Transformative Powers of Silicon

Also in this issue:

- *Atmospheric Ozone*
- *Earthquake Investigations*

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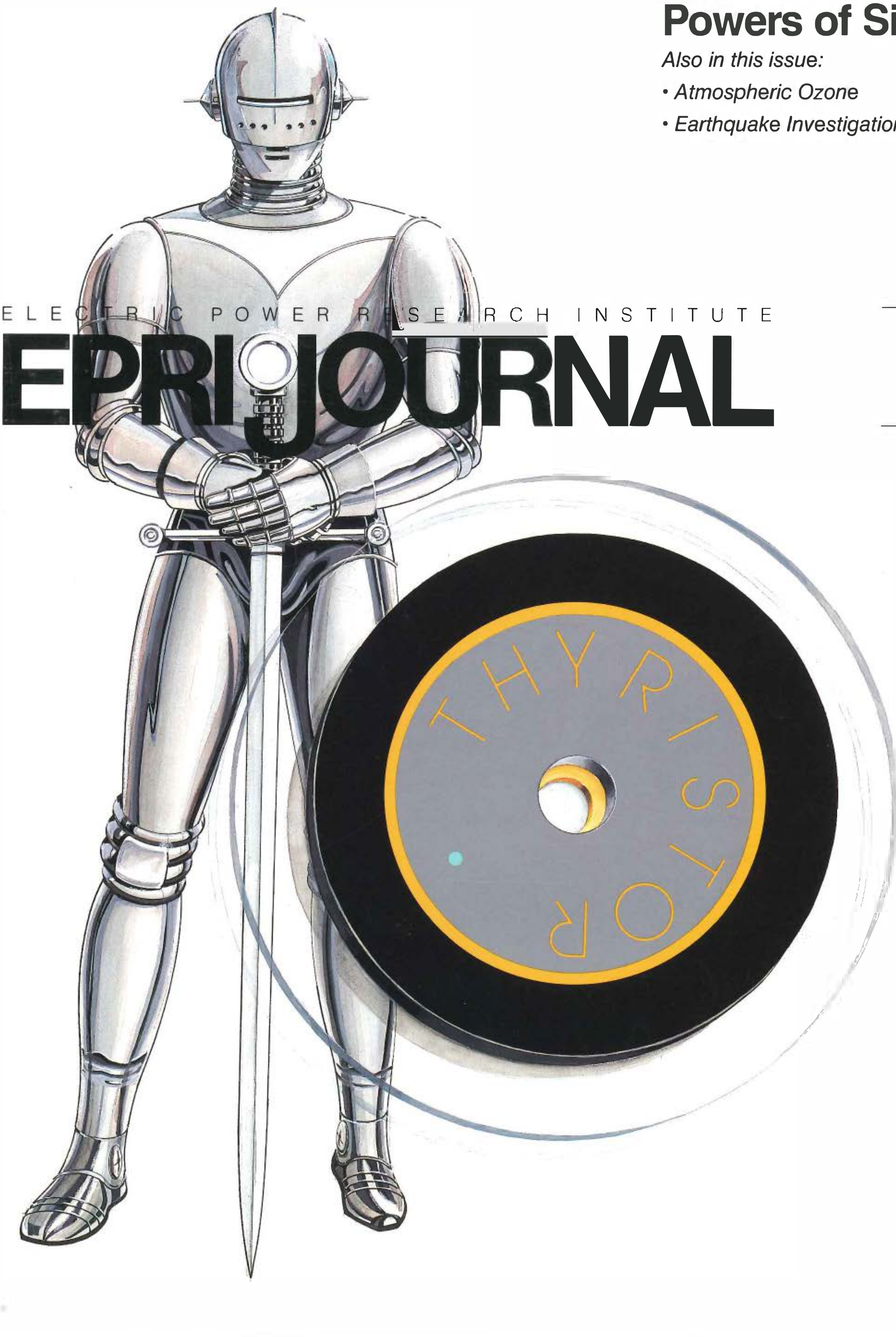

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Cover: Silicon-based thyristor technology has the power to transform the nation's electricity delivery system from today's electromechanically-controlled system into a sleeker, all-electronic version fit for the 21st century.

EDITORIAL

FACTS and the Future

The future performance of America's power network depends on the introduction of new technologies that can make its operation more flexible. During recent years, unprecedented demands have been placed on this network, including a rapid increase in bulk power sales. At the same time, construction of new transmission lines has virtually ceased. By making the power system more highly automated and easier to control, a variety of advanced technologies can help relieve existing bottlenecks in the system and provide a basis for sustained growth.

In order to provide coordinated development of the various technologies involved, EPRI has taken the lead in research related to flexible ac transmission systems, or FACTS. As this month's cover story shows, the EPRI development effort includes work on power electronics devices, hardware and software for advanced communication and control, and implementation strategies for FACTS. Already several of these technologies are becoming available for utility applications.

An important advantage of FACTS, as it is being promoted and developed by EPRI, is its inherent modularity. Utilities will not have to make radical changes in their networks at once or become dependent on the proprietary system of a single supplier. Part of EPRI's approach is to provide design specifications and integration strategies that will enable utilities to adopt only those FACTS technologies needed for specific purposes, from manufacturers of their choice.

Although such an approach means that changes in the transmission network may come gradually, the long-term effect of FACTS will nevertheless be profound. Utilities will be able to control the flow of power over their lines with speed and selectivity not possible today. As a result, power exchanges will become much easier to implement, while existing transmission bottlenecks can be eased. Several more years of research will be needed, however, for FACTS to fulfill its promise—research made even more urgent by the steadily increasing demands on America's transmission network.

Narain G. Hingorani

Narain G. Hingorani, Vice President
Electrical Systems Division

DEPARTMENTS

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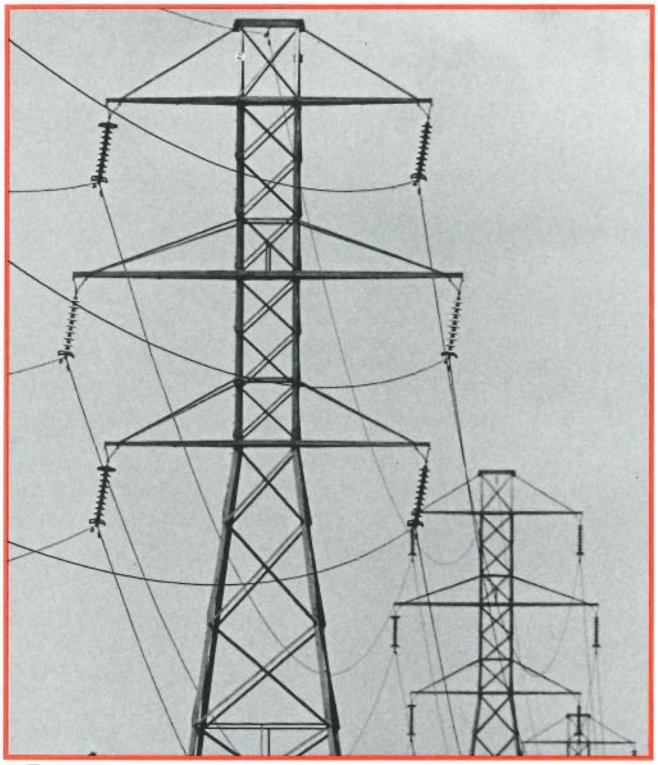
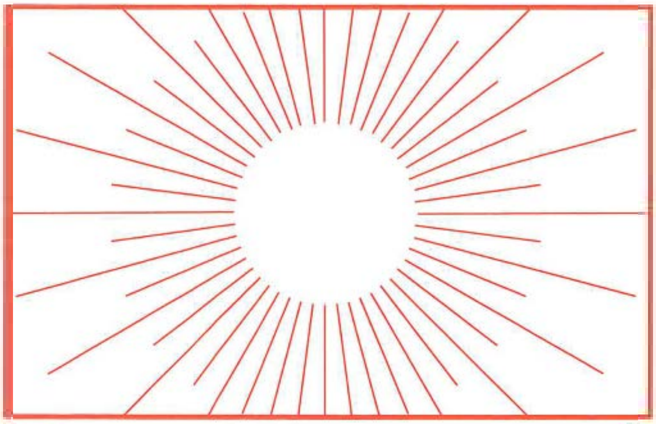
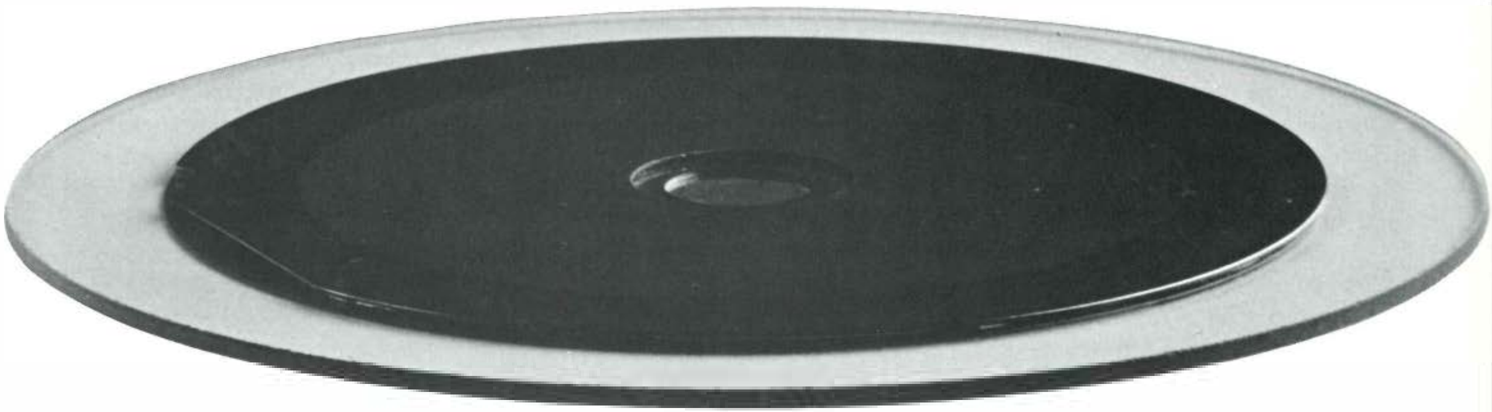


4 Transmission

14 Ozone



The Future of Transmission
Switching to Silicon



Silicon thyristor technology promises to transform the nation's transmission system with fast, "smart" solid-state switching devices that eliminate the bottlenecks encountered with conventional, electromechanical equipment.

For the next several years, the high-voltage transmission network of the United States will face unprecedented challenges and opportunities. The challenges stem largely from a rapid increase in interutility power transfers over the network, in addition to the continued steady growth of power delivered directly from the utilities' power plants to their customers. An increasing number of cogenerators and independent power producers are also demanding access to the network. In the United States, as in many other parts of the world, transmission systems were not designed to cope with the present magnitude of bulk power transfers and third-party access. Moreover, the construction of new lines to handle load growth and increased numbers of bulk transactions has been stymied for a variety of regulatory, environmental, and public policy reasons. As a result, America's transmission network now has many limitations, which represent a difficult challenge for the future.

There is a new opportunity to handle the immediate challenge, while establishing an improved foundation for long-term growth, through the development of technology that can make the present transmission system more flexible. "In 20 years the U.S. transmission system will look very different from the present system," says Narain Hingorani, EPRI vice president, Electrical Systems Division. "Solid-state, high-power electronic switches will provide much greater control speed and flexibility. The whole system will also become more highly automated, enabling dispatchers to direct more power over selected lines."

Unlike the switched networks used in telephone systems to direct calls to a specific party, alternating-current (ac) electric power transmission networks are not easily controlled in terms of directing the flow of power. Because today's utility transmission systems are so closely interconnected, this lack of control means that a bulk transfer of power from Ontario Hydro power plants to New York City, for example, may not follow the most direct corridor of lines and may interfere with transmission operations as far away as Ohio. This phenomenon is known as loop flow.

EPRI has developed a vision of the advanced transmission system utilities need to cope with increasingly demanding conditions. Called FACTS (for flexible ac transmission system), this system could overcome loop flows and provide a more sophisticated degree of control through a combination of high-power electronic devices and computerized system automation. Specifically, large solid-state switches, or thyristors, would be used in various types of controllers to manipulate alternating current on transmission lines. With such thyristor-based devices and with high-speed coordination provided by an advanced system of communications and computer hardware and software, utilities would be able to increase the loading on existing transmission lines and handle more transactions without compromising reliability.

Recognizing both the challenges and the opportunities ahead, EPRI has launched a seven-year, $20 million research program devoted to FACTS. This effort will involve numerous specific projects, ranging from the evaluation of existing transmission system performance to the development of hardware and the coordination of strategies for implementing FACTS on host utility systems. Some thyristor-based devices related to FACTS have already been developed and tested, so utilities have begun to incorporate particular elements of FACTS to meet the needs of their own transmission systems.

"We can no longer assume that the electric power system of today represents mature technology," Hingorani says. "In the long run, power will be controlled by thyristors at several stages between generation and end use. Utilities will be able to manage their systems to a much greater extent than ever before possible. But research on the technologies involved in FACTS is urgently needed. Transmission systems are the lifeline of the electric power industry, and the competitive position of electricity among the energy choices now open to utility customers is at stake. That's why EPRI is acting decisively to take the lead in this vital area."

Most complex machine

According to a recent EPRI study, the increase in bulk power transfers over transmission lines has greatly exceeded the growth rate of load and that of generating capacity for several years. This increase includes both the interchange of power between utility members of a power pool and the wheeling of power across a utility's lines, even though the utility may not be involved as either buyer or seller. Taken together, such bulk transactions now amount to roughly one-third of electricity sales to ultimate customers.

Not surprisingly, given the limited construction of new lines, bottlenecks are appearing in areas with overloaded transmission systems. Voltage and frequency fluctuations, in particular, are becoming more common as free flows of power spread across interconnected systems. Most of the devices available today for taming wayward loop flows or stabilizing voltages are mechanically switched—meaning that system response to changing conditions is slow and device maintenance costs are high. There is an immediate need for faster, more reliable alternative control technologies.

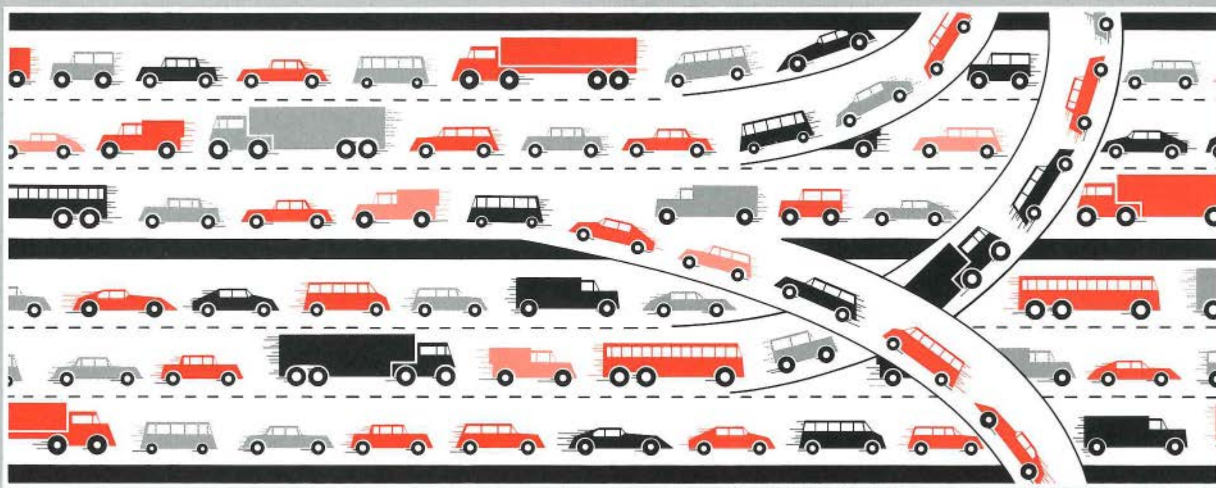
"The U.S. power system is perhaps the most complex machine ever created by man," asserts Frank Young, director of the Electrical Systems Division. "But we're asking this machine to perform functions that weren't even conceived of by its original designers. In some cases, a transmission line can be upgraded by raising voltage or adding new conductors along an existing right-of-way. A more fundamental solution, however, is to use high-power electronic technology to make the whole system 'smarter' and thus more responsive to changing needs."

Young emphasizes that the transition from mechanical to electronic control will require several stages of development and implementation. The first step—production of semiconductor materials capable of handling high voltage and current—has already largely been accomplished (*EPRI Journal*, December 1986). Next comes the step of designing and testing a new generation of solid-state devices, generally based on thyristor technology, that can perform the control functions needed by transmission systems. Finally, these materials and devices—the ingredients for a "second electronics revolution"—must be demonstrated in actual utility system operation. In addition, a parallel effort must be undertaken to develop communication and computer capabilities that can take advantage of the greater speed and flexibility provided by the new control hardware.

The bottom line of this FACTS development effort can be measured both physically and economically. The ultimate physical capacity of a transmission system is set by the so-called thermal limit of its lines—roughly speaking, the

The Key Attributes

Flexible ac transmission systems (FACTS) will maximize network power transfer by using alternative circuit paths to greatest advantage. The trick is to compensate for varying patterns of generation, load, and line characteristics that limit the performance and capacity of individual circuits. Three key improvements are under research and development.



POWER FLOW

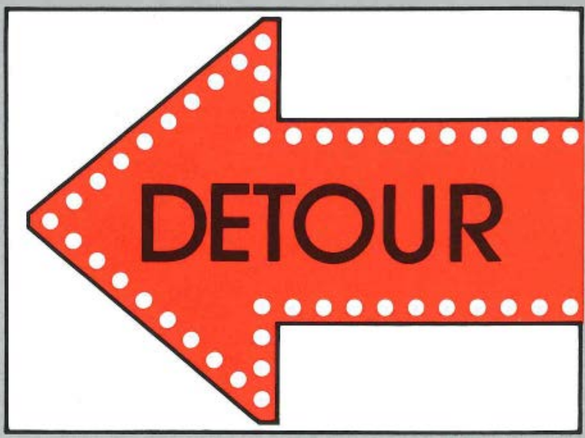
• Greater power transfer will come with thyristor-based components that make sure each line carries its full capacity, especially during "rush hour" peaks. Controllable increments of resistance, capacitance, and inductance will compensate for the electrical phenomena that inhibit power flow in ac networks.

VOLTAGE CONTROL

• More closely regulated voltage, imperative for a densely interconnected high-tech world, will be achieved by thyristor-governed control—adjustments of circuit parameters that limit voltage swings to no more than plus or minus 5%.

