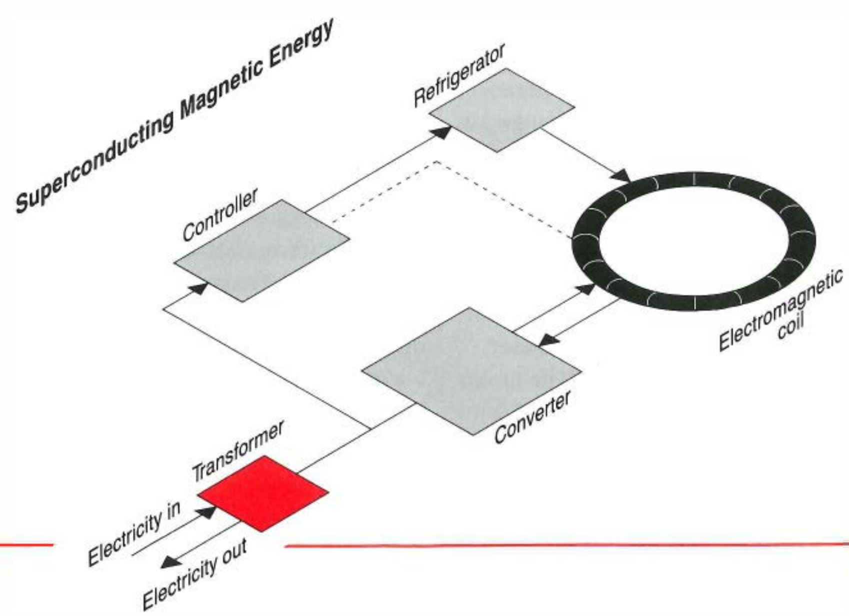
have encountered opposition from environmental groups. To be economical, pumped-storage plants have to be large—in the 1000–2000-MW range—which makes for long lead times and a capital cost of about $1000/kW. Underground pumped hydro, in which the lower reservoir would be excavated from subterranean rock, may provide more flexibility in siting plants, and EPRI R&D has shown that this approach is technically feasible. It would add significantly to a plant's capital cost, however, and no underground pumped-hydro plants exist or are being built at this time.

SUPERCONDUCTING MAGNETIC ENERGY STORAGE

A distant prospect that holds considerable promise, SMES may someday enable utilities to store electricity directly with unparalleled efficiency. Off-peak power, converted to direct current, would be fed into a doughnut-shaped electromagnetic coil of superconducting wire. The coil, some 1000 meters in diameter, would be installed in a trench and kept at superconductive temperature by a refrigeration system. A SMES unit could store and discharge power at ac-ac efficiencies of 90% or more and switch between charging and discharging within 20 milliseconds.

EPRI and the Department of Defense are evaluating the design and cost of a pilot-scale (10-MW, two-hour-capacity) SMES plant that uses low-temperature superconductors cooled by liquid helium. Such a plant is expected to be operational in 1994. This pilot-scale and commercial-scale plant may lead to larger, demonstration-scale and commercial-scale plants.

Developing a commercial SMES plant presents economic and technical challenges. Because of the high cost of liquid helium, only plants with 1000-MW, five-hour capacity are economically attractive. This situation may change, however, if a new class of so-called hot superconductors can be put to work in a SMES system. These ceramic materials become superconducting at temperatures that can be maintained by less-expensive liquid nitrogen, and with advances in other plant components, they may make SMES economical on a smaller scale.



Estimated Costs for Energy Storage Technologies

Costs are given in constant 1989 dollars and include engineering, land, and material expenses. Allowance for interest and escalation during construction is included. The total cost equals the product of energy-related costs and hours of storage added to power-related costs. CAES costs are for plants based on salt geology. Aquifer-based plants cost about 5–10% less; rock-based plants cost about 10–75% more, depending on plant capacity.

Technology		Power-related cost ($/kW)	Energy-related cost ($/kWh)	Hours of Storage	Total Cost ($/kW)
CAES	Small module (25–50 MW)	575	5	10	625
	Large module (110–220 MW)	415	1	10	425
Pumped-hydro	Conventional (500–1500 MW)	1000	10	10	1100
	Underground (2000 MW)	1040	45	10	1490
Battery	Lead-acid (target) (10 MW)	125	170*	3	635
	Advanced (target) (10 MW)	125	100	3	425
SMES	(Target) (1000 MW)	150	275	3	975

*Lead-acid battery cells must be replaced after about 15 years, at a cost of about $85/kWh for 250 cycles/year duty.

"Reliability is perhaps the most frequently cited attribute," says Chao, "but reliability can mean different things to different customers." Some customers, such as semiconductor manufacturing firms, he explains, may want advance warning of an outage so they can reschedule production. Others, such as poultry processors, are more concerned with the duration of an outage because they deal in a perishable product whose value depends on refrigeration. There are also customers willing to endure occasional interruptions in exchange for lower rates. "So there is a spectrum of customers out there," says Chao. "Offering them a spectrum of services is one of the key strategies utilities can use to be more competitive, and storage is one of the key technologies to provide the flexibility to enable utilities to do that." The example here would be installing a battery system at or near the customer's facility to provide a buffer against unexpected outages.

"It's important to note that energy can be stored on both sides of the meter," says Clark Gellings, director of the Customer Systems Division. For example, installing thermal energy storage systems in homes and businesses makes it possible for off-peak energy to be used for heating and cooling during peak periods, reducing customers' electric bills and helping utilities smooth their load curves. Batteries too can be used to store energy on the customer side, with electric vehicles providing an example. "In addition, innovative rates can influence customers to change their production to effect changes in load shape," says Gellings.

Another novel application for storage lies in the area of transmission planning. The forces that are reshaping the structure of the industry—nonutility generation, power wheeling, and deregulation—have increased the burden on the transmission lines that carry bulk power between generators and load centers. "The power system is a machine that was designed to perform certain functions," says Frank Young. "If we want it to perform other functions—such as allowing large blocks of electricity to go looking for competitive markets—we have to add some more equipment."

While pressures on the transmission system increase, the costs of building a new transmission line have also increased—to as much as $750,000 per mile—and obtaining rights-of-way and the necessary approvals to install new lines can take five to seven years or more. In many cases it's not possible to install new lines to large metropolitan load centers, even though the demand from those centers has the existing lines loaded to capacity during peaks. "Batteries and other fast-response storage technologies can help in the operation of transmission and distribution systems," says Robert Schainker. "Installing a storage plant near a load center—a battery system at a substation, for example—may be an attractive alternative to adding a new transmission line or upgrading an existing one. You can charge the battery at night when the line isn't loaded, then feed that stored energy into the distribution system to serve the peak load the following afternoon."

Placing storage units close to metropolitan load centers could also bring environmental benefits. Heightened concern over air quality may result in legislation to further reduce emissions from fossil-fired plants and perhaps restrict their deployment in some areas. Environmentally benign storage technologies could be used to park baseload power from remote generators without adversely affecting air quality in urban load centers.

Hub and spokes

Competition, new players, and possible regulatory restructuring may lead to even greater changes in the way utilities do business—perhaps even in how they are physically configured. In light of such pressures and opportunities, EPRI has been exploring ways to integrate storage technologies into utility systems to fully exploit their potential. "One intriguing idea is that a storage plant could serve as the hub of a utility, just as certain airports serve as hubs for airlines," says Birk. "In each case the hubs serve the same purpose, which is to organize and use production and delivery systems to meet demand and expand into new markets in the most profitable way."

In this arrangement, now familiar to air travelers, passengers are moved through a central hub airport, with routes to various points of origin and destination radiating from the hub like spokes. The hubs thus function as short-term storage systems that enable the airlines to manage passenger flow more efficiently than if all flights were conducted on a point-to-point, nonstop basis. The hub-and-spokes system brought several benefits to the airlines, Birk says. "It enabled them to fill up their planes, which served to lower costs—not by simply cutting expenses, but by using their capacity with greater productivity. It also allows them to expand into new markets in a synergistic fashion." A key characteristic of hub systems, he explains, is that the number of markets served increases exponentially rather than linearly as units of productive capacity are added. Connecting a single new city to the hub connects it to all the cities served by the hub. "So when an airline adds service to a new city," says Birk, "it expands its business on all its planes; it gets an exponential benefit—a neat way to add business and gain leverage in the marketplace." Birk believes that energy storage hubs can bring similar benefits to utilities by allowing new generation systems to supply a multitude of customers regardless of their reliability, power quality, or load shape requirements. Furthermore, just as hub cities allow airlines to fill their planes, storage plants allow utilities to fill their spokes—the transmission system.

In fact, such a hub-and-spokes concept could provide essential offensive and defensive advantages as the U.S. electric power industry, particularly power generation, experiences a changing business climate, including competition, restructuring, and merger activity.

Birk again uses the experience of the airlines as a familiar example. "Prior to 1978, the airline business involved moving passengers from point A to point B on the cheapest route," he says. "In the immediate aftermath of deregulation this practice continued and actually intensified, with numerous low-cost carriers entering the business, often with stripped-down service, and competing on the basis of cheaper fares." As competition heated up, however, many of the low-cost carriers that had suddenly sprouted up were just as suddenly forced out of business, or acquired by other airlines.

"It's clear that cost cutting was not the whole answer," says Birk. "While cost is certainly important, the airlines soon found that winning the game required something more, and they developed the hub-and-spokes system."

The hub-and-spokes concept is not unique to airlines. Analogous systems have evolved in the railroad, telecommunications, and natural gas industries, each of which developed a variant of the hub system to more effectively manage traffic between supply and destination, whether the traffic consisted of freight, passengers, gas, or electrons.

Dean Boyd, chairman of Decision Focus, Inc., performed a study under EPRI sponsorship to examine patterns in industries undergoing transition to extract lessons for utilities. Boyd's study found that industries where hub systems are effective share several characteristics: They have markets with a high degree of geographical dispersion and time variation, combined with products with a limited shelf life, which provides the potential for a high degree of product differentiation. They also have delivery systems capable of consolidating production to meet demand. It is this consolidation—performed by hubs—that is the key to achieving market leverage.

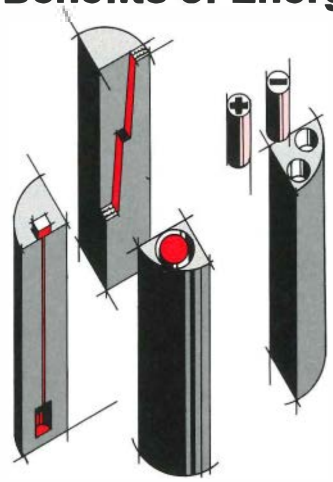
It's significant to note that under these generic criteria, electric utilities already have hub systems. The transmission system provides the means to consolidate production from a diverse set of generation sources to serve a diverse set of customer demands. According to Boyd, integrating energy storage into transmission systems may provide the ultimate tool for consolidating production, allowing utilities to fully exploit the advantages of the hub-and-spokes concept.

"In other industries undergoing transition, all the real action has been at the hubs," says Birk. "They are the building point for business expansion, and the primary business decision is the establishment and strengthening of the hubs. Ownership of the supply and destination sides is a secondary business decision, because control of the hub-and-spokes system provides leverage over the supply system and a competitive edge in distribution. That doesn't mean synergistic business opportunities can't evolve as a result of building a strong hub. For example, railroads have bought trucking and barge companies as well as pier facilities. They are also buying coal leases and operating as coal producers as well as transporters."

Birk and Schainker envision a future in which some 10% of the nation's generating capacity is represented by storage plants, employed in hubs of various sizes across the United States. Large, centralized storage hubs could serve broad regions, with smaller, distributed hubs serving particular load centers or individual customers, or storing power from third-party generators. Schainker elaborates: "At some point in the future, every major load center in the country may be served by a storage hub. Interties, where transmission lines from generators meet a substation, are natural locations for storage. The interconnection between a cooperative and a host utility is an obvious hub location," he says. "It's a logical place to put a storage device to take advantage of the fluctuating price of power."

Such a vision won't be realized overnight, of course; it will evolve gradually as utilities come to recognize the full economic value of storage. "A factor that has slowed the acceptance of storage is the lack of planning tools that accurately quantify its benefits," says Birk. "But it's quite possible that applications will drive the development of planning tools. Every existing storage plant has provided benefits in excess of original expectations, largely because dispatchers have learned how to exploit the storage plant's rapid response in system operation. With the development of tools that accurately model the performance benefits of storage, I think we'll see increased deployment of

Dynamic Benefits of Energy Storage



Because energy storage technologies can start up quickly and respond rapidly to load fluctuations, they can be used instead of slower fossil-fired units for following load and providing spinning reserve. In addition, their nimble response makes energy storage plants well suited to frequency regulation and voltage and power-factor correction. Using a storage plant for frequency control can free a fossil-powered unit from this task and allow it to be loaded up to its most cost-effective rating. While these so-called dynamic benefits of energy storage are intuitively valuable, until recently they have been difficult to quantify by means of the standard production cost codes designed for generation-based technologies. Consequently, utility planners who rely on explicit costs and benefits in evaluating capacity additions have been unable to accurately incorporate the dynamic benefits into their analyses.

The principal challenge in quantifying dynamic benefits has been representing the chronology of events involved in demand fluctuations and unit commitment; the traditional production-cost models lack the chronological details to model dynamic benefits. EPRI has sponsored the development of two new computer models, DYNAMICS and DYNASTORE, which make it possible to represent dynamic benefits more accurately. DYNASTORE simulates unit commitment and economic dispatch of a utility system over a 7-day period using 10-minute time steps. The models are currently being tested and will be available through EPRI's Software Center.

Case studies conducted with DYNASTORE demonstrated significant savings from energy storage. Storage spinning reserve and commitment benefits accounted for approximately 48% of daily fuel cost savings, conservatively equivalent to $300/kW in capital costs, although the value will vary dramatically from one utility to another. Other EPRI studies conducted for different storage technologies have indicated that, on average, the savings associated with dynamic benefits are equal to or greater than the fuel savings associated with meeting peak demand with off-peak energy. □

storage plants in the future."

Once storage has been deployed, the common utility position, as expressed by PG&E's Donald Brand, is "I don't know how we managed to get along without it." Brand was referring to PG&E's new 1200-MW Helms pumped-storage plant, which began operation in 1984.

Schainker points out that utilities now can choose from an expanded list of storage options that offer a spectrum of capacity sizes and hours of storage. Choosing which storage technology to use depends on a particular utility's existing generation mix, load shape, and budget. Compressed-air energy storage, for example, is the best candidate for intermediate duty, while batteries are best suited for peaking service. "Our studies show that a utility can gain significant strategic benefits with about 10% of its generating mix supplied by storage," says Schainker. "And it's important to note that in many cases only a few hours of storage are necessary to realize those benefits."

While large, centralized hubs may require storage capacities on the order of 1000 MW, smaller systems using battery or compressed-air storage could enable their owners to exploit niche markets in the near term, according to Birk. These early entrants will reap the biggest benefits because they will take advantage of the maximum price differential between peak and off-peak power.

An example of such an early niche-market application is provided by Crescent Electric Corp., a North Carolina cooperative that operates a 500-kW battery system that previously was successfully evaluated in the Battery Energy Storage Test facility operated by EPRI and the Department of Energy. The battery's one hour of storage allows Crescent to clip peak charges on their purchased power.

Another real-world example is provided by Britain, whose nationalized Central Electricity Generating Board is in the process of privatizing the electric power system. The new structure comprises two competing generation companies, a privatized transmission grid, and regional distribution systems. The 1800-MW Dinorwig pumped-hydro facility in Wales will operate in the transmission grid as a hub separating the generation and distribution sectors.

Minimizing risk

The changing business climate may encourage even greater utility focus on financial considerations. In a more market-driven arena, penalties associated with oil-price shocks and other uncertainties will be more keenly felt. To remain competitive, utilities' strategic objectives will shift from a production orientation to a market orientation, from minimizing required revenues to maximizing the value of the company to its stockholders.

These conclusions were reached in an EPRI-sponsored study that examined the impact of energy storage on utility bottom-line performance. The study results will soon be available in an EPRI report, *Strategic Assessment of Storage Technologies.* The study contractor, Polydyne, Inc., compared the value of utility systems with and without storage. The study's major finding is that the corporate market value of a utility improves significantly when storage technologies are added in lieu of oil- and gas-fired plants for intermediate and peaking generation. The increase in value results from reducing the risks and uncertainties in operational cash flows that stem from large uncertainties in future oil and gas prices.

"In the past, utilities were less vulnerable to oil-price shocks, as a result of the allowability of passing these costs on to the customer, and so had less incentive to create a generation mix that was insensitive to those shocks," says Schainker. "In today's more complicated environment, where market forces play a larger role, that's changing. Now utilities have to shield themselves from oil shocks and other uncertainties to protect themselves." Storage plants will be charged from the cheapest source, whether it be coal, nuclear, municipal waste, solar, wind, or hydro. A utility with storage will therefore be less vulnerable to fuel-price shocks, Schainker says, and so be able to increase its market share.

Planning for an uncertain future

The forces that will determine the course the utility industry will ultimately take are shaped by the interaction of numerous players: regulators, economists, and utility companies and their customers and shareholders. The eventual outcome cannot yet be predicted with any confidence, but regardless of how the industry's business structure evolves, the need for a reliable and low-cost supply of power will remain, and the need will be served by technology. The utility industry must develop competitive strategies to remain strong in an uncertain future, and energy storage may be a key element in developing strategies that can meet present challenges, as well as open future opportunities. ■

Further reading

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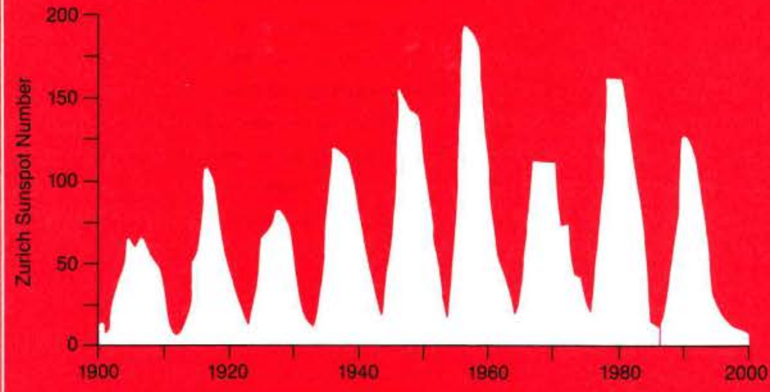
This article was written by David Boutacoff. Background information was provided by Kurt Yeager, James Birk, and Robert Schainker, Generation and Storage Division; Frank Young, Electrical Systems Division; Hung-Po Chao, Business Management Group; and Clark Gellings, Customer Systems Division.

A Storm

Sunspot activity that leads to solar magnetic disturbances on the earth has historically risen and fallen in cycles of approximately 11 years. While the magnitude of such activity is difficult to predict with accuracy, strong magnetic storms earlier this year suggest that the forecast made in 1986 for the upcoming 1991 peak may be too low. Many forecasters now feel that this peak may rival the extreme measured in 1957.



Source: *QST*, May 1986

Like a lightning stroke on a distant horizon, a sudden jump in magnetometer readings across eastern Canada at 10 p.m. on March 12 foretold an approaching storm. By midnight official warnings had been sent out: a large burst of charged particles was on its way from the sun and would soon be interacting with the earth's magnetic field. Power system operators as far south as Pennsylvania were told to expect a strong solar magnetic disturbance over the next several hours.

Silently and invisibly, the huge magnetic storm burst with full intensity at 2:45 EST the next morning, inducing significant electric potentials in the earth that meant serious trouble for Hydro-Quebec's power network. Within seconds, five major transmission lines carrying power to Montreal from hydroelectric facilities at James Bay were knocked out of service. The resulting loss of 9450 MW—serving over 40% of the utility's load—sent frequency and voltage excursions throughout the rest of the Hydro-Quebec power system.

As automatic load shedding struggled unsuccessfully to maintain balance, the

From the Sun

As recent outages have shown, magnetic disturbances triggered by solar flares are capable of disabling entire utility systems. And the worst may be yet to come: the current magnetic storm season is not expected to reach its peak until 1991.

system became increasingly unstable, and protective devices automatically isolated generators at Churchill Falls and Manicouagan. By 2:46 all of Quebec province was blacked out, and utilities in the northeastern United States had lost 1325 MW of power they had been importing from Hydro-Quebec. Restoration time was prolonged because of equipment damage; even by noon, 17% of Hydro-Quebec customers still lacked electricity, and the intense disturbance also damaged utility equipment over a wide area, including some in the United States.

From sun to power system

Although their consequences are usually not this severe, solar magnetic disturbances, or SMDs, are neither rare nor unexpected. In the arctic region they are responsible for the spectacular auroral displays commonly known as the northern lights, and the potential of SMDs for disrupting power transmission and communications has been recognized for nearly 50 years. But the recent Canadian storm was unusual in its intensity—a disturbing development, since the current magnetic storm season is not

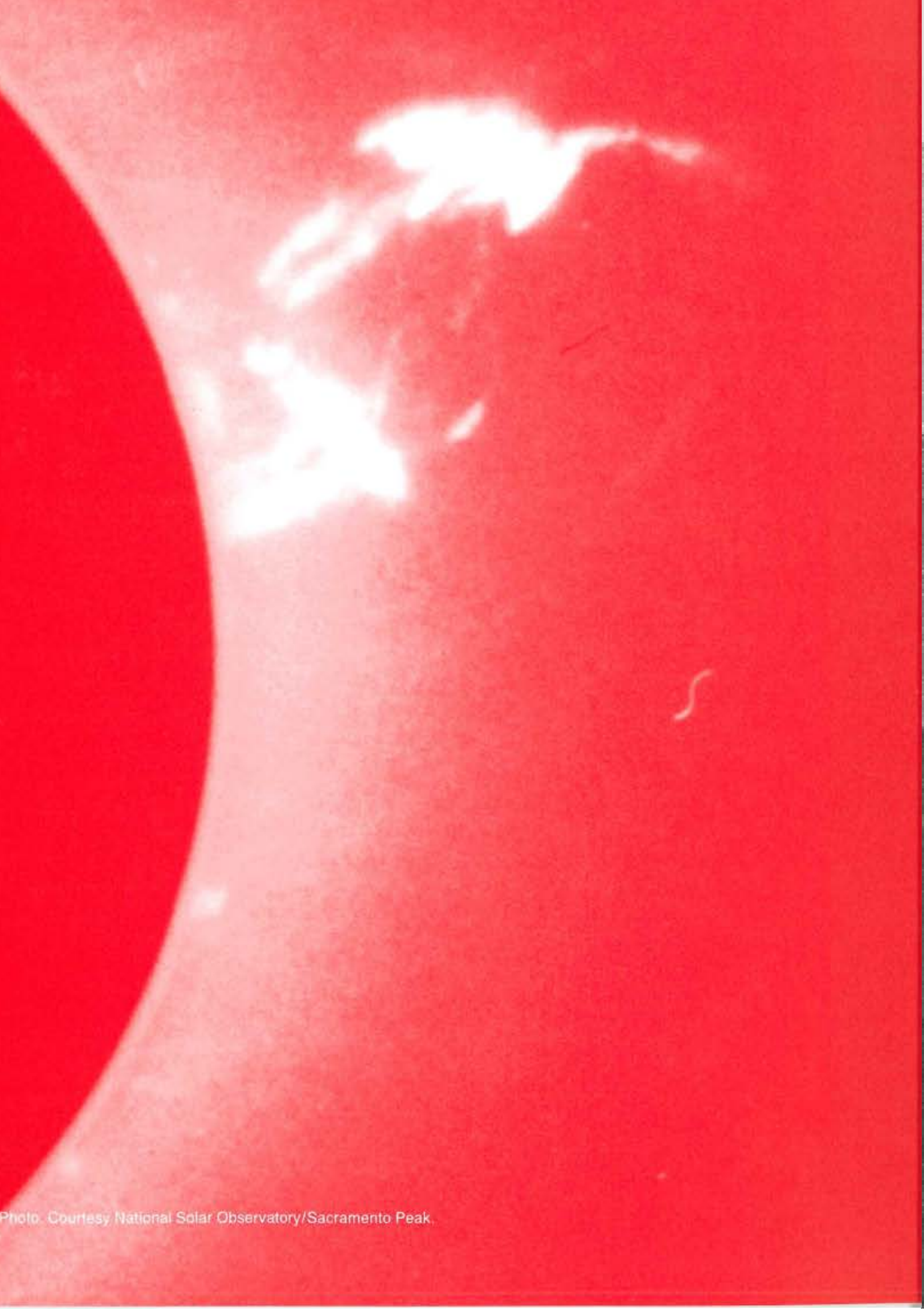
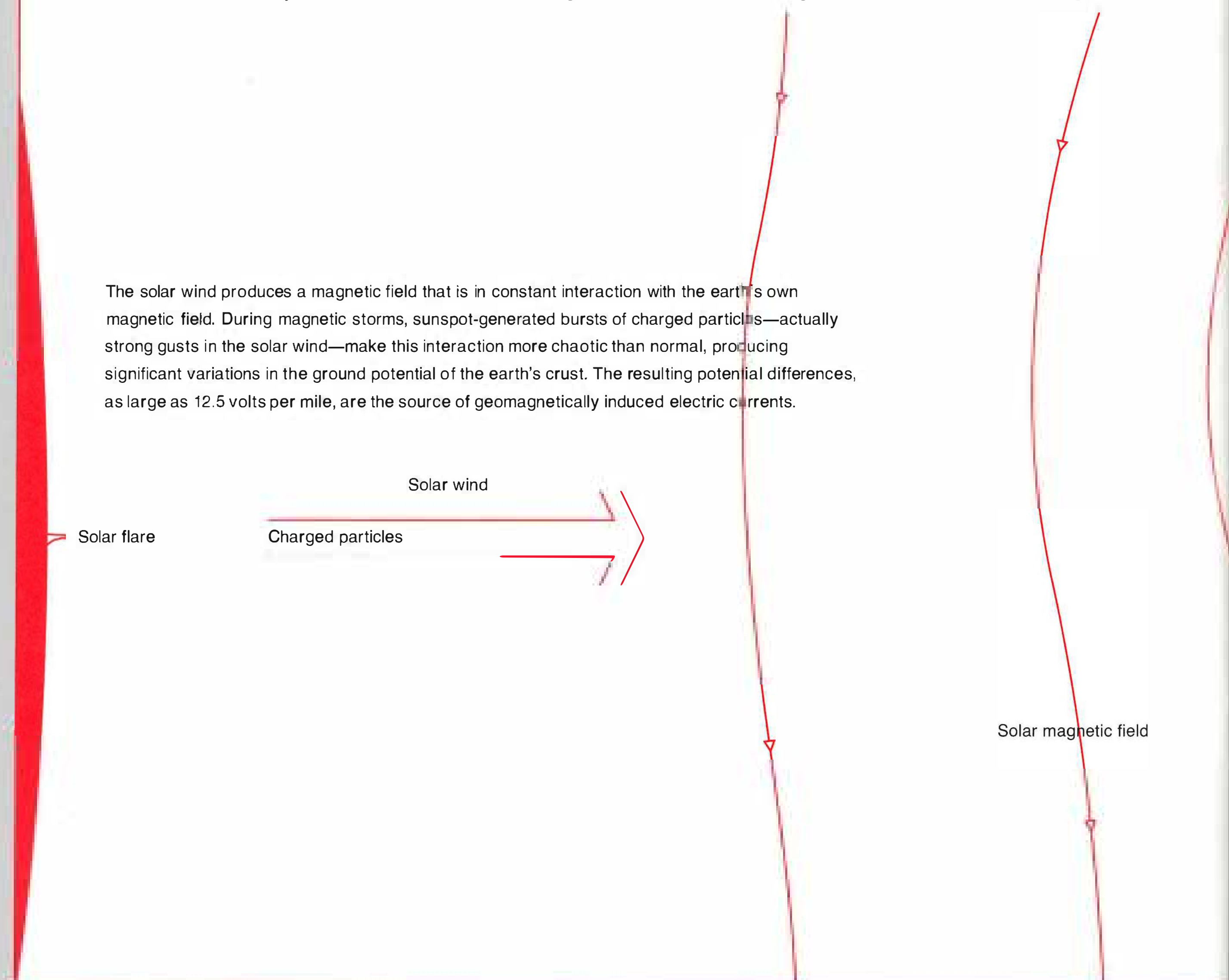


Photo: Courtesy National Solar Observatory/Sacramento Peak.