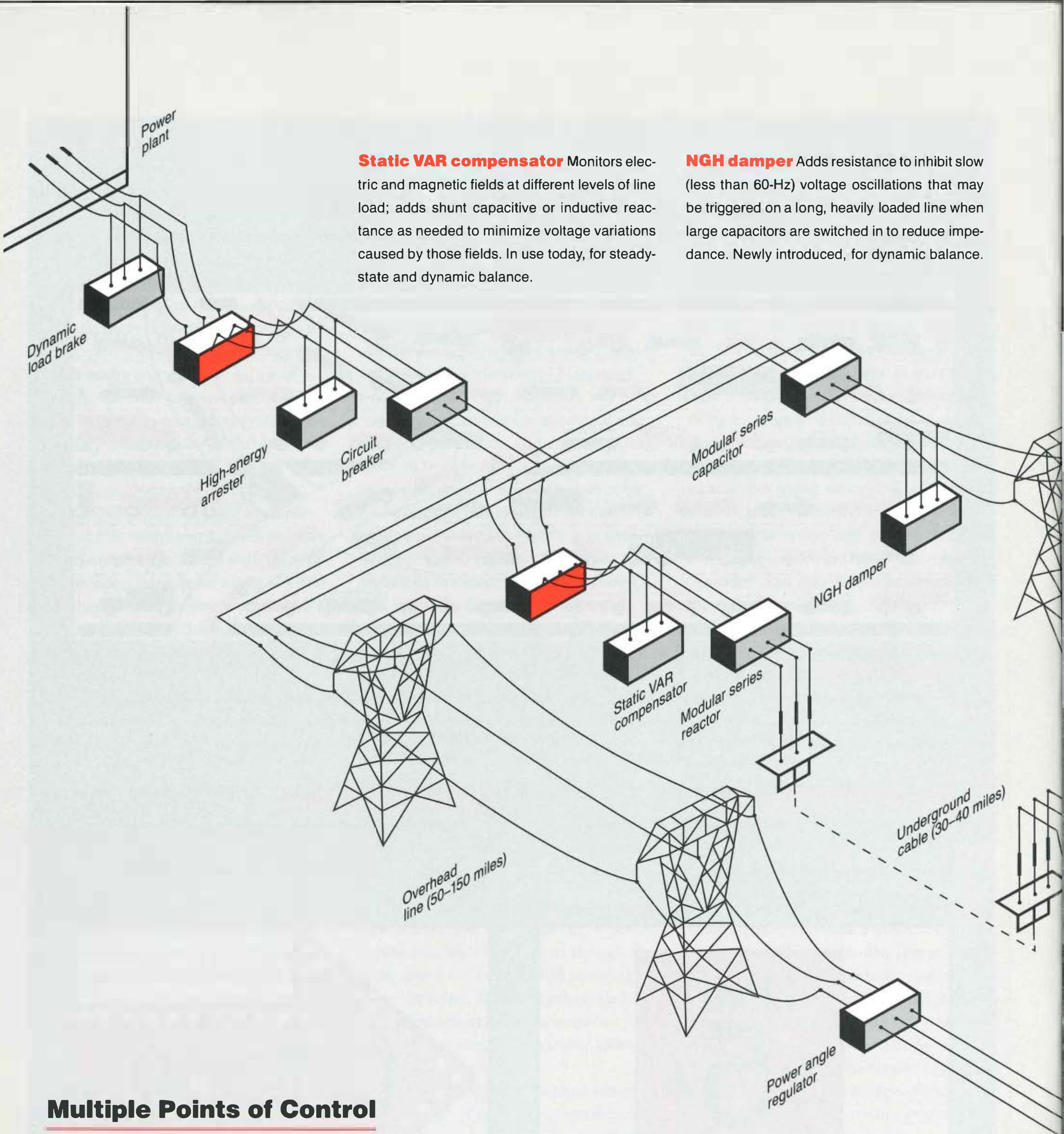
STABILITY CONTROL

• Constant dynamic balance—free of cascading electrical snarls when a line or a generator is lost—will be maintained by virtually instantaneous thyristor action to divert power smoothly along alternative paths.



Static VAR compensator Monitors electric and magnetic fields at different levels of line load; adds shunt capacitive or inductive reactance as needed to minimize voltage variations caused by those fields. In use today, for steady-state and dynamic balance.

NGH damper Adds resistance to inhibit slow (less than 60-Hz) voltage oscillations that may be triggered on a long, heavily loaded line when large capacitors are switched in to reduce impedance. Newly introduced, for dynamic balance.



Multiple Points of Control

FACTS equipment will be distributed to many points across the transmission system and can be introduced to replace conventional hardware as the new technology becomes available. All these specialized FACTS components exploit the solid-state thyristor, a transistor-like device that can switch and adjust electrical components on high-voltage, high-current power lines at electronic speeds.

Power angle regulator In effect, a solid-state rheostat; will change the power angle on a phase-shifting transformer as frequently as necessary—in milliseconds and without arcing—to control parallel flows. Under development, for improved power flow and dynamic balance.

Modular series capacitor. A special-purpose thyristor control for adding or subtracting series capacitance so as to adjust the impedance—and thereby the power flow—of a circuit. Under development, for better power flow and dynamic balance.

Dynamic load brake. A large, variable resistor with fast-acting thyristor control; will substitute for momentarily lost load on a generator so that the generator will maintain exact speed and output frequency, thus staying synchronized with the system. Under development, to control dynamic balance.

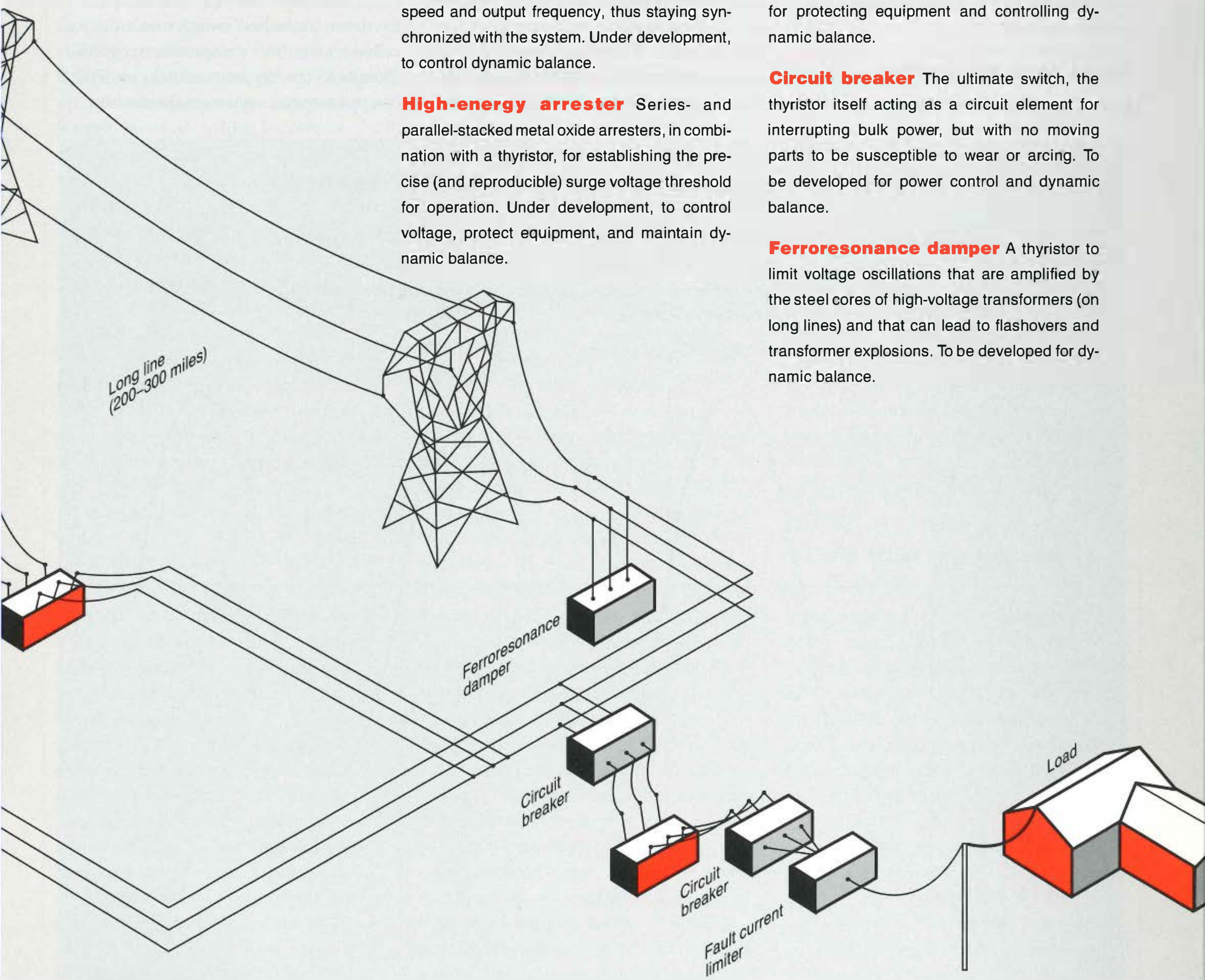
High-energy arrester Series- and parallel-stacked metal oxide arresters, in combination with a thyristor, for establishing the precise (and reproducible) surge voltage threshold for operation. Under development, to control voltage, protect equipment, and maintain dynamic balance.

Modular series reactor. Another special-purpose thyristor-controlled circuit component; will add series inductance to underground cables to prevent their overloading and overheating. To be developed as a control for cable power flow and dynamic balance.

Fault current limiter A thyristor-based component for fast and precise impedance switching, thus preventing fault currents from damaging lines and apparatus. To be developed for protecting equipment and controlling dynamic balance.

Circuit breaker The ultimate switch, the thyristor itself acting as a circuit element for interrupting bulk power, but with no moving parts to be susceptible to wear or arcing. To be developed for power control and dynamic balance.

Ferroresonance damper A thyristor to limit voltage oscillations that are amplified by the steel cores of high-voltage transformers (on long lines) and that can lead to flashovers and transformer explosions. To be developed for dynamic balance.



amount of power that can be carried before conductors start to overheat and sag toward objects below. Portions of today's transmission systems are restricted to power levels well below their ultimate limit because of other factors, such as voltage and stability. In some cases, introducing FACTS technology could double the amount of power carried over a line. Taking even a conservative case of a 25% power increase on a 2000-MW line, the economic benefit to the utility would be approximately $10 million per year.

Three basic approaches

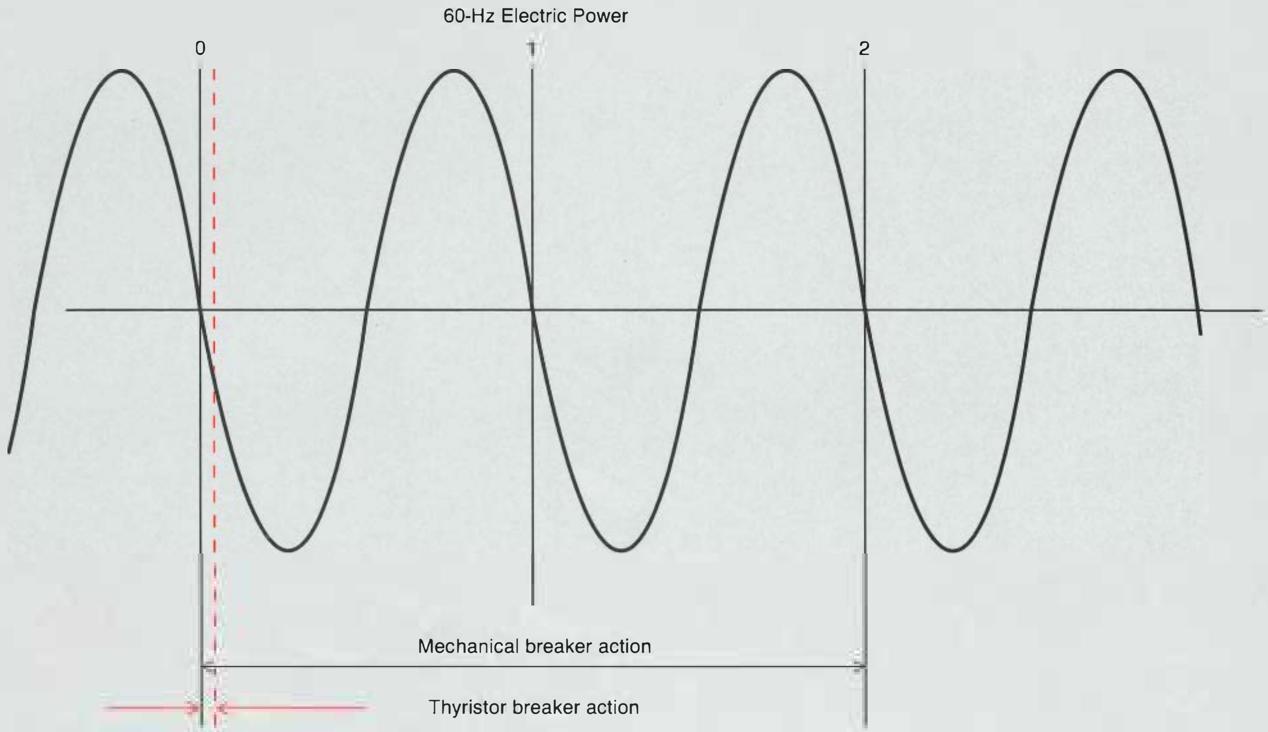
Increasing the power transfer capability of a line usually involves one of three basic approaches: maintaining the proper voltage, optimizing the power angle (phase difference between voltages at opposite ends of a line), or changing the impedance (total opposition to ac flow). Each of these parameters can be controlled at high speed by thyristor-based devices now being developed or tested as part of EPRI's FACTS program.

Controlling voltage in an ac circuit is complicated by the existence of reactive power (expressed as volt-amperes reactive, or VARs). Reactive power is the power required to maintain the electric and magnetic fields surrounding a power line. Electric fields tend to raise the voltage on a lightly loaded line. Their effect is counteracted by connecting shunt reactors onto the line. Magnetic fields associated with heavy current flow tend to reduce the voltage on a line. That effect is counteracted by connecting shunt capacitors.

On some power systems, it is possible to experience both extremes of voltage in a single 24-hour period. To handle such cases, shunt reactors and shunt capacitors have been combined with a thyristor-controlled switch into a device called a static VAR compensator, or SVC. Thanks to the thyristor switch, an SVC can operate not only to make steady-

Electronic Speed in a Power Circuit Breaker

Operating speed dramatizes the promise of thyristors for many FACTS applications. For example, today's mechanical circuit breaker takes as long as 2 cycles to open after a signalled need for current interruption. Tomorrow's solid-state electronic breaker will act in 1/32 of a cycle—more than 60 times faster.



state voltage corrections but also to respond very rapidly during a disturbance on the line—minimizing voltage depression during a fault and voltage overshoot during fault recovery. Some SVCs are already commercially available and will play a major role in FACTS voltage control strategies. Research to improve the design of SVCs, so that their size and cost can be greatly reduced, is also under way.

Power angle changes can sometimes be used to solve the problem of loop flows. A few regions now use phase-shifting transformers to redirect power flow from one line to another. Changing the power angle setting of such a transformer, however, which involves a motor-driven tap, can take as long as a minute and a half. Also, the number of resettings per day is usually limited to 10 or so, since tap changes create arcing and thus eventually wear out the equipment. Using thyristors to change the tap setting would reduce the time involved to milliseconds and, because there are no moving parts, would virtually eliminate the need to restrict the number of daily resettings. Developing such an advanced power angle regulator is one of the specific goals of the present research program.

Devices for rapidly changing the impedance of a transmission circuit—a capability previously unavailable—will prove useful in a variety of ways. One such device is currently undergoing utility demonstration; three others are to be developed as part of the FACTS program. Each is designed to counteract a specific problem.

Southern California Edison, for example, has in commercial use a thyristor-controlled device that suppresses low-frequency oscillations, which can occur when large capacitor banks are inserted in series with the circuit to reduce impedance on long transmission lines. Called the NGH subsynchronous resonance damper after its inventor, EPRI's Narain G. Hingorani, the device automatically changes the impedance of a transmission circuit enough to keep its voltage from resonating at frequencies below 60 Hz. Earlier, such resonance problems had become severe enough at one Southern California Edison plant to damage a generator shaft by creating a heavy torque on it.

Another approach to changing the impedance of a transmission circuit is to have a thyristor directly control a variable amount of capacitance inserted in series on a line. Current practice involves adding capacitors to a line by switching them in large, discrete units. A modular series capacitor with thyristor control would be able to dial in or out just the right amount of capacitance during steady-state conditions and could also react quickly enough to help stabilize the transmission system during a disturbance.

One extreme type of disturbance, the voltage surge caused by a lightning strike on a line, requires an additional measure of protection. Surge arresters give this protection by providing a low-impedance path to ground when voltage rises above a specified level. The current generation of metal oxide surge arresters depends on the properties of certain materials (such as zinc oxide) to reduce resistance sharply as voltage increases. The threshold voltage for such devices, however, cannot be set precisely or changed easily. By using thyristor control to ground a voltage surge, advanced arresters will have increased precision, flexibility, and safety, and probably a lower cost.

The final type of impedance-changing device now under development addresses the problem of how to dissipate energy quickly when a generator is suddenly cut off from part or all of its load—for example, during a line fault nearby. If no attempt is made to absorb energy from the generator, it can quickly begin to speed up and force a plant shutdown lasting hours. If a large resistor installed at a power plant could be brought on-line when needed to convert the generator's energy to heat, the unit could continue to operate at a steady speed and then be reconnected promptly when the fault was cleared. Such resistors have found only limited use so far because they are not variable and the mechanical switches that control them are slow. A dynamic load brake controlled by thyristors would be able to add just the right amount of resistance to reduce the acceleration of a generator and allow it to remain synchronized with the system.

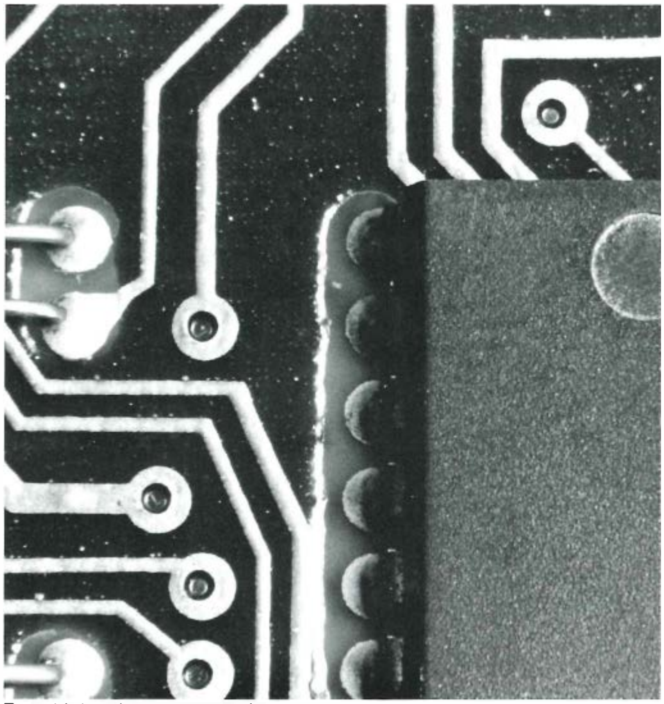
"The basic methods and materials used to control transmission systems haven't changed substantially over the last 25 years," says Robert Iveson, technical adviser in the Electrical Systems Division. "FACTS will change that. Static VAR compensators and NGH dampers are already in utility use. Power angle regulators, modular series capacitors, high-energy arresters, and dynamic load brakes with high-speed controllers are being developed as part of our current FACTS research. The system is already beginning to evolve—and the end result will be a real revolution in power transmission."

Dc and other applications

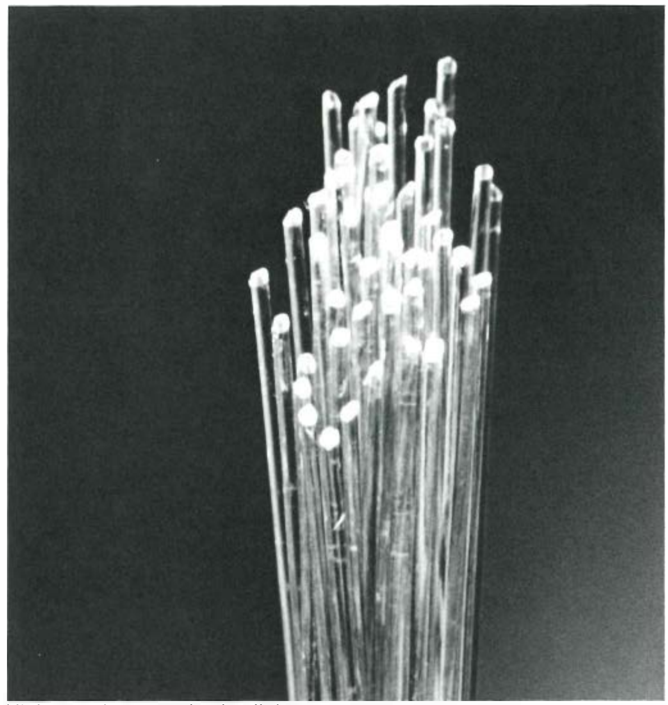
One of the first applications of thyristor technology was the conversion of ac to dc power, and the use of dc lines embedded in the larger ac network can be an important part of FACTS. Such lines are ideal for delivering bulk power across large distances between specific locations by effectively reducing the power angle difference between them. The 800-mile Pacific Intertie, for example, already provides a dc link between the hydroelectric plants of the Pacific Northwest and the rapidly growing cities of the Southwest. The primary advantage of such dc ties is that they add greater control and stability to

Four Facets of FACTS

Truly flexible ac transmission technology entails more than thyristors, although their speed and versatility are central. Software, computers, and communications must be comparably sophisticated and swift to interpret electrical networks under widely varying circumstances, calculate what actions or compensation is needed from moment to moment, and then deliver all the right messages to all the right places—reliably, 24 hours a day.



Fast, high-volume computation



High-speed communication links

High-capacity thyristors

Powerful, adaptive software

the total transmission system. Power flow can be directed at will from point to point.