Trouble From a Gust of Solar Wind

The earth is constantly bombarded by a stream of charged particles from the sun, known as the solar wind. When disturbances occur in the sun's outer layer, sudden bursts of particles shoot outward in a shock wave. These gusts of solar wind travel outward at 500 to 1000 kilometers per second, compressing the earth's magnetic field when they collide with it, some 48 to 134 hours later. During this compression, particles are diverted toward the earth's polar regions, where they form east-west currents around a so-called auroral oval high in the atmosphere.

These high-altitude currents change rapidly in response to variations in the solar wind. Such changes shift the earth's magnetic flux lines, creating electric potentials—just as shifting flux lines through a coil of wire produces a voltage in a generator. Currents induced by these potentials at ground level would ordinarily flow through the earth itself, but the presence of grounded neutrals of a transmission system provides a parallel path. Such geomagnetically induced currents (GICs) in transmission lines can be particularly

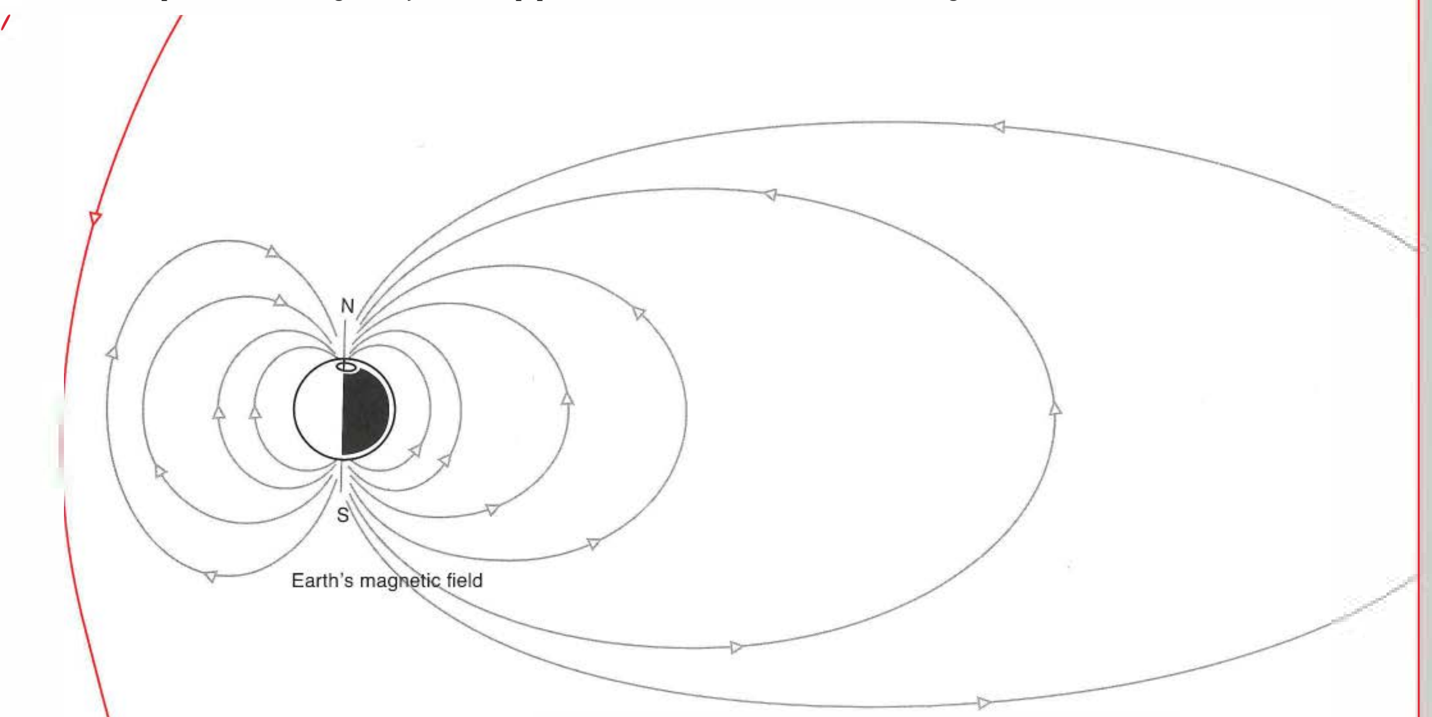


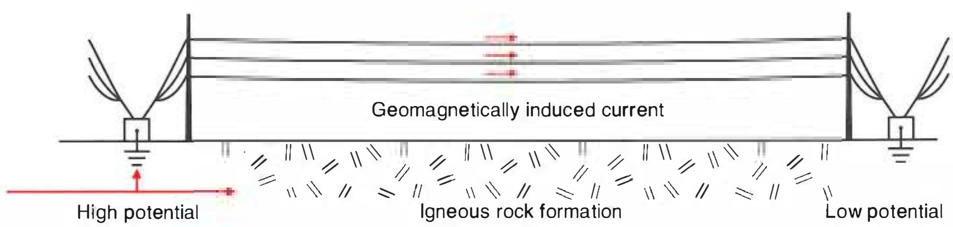
The solar wind produces a magnetic field that is in constant interaction with the earth's own magnetic field. During magnetic storms, sunspot-generated bursts of charged particles—actually strong gusts in the solar wind—make this interaction more chaotic than normal, producing significant variations in the ground potential of the earth's crust. The resulting potential differences, as large as 12.5 volts per mile, are the source of geomagnetically induced electric currents.

intense where the earth's crust has a high resistance to electricity.

Meanwhile, some of the electrons in the auroral oval current get accelerated downward, so that they penetrate the ionosphere. There they collide with oxygen and nitrogen molecules forcefully enough to raise the molecules' internal energy level or even cause them to break apart. These energetically excited atoms and molecules then emit radiation, which we see as the northern lights.

The first observed association between a solar flare and a subsequent auroral display was made in 1859. Since then, a variety of other effects have been documented, ranging from disruption of flow-monitoring systems in pipelines to disorientation of birds that depend on the earth's magnetic field for navigation. (Some pigeon fanciers' clubs cancel races when magnetic disturbances are anticipated.) With solar activity expected to reach a peak over the next couple of years, considerable international effort is being made to improve both long-term and short-term predictions related to magnetic storms and their effects. ☐

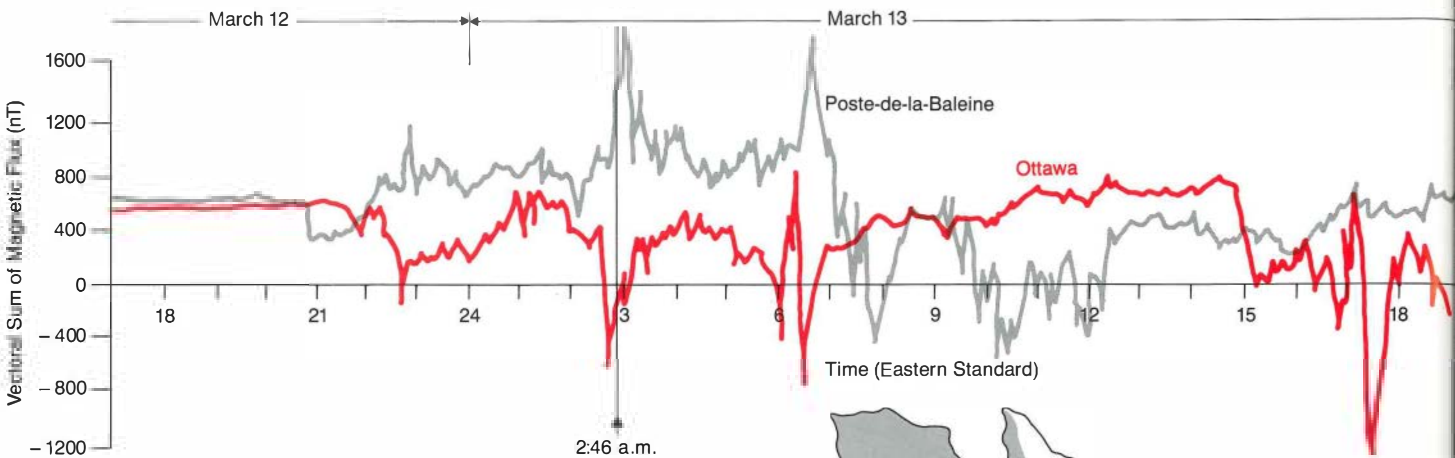


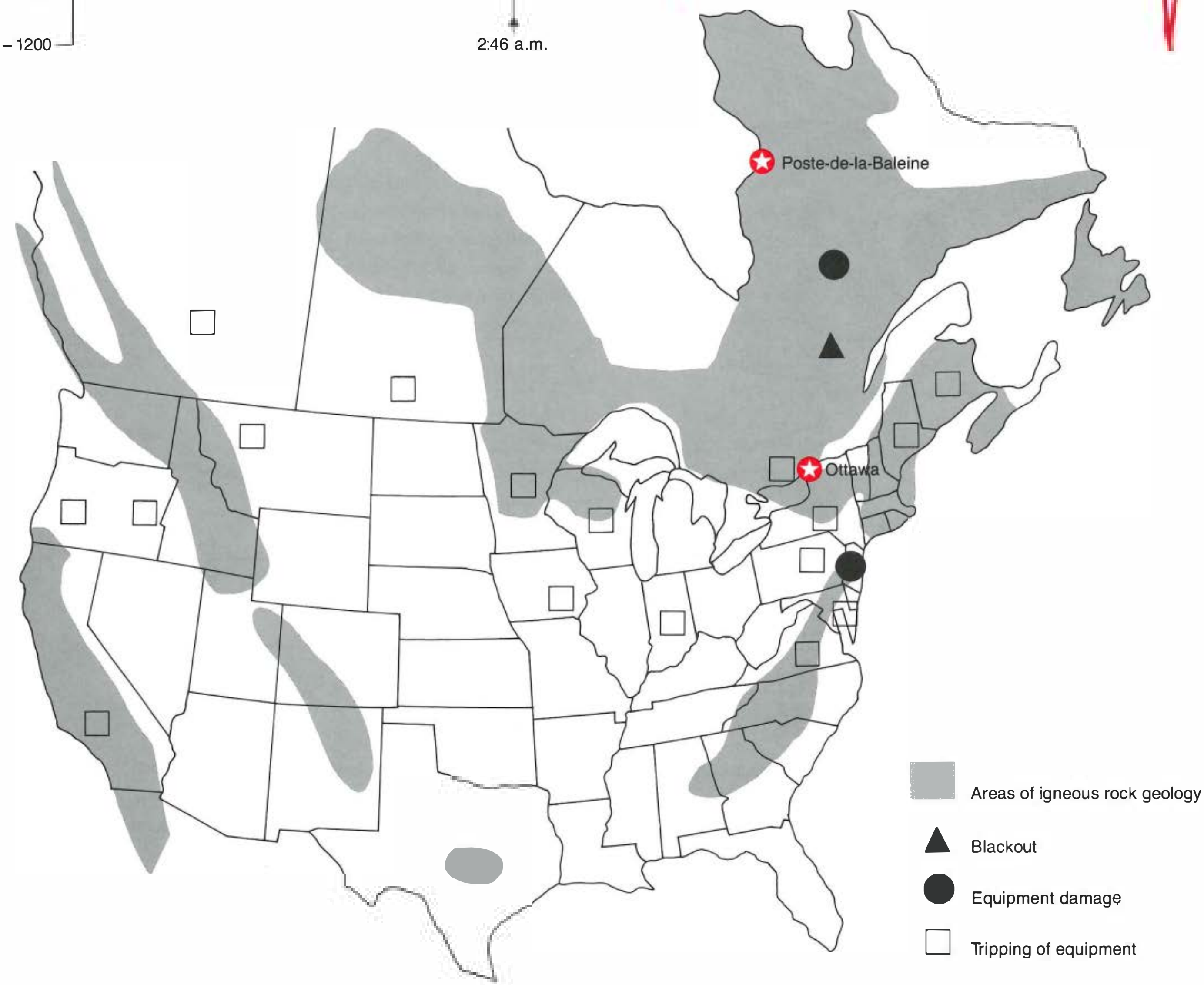


Electric currents induced in the earth by magnetic storms normally travel uneventfully through the earth itself, from areas of high potential to areas of low potential. But patches of earth that conduct poorly, such as those composed of granite or other igneous rock, can cause some of the current to take the easier path through a utility's transmission lines, leading to problems on the entire system.

Trouble on the System

A magnetic storm predicted late at night on March 12, 1989, had magnetometers across eastern Canada jumping. Extreme differences in ground potential and the large expanse of igneous rock underlying the area caused geomagnetically induced current to travel through portions of the Hydro-Quebec power system, triggering loss of lines and bringing the system down completely at 2:46 the next morning. Effects of the magnetic storm were noted as far away as southern California.





forecast to reach its peak until 1991. Utilities are likely to be facing further troubles with SMDs for at least several years.

The bursts of charged particles—mainly electrons and protons—that cause SMDs are produced by solar flares and other activities that generally rise and fall over an 11-year cycle, in accordance with the number of sunspots observed. The exact cause of these flares remains unknown, and the likelihood that a particular flare will produce a major SMD on earth is difficult to determine. On the basis of observations of solar activity and extrapolation from past experience, warnings of magnetic storms that might affect U.S. utilities are issued by the Space Environment Sciences Center of the National Oceanic and Atmospheric Administration, the Geological Survey of Canada, and the Geophysical Institute of the University of Alaska. Such warnings have a limited predictive value for utilities, however, since ground-level magnetic anomalies vary greatly from one place to another during even major SMDs.

When an SMD produces strong perturbations of the earth's magnetic field in the vicinity of a utility network, several disruptive effects can occur in rapid succession. First, magnetic field fluctuations lead to differences in electrical potential of 5–10 volts per mile of very low frequency (almost dc) along the earth's surface in a generally east-west direction. These potential differences cause some of this quasi-dc current to enter the power conductors through the neutral grounds of transformers. The magnitude of the induced current depends on a variety of factors, including the location, length, orientation, and resistance of a line, as well as the resistivity of the ground beneath the line. As these quasi-dc currents flow through a grounded neutral of a transformer, the transformer core may saturate, pulling down line voltage and creating harmonic distortions. These harmonic currents may then overload the shunt capacitors that help maintain system voltage, causing protective relays to operate and thus removing the capacitors from service.

"It's a double-edged effect," says Robert Iveson, technical adviser in the Electrical Systems Division. "To lose the capacitor bank is the worst thing that can happen when system voltages start to drop. It's like pulling the pole from under the middle of a sagging clothesline."

The saturation of transformer cores for long enough periods of time can also cause them to overheat, resulting in loss of transformer life or even permanent damage. At one U.S. nuclear power station, for example, damage to a major step-up transformer apparently sustained during the March 13 SMD has put it out of service for months. In addition, harmonic voltage distortions can cause misoperation of protective relays and overload shunt capacitor banks, and magnetic disturbances can disrupt communications, making it harder for operators to control their power system as problems develop.

The vulnerability of a particular utility network to SMDs depends mainly on its latitude and the geological formations underlying its transmission lines. Because the interaction between the earth's magnetic field and charged particles from the sun is strongest near the magnetic poles, both the occurrence and magnitude of induced line currents are greater at higher latitudes. For example, during a three-year test period that began in 1969, a recorder at the Corner Brook substation of Newfoundland and Labrador Hydro measured a monthly average of 39 geomagnetically induced current (GIC) events with a mean current strength of 16.5 amperes; similar instrumentation at the Jewett substation of Texas Electric Service recorded only 0.05 GIC event per month with a mean strength of less than 4 amperes.

The effect of latitude can be aggravated by geological conditions, especially the occurrence of igneous rock beneath a transmission network. Such rock has a very high electrical resistance, so that currents induced in the ground flow more easily through the neutral lines than through the earth itself. The 1969 study showed, for example, that the Pleasant Valley substation of Consolidated Edison—located on the igneous rock formation associated with the Appalachian Mountain chain—had a relatively high mean current strength of 13.4 amperes for its GICs (more than enough to saturate transformers), although an average of only 1.82 events were recorded per month.

In addition to disrupting power transmission, solar magnetic disturbances can interfere with the high-volume communications needed for such automated utility functions as load management, remote meter reading, and distribution switching. Channels using AM radio and direct lines are particularly susceptible to degradation. However, the increased use of fiber optics, which are invulnerable to magnetic fields and induced currents, may provide an attractive solution to such communications problems.

Trouble ahead?

The role of SMDs in power system disturbances was discovered in 1940, when two transformers were tripped in Pennsylvania. The most intense period of solar activity ever recorded—measured in terms of sunspots per month—occurred in 1957. Such heightened activity generally means that SMDs will be created more frequently and will produce stronger ground-level magnetic fields. Solar activity in the current cycle is already greater than that observed in a similar period in the 1957 cycle, so vulnerable utilities may experience an unusual number of strong magnetic storms over the next two or three years. The effects could be particularly severe if a power system happened to be subjected to lightning strikes at the same time magnetic disturbances were occurring.

Over the short term, a variety of adjustments can be made to a power system to help it ride through an SMD successfully. The trip levels of protective relays, for example, can be reset to discriminate better between currents induced by magnetic disturbances and those resulting from a fault. Such resetting would be particularly important in keeping shunt capacitors and static VAR compensators on-line to help maintain system voltage. Also, in response to an SMD alert, utilities could reduce power transfers and add more reactive reserve capacity to give their systems more resiliency in compensating for voltage excursions.

Better predictions of SMD occurrence and intensity could help utilities anticipate the possible effects more precisely. One set of experiments that showed particular promise for improving predictions was conducted from 1980 to 1982, using the International Sun-Earth Explorer 3 (ISEE-3) satellite. In these experiments, the direct measurement of particle fluxes from solar flares not only gave positive warning of sudden impulses but also indicated more accurately how they would interact with the earth's magnetic field. However, in mid-1982, ISEE-3 was released from earth orbit to study a comet, so direct data on particle fluxes are no longer available.

During the last cycle of sunspot activity, EPRI conducted research designed to help utilities predict the effects of magnetic storms and mitigate the disruptions they can cause. In one early EPRI project, from 1977 to 1980, Minnesota Power & Light and the University of Minnesota studied the effects of GICs on a new 466-mile, 500-kV ac transmission line connecting hydroelectric generators in Manitoba to customers in the Duluth and Minneapolis-St. Paul areas. The line was considered susceptible to GICs both because of its northern latitude and because it spans a large region of igneous rock. The detailed study involved both on-site data collection and analytical modeling of how induced currents might affect the power system under various conditions.

Among other results, this study showed that a voltage drop of as much as 20% could occur at certain points on the 500-kV ac line during a severe SMD. It also determined that adjacent dc transmission systems could be affected indirectly, since harmonics created in the ac line might overload filters at the converter terminal connecting the ac and dc systems. (Such overloading of ac/dc filters reportedly occurred in at least one case during the March 1989 SMD.) The researchers concluded that their investigations "reveal the serious nature of the voltage drop and real and reactive power flow changes that can occur on an interconnected power system during geomagnetic storms," and they recommended more than half a dozen specific areas for further study.

Solutions for SMDs

Utilities can avoid damage from solar magnetic disturbances in a number of ways, depending on their situation:

Retrofitting transformers with a neutral blocking and ground device—essentially a capacitor installed on the transformer's neutral that blocks the geomagnetically induced current before it reaches the transformer core. For shunt capacitor banks and static VAR compensators, relay settings can be changed to be less sensitive to voltage and current perturbations.

Specifying designs for new lines that include series capacitors on the conductors themselves. Installation of these capacitors on each phase of a line could provide effective protection for multiple transformers, while providing the additional advantage of reduced line impedances.

Altering operating practices when disturbances are expected. Utilities can back off on power transfers, reduce the overall system loading, and leave enough VAR reserve in the system to absorb the shock of an SMD.

Protecting transformers

A direct outgrowth of this pioneering work was an EPRI project to develop a device that could directly protect susceptible transformers from GICs. Again, the principal contractor was Minnesota Power & Light. A variety of active and passive devices were considered before researchers decided on using a capacitor in the neutral of a transformer to prevent GICs from reaching the core. Although capacitors allow ac currents to pass easily, they block the quasi-dc currents induced by magnetic disturbances.

Called a neutral blocking and grounding device (NB/GD), the protective electromechanical equipment had three major parts: a capacitor to block GICs, a pyrotechnically triggered spark gap to protect the capacitor from overvoltages due to faults, and a manual bypass switch. Each NB/GD unit was estimated to cost only $8000 (1983 dollars), with total installed costs of about $25,000.

Complete specifications for the NB/GD were developed, and a prototype model was built and successfully tested in the laboratory. Recently, EPRI initiated a project to reevaluate the NB/GD, taking into account advances in zinc oxide surge arrester technology. Researchers will consider the possibility of using this technology for capacitor protection instead of the pyrotechnically triggered switch, which would have to be rearmed each time it responded to a fault. They will also conduct field demonstrations of the NB/GD.

Some transformers are connected to

lines that already have series capacitors installed to provide reactive compensation. These transformers would not be affected by GICs, since the capacitors block direct current. Although the installation of such capacitors on each phase of a line could provide effective protection against the effects of SMDs for multiple transformers, this solution would generally be more expensive than adding a capacitor to the neutral of a single transformer.

EPRI has also sponsored experimental and analytical studies to determine more precisely the effect of GICs on transformer performance and reliability. This work, conducted by General Electric, initially indicated that transformer heating caused by induced currents should not result in permanent harm in a well-designed transformer. After the damage caused by the SMD on March 13, however, the industry has begun to reexamine the effects of GICs on power transformers.

"It's important to remember that these very large transformers are generally custom-designed," notes Robert Iveson. "Therefore, we need to find out whether the recent damage represents a generic problem or one caused by some factor unique to the individual unit affected. Although the failure mechanisms are not yet definitely understood, this appears to be the first time that geomagnetically induced currents are suspected of actually having damaged a transformer, and careful diagnostic examination by the parties involved is already under way."

Research challenges

Since the last peak of the solar activity cycle, about a decade ago, one relatively new type of power system equipment has come into much more common use—the static VAR compensator (SVC). This thyristor-controlled device can either support or reduce the voltage on a transmission line by shunting current through a capacitor or an inductor. One major advantage of SVCs over older devices is that, in addition to controlling steady-state voltage conditions, they can react quickly to mitigate voltage disturbances.

During the March SMD, several SVCs apparently experienced electrical stress. Because of the growing importance of SVCs, determining the possible effects of magnetically induced currents on them will receive high priority during the current peak of solar activity. EPRI has initiated a retrospective study of SVC technology to determine how such devices functioned during the magnetic storm and to assess damage that may have occurred. The information produced by this research can then be used by utilities to modify existing SVC controls and protective relays so that they react correctly to induced currents; it can also be used by manufacturers to incorporate protective features into future SVC designs.

"EPRI research completed since the last peak of the solar activity cycle has given our members the ability to analyze and control geomagnetically induced currents," says Stig Nilsson, program manager in the Electrical Systems Division. "None of our member utilities, however, has installed GIC-blocking capacitors because in 1979, when the device was developed, solar activity was ending its cyclic peak. We are now updating this research to see if the cost of the blocking system can be reduced. We are also exploring ways of improving the early warning system for solar magnetic disturbances, so that utility operators can better adjust generation patterns to prepare for the possible loss of critical circuits."

In addition to R&D initiatives already undertaken, several other research challenges have been raised by the growing concern over magnetic storms. One of the most insidious aspects of SMD occurrences is that overloads caused by harmonics and GICs may be reducing the life expectancy of some equipment without utilities being aware of it. Some utilities have detected carbon dioxide in the oil of their transformers since the March 13 SMD, which indicates that overheating has occurred. To help detect and ameliorate such silent damage, EPRI will establish a program that may allow member utilities to monitor induced currents and report results according to a prescribed protocol.

Forecasting improvements would also help utilities respond more effectively to SMDs when they occur. The Space Environment Sciences Center, for example, is considering a new reporting format that would predict geomagnetic activity in terms of easily understood probabilities. The current, 9-degree "K index" used to describe magnetic storms is strongly site-dependent and is not optimized for issuing real-time warnings. EPRI intends to cooperate with the North American Electric Reliability Council (NERC) to reassess the way SMD predictions are made and reported to utilities.

In order to pool the rapidly growing information in this field, EPRI will hold a seminar November 8–10 for member utilities concerned about SMDs. During this seminar, which is being organized by project manager Ben Damsky, EPRI will present results from recent research, and utilities will be invited to share their experiences from the March SMD. In addition, future research needs will be considered.

"As EPRI has matured, this kind of service approach to outstanding problems has become an essential part of our function," says Narain Hingorani, vice president, Electrical Systems Division. "Because the Institute has been conducting research on magnetic disturbances for many years, we have been able to respond quickly to our members' requests for help after the recent severe episode. Such help is not readily available elsewhere, and we've received outstanding cooperation from affected utilities and other agencies in both the United States and Canada." ■

This article was written by John Douglas, science writer. Technical background information was provided by Robert Iveson, Stig Nilsson, and Narain Hingorani, Electrical Systems Division.

MANAGING THE GASLIGHT LEGACY

… gas plant in Berlin around the … century. From Hans Kraemer, *Weltall und Mens*… 1902–1904)

The process used over a century ago to manufacture fuel for gas lighting has left today's utilities with a difficult environmental legacy. A recent seminar brought together top scientists from the electricity and gas industries to exchange ideas, information, and techniques for dealing with the wastes from long-disused manufactured gas plants.

Beginning around 1850, a generation before the start of the electric age, gaslight first illuminated America's streets and buildings, and it provided ready competition for Mr. Edison's new service for well onto a hundred years in some eastern cities. But the gas used then was not the natural gas we use today, which comes from underground formations and which only began to be widely transported in interstate pipelines in the 1950s. What fueled the gaslight era was coal and, to a limited extent in the later years, oil.

In well over 1000 plants, some small and some large—at least one of which could be found in nearly every town—gas was manufactured from coal and oil by any of several commercial processes, including a coke-oven method of carbonization. The most prevalent form of such manufactured gas, or town gas, as it was generically known, was made by alternately reacting coal or coke with air and steam in large, oven-like chambers.

The process produced a hot gas rich in hydrogen, carbon monoxide, and sulfur compounds. The gas's relatively low heating value was enriched to as much as 1000 Btu/ft^3—about the same as natural gas—by thermally cracking petroleum oils in it to add methane, ethane, or other light hydrocarbons.

Large volumes (even by today's standards) of manufactured gas were produced over the years at such plants, commonly known as the town gasworks, as cities grew and prospered. The gas plants also yielded large quantities of byproducts—complex mixtures of coal tars, sludges, and oils, and other chemicals from the early gas-scrubbing systems. Forerunners of today's petrochemical industries emerged around the turn of the century as ways were found to refine and process much of the coal tar into a variety of products, but substantial volumes remained on the sites where gas was manufactured.

Practices employed then to protect the environment not being what they are today, most residues were disposed of on site in pits, ponds, or landfills. Purifier boxes in which product gas was passed over iron oxides for sulfur removal also left behind ferrocyanide compounds, which display a characteristic Prussian blue color.

Some manufactured gas plants (MGPs) were converted to oil gas production in their later years and operated right up to the 1950s. But many were closed and demolished decades earlier. Most were owned by the corporate predecessors of today's gas distribution companies, many of which are now part of electric and gas utilities.

Over the last 10–15 years, utilities have been rediscovering the size of the manufactured gas industry as they attempt to redevelop real estate holdings or prepare properties for sale. The remains of some gas plants lie beneath what may now be utility substations or service yards. Other sites were abandoned—in some cases, forgotten—long ago, only to be remembered when new activity revealed evidence of wastes left in the ground.

Managing the investigation, risk assessment, and possible remediation of these manufactured gas plant sites has become an important issue for many utilities. Three such sites have been listed by the U.S. Environmental Protection Agency (EPA) on the Superfund National Priority List for cleanup, and five others are proposed for inclusion.

But for most sites there are few specific regulatory requirements. This is, in part, because of the typically low health risks posed by most sites, the many uncertainties surrounding the nature and extent of environmental contamination and the possible effects of remedial action, and the higher priority of other chemical waste sites of more-immediate concern to federal and state regulatory agencies.

But the potential for groundwater contamination with organic chemicals, the commercial value of many of the properties, and the strict liabilities imposed by hazardous waste laws are all factors that are causing utilities to carefully investigate and assess their manufactured gas plant sites and, where necessary, to develop remediation-restoration plans.

For several years, EPRI and the Gas Research Institute (GRI) have sponsored a series of technical studies in a coordinated R&D response to utilities' needs in MGP site management. The programs are a mix of applied and basic research designed to yield results of value and assistance to utilities in the near term, as well as long-term fundamental data for cost-effective and innovative MGP site characterization, risk assessment, and restoration strategies.

In a recent effort to share research results to date and outline ongoing work, EPRI, GRI, and the Edison Electric Institute brought together contractors, leading experts, and utility specialists for a two-and-a-half-day technology transfer seminar last April. The insights and experiences related there suggest that the issues posed by MGP sites from the utility industry's distant past can challenge the limits of current understanding of the behavior of chemicals in the environment and pose difficult choices about the best site management strategies.

Assessing the distribution of chemicals

The conference was organized according to the three major aspects of MGP site management: investigation, risk assessment, and site remediation-restoration. The investigative phase involves defining the boundaries of the waste materials and characterizing the nature and extent of chemical contamination of the soil and groundwater (and possibly surface water) at a site.

Risk assessment uses site-specific data in a quantitative evaluation of health risks arising from the various exposure pathways. Remediation-restoration options are evaluated to identify cost-effective site management strategies. These can run the gamut from waste removal by excavation, treatment of contaminated soils to remove or reduce concentrations of organic and inorganic chemicals (including passive remediation by natural microorganisms), on- or off-site treatment of groundwater, and possible new techniques to enhance biodegradation of waste components.

Because of scientific, technological, and regulatory uncertainties, the lack of commercial approaches or standard techniques for sampling and analysis, and other factors, site management can lead to substantial costs to utilities over time.

Much of EPRI's and GRI's R&D effort involves gathering the data and developing the methods and tools that can help utilities limit MGP site management costs. For example, GRI published a four-volume set of technical handbooks for MGP site management in 1987, documenting state-of-the-art methods for site investigation, risk assessment, and remediation-restoration.

Once a site investigation has begun, a multiphased approach that defines risk management and remediation objectives and uses screening techniques for fieldwork is the way to ensure that adequate information is available in the later phases, according to John Ripp of Atlantic Environmental Services. Ripp told the conference that the first task—a background evaluation—should determine the sources and pathways of contamination, the immediate threat, if any, to the surrounding population or environment, and whether there are nearby sources of contamination other than the MGP site.

For clues to how the gas plants were laid out—clues that, in turn, provide insight to the locations of contaminants—a good start is often an insurance map of a city prepared by the Sanborn Map Co., Ripp noted. The earliest of these fairly detailed maps, made for virtually all manufactured gas plants, were first drawn in the late 1850s; the maps were updated every 10–15 years. The Chicago Public Library has a complete set.

A preliminary walk-through or field investigation may include soil gas surveys and other tests for volatile or semivolatile organics in the ground, giving a quick idea of the possible presence or migration of organic compounds derived from the MGP wastes. A number of rapid sample screening techniques—including field extraction and fluorescent scanning—are under development to provide feedback to site investigators right away or within about a day.

Ripp discussed the requirements for detection and sampling of non-aqueous-phase liquids—unique, mostly heavier-than-water forms of coal tar found at MGP sites—which have the greatest concentrations of polycyclic aromatic hydrocarbons (PAHs), often the chief class of contaminants of concern. PAHs are fairly ubiquitous in the natural and man-made environments, but some of the hundreds of different PAH compounds are known animal and suspected human carcinogens.

Dennis Unites, also of Atlantic Environmental, surveyed the various waste types and categories. Besides PAHs, which account for 20–40% of the waste volumes, sites typically also contain smaller amounts of phenolic compounds and volatile, light aromatic hydrocarbons, various inorganic sulfur and nitrogen species (including some ferrocyanides), and small amounts of trace metals.

Residues in place at MGP sites are not regulated by name under hazardous

Investigating and Characterizing MGP Sites

MGP sites vary considerably in size, type of location, and extent of contamination. Many sites are distinguished by their large gas-holding tanks and the smaller vessels used in purifying the coal gas. The first steps in MGP site management include hydrologic, biological, and geochemical studies to determine the nature and extent of chemical wastes present in soil, groundwater, or surface waters. Such activity encompasses drilling wells and test borings for water quality sampling and analysis, as well as soil gas surveys. Samples may be analyzed in field laboratories, using techniques including gas chromatographic analysis. New technologies such as supercritical fluid extraction and microextraction are also being developed for field use.

▲ A typical site

Sample analysis by microextraction ▼

Supercritical fluid extraction apparatus ▼

▲ Groundwater well drilling

Field-model gas chromatograph ▼

Soil gas survey sampling ▼

waste provisions of the Resource Conservation and Recovery Act, the applicable federal law. But if they are moved off-site as part of remedial action, federal rules might apply.

Evidence from soil, sediment, and groundwater samples from about 10 MGP sites indicates that groundwater contamination at most sites is not extensive, according to Ishwar Murarka, program manager for land and water quality studies at EPRI. Murarka presented some results of ongoing analysis of extensive soil and groundwater data supplied by various utilities as well as from EPRI field studies. Among other things, the data show substantial attenuation—to fractions of a part per million (ppm)—in the levels of five key PAH compounds within a few hundred feet at most sites.

The big questions in assessing the extent of chemical contamination from MGP wastes relate to the foot-shaped plume that may extend through the soil and groundwater, Murarka explained. How deep is it, and how far out does it go? He described the many mobilization and transport processes that can release waste compounds and distribute them away from sites, including solubilization in water, volatilization to the vapor phase, biotransformation by natural microorganisms, and dispersion by moving water.

"Some of the same environmental processes that carry wastes away from a site also tend to remediate the situation over time," Murarka noted. Greatly improved scientific understanding of the distribution and mobility of chemicals in MGP wastes, as well as of other utility wastes, is expected to come from a comprehensive series of EPRI research projects on the environmental behavior of organic substances.

The importance of locating buried waste sources and mapping their plumes in soil and groundwater was highlighted in a presentation on EPRI-funded work that extensively characterized an MGP site. Barbara Taylor, of Cambridge Analytical Associates, described the conventional and innovative techniques for sampling and analysis used directly at the site. For insights into the release, transport, and transformation of organic chemicals from MGP wastes, Cambridge Analytical Associates and Atlantic Environmental Services conducted state-of-the-art hydrologic and geochemical investigations. Limited microbial studies were also performed at the site by a team from Cornell University.

Taylor noted that measured concentrations of naphthalene, a semivolatile organic, served as an indicator of how far a plume may travel and how thick and wide it may become. On-site analysis of soil and groundwater samples in a lab trailer during the project turned out to cost only about a fifth of the estimated cost of shipping and analysis at a commercial laboratory, besides giving almost immediate results, according to Taylor. Low-cost and quick results for sample analyses are key needs for MGP site investigations.

One of the field screening techniques on which EPRI and GRI have sponsored work—a soil gas survey to detect volatile organics as a means of predicting locations of soil or groundwater contamination—has been used at a number of MGP sites with mixed results.

The technique, which detects volatile organics in subsurface gas, involves forcing a ½-inch-wide slotted venting column about 4 feet into the ground. Gas collected from the column is analyzed with a portable gas chromatograph (GC), the signatures from which can be used to distinguish, for example, between tar and petroleum product contamination. Atlantic Environmental's Carol Roberson suggested that gas surveys are most valuable and accurate in indicating contamination when soils are dry, where they have a high permeability and a low organic carbon content, and where barriers (such as paving) help confine the material being targeted.

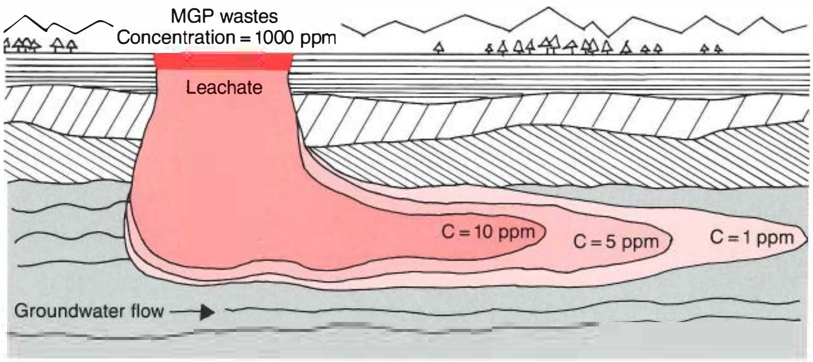
For determining concentrations of PAH compounds in soil samples, Marvin Dudas of the University of Alberta reported the promising use in the field of a technique employing supercritical fluid (carbon dioxide) for extracting samples, followed by GC analysis. This approach is far quicker and less expensive than, and almost as accurate as, EPA-specified procedures. Developed by Battelle, Pacific Northwest Laboratories under EPRI sponsorship, the technique can be readily adapted to field use, unlike conventional methods.

Data from soil and groundwater samples can be extensive, and their interpretation, taking into account chemical-specific properties, can be a major analytic undertaking. Steven Gherini, of Tetra Tech, explained that a powerful EPRI software tool (first released in 1986) for predicting the movement of compounds in groundwater has recently been enhanced to aid utilities in MGP site investigations. MYGRT, a PC-based solute migration simulation model, was originally developed for inorganics and metals.

MYGRT Version 2.0 incorporates advection, dispersion, chemical retardation, and biodegradation processes to account for movement or disappearance of organic compounds in groundwater. Some of the key data needed for using the model are available in EPRI's extensive database of chemical properties, thermodynamic constants, sorption constants, and biotransformation rates for 53 key organic compounds.

Predicting the Movement of Chemicals in Groundwater

A key aspect of MGP site characterization is assessment of the extent of, or the potential for, leaching of waste compounds into groundwater. An important EPRI screening tool available to utilities for such assessments is MYGRT Version 2.0, a PC-based model for predicting the movement and concentrations of solutes in groundwater over time. Originally developed for inorganic chemicals associated with coal ash landfills, MYGRT has been enhanced with an extensive database of organic chemicals of interest in MGP site studies. Analytic results from MYGRT can become input for a more comprehensive site risk assessment using the EPRI SITES model.



Evaluating MGP risks

After site investigation and characterization work is performed, but prior to any remedial action, a careful analysis should be made of possible health risks, if any, to the public from MGP residues. Not only does risk management represent a more objective and quantitative means of assessing the relative magnitude of possible health risks and of comparing options for dealing with them, risk analysis can also provide a defensible, systematic decision basis for site remedial actions and help hold down those costs.

Atlantic Environmental Services' Charles Menzie outlined the four major elements of a risk assessment. Hazard identification, usually begun during site characterization, determines what chemicals are present. An exposure assessment analyzes the various pathways (groundwater, soil, fish, etc.) for both current exposures as well as those that might occur under different conditions. A dose-response assessment relates the potential toxicity or carcinogenicity of the waste constituents to the incidence of possible human health effects. These factors are then used to quantitatively derive a risk characterization that is an estimate of the expected incidence of an adverse effect among all those potentially exposed.

Quantitative risk estimates can be calculated for both health effects and environmental impacts. They may include estimates of yearly effects or of individual lifetime risks. For example, the EPA uses a lifetime cancer risk criterion for exposure to toxic chemicals of anywhere from 10^{-7} to 10^{-4}, depending on specific circumstances. Within this range, a risk level of 10^{-6} is often used as a benchmark for decision making. This risk level would mean less than one fatal cancer could be expected among a million individuals exposed over their lifetime.

Only a handful of sites have been the subject of significant remedial or restoration work to date, but the experience base with risk assessments extends to over 20 MGP sites, said Menzie. From those cases, Menzie summarized key lessons regarding exposure pathways, land use, imminent hazards, and critical MGP chemicals and their properties.

There are several pathways through which MGP chemicals can reach humans. Only a few may be applicable at a given site. According to Menzie, groundwater contamination is usually not a major source of health risk because the water that may flow beneath a site typically is not a local source of drinking water. Still, the few MGP sites on the EPA Superfund list were proposed because of groundwater contamination. But according to EPRI's Ishwar Murarka, experience at MGP sites so far indicates that, from a human health standpoint, groundwater contamination may be only a minor concern.

Regarding another potential exposure pathway—the infiltration of volatile organic vapors into nearby buildings through the ground—little is known. Contamination of riverbed sediments with MGP chemicals and bioconcentration in fish are presumed to be important exposure pathways, although high levels of PAH compounds have not been found in most local fish at sites where MGP wastes have entered aquatic ecosystems.

Among other lessons: Planned and future uses of the land at MGP sites are key factors influencing exposure risks. Imminent health or environmental hazards tend to be rare, but if there is tar seepage into water bodies, the problem can become highly visible. For risks to be present there must be exposure, but most MGP tars are buried, are bound to soils, and are unavailable to typical exposure paths, unless and until construction or remediation activities provide a new path.

Some MGP chemicals are more important in risk assessments than other compounds. A few PAH compounds in soils can represent a chronic cancer risk that dominates a quantitative risk analysis and also drives site remediation planning. But volatile organics can also pose chronic risks from drinking and inhalation; these chemicals are the focus of concern over groundwater.

Certain other chemicals, particularly some aromatic hydrocarbons, such as naphthalene, may pose no health hazard, but their odors—noticeable at soil concentrations as low as 5 parts per billion (ppb)—can cause aesthetic problems and public concern. The cyanide wastes are not thought to pose an imminent hazard because of their fairly stable, insoluble chemical forms.

Still, conceded Menzie, more and better information is needed about the actual health risks of some MGP waste compounds. The kind of detailed dose-response toxicity and carcinogenicity data needed to complete a risk assessment are not available for many MGP chemicals, and conservative assumptions typically are made in the absence of such information. But help is on the way.

Ronald Wyzga, EPRI program manager for health studies, described plans for a major toxicity study of MGP wastes. The project will evaluate the toxicity of source materials and soils containing various concentrations of PAHs. It will also assess the effects of soil matrix and route of exposure on the bioavailability of MGP wastes and of benzo[a]pyrene.

Although benzo[a]pyrene is often used as a surrogate for all PAHs, there are few toxicity data that are entirely appropriate for applications in risk assessment. For example, many data are based on less-than-lifetime exposure to very high levels in mice—a protocol that is likely to result in higher risk estimates than would be obtained from a conventional lifetime exposure experiment, said Wyzga.

A two-year, chronic, whole-animal bioassay in mice is being planned to generate data suitable for estimating cancer risks. Plans include a comparison of the toxicity of MGP wastes with the toxicity of benzo[a]pyrene alone. In this way, the potency of the mixture relative to that of a single potent component can be assessed, and the role of benzo[a]pyrene in the mixture's overall toxicity can be determined.

Since EPA is considering regulatory action based on the levels of benzo[a]pyrene in drinking water, the planned bioassay is both timely and important. Major results may be available by 1993. "We've launched a program that we believe will significantly reduce the uncertainties in estimates of the health risks of MGP wastes," Wyzga added.

As Wyzga noted, better toxicity information can only lead to more-accurate and more-credible risk assessments. Indeed, one of the uses of a site risk assessment is to help utilities set priorities among multiple sites. Kurt Runke of Decision Focus noted that many utilities with MGP sites have more than 10 each. Staff and budget limitations usually mean that they cannot all receive the same level of attention simultaneously.

Runke described two new priority-setting tools being developed for EPRI to help utilities evaluate future actions at MGP sites. One, the site-screening and priority-setting system, is based on EPA's hazard ranking system for scoring site characteristics to give a quick estimate of relative risks on a computer spreadsheet program. It has been tested on 29 site cases so far and has helped develop coherent priorities from a diverse array of sites, said Runke.

The other, known as simplified risk analysis, is a shortcut method for use at the start of a site study, when only limited data are available. But it incorporates more information than the site-screening system does, and it analyzes individual exposure pathways to estimate levels of risk to individuals and groups. The methodology has not yet been implemented as a software program.

Both tools, ultimately, are only parts of an assortment of techniques that can help utilities choose a course of action for one site or for several. EPRI's Victor Niemeyer detailed the powerful, integrating capabilities of SITES, a computerized decision-support model that can help utilities organize and make effective use of all the relevant information on an MGP site.

As Niemeyer described it, SITES can take into account the many uncertainties in key analysis variables; rapidly perform complex calculations; estimate in detail the exposures, risks, and costs of remedial options; identify the key contributors to risks; and determine which remedial actions are warranted to control them. Analyses using the model, some of which were included in submissions to regulatory agencies, have been conducted at eight MGP sites.

In some cases the SITES framework identified increased risks from remedial work, but generally it found risks to be low. Isolation of waste in its current location was usually identified as the most cost-effective management option. EPRI plans similar analyses of a larger data set using SITES, as well as development of additional methodologies as part of a package that will directly support utility risk analyses.

Besides insight into remedial options and costs, one likely use of information from an MGP site risk analysis is in communicating with the public. "If you have an MGP site, you will definitely be asked to communicate the risk of that site to the public," said Bruce Rasher of Consumers Power, who presented a case study of how the Michigan utility communicated with various audiences about one MGP site a few years ago.

EPRI's Chris Whipple presented results of some recent work to apply improved communications techniques in discussing MGP risks with the public. He and Steven Swanson of Clement Associates also discussed current EPRI-funded development of a state-of-the-art utility handbook on risk communication, expected to be completed next year.

Remediation of MGP sites

Once a site has been substantially investigated and characterized, the risks it poses may warrant the treatment of both organic chemicals (in tars and sludges) and inorganic chemicals (from the gas purifiers) in soil as well as in groundwater. GRI has documented several technologies in its technical guides. GRI and EPRI, meantime, are investigating a wide range of both near-term and long-term alternatives for treatment of MGP wastes.

The key to holding the line on the cost of remedial work is to have conducted sufficient site investigation and sampling, as well as risk assessment, in advance. Detailed knowledge of the site, especially what is happening underground, provides a basis for targeting and limiting excavation and treatment.

To address contaminated soils and groundwater at MGP sites, a hierarchy of restoration strategies is called for, according to David Nakles, of Remediation Technologies. The hierarchy addresses the most important exposure pathways and usually begins with removal of the wastes in gas holders, excavation of contamination hot spots identified, or capping the ground over parts of a site. Then the work may shift to limiting off-site waste migration in groundwater by various methods, including construction of slurry walls and other containment or pump-and-treat techniques. At the bottom of the hierarchy comes *in situ* or extended treatment of contaminated soils, including thermal, biological, and physical-chemical treatment technologies to remove tars or inorganic contaminants.

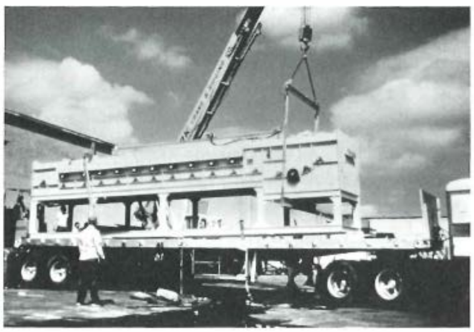
Some hydrocarbons from highly contaminated soils and sludges can be processed for use as boiler fuel, reducing waste volumes and saving some of the expense of disposal, said Nakles. Incineration is an expensive, although effective, treatment option. Biological treatment and soil washing offer potentially lower cost, but perhaps also lower treatment efficiencies. Groundwaters or surface waters with moderate contamination can be disposed of at a public water treatment works or treated using biological and chemical processes, leaving them suitable for use on-site. GRI is presently studying this option closely.

Innovative technologies are being developed for the higher-volume MGP wastes. One, using finely ground coal to agglomerate slurried tar wastes and remove the hydrocarbons from lightly contaminated soil and gravel, has been under development by the Alberta Research Council in Canada for a consortium including EPRI and several U.S. utilities. EPRI's Conrad Kulik reported encouraging results from a 6-ton/day pilot plant near Alberta and described plans for a 100-ton/day mobile unit.

Options for Remediating MGP Sites

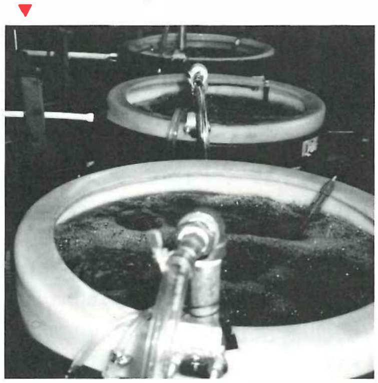
A risk assessment may support a decision to remediate an MGP site. A hierarchy of remediation options includes removal or containment of the immediate source of contamination, involving excavation and soil treatment. The leachate plume that may extend beneath the original waste material may require soil and groundwater removal and treatment. Contaminated groundwater some distance from a site may also be pumped and, possibly, disposed of at a public water treatment works. Natural processes also tend to reduce chemical concentrations in soil and groundwater over time. Potentially lower-cost remediation options being pursued by EPRI and others include techniques to promote biodegradation of wastes by natural microorganisms, low-temperature thermal treatments for removing organic contaminants from soil, and physical treatment options, including coal agglomeration. The latter technology uses ground coal in a slurry to separate hydrocarbon material from soils contaminated with tar wastes.

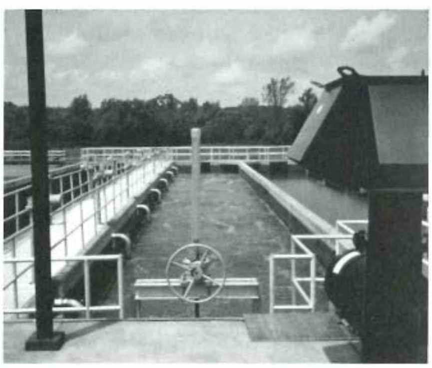
▲ Source removal by excavation



▲ Pilot thermal desorption unit

Groundwater treatment ▼





▲ Municipal water treatment plant

Enhanced on-site bioremediation ▼

Tar waste agglomerate ▼

Operating since mid-1988, the pilot plant has successfully recovered as much as over 99% of the hydrocarbons from raw MGP waste materials. The process has reduced levels of coal tar in sandy soils from 6% by weight to about 600 ppm; indications are that even more complete removal is possible. "This is a major advance for a process that can handle the diverse waste mix typical of MGP sites," said Kulik.

The agglomeration technology is expected to cost less than $100 per ton of contaminated soil, but that will be better defined with the 100-ton/day prototype mobile unit the consortium plans to begin building next year and hopes to have ready for commercial use in 1992. If all goes well, the unit could travel to various MGP sites and treat wastes on-site.

Another alternative to incineration of contaminated soil is thermal desorption, in which soil is heated in a kiln to separate the wastes. The promise of greater throughputs and shorter residence times than with incinerators is the basis of hope for reduced treatment costs. Richard Helsel of International Technology, a leading chemical waste management firm, reported good results with a pilot-scale, indirectly heated rotary desorber. IT's unit managed to reduce PAH levels in different MGP soils to as low as 10 ppb by heating the material to 300–400°C for 10–20 minutes. In some instances, the process also effectively removed cyanide compounds.

For groundwater contaminated with MGP chemicals, there has been concern that site remedial work could require pumping large volumes that might themselves present disposal problems. But pilot tests using activated sludge reactors indicate that MGP groundwaters can be effectively cotreated with municipal waste waters at publicly owned treatment works, according to Andrew Middleton of Haniel Environmental Services.

As long as the groundwaters from MGP sites are less than 5% of the treatment works' influent, there should be no impact on operations or treatment quality, said Middleton. Treatment of higher proportions may be limited by levels of volatile organics or the accumulation of certain PAHs in the treatment process sludge, but pretreatment of the contaminated groundwaters could make them acceptable at municipal facilities.

The search for a superbug

Conferees heard a number of presentations on a new and exciting category of possible site remediation methods. Because natural soil microorganisms are known to eat some hydrocarbon molecules, there are high hopes that biological remediation could offer the most cost-effective methods of cleaning MGP sites. Some of these methods have been successfully used by the creosote industry to treat contaminated soils.

Edward Neuhauser of Niagara Mohawk Power reported the results of work performed for the utility to evaluate the potential of aerobic and anaerobic biodegradation of PAH compounds in soil. From mixed results came a conclusion that solubility in water plays a key role in whether PAHs in soils will rapidly biodegrade.

John Smith of Remediation Technologies, the utility's contractor in that case, explained the current theory of the adsorption-desorption processes that solubilize some PAHs and thus make them amenable to biodegradation.

"The hypothesis we're coming to is that biodegradation will only occur if the PAHs can get into the bulk water phase," said Smith. The heavier the molecular weight of a PAH (the more rings in its chemical structure), the less able it is to solubilize and be biotransformed by microorganisms. GRI is funding experiments to develop a model and protocol to predict when PAHs in different soils will biodegrade.