The growing capabilities and declining cost of thyristors may enable them to be used in a variety of power control devices beyond those currently under development. Modular series reactors, which would employ thyristors to add variable amounts of inductance to a line, could be used to limit the flow of power through underground cables to avoid overloading them. Thyristor-controlled ferroresonance dampers could prevent the oscillations that sometimes occur in large transformers at the end of a long power line—causing them to explode. In a fault current limiter, thyristors would quickly change the impedance of a faulted line to prevent currents from growing large enough to cause equipment damage.

The ultimate use of thyristors would be as circuit breakers. This application would be particularly important in regions with frequent power interruptions due to storms, where reduced maintenance costs could make these breakers competitive with the more common, mechanical types. In addition, faults could be cleared almost instantaneously, minimizing damage to equipment and interruption to customers.

The timetable for investigating these and other potential applications depends largely on how quickly thyristor technology itself improves. The power-handling capability of a thyristor depends in part on the diameter of the silicon wafer from which it is fabricated. Today's largest commercial thyristors are made from 100-mm (4-in) wafers, but recent advances in materials research have brought a 150-mm (6-in) chip close to commercialization. New package designs, which replace heavy, expensive metal contact surfaces with silicon, will greatly reduce the cost and size of future thyristors.

At the same time, the internal structure of thyristors is also changing. The greatest barrier to more widespread use of thyristors in transmission applications has traditionally been that, although easy to turn on, they are difficult to turn off. Now a new gate-turnoff (GTO) thyristor—invented in the United States and recently commercialized in Japan—offers a partial solution. The GTO thyristor may simplify the circuitry of some devices, such as the power-conditioning equipment being used at Southern California Edison's new battery energy storage facility. However, the higher losses and cost of GTOs, compared with conventional thyristors, will probably continue to limit their use.

A more promising technology, currently being developed by EPRI, involves turning a thyristor off and on by means of metal oxide semiconductor (MOS) microcircuitry placed directly onto the surface of the thyristor wafer. This MOS-controlled thyristor, or MCT, would be able to switch large line currents by using a very small control current. Its turnoff speed is less than one-third of the GTO's, and it has considerably lower energy losses. MCTs are expected to be available for use in ac-dc conversion and other transmission applications within three to five years.

Open to ideas

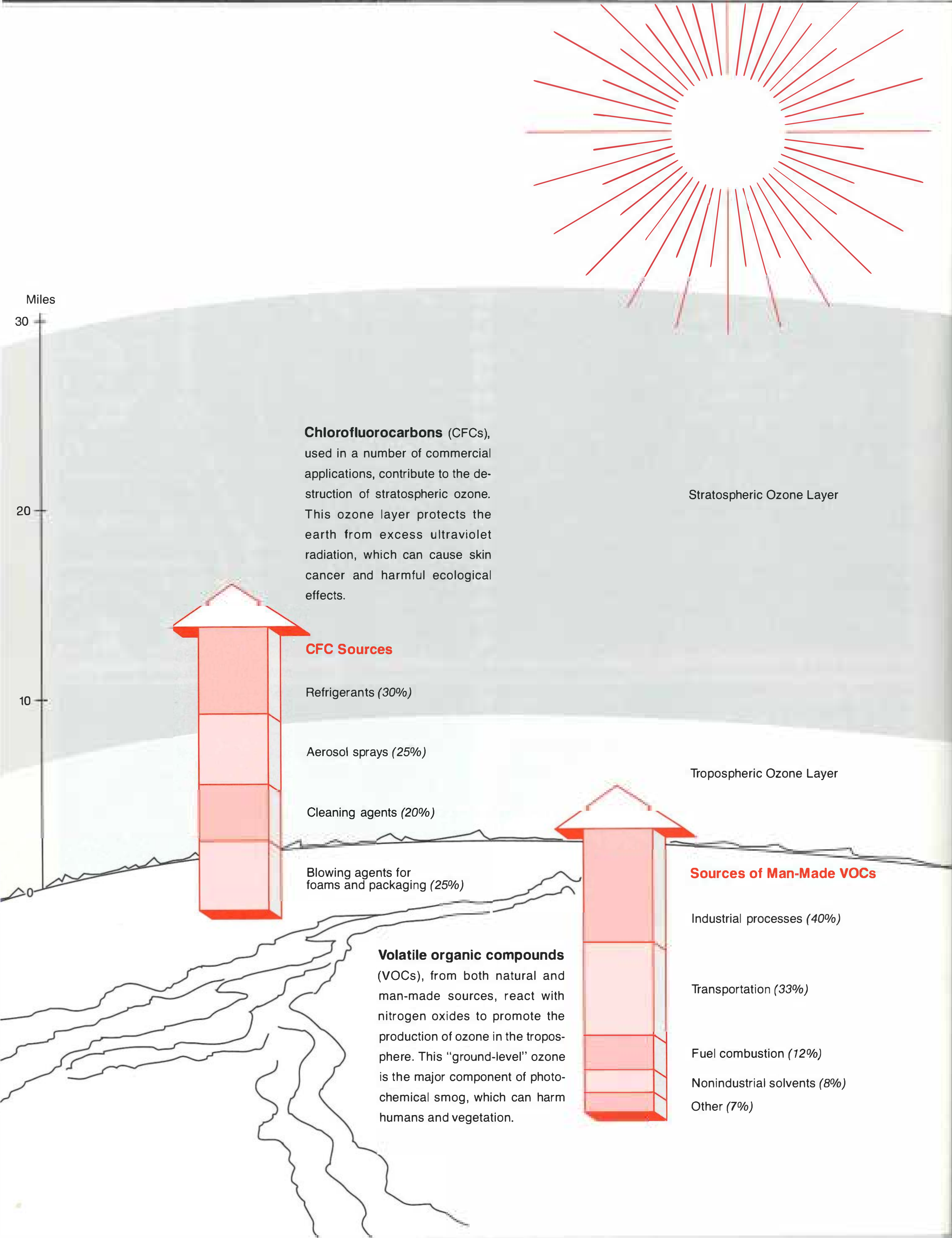
EPRI's research program to develop the many aspects of FACTS began in late 1988 and is divided into two phases. The first phase, which is expected to last three or four years, will involve the evaluation of the technical and economic benefits of FACTS and the development of design specifications for specific power control devices. The thermal performance of present transmission systems will also be evaluated and overall control strategies worked out. The second phase, involving actual hardware development and demonstration on utility systems, could begin as early as 1990.

"We need to follow a systems approach to FACTS, even at the earliest stages," Frank Young emphasizes. "Although it can be implemented piecemeal, the pieces have to fit together. By the time prototypes of phase angle transformers and modular series capacitors are ready for utility demonstration, the strategies for integrating them into a transmission system must also be available. Just as existing software helps an operator dispatch generators, for example, FACTS-related software will help him dispatch impedance, phase angle, and voltage as well."

Economic and social forces, in addition to the technological developments discussed here, will help shape transmission systems of the future. Increased competition in the utility industry, for example, may bring fundamental changes to the U.S. transmission network, such as the development of a new hierarchy of control centers and the "unbundling" of services according to different customer needs. And the addition of generating capacity in smaller increments, more widely dispersed geographically, may contribute to the difficulty of maintaining control of transmission systems. Such changes are likely to create a demand for even more flexibility and control, requiring still further technological advances.

"We need to keep looking for new ways to utilize thyristor technology to satisfy changing needs," concludes Narain Hingorani. "Think of how many different uses have been found for transistors. Right now we're working on only half a dozen or so configurations of thyristors, and we must remain open to new ideas. I particularly want to see more people get involved—for example, those now working on end-use technology—so that we can find more ways to adapt the FACTS concept to meet the requirements of utilities and their customers." ■

This article was written by John Douglas, science writer. Technical background information was provided by Narain Hingorani, Frank Young, and Robert Iveson, Electrical Systems Division.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Chlorofluorocarbons (CFCs), used in a number of commercial applications, contribute to the destruction of stratospheric ozone. This ozone layer protects the earth from excess ultraviolet radiation, which can cause skin cancer and harmful ecological effects.
Stratospheric Ozone Layer
CFC Sources
Refrigerants (30%)
Aerosol sprays (25%)
Cleaning agents (20%)
Blowing agents for foams and packaging (25%)
Tropospheric Ozone Layer
Sources of Man-Made VOCs
Industrial processes (40%)
Transportation (33%)
Fuel combustion (12%)
Nonindustrial solvents (8%)
Other (7%)
Volatile organic compounds (VOCs), from both natural and man-made sources, react with nitrogen oxides to promote the production of ozone in the troposphere. This "ground-level" ozone is the major component of photochemical smog, which can harm humans and vegetation.

Concern Over Ozone

Atmospheric ozone presents two distinct challenges: preventing its buildup at ground levels, where it contributes to urban smog, and preventing its destruction in the stratosphere, where it protects us from ultraviolet rays.

Ozone, the three-atom variant of oxygen, seems an unrivaled paradox among gases in the earth's atmosphere. Ozone occurs in two separate regions of the atmosphere and creates a different concern in each place. Where ozone is essential, it is being diminished. Where it is unwanted, ozone sometimes accumulates.

In the stratosphere, which starts at 7–12 miles above the earth and extends to about 30 miles out in near space, a layer of ozone of about 300 parts per billion (ppb) helps sustain life on the planet by absorbing much of the sun's dangerous ultraviolet (UV) radiation.

In the lower reaches of the more familiar troposphere (which extends unevenly from the ground up to 6–10 miles), ozone is considered an air pollutant. A key component of urban smog, ozone can irritate lungs or damage certain plants at concentrations near the ambient levels in many areas. Although ozone levels are typically much lower in the lower atmosphere, they can range from a few tens of ppb to a level greater than that in the stratosphere, depending on location. Ozone is not emitted directly from any source, yet over 60 major U.S. urban areas do not now meet federal air quality standards limiting ozone to 120 ppb.

Ozone is created naturally in the stratosphere through the chemical destruction of oxygen, which is induced by sunlight. Scientists have recently confirmed that chlorine and bromine from man-made sources are, at times, destroying stratospheric ozone faster than it is replenished, with potentially adverse consequences for human health and agriculture.

An unexpected, and still not completely explained, marked depletion of ozone—a hole the size of the United States or larger—over Antarctica has recently been observed for 4–6 weeks during the Antarctic spring. The hole is the result of both unique meteorological conditions and chemical reactions that apparently allow virtually every atom of chlorine that finds its way there to destroy, unchecked, up to 100,000 ozone molecules.

Major international controversy has developed over the call by many of the world's industrialized nations (including the United States) for the complete phaseout by the end of this century of the widespread use of chlorofluorocarbons (CFCs)—the major source of what ultimately becomes ozone-destroying free chlorine in the stratosphere.

Back at ground level, other battles of several dimensions are heating up again as Congress considers tightening provisions of the Clean Air Act, including those relating to tropospheric ozone. The Environmental Protection Agency, meanwhile, is pondering action against states with air quality districts that do not meet federal ozone standards.

As concern over tropospheric ozone pollution grows, prospects appear ever more likely for greater controls on the many man-made sources of ozone precursors—reactive hydrocarbon gases and nitrogen oxides—including motor vehicles and fossil-fuel-fired industrial plants, residential and commercial activities, and utility generating stations. Residents of southern California, for example, are facing far-reaching changes if efforts proposed to control ozone pollution there are adopted and enforced. Elsewhere, there is evidence that hydrocarbon emissions from natural sources can combine with nitrogen oxides to produce ozone levels that in some cases approach the limit set as the national air quality standard.

Lost in the ozone

"In trying to sort out reports of stratospheric ozone loss and the occasional summer smog 'ozone alert,' the public can get confused by the distinctly different environmental issues associated with this important gas," notes Chuck Hakkarinen, technical manager in EPRI's Environment Division. "The atmospheric and chemical processes involved are different for the two problems. But there may be a link because the loss of ozone in the upper atmosphere could increase the ultraviolet radiation that reaches the earth's surface. More UV radiation would mean more energy is available to drive the photochemical reactions that create ground-level ozone," Hakkarinen postulates.

Concerns that pollutants could damage stratospheric ozone were first raised in 1970 amid plans to develop very high flying supersonic transport (SST) aircraft. It was feared that nitric oxide derived from engine exhaust would destroy ozone through a catalytic chain reaction. The United States eventually abandoned SSTs on economic grounds (Britain and France went on to jointly develop the Concorde), and the impact of the small present SST fleet on stratospheric ozone has been shown to be small. But the controversy spurred scientific studies that established that the chemistry of the upper regions of the atmosphere could be upset by human activity.

In 1974, atmospheric scientists Sherwood Roland and Mario Molina theorized that emissions of several chlorinated compounds in the CFC family, although inert in the lower atmosphere, could be wafting all the way up to the stratosphere, where they are chemically decomposed by UV radiation, producing free chlorine that, in turn, attacks ozone vigorously.

Any significant net loss of ozone in the stratosphere was suspected of implying a range of potential negative biological effects, including increased human skin cancers and eye cataracts. The EPA has estimated that the increased UV from each 1% depletion in stratospheric ozone could lead to a 2% increase in skin cancers among fair-skinned people. No one knows if this estimate is reliable.

On the basis of little more than theory at the time, the United States, Canada, Sweden, and Norway banned the use of CFCs in aerosol cans in 1978. But more than a million tons of CFCs are still produced annually around the world for wide use as propellants, refrigerants, foam-blowing agents, and solvents. Halon gases containing bromine, which are used as fire-extinguishing agents, also destroy ozone. But halons are considered to account for less than 10% of stratospheric ozone destruction, because their emissions are a thousand times less than the emissions of CFCs.

Indications from satellite instrument data of stratospheric ozone loss first began to be seen over Antarctica around 1979, but for some time the data were discounted because of doubts about their accuracy and reliability. A British survey team's announcement in 1985, however, of a measured substantial decline in ozone concentrations above Antarctica over the preceding eight years, which was not predicted by any model or theory, sparked an intensive international scientific reassessment. The group reported a sharp drop in ozone during the months of September and October (the Antarctic spring)—a decline of almost 40% from levels routinely observed 20 years earlier.

Broad-based confirmation of such ozone depletion, as well as the measurement of very high levels of chlorine monoxide—the chemical link between ozone destruction and CFCs—prompted the 1987 Montreal Protocol, which some 36 nations (at last report) have ratified. It calls for a freeze in CFC production at 1986 levels to take effect this summer. The goal is a 50% reduction in total CFC use by 1999.

Because CFC compounds are inert—the essence of their commercial utility—they also can remain in the atmosphere for 40–150 years. Several CFC compounds also readily absorb infrared energy in the lower atmosphere, making them doubly indicted as both stratospheric ozone destroyers and as more-efficient greenhouse gases, molecule for molecule, than carbon dioxide.

Outlook now more mixed

At the time, the 1987 Montreal Protocol was hailed as a precedent-setting international agreement to take action in the face of scientific consensus on a clear threat of global environmental damage. Now, however, a more mixed outlook has developed for stratospheric ozone.

The recently measured loss over Antarctica is more complete (up to 90%) in some areas and lasts longer than was observed earlier. Levels of UV radiation typical of summer were recorded in areas underlying the zone of greatest ozone loss during the most recent Antarctic spring. Recently analyzed data suggest that ozone losses averaging 3% above model predictions have occurred over northern hemisphere latitudes (including North America) from 1978 to 1985; the losses have been greater at higher latitudes.

Extremely cold temperatures (−75°C to −85°C) and the formation of a massive, persistent polar vortex (rotating air mass) during the dark winter are now known to play a key role in the development of the ozone hole over Antarctica in spring. Ice crystals of water and nitric acid that form in the high-altitude clouds of the vortex enhance the release of free chlorine from otherwise inactive forms, helping to set in motion a cycle of ozone destruction. Similar, but less intense or ideal, conditions for ozone destruction have been confirmed over the Arctic region, although no hole over the North Pole has been observed so far.

Coupled with growing awareness that, even with a worldwide freeze on CFC emissions at current levels, the amount of chlorine in the stratosphere will continue to increase for decades, such news led to the dramatic call earlier this year by the European Community—quickly endorsed by the United States—for a complete phaseout of CFCs by 1996. The move coincided with a 123-nation conference organized by British Prime Minister Margaret Thatcher at which it appeared that many less-developed countries do not share the West's sense of urgency or conviction concerning CFCs.

Last May, at a meeting in Helsinki, Finland, sponsored by the United Nations Environment Program to review the Montreal Protocol, 80 nations declared support for a full CFC phaseout by 2000. Meantime, U.S. and international research groups are preparing for another major scientific review of the strato-

Ozone Chemistry in the Stratosphere

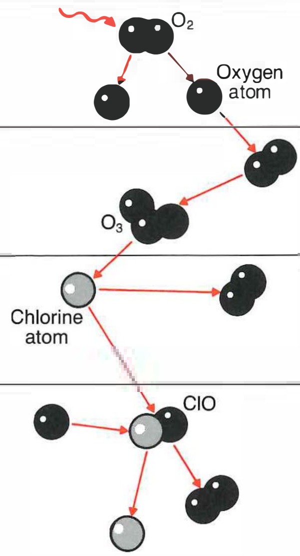
Stratospheric ozone is created and destroyed in a natural cycle that has been functioning in relative equilibrium for thousands of years. The presence of chlorine, released from man-made chlorofluorocarbons by ultraviolet light, disrupts the cycle; each free chlorine atom is thought to be capable of destroying as many as 100,000 ozone molecules.

1. Ultraviolet radiation breaks the chemical bond of an oxygen molecule (O_2), resulting in two free oxygen atoms.

2. A free oxygen atom bonds with another oxygen molecule, creating a molecule of ozone (O_3).

3. A free chlorine atom reacts with the ozone, breaking its fragile bond to create chlorine oxide and an oxygen molecule.

4. A free atom of oxygen breaks up the chlorine oxide and creates another oxygen molecule and a free chlorine atom. The chlorine atom moves on to react with another molecule of ozone.



Ozone Chemistry in the Troposphere

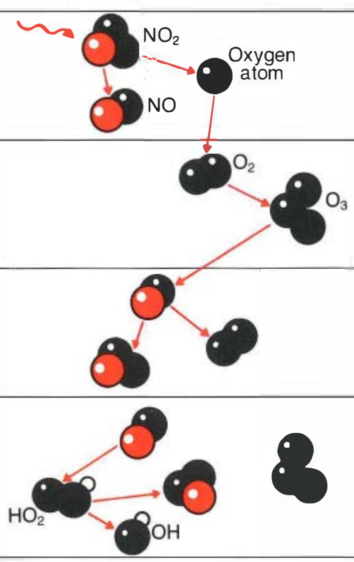
Tropospheric ozone is also produced and destroyed in a natural cycle, this one involving oxygen and nitrogen oxides (NO_x). The ozone is normally created and destroyed daily in equal amounts, but volatile organic compounds (VOCs) from both man-made and natural sources contribute reactive (free-radical) species that interfere with the normal cycle, allowing ozone to accumulate.

1. Ultraviolet radiation breaks nitrogen dioxide (NO_2) into nitric oxide (NO) and a free oxygen atom.

2. The free oxygen atom bonds with an oxygen molecule (O_2) to form an ozone molecule (O_3).

3. The ozone molecule would normally react with the NO to produce NO_2 and an ordinary oxygen molecule.

4. Instead, the NO combines preferentially with HO_2, formed from photochemically reactive VOCs, leaving the ozone molecule intact.



spheric ozone situation this August.

There is at least some good news about stratospheric ozone. There are indications of small to negligible effects on Antarctic plant and animal life from the increased UV radiation of the last few seasons. Ocean plants called phytoplankton at the bottom of the Antarctic food chain, believed most vulnerable to the extra UV, have been observed to be only somewhat less efficient in photosynthesis. And outside of Antarctica there have been no reports of measured increases in UV radiation.

An unanswered commentary of researchers, based on modeling results, is that the 11-year solar sunspot cycle may have had a negative effect on total stratospheric ozone equal to or greater than that of CFCs. A sunspot minimum during 1979–85 would have emitted less high-energy radiation at the earth, reducing molecular oxygen ionization and creating less ozone. The trend of declining stratospheric ozone could be totally masked or even reversed in the next few years until the solar cycle peaks in 1991. Beyond that, however, ozone depletion would be expected to accelerate again, possibly faster than it has up to now.

"The good news, for the time being, is that the magnitude of the reduction of stratospheric ozone is comparable with natural variation between the trough and the peak of the solar sunspot cycle," observed the British scientific journal *Nature* editorially last year. "If the secular reduction of stratospheric ozone so far can be swamped by the effects of the sunspot cycle, it cannot so far have done much damage. The next solar sunspot cycle could, of course, be a different case."