There are promising techniques to accelerate biodegradation, as discussed by Vipul Srivastava of the Institute of Gas Technology. "These organisms are pretty

Utility R&D for Manufactured Gas Plant Sites

To address the needs of utilities in managing manufactured gas plant (MGP) sites, EPRI and the Gas Research Institute (GRI) are coordinating a series of research and development projects spanning the three primary aspects of site management.

SITE INVESTIGATION

This work focuses on sampling and analytic techiques for characterizing MGP sites. GRI has documented current techniques. EPRI is sponsoring a comprehensive program on the environmental behavior of organic substances (EBOS) to describe the distribution and movement of MGP waste constituents. Both groups have projects under way to extend the state of the science on waste chemical migration and transformation.

Waste characterization

- Contaminant leaching potential of hydrocarbons and some metals (EPRI)
- Chemical characteristics of typical site odorants and cyanides (GRI)

Rapid field measurement of semivolatiles

- Development of supercritical fluid extraction and microextraction techniques (EPRI), and of fluorescent scanning and soil gas survey techniques (GRI)

RISK ANALYSIS

Here the emphasis is on developing risk analysis and management methodologies, chemical-specific databases, and exposure and dose-response data needed to better estimate the risks associated with MGP sites and to select effective management strategies.

Methodologies

- Computer model (SITES) for consolidating source term, transport and fate, and dose-response information for risk management (EPRI)
- Site screening and prioritization system and simplified risk analysis approach (EPRI)

Chemical databases

- Development, through the EBOS project, of specific information on 53 MGP waste chemicals for estimating their environmental mobility potential in soil, groundwater, and surface water (EPRI)

Dose-response data and models

- Bioavailability of contaminants in the soil matrix (EPRI, GRI)
- Overall toxicity assessment of MGP wastes, including a chronic, whole mammalian bioassay for cancer risk data (EPRI)

SITE REMEDIATION-RESTORATION

Sites may require treatment of organic and inorganic chemicals in tars, sludges, contaminated soils, and groundwater. GRI and EPRI are investigating several near- and long-term alternatives.

Recycling of hydrocarbons as fuels

- Processing of tars to produce liquid (GRI) and solid fuels (EPRI)
- Combustion tests of waste-derived fuels (EPRI)

Thermal treatment

- Fundamental studies on desorption of organics from soils (GRI)
- Bench- and pilot-scale thermal desorption tests on MGP soils (GRI)

Biological treatment

- Soil treatment and composting and enhanced microbial degradation (GRI), molecular microbial ecology of PAH-degrading microorganisms, and *in situ* biological treatment (GRI, EPRI)
- Cotreatability of MGP groundwater with municipal waste water and treatment in biological reactors (GRI)

Physical-chemical treatment

- Soil and sludge stabilization and immobilization, soil washing for organic contaminant extraction, and *in situ* extraction (EPRI, GRI)
- Groundwater treatment with sand filtration, air stripping, and oxidation-ozonation (GRI)

capable creatures, but sometimes they need help," said Srivastava. "If you give them enough help, they will increase the biodegradation of PAHs." The techniques tested by IGT in the laboratory include the use of bioemulsifiers to increase waste solubility, chemical oxidants or biologically produced chemicals to improve the bioavailability of certain waste compounds to the microorganisms, and PAH-degrading enriched cultures and intermediate enzymes.

The field of genetic ecology offers the potential for actually manipulating the genes of soil microorganisms to increase their density and the efficiency with which they eat PAHs. EPRI's Robert Goldstein, who is managing exploratory research in pursuit of such approaches, surveyed the factors affecting the occurrence and abundance of degradative genes and strategies to amplify *in situ* their abundance in the indigenous organisms.

The ultimate goal is a means of biologically treating MGP wastes in the ground. Early laboratory work under way at the University of California at Irvine holds promise, said Goldstein. Several utilities and federal agencies are cosponsoring the research. Results so far have shown that "the genes necessary have always been present in organisms found in the wastes and that we can manipulate the density and expression of them through environmental factors," he added.

Specific genetic systems to degrade the heavier PAHs (those with three or more rings) have yet to be identified, however. But Goldstein said there appear to be no overwhelming obstacles to eventual success, and he speculated that methods to stimulate the microorganisms of interest could be developed and be in use at MGP waste sites within five years.

What might also be available by then is a kind of dipstick that could probe for the desired genes in soil microorganisms and indicate the potential for biodegradation, according to James Blackburn of the University of Tennessee. Blackburn described promising work at UT funded by GRI to develop protocols and methods for optimizing the biological processes of interest. He leads a team of researchers using microbial systems analysis and gene probe technology to try to understand the mechanisms of the biodegradation process for purposes of process design, optimization, and scale-up.

Steven Aust, of the biotechnology center at Utah State University, reported partially successful tests using white rot fungus (*P. chrysosporum*) to biodegrade coal tar and creosote-contaminated soils. By a process involving an oxidative enzyme, the fungus is able to mineralize a variety of environmental pollutants that are otherwise difficult to solubilize or adsorb, said Aust.

In the meantime, more-conventional bioreclamation techniques are already available and are planned for application at an MGP site. Peter Sawchuck of Keystone Environmental Resources summarized work at the site, where a combination of groundwater containment with trenches and *in situ* subsurface anaerobic bioreclamation using nutrient addition has been selected.

The approach provides a permanent, relatively low-cost solution that is compatible with planned commercial development of the property, he explained. Although the installed system will cost over $1 million, not including remedial investigations, it may allow the site owner to avoid having to do full groundwater treatment for over 30 years, Sawchuck added.

Another success story in site restoration was reported by James Lingle of Wisconsin Electric Power. Lingle recounted the site's history and the series of investigative and remedial steps that led to its reuse as the location of a restaurant.

Utilities taking the initiative

Representatives of several utilities spoke at the conference of their companies' experiences with one or more of the various aspects of MGP site management: investigation and characterization, risk assessment and communication, or site remediation and restoration for reuse. The details of each of those experiences are less important, perhaps, than the general messages that seemed to come through—among them, that utilities in general are not waiting for specific regulatory mandates to take steps to properly manage MGP sites.

Utilities are working in consultation with appropriate regulatory agencies to assess the risks of MGP sites and determine and implement cost-effective remedial measures where necessary. But utilities also must be cost-conscious: the time needed to evaluate and restore sites and the number of sites that exist indicate the necessity of a rational prioritization of steps based on relative risks. Likewise, utilities are not anxious to pioneer new and perhaps also costly remedial technologies, but their willingness to spend significant sums to isolate and contain and even to restore sites has been demonstrated.

In the long, historical view, utilities are writing the final, positive chapters in a sometimes unpleasant history of an energy form that heated and lighted America's first century and was a forerunner to today's modern coal gasification technologies. Remnants of the gaslight era are today becoming examples of utilities' environmental stewardship. ■

Further reading

Chemical Data for Predicting the Fate of Organic Compounds in Water, Vols.1–2. Final report for RP2879-2, prepared by Tetra Tech, Inc., June 1989. EPRI EA-5818.

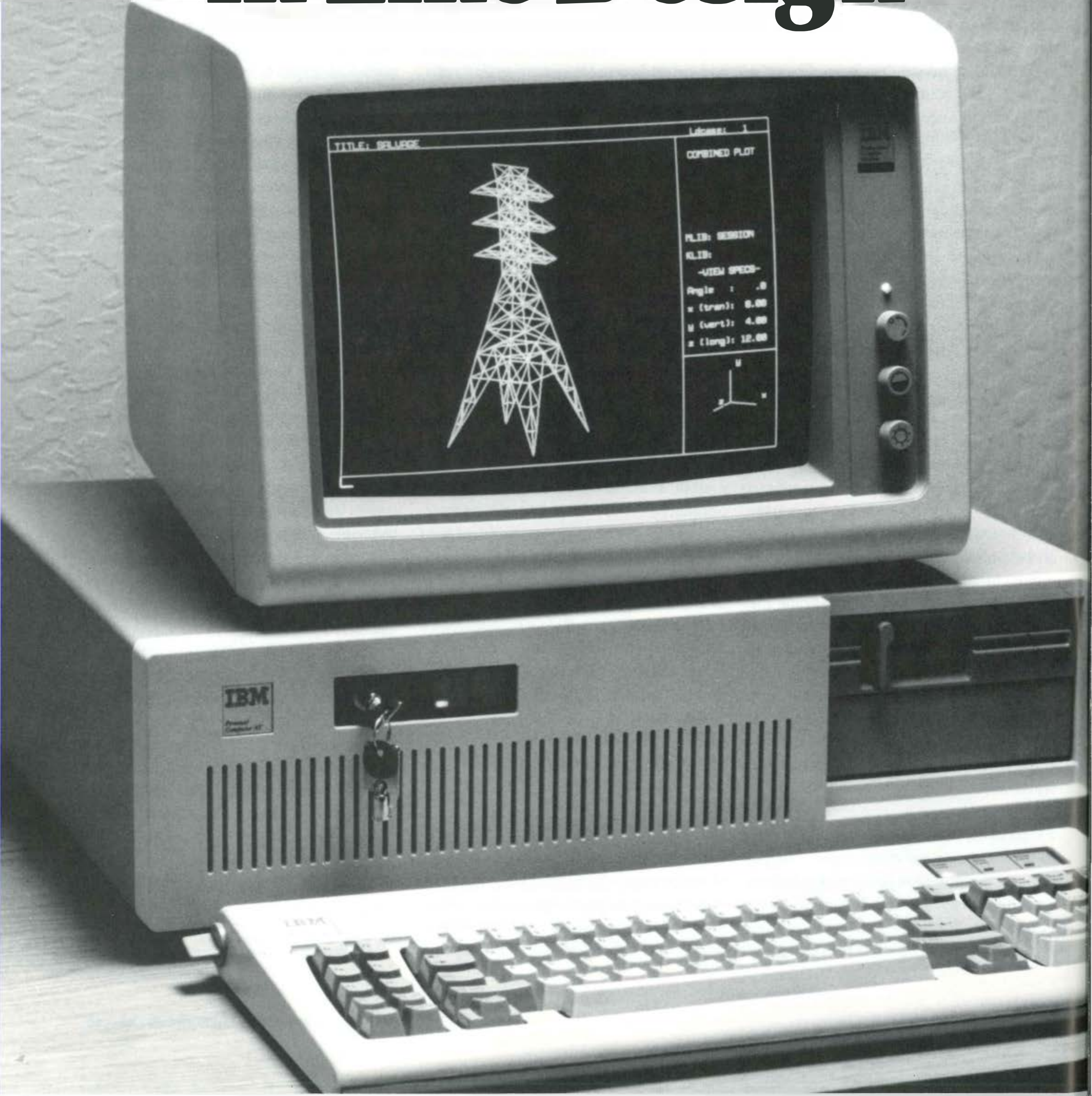
Screening of Contamination Potential and Site Cleanup at Manufactured Gas Plant and Pole Treatment Sites. Final report for RP2634-1, prepared by CH2M Hill, March 1989. EPRI EN-6213.

Gas Research Institute. *Management of Manufactured Gas Plant Sites,* Vols. 1–4. 1987.

Edison Electric Institute. *Handbook on Manfactured Gas Plant Sites.* September 1984.

This article was written by Taylor Moore.

TLWorkstation
Expert Assistance in Line Design



Now in use by over 100 utilities nationwide, the TLWorkstation software program offers engineers a sophisticated, PC-based design tool that covers virtually all aspects of a transmission line project.

A decade ago, heavy rains and melting snow swelled the Salt River in Phoenix, Arizona. Torrents of water spilled from the dams and raged over the normally dry riverbed, toppling power lines and flattening bridges. While the flood was the worst in the recent history of the river, engineers at the local utility soon learned that it wasn't unusual: the next winter the river offered a repeat performance.

With the unpredictable yet powerful nature of that river in mind, engineers for the water and electric utility, the Salt River Project, knew they were in for a challenge when it came time, years later, to plan a new, 230-kV line that would slice across the meandering river banks and supply more power to Phoenix. But with the help of a software package developed by EPRI, they finished the project with confidence and saved about $1 million.

That software package, EPRI's TLWorkstation,™ is designed to help utility engineers through every step of transmission line design, from selecting appropriate lattice towers to computing the magnetic fields of overhead conductors. Since the release of the first official version three years ago, many users—like the Salt River Project engineers—have reported substantial savings in time and money. Recently, EPRI released the first phase of a new, advanced version of the software, designated 2.0. Utility engineers say it is even more user-friendly than past versions. Phase two of version 2.0 is expected to be released by the end of the year.

For many utilities, TLWorkstation helps tap unused potential in existing transmission lines. But for others, like the Salt River Project, the software helps develop entirely new lines that are more economical and stronger than past designs. For the Salt River engineers, the challenge was to design foundations that could succeed where others had failed. Aside from withstanding the forces of wind and wire tension, these concrete piers had to hold up against the impact of the Salt River, which gushed at a rate of 200,000 cubic feet per second in the 1979 flood. Using TLWorkstation's foundation design and analysis module (MFAD), the engineers discovered they could opt for smaller-diameter poles made from thicker steel plate. This in turn cut down on the diameter of the costly concrete piers, some of which ran as much as 90 feet deep in areas prone to soil erosion. Overall, engineers were able to reduce foundation diameters by up to 2 feet and pier depths by up to 10 feet. While the initial investments in special-order poles and geotechnical and engineering costs tallied $200,000, the effort clearly paid off—producing net savings of $980,000.

Few utilities knew of TLWorkstation when the Salt River Project designed those foundations, but the software's use has spread rapidly in recent years. It is now being used at more than 100 utilities nationwide. Numerous consultants are also familiar with the software. Some, like Paul Rice, a project engineer with Commonwealth Associates of Jackson, Michigan, have even joined TLWorkstation user groups in an effort to keep up with the new technology.

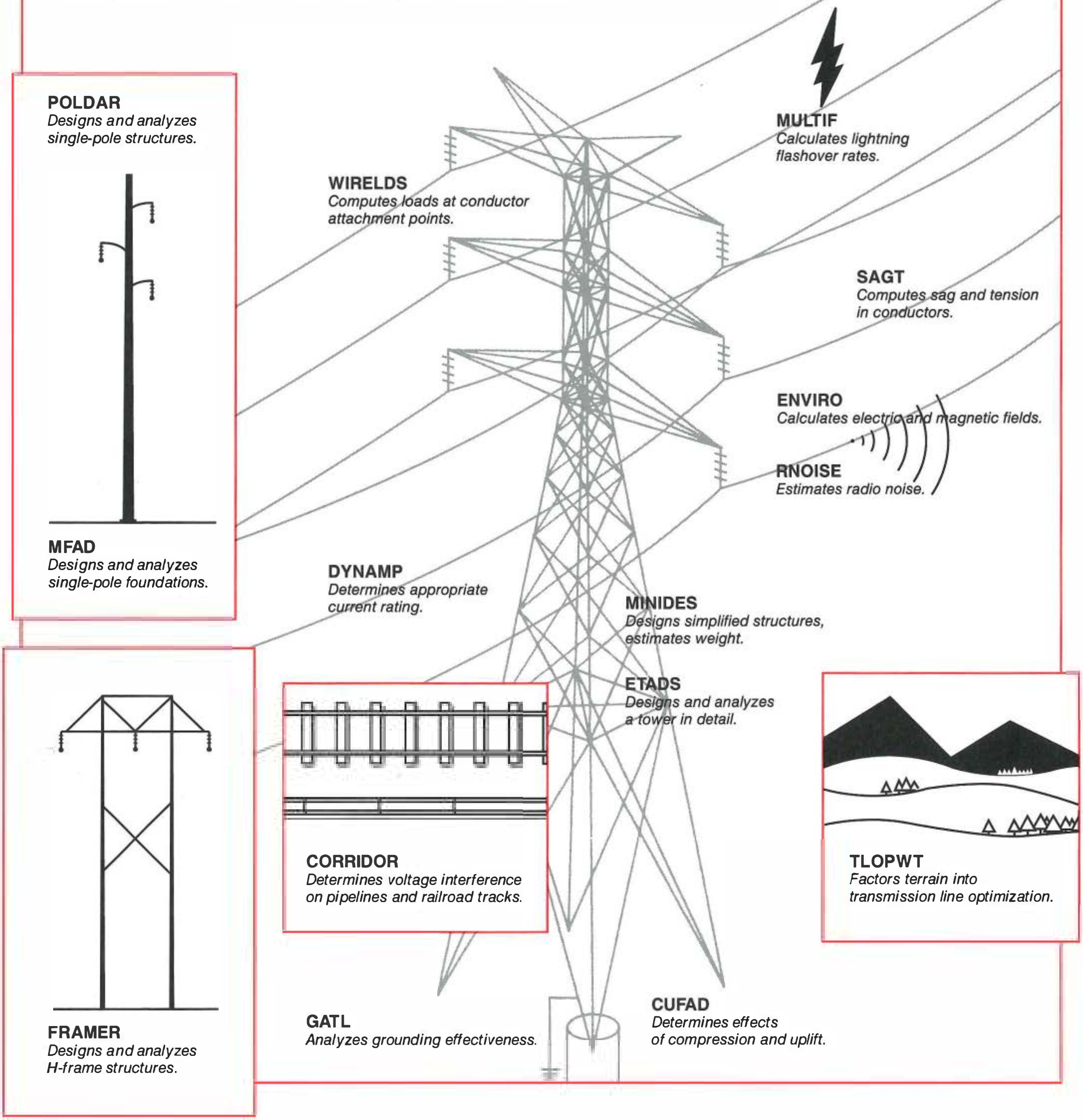
"As a consultant, if you don't have TLWorkstation and aren't able to use it, you're going to get left behind," Rice says. "We are trying to get more experienced with the program. More people in the industry are talking about TLWorkstation and using it as a benchmark." As Rice points out, TLWorkstation is helping reduce duplicated efforts among numerous consultants and utilities who have developed their own programs over the years. Some consultants say they now abandon their in-house computer programs in areas where TLWorkstation's capabilities overlap.

"As TLWorkstation programs have come out, we've used our in-house programs less and less," notes Ken Simpson, senior project engineer with Sargent & Lundy. "I'd say it's becoming sort of a de facto industry standard." Sargent & Lundy, a consultant to EPRI on various stages of TLWorkstation's evolution, has its own mainframe computer program to design transmission towers. But in a recent job for Public Service of Indiana, the consultant used TLWorkstation modules TAG and ETAP (now combined in the ETADS module). The task was to model and analyze several transmission towers to determine whether they were capable of handling a fiber-optic cable for MCI Telecommunications. When the project was complete, Sargent & Lundy delivered the models to the utility on floppy disk. "What TLWorkstation has allowed us to do is open up a line of communication with consultants and talk on the same wavelength," says Dan Fleck, a senior transmission engineer at PSI. "It's a common bond because we have one program."

To Fleck, the benefits of having used the

Software That Does It All

TLWorkstation's 16 task modules help utility engineers through every aspect of transmission line design, from detailing complex lattice towers to estimating radio noise. The recently added project input module (PIM), not shown here, makes the package more convenient to use on multitask projects by pulling common data from separate modules together into one file.



software are not necessarily over. "If in the future the towers require additional analysis, we will not have to model them again, but just add in the loads and run the ETADS program." To model or build a lattice tower on the computer, an engineer actually draws it on the screen. Each angle must be documented. Factors like the weight of the wire, the strength of the wind, and ice on the lines all play a role in determining that structure's capacity to hold another line. Modeling just one complex tower could occupy up to 40 man-hours, by Fleck's estimate.

Designed for the industry

TLWorkstation has been created exclusively for the use of utility engineers designing transmission lines. Many users have found this a key benefit. While other available software programs, like NASTRAN and STRUDL, focus on generic engineering concerns, TLWorkstation takes the specific details of transmission line design into account. "Utility structures are so different from many others that they require even more complex and sophisticated analysis software," says Richard Kennon, manager of EPRI's Overhead Transmission Lines Program. For instance, Robert Kondziolka, senior engineer for the 230-kV line that cut across the Salt River in Phoenix, says that MFAD was the only available program able to calculate nonrecoverable deflection—the amount a foundation fails to rebound after it is "loaded" by the impact of wind, wire tension, and rushing water. Knowing the nonrecoverable deflection was essential to minimizing the diameters and depths of the piers.

Another phenomenon of concern unique to transmission line design is uplift, or the tendency for two legs of a four-legged tower to lift from the ground in high winds. Simultaneously, the remaining tower legs are compressed. Other design methods take into account general concerns like soil conditions, installation methods, and tower loadings; but only TLWorkstation offers a module, called CUFAD, specifically geared toward the problems of uplift and compression.

The industry-specific nature of TLWorkstation also helps smooth communication between engineers. "Because TLWorkstation has been developed for the power industry—for utilities like us—it uses the right terminology and provides the right documentation needed for files," Kondziolka says. Communication between the user and the system is also improved.

"What TLWorkstation has done," says Paul Lyons, project manager at EPRI, "is to take the most sophisticated methods we can find out there and put them in such a form that communications with users employ terminology they're accustomed to using. When the computer talks about a structure, it's a lattice tower, not a building. The user doesn't have to translate."

Backed by field tests

Users say they can rely on TLWorkstation because its parameters are based on field tests. "Each TLWorkstation task module is the result of the latest technology, whether it be geotechnical engineering, structural analysis, electromagnetic interference, or corona and field effects," Kennon notes. "Many task modules contain new computational methods or algorithms, and all have been confirmed with full-scale tests and field measurements."

Structural tests on full-size transmission towers are performed at the Transmission Line Mechanical Research Center in Haslet, Texas. "Everything we've done has been proved in real life—in living color!" Kennon says, pointing to a photograph of the plant on the wall beside his office desk. At the 208-acre design laboratory, transmission towers are shaken and yanked. Weather conditions, material durability, and strength under stress are all taken into account. As a supplement to this mechanical research, another EPRI facility, the High-Voltage Transmission Research Center in Lenox, Massachusetts, focuses on electrical tests, measuring phenomena like radio noise with sophisticated equipment.

By contrast, the validity of other new software programs is in many cases measured against accepted standards or against software packages that have been around for years. But research behind TLWorkstation has even proved some of these standards wrong. For example, Kennon says, a handbook that utilities had relied on for years claimed that induced voltages on pipelines or railroad tracks in a shared corridor would be highest at the midpoint between such discontinuities as sharp turns and insulators. EPRI research disagreed. The TLWorkstation module for assessing this kind of voltage interference (CORRIDOR) showed that the voltage would be highest at the points of discontinuity, not between them. Moreover, according to CORRIDOR, the handbook's voltages were 10 times too high. To be certain, EPRI measured induced voltages on a natural gas pipeline that runs parallel to a Southern California Edison line for 50 miles. Sure enough, the measurements backed CORRIDOR's analysis.

TLWorkstation's exacting analysis and quick response capabilities make it convenient for utility engineers to design each tower or foundation individually, according to its unique environmental conditions. Traditionally, engineers have designed transmission lines in zones, assuming the worst-case conditions for each structure in a given group. Explains Kennon, "The designer's best weapon against uncertainty was deliberately added capability."

Engineers for the Salt River Project found that in using MFAD, they essentially could custom-design each foundation in the river banks. Having the individual designs on computer also allowed for quick and easy changes when on-site conditions were found to be different than expected. "A complete and thorough redesign or analysis could be developed during construction in 15 minutes, without the need for . . . conservative approximations, estimates, or unnecessary cost exposure," Kondziolka wrote in a special report.

For other engineers, TLWorkstation helps realize the full potential of existing lines—a very attractive benefit, Kennon points out, given utilities' increasingly limited access to new rights-of-way. "Today's challenge is to discover all the capability, uncover all the usefulness in the existing transmission plant," he says. Southern California Edison engineers used TLWorkstation's DYNAMP module, along with other available systems and empirical data, to assess the full potential of their lines. With these advanced methods, the SCE engineers were able to calculate expected conductor temperatures under a variety of loading and weather conditions. Their findings: peak conductor temperatures at maximum currents were as much as 50°C below safe operating temperatures, even though the maximum currents were 23% to 81% higher than the utility's standards. SCE found it could increase the current running through its transmission lines by up to 18% systemwide. Over a service territory of 50,000 square miles, stretching from the coast near San Diego northward to the Sierra Nevada and across the Mojave Desert to the Nevada border, the benefits have been substantial. In all, SCE has saved more than $10 million on conductor replacement projects that were postponed or canceled altogether.

Alonso Rodriguez, research engineer for SCE, reports that DYNAMP's results were within 10% of field measurements. "The close agreement with the actual measurements gave us confidence to extrapolate to parts of the system where we did not make measurements," he says.

Similarly, engineers at Commonwealth Electric in Massachusetts reported time and money savings from using the MFAD module on a new 13.7-mile, 345-kV transmission line stretching from the Cape Cod Canal to Hyannis. Increased residential and business growth on Cape Cod created an immediate demand for the line.

"The line had to be developed quickly," recalls Robert C. Tegelaar, director of research and development. "MFAD was crucial to getting the job done on time." Brad Curtis, the company engineer who designed the line's 151 foundations, says he averaged 8 foundations a day with MFAD. An added challenge was that the line had to be built without guy wires to save valuable right-of-way space. This meant the piers—which ranged dramatically in size, depending in part upon the soil conditions—had to be bigger. The largest was 13 feet in diameter and 40 feet deep. It alone cost $70,000. Utility officials estimate they saved at least $340,000 in material and labor for the $1.8 million project. "The critical thing is that there's a lot of money at stake and MFAD allows you to take some of the uncertainty out of the design," Tegelaar says. "And the more uncertainty you have, the more fat you have to build into the size and the cost of the foundations."

User-friendly

With every version issued, TLWorkstation is becoming more user-friendly. Making the software program easy to use has been an important goal right from the start of EPRI's 14 years of research. "We don't write software in a vacuum," Kennon says. "Our contractors typically are not software people. They're engineers."

Unlike mainframe programs, TLWorkstation does not rely on cryptic computer languages. It interacts with the user in English. To use it, Kennon says, the engineer "doesn't have to know a lot about a PC computer. He has to know how to turn it on, how to type the letters TLW, hit the return key, and how to follow instructions from there on." With the 2.0 version, all task modules have common-looking front ends. In addition, more data can now fit onto one page. But, Kennon cautions, the program "is not an engineer in a box. It assumes the user is an expert in the technology and is capable of making proper design decisions."

O. Frank Elliott, director of structural engineering for Virginia Power, says 2.0 is much more user-friendly than previous versions. In the past, he notes, the user had to enter commands to tell the program what to do. Now, the program offers menus and the user can select a given task. "It carries you through what you have to do, step by step, and it won't let you go past a given step until you've done everything necessary in the area you're working in."