In the research into stratospheric ozone to date, EPRI has only counted itself among the interested observers of the work of others, mainly government agencies and university-based scientists. With a growing program focus on climate change and its direct and indirect implications for utility operations and the demand for electricity, however, EPRI's Environment Division now also plans to explore further the CFC-ozone issue.

"It's already been suggested that, even if we cut back on CFC emissions, the ozone loss is going to get worse before it gets better," notes Hakkarinen, who is managing the study. "So we're trying to identify more clearly what stratospheric ozone levels should look like over time if CFC production does decline. We would like to know when and what sort of changes in stratospheric ozone to anticipate so that industries could have some validation of whether the controls on CFCs are important."

In the near term, meanwhile, the most significant consequences of CFC controls will be felt indirectly by utilities through their customers. Because of the ubiquity of CFCs in commercial use, all manner of industries and their products stand to be affected by voluntary reductions and new EPA regulations implementing the Montreal Protocol. EPRI's Customer Systems Division is sponsoring analyses of the implications of CFC cutbacks and possible substitutes.

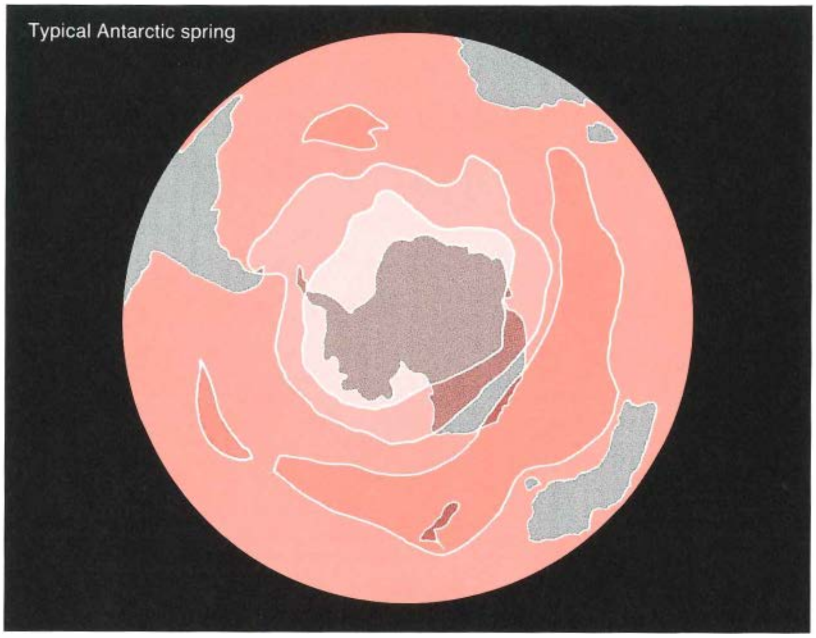
"The potential impact on electric power demand and energy consumption is very large," says Arnold Fickett, vice president and Customer Systems Division director. "Utilities have a strong interest in seeing that the alternatives that evolve will be safe and energy-efficient and not exacerbate loads."

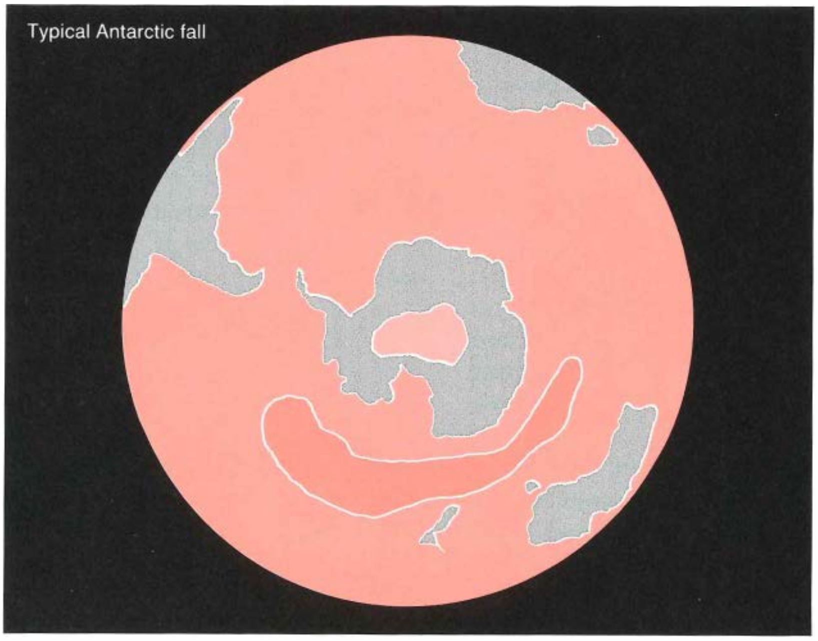
Ozone closer to home

While much of the industrialized world has set in motion costly and controversial changes designed to stem the loss of high-flying ozone in the stratosphere, the problem closer to the ground is quite the opposite—even small concentrations can be too much. Here, ozone pollution accumulates when reactive hydrocarbon gases (from gasoline, solvents, and natural emissions), also known as volatile organic compounds (VOCs), disrupt the usual cycle of ozone formation and destruction involving molecular oxygen and nitrogen oxides (NO_x).

A Thinning Over the South Pole

The "hole" in the stratospheric ozone layer over Antarctica is actually a large zone of reduced ozone concentration observed during the Antarctic spring (September and October) over the last decade. Although the release of certain chlorofluorocarbons to the atmosphere is believed to be responsible for such reductions, the ozone hole is also dependent on Antarctica's unique climate and seasonal patterns. A large polar air mass, extremely cold temperatures at high altitudes, and the emergence of spring sunlight after the dark polar winter create chemical conditions ideal for ozone destruction. Ozone levels are similar to those elsewhere around the globe during other seasons of the year.





The ratio of VOCs to NO_x is known to play a more important role than their absolute concentrations in ozone formation and peak ozone levels. How fast ozone accumulates is closely related to the availability of highly reactive (free radical) species produced when molecules of VOCs decompose in sunlight. These species interfere with the oxygen-NO_x reaction, also driven by sunlight, that normally creates and destroys equal amounts of ozone.

The reactions and atmospheric processes involved are also related to the chemistry and physics of acid rain formation and the production of aerosol particles. "All of the end products of air pollution that are suspected of being undesirable—from sulfuric or nitric acid in precipitation, to ozone, to aerosol particles that scatter light and thus obscure our field of view—are formed in the atmosphere from ozone and precursor emissions, for the most part, and the chemistry is interactive," says Peter K. Mueller, EPRI program manager for atmospheric sciences in the Environment Division.

Emissions of both NO_x and VOCs have man-made and natural sources. The bulk of the NO_x, however, amounting to some 20 million tons a year in this country, comes from the combustion of fossil fuels in motor vehicles, industry, commerce, and utility generating plants. Natural sources such as forest fires, decomposing plants, and lightning generate a comparatively small amount of NO_x; lightning can be a significant source locally for short periods.

Sources of VOCs are much more diverse. Trees and shrubs are a major natural source of reactive hydrocarbons, emitting an estimated 20 million tons each year, mostly as isoprene and pinene. Man-made VOC emissions, estimated to account for another 20 million tons per year in this country, originate from a wide variety of industrial processes, incomplete combustion in motor vehicle engines, other fossil fuel combustion, use of organic solvents (mostly petroleum)—even from gasoline vapors at the service pump.

Trace background levels of ozone are believed to have always been present in the troposphere, partly the result of convective transport from the stratosphere and partly due to natural tropospheric photochemistry. A long record of measurements on the outskirts of Paris around the turn of the century suggests that tropospheric ozone levels in central Europe 100 years ago averaged 10 ppb.

A current issue in atmospheric science is whether tropospheric ozone in industrial countries is increasing. Levels in rural areas of the United States with no significant man-made NO_x and VOC emissions are believed to be typically 30–40 ppb; at remote Pacific islands, levels are 20–30 ppb. At the other extreme, half a dozen U.S. cities frequently experience three-hour peak ozone concentrations of 150–200 ppb, particularly in summer when there are stable, high-pressure weather systems overhead. In Los Angeles, ozone has been measured at levels as high as 290 ppb.

According to the EPA, 65 urban areas in the United States exceed the National Ambient Air Quality Standard (NAAQS) for ozone of 120 ppb. The health-based NAAQS is a one-hour average concentration, not to be exceeded more than once a year over a three-year average. It is set by the EPA to protect sensitive people, such as children and heavily exercising people. Some recent research suggests that respiratory responses occur after extended exposure to ozone levels even lower than 120 ppb.

Meanwhile, some field as well as modeling studies suggest that natural VOC emissions from trees in rural areas can react with even trace levels of NO_x from nearby or more distant sources to generate ozone levels that approach the NAAQS. It has been suggested that such biogenic hydrocarbons may play a substantial role, for example, in the routinely high ozone levels in and around Atlanta, Georgia.

The amount of VOCs from the dense pine forests that surround the sprawling southeastern city is comparable to the amount of man-made hydrocarbons emitted in the urban area. Researchers at the Georgia Institute of Technology have suggested that, because a substantial reduction in the area's man-made VOC emissions in recent years has not resulted in a corresponding decrease in ozone, the remaining baseline of biogenic VOCs could mean that significant reductions in urban and power plant NO_x emissions also might be required before ozone levels would meet air quality standards.

Computer simulations of different urban airsheds suggest that NO_x reductions can increase or reduce ozone levels, depending on the relative proportions of VOCs and NO_x, sunlight, and other factors. The models also suggest that reducing VOCs will always tend to reduce ozone formation.

Most regulatory strategies for reducing urban ozone have, in fact, focused on reducing VOC emissions but have met with only mixed success. This is partly because of the ubiquity and numbers of sources, including every running motor vehicle, open can of paint or solvent, and dry cleaning establishment, to name just a few. Moreover, in the case of automobiles, growth in the number of vehicles and miles traveled in many regions has begun to outpace the emission reductions per vehicle mile achieved so far.

More than a health issue

The NAAQS for ozone is set primarily to protect human health. This month officials of the new administration were expected to outline what actions they will take in states with air quality districts out of compliance with ozone standards. Several bills in Congress could set tough new penalties for nonattainment areas, including steep permit fees for emissions sources, tighter tailpipe emissions limits, and gasoline vapor recovery requirements and VOC volatility restrictions.

Reducing ozone levels is the goal of a sweeping, new, long-term antismog plan proposed recently by authorities in southern California and intended to bring the four-county Los Angeles area into compliance with federal air quality standards by 2007. The far-reaching plan supersedes older ideas that should have achieved the NAAQS by now, and it could mean major changes in the way southern Californians live and work in the years ahead. Proposals, which center on further limiting VOC emissions, include bans on household sources such as charcoal-lighter fluid, gasoline-powered lawnmowers, and all aerosol cans, as well as drive-up service windows and free parking in commercial districts. Emissions controls would be placed on bakeries, breweries, and dry cleaners—all potential sources of VOCs.

But protecting human health is not the only motivation for reducing ozone. For reasons analogous to why humans are sensitive to the highly reactive gas, so are many plants. Ozone interferes with photosynthesis, causing reduced yields in the case of crops and retarded growth in the case of sensitive tree species.

According to EPRI research managers, the evidence of significant damage to plant life from ozone is far less ambiguous than that for health effects. "Visible damage or reduced growth in certain crop and tree species is well documented, but ozone's effects on complex forest ecosystems are not as well understood," says Lou Pitelka, project manager in the Ecological Studies Program. "It may alter forest plant life by eliminating ozone-sensitive species, reducing nutrient levels, and changing mortality rates.

"On a regional basis, researchers regard ozone as potentially the most serious pollutant threatening American forests," adds Pitelka. "It is the primary cause of decline in the ponderosa pine forests of southern California. While it does not appear to be the primary cause of forest decline in the eastern United

Research on Crops and Forests

Most EPRI-funded research on ozone issues relates to tropospheric pollution. Besides air quality studies that model the atmospheric physics and chemistry of ozone in the larger context of pollutant emissions, EPRI has funded major plant and forest studies that have included a focus on ozone. This work has confirmed significant reductions in specific crop yields and reduced growth in certain tree species at common ambient levels. Continuing studies of forest systems are examining the interactive effects of ozone and other environmental factors.

States, many researchers suspect ozone of being a potential culprit in weakening certain species and making them vulnerable to other stresses, or in further damaging species that are already weakened by other factors."

EPRI has sponsored research on the effects of ozone on crops and forest plants. The work has confirmed significant yield reductions in soybeans, wheat, corn, and potatoes at ambient ozone levels. More-recent work on forest ecosystems is focusing on how ozone interacts with other factors in affecting forest vegetation.

On the atmospheric sciences front, ozone measurements and reaction chemistry have been explicitly accounted for in numerous EPRI-sponsored air quality studies. Now, according to Peter Mueller, researchers are preparing for the next step: to connect and integrate models of differing spatial and temporal dimensions and specificity to provide a comprehensive simulation of emissions and atmospheric transport and conversion.

Such "embedded" modeling would bring a long-sought improved capability of evaluating trade-offs inherent in different emissions control strategies. One goal of the modeling work is to be able to analyze the potentially different role of dispersed versus point sources of, for example, NO_x emissions. Or, the locations of sources within a region might make a difference in ozone levels, depending on the sequence of reactant blending.

"One current issue is whether NO_x emissions in rural areas are mixing with natural hydrocarbons from vegetation and producing ozone levels that not only have the potential for local damage to plants, but may also be transported into urban areas and be adding to what is already there so that the air quality standard is exceeded," explains Mueller. "The embedded models that need to be developed would help to quantify and evaluate suspicions along these lines.

"At the same time, the models would help address what is happening with visibility and fine particles. You can't separate the fine-particle, acid aerosol, and ozone problems from the health effects issues in urban areas. We are moving toward addressing these in an integrated approach," Mueller adds.

Mueller also thinks there may be a further link between stratospheric ozone and tropospheric ozone production. "If stratospheric ozone has diminished significantly, we should be seeing increased levels of UV radiation all around the world, but so far more UV has only been seen in Antarctica. What could explain this? One possible explanation is that, because ozone, wherever it is, absorbs UV radiation, ozone in the troposphere may be offsetting whatever added UV radiation the earth may be getting from decreased ozone in the stratosphere. We certainly don't know the answer yet."

Spotlight on ozone

Ozone has emerged center stage in the complex web of global and regional environmental concerns related to man's influence on the environment. Discovery of an ozone hole in the stratosphere over Antarctica catalyzed an international response with significant near-term implications for technology and industries that depend on CFCs. But it has also revealed sharp differences among nations in their attitudes on the appropriate balance between economic development and protection of the global environment. Developments in the next few years could be a bellwether for the direction of change in response to broader policy questions involving world climate and greenhouse issues.

In America's everyday world of freeways, cars and trucks, record power demand, summer heat waves, and hazy, brown horizons, however, ozone is at the center of concern over the environmental and health effects of increasing air pollution and the focus of emissions control strategies. Although stratospheric ozone and tropospheric ozone really are separate issues, the continuing need for scientific insights to inform the policy and regulatory debates is a common thread between them. ■

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This article was written by Taylor Moore. Technical background was provided by Chuck Hakkarinen, Peter K. Mueller, and Lou Pitelka, Environment Division.

Real-World Lessons in Seismic Safety

A detailed site investigation of last year's Armenian earthquake provides the latest data points in research to verify the ruggedness of safety-related equipment at U.S. nuclear plants. This effort has already paid off in NRC approval of qualification procedures based on documented real-world experience.

Striking with sudden fury on a calm winter morning, a large earthquake hammered Armenia on December 7, 1988, with devastating consequences. Although the Soviet republic lies in an earthquake-prone area and its residents were used to being jostled by temblors, the magnitude 6.9 quake was the most destructive to hit the region in centuries. Within moments, hundreds of modern multistory buildings—schools, hospitals, apartment houses, and industrial facilities—collapsed in ruins. Hundreds more were damaged beyond repair and would have to be demolished. The tragedy left at least 30,000 people dead and half a million others without homes or jobs.

By December 16, as aftershocks still jarred the region and emergency crews labored in the rubble, an EPRI representative was en route to Armenia, sharing a Soviet military transport with 18 other earthquake experts, seismic instruments, emergency medical supplies, and expedition gear. Peter Yanev, chairman of EQE Engineering and a specialist in earthquake effects on power and industrial facilities, flew to the region on EPRI's behalf as a member of the postdisaster study team quickly organized by the U.S. Academy of Sciences and its Soviet counterpart. Through an independent technical exchange agreement between EPRI and the I. V. Kurchatov Institute for Atomic Energy in Moscow, a national lab, Yanev was granted access to several power facilities, including the Armenia Nuclear Power Plant.

The Soviet trip is part of EPRI's post-earthquake investigation project, which is collecting data on the performance of structures and equipment in power and industrial facilities worldwide that have experienced earthquakes. The project's goal is to use the data to demonstrate the seismic ruggedness of similar structures and equipment in nuclear power plants, in particular the equipment needed to shut down the plant safely in the event of a severe earthquake. Immediately after a major earthquake such as the one in Armenia, EPRI dispatches a team of seismic experts to investigate how power and industrial facilities responded to the shaking. Since the project was launched in 1985, EPRI has completed nine investigations of six major earthquakes, from California to far-flung areas such as New Zealand and Central America. Findings from these investigations are published in EPRI reports as part of the post-earthquake investigation project; the information is also incorporated into an extensive seismic experience database being developed by the Institute.

The estimated savings to nuclear utilities using these earthquake experience data range from $10 million to $35 million per unit, with overall savings expected to run more than $2 billion. And applied on a broader level, the data can provide valuable lessons for nonnuclear power facilities as well as other industries. "We've gained tremendous practical knowledge during these investigations," says Robert Kassawara, who manages the post-earthquake investigation project for EPRI's Nuclear Power Division. "Learning about the effects of actual earthquakes on structures and equipment provides a real-world perspective that is missing under simulated conditions."

Seismic safety

The real-world lessons from these investigations will help ensure that safety systems in nuclear plants will perform even during the most powerful earthquakes. Every nuclear unit in the United States is outfitted with equipment designed to shut down the plant safely during the most violent earthquake believed possible based on local geologic and seismic conditions. The Nuclear Regulatory Commission (NRC) requires this safety-related equipment to meet rigorous seismic qualification criteria, verified by extensive analysis and testing using shake tables to simulate earthquake motions.

But the qualification procedures have changed considerably since nuclear plants were first introduced. The equipment in older plants may be suitably rugged, but it was installed when design requirements, seismic analyses, and documentation procedures were less formal than today's stringent standards. The seismic performance of this earlier equipment must be verified, but for several reasons it's not practical or cost-effective to perform this verification by means of the current analytical and testing methods. For example, identical vintage equipment may not be available, and removing installed equipment from a plant for laboratory testing may result in excessive downtime. In addition, because some of the installed equipment may be irradiated, transporting it to a testing lab may present difficulties. For these reasons, the NRC in 1980 designated the seismic qualification of equipment in operating nuclear plants as an unresolved safety issue, with the objective of developing alternative methods for qualifying the equipment.

In response, several nuclear utilities formed the Seismic Qualification Utility Group (SQUG) in 1982 to craft a practical approach to resolving the issue: using seismic experience data to assess the equipment's ruggedness. This approach uses field data on equipment performance in actual earthquakes, supplemented by the large body of existing seismic test data developed from shake-table testing and analysis. EPRI launched the postearthquake investigation project in 1985 to formalize the gathering of earthquake data begun by SQUG. Together, SQUG and EPRI have developed procedures and guidelines for using these data to evaluate the 20 generic classes of electrical and mechanical equipment needed to shut down a nuclear plant safely. The NRC approved the guidelines and procedures in 1987. Commonwealth Edison estimates that SQUG's guidelines and procedures will save $35–50 million in seismic qualification at each of its six older nuclear units.

"This approach is a hands-on, practical way of showing that this equipment can meet the earthquake requirements for which it was designed," says Kassawara, "and can in fact sustain earthquake loads considerably in excess of design. Very few earthquakes, all of them small, have occurred at nuclear power plant sites. However, nonnuclear power plants and many industrial facilities have equipment that is identical or similar to that found in nuclear plants. By gathering information on the seismic performance of this equipment we can draw a direct parallel to the safety systems in operating nuclear plants." The experience-based approach also serves to moderate some of the overconservatism of traditional seismic qualification procedures, says Kassawara. "We have found that industrial-grade equipment is extremely rugged and survives powerful earthquakes—provided certain conditions and caveats are met. For example, it's absolutely essential that the equipment be properly anchored."