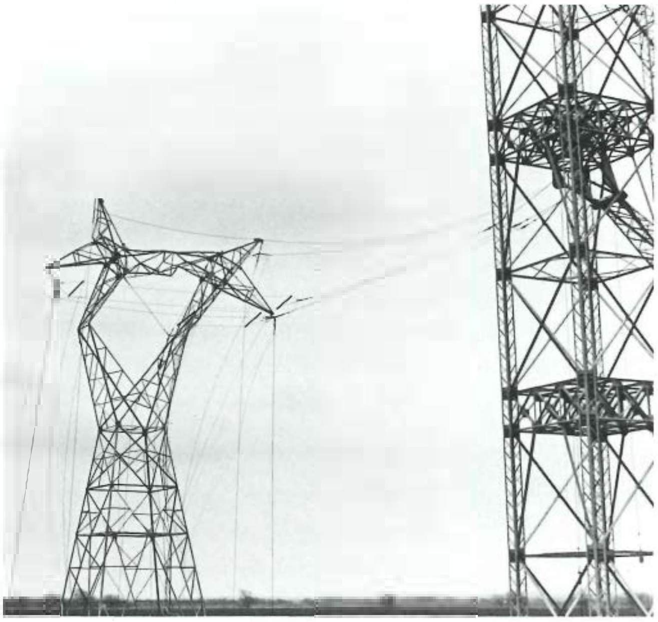
"The main benefit of TLWorkstation is that it's interactive," says George Justice, supervisor of civil structural engineering for Illinois Power. "You're able to sit down and play 'what if' games to modify what you're thinking and get results fairly quickly—in contrast to the old batch-type mainframe programs we used before TLWorkstation."

Brad Curtis of Commonwealth Electric says, "I'm not by any means a computer expert." But within a week of using the MFAD module to design the foundations for the 345-kV line to Cape Cod, he felt proficient with the program. "I taught myself how to use it," he says, stressing that he relied on the accompanying manual for guidance. Once he had the needed data in hand, it was almost as simple as filling in blanks on the screen, he remarks. What he plugged into his IBM-compatible personal computer were figures on soil density and stresses affecting the foundations, among other numbers. In return, the computer offered the diameters and depths required for the foundations to be successful.

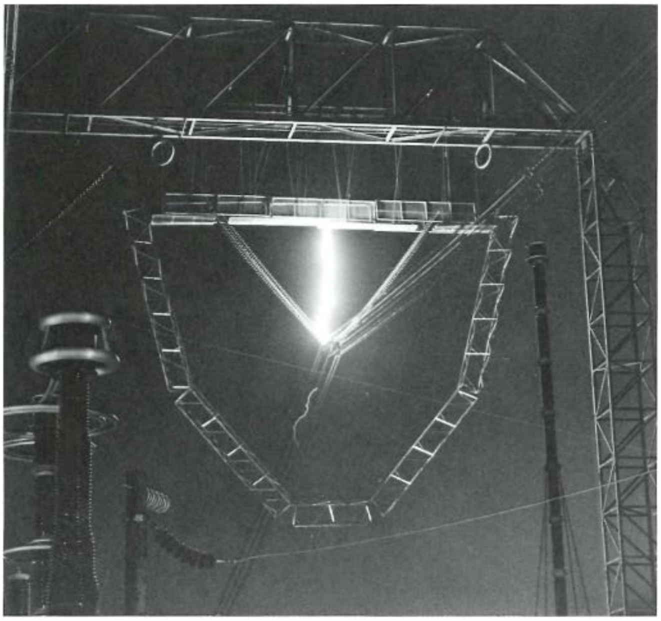
To help TLWorkstation users, EPRI holds seminars on the various task modules about six times yearly. Two user groups also have been established, for the West Coast and North Central regions of the United States. In addition, a TLWorkstation newsletter, published by Power Computing Co. of Dallas, offers users a forum for feedback, positive and negative. (Power Computing is a consultant on TLWorkstation and has designed the front ends for all the task modules.)

Data From Real Life

Unlike many software programs, TLWorkstation offers results that are based on field tests of life-size structures. Data from actual transmission lines under construction and from experiments at two EPRI laboratories—the Transmission Line Mechanical Research Facility (TLMRF) in Haslet, Texas, and the High-Voltage Transmission Research (HVTR) center in Lenox, Massachusetts—are incorporated into the appropriate task modules.



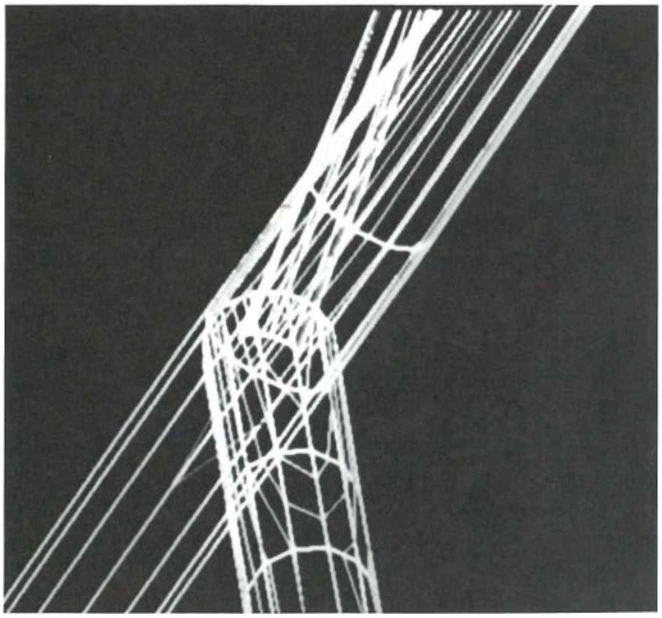
A 115-foot lattice tower snaps during a simulated wind-load test at EPRI's Texas facility.



A simulated lightning bolt zaps through a lattice tower window during flashover tests at the HVTR center.

A directly embedded pole in Virginia leans under pressure during a test of soil response.

TLMRF results make it convenient for utility engineers to stress-test an H-frame structure from an office computer.



What's New with TLWorkstation

The fact that version 2.0 of TLWorkstation™ has only 16 modules—the same number offered in the original version—is deceiving. New task modules and features have been added, while some of the original modules have been incorporated into a single, enhanced, and highly sophisticated module. Key changes include the following:

Database management system The addition of this feature marks a giant step toward a more project-oriented software package. The new system, called BTRIEVE, is a commercial software program developed by Novell, Inc. It operates as a file manager and allows task modules to share common data. Now, the output from one task module can be used as input for another. For instance, conductor loads generated by WIRELDS can be transferred to POLDAR, which will incorporate this information in its analysis of a transmission line constructed with poles. The database management system has been implemented only for some of the task modules that share common data. But it will be expanded in the future to become a common repository for all data. When there is a request for a report on a specific project, the engineer will need to access only one file, instead of gathering information from numerous files representing various phases of the project.

PIM Another step toward a project focus is this new project input module. PIM combines data common to various task modules into one file. This feature is a timesaver and a convenience for the user, who no longer has to answer the same question in numerous task modules.

ETADS The most sophisticated and complex of all the task modules, ETADS is a tower analysis and design system that comprises two former modules, TAG and ETAP, plus five other submodules. It is most efficient when used with advanced hardware, including a 386 processor, and with an OS/2 operating system. All types of transmission lines and structures (e.g., lattice, tubular steel, and wood pole, guyed or freestanding) can be modeled and stress-tested on the computer by using ETADS. One key advancement is that ETADS has more than quadrupled the options from which a user can select in designing a tower. For instance, a polybeam or multisided tubular steel beam option is now available, whereas in the past the user had to work from a more generic element and input data to simulate such a structure. ETADS can also calculate the buckling capacity of a beam. Other improvements include graphic capabilities. Three-dimensional geometry plots display deformations of transmission line structure models. Axial stresses on lattice structures can be calculated and displayed in colors that correspond to their severity. Stresses on tubular structures can be calculated and displayed graphically in three-dimensional, color-contoured pictures. Analyses of static and dynamic transmission poles and towers can be displayed on X-Y graphs, for which the user can select parameters and value ranges.

FRAMER* This new module analyzes, designs, and assesses the reliability of an H-frame transmission structure. It simplifies the modeling of planar structures, reducing input data requirements.

WIRELDS* Also new, this module computes loads at conductor attachment points, given any combination of temperature, wind speed, and ice cover. Output data can then be used in other task modules.

MINIDES* The companion task module to WIRELDS, MINIDES creates preliminary designs for all types of overhead transmissionline structures, including lattice, tubular, wood, concrete and steel, guyed or unguyed. It also estimates the weight of these structures.

POLDAR Formerly POLDA, this pole design and analysis module now offers reliability assessment of unguyed transmission poles.

TLOPWT* Formerly TLOP, a transmission line optimization program, this module now factors terrain characteristics into its analysis. It analyzes the direct cost of a line and the expense of electricity losses and line maintenance in order to identify the most economical design.

RNOISE A new module, RNOISE estimates the level of radio frequency noise from transmission lines.

MULTIF This module, which calculates lightning flashover rates, has been enhanced.

DYNAMP Enhancements have also been made to this module, which determines the current rating of overhead conductors.

*To be available in phase 2 of version 2.0.

As utilities learn more about TLWorkstation, they are helping improve the system. Elliott and Justice are among the utility engineers who performed beta tests on the 2.0 version. (Beta tests are conducted during the final stage of software development and are intended to help get the bugs out of a system.) The new Advisory Committee on TLWorkstation, composed of frequent users of the software, oversaw the beta testing and is setting goals for future development.

Input from utilities over the years has been important to TLWorkstation's development, Lyons says, noting that the best feedback often comes during the beta-testing process. Typically, EPRI provides the utilities with sample problems. Often, though, engineers check the system against structures they've already analyzed. Sometimes, they stumble across a significant omission in a module. In an early round of testing for the tower analysis and design module (ETADS), for example, one user discovered that the module did not have the capability of conveniently modeling double angles on transmission towers. Fitted back to back, double angles offer more support than single angles. EPRI ended up including that capability in ETADS.

The ETADS module in version 2.0 is particularly demanding in terms of computer hardware. In fact, the entire software package—as it becomes more advanced with each version—requires increasingly sophisticated hardware. Typically run on an IBM PC-XT or IBM PC-AT and their clones, TLWorkstation now operates best on more advanced hardware like the IBM PS/2. The AT microcomputer, which typically has been used with TLWorkstation, is "rapidly becoming obsolete technology," Lyons says. EPRI is encouraging utilities to opt for a more advanced system.

Users of the ETADS module have reported that it is unbearably slow with an AT and tolerable with an IBM PS/2. But Kennon notes that the module has since been compiled for use with the OS/2 operating system, which has more memory than the DOS operating system. With the OS/2 system, Kennon says, ETADS "runs like a scared rabbit." ETADS can also be used with minicomputers and mainframes. "It wouldn't surprise me to learn that this is the largest, most complex, most sophisticated program anybody has ever put on a PC computer," Kennon says of ETADS. "It's a monumental accomplishment."

A glance at the future

TLWorkstation has come a long way since the first version was introduced three years ago. And with the newest, 2.0 version, the program is finally moving toward a project orientation. "A utility can begin to think in terms of using this software for complete projects rather than individual tasks," Kennon said. "We've always intended to have that. It's always been in our dreams, but we're now beginning to get there."

EPRI continues to plan improvements for the future. Few other modules will need to be made as sophisticated as ETADS, Kennon says. And the program's emphasis will remain on major design concerns, like conductor and tower selection, leaving the smallest engineering details to skilled craftsmen and commercial, engineering-oriented software programs.

Among enhancements planned for future versions of the software are a module called MULTIFAD, a pole and tower foundation design package. This new module would address side and moment loads on transmission towers, combined with uplift and compression forces. In the electrical area, a program called ECCAPP, which calculates the effect of short circuits on pipelines and railroad tracks, may be added to TLWorkstation. This program currently is accessible only on minicomputers and mainframes. A third objective is to add structural optimization to ETADS, which would allow the engineer to change the geometry of a transmission tower and make it lighter. And finally, EPRI is experimenting with the transmission line optimization program, to make it more interactive and specifically applicable to upgrading lines. This plan is to develop a work sheet format, with questions and answers on the same page. The user would be able to change some figures on the form and, with a blip of the computer screen, receive new values for those figures. Currently, input and output are kept in separate files.

When TLWorkstation was in the early stages of development, EPRI researchers predicted it would encompass up to 50 modules by 1990 and would include such tasks as bookkeeping and detail engineering. Since then, however, the software's focus has turned more specifically toward design and analysis. As a result, fewer modules are expected to be added. "We expect it to be a fully mature product certainly within the next five years," Kennon says. In the meantime, projects are under way at EPRI to develop similar software packages in the areas of underground transmission and distribution.

Today, TLWorkstation is more advanced and easier to use than ever before. But like other forms of advanced technology, the software package poses a peculiar challenge for tomorrow's engineers: to maintain their understanding of the tasks the program has taken over from them. Steve Dayney, a transmission engineer and TLWorkstation user with Public Service of Colorado, puts it simply. "It's sort of like when you were in the third grade and you learned your multiplication tables by heart," he says. "Now, you don't have to learn your multiplication tables. You just go to your calculator." ■

This article was written by Leslie Lamarre, science writer. Technical information was provided by Richard Kennon, Electrical Systems Division.

TECH TRANSFER NEWS

Targeted Chlorination Controls Biofouling

After a 10-month test period at New England Power's Brayton Point plant, targeted chlorination using a system of fixed nozzles appears to be more cost-effective than bulk chlorination, the method used by most utilities to arrest microbiological fouling in steam condensers. The new technique also reduces residual chlorine in discharge waters.

These field findings indicate that EPRI's targeted chlorination design is commercially feasible and ready for wider application. Design guidelines for application are in production, and a videotape on the Brayton Point system has been released. A workshop on targeted chlorination is scheduled for November 9–10 of this year in Providence, Rhode Island.

Microbiological fouling (slime and algae buildup on condenser tube surfaces and tubesheets) costs utilities millions of dollars annually because of increased heat rate and cleanup outages. EPRI's targeted chlorination design features injection nozzles in the condenser waterbox about 4 feet from the tubesheet surface. The chlorine is delivered sequentially to targeted areas of the tubesheet until the entire surface is covered. The proximity of the nozzles to the condenser tubes results in a high chlorine concentration at condenser tube surfaces, thereby maximizing biofouling control.

Historically, the remedy for biofouling has been to inject concentrated chlorine at the plant's cooling water intake. But dilution and chemical decay weaken the concentration of the chlorine and inhibit its effectiveness, requiring larger amounts of chlorine as compensation. Moreover, recent EPA guidelines limiting residual chlorine discharges downstream have made the bulk chlorination method less effective. EPRI therefore developed the fixed-nozzle targeted chlorination design as an alternative.

To compare the two methods, investigators at Brayton Point targeted one condenser and subjected another to bulk chlorination. Cleanliness in the condenser treated with targeted chlorination improved 15–20% over that in the parallel condenser using bulk chlorination. The levels of anaerobic sulfur-reducing bacteria, which can aggravate corrosion on condenser tubes, fell dramatically. Reduced turbine back pressure improved plant thermal efficiency and will save the utility an estimated $50,000 annually in fuel costs, while reductions in condenser cleanings are expected to save another $40,000.

Residual chlorine in the cooling water fell to undetectable levels and was consistently below the current EPA limits of 0.2 part per million. And chlorine consumption dropped 80%—from 150 pounds per day with bulk chlorination to 30 pounds per day—at an annual saving of $10,000.

Targeted chlorination is most effective in open-loop, one-pass condensers, but it is also applicable to other plant types. And although the fixed-nozzle design at Brayton Point was used on a condenser cooled with salt water, testing of another targeted chlorination design by the Tennessee Valley Authority has confirmed its applicability to units cooled with fresh water. An informal EPRI survey indicates that as many as 1000 generating units across the country will be able to use the technology. ■ *EPRI Contact: Winston Chow, (415) 855-2868*

Knowledge Engineering Handbook Available

Expert (or knowledge-based) systems are a fast-moving development in the field of artificial intelligence. They are special programs designed to distill the factual knowledge and expertise of specialists, especially for troubleshooting. As a substitute for personal consultation, expert systems have a wide application in industry, including power plants—where during off-hours, for example, it may not be convenient or economical to have an expert available.

For many power system applications, however, expertise remains isolated in the minds of a small number of utility personnel. Utilities need help in what has become known as knowledge engineering—the acquisition, representation, and verification of knowledge for expert systems.

To meet this need, EPRI has prepared a handbook, mainly for use in utility workshops but suitable also as a stand-alone textbook for programmers and engineers interested in building expert systems. *The EPRI Knowledge Acquisition Workshop Handbook* (NP-6240) offers a comprehensive, detailed introduction to knowledge acquisition. In seven sections, the book presents an overview of knowledge engineering processes, complete with discussions of concepts and techniques for knowledge acquisition and for representation of the knowledge acquired, and techniques for verification and validation of an expert system once it is complete.

Nine methods of eliciting information from experts are described, each with distinct drawbacks and benefits, and each applicable to a particular kind of knowledge. One example is a wide-ranging unstructured interview; another is model criticism, in which the expert is asked to evaluate a model of his knowledge as already compiled and represented by the knowledge engineer.

A section on knowledge representation distinguishes the different types of knowledge employed by expert systems and presents uncertainty as a class of knowledge. A variety of methods for representing knowledge are discussed, and simplified examples are used to distinguish between the various methods in terms of applicability and function. Other sections in the handbook examine different types of expert systems, as well as techniques for extracting information from text sources.

A final section on verification and validation examines quality assurance methods for determining that an expert system was created correctly and functions properly. The workbook includes a catalog of expert system and knowledge acquisition tools. Viewgraphs and a videotape of an EPRI workshop are available. ■ *EPRI Contact: Joseph Naser, (415) 855-2107*

Food Service Industry Reports Released

Utilities that want to improve energy efficiency and offer additional electric services to commercial restaurants can turn to two new EPRI publications for current information on the food service industry.

The Food Service Sourcebook: A Quick Reference Guide to Industry Information and Sources (EM-6135) is a comprehensive listing of restaurant operators, industry associations, broadline distributors and buying groups, equipment manufacturers, and representatives of the National Electric Customer Assistance Network. The book includes discussions of expected food service market growth, describes electric utility food service programs, and includes an index of leading food service parent and subsidiary companies. It concludes with a bibliography of industry publications.

A related communications tool, *The Food Service Industry: A Presentation Package With Supporting Text* (EM-6148) is a compilation of restaurant energy use and electric food service information suitable for two presentations—one to members of the food service industry and another to utilities. The package comes complete with two half-hour scripts and illustrations for overhead projection. A set of 35-mm slides is available on request from the project manager. Part I, "An Important Electric Customer," is intended for presentation to food service personnel and highlights equipment options for the food service industry. Part 2, "An Electric Utility Perspective," is intended for utility professionals interested in the current market position of electricity in the industry. It includes data for market analyses, discusses the benefits of electric food service equipment, and describes technologies under development at EPRI.

Copies of the publications are available from Research Reports Center, (415) 965-4081. ■ *EPRI Contact: Karl Johnson, (415) 855-2183*

PCB Soil Tester Ready for Field Trials

EPA regulations require that all spills that might contain polychlorinated biphenyls (PCBs) be cleaned up within 48 hours. All oil spills are considered contaminated unless proved otherwise. Up until now, this approach has necessitated an immediate start on every cleanup.

From now on, however, utilities will be able to test soil samples directly for PCBs first, by means of the Clor-N-Soil™ kit. This quick screening test, now undergoing field trial, yields a complete on-site soil chemical analysis in 10 minutes or less.

Like EPRI's Clor-N-Oil™ chemical kit, introduced six years ago for field testing samples of transformer oil for PCBs, this new quick-detection kit is highly portable and easy to use. It weighs about 5 ounces, contains everything needed for the analysis, and works in all types of soil. Testing can be performed by linemen without expertise in chemical analysis.

EPRI is offering the Clor-N-Soil kit to member utilities interested in sharing test data in a comprehensive report. For information on the test program, contact Yolanda Gale, (415) 855-2639. For technical information, contact the developers of the product, Dexsil Corporation, (203) 288-3501. ■ *EPRI Contact: Vasu Tahiliani, (415) 855-2315*

Exploratory Research

A Theoretical Framework for Cold Fusion Mechanisms

by Mario Rabinowitz, Electrical Systems Division, and David H. Worledge, Nuclear Power Division

Nuclear fusion would appear to be an ideal source of energy for many reasons. Fuel costs are likely to be low, since one of the potential fuels, deuterium, occurs in vast amounts in the oceans. In addition, there is relatively little radioactivity associated with fusion compared with nuclear fission as an energy source. Because of the large conversion of mass to energy, fusion can produce a million times more energy per atom than a chemical reaction. Much work has been done for over three decades on high-temperature plasma-controlled fusion, but the achievement of sustained, controlled fusion reactions in high-temperature plasmas still seems remote.

On March 23, 1989, Professors Stanley Pons and Martin Fleischmann announced their achievement of sustained, controlled fusion at room temperature in a palladium (Pd) electrolytic cell using heavy water (deuterium oxide) as the electrolyte. While the use of high-temperature plasmas may be likened to a brute-force approach to fusion, the new cold fusion concept may be characterized as a finesse approach.

Pons and Fleischmann's results were particularly surprising to the scientific community because there had been no hint of a fusion-type reaction in other circumstances where the same isotopes were involved. Specifically, liquid solutions of deuterium oxide and of tritium oxide have densities comparable to that of the deuterium in the palladium in Pons and Fleischmann's experiment, yet fusion has not been seen in these liquids. In addition, palladium and other metals such as platinum have been used to purify hydrogen and its isotopes from other gases, since the hydrogen isotopes move readily through windows of these metals but other gases do not. However, fusion has not been observed in these circumstances either. Therefore, for fusion to occur at the reported levels in such metals, it appears that hitherto unconsidered physical mechanisms must be present in the solid that are not present in the liquid.

Providing a reasonable theoretical description of these mechanisms is important to the work at hand. Science progresses with a good combination of experiment and theory, each giving direction to the other. At present, the experimental work appears to be way ahead of the theoretical work. Yet a good theoretical model or framework can do much to guide experimental work and provide it with coherence. The following theoretical framework provides possible explanations for what has been observed in cold fusion experiments to date.

Basic concepts

There are four essential ingredients, or processes, for sustained controlled nuclear fusion of either the hot or the cold variety: tunneling probability, collision frequency, fusion probability, and sustaining the reaction. The power delivered by nuclear fusion—the fusion rate—is proportional to the product of the first three processes. The fusion probability is dependent on processes that occur inside the nuclear well and determine the reaction products. The fourth process involves preventing the reactions from being poisoned and ensuring the deuterium and tritium fuels are replenished. The ability to achieve fusion at low temperature appears to be related most strongly to unexpected opportunities with regard to the first two processes: increases in both tunneling probability and collision frequency in the center-of-mass system.

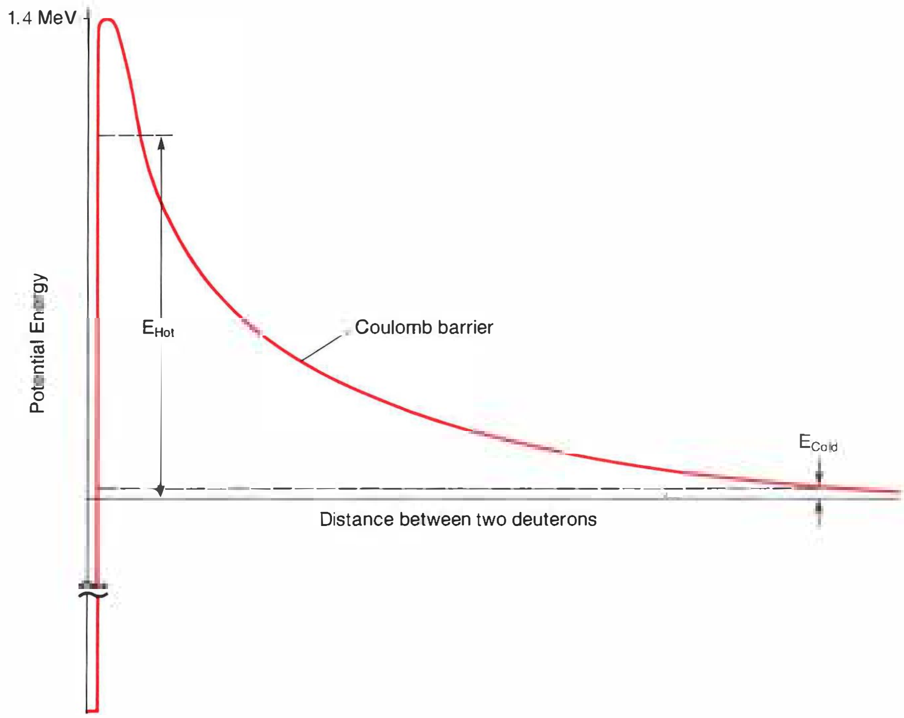
The fusion rate is extremely sensitive to the tunneling probability, expressed as the tunneling coefficient. Even small variations in the relevant variables can substantially change this coefficient, which in practical terms is a measure of how easily two atomic nuclei can overcome the barrier of their electrical mutual repulsion. Tunneling is considered to be a quantum mechanical phenomenon in which a particle whose energy is less than the poten-

ABSTRACT *The solid state of palladium presents a rich environment for enhancing the fusion rate of light isotopes. First, the periodicity of the crystal lattice can greatly reduce the effective mass of hydrogen nuclei, allowing them to tunnel through the Coulomb barrier more easily. In addition, the lattice may provide preferential pathways of motion, making it more likely that nuclei will collide and fuse. The fusion rates that may be calculated for these mechanisms can account for the energies reported in recent cold fusion experiments.*

tial energy of a barrier can nevertheless be found on the other side of the barrier (Figure 1). For fusion to occur, the deuterium nuclei (deuterons) and/or the tritium nuclei (tritons) must overcome the repulsive Coulomb barrier. Once this barrier is overcome, the attractive nuclear force dominates, allowing the nuclei to fuse. Due to the periodic potential of the lattice ions in a solid and the quantum mechanical wave nature of the particles that move freely in this lattice, it is possible for the effective mass of the particle in the solid to differ from its mass in free space (free-particle mass). Calculations presented later in this paper show that it is possible for the effective mass of the deuterium nuclei in a solid to be sufficiently less than the mass of deuterons in free space to increase the tunneling coefficient by many, many orders of magnitude.

As stated earlier, the fusion rate is also proportional to the collision frequency of the deuterium nuclei. In three dimensions, the collision frequency (F_3) per particle is given as $F_3 = ncv$, where n is the number density, c is the cross section, and v is the mean thermal velocity. We expect this number to be roughly the same in the liquid state and in ordinary solid solution.

Figure 1 **Hot plasma fusion is achieved by imparting enough energy (E_{Hot}) to the deuterons that they can tunnel through the Coulomb barrier near the top, where it is relatively "thin." With cold fusion in a metal such as palladium, the periodicity of the solid's lattice can reduce the deuteron's effective mass to as little as 1/100 of its mass in free space. As a result, it can tunnel much more successfully at the low energies (E_{Cold}) supplied in cold fusion experiments.**



There may be preferential pathways in a solid that decrease the degrees of freedom in the solid so that the fusing particle (deuterium or tritium) is confined essentially to two- or one-dimensional motion in the solid—that is, the particles may be able to move only in certain planes or channels. Decreasing the dimensionality, or degrees of freedom, decreases the number of ways potentially colliding particles can miss each other. The two-dimensional case may be thought of as being similar to the collision of marbles on a table top. The table top need not be flat as long as the marbles are confined to moving on its surface. The one-dimensional case may be considered similar to marbles constrained to move in a tube, and the tube need not be straight. In this one-degree-of-freedom case, the marbles cannot avoid collision.

The actual solid lattice is much more complicated than this simplified marble example, because on the atomic and subatomic scale the world is quantum mechanical and because it is difficult on this scale to restrict particles to only one or two degrees of freedom. However, for the purposes of numerically illustrating that a significant increase in collision frequency may be achieved in such cases, let us consider some very simple equations as crude approximations of the real situation. In two dimensions the collision frequency is $F_2 = n^{2/3}c^{1/2}v$. In one dimension the collision frequency is $F_1 = n^{1/3}v$.

Depending on the particular values of n and c when the particles are confined to planar or channel motion in the solid, F_2 can be roughly up to several orders of magnitude larger than F_3, and F_1 can be many orders of magnitude larger than F_3. Thus we can see the importance of restricting the motion of the particles to one or two dimensions. Not all the volume of the solid is available to the deuterons, which increases the effective number density. Similarly not all the volume of the channels or planes is available to the deuterons, increasing the effective number density further. With respect to the collision frequency, the much bigger effect is due to the increased cross section. However, the effects of increasing the number density and reducing the dimensionality also serve to substantially increase the collision frequency compared with a free-space plasma, and thus greatly enhance the fusion rate.

Conclusions

The solid state presents a rich environment for enhancing the fusion rate of light isotopes, as it permits control of a number of the governing variables related to tunneling probability and collision frequency. The cold fusion rate greatly increases with a reduction in the effective mass of the fusing nuclei in a solid lattice environment because of an exponential increase in the tunneling coefficient. This reduction in effective mass occurs outside the Coulomb barrier because of the periodic potential of the ionic lattice. Enhancement due to this effect can account for the recently

Table 1
DEUTERON-DEUTERON FUSION RATE IN $PdD_{0.6}$
(fusions/cm3/sec)

Energy (center of mass)	Ratio of Effective Mass to Free Mass			
	1.0	0.1	0.02	0.01
0.025 eV	10^{-156}	10^{-27}	10^{6}	10^{15}
0.15 eV	10^{-152}	10^{-25}	10^{8}	10^{16}
1.0 eV	10^{-139}	10^{-22}	10^{11}	10^{18}

claimed cold fusion rates in a manner that may be unique to the crystal environment. In free space, the fusion rate between deuterons at ambient temperature would be 10^{-2696}/cm^3/sec, which is vanishingly small.

The effects of deuteron effective mass are calculated in Table 1, where the number of deuteron-deuteron fusions/cm^3/sec is calculated for $PdD_{0.6}$, at which the deuteron number density is that of liquid deuterium, 4×10^{22}/cm^3. The fusion rate is calculated for a series of values of effective mass for center-of-mass (CM) energies 0.025 eV, 0.15 eV, and 1 eV, such as could be found in the high-energy tail of the energy distribution. $E_{Lab} = E_{CM}$ corresponds to symmetric collisions of deuterons in transit between interstitial sites, which may be more likely in a lattice that provides preferential pathways of motion than in a high-temperature plasma. This mechanism can also increase the fusion rate by many orders of magnitude. As Table 1 shows, fusion rates that may be obtained by these mechanisms are high enough to account for the reported energies attributed to cold fusion.

In addition to explaining reported fusion rates in terms of claimed energy output (as supported in part by the tritium count rates reported at Texas A&M University and elsewhere), this theory also shows that there is not a strong temperature dependence of the fusion rate right up to the melting point of palladium of 1828 K, corresponding to $E = 0.152$ eV. If the decreased solubility of deuterons in palladium and hence decreased density were included, there might even be a decrease in the fusion rate as the temperature was increased.

It is well established that interstitial species such as deuterons respond to a local applied electric field with an effective charge that may be greater or smaller than the free charge. Values between 0.3 e and 1.0 e have been measured and may likewise have a strong effect in increasing the fusion rate, though care must be taken in properly introducing the effective charge of the deuterons into the analysis.

Other theorists have postulated similar concepts of effective mass and effective charge for the electrons in a solid to account for cold fusion. Even if the electron concepts are not applicable to the enhancement of the fusion rate, the concept of effective fusing particle mass still appears valid, as it is applied outside the barrier, where the inertia of the unbound deuterons is determined by the periodicity of the lattice. (The free mass is appropriate inside the nuclear well.)

Although many further experimental data are needed to establish the claimed cold fusion results as incontrovertible scientific fact, these claims have nevertheless focused theoretical attention on the possibilities of fusion in a crystal lattice and deserve to be scrutinized carefully by the scientific community. There are not enough experimental data yet to discriminate between theories, much less pick one theory over another. The theory presented here will need to be tested by hard experimental facts, as will all the others. However, it should be noted that this theory is one—perhaps the first—that has generally good agreement with the known data.

Industrial Electrotechnologies

Dielectric Heating and Drying

by Robert D. Jeffress, Customer Systems Division

Conventional drying of bulk materials involves heating them with a stream of hot air blown over the surface or through the material. The hot air first evaporates the free moisture from the surface; as that moisture evaporates, it is replaced by moisture from the interior which spreads to the surface. Surface drying by convective hot air is highly efficient, but as the surface dries out, the heat must be transferred by conduction through the material to reach the inner core of moisture and evaporate it.

The use of dielectric heating during the latter stages of the drying process is particularly effective, since the electromagnetic radiation penetrates directly into the material (unaffected by the vapor flow) and heats the water at the core. Very often, the evaporation of only a part of this water is sufficient to drive the remaining water to the surface because of the 1:1000 volume increase when water is converted to steam. Low-cost hot air is then sufficient to evaporate the additional surface water.

The literature is replete with techniques for calculating drying times for bulk materials by means of the conventional heat-transfer processes of conduction and convection combined with mass transfer. Materials properties such as heat capacity, conduction, and diffusion are all well known for industrial materials of interest. Unfortunately, no theory has yet been developed for calculating heat and mass transfer in the presence of electromagnetic heating, nor are dielectric properties known for the common bulk materials that

ABSTRACT *A broad-based research, development, and demonstration program for the efficient use of dielectric heating and drying in industrial applications is in progress. The EPRI-sponsored program is focusing on dielectric heating applications to enhance industrial productivity and product quality and address environmental issues.*

often require drying. Current dielectric heating applications are developed on an ad hoc basis, and the test information is often jealously guarded by the manufacturer. Until good analytical tools and properties data are generally available, there will be no widespread use of dielectric heating.

Research and development

The EPRI dielectric research, development, and application program at the University of Texas is, in part, designed to overcome these difficulties by providing a detailed understanding of heat and mass transfer (with electromagnetic contributions) in common industrial materials. Complex mathematical models of the processes have been formulated and tested on the Cray computer. These programs yielded good results but are not practical for everyday use in industry. They are being simplified (with little practical loss in precision) for use on the IBM PC.

Properties data on common materials are being compiled from the available literature (the data often disagree), and two test setups are being constructed to measure dielectric properties directly in the laboratory. One will measure dielectric properties in the microwave regime (the 2450-MHz frequency), and the other will measure properties in the radio-frequency regime (the 13- and 27-MHz frequencies). An ongoing compilation of properties data will be published in the open literature.

Confirmation of the theoretical models will be accomplished by comparison with actual data from the test equipment at the University of Texas laboratory. A 6-kW microwave test apparatus has been constructed to heat bulk materials with hot air and microwave energy concurrently. The apparatus operates at the FCC-approved frequency of 2450 MHz and is automatically controlled by an IBM PC for hands-off testing. In addition to controlling the testing, the computer reduces the heat to produce a drying curve in real time.

A second apparatus in the laboratory will heat materials with 8 kW of radio-frequency energy at 13 or 27 MHz concurrently with hot air. This apparatus is also fully computer controlled. In addition, the laboratory has thermal-imaging equipment to measure the heating patterns produced in materials when they are irradiated by microwave energy.

Applications testing

The bottom line in any dielectric-drying application is the economics: can the manufacturer reduce the product costs? A computer program is in preparation to estimate the costs of enhanced dielectric drying of bulk materials. The program will use technical input from the theoretical models covered earlier. A detailed study of the cost of radio-frequency and microwave industrial equipment has been completed. This study will form part of the computer program database.

In addition to the research activity already covered, the EPRI dielectric program at the University of Texas is investigating potential applications in industry. Applications are typically suggested to the laboratory by EPRI member utilities through the dielectric application program administered by the EPRI Center for Materials Fabrication. Testing has been conducted on the drying of thermoplastic elastomers, hardwood veneer, ceramic materials, and grain pet food.

Pet food is conventionally dried in hot-air tunnel dryers from 23% moisture content to approximately 9%. It passes through a dryer on a conveyor at a depth of 7 inches, and drying time is 20 minutes. Plant conditions simulated in the laboratory resulted in a drying time of 26 minutes, which was used as the base time.

The drying time was reduced to 14 minutes with the assistance of 1 kW/ft^2 of absorbed radio-frequency power throughout the entire drying cycle. This is equivalent to an 87% increase in throughput. The bed was increased in thickness to 12 inches, and the tests were repeated. With the same power (1 kW/ft^2 over the entire drying cycle), it took the thicker bed approximately 21 minutes to dry. This represents an increase in throughput of 113%. Tests clearly show that radio-frequency augmentation can significantly increase output of production-line drying of grain pet food. Tests are planned to further evaluate the use of radio-frequency energy and to optimize the process economics.

With the participation of industrial sponsors, plans for the remainder of 1989 include the drying of plastic pellets (prior to injection molding) and gypsum wallboard.

Member utilities with customers interested in increasing the performance of their drying operations are encouraged to contact the EPRI Center for Materials Fabrication for product analysis and testing.

Drying of textile yarns

In the manufacture of cloth, the longitudinal yarns are formed into a web with perhaps 1500 yarns and wound on a large spool for mounting on a weaving machine. To improve weaving efficiency, the yarns are coated with polyvinyl alcohol plus additives (called size), which, when it dries, stiffens the yarns to improve weaving efficiency. One additive, kettle wax, prevents the yarns from sticking to the drying cans but weakens the size.

Experiments were conducted at Auburn University to dry the yarns with radio-frequency energy. It was postulated that radio-frequency drying might result in superior yarn properties and that less sizing would be necessary if it were possible to eliminate the kettle wax, which decreases the strength of the size. Other benefits were cooler working conditions and easy start/stop features.

A small laboratory apparatus was constructed at Auburn to dry a 6-inch-wide web containing 150 yarns in a stray-field radio-frequency application operating at 27 MHz. The apparatus effectively dried the web of yarns, but laboratory analysis has shown that the quality of the yarns was only equivalent, not superior, to the quality of those dried with conventional steam-can dryers. The studies have shown that significant cost reductions may be achievable in downstream textile-finishing processes through elimination of kettle wax and reduction in the amount of size. The cost of the sizing operation itself, however, increased with the substitution of radio-frequency equipment for the steam cans. Studies are progressing at West Point Foundries, a manufacturer of textile equipment, to fully assess the economics.

Ceramic sintering

Microwave heating is commonly used for low-temperature applications such as cooking and drying; hence there is a tendency to think that it is useful only for that type of application. On the contrary, microwaves—pure electromagnetic energy—can heat products to the highest possible temperature. This capability is used to sinter fine ceramic products, where temperatures of 2500–4000°F are required.

Applying the heat throughout the workpiece can achieve extremely rapid heating. This rapid heating limits undesirable grain growth, which would ordinarily occur with more conventional heating methods. (Large grain size is a problem because the ceramic has lower strength.)

A microwave sintering project conducted at Northwestern University tested rods with a diameter of 4 mm. Silicon nitride and silicon carbides were difficult to sinter because they required temperatures of approximately 4000°F. Of the lower-temperature materials, alumina and alumina-TiC were successfully sintered. Alumina exhibited an average grain size of 0.77 mm for doped specimens sintered at 1600°C, with a density of 99%. This is a remarkably small grain size for this particular powder at this density. Microwave sintering of alumina-TiC (a fine ceramic that cutting tools are commonly made from) was particularly easy because of its lossy nature at low temperatures and its higher conductivity at more elevated temperatures.

For sintering high-temperature materials such as silicon nitride and silicon carbide, a special cylindrical resonant cavity was constructed to reflect radiant heat to the specimen from its silver-plated interior. Although the reflective cavity allowed increases in temperature well over those that could be achieved in a nonreflective cavity, these were still inadequate to achieve sintering temperatures before plasma generation and arcing limited the capability of the microwave field to heat the specimen to sintering temperatures. Northwestern investigators recently discovered techniques that offer opportunities for heating specimens to higher temperatures (patent applied for).

The research clearly demonstrated that there are opportunities for microwave sintering of fine ceramics, but it also highlighted the need for additional R&D. The EPRI Center for Materials Fabrication is now transferring information learned during this study into an industrial collaborative project with emphasis on research leading to commercial applications of microwave-sintered ceramics. Industrial sponsors participating in the project are helping to identify potential applications, broadening technology transfer and accelerating industrial use of the technology.

Power Electronics and Controls

Power Electronics Applications Center

by William M. Smith, Customer Systems Division

EPRI has long recognized that power electronics can enhance the productive use of electricity in residential, commercial, industrial, and utility applications. Also recognizing that intense worldwide competition in solid-state technology challenges U.S. manufacturers to improve state-of-the-art power electronics components and systems, EPRI created the Power Electronics Applications Center. PEAC is operated by the Tennessee Center for Research and Development.

To ensure a comprehensive and integrated approach to the development of power electronics and control systems, PEAC's R&D activities are organized into three program areas:

- Power electronics technology development, which includes investigation of devices and components, as well as of novel circuits and controls
- Controls and systems applications for design and field application of macroscopic controls and power electronics systems
- Power quality, which includes laboratory research, field measurements, and training in diagnosing and mitigating power quality problems

Power electronics technology development

Power semiconductor devices (diodes, transistors, and thyristors) and passive circuit components (primarily capacitors, inductors, and transformers) are the basic building

ABSTRACT *The EPRI Power Electronics Applications Center provides a national focus to promote the use of power electronics for improving the efficiency and productivity of electric utilities and their customers. PEAC activities focus on the research, development, and application of power electronics technologies; market and technology applications assessments; and information dissemination and technology transfer.*

blocks of power electronics systems. These systems range from television sets and personal computers to adjustable-speed drives for refined motor control and uninterruptible power supplies for enhanced power reliability. PEAC's R&D efforts focus on the development of power-integrated circuits—hybrid devices that incorporate many active elements and controls within a single package—and advanced, high-power metal oxide semiconductor (MOS)-controlled devices.

Two key features differentiate power semiconductor performance—power rating and switching speed. While the need for increased power ratings clearly affects the range of applications for power electronics devices, the switching speed can sometimes represent the more critical need.

Switching speed derives its importance from the fact that power electronics devices emit an approximation of the desired (generally sinusoidal) voltage and current waveforms. This is done by emulating the specified frequency and magnitude, for which the timing and magnitude can be varied, with a series of short-duration pulses. The faster the pulses switch on and off, the greater the flexibility and accuracy of the output waveforms, and the wider the applicability and energy efficiency.

In general, as the power-handling capability of a power semiconductor device increases, its switching speed at efficient operation decreases. The power electronics industry has made significant progress over the past several years in pushing devices to higher speeds, at higher voltage and current levels. As a result of this progress, many new, innovative circuits are now limited by passive circuit elements, particularly magnetics (e.g., transformers and inductors).

PEAC's research on devices and components involves the application and development of advanced semiconductor switches and more nearly lossless passive circuit elements. Specific activities include promoting the application and development of advanced discrete devices and power-integrated circuits through device modeling, testing, and packaging; monitoring performance reliability and failure modes of commercial and prototype power devices in circuits; and developing advanced passive components compatible with future high-frequency-circuit requirements. (High-frequency operation can have many benefits, such as reduced size and weight requirements for electric motors and magnetic storage elements.)

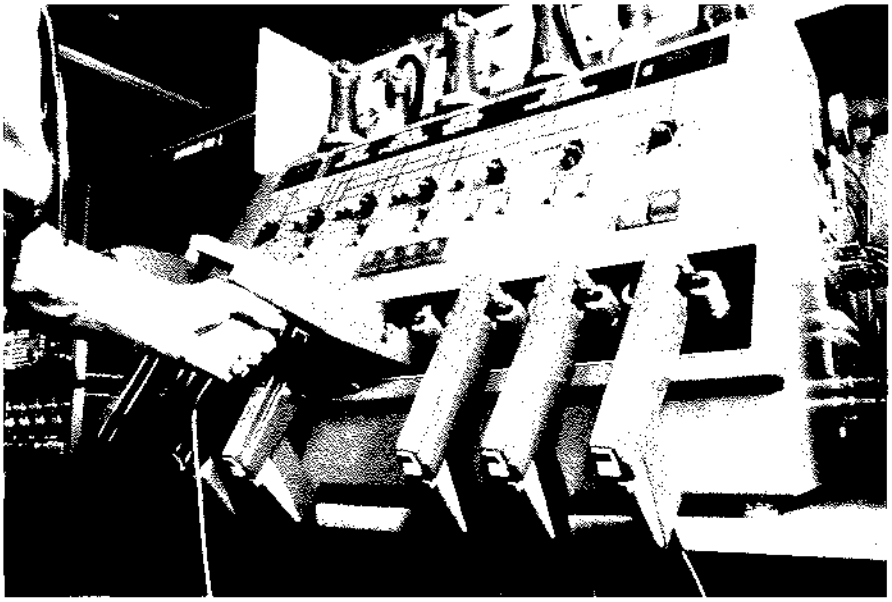
Power electronics devices and components have to be integrated into specific circuit topologies (configurations) to provide functions that meet the needs of specific applications. Recent and foreseeable developments in power devices make possible new circuits with increased efficiencies and less harmonic distortion (which will improve power quality). PEAC's circuits and controls research seeks to facilitate the introduction of revolutionary circuit configurations and topologies into the various end-use applications. Specific activities include developing new circuit topologies (e.g., resonant and quasi-resonant link circuits) for high-power, high-frequency applications; integrating new devices, such as the MOS-controlled thyristor, into power electronics circuits to exploit the simplified control requirements and more-efficient switching properties of these devices; developing microprocessor-based control systems to improve performance and reliability for power electronics circuits; developing analysis tools to simulate electrical and thermal performance, evaluate power quality and reliability, and assess the economics of a given design; and developing design rules to aid designers in developing, and optimizing the power of, electronic circuits and controls for end-use applications.

Controls and systems applications

Macroscopic controls range from simple time- and temperature-dependent controllers to sophisticated state-dependent adaptive systems that incorporate microprocessors. Power electronics systems include adjustable-speed drives, uninterruptible power supplies, active power-conditioning systems, ac-dc converters, dc-ac inverters, ac-ac frequency converters, and dc-dc level shifters. In essence, power electronics equipment allows the user to convert the fixed-voltage and -frequency electricity provided by the utility to the voltage and frequency needed for a specific application. This equipment is widely used across the residential, commercial, industrial, and utility sectors.

Current controls and systems applications research at PEAC focuses on accelerating the use of advanced devices and circuits in these systems and documenting the productivity increases, product quality improvements, and cost reductions achievable through the use of this equipment. For adjustable-speed drives, uninterruptible power supplies, and active power-conditioning systems, specific activities include developing directories of manufacturers; documenting system implemen-

Figure 1 The Power Quality Test Facility will be used for conducting controlled experiments on utility and customer equipment in order to quantify both the sensitivity of these systems to power disturbances and the production of waveform distortions. Shown are hand-held probes from a test machine that measures equipment voltage and current.



tation; formulating generic methods for application assessment; and developing advanced equipment that incorporates new developments in devices and circuits.

Power quality

Electronic equipment is available today to perform many important tasks. However, much of this equipment is highly sensitive to the specific characteristics of the electricity supply (e.g., waveform, frequency, voltage level). The need to manage power quality and to protect sensitive electrical loads from disturbances has created a new challenge.

PEAC's power quality efforts (Figure 1) will make it possible to quantify the costs and benefits associated with power quality (through laboratory research and field measurements), improve the understanding of power quality issues and solutions (through educational services), and assist in the development of nationally recognized guidelines and recommended practices. Specific activities include assessing power electronics and computer equipment to determine both sensitivity to and potential for creation of power disturbances; assessing the costs of poor power quality, as manifested in lost productivity and shortened equipment lifetimes; developing a power quality training program for utility field engineers on detecting, analyzing, and mitigating power quality problems; and providing data to assist in developing power quality guidelines and recommended practices in cooperation with other organizations concerned with power quality issues.

PEAC's Power Electronics Laboratory is a focal point for numerous activities in equipment development and performance monitoring. The laboratory now houses unique power quality facilities that will eventually support training for utility field engineers in power quality problem detection, analysis, and mitigation. Through a collaborative program, the laboratory also serves as the primary location for research conducted by the University of Tennessee under the direction of the PEAC chief scientist. Collaborative research with other universities is anticipated.

PEAC's ultimate goal is the adoption of advanced power electronics technologies by U.S. industry; its emphasis is on electric utility and utility customer applications. Because laboratory research tends to focus on the basic building blocks of a technology, technology evolution tends to flow from devices and components to circuits and controls, which are applied in systems. At the same time, end-user requirements and market demand are determined at the systems level. The end user sees how a system works but may not be aware of the components that make it work.

Information on technology needs flows from the marketplace back into systems needs, which are then reflected in circuit, control, device, and component development needs. PEAC's communications and technology transfer provide a critical pathway for the flow of power electronics information.

These communications activities aim to inform and educate electric utilities about power electronics issues, applications, and opportunities so that they can help their customers improve their productivity, efficiency, and lifestyles. These activities also facilitate the flow of information among utilities, researchers, manufacturers, and end users. To meet this objective, PEAC assists researchers in maintaining awareness of market requirements, assists research centers in transferring new technology from laboratory to manufacturer, and assists manufacturers and utilities in accelerating acceptance and implementation of power electronics technologies into the U.S. marketplace.

PEAC publishes a variety of documents to meet these communications objectives:

- *TechCommentary:* a discussion of specific aspects of current or emerging technologies and their application
- *TechApplication:* a short case study of a technically and economically successful power electronics technology application
- Brochures: overviews of programs or activities to inform the power electronics community of opportunities for further development
- Product directories: continuing, up-to-date references on available equipment
- Newsletter: a quarterly designed to inform subscribers about PEAC activities
- Research reports: in-depth technical reports on R&D projects

Other activities include workshops, seminars, and the periodic Power Electronics Applications Conference. PEACon brings together power electronics professionals to discuss issues, share ideas, and become informed about PEAC's R&D projects.

Need for collaboration

In the fast-changing power electronics industry, collaborative ventures present a way to share R&D costs and risks to achieve common goals in technology development. PEAC has begun to establish the strong collaborations necessary to implement research, development, information dissemination, and technology transfer. Projects may include subcontracting to industry or universities, or they may be conducted solely by PEAC. Priority will be given to projects cosponsored by EPRI.

PEAC has begun its significant journey toward becoming a primary focus for cutting-edge research, development, and applications in power electronics and controls. EPRI and PEAC strongly encourage collaborative participation with manufacturers, universities, research centers, end users, and member utilities.

Renewable Resource Power Plants

Wind Systems

by John Schaefer, Generation and Storage Division

ABSTRACT *The wind power industry in the 1980s provides a variety of lessons in energy technology development, ranging from engineering and testing to the development of data to determine wind power economics. Alone among the alternative energy technologies, wind power offers utilities with good wind resources pollution-free electricity that is nearly cost-competitive with today's conventional sources.*

A decade ago, attention was focused on development programs for large, multimegawatt wind turbines that borrowed heavily from sophisticated aerospace technology. Of much greater significance over that 10-year period, however, has been the private development of small to midsize turbines, ranging from 17 to about 600 kW in nameplate rating. The industry began in 1981 with 144 midsize turbines totaling 7 MW and as of 1989 has grown to approximately 17,000 turbines, mostly in California, totaling 1500 MW. Only one multimegawatt turbine remains operating in the United States.

But total capacity tells only a part of the story; what matters to utilities and other investors is revenue developed, and this in turn depends on energy produced. Two major factors determine energy production: wind speeds at the sites where turbines are installed, and turbine design and maintenance practices.

Turbine siting

Three areas in California contain the great majority of U.S. wind power plants: the Altamont Pass, east of San Francisco; the Tehachapi Pass, north of Los Angeles; and the San Gorgonio Pass, east of Los Angeles. EPRI has monitored turbine performance in all three areas, as reported in *Assessment of Wind Power Station Performance and Reliability* (GS-6256).

Located in the windiest area, the turbines monitored at San Gorgonio consistently averaged 26–27% annual capacity factors, whereas those at the Altamont averaged 19–22%. Because EPRI monitored machines with the best maintenance and the most extensive data collection, these capacity factors are probably higher than those of other machines in the same areas.

Performance variations among turbines installed in the same area illustrate the importance of micrositing, the specific placement of each wind turbine. For example, one group of 58 turbines at San Gorgonio showed capacity factors of 35–39% over a four-year period, whereas another group of 20, only a few miles away, averaged 14–15%.

In relatively flat terrain like San Gorgonio, turbines are usually arranged in rows. Array effects for turbines inside the array and downwind from other turbines reduced energy production 3–15%, compared with turbines in the first row.

Developers in the early 1980s typically overestimated the energy their power plants would produce, in part because of inadequate wind-speed data. Because turbine output is proportional to the cube of the wind speeds in most of the power curve, wind speeds at each turbine site are a crucial factor in determining wind power economics.

Although wind power plant designers are testing computer programs that assist in micrositing, one important lesson from wind power's first decade is the importance of measuring wind speeds for at least a year (with meteorological, or met, towers and wind-speed recorders at several elevations) before installing turbines. Empirical data from met towers not only enable developers to make more accurate projections of the electric energy that can be generated annually at a particular site, but also provide necessary input for the micrositing computer programs. Making use of computer programs is faster but riskier than waiting a year for empirical data; using both provides the best results.

Turbine design and maintenance

Designs for midsize wind turbines fall into two architectural categories, based mainly on their continental origins. U.S. turbine designers have minimized material usage to keep costs low, as is illustrated by the ESI turbine design; Japanese and European turbines, like the Bonus, typically weigh two-and-one-half times per kW as much as their American counterparts (Figure 1).

A variety of choices were available for wind turbine architecture, including upwind or downwind orientation; tubular or lattice towers; stall or pitch regulation with full or partial span; various braking schemes; single- or two-speed operation; wood, epoxy, or fiberglass blades; and various yaw control mechanisms. A recent analysis of some 4500 wind turbines conducted by R. Lynette and Associates concludes that, with a few exceptions, the best design choices are not immediately obvious (GS-6245). Both good and bad performances have been obtained from all these architectural features.