Lessons in the rubble

Despite the tremendous damage to buildings, the inherent ruggedness of the industrial-grade equipment inside was demonstrated even in Armenia, where in some cities the damage wrought by the quake resembled the aftermath of a bombing raid. "It was devastation such as that produced by a war," says Yanev. "After investigating 26 earthquakes I thought I'd seen it all, but the damage in Spitak—the city closest to the epicenter—was the worst I'd ever seen." Spitak suffered virtually 100% destruction, with hardly a single functional building left standing. Much of the equipment in the industrial facilities was damaged by collapsing buildings. Unanchored and poorly anchored equipment slid and toppled. Nevertheless, says Yanev, "properly anchored equipment and piping that had not been struck by falling debris performed very well."

The U.S. team traveled to several cities in the strongly shaken area and documented the earthquake's effects on structures, power systems, and lifelines such as roads, bridges, and communications systems. The Armenian experience provides a striking example of the capacity of a strong earthquake to damage modern construction, according to Yanev. "Rarely has the importance of systematic risk identification and proper seismic design and construction in earthquake-prone areas been more apparent," he says.

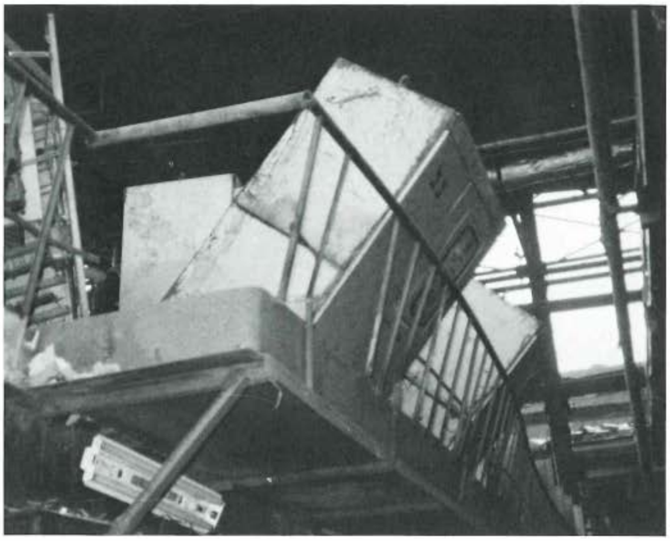
Armenia lies within a large seismic belt stretching from the southern Mediterranean to India. Most earthquakes in this region are caused by the movements of the Eurasian and Arabian tectonic plates, which are converging at the rate of about two centimeters per year. Over millennia this collision process has caused extensive folding in the earth's crust and given rise to the Caucasus Mountains. Although historical records show that powerful earthquakes occurred in the region, only limited scientific information was available until 1951, when Soviet seismologists installed a network of seismic instruments throughout Armenia. The most recent damaging earthquake was an estimated magnitude 5.7 event in 1926, which killed about 400 people, but large earthquakes are common throughout the region.

The December 7 earthquake struck just north of the city of Spitak, about 75 kilometers north of Yerevan, the Armenian capital. Four minutes after the main earthquake, a magnitude 5.8 aftershock slammed the region. Several large cities in the epicentral region sustained massive damage and high casualties. Leninakan, with 290,000 inhabitants Armenia's second largest city, was 80% destroyed or heavily damaged. Kirovakan, population 150,000, was also heavily damaged. The small cities of Spitak and Nalband, which lie practically astride the fault rupture, were virtually destroyed; nearly all structures collapsed and the majority of the inhabitants were killed. Some 350 smaller towns were affected by the earthquake, with about 58 being completely destroyed.

The primary reason for the high death toll was the partial or total collapse of relatively modern buildings that had not been designed to withstand the shaking of such a strong earthquake. Soviet building construction is under the direction of a central agency in Moscow, which develops a limited number of generic building designs that are implemented throughout the Soviet Union. The basic

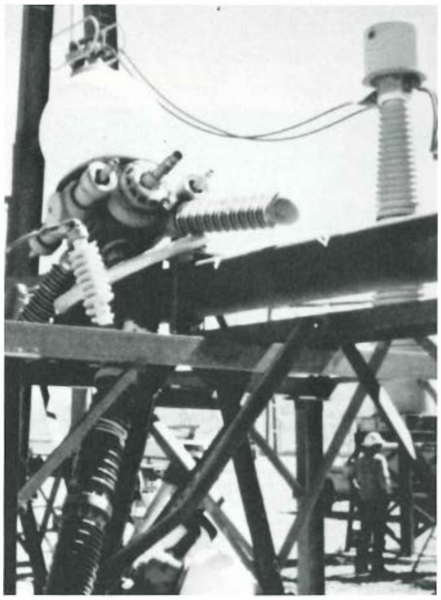
Bracing for Quakes: The Importance of Proper Anchorage

Performance under actual earthquake conditions provides valuable lessons on the seismic reliability of structures and equipment. In all the earthquakes studied, industrial-grade equipment that was properly anchored and installed in well-designed structures of steel or concrete suffered no damage or loss of function. Amid the rubble of the collapsed control building at a substation in Nalband, Armenia, electrical control cabinets apparently remained intact or had limited damage, while electrical cabinets at the Spitak sugar refinery a few miles away toppled when poorly executed puddle welds failed to stabilize them during high-intensity ground motion.



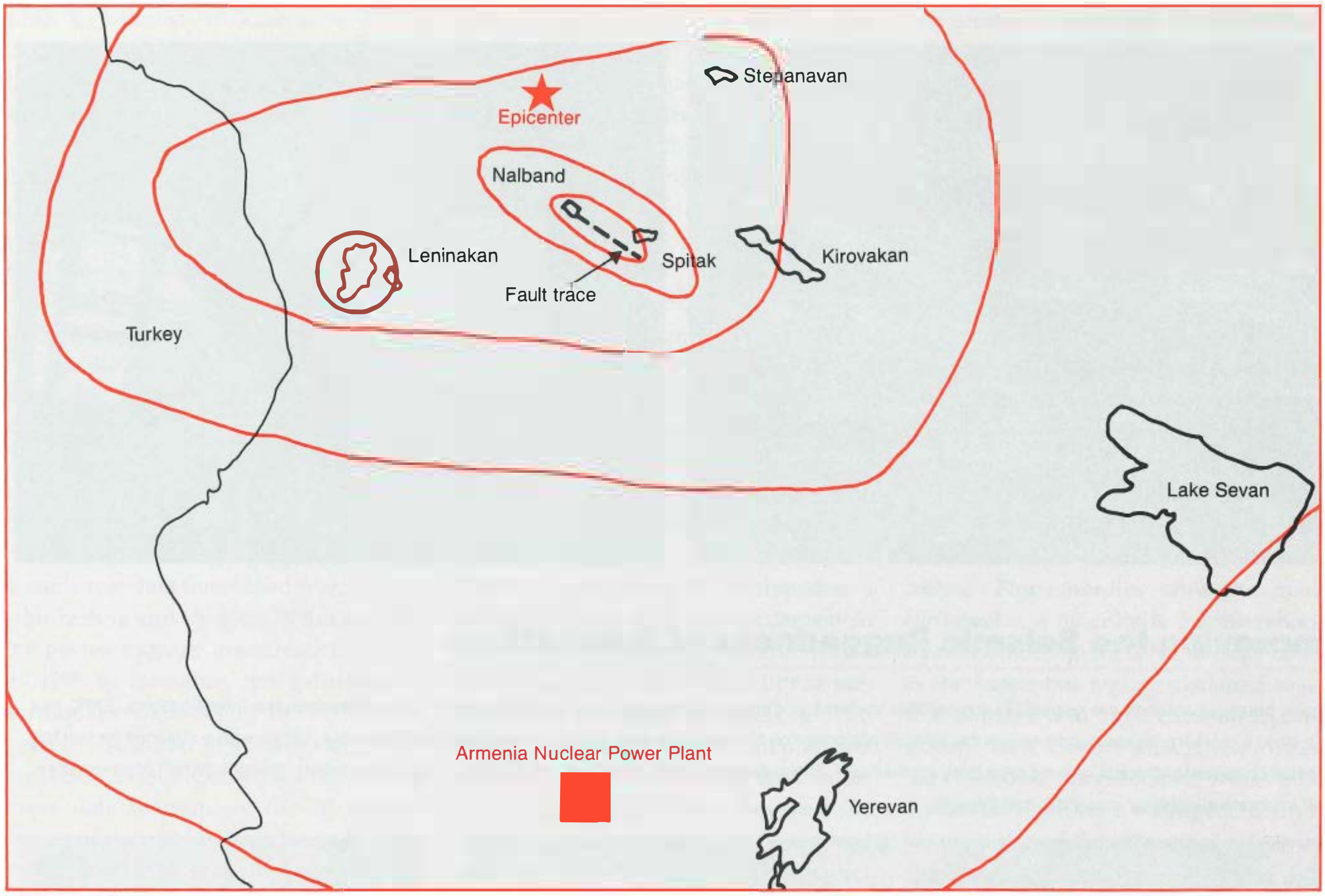
Improving the Seismic Ruggedness of Substations

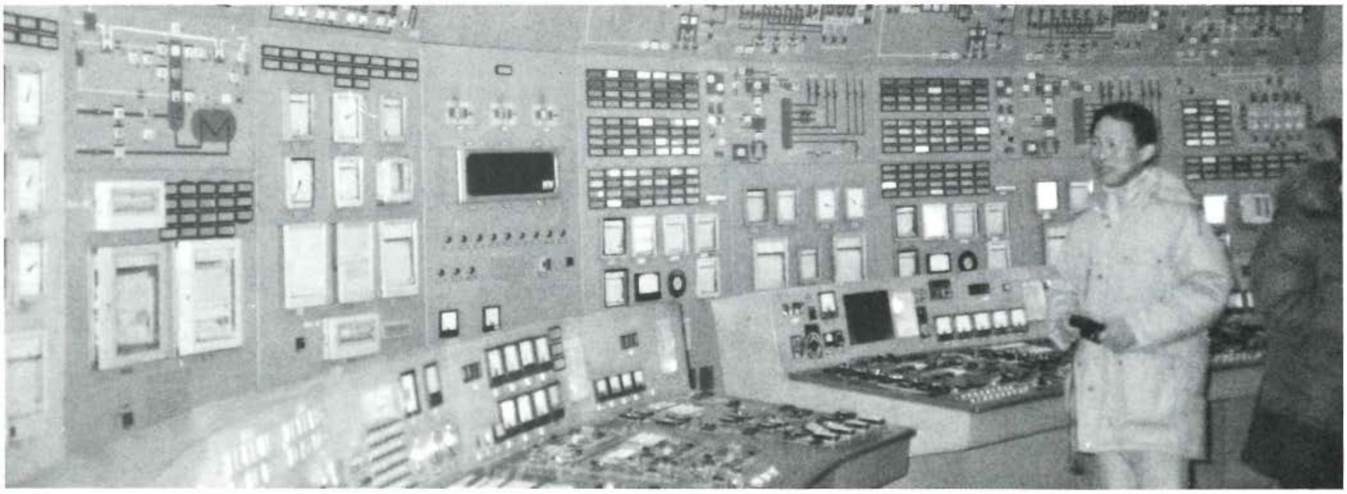
Power plant substations are especially susceptible to damage during earthquakes. As an outgrowth of the postearthquake investigations, EPRI has launched a project to assess and improve the seismic performance of vulnerable switchyard components and to provide utilities with guidelines for making gradual changes to upgrade seismic capability at small cost. The guidelines will encompass anchorages, connection details, the attachment of power lines, and alternative insulator materials and designs.



Nuclear Plant Undamaged in Earthquake

The two-unit Armenia Nuclear Power Plant, located about 75 kilometers south of the epicenter, was outside the most strongly shaken area and continued to operate during and after the earthquake. Nevertheless, the Soviets shut down the plant in March because of the prohibitively high cost of installing additional seismic reinforcement.





designs do not incorporate seismic features. If a building is to be located in a seismically active area, a local agency modifies the basic design to be earthquake resistant—seismic reinforcement is thus added more or less as an afterthought, rather than incorporated into the design from the start. The modifications typically are not extensive, and must be made within strict cost and production limits.

Wood and structural steel, which have the inherent flexibility to "give" under earthquake loads, are in short supply in Armenia, and the buildings there were constructed of masonry with precast concrete elements. The violent shaking caused these buildings to collapse into compact piles of rubble that left few spaces to shelter survivors. Yanev found that older structures, built with cut stone and wood roofs, generally performed better than the newer structures with concrete floors that were inadequately connected to the walls. Compared with poorly designed concrete structures, steel-frame buildings and other steel structures such as construction cranes sustained far less damage. At the Spitak sugar refinery, which had many steel-frame buildings, the earthquake shook apart the precast concrete and masonry facades but left the steel frames standing.

Effects on power systems

Electric power in the strongly shaken area was interrupted for four to seven days. Yanev examined two electrical substations in the epicentral region, a 220-kV facility in Leninakan and a 110-kV facility near Nalband. Although the Leninakan station sustained damage to capacitor racks, ceramics, and circuit breakers, the anchored equipment inside the control house was undamaged. The more severe ground motion at the Nalband station almost totally destroyed it. The under-reinforced masonry and precast-concrete control house collapsed completely and struck nearby bus structures as it fell. Even so, some equipment inside the col-

Earthquake Data Bring Safety and Savings

Information gathered from EPRI's postearthquake investigations has been used by the Seismic Qualification Utility Group (SQUG) in developing new procedures for demonstrating that the safe-shutdown systems in nuclear power plants will function properly during and after a powerful earthquake. Older plants may contain equipment installed prior to the current seismic qualification standards established by the Nuclear Regulatory Commission, which call for qualifying the equipment on shake tables and by mathematical analyses. However, such testing of equipment already installed in operating plants is impractical, requiring duplication or removal from operation. Recognizing this, the NRC in 1980 designated the seismic qualification of equipment in operation as "unresolved safety issue A-46." SQUG was formed to resolve USI A-46 by developing alternative qualification procedures that would provide a level of safety comparable to that achieved by the current requirements. SQUG currently represents 33 U.S. utilities and 3 foreign utilities.

The SQUG approach draws on field experience data on the performance in earthquakes of industrial equipment that is identical or similar to equipment in nuclear plants. These data are supplemented with existing seismic test data from laboratory shake-table testing and analyses. Under contract to the NRC, Lawrence Livermore National Laboratory conducted a study in 1983 that concluded that the use of seismic experience data is feasible and can be as effective as current qualification methods. The same year, SQUG and the NRC formed a five-member senior seismic review and advisory panel to provide expert opinion and consulting services on the use of experience data. SQUG has developed a generic implementation procedure that utilities can use to evaluate the seismic ruggedness of the 20 generic classes of electrical and mechanical equipment needed to bring a plant to a safe shutdown. The NRC approved the SQUG methodology in 1987. EPRI has actively supported the SQUG effort through development of equipment anchorage guidelines, generic test spectra, and relay evaluation techniques—all critical supplements to the overall experience-based approach.

In addition to providing assurance that safety-related equipment will perform properly during an earthquake, use of the experience-based procedures in place of the current analytical approaches is expected to save nuclear utilities more than $2 billion. □

lapsed building, including electrical control cabinets and metal-clad switchgear, apparently remained intact or sustained limited damage, and was supporting sections of the building's roof. Transformers, circuit breakers, and capacitor banks were severely damaged, and Soviet authorities had to bring in a rail-mounted substation to restore electric power to the region. Steel transmission towers throughout the strongly shaken area performed with no reported damage. Wooden power poles also survived intact, except for a few cases where partially rotted poles snapped at their bases.

The two-unit Armenia Nuclear Power Plant, which is located about 75 kilometers south of the epicenter and outside the strongly shaken area, continued to operate during and after the earthquake. The units are of the Soviet VVER-440 class, similar to the western pressurized water reactor. The plant was shut down shortly after the earthquake for 48 hours to conduct a safety inspection. The plant's operators found no significant damage, and when the plant was restarted all systems functioned normally.

Like some other nuclear plants in the Soviet Union, the Armenian units lack a full containment or an emergency core-cooling system. These omissions, coupled with inadequate seismic design, have resulted in the decision to close the plant. According to Yanev, the Soviets acknowledge that although Unit 2 has been designed to resist some level of earthquake loading, both of the units would require a substantial amount of additional seismic reinforcement to remain safe, and the price of such an extensive retrofit would be prohibitively high—perhaps as much as building a new facility. Because the plant is near a major agricultural region, and to ease fears of a Chernobyl-style accident, the Soviets shut down both units in March. Soviet officials also announced that construction of six other nuclear plants, three of them in the Caucasus region, would be halted or suspended because of the earthquake hazard

EPRI's Seismic Projects Worldwide

Seismic data gathered around the globe are improving our understanding of earthquake phenomena and the ways structures and equipment respond to ground motion. EPRI's seismic program is applying these data in developing safe seismic designs and cost-effective qualification procedures.

Palm Springs, California: Postearthquake investigation, July 1986.

Parkfield, California: An array of strong-motion sensors installed near the San Andreas fault is providing data on soil liquefaction and the spatial variation of ground motion over an area of a typical nuclear plant containment.

Whittier, California: Postearthquake investigation, October 1987.

Georgia: Trial review at the Hatch Unit 1 BWR plant using EPRI methodology for evaluating seismic margins.

Illinois: Trial review of the Zion plant using the SQUG experience-based procedures for seismic qualification of equipment in operating plants.

New York: Trial review of the Nine Mile Point plant using the SQUG generic implementation procedures for seismic qualification of equipment in operating plants.

South Carolina: Trial review at the Catawba Unit 2 PWR plant using EPRI methodology for evaluating seismic margins.

Cerro Prieto, Mexico: Postearthquake investigation, 1987.

Lazaro Cardenas, Mexico: Postearthquake investigation, September 1985.

Southwestern Mexico: Seismic instruments installed at industrial facilities will provide accurate data on the actual earthquake motion experienced by structures and equipment.

San Salvador: Postearthquake investigation, 1986.

Whakatane, New Zealand: Postearthquake investigation, March 1987.

Tadotsu, Japan: A 15- by 15-m shake table has been used to obtain data on the response of large-diameter pipe to high-intensity motion.

Hualien, Taiwan: A dense array of seismographs will provide motion recordings at a site with stiffer soil than Lotung.

Lotung, Taiwan: EPRI and Taiwan Power Co. constructed and instrumented models of concrete reactor containments to collect data on the interaction of soil and structures during earthquakes. The one-fourth- and one-twelfth-scale models are sited in an active seismic region within a dense array of seismographic instruments operated by the University of California.

Armenia: Postearthquake investigation, December 1988.

and for other safety-related reasons. The Soviets have been exploring the feasibility of converting the Armenian plant to a natural gas facility.

SQUG and EPRI plan to continue to develop the seismic experience database for use in future seismic equipment qualification; each investigation provides useful lessons that contribute to the robustness of the database. "The primary value of the data that we collect lies in the consistency of findings over multiple investigations," says Kassawara. "But each investigation makes a unique contribution as well. For example, our investigations of the 1987 New Zealand earthquake yielded valuable information on the seismic performance of above-ground storage tanks, in addition to that of equipment in many industrial facilities."

The 1986 Palm Springs earthquake provided an excellent opportunity to study the effects of earthquake motion on several types of modern switchyard equipment. Southern California Edison's Devers substation, located near the epicenter and in view of the fault rupture of the magnitude 5.9 quake, was equipped with seismic instruments that recorded a peak ground acceleration of 0.97g—the highest ever measured at a major power facility. Control and instrumentation systems at the substation were undamaged, but the ceramic components of the switchyard equipment sustained moderate to extensive damage. Heavy damage was also incurred at the Sylmar converter station in the 1971 San Fernando earthquake. In both cases, costs for replacement, repair, and loss of service were substantial. These experiences have spawned a new project to compile data on the seismic performance of switchyard equipment. "Switchyards are vulnerable to earthquakes, even relatively small ones, largely because the ceramic components are brittle," says Kassawara. "Inadequate anchorage of transformers also results in damage in larger earthquakes. We are looking at ways to improve the margins on those components, and to apply lessons from the investigations in developing good practices for switchyard design."

In another new project, the Institute is installing seismic instruments in several industrial facilities in southwestern Mexico, where earthquakes occur on a fairly regular basis. "We want to get some seismic records of what actually happens inside buildings," says Kassawara, "to learn just what the equipment is actually experiencing. We've had to extrapolate from records taken nearby, but we want to get data on what the actual earthquake movement was inside the plant. We're usually frustrated by an insufficient number of seismic recordings."

A restless earth

Part of the difficulty of studying earthquakes, and preparing an industrial society to deal with them, lies in the disparity between human and geologic time frames. The development of industrial society has occupied but a brief moment in geologic time, and modern scientific study of earthquakes spans only about 50 years. Powerful earthquakes strike infrequently, making them hard to study, and lessons from violent earthquakes can be forgotten by successive generations. Earthquakes also strike without warning, never failing to catch the unprepared by surprise. Although the United States has not experienced catastrophic loss of life comparable to the Armenian disaster, there is danger in complacency. Growing populations in earthquake-prone areas have created conditions that could lead to large loss of life and property.

"The big lesson from Armenia is that the same thing can happen here in the United States," warns Yanev. "Soviet seismologists essentially knew that a big earthquake would come along sooner or later, but the people weren't prepared for it. And we have similar situations here in this country. In the nuclear power industry we've gone to extremes to make sure our plants are seismically designed, but the amount of seismic consideration given to conventional construction seems to be proportional to the frequency of earthquakes."

In the United States the lack of preparedness is less of a problem in well-known earthquake zones such as California, which is jostled by minor temblors every few months and shaken strongly every few years; the real danger is in areas where earthquakes are rare. For example, the public generally does not know that the most widely felt earthquakes to strike the United States in historical memory occurred in New Madrid, Missouri, in 1811 and 1812. These earthquakes, estimated at magnitude 8, were felt as far away as Boston. Damage and casualties were light only because the immediate area was sparsely inhabited at the time.

On the positive side, Yanev emphasizes that modern earthquake engineering provides effective protection. With regard to the SQUG project for seismic qualification of equipment in nuclear plants, the Armenian investigation provided good examples of reliable performance under actual earthquake conditions. "The good lesson is that we're doing it right," he says. "Even under the highest-intensity shaking, properly installed and anchored industrial equipment was undamaged, and steel-framed industrial structures performed well. Amid all the destruction, we saw what we had hoped to see: systems performed as designed." Nevertheless, Yanev stresses that much remains to be learned, and that each investigation provides more information. "We haven't seen it all," he says. "There are always new lessons. Laboratory testing, experiments, and analysis are certainly useful, but they cannot substitute for the real thing. The earth is still our best testing laboratory." ■

This article was written by David Boutacoff, with background information provided by Robert Kassawara, J. Carl Stepp, and Ian Wall, Nuclear Power Division, and Peter Yanev, EQE Engineering.

TECH TRANSFER NEWS

First Electric Utility Reference Guide on CD-ROM

Imagine holding thousands of volumes of EPRI research between a thumb and forefinger. You can do just that with ElectriGuide™ CD-ROM, the most comprehensive electronic reference guide ever assembled for the electric utility industry. The first electronic database for electric utilities to use compact disc, read-only memory technology, ElectriGuide makes information on thousands of EPRI R&D projects, publications, and products available on a single optical disc that can be read by a personal computer. With the appropriate keyword search, users can browse through a vast amount of information and selectively print documentation on EPRI research.

The disc holds three major EPRI databases comprising over 30,000 entries. The Electric Power Database (EPD) provides descriptions of 22,000 research projects by EPRI, U.S. and Canadian electric utilities, and others, including the Canadian Electrical Association, CRIEPI in Japan, and Mexico's Instituto de Investigaciones Eléctricas. The EPRI Publications Database (PUBS) offers descriptions of 7000 publications, including abstracts of all EPRI technical reports and computer software and information about technical brochures, videotapes, R&D information sheets, and *EPRI Journal* articles. The EPRI Products Database (PRODBOOK) presents summaries of 850 products resulting from EPRI-sponsored research.

Other databases included on the disc feature a range of EPRI print and electronic media materials on specific research topics. An electricity transmission and distribution database contains brochures, a catalog of research projects, and information sheets on specific R&D activities. Another database offers information (including brochures, commentaries, and case studies) on new electrotechnologies in U.S. industries.

A powerful tool for technology transfer, ElectriGuide comes equipped with a detailed demonstration of advanced CD-ROM uses, including storage, retrieval, and printing of color slides, full-text technical reports, audiovisual presentations, and text-graphics brochures with magnification. The disc also contains extracts from Mediabase,™ an EPRI personal computer graphics database, featuring color slide and script presentations and other printed media relating to customer-oriented R&D. EUCAT,™ an electronic version of the 1988 Energy Utilization R&D Catalog, is also on the disc; it describes 140 EPRI products related to energy use.

Now on an industry-standard 4¾-inch optical disc, ElectriGuide can be read by IBM-compatible personal computers and used with either color or monochrome monitors and laser or dot-matrix printers. Also needed are a CD-ROM drive and interface. CD-ROM drives, which are reliable and easy to install, can be purchased for about $600 and are available from most computer dealers.

ElectriGuide was developed for EPRI by Knowledge Access International, and was prepared with their KAware™ Retrieval System software.

"ElectriGuide provides more information in a more cost-effective, easier-to-use manner," says Les Harry, industrial program manager in EPRI's Customer Systems Division. "It allows utility users to find, scan, and print EPRI's entire library of application materials right from the desktop—when they want it, the way they want it." ■ *EPRI Contact: Joe Judy, (415) 855-8936*

Fish Protection Report Aids Hydro Relicensing

Utilities that operate hydroelectric facilities face increasingly rigorous fish protection regulations, and compliance with these regulations is costly. One example is the Columbia River Basin Fish and Wildlife Program, established by the Pacific Northwest Electric Power Planning and Conservation Act, which required the Bonneville Power Administration to evaluate improved screen designs for protection of salmon and steelhead trout. In order to perform the evaluation, BPA needed first to conduct a survey of literature on existing technologies, then to test improved protection designs. BPA estimated costs for a comprehensive literature survey alone at around $150,000.

Fortunately, an earlier study undertaken by EPRI eliminated the need for BPA to perform one of its own. EPRI researchers had already surveyed the industry, identified hydro plants with fish protection systems, and solicited reports on their effectiveness. Using data from 100 sites, the project team compared existing system designs, examining them in terms of effectiveness, engineering criteria, biological advantages and disadvantages, and operational requirements.

The results of that project, documented in *Assessment of Downstream Migrant Fish Protection Technologies for Hydroelectric Application* (AP-4711), saved BPA $150,000 and considerable time in initiating fish protection efforts.

BPA plans to follow the EPRI survey in evaluating future fish protection systems. The utility is particularly interested in standardizing screen designs for use at small hydro sites that incorporate off-stream canals.

"Thanks to the EPRI report, we can—when appropriate—move promptly to test new and existing fish screen designs under uniform hydraulic conditions created in off-stream channels," says BPA's Stephen Smith. The report should also be useful to other utilities in meeting hydro plant relicensing requirements. ■ *EPRI Contact: Charles Sullivan, (415) 855-8948*

Plasma Process for EAF Dust Treatment

Electric furnace steelmakers currently account for 38% of U.S. steel production, and steady growth is expected to continue into the next century—a fact of considerable interest to utilities, since a steel mill with electric furnaces is in many cases a utility's largest customer. A major problem confronting these steelmakers recently has been the disposal of electric arc furnace (EAF) dust—some 20 to 40 pounds of extremely fine particles generated for each ton of steel produced. Made up mainly of iron and zinc oxides, the dust is formed in EAF exhaust gases. Traditionally, the dust was placed in commercial landfill sites, but because it also contains relatively small amounts of leachable lead, cadmium, and chromium, the Environmental Protection Agency has classified it as hazardous waste. Under current legislation, landfill sites for such waste must be retrofit with double protective liners.

To find a better solution to the dust problem, the EPRI Center for Metals Production (CMP), along with 21 steel companies and one industrial gas supplier, cofunded development and pilot-scale testing of the Tectronics plasma process, an EAF dust disposal technology that recovers zinc while producing a nonhazardous, disposable slag. The process, refined at a Tectronics test installation in England, is currently undergoing its first commercial demonstration—by Florida Steel Corp. in Jackson, Tennessee.

To reduce zinc and lead oxides, the process uses a plasma furnace with controlled temperature and carbon feed rate. It produces an exhaust stream rich in zinc vapor and an oxidic slag, which is periodically tapped from the furnace. A splash condenser allows for the higher-valued zinc (45¢ per pound) to be recovered.

Gases leaving the condenser consist mainly of carbon dioxide, carbon monoxide, and small amounts of lead in zinc vapor not removed in the condenser. A combustion chamber housed in the stack exiting the condenser burns any residual vapor to form zinc oxide, which is then recovered in the baghouse. Gases leaving the baghouse pass through a scrubber to remove any sulfur dioxide present.

Florida Steel plans to use the Tectronics plasma process to treat 5000 tons of dust per year, at an estimated savings over conventional methods of about $150 per ton. The CMP will monitor startup of the process at Florida Steel in collaboration with International Mill Service and the Tennessee Valley Authority. TVA expects new revenues of about $225,000 per year through Florida Steel's use of the process. ■ *EPRI Contact: Robert Jeffress, (415) 855-2101*

Valve Actuator Repair Guidelines

The reliability of motor-operated valves in nuclear power plants has been the subject of several reviews and investigations by both government and industry. Motorized valve actuators—electromechanical devices used to control the movement of a valve from a remote location—are critical to valve performance. When an actuator fails, its timely return to an operable status is often imperative. Unfortunately, in some cases a failed actuator is fixed and returned to service without determining the root cause of the failure. In a recent five-year period, malfunctioning actuators were responsible for the issuance of 565 licensee event reports; improperly adjusted control switches and less-than-adequate maintenance practices were cited as primary contributors.

Until recently there was no industry-wide set of guidelines for maintaining Limitorque motorized valve actuators in nuclear power plants. EPRI's Nuclear Maintenance Applications Center sponsored the development of guidelines for this equipment in order to document improved maintenance practices developed by utilities and to integrate descriptions of tasks related to actuator inspection, maintenance, engineering, and testing. *Technical Repair Guidelines for the Limitorque Model SMB-000 Valve Actuator* (NP-6229) presents repair, maintenance, and adjustment instructions, as well as troubleshooting techniques. The comprehensive, 20-chapter volume details the actuator's mechanical operation, electrical control, design change and modification history, and environmental qualification summary. The guide also includes instructions for performing preventive maintenance inspections, discusses failure modes and valve problems that can affect actuator reliability, and cites root causes of actuator failure and appropriate corrective actions. Disassembly inspection and repair, reassembly, preoperational and postoperational testing, and spare parts and storage requirements are also discussed. A special section with NRC, INPO, EPRI, and IEEE references is included. ■ *EPRI Contact: James Lang, (415) 855-2038*

Steam Generator Reliability

Steam Generator Simulation Tests

by S. P. Kalra, Nuclear Power Division

ABSTRACT *The steam generator in a pressurized water reactor provides the heat sink for the primary nuclear heat and generates steam to run turbines for the production of electric power. A detailed knowledge of both the thermal and the mechanical response of steam generators is essential to enhancing the reliability and performance of PWR plants. EPRI is a major participant in a large-scale test program geared toward creating a steam generator response database. Six nations are cooperating in the program, which is scheduled to be completed this year. The program contractor is CEA, the French atomic energy commission.*

Particularly important in the analysis and enhancement of steam generator performance is the accurate understanding of the thermal-hydraulic, two-phase boiling flow distribution within a tube bundle and its mechanical interaction with the tubes, which may result in mechanical vibration (e.g., at the U-bends). For the past several years, EPRI has been extensively involved in developing advanced three-dimensional methods, such as the ATHOS and PORTHOS codes, to predict such responses. These codes calculate the detailed distribution of two-phase flow conditions, which is necessary to evaluate flow-induced vibration behavior. However, these prediction tools must be validated with relevant three-dimensional data, generated under appropriately large scale simulation conditions.

In view of the industry's need for qualified advanced analysis tools, EPRI has played a major role in forming an international cooperative program. The participants are the United Kingdom (CEGB), Canada (COG), Italy (Ansaldo), Japan (MHI), France (CEA, EdF, Framatome), and the United States (Westinghouse, EPRI).

The focus of this program, known as CLOTAIRE, is to conduct large-scale tests for developing an appropriate three-dimensional database for both thermal-hydraulic and flow-induced mechanical response in the U-bend region of a natural circulating U-tube steam generator. The CLOTAIRE experiments are devoted to providing data for the qualification of advanced steam generator codes, which provide simulation of boiling two-phase flows, and for flow-induced vibration (FIV) predictions. This procedure requires a well-controlled reference data bank of local measurements, especially of the flow field. The CLOTAIRE mock-up (Figure 1) is designed to meet such needs.

Determining local voids and velocities

One of the major challenges in the measurement technique is the accurate determination of local voids (the fraction of steam in a two-phase mixture) and velocities, which are essential for validation of advanced steam generator codes such as PORTHOS. These measurements are extremely difficult under the prototypical conditions (high temperature and pressure, e.g., 288°C, 72 bar) in a U-tube steam generator. A fluid-to-fluid (water-to-freon) modeling approach was used to meet this challenge. Specific experiments outlined in the literature have clearly demonstrated that steam-water mixtures encountered in steam generators can be reliably modeled with freon two-phase mixtures, provided that governing parameters such as liquid-density-to-vapor-density ratio, Froude number, and to a lesser degree, Weber number are closely simulated.

Such simulations not only greatly reduce costs but also make possible the extensive use of sophisticated instrumentation for taking complex measurements. For example, bi-optical probes (BOP), which can provide information on the local void fraction and the velocities of the dispersed phase, as well as flow regime conditions, are being used for this experiment. In addition, sophisticated instrumentation is being implemented extensively for temperature, pressure, liquid (single-phase) velocity, and vibration measurements.

CEA, the French atomic energy commission, is the contractor; along with EdF and Framatome, it provides more than 50% of the cost share for this project. The design, fabrication, and commissioning of the facility have been successfully completed on schedule, and testing has been initiated. The test matrix comprises 45 tests: 10 steady-state thermal-hydraulic tests, 30 FIV tests in the U-bend region, and 5 transient response tests.

CEA has done both development and extensive evaluation of BOPs. Calibration under similar flow and geometric conditions has been successfully completed. The calibration provides a high degree of confidence in the flow field data.

Successful local measurements of void fractions and velocities using BOPs in the CLOTAIRE test facility have been performed for a nominal test condition. A complete test includes approximately 2500 different local BOP measurements within the tube bundle. These measurements are the core of thermal-hydraulic testing for qualifying advanced multidimensional steam generator methods for industry use (Figure 2).

Avoiding FIV damage

In light of an event (tube failure caused by vibration) at Virginia Electric and Power Company's North Anna-1 plant, one of the major questions facing the industry is how to accurately interpret and evaluate the boiling (two-phase) flow interaction with a U-bend structure and with antivibration bars (AVBs). A relevant database is needed to develop a prediction methodology for avoiding FIV damage and enhancing the reliability and availability of steam generators. In view of such industry needs, EPRI took the initiative in modifying the program, which is skewed toward generating relevant FIV information for validating this predictive methodology.

The FIV test matrix consists of a range of load conditions, circulation ratios, and AVB configurations (including asymmetric-gap-size effects). The test conditions include FIV resulting from both turbulent and fluid-elastic instability excitation modes. Note that the FIV tests also include flow distribution measurements using BOP at the U-bend.

A large number of supporting separate-

Figure 1 The CLOTAIRE mock-up. This large-scale (0.7-scale, 14-meter-tall) test facility simulates a natural circulating U-tube steam generator in a PWR. It simulates prototypical thermal-hydraulic conditions on the basis of scaling laws and can be operated in both natural and forced circulation modes. Thirteen elevations of thermal-hydraulic and flow-induced vibration instrumentation have been incorporated, and include nine elevations to provide local void fractions and vapor velocities. The instrumentation appears along the tube bundle, at the U-bend, and above the tube bundle.

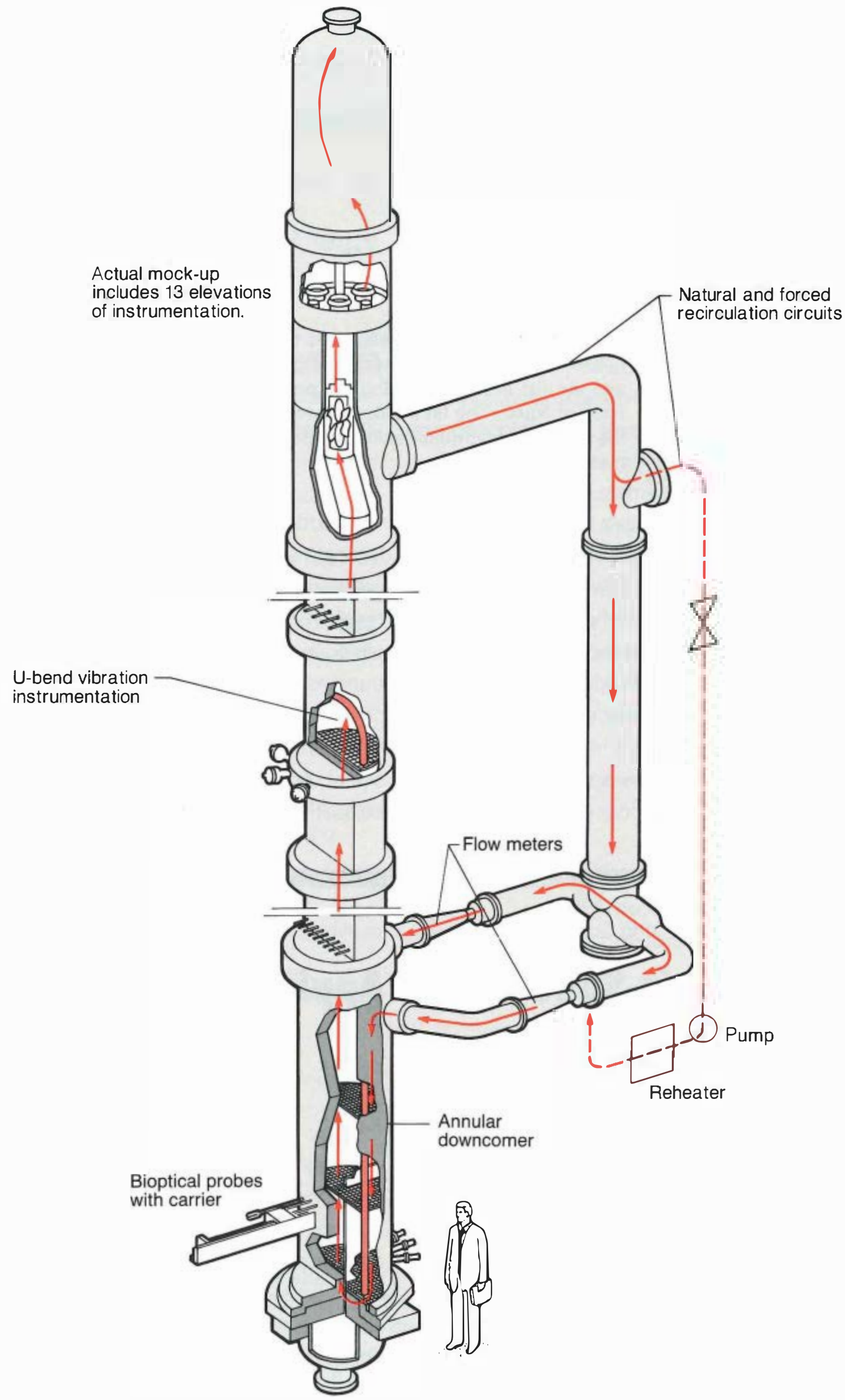
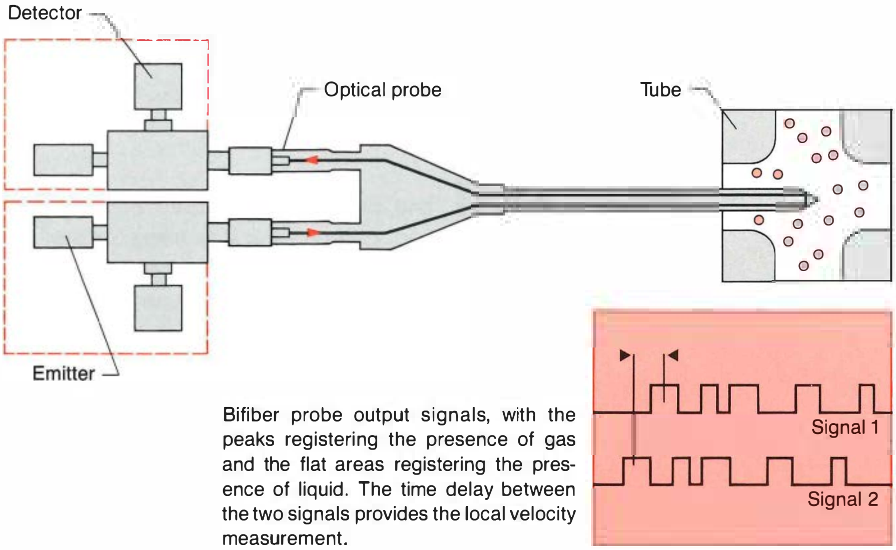


Figure 2 Optical probe. In a two-phase flow of liquid and gas, the probe provides the local void measurement by reflecting light when gas is at the probe and allowing light to pass when liquid is at the probe. Although a single-fiber probe is shown to illustrate this principle, a bifiber probe is used to measure both void and velocity.