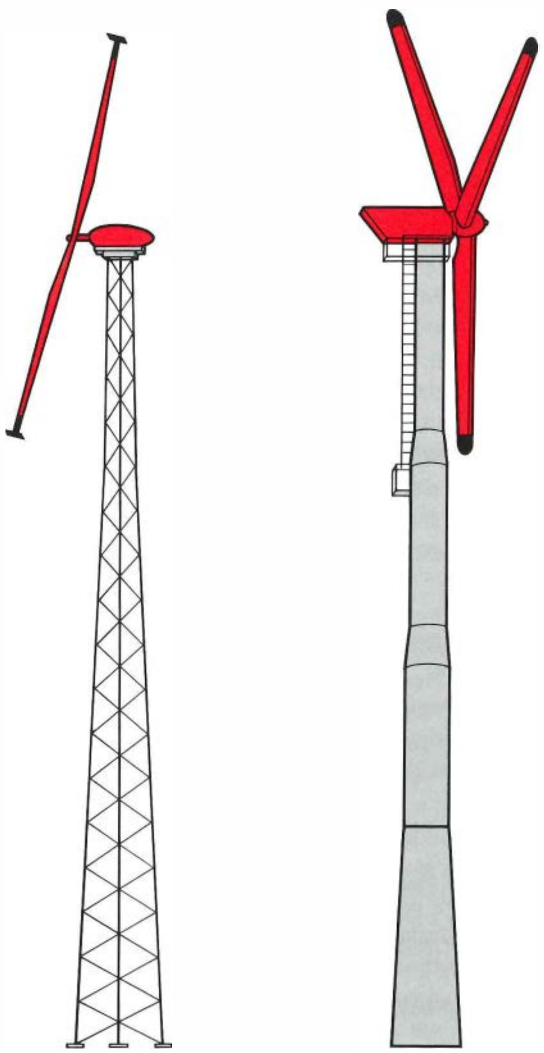


Figure 1 U.S.-designed wind turbines, such as the ESI (left), use less material than the heavier-duty European machines, like the Danish-made Bonus turbine (right); as a result, the U.S. turbines often are more cost-effective.

Besides the wind speeds at the turbine's site, the factors that influence electricity production are the turbine's reliability and the efficiency with which it extracts energy from the wind.

In general, the U.S. turbines convert wind energy to electric energy more efficiently than do the European turbines, because of their more-efficient airfoils and in some cases their use of variable pitch control. However, nothing comes without a cost—variable pitch control, for example, comes at the cost of greater complexity.

One major source of inefficiency, with up to 15% losses in some cases, is blade soiling. A short-term solution is washing, particularly during the bug season, but the better long-term solution is to use airfoils that operate more efficiently with rough surfaces. Airfoil research continues with private and government support.

Reliability, as reflected by wind turbine availability, continues to be a problem for some turbines. Ranges of availabilities tell as much as averages. The average annual availability for a 975-turbine sample is a tolerable 89%; individual groups range from 98%, for the best-maintained turbines, to a low of 63%. The higher values reflect the future of wind power better because they are based on utility-grade maintenance programs, which are essential to high availability. European machines, while not without problems, have generally proved more reliable than early U.S. models.

Reliability depends on location as well as on design and maintenance. Energetic sites produce more electricity, but they also produce more damage. As an example, for sets of identical turbines, twice as many maintenance events were counted at Tehachapi and San Gorgonio as at the Altamont Pass, where winds are lighter. Array effects are perversely apparent in both production and reliability; turbines inside arrays encounter less wind energy, but because of turbulence from upwind turbines they also suffer more damage.

Failures have occurred in almost every turbine component: blades, gearboxes, brakes, controls, generators, cables and wiring, yaw systems, and even towers. The variation in component reliability levels is illustrated by the wide range in numbers of unscheduled maintenance events per year. Rotors, which include blades, hubs, aerodynamic brakes, teeter mechanisms, and pitch control mechanisms, serve as a good example. Some have been practically trouble-free, at 0.05 event per year, and others have been unacceptably troublesome, at 4 events per year. Similar observations can be made for other components and for turbines as a whole.

One conclusion is that components with reliable designs are available. An optimistic wind power plant operator puts it differently: "We have the best component designs running here in the Altamont, but they aren't all assembled in one machine yet."

But designing a reliable wind turbine is more than assembling reliable components. Comprehensive failure analyses of some machines showed that the designers had failed to evaluate dynamic loads, load paths, stresses, and fatigue. In some cases engineering tools were not available to carry out these analyses, and in others the available ones were not used. Compounding this problem, turbine manufacturers sometimes failed to field-test their designs adequately or at all. Moreover, in the rush to build machines to meet year-end tax credit deadlines, quality assurance in manufacturing sometimes suffered. The combination of immature designs and poor quality control contributed to poor availability.

Prospects for the industry

Encouraged by tax credits, the industry's rapid growth in the early 1980s created a situation in which responsibility was passed from one participant to another. Turbine manufacturers sold their products to developers, who in turn installed them and sold them to individuals and limited partnerships. Typically, the developers carried the responsibility for operating and maintaining the turbines, supported by guarantees from the manufacturers and by insurance policies that covered repairs and loss of revenue when machines failed to run. Because many turbine suppliers and developers eventually declared bankruptcy, the insurance companies shouldered much of the repair and retrofit burden.

During this same period, an alternative scenario unfolded in which a single firm—U.S. Windpower—designed and manufactured turbines, developed sites, installed turbines, operated them, and sold electricity to Pacific Gas and Electric. Under this scenario no buck-passing was possible, and because U.S. Windpower was adequately financed, it was able to do its engineering and testing carefully. The firm is now operating about 3400 100-kW turbines in the Altamont and is testing a prototype 300-kW turbine.

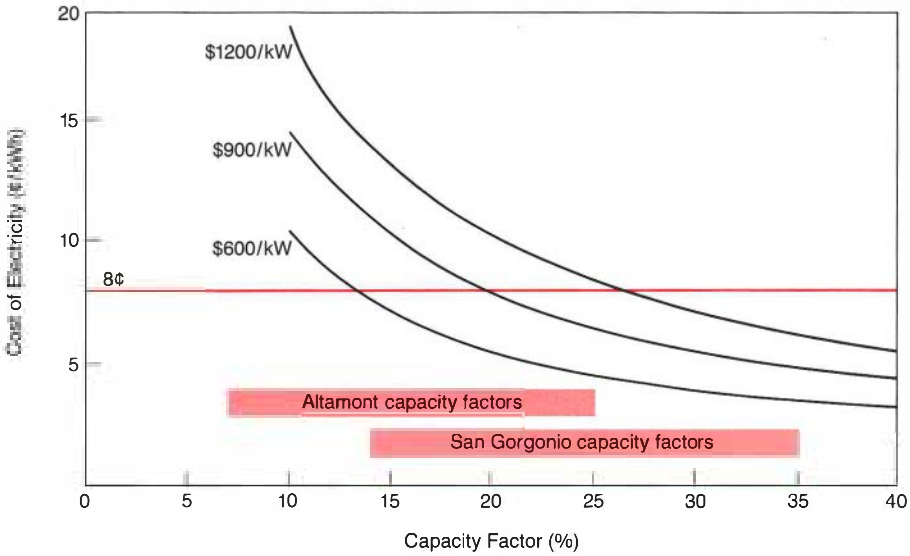
In spite of its technical and economic problems, the wind power industry continues to be optimistic, both because there is increased interest among utilities in nonpolluting electricity sources and because wind power costs are now approaching par with those of other, more conventional sources.

Wind electricity costs have a fixed component, which depends on the original investment, and a variable component, which depends on operating and maintenance expenditures. Good historical data are now available for estimating both costs.

Operating and maintenance costs calculated from the sample of 975 turbines range from 0.5¢ to 1.7¢ per kWh, averaging about 1¢. Investment costs for wind turbines and the balance of the systems (wiring, transformers, switchgear, roads, installation, and the like) are $900 per kW and up. Another key factor in the calculation is the annual average capacity factor; the higher this measure, the more the energy output over which the fixed charges can be distributed. Finally, the fixed-charge rate for annual amortization of the original investment is important; the lower this value, the lower is wind electricity's cost.

In good sites, wind power costs about 8¢ per kWh (Figure 2), just about the same as power from more conventional sources. Caveats to this statement reflect the lessons of the 1980s. Capacity factor can be estimated ahead of time only with careful wind measurements. Operating and maintenance costs are

Figure 2 The cost of electricity depends on the investment cost, the capacity factor achievable, and the operating and maintenance costs. Data shown are based on a 20-year life, a 12% rate of return, and operating and maintenance costs of 1¢ per kWh.



as low as 1¢ per kWh only if there are enough identical turbines at a site to justify adequate maintenance facilities, and 20-year turbine life has yet to be demonstrated.

Like many other technological industries, wind power is going international. Because of expanded concern for the environmental costs of fossil fuel and nuclear power, Europe is becoming the center of wind power research and development. Wind power research and development continue in Denmark, Scotland, Japan, England, Holland, Germany, and Austria. Not surprisingly, foreign firms are still supplying turbines to wind power plants in the United States. What is perhaps surprising is that if it were not for U.S. Windpower, the vast majority of installations in this country would now be of foreign origin.

Power System Planning and Engineering

Power System Reliability Evaluation

by Mark G. Lauby, Electrical Systems Division

ABSTRACT *Sophisticated reliability evaluations are needed to meet the challenge posed by the increasing size and complexity of modern power systems. EPRI is pioneering efforts to perform integrated generation and transmission reliability analyses to help utilities optimize system design and expansion plans, improve system operation, effectively communicate reliability issues to regulators and the public, and begin work in the area of value-based planning.*

In planning, designing, and operating power systems to supply electricity to customers as economically as possible, utilities must also maintain acceptable reliability. Though current methods of evaluating reliability examine the contributions of both generation and transmission to system reliability, the enormous capital costs and the increasing complexity of power systems have aroused industry interest in developing advanced methods for reliability evaluations. Increasing utility interest in value-based planning is another motivation for developing advanced reliability evaluation methods. Value-based planning involves quantifying the customer's cost during a power interruption. When this cost is known, the value to a customer of increasing generation and transmission reliability can be quantified.

Assessments of power system reliability involve two basic aspects—adequacy and security. System adequacy refers to the need for sufficient generation and transmission capacity to meet system load. Adequacy assessment includes analysis of system problems occurring under static conditions (e.g., overload of transmission and bus voltage limitations) that may result in partial load curtailment. A steady-state reliability evaluation is an assessment of power system adequacy. System security, the other basic aspect of reliability, refers to the ability to respond to sudden disturbances (e.g., lightning strikes or line-to-ground faults) without widespread outages. Security assessment includes analysis of such problems as instability, overload cascading, and voltage collapse, which may result in total system shutdown.

Assessment criteria

The criteria used to assess power system reliability can be categorized as either deterministic or probabilistic. In the deterministic approach, the initial system design is explicitly evaluated for precontingency conditions (load and generation patterns) selected by a mixture of judgment, tradition, and experience. Although utilities have used this approach in the past, the increasing size and complexity of power systems call for it to be augmented by probabilistic methods.

In the approach based on probabilistic reliability criteria, the risk of system failure is assessed on the basis of outage statistics for system components. The probabilistic approach has been implemented by means of two different methods—the analytical method and the Monte Carlo simulation method. One common way to perform an analysis of transmission reliability with the analytical method is to use contingency enumeration, which systematically selects and evaluates contingencies for one or more precontingency conditions. The Monte Carlo method, on the other hand, uses random sampling to determine both the precontingency conditions and the contingencies to be evaluated.

Planners have recognized the need for a quantitative, probabilistic evaluation of system performance since the 1930s. Probabilistic methods are today widely accepted by planners for assessing the adequacy of installed generating and transmission capacity. These methods seek to eliminate the dependency on judgment in the selection of contingencies by attempting to look at all those that are significant. Because these techniques are also explicitly concerned with the impact on the customer, the reliability measures that they use are easily understood by the consumer of electricity. For example, one accepted probabilistic criterion is the loss-of-load expectation (LOLE). Using this criterion, planners could predict that in 10 years there would probably be one occasion on which load would not be met.

An effective steady-state reliability evaluation requires analysis of generation reliability, analysis of transmission reliability, and analysis of combined reliability (the interaction of generation and transmission). Although both the contingency enumeration method and the Monte Carlo method can be used to help determine each of these components, some studies show that one or the other of these methods may yield increased accuracy for some of these components.

Generation reliability

The goal of EPRI research on power system reliability is to use probabilistic and deterministic criteria to enhance steady-state reliability evaluations. In the area of generation reliability, the existing methods, available for several years, do not explicitly recognize many unit and system operating considerations that influence system reliability. To address this need, EPRI has identified these operating considerations and developed three computer models capable of incorporating the effects into generation system reliability evaluations (RP1534-1).

OPCON and OPPLAN use two different analytical methods of modeling unit operating characteristics, and GENESIS, a detailed Monte Carlo network simulation model, calculates generation system reliability indices. These programs effectively model single-area power systems with no free-flowing ties to other areas.

Because many utilities operate as members of interconnected power pools, a pool-modeling capability was needed. EPRI expanded the OPCON model to form OPRINS, which makes it possible to study interconnected systems with up to 10 areas, and expanded GENESIS to form GENAREA and GENPOOL, which can simulate 2-area and 3-area systems (RP1534-2). Utilities can use these programs to evaluate alternative operating policies, coordinate power transfers with neighboring utilities, evaluate the benefits of interconnections, and improve generation system reliability.

The Monte Carlo type of model (similar to the one used in GENESIS) may be more appropriate than the analytical approach for the evaluation of generation reliability. A Monte Carlo model can be executed for many randomly selected precontingency conditions (generation patterns) and thus can capture the diversity of generation outage states.

Transmission research

Transmission network reliability is also critical to overall steady-state system reliability and should be considered, while taking into account both reserve margins and outages, when optimizing the total generation requirements. For example, even if generating capacity is adequate, it may not be in the right place and transmission capability may be inadequate to carry the required load. To achieve the required reliability at the load points in value-based planning, enhanced transmission reliability is used instead of adding generation capacity.

To analyze transmission reliability, the contingency enumeration method may be most appropriate. This method can be used in the initial screening of precontingency conditions (load and generation patterns) to determine the cases where transmission capability is most critical. Those cases can then be examined in detail (using preset load and generation patterns) to study transmission adequacy or the addition of transmission as an alternative to generation.

At any rate, reliability evaluation of a bulk power transmission system requires component outage data, as well as uniform definitions and reporting procedures to facilitate comparison of data. EPRI has developed a set of consistent definitions, formats, and procedures for use in the collection of outage data on bulk transmission systems (RP1283-1). In a related project, statistical methods were identified and developed for analyzing data and forecasting outage statistics on major power system components, such as generating units, transmission lines, and transformers (RP1468-1).

A follow-on project developed mathematical models for predicting forced outages of single and multiple transmission lines (RP1468-2). These models were validated by comparing the number of forced outages predicted with the number that actually occurred on one line. This effort resulted in the development of an instruction set called Transmission Outage Performance Prediction (TOPP), for use with the commercially available Statistical Analysis System (SAS) software package.

These methods can then be used to develop outage data for use in any transmission reliability model. Because there was no statistical model to address transmission reliability, EPRI developed SYREL (RP1530-1). A contingency enumeration model, SYREL is used to systematically select and evaluate contingencies, classifying them according to system failure criteria. The severity of a system problem is assessed by computing the amount and location of load curtailment necessary to eliminate the problem. Hence, area or bus reliability indices that measure the frequency, duration, and amount of expected load curtailment can be computed for small-scale power systems (up to 150 buses).

A follow-on project tested new methods of assessing large-scale bulk transmission system reliability and prepared functional specifications for a production-grade program currently under development (RP1530-2, -3) and tentatively designated BSTRE (bulk system transmission reliability evaluation).

Combined reliability

While the strength of some models (e.g., SYREL) is transmission system reliability evaluation and the strength of other models (e.g., GENESIS) is analysis of generation system reliability, no model in general use in the U.S. utility industry effectively simulates combined transmission and generation reliability. Such a model is needed to provide a measure of outages resulting from a combination of the effects of both systems.

An EPRI project studied combined system reliability and identified indices that best represent this reliability (RP2581-1). Project findings illustrate that combined generation and transmission outage events can contribute significantly to the unreliability of a composite system. Investigators also concluded that the ability of the Monte Carlo method to simulate many randomly selected combinations of precontingency conditions (e.g., generation patterns) and many contingencies (e.g., transmission line outages) makes this the most appropriate method for application to composite modeling.

EPRI is developing a Monte Carlo–based, production-grade program, called CREAM (combined reliability evaluation analysis using Monte-Carlo methods) for combined system reliability evaluation. This program, intended for analysis of medium-sized bulk power systems (up to 500 buses), will be used by system planners and designers to compare system designs, justify new facilities, and identify system weaknesses.

Probabilistic reliability indices promise to fulfill the needs of the planner for system design and expansion, and the needs of the public for communication of reliability information. Using both the refined and new methods, utilities will be able to predict what times of the year coincide with higher probabilities of outages and accordingly schedule preventive maintenance. In the future, combined reliability methods will provide more comprehensive indices for assessing power system reliability and will aid in value-based planning efforts (including trade-offs between added generation versus transmission).

Nuclear Plant Operations and Maintenance

Preventing Station Blackouts

by Harvey Wyckoff, Nuclear Power Division

ABSTRACT *The prolonged loss of all ac power to a nuclear power plant can have serious consequences. To reduce this risk the nuclear industry and the NRC have worked together to specify measures that minimize the probability and consequences of a blackout. These measures depend on accurate reliability data about the plant's ac power sources, and until recently such data did not exist. Three years of EPRI effort resulted in the creation of databases that played a role in helping industry reduce the blackout risk.*

On May 12, 1988, the NRC affirmed a package of industry-proposed initiatives for ensuring that nuclear power plants have the capability to prevent and deal with station blackouts. This was the culmination of a five-year industry/NRC effort to fashion an upgrade program to achieve a major reduction in blackout risk in the most cost-effective manner. The nuclear power industry had proposed the initiatives in response to a long-term NRC and industry recognition that station blackout is one of the more important potential upset conditions. The purpose was to further reduce the probability of station blackouts at nuclear power plants and to further enhance the ability to cope with a blackout if it should occur. The industry worked with the NRC staff to include regulatory input. The result was a package of initiatives that the NRC endorsed and that both the industry and the NRC judge to be worthwhile and capable of meeting their needs.

Station blackout is defined as the loss of ac power from both off-site sources and on-site safety-grade emergency sources. Blackout, though rare, is possible. In the event of a station blackout, the capability to cool the reactor core is dependent on the availability of systems that do not require ac power—such as pumps driven by steam turbines or diesel engines—or on on-site non-safety-grade ac sources. It is also dependent on the ability to restore off-site or safety-grade on-site ac power within a number of hours. The concern is that a prolonged station blackout might result in a core damage accident.

Station blackout is of interest because there are instances when nuclear units become disconnected from all sources of off-site power and also instances when the reliability of diesel generators slips below the desired minimum. To date, there has never been a station blackout that was a particular threat. There have been four instances in which a plant experienced a short blackout. The shortest lasted 4 minutes and the longest, 25 minutes.

Though none of these events posed a significant risk, they showed that the simultaneous loss of off-site and emergency on-site ac power can occur.

Plants have always had a number of features for dealing with the consequences of a station blackout. Some plants have non-safety-grade on-site sources of ac power, such as generators driven by gas turbines or diesel engines. All BWR plants have steam turbine-driven or diesel-driven high-pressure pumps for injecting water into the reactor, and most have some means of routing water from the diesel-driven fire pump to the reactor. All PWR plants have, or are installing, steam- or diesel-driven auxiliary feedwater pumps for removing heat from the reactor. These generally are viewed as backup levels of defense.

Equipment driven from off-site and from safety-grade emergency on-site ac sources is the first line of defense at most plants. The extent of a plant's susceptibility to a station blackout is in major part judged by the reliability of the off-site power and the reliability of the on-site safety emergency power sources. EPRI helped the industry and the NRC reach their blackout resolution goals by accurately and realistically determining these reliabilities.

EPRI's role

In its role of providing technical input to the industry's effort, EPRI was privileged to assist in a highly successful pioneering effort. This was the first time an industrywide organization was pulled together to address a major generic technical issue. The Nuclear Utility Group on Station Blackout (NUGSBO) was organized in the spring of 1984. By the fall of 1985, NUGSBO had support from most of the nuclear utilities. Through NUGSBO the industry as an entity was able to develop a technical basis for dealing with the blackout issue, for achieving industry agreement on how to proceed, and for interacting with the NRC. NUGSBO's goal was the reasonable resolution of the blackout issue. In the fourth quarter of 1985, the newly organized Nuclear Management and Resources Council (NUMARC) established a working group to oversee the industry's efforts on the issue. Created by the nuclear utilities, NUMARC addresses technical issues common to the industry and coordinates the industry's interactions with the NRC. The NUMARC working group asked NUGSBO to continue as the lead technical organization for the station blackout effort.

From the beginning EPRI was active in providing technical input to NUGSBO. Fortunately, EPRI's several years of intense previous effort yielded valuable immediate input. The NRC's heightened interest in station blackout was heavily focused on the reliability issue. There had previously been no formal effort to develop highly accurate, consistent, industrywide reliability databases. The data void relative to off-site power was particularly notable. There had never been a comprehensive effort to collect these data or to establish rules for defining loss of off-site power. Plants' reports had generally not distinguished between partial losses and complete losses. Though various organizations made limited attempts to pull together reliability data for loss of off-site power, these efforts generally did not include in-depth investigations of the events that had occurred during the past several decades. It was this large step that was to differentiate the EPRI effort from most previous efforts.

There was a similar need for accurate information about emergency diesel generator (EDG) reliability at U.S. nuclear plants. The NRC some years earlier had set forth a method and criteria for determining what should be considered an EDG failure. These NRC rules, crafted to meet regulatory needs, encompassed a simplified methodology that yielded highly conservative results. In this case, too, there had been no all-out effort to investigate each failure reported and to determine whether plants were uniformly classifying such events.

Just as the industry/NRC blackout efforts hit stride in 1984 and 1985, the three years of EPRI efforts were coming to fruition, and accurate reliability data became available. With these data, the picture regarding the risk from station blackout changed dramatically.

Off-site database

EPRI published its first loss of off-site power database for U.S. nuclear plants in June 1984. It included data for all years from the beginning of commercial nuclear power through 1983. EPRI's goals for the database were very demanding. For each event, the data collected indicate how long all off-site power was truly unavailable, as opposed to available but not used. Upon loss of all off-site power, a plant's emergency diesel generators assume the load. Even though it may be possible to resupply plant loads from off-site power very quickly, most nuclear plants stay on the diesel generators until a convenient moment presents itself for switching back to off-site power. Also, in many events backup off-site power is available but is not used, and this important fact had previously gone unreported.

To create a database sufficiently detailed to reflect these subtleties, it was necessary to review or reinvestigate past events. When this effort was launched, Oak Ridge National Laboratory was preparing a similar database for the NRC. Oak Ridge had assembled a large file of information and had turned to an IEEE working group to acquire additional information on selected events. EPRI concurred with this effort; it further came to believe that most events should be reinvestigated, and decided to devote better than a year of effort to the task.

During the first several years, EPRI, Oak Ridge, and the IEEE working group cooperated in researching losses of off-site power, and ultimately the EPRI and Oak Ridge databases were essentially identical. EPRI has continued to investigate each new loss and to keep the database current.

In 1989, for the sixth consecutive year, EPRI has updated and published the loss of off-site power database for U.S. nuclear plants. In 1983, prior to when the EPRI effort began, the data available indicated that there was a 15% chance that a nuclear plant would lose all contact with off-site power sometime during a year. The database study's initial investigation of all past losses indicated only an 11% chance of losing off-site power. The data also showed that the indicated reliability was heavily influenced by the experience during the startup years of the industry, and that reliability in recent years was much better.

During the past three years, there have been seven losses of off-site power at U.S. nuclear plants, or about two per year. This is only 0.033 loss per site year. Even the long-term average, which includes the less favorable experiences of the 1960s and 1970s, is only 0.070 loss per site year. The median duration of all losses of off-site power is one-half hour. Weather events have a potential for longer outages. In past years there have been 16 losses of off-site power due to weather, including 8 significant weather-caused outages and 8 of minor importance. The median duration of losses of off-site power caused by weather alone has been one and one-half hours. In most instances a source of off-site power is restored in a relatively short time. In about seven-tenths of all losses, off-site power was available in less than one hour. In four-fifths of the instances it was available in less than two hours; for nine-tenths of the losses it was available in less than four hours.

EPRI's investigative efforts have documented the nuclear power industry's continuing improvements in off-site power reliability and the excellent levels of reliability that are being achieved. Having documentation of this performance was an important factor in demonstrating that U.S. nuclear plants are at minimal risk from loss of off-site power.

EDG reliability

Before 1985 there were no comprehensive, uniform efforts to collect industrywide records of nuclear plant emergency diesel generator reliability. Those surveys that had been undertaken were based on the extremely conservative success/failure criteria and methodologies that resulted from earlier regulatory efforts. The outcome led to NRC uncertainty about the reliability of these generators.

To help the industry get the facts in hand, EPRI took the lead in organizing, investigating, and compiling a realistic EDG reliability database. The survey covered the years 1983, 1984, and 1985. The survey was managed by EPRI, but the data were provided by the nuclear utilities. There was a concerted effort to make the survey comprehensive and to report the experience of all utilities in a rigorously consistent manner. The goal was to develop values that accurately indicated the contribution of EDG unreliability to plant risk. The first principle for judgment was always "Would the EDG have fulfilled its mission in a real emergency?"

EPRI provided the utilities with detailed guidance for determining EDG successes and failures. For the most part, the data were developed from original operating records. Data development generally required 100–200 hours of effort per nuclear unit. The data and success/failure judgments were then reviewed by EPRI and the utility. Where it was evident that a utility interpreted criteria differently than was intended or differently than other utilities did, the data were adjusted to achieve consistent treatment. The survey included 154 EDGs and 424 EDG-years from 75 nuclear units on 52 sites.

The survey gathered data from both tests and unplanned demands. The results are based on 22,104 start demands and 13,808 load-run demands. The survey showed that overall EDG reliability is excellent: 98.6% for tests and unplanned demands and 97.8% for unplanned demands only. There is good consistency: the years 1983, 1984, and 1985 all turned in similar results. In fact, with both the start-phase reliability and load-run-phase reliability at such high levels, there is little opportunity for generic EDG improvement. Real, unplanned demands account for only 2% of all EDG starts; the rest is testing.

As with off-site power, the reliability of on-site emergency power is excellent. Fortunately, the information was available by the time the industry most needed it. The Institute of Nuclear Power Operations is now keeping this database current.

In the main, the nuclear power industry has succeeded in developing an approach for ensuring that the risk of station blackout is suitably small. Through NUGSBO and NUMARC, the industry has proposed a program that will give that assurance and has worked with the NRC to gain regulatory acceptance. The major efforts by EPRI to accurately determine the reliability of off-site power sources and of on-site safety-grade emergency power sources were an important contributor to NUGSBO's and NUMARC's, and hence the industry's, success. But the efforts still have a little way to go. In resolving the blackout issue, the industry committed to defining a more formalized, industrywide approach to ensuring EDG reliability. EPRI now is providing technical support to NUMARC on this effort.