Bifiber probe output signals, with the peaks registering the presence of gas and the flat areas registering the presence of liquid. The time delay between the two signals provides the local velocity measurement.

effects experiments have been performed to ensure accurate presentation of FIV behavior. The CLOTAIRE testing is well under way. The nonsupported tube (without AVBs) showed strong sensitivity in damping and displacement for the two-phase flow conditions at the U-bend. Inner and outer rows exhibited significantly different responses. These preliminary test results are being evaluated by CEA and the program participants.

In addition to providing support for obtaining the database, the project participants are also providing support for analyzing the results. For example, Westinghouse has completed a detailed study for CLOTAIRE tube bundles to support FIV testing and the concerns of AVB design.

Westinghouse used the EPRI three-dimensional code ATHOS for thermal-hydraulic calculations, which take into account the influence of hot and cold legs, two-phase slip, and the influence of AVBs. The best-estimate calculations indicate fluid-elastic instability only if the U-bend is not supported by AVBs at the nominal conditions. Framatome also performed such calculations, using CAFCA (the French three-dimensional code), and the results agree well with the CLOTAIRE mockup. This analysis will be further assessed upon completion of the FIV tests.

Assessing transient responses

EPRI's three-dimensional steam generator code PORTHOS, based on two-fluid modeling, can simulate both steady-state and transient responses. Therefore, for assessing the transient capability of the code, transient tests are also part of this effort. The transient response tests include vapor and feed flow transients, low feed versus reflooding, U-tube bundle uncovering, and recirculation phenomena at low-power conditions. BOP measurements for void and velocity will be provided at several fixed locations. In addition to code validations, these tests will also provide overall system response characteristics, which are needed for achieving phenomenological understanding and assessing other transient methods.

The information generated under the CLOTAIRE program will be available to members in proprietary two-tier EPRI reports.

Power Electronics and Controls

Adjustable-Speed-Drive Applications

by Marek Samotyj, Customer Systems Division

Adjustable-speed drives (ASDs) are power electronics systems for controlling motor speed. They consist of a rectifier for converting 60-Hz power to dc and an inverter for converting dc to the full range of ac frequencies required to control motor speed. In addition, a solid-state microelectronics control system adjusts the frequency and voltage of the inverter to the proper value for motor speed requirements.

Motor speed is controlled in accordance with such process requirements as water flow or air flow. Directly controlling flow with motor speed makes it possible to eliminate valves, dampers, or vane controls. These throttling-control systems have in the past been widely used for pumps and fans in power plants. Throttling systems are inefficient, however, and in cases of large pressure drops, they consume not only unnecessary power but also unnecessary maintenance dollars.

The technology of ASD inverters for large power plant squirrel-cage induction motors has gone through several generations since this project began in 1982, and a number of these technologies have been demonstrated in the study. Circuit improvements have been made to reduce costs and provide better control of electrical harmonics at the input and output of ASDs. The use of input transformers

ABSTRACT *Since 1982 EPRI and Bechtel have been conducting a major study on the application of adjustable-speed drives to ac induction motors used in power plant operations. In field tests at five power plants, high-power ASDs were found suitable for use on existing plant induction motors for forced-draft fans and boiler feedwater pumps. With substantial fuel cost savings, conversions from constant- to adjustable-speed operation demonstrate efficient control of large induction motors.*

has become standard for the control of input harmonics and common-mode voltage. Current-source GTO-PWM (i.e., gate-turnoff-thyristor-based, pulse-width-modulated) inverters and other schemes are being used for harmonics control and the prevention of eddy-current heating and shaft torsional vibration in the motor. Cooling systems have been improved, and better environmental packaging for power plant ASD applications has been developed.

ASD field tests

Three different types of ASDs were installed at five sites (Figure 1).

▫ At Sierra Pacific Power's 110-MW Ft. Churchill Unit 2, an ASD was installed on a 1750-hp, 4000-V, 3600-rpm boiler feedpump motor. The ASD is a 12-pulse-input, 12-pulse-output current-source inverter rated at 2000 hp and capable of operating to 63 Hz. It went into service in December 1984.

▫ At Gulf State Utilities' Willow Glen Unit 1, an ASD was installed on a 2250-hp, 4000-V, 3600-rpm feedpump motor. The ASD is a modified load-commutated inverter with 6-pulse input and 6-pulse output and no input transformer. It has been in service since January 1986.

▫ At Iowa Public Service Co.'s George Neal Unit 2, two 6300-hp ASDs were installed on two 7000-hp boiler feedpump motors rated at 4000 V and 3600 rpm. The ASDs have 12-pulse input. The output is a 6-pulse modified load-commutated inverter. These ASDs went into service in December 1987.

▫ At Oklahoma Gas and Electric's 700-MW Seminole Unit 1, two 5500-hp ASDs were installed on two 4000-hp forced-draft fans rated at 4000 V and 890 rpm. The ASDs are 12-pulse-input, 6-pulse-output, current-source GTO-PWM units. They went into service in December 1987.

▫ At Sierra Pacific Power's Tracy Unit 3, a 2000-hp ASD was installed on a 1750-hp boiler feedpump motor rated at 4000 V and 3600 rpm. The ASD is a current-source GTO-PWM unit with an input transformer, a 6-pulse rectifier, and a 6-pulse inverter. It was placed in service in December 1987.

Field tests are being conducted to verify ASD-derived economics, confirm ASD reliability, investigate the effects of harmonics on auxiliary systems, and determine operating benefits. The principal concern of utilities in using this new technology has been reliability. The study has shown that electronics equipment can be very reliable if the manufacturer pays particular attention to tried and proven components, tried and proven control circuits, and suitable voltage and current margins for power and control components. Reliability is also enhanced by sound engineering in the areas of cooling systems, housing, and integration of ASD controls with boiler controls.

In addition to concerns about ASD relia-

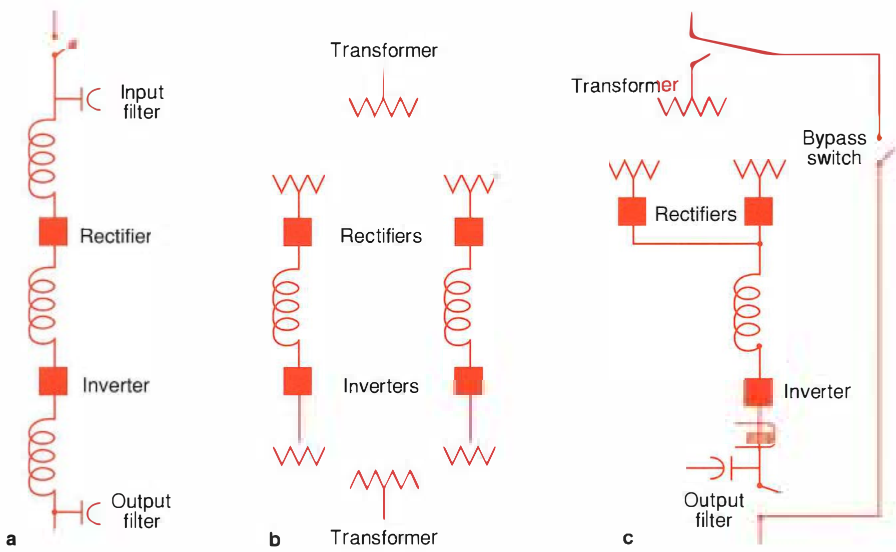


Figure 1 Three inverter types were studied in an EPRI-Bechtel field-test program of ASD technology for large power plant induction motors. Since the program began in 1982, the technology has gone through several generations, and the devices have yielded more simplified circuit design and higher drive reliability. The types shown here demonstrate the technology's rapid evolution: (a) a 6-pulse-input, 6-pulse-output modified load-commutated inverter with input and output filters; (b) a 12-pulse-input, 12-pulse-output inverter system; and (c) a 12-pulse-input, 6-pulse-output modified load-commutated inverter with an output filter and dc-link commutation.

bility, utilities have concerns about the flow of ASD-produced voltages and current harmonics to the power system. The tolerance of auxiliary power systems (forced-draft fans and boiler feedpumps) to harmonics is still not well understood. The amount of harmonics flowing to the auxiliary power system can be influenced by several system design considerations: the number and rating of ASDs on each auxiliary bus; the use of 6-pulse, 12-pulse, or 18-pulse rectifiers; the impedance in the system; the use of input transformers for multiple phase-shifted rectifiers and for a ground in the ASD system; the use of input filters; and the amount of filtering on the dc link.

A real-time spectrum analyzer was used to measure input power, output power harmonic currents, and voltages. The analyzer was connected to the input breaker potential and current transformers and to ASD output current and voltage transformers. With current and voltage signals reduced to the level of about 5 V rms and using the two-voltmeter connection, it was possible to determine the fundamental frequency and each harmonic for current and voltage; calculate power in the fundamental frequency and in harmonics; calculate energy by multiplying voltage and current and integrate the result; determine additional motor losses from harmonics; and calculate ASD efficiency.

Second-generation ASDs

Knowledge gained at the five study installations, as well as at many other recent utility installations of induction-motor ASDs, has contributed to a second-generation ASD designed specifically for power plants. Features of power-plant-specific ASDs include input transformers for 12-pulse or 18-pulse converters; system grounding to stabilize dc-link voltage and eliminate motor overvoltage; built-in design tolerance for bus voltage swings, spikes, and interruptions; water-cooled thyristors and a control panel for simplified cooling; and control of resonance between output filter and motor.

This EPRI study should encourage the use of large ASDs for converting fixed-speed power plant squirrel-cage induction motors to adjustable-speed operation for process control and plant efficiency. In evaluating commercially available ASDs in power plant environments, the study has drawn the following conclusions:

- Boiler feedpumps are good economic choices when used in sliding-measure applications.
- Forced-draft fans are more efficient when excess air is properly controlled.
- Gas-recirculating-fan ASDs control boiler temperatures within a very narrow temperature band.
- Verification of pump and fan curves with manufacturers is needed.
- Torsional/lateral vibrations can be eliminated by removing the exciting frequency.
- Heat rate can be improved with ASDs on large motors.
- Fan noise can be reduced by one-half at reduced speeds.

Program results from adjustable-speed-drive conversions showcase the advances being made in power electronics control of large induction motors for power plant use. Future applications should continue to yield results that are efficient and economical.

System Planning

End-Use Technical Assessment Guide

by Tim Yau, Customer Systems Division

While many methodologies and data for end-use technology assessment exist today, they are incomplete and fragmented. Therefore, EPRI has developed two volumes on end-use technologies for its Technical Assessment Guide (P-4463-SR), or TAG.* The purpose of these volumes, together called the End-Use TAG, is to ensure consistency, completeness, user-friendliness, and flexibility in end-use assessment. To maintain data currency and keep pace with technology development, the End-Use TAG will be periodically updated. The new volumes—Volume 2 and Volume 4—address technology performance data and economic assessment methodology, respectively.

Residential guide

The economic competitiveness of a particular gas, oil, or electric end-use application depends on many factors. The important factors are efficiency of the end-use equipment, thermal integrity and size of the building, climate, electricity and gas rates, equipment and operating first costs, and the customer's required rate of return. It is essential that all common factors be held constant when comparing competing end-use technologies. The End-Use Residential TAG (Volume 2, Part 1) facilitates this task for utility planners and marketing personnel in two ways. First, it provides the necessary data sources in a consistent format; second, it spells out a user-friendly, step-by-step procedure for assessing the economic viability of competing end-use technologies.

Cost and performance data are available for 30 gas, oil, and electric HVAC (heating, ventilating, and air conditioning) technologies. Cost data include first costs and installation costs, which vary with the size and efficiency of the particular equipment selected. Performance data include energy efficiencies that vary with the climate of the location where the equipment is installed. To assist users not familiar with some of the HVAC technologies,

*TAG is an EPRI service mark.

ABSTRACT *Using two new volumes of EPRI's Technical Assessment Guide, utilities can quickly screen residential, commercial, and industrial end-use technologies to assess their economic performance and identify promising electricity-driven candidates. These new TAG volumes on end use compare technology options and financial variables from several perspectives.*

the guide includes a general description of each technology's characteristics.

The use of consistent assumptions is the overriding criterion in developing cost and performance data on different technologies. For most residential technologies, a wide range of cost and performance characteristics exists. In the End-Use Residential TAG, market information is used to establish the average performance and cost characteristics of each technology. While this provides a good national perspective on the competitiveness of various end-use technologies, individual situations may differ from the general findings. For situation-specific studies, customized data should be used.

The End-Use Residential TAG defines the thermal characteristics of four types of buildings: detached single-family homes, mobile homes, town houses, and low-rise apartment buildings. The user can specify the square footage for the study and can select one of 10 thermal-integrity levels for detached single-family homes. EPRI's ESPRE computer program is used to calculate energy requirements for 13 preselected building structures at 40 locations in the United States (Figure 1). Most users will find the buildings and their locations a close representation of their specific situation. For other users, regression equations are provided to approximate their specific situation.

The guide also offers a step-by-step procedure for the economic analysis of end-use devices from the customer's perspective. Capital, maintenance, and energy costs are considered, taking into account device efficiency, building structure, and financial variables. Financial tables and economic equations are included for easy reference.

The data sources and the economic comparison procedure have been stored in a Lotus spreadsheet format for easy access through personal computers. The PC version of the Residential TAG is menu-driven and user-friendly, enabling new users to derive meaningful results in less than an hour.

Commercial guide

The End-Use Commercial TAG (Volume 2, Part 2), much like the Residential TAG, provides the user with a consistent reference framework for the economic comparison of end-use devices. The user decides what type of commercial-sector end-use devices to consider, as well as what type of business (a grocery store or a high-rise office building, for example) and what climatic region. The guide provides information on a large number of end-use devices and on the design and

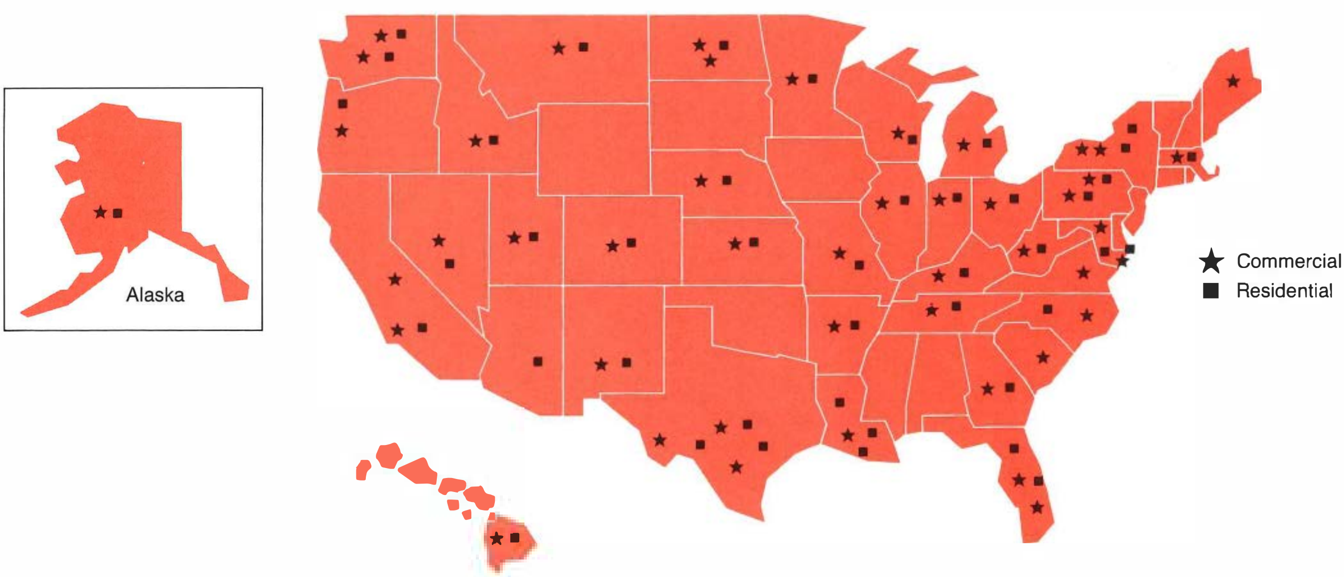


Figure 1 The End-Use Residential and Commercial TAGs give thermal energy requirements for buildings in 40 locations throughout the United States. Regression equations are provided for developing good estimates for locations not shown.

thermal characteristics of many building types in many different locations.

Nine standard building types are described, each representing a major consumer of electricity. For each building type, the business activities, hours of operation, and building-shell characteristics are specified. Characteristics for two building-shell designs are provided—baseline and energy-efficient. The baseline design reflects current practice for the design of commercial buildings, and the energy-efficient design represents the future standard design.

Calculations to determine energy requirements for the various building types were performed with the widely used and highly detailed thermal-simulation computer program DOE.2, and samples of the calculations were verified with actual data. As a result of this effort, the End-Use Commercial TAG provides energy requirements for each of the nine building types—for either the baseline or the energy-efficient standard and for any one of 40 locations (Figure 1). For most users, the data provided are sufficient. For users who desire to customize the data to reflect an individual situation, regression equations are available.

A step-by-step procedure for the economic analysis of commercial end-use technologies is also presented; in contrast to the Residential TAG, however, no computerized version is available. The reasons are the diversity of the commercial sector, the complexity of commercial building design, and the difficulty in performing a customized commercial-sector economic analysis. A computer version that can effectively use customized data, however, may be released later.

Industrial guide

The End-Use Industrial TAG (Volume 2, Part 3) provides utilities with reference data on industrial markets and technologies, serves as a starting point for seeking additional information, and develops a framework for evaluating the costs, performance, and application of electrotechnologies. For many applications, electricity-based technology holds an advantage over other energy sources because it offers improved productivity and environmental quality, lower production costs, and higher product quality. The guide's objective is to correctly capture the costs and benefits of electrotechnologies.

For each industry group designated by Standard Industrial Classification (SIC) codes 20 through 39, the guide describes the business outlook and opportunities for demand-side management. Electrotechnologies are listed that can meet utility demand-side management objectives while improving customer productivity. For each electrotechnology that can substitute for other fuel types, the electricity-based process is described, as well as its applications, benefits, and costs. These can be compared with similar information given for conventional technologies.

Fundamentals and methods

TAG Volume 4 provides guidelines for analyzing end-use technologies and demand-side management activities from several different perspectives, including the customer's and the utility owner's. It complements Volume 2, which presents economic analysis methodology for assessing the merits of a technology from the end user's perspective but does not consider the impact on other customers, utility owners, and the public at large. Volume 4 contains an analytical framework to assess the costs and benefits of a particular demand-side management strategy from a multitude of different perspectives.

Advanced Fossil Power Systems

Shell Coal Gasification

by Norman Stewart, Generation and Storage Division

The Shell coal gasification process (SCGP) is currently being demonstrated and optimized in a 250–400-ton/day plant at Deer Park, Texas. The plant, designated SCGP-1, was completed in April 1987, began initial shakedown operations in July 1987, and entered the demonstration phase in December 1987. This phase was highlighted by a 1528-hour continuous run, which ended with a voluntary shutdown on May 3, 1988, and by the achievement of 83% overall availability over the five-month period. Since the demonstration phase, the plant program has focused on using a variety of feed coals and on providing operating data to optimize the process and confirm new process features.

The Shell process uses a high-pressure, entrained-flow, slagging gasifier. Dry pulverized coal is pneumatically conveyed as a dense phase by using either nitrogen or fuel gas and is introduced with oxygen into the gasifier through horizontally opposed burners. The raw syngas flows upward, carrying with it some of the ash from the coal. These solids are removed from the gas in downstream process steps. The remainder of the coal ash flows down the wall of the gasifier and is removed as slag from the bottom. Cooled product gas is recycled and mixed with the hot gas exiting the gasifier to cool the gas and solids so that the solids are no longer sticky upon entering the heat recovery section. Shell Oil's syngas cooler design includes superheating as well as evaporative and economizing sections.