New Contracts

Project	Funding/ Duration	Contractor/EPRI Project Manager
Business Management		
Effects of Fuel Switching on Gas Market Risks (RP2369-42)	$164,500 9 months	Putnam, Hayes & Bartlett, Inc./*J. Platt*
The Financially Driven Power Plant: The PC Alternative (RP2379-20)	$19,500 8 months	Energy Ventures Analysis Inc./*J. Platt*
Research Issues in Transmission Service Valuation (RP2767-4)	$127,800 8 months	Applied Decision Analysis, Inc./*H. Mueller*
Customer Systems		
EV Battery and Associated Component Testing (RP1136-33)	$294,900 12 months	Electrotek Concepts Inc./ *R. Swaroop*
Electric Vehicle Performance Testing (RP1136-35)	$210,000 9 months	Electrotek Concepts Inc./ *G. Purcell*
HT 2000 Market Assessment Study (RP2033-28)	$49,000 3 months	Opinion Research Corp./ *J. Kesselring*
An Assessment of Moisture Problems With Horizontal Radiant Barriers (RP2034-30)	$37,600 7 months	Martin Marietta Energy Systems Inc./*J. Kesselring*
ESPRE Program Enhancements and User Support (RP2034-33)	$105,000 12 months	Arthur D. Little, Inc./ *J. Kesselring*
Integrating Pricing Strategy With Corporate Strategy (RP2343-3)	$50,000 7 months	Booz, Allen & Hamilton, Inc./*W. LeBlanc*
Predicting and Measuring Customer Response to Innovative Pricing (RP2343-4)	$50,000 8 months	Barakat, Howard & Chamberlin Inc./ *W. LeBlanc*
Electrical Systems		
Lateral- and Moment-Loading Foundation Design (RP1493-7)	$614,900 52 months	GAI Consultants, Inc./ *V. Longo*
Seasonal Variations in Ground Grid Parameters (RP1494-8)	$55,100 14 months	Southern Electric International Inc./ *G. Addis*
External Static Electrification in Power Transformers (RP1499-16)	$186,000 12 months	McGraw-Edison Power Systems/*S. Lindgren*
Improved Ammoniacal Copper Carboxilate Wood Preservative (RP1528-5)	$153,700 56 months	Mississippi State University/ *H. Ng*
Continued Monitoring of Field Stakes (RP1528-6)	$102,600 56 months	Michigan Technological University/*H. Ng*
Computer Program for Evaluating Distribution Automation (RP2021-2)	$198,600 7 months	Power Computing Co./ *T. Kendrew*
Development of an OS/2 Version of the Electromagnetic Transients Program (RP2149-11)	$41,500 3 months	Electrotek Concepts Inc./ *M. Lauby*
Molecular Dynamics of Icing on Cables and Structures (RP2367-2)	$90,000 25 months	Massachusetts Institute of Technology/*T. Kendrew*
Study of Critical Problems in Power Industry: Voltage Collapse (RP2473-36)	$100,000 24 months	Howard University/ *D. Maratukulam*
Robust Solution Methods for Nonlinear Network Analysis (RP2473-38)	$75,300 21 months	Arizona State University/ *M. Lauby*
Dynamic Break Stability Studies (RP2473-39)	$50,000 23 months	Montana State University/ *D. Maratukulam*
AI Approach to Varistor Development (RP2667-4)	$159,800 12 months	Westinghouse Electric Corp./*H. Mehta*

Project	Funding/ Duration	Contractor/EPRI Project Manager
Environment		
Body Burden Modeling (RP2310-6)	$199,900 10 months	Resource Planning Corp./ *A. Silvers*
Characterization of Summertime Acidic Particles and Gases (RP2434-8)	$171,800 25 months	Harvard University/*M. Allan*
Microbiological Characterization of a Manufactured Gas Plant Site (RP2879-5)	$58,900 11 months	Cornell University/ *I. Murarka*
Environmental Partitioning and Release of Organics (RP2879-7)	$569,000 18 months	University of Texas at Austin/*M. Elrashidi*
Assessment of a Study of Possible Occupational Health Effects of Ionizing Radiation Among Nuclear Utility Workers (RP2920-6)	$125,000 14 months	National Academy of Sciences/*L. Kheifets*
Exploratory Research		
De-embrittlement of Annealed Metallic Glass Ribbons (RP2426-21)	$151,000 36 months	Institut fur Metallphysik/ *R. Jaffee*
Advanced Materials for High-Temperature Fuel Cells (RP2706-5)	$319,000 36 months	Argonne National Laboratory/*R. Goldstein*
Application of Expert Systems to Power Electronics (RP8000-40)	$303,000 36 months	Tennessee Center for Research and Development/*B. Banerjee*
Problems in Aerosol Research (RP8000-41)	$112,500 32 months	Massachusetts Institute of Technology/*J. Maulbetsch*
Microwave Assisted Surface Enhanced Reactions (RB8000-45)	$170,00 12 months	SRI International/ *K. Amamath*
Electro-Optic Measurements in Dielectrics (RP8000-46)	$100,000 24 months	Massachusetts Institute of Technology/*S. Lindgren*
Generation and Storage		
CFBC Testing of Illinois Coal (RP718-11)	$50,900 1 month	Babcock & Wilcox Co./ *E. Petrill*
Support of AFBC Fuel Characterization Computer Code Development (RP718-12)	$25,000 3 months	Manufacturing and Technology Conversion/ *E. Petrill*
Cold Metal Analysis of FBC In-Bed Tube Wear (RP979-26)	$62,700 11 months	Foster Wheeler Power Products Ltd./*J. Stallings*
Pulse-Jet Baghouse User Survey (RP1129-21)	$99,000 7 months	Victor H. Belba/*R. Chang*
Baghouse Performance Optimization for Monticello Station (RP1129-23)	$148,400 14 months	Southern Research Institute/*R. Chang*
Analysis of AFBC Fuels Characterization Methods and Results (RP1179-39)	$93,400 16 months	Martin Marietta Energy Systems Inc./*E. Petrill*
Laboratory Methods for Evaluating Generic Cooling Water Additives (RP1261-18)	$198,000 18 months	Battelle Memorial Institute/ *W. Micheletti*
ECS Update Newsletter (RP1402-42)	$82,400 24 months	Crescent Project Management/*L. Angello*
Feedwater Heater and Feedpump R&D for Improved Coal-Fired Power Plants (RP1403-22)	$831,300 19 months	ABB Power Generation Inc./*J. Bartz*
Sampling and Analytical Services for Texaco Wastewater Treatment Pilot Plant (RP1459-30)	$157,200 10 months	Radian Corp./*N. Holt*

New Technical Reports

Requests for copies of reports should be directed to Research Reports Center, P.O. Box 50490, Palo Alto, California 94303; (415) 965-4081. There is no charge for reports requested by EPRI member utilities, U.S. universities, or government agencies. Others in the United States, Mexico, and Canada pay the listed price. Overseas price is double the listed price. Research Reports Center will send a catalog of EPRI reports on request. For information on how to order one-page summaries of reports, call the EPRI Hotline, (415) 855-2411.

CUSTOMER SYSTEMS

Bidding for Electric Resources: An Industry Review of Competitive Bid Design and Evaluation
CU-6089 Final Report (RP2733-4); $295
Contractor: Strategic Decisions Group
EPRI Project Manager: W. LeBlanc

Proceedings: The Third Annual EPRI-CRIEPI Conference
CU-6267 Proceedings (RP2982-1); $32.50
EPRI Project Manager: P. Hanser

Evaluation of Electric Vehicle Battery Systems Through In-Vehicle Testing: Third Annual Report
CU-6329 Final Report (RP1136-27); $100
Contractor: Electrotek, Inc.
EPRI Project Manager: R. Swaroop

Proceedings: International Workshop on Innovative DSM Techniques
CU-6332 Proceedings (RP2381-6); $100
Contractor: Pacific Consulting Services
EPRI Project Manager: V. Rabl

Demand-Side Management Strategies for the 90s: Fourth National Conference on Utility DSM Programs
CU-6367 Proceedings (RP2548-6); Vol. 1, $100; Vol. 2, $100
Contractor: Synergic Resources Corp.
EPRI Project Manager: S. Braithwait

Analysis of Electric Alternatives to Cogeneration in Commercial Buildings
CU-6378 Final Report (RP2480-4); $1000
Contractor: Dames & Moore
EPRI Project Manager: M. Blatt

ELECTRICAL SYSTEMS

Fault Current Limiters—Basic Concepts and Associated Technologies
EL 6275 Final Report (RP993-1); $32.50
Contractor: State University of New York at Buffalo
EPRI Project Manager: J. Porter

ENVIRONMENT

Chemical Data for Predicting the Fate of Organic Compounds in Water, Vol. 1: Technical Basis
EA-5818 Final Report (RP2879-2); $32.50
Contractor: Tetra Tech, Inc.
EPRI Project Manager: I. Murarka

Identification of Ions Near HVDC Transmission Lines
EN-6391 Final Report (RP1774-3); $25
Contractor: Georgia Institute of Technology
EPRI Project Manager: S. Sussman

EXPLORATORY RESEARCH

Microbial Corrosion: 1988 Workshop Proceedings
ER-6345 Proceedings (RP8000-26); $40
Contractor: Structural Integrity Associates
EPRI Project Manager: D. Cubicciotti

Horizontal-Flow Boiling Heat Transfer Using Refrigerant Mixtures
ER-6364 Final Report (RP8006-2); $40
Contractor: National Bureau of Standards
EPRI Project Manager: J. Kim

Assessment of Higher-Temperature Superconductors for Utility Applications
ER-6399 Final Report (RP2898-3); $25
Contractor: Los Alamos National Laboratory
EPRI Project Manager: M. Rabinowitz

GENERATION AND STORAGE

Power Plant Performance Monitoring and Improvement, Vol. 6: Economic Dispatch Optimization
CS/EL 4415 Interim Report (RP1681, RP2153); $55
Contractor: Potomac Electric Power Co.
EPRI Project Managers: R. Leyse, D. Maratukulam

Proceedings: Weld Repair of High- and Intermediate-Pressure Turbine Rotors for Life Extension
GS-6233 Proceedings (RP2596); $200
EPRI Project Managers: J. Byron, T. McCloskey

Sigma Phase in 316 Stainless Piping, Main Steam Piping Failure: Eddystone-1 Plant
GS-6286 Final Report (RP1403-10, -13); $25
Contractors: Combustion Engineering, Inc.; ManLabs, Inc.
EPRI Project Manager: R. Jaffee

Evaluation of a Dow-Based Gasification–Combined-Cycle Plant Using Low-Rank Coals
GS-6318 Final Report (RP2699-9); $40
Contractor: Fluor Daniel, Inc.
EPRI Project Manager: M. Gluckman

Improved Temperature Sensors for Large Generators
GS-6338 Final Report (RP2487-1); $32.50
Contractor: Westinghouse Electric Corp.
EPRI Project Manager: J. Stein

Fireside Corrosion in Low-NO_x Combustion Systems
GS-6339 Topical Report (RP2154-3); $32.50
Contractor: Babcock & Wilcox Co.
EPRI Project Manager: D. Eskinazi

Identification of Power Plant Auxiliary System Problems
GS-6354 Final Report (RP2626-1); $40
Contractor: General Electric Co.
EPRI Project Manager: J. Stein

Converter-Optimized Induction Motors: Feasibility Study
GS-6355 Final Report (RP2624-2); $32.50
Contractor: University of Wisconsin at Madison
EPRI Project Manager: J White

Coal-Oil Coprocessing: Phase 2
GS-6357 Final Report (RP2657-1); $40
Contractor: Hydrocarbon Research, Inc.
EPRI Project Manager: C. Kulik

Guidelines for Drilling and Testing Core Samples at Concrete Gravity Dams
GS-6365 Final Report (RP2917-5); $250
Contractor: Stone & Webster Engineering Corp.
EPRI Project Manager: D. Morris

Liner-Waste Compatibility Studies for Coal-Fired Power Plants
GS-6381 Interim Report (RP1457-1); $150
Contractor: Matrecon, Inc.
EPRI Project Manager: M. McLearn

NUCLEAR POWER

Preliminary Assessment of an Inflatable Inspection Probe, Phases 1 and 2
NP-5286 Interim Report (RP2673-1); $25
Contractor: Battelle, Columbus Laboratories
EPRI Project Managers: M. Behravesh, M. Avioli

MULTEQ: Equilibrium of an Electrolytic Solution With Vapor-Liquid Partitioning and Precipitation, Vol. 1 (Revision 1)
NP-5561-CCM Vol. 1 Rev. 1 Computer Code Manual (RPS407-30); $32.50
Contractor: S-Cubed
EPRI Project Manager: J. Paine

Below Regulatory Concern Owners Group: A General Review of the IMPACTS-BRC Code
NP-5675 Final Report (RPB101-12); $32.50
Contractor: Battelle, Pacific Northwest Laboratories
EPRI Project Manager: P. Robinson

Below Regulatory Concern Owners Group: Assessment of the IMPACTS-BRC Code
NP-5679 Final Report (RPB101-11); $1000
Contractor: Rogers and Associates Engineering Corp.
EPRI Project Manager: P Robinson

MAAP 3.0B Simulation of the First 174 Minutes of the TMI-2 Accident
NP-6206 Final Report (RP2852-1); $25
Contractor: Fauske & Associates, Inc.
EPRI Project Managers: G. Thomas, I. Wall

A Finite-Element Model for Eddy-Current Nondestructive Evaluation
NP-6212-M Final Report (RP1395-2); $32.50
Contractor: Colorado State University
EPRI Project Manager: M. Avioli

Management Strategies for Treatment and Disposal of Utility-Generated Low-Level Radioactive Waste
NP-6225 Final Report (RP2691-1); $32.50
Contractor: Rogers and Associates Engineering Corp.
EPRI Project Manager: R. Shaw

BWR/6 Startup and Transient Tests at Grand Gulf Nuclear Station
NP-6230-M Final Report (RP1561-4, -5); $25
Contractors: Middle South Utilities/SERI; General Electric Co.
EPRI Project Manager: P. Kalra

PWR Pilot Plant Life Extension Study at Surry Unit 1: Phase 2
NP-6232-M Final Report (RP2643-1); $32.50
Contractors: Virginia Power; Westinghouse Electric Corp.; Virginia Polytechnic Institute and State University; Grove Engineering, Inc.; Stone & Webster Engineering Corp.
EPRI Project Manager: J. Byron

SIGTRAN: A Kinetics Linkage Code for the Reactor Analysis Support Package (RASP)
NP-6241 Final Report (RP1761-17); $40
Contractor: EI International, Inc.
EPRI Project Manager: L. Agee

Toughness of Ferritic Piping Steels
NP-6264 Final Report (RP2455-8); $62.50
Contractor: Babcock & Wilcox Co.
EPRI Project Manager: D. Norris

Accuracy of Ultrasonic Flaw Sizing Techniques for Reactor Pressure Vessels
NP-6273 Final Report (RP1570-2); $32.50
Contractor: J. A. Jones Applied Research Co.
EPRI Project Manager: G. Dau

Earthquake Experience Data on Anchored, Ground-Mounted Vertical Storage Tanks
NP-6276 Final Report (RP2907-1); $32.50
Contractor: EQE Engineering, Inc.
EPRI Project Manager: H. Tang

Evaluation of Fuel Performance at Oconee Unit 2
NP-6285-M Final Report (RP2229-4); $25
Contractor: Babcock & Wilcox Co.
EPRI Project Manager: R. Yang

Implications of Possible Reduction in Radiation Exposure Limits
NP-6291 Final Report (RP2494-3); $25
Contractor: J. E. Le Surf, Consultant
EPRI Project Manager: C. Wood

CAFTA User's Manual: Version 2.0
NP-6296 Final Report (RP2507-1); $47.50
Contractor: Science Applications International Corp.
EPRI Project Manager: J. Gaertner

Ultrasonic Examination of Cast Stainless Steel
NP-6299 Topical Report (RP1570-2); $32.50
Contractor: J. A. Jones Applied Research Co.
EPRI Project Manager: G. Dau

Seismic Wave Attenuation in Eastern North America
NP-6304 Final Report (RP2556-9); $32.50
Contractor: Teledyne Geotech
EPRI Project Managers: C. Stepp, J. Schneider

Calculating the Tearing Resistance of Ductile Steels
NP-6310 Final Report (RP1757-65); $25
Contractor: Novetech Corp.
EPRI Project Manager: D. Norris

VIPOWR-02: A RASP Interface Program for Thermal-Hydraulic Synthesis
NP-6323 Computer Code Manual (RP1761-17); $25
Contractor: EI International, Inc.
EPRI Project Manager: L. Agee

Release of Volatile Fission Products From Irradiated LWR Fuel: Mass Spectrometry Studies
NP-6328 Final Report (RP2136-1); $25
Contractor: Argonne National Laboratory
EPRI Project Managers: R. Vogel, R. Ritzman

Vibration Monitoring of Main Coolant Pumps: Guideline and Reference Data
NP-6337 Final Report (RP1556-4); $32.50
Contractor: Ontario Hydro
EPRI Project Manager: J. Weiss

PWR Steam Generator Tube Fretting and Fatigue Wear
NP-6341 Final Report (RPS174-2, RPS310-2); $70
Contractor: Siemens AG–KWU Group
EPRI Project Manager: D. Steininger

Studies on the Radiation Stability of Cesium Iodide
NP-6344 Final Report (RP2136-2); $32.50
Contractor: Atomic Energy of Canada Limited–Whiteshell Nuclear Research Establishment
EPRI Project Manager: R. Ritzman

Seismic Margin Assessment of the Catawba Nuclear Station, Vols. 1 and 2
NP-6359 Final Report (RP2722-1); Vol. 1, $40; Vol. 2, $70
Contractors: NTS Engineering; Duke Power Co.; Pickard, Lowe and Garrick; Woodward-Clyde Consultants
EPRI Project Manager: R. Kassawara

Guidelines for Improving Fuel Reliability
NP-6361 Final Report (RP2229-3); $32.50
Contractor: S. M. Stoller Corp.
EPRI Project Managers: R. Yang, P. Rudling

Examination of Pits in Trojan Nuclear Power Plant Steam Generator Tubes
NP-6362-M Final Report (RPS407-32); $25
Contractor: Combustion Engineering, Inc.
EPRI Project Manager: J. Paine

New Computer Software

The Electric Power Software Center (EPSC) provides a single distribution center for computer programs developed by EPRI. The programs are distributed under license to users. No royalties are charged to nonutility public service organizations in the United States, including government agencies, universities, and other tax-exempt organizations. Industrial organizations, including nonmember electric utilities, are required to pay royalties. EPRI member utilities, in paying their membership fees, prepay all royalties. Basic support in installing the codes is available at no charge from EPSC; however, a consulting fee may be charged for extensive support.

For more information about EPSC and licensing arrangements, EPRI member utilities, government agencies, universities, and other tax-exempt organizations should contact the Electric Power Software Center, Power Computing Co., 1930 Hi Line Drive, Dallas, Texas 75207; (214) 655-8883. Industrial organizations, including nonmember utilities, should contact EPRI's Manager of Licensing, P.O. Box 10412, Palo Alto, California 94303; (415) 855-2866.

CAFTA: Computer-Assisted Fault Tree Analysis
Version 2.0 (Prime); NP-6296
Contractor: Science Applications International Corp.
EPRI Project Manager: John Gaertner

CIRTOU: Commercial-Industrial Time-of-Use Rates Model
Version 2.0 (IBM PC)
Contractor: Laurits R. Christensen Inc.
EPRI Project Manager: William Smith

CLASSIFY: Residential Customer Preference and Behavior
Version 1.22 (IBM PC); EM-5908
Contractor: Synergic Resources Corp.
EPRI Project Manager: Larry Lewis

COMPACT: Commercial Sector Demand-Side Management Impact Assessment
Version 1.1 (IBM PC)
Contractor: Spectrum Economics
EPRI Project Manager: Phillip Hanser

EGEAS: Electric Generation Expansion Analysis System
Version 4.0 (IBM PC); EL-2561
Contractors: MIT; Stone & Webster Engineering Corp.
EPRI Project Manager: Neal Balu

EMTP: Electromagnetic Transient Program
Version 2.0 (APOLLO, VAX); EL-4541-CCMP
Contractor: Westinghouse Electric Corp.
EPRI Project Manager: Mark Lauby

CALENDAR

For additional information on the meetings listed below, please contact the person indicated.

AUGUST

21
Utility Options for Meeting Dissolved-Oxygen Limits for Hydro Power Plant Discharges
Niagara Falls, New York
Contact: Chuck Sullivan, (415) 855-8948

22–24
Availability and Technology Improvements In Plant Auxiliaries
Minneapolis, Minnesota
Contact: David Broske, (415) 855-8968

29–31
First International Conference on Fossil Power Plant Construction
Cincinnati, Ohio
Contact: Murthy Divakaruni, (415) 855-2409

SEPTEMBER

6–8
Hydro Operations and Maintenance
Boston, Massachusetts
Contact: Chuck Sullivan, (415) 855-8948

25–28
Petroleum Contaminated Soils
Amherst, Massachusetts
Contact: Mary McLearn, (415) 855-2487

26–28
Conference: Heat Rate Improvement
Knoxville, Tennessee
Contact: Robert Leyse, (415) 855-2995

26–28
Power Quality Training for Utilities
St. Louis, Missouri
Contact: Marek Samotyj, (415) 855-2980

27–29
Applying Structural Research Results
Haslet, Texas
Contact: Paul Lyons, (817) 439-5900

OCTOBER

1
Bulk Transmission System Adequacy Assessment
Atlanta, Georgia
Contact: Neal Balu, (415) 855-2834

3–5
FASTCHEM, FOWL, and MYGRT: Codes for Modeling Solutes in Groundwater
Chicago, Illinois
Contact: Dave McIntosh, (415) 855-7918

3–6
PCB Seminar
San Diego, California
Contact: Gil Addis, (415) 855-2286

3–6
Steam Turbine Blade Life Management
Rochester, New York
Contact: Tom McCloskey, (415) 855-2655

10–12
EPRI Fuel Supply Seminar
Charleston, South Carolina
Contact: Jeremy Platt, (415) 855-2628

10–12
Conference: Municipal Solid Waste
Springfield, Massachusetts
Contact: Cindy Farrar, (415) 855-2180

12–13
Seminar: Piping Seismic Research Results With Emphasis on Snubber Reduction
Burlingame, California
Contact: Y.K. Tang, (415) 855-2473

16–19
Coal Quality Development
Pittsburgh, Pennsylvania
Contact: Clark Harrison, (412) 479-3505

17–19
On-Line Coal Analysis Applications
Pittsburgh, Pennsylvania
Contact: David O'Connor, (415) 855-8970

17–20
Transmission Line Foundations
Palo Alto, California
Contact: Vito Longo, (415) 855-2287

26–27
Fuel Cell Workshop
Orlando, Florida
Contact: Rocky Goldstein, (415) 855-2171

30–November 2
Technologies for Generating Electricity in the 21st Century
San Francisco, California
Contact: Sy Alpert, (415) 855-2512

NOVEMBER

1
Conference: Demand-Side Management
Toronto, Canada
Contact: Clark Gellings, (415) 855-2610

1–2
1989 Fuel Oil Utilization Workshop
Tampa, Florida
Contact: William Rovesti, (415) 855-2519

13–15
Conference: Marketing Electric Vans
Teaneck, New Jersey
Contact: Jim Janasik, (415) 855-2486

13–17
Battery Contractors Conference
Washington, D.C.
Contact: Glenn Cook, (415) 855-2797

14–16
Conference: Plant Maintenance Technology
Houston, Texas
Contact: John Tsou, (415) 855-2220 or Dave Broske, (415) 855-8968

28–December 1
Expo and Seminar: Meeting Customer Needs With Heat Pumps
Atlanta, Georgia
Contact: Mort Blatt, (415) 855-2457

FEBRUARY

21–23
EPRI Food Service Symposium
New Orleans, Louisiana
Contact: Karl Johnson, (415) 855-2183

MARCH

6–9
International Symposium: Performance Improvement, Retrofitting, and Repowering Fossil Fuel Power Plants
Washington, D.C.
Contact: Gary Poe, (415) 855-8969

20–23
EPRI-EPA Symposium: Transfer and Utilization of Particulate Control Technology
San Diego, California
Contact: Ramsay Chang, (415) 855-2535

JULY

29–August 3
International Conference: Indoor Air Quality and Climate
Toronto, Canada
Contact: Cary Young, (415) 855-2724

Authors and Articles


Birk


Schainker


Iveson


Nilsson


Hingorani


Kennon

Emerging Strategies for Energy Storage (page 4) was written by David Boutacoff, *Journal* feature writer, with technical assistance from two senior research staffers in EPRI's Generation and Storage Division.

Jim Birk, director of the Storage and Renewables Department since October 1988, directed R&D programs in advanced energy conversion and storage for the preceding 3 years. He came to EPRI in 1973 as a project manager for battery storage development. Before that he was a senior scientist with Rockwell International for 7 years.

Robert Schainker, manager of the Energy Storage Program since 1985, has been with the program since 1980. Before that he managed combustion turbine development projects for 2 years. Schainker was formerly with Systems Control, Inc. ■

A Storm From the Sun (page 14) was written by John Douglas, science writer, with technical guidance from three research leaders in EPRI's Electrical Systems Division.

Bob Iveson, now a staff technical adviser, is much concerned with the electrical phenomena that influence transmission system performance. For 9 years, until early 1988, he managed EPRI's Power System Planning and Operations Program. Before that he was with New York State Electric & Gas for 20 years, spending 9 of those years as supervisor of transmission planning for the New York Power Pool.

Stig Nilsson, longtime manager of the Transmission Substations Program, has been with EPRI since 1975. He worked briefly for Boeing Computer Services in the early 1970s, and before that he was with Sweden's ASEA for 11 years, coming to the United States in 1967 to install and test control equipment on the Pacific Northwest–Southwest HVDC Intertie.

Narain Hingorani, Electrical Systems Division vice president for the past three years, previously headed the Transmission Department. He came to the Institute in 1974 after 6 years with the Bonneville Power Administration. Still earlier, he spent 11 years in research, teaching, and consulting on the faculties of three British universities. ■

Managing the Gaslight Legacy (page 22) was written by Taylor Moore, the *Journal*'s senior feature writer, who attended an April 1989 technology-transfer seminar on how to deal with the soil and groundwater contamination that continues to show up at sites of long-ago gas utility operations. ■

TLWorkstation: Expert Assistance in Line Design (page 32) was written by Leslie Lamarre, science writer, in cooperation with **Richard Kennon,** of EPRI's Electrical Systems Division.

Kennon, manager of the Overhead Transmission Lines Program since 1978, is also responsible for EPRI's mechanical and high-voltage test facilities for lines, poles, and towers. He joined EPRI in 1975 after nearly 23 years with Westinghouse, eventually as manager of capacitor equipment engineering. ■

Correction: Bill Sun's professional background and responsibilities were incorrectly described in the April/May issue of the *Journal.* He manages the Control and Diagnostics Program of the Nuclear Power Division, where his responsibility since 1983 has been the development of instrumentation for diagnostic, control, and expert system uses. His earlier EPRI research management involved the thermal-hydraulic performance of reactor safety systems. Sun came to EPRI in 1977 after more than 4 years at General Electric, where he was a technical group leader. ■

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