Feeding the coal to the gasifier in a dry state is the primary technological feature that distinguishes the Shell process from other entrained-flow processes, such as those of Texaco and Dow. These processes rely on a coal-water slurry to introduce the coal into the gasifier. EPRI has supported demonstration

ABSTRACT *A major plant test program nearing completion has demonstrated that the Shell coal gasification process can yield reliable, environmentally sound performance with different types of coal. New process concepts are now being validated to provide data for future commercial plant design and operation.*

of the Shell technology to ensure that this alternative gasification option is pursued and that the critical technical issues are addressed and understood.

The capacity of SCGP-1 is nominally 200 tons/day of moisture- and ash-free coal. This plant size was set by the need to demonstrate equipment and configurations that would be used commercially while maintaining a balance between costs expended and the knowledge gained. A commercial plant module is anticipated to have a capacity of 1000–2000 tons/day. Some critical pieces of equipment in SCGP-1, such as valves, are actual commercial sizes.

The SCGP-1 plant (Figure 1) consists of coal receiving and preparation equipment, a dry coal feed system, a high-pressure gasifier, a syngas cooler, a solids removal system, and gas and water treatment systems. It is representative of a coal-to-gas single-train gasification block. Oxygen is supplied by a commercial pipeline from an existing air separation unit in the vicinity. The product gas is burned in Shell Oil's adjacent Deer Park Manufacturing Complex central power station boiler.

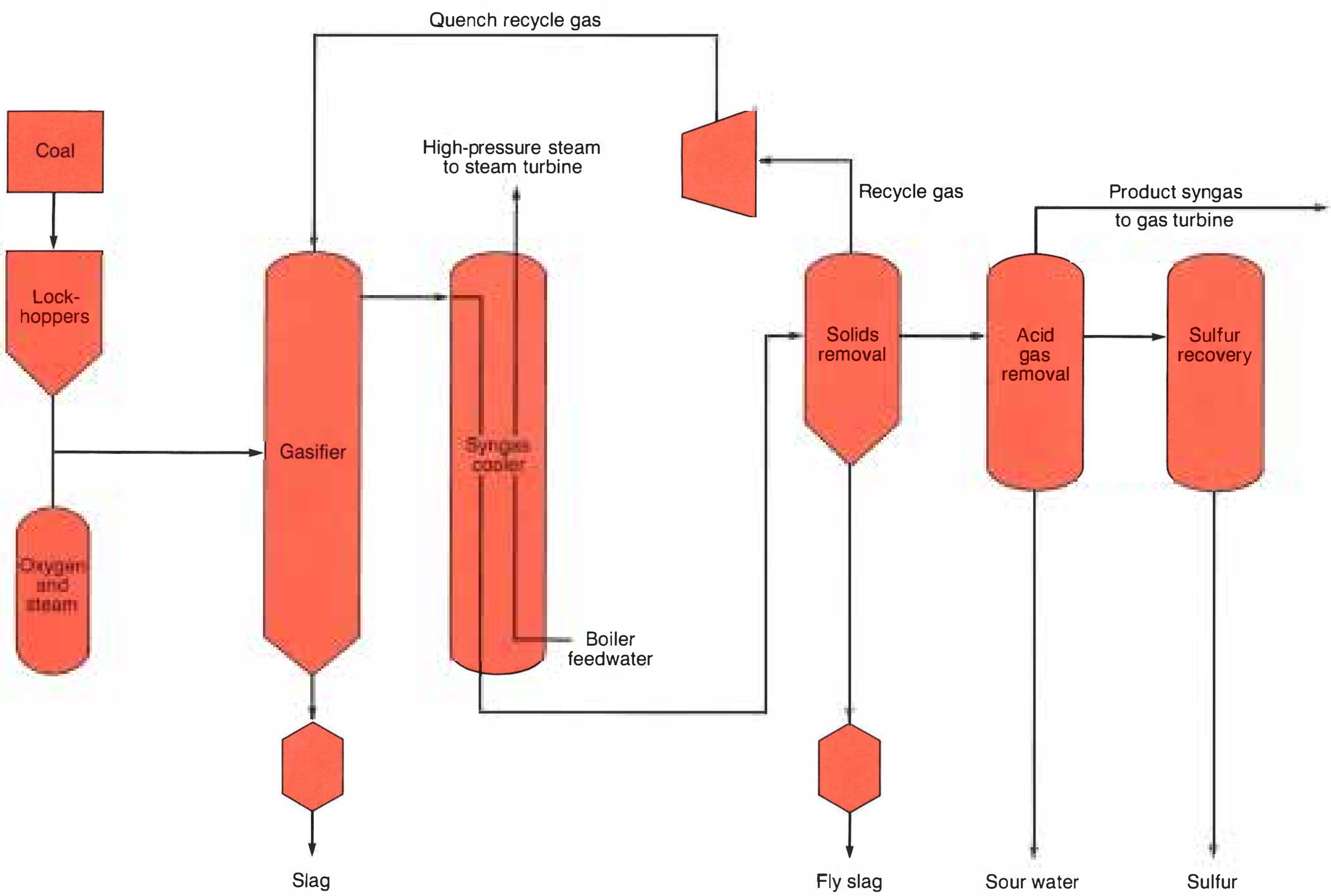


Figure 1 Shell slagging gasifier flow scheme. In the Shell coal gasification process, pulverized and dried coal is pressurized in lockhoppers and transported with gas to the gasifier, where it reacts with oxygen to produce raw synthesis gas. The raw gas is then cleaned of slag, particulates, and acid gas before being transported as product synthesis gas.

Table 1
SCGP-1 PERFORMANCE DURING SHAKEDOWN AND DEMONSTRATION

	Overall Range	1528-Hour Run	Design
Gas Composition (%)*			
H_2	22.7–34.6	27.7–29.8	28.4
CO	54.8–69.0	66.5–69.0	65.2
CO_2	2.2–10.8	2.2–2.4	5.3
CH_4	0.001–0.014	0.001–0.010	0.04
$H_2S + COS$	1.1–1.3	1.1–1.2	1.0
Carbon conversion (%)	96–99	97–98	98.5

*Moisture- and nitrogen-free basis. The product gas contained approximately 8% nitrogen and 2% water.

Acid gas is routed to the Complex's sulfur recovery unit to produce elemental sulfur, which is sold as a commercial product.

The comprehensive multiyear test program at SCGP-1 includes operation on several different feed coals, development of alternative gas cleanup and wastewater treatment schemes, and development and demonstration of process improvements. Results will confirm equipment lifetimes and will verify and extend scale-up information necessary for commercial designs. With completion of the test program, Shell Oil expects scale-up of all equipment to be straightforward. Participating with Shell Oil in the program are Shell Internationale Petroleum, Shell Internationale Research, Deutsche Shell, and EPRI.

Operating results

The coal used throughout the shakedown and demonstration phases was an Illinois No. 5 bituminous coal supplied by Turris Coal. As received, this coal contains about 18% moisture and 9% ash and has a heating value of 10,300 Btu/pound. Its sulfur content is about 3%, also on an as-received basis.

The coal feed rate ranged from 105 to 235 tons/day, as received, or about 45% to 105% of target capacity for this specific feed coal. During the 1528-hour demonstration run, the coal feed rate was maintained at the design rate of 229 tons/day for 95% of the time. Gasifier operating pressure was 345–355 psia. Table 1 summarizes SCGP-1's performance relative to design expectations. Carbon conversion has been quite favorable when compared with the design value.

The demonstration phase comprised five months, with nine runs and 3005 hours of actual operation. The net availability during that period was 82%. Figure 2 shows plant availability through both the shakedown and demonstration phases. All of the eight nonscheduled shutdowns had mechanical or operational causes that were unrelated to the process itself. The shutdowns were caused by three relief valve failures, leaking coal feed filter bags, another valve failure, an external loss of boiler feedwater, a leaking flange, and a burner trip.

The first eight operating runs, ranging in duration from 150 to 300 hours, were completed between December 1987 and February 1988. With the ninth run, the objective of a 1000-hour run was achieved by mid-April. The decision was made to continue that run to approximately 1500 hours to coincide with a planned shutdown of the manufacturing complex's boiler system, which would require a shutdown of SCGP-1 in any case. The specific time and date were selected in advance, and the plant was shut down at noon on May 3. As confirmed during the ensuing inspection, there were no process or mechanical problems that would have precluded continuation of the run beyond the 1528-hour mark.

The SCGP-1 dry feed system performed well throughout the demonstration phase at both full and reduced rates. Coal and oxygen flows were stable and reliable. Coal flow typically had a standard deviation of about 0.75% or less. Precise control of the oxygen/coal ratio was demonstrated consistently, and process response to changes in this ratio was studied at various operating conditions.

The gasifier and syngas cooler systems achieved design performance at both full and reduced rates. Slagging efficiency (the percentage of as-fed ash removed from the gasifier as slag) was in the design range of 40–60%. Carbon conversion (the percentage of as-fed carbon converted to syngas) varied between 96% and 99%. Heat recovery in the syngas cooler was greater than design, with no apparent heat transfer loss due to long-term fouling by fly slag. The production of superheated steam in the syngas cooler met design expectations.

SCGP-1 also exhibited capabilities for handling turndown. The unit was turned down rapidly from 100% to 45% capacity in seven minutes, or at a rate of 7% per minute, while maintaining product gas quality and control of plant subsystems. Additional tests involving greater turndown are planned.

Burners, a particularly critical item of equipment, have exhibited excellent performance and reliability. Including runs after the shakedown and demonstration phases, the burners have amassed over 3000 hours of operation. On the basis of these data, Shell Oil projects a burner lifetime of at least one year, which meets the company's commercial plant target.

Environmental requirements

SCGP-1 has met or exceeded all environmental requirements. Sulfur in the product syngas was 40 ppm, well below the 120-ppm limit set to meet manufacturing complex requirements. With the syngas combusted in the power station boilers along with the normal refinery fuels, total NO_x emissions for the complex were maintained within the permitted level. Effluent water routed to the complex's biotreater also easily met specifications. Bottom slag and fly slag were used for paving, roadbed grading, and other construction applications within the complex and for nonhazardous landfill.

In addition to the demonstration of key gas- and water-treating technologies, semimobile slipstream units were employed to cost-effectively develop other treatment options and improvements. Extensive operation of the gas-treating unit in parallel with SCGP-1 has produced design data on various solvents that can be applied directly to the design of commercial treatment facilities. Among the solvents tested in the slipstream unit were MDEA (monodiethanolamine) and Sulfinol-M*; Sulfinol-D was used directly in SCGP-1. All of these solvents are viable options for commercial applications, with the choice depending on specific sulfur removal requirements, the amount of sulfur in the coal, and the economics of each solvent system.

Three types of biotreatment systems were tested in the water-treating slipstream unit: an Orbal reactor, a rotating disk contactor, and a staged reactor. Each system provided excellent contaminant removal. The efficacy of treatment was confirmed via acute toxicity testing of the biotreated effluent streams, using fathead minnows and Daphnia shrimp. The aqueous effluent streams were not toxic to either of these test species.

*A registered trademark of Shell Oil Co.

Column leachate studies were carried out with the SCGP-1 slag and fly slag produced in the demonstration run. Trace elements in the leachates were well within allowable limits.

Commercialization efforts

The SCGP design has been employed in several EPRI-sponsored site-specific paper studies of coal gasification–combined-cycle power plants. Northeast Utilities, Potomac Electric, Virginia Power, Baltimore Gas & Electric, and Florida Power & Light have participated with EPRI, Shell, and an independent contractor in carrying out these studies. The coal-to-busbar heat rate for the designs ranged from 8800 to 9100 Btu/kWh, depending on the degree of gasification and power block integration and other site-specific factors. These heat rates are favorable for coal-fired plants, and heat rates and capital costs for the Shell technology are competitive with other gasification processes when consistent assumptions are made for comparison purposes.

It was announced on May 1, 1989, that a commercial demonstration coal gasification–combined-cycle power plant based on Shell technology is to be built in Buggenum, The Netherlands. The 250-MW plant is scheduled to start up by the end of 1993.

Further work at SCGP-1

Since completion of the demonstration phase in June 1988, the objectives of the test program have been to optimize the process and to gain operating experience and gather data on a variety of coals. Several new process configurations and equipment to improve overall plant efficiency, reliability, and capital costs have already been successfully demonstrated. Further testing to complete this process optimization activity has been planned.

Process performance with a wide spectrum of coals of commercial importance is also being demonstrated. SCGP-1 has operated successfully, at full and reduced rates, on a high-ash-fusion-temperature central Appalachian coal, a high-ash-fusion-temperature Australian coal, and a western subbituminous coal. Carbon conversion with these coals (and also in subsequent operations with the Illinois No. 5 coal) has consistently been in the 98.5–99.5% range. All equipment systems, including coal feeding, syngas cooling, solids removal, and gas treating, performed well on these coals. Runs with other coals, including a Pittsburgh No. 8 coal selected by EPRI, are planned to demonstrate the broad coal flexibility of the Shell technology. Specific data on all these coals will be reported at a later time.

The plant operating program has already demonstrated the commercial readiness of the Shell process. Smooth plant operation with a variety of coals and under a variety of test conditions indicates the reliability of the process and mechanical features of the Shell technology. Extensive environmental testing confirms the environmental cleanliness of the process. Many of the key test programs have been completed, validating new process concepts and providing data for commercial plant design and operation. Remaining testing and data-gathering objectives have been identified, and the work is expected to be completed in the near future.

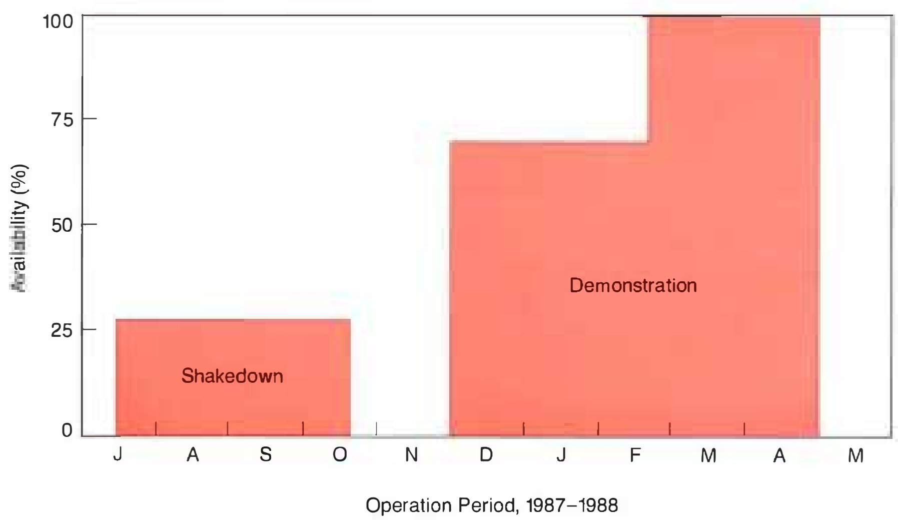


Figure 2 Shell coal gasification process plant availability. The five-month, 3005-hour demonstration phase of operation culminated in a 1528-hour uninterrupted run. Net availability during the demonstration period was 82%. Three months of shakedown preparation followed by downtime for maintenance and inspection were required before the actual demonstration.

Atmospheric Chemistry

Measuring Trace Gases With FM Spectroscopy

by D. Alan Hansen, Environment Division

Acid rain, global warming, stratospheric ozone depletion, tropospheric ozone buildup, and air toxics are all manifestations of atmospheric chemistry that can affect the quality of our lives on local to global scales. Research on atmospheric chemistry seeks to understand the processes culminating in these manifestations so that effective action can be taken to ameliorate their real or potential deleterious effects.

Knowledge and understanding of atmospheric chemistry generally grow with the ability to measure the trace constituents that, in large part, fuel the processes. These constituents are present in minute amounts (from less than one part per trillion to several parts per ten thousand); yet some of them influence the processes disproportionately, given their relative concentrations. One example is the hydroxyl radical, typically present at a few hundredths of one pptv (part per trillion by volume), which vigorously reacts with, and therefore controls the atmospheric lifetime of, many other trace gases. Another is ammonia, with airborne levels of around one ppbv (part per billion by volume), which is both consumed and released at the ground, and which influences the acidity of clouds and rain and thus can alter the rate of conversion of dissolved sulfur dioxide to sulfuric acid. Because of the lack of reliable, accurate, and fast methods of measurement, data on these and other trace gases are scarce. As a result, knowledge of their contributions to atmospheric chemistry is imprecise.

ABSTRACT *Newly developed FM spectroscopy has been shown in the laboratory to have unprecedented sensitivity, selectivity, and speed for the measurement of ambient concentrations of a broad suite of atmospheric trace gases. Further, it has the potential to measure, with more accuracy and greater flexibility than previously possible, the surface fluxes of many of these gases. Its use in both of these applications will provide new information that should substantially improve our understanding of the roles these gases play in atmospheric chemistry.*

Measuring trace gases

An EPRI-sponsored measurement technique that overcomes this limitation for many trace gases has now reached the laboratory prototype stage. It is frequency-modulated spectroscopy (FMS). In its double-modulated form (two-tone FMS, or TTFMS), it has been developed and refined by researchers at SRI International and the University of Virginia into the most sensitive and selective molecular absorption spectroscopic technique available today.

In the infrared portion of the spectrum, all molecules (except for symmetrical diatomic ones, such as O_2 and N_2) absorb radiation at specific wavelengths corresponding to the vibrational excitation of the bonds connecting the atoms. No two different molecules have the same absorption spectra, and in small molecules the spectra can be composed of very sharp absorption features (lines), many of which are isolated from those of other types of molecules. It is by selecting a laser wavelength corresponding to one of these isolated lines that the exceptional selectivity of infrared absorption spectroscopy is achieved. And it is the ingenious ways the researchers have found to eliminate traditional sources of optical and electronic noise that have yielded the extreme sensitivity inherent in TTFMS.

TTFMS uses a diode laser as the light source. The laser is modulated simultaneously at two arbitrary but closely spaced frequencies, and the beat tone between these two frequencies is monitored as the laser carrier and associated sidebands are tuned through an absorption line. TTFMS has extended the sensitivity of molecular absorption spectroscopy at least two orders of magnitude beyond that of other techniques in use today, such as second derivative tunable laser diode spectroscopy (whose development EPRI earlier supported for the successful measurement of ambient hydrogen peroxide).

TTFMS sensitivity

Table 1 lists a number of trace gases of interest because of their involvement as greenhouse gases (CH_4, CO_2, N_2O); oxidants or their precursors (H_2O_2, NO, NO_2); contributors to acid rain (HNO_3, NH_3, NO_2, NO); toxicants (PAN, PH_3, CO, HCN); or contributors to stratospheric ozone cycles (CH_4, N_2O). The minimum detectable concentrations (MDCs) shown assume a 1-minute signal averaging time; a 20-torr measurement pressure (1 atmosphere is 760 torr; the lower pressure is achieved by drawing the sampled air through a low-pressure vessel); and an optical pathlength of 100 meters (generally achieved with a multiple-reflection optical cell). Shorter pathlengths and averaging times and higher pressures would result in higher MDCs. (The sensitivity is inversely proportional to the square root of the averaging time.)

Although all the gases listed can be measured with other technologies, none of those technologies can achieve TTFMS's sensitivity and freedom from interference (selectivity) for a comparable averaging time. This capability is particularly crucial for defining ambient concentration ranges for such gases as H_2O_2, HNO_3, N_2O, and NH_3, which have considerable variability both vertically and horizontally in the atmosphere or which have substantial fluxes to or from the earth's surface.

The inability to measure fluxes has been a particularly nettlesome problem. Of the methods available for measuring fluxes, one —eddy correlation—is especially desirable because of its directness and because it does not rely on the use of chambers or other devices that can influence radiation, heat, or moisture, which themselves can influence the flux of the gas of interest. However, eddy correlation measurements do rely on a chemical sensor that can make about 10 measurements a second.

The difficulty arises because the averaging time of conventional instruments is so long over the ambient concentration range of such gases as H_2O_2, HNO_3, and NH_3 that they cannot be used for eddy correlation. That means that, at present, there exists an inaccurate picture of the contribution of surface fluxes to the atmospheric mass balance of these and other species.

The extraordinary sensitivity of TTFMS gives it the potential to fill this measurement need for the shorter averaging times necessary for eddy correlation, because for every two orders of magnitude of reduction in averaging time, only one order of magnitude of sensitivity is sacrificed. Thus, TTFMS in an eddy correlation system should be able to measure, for example, NH_3 fluxes at ambient concentrations of less than 4 pptv.

Plans for TTFMS call for its adaptation from a laboratory prototype to a field-deployable system capable of measuring both ambient levels of trace gases and their surface fluxes. Because of its importance in moderating rain acidity, NH_3 will be the initial target gas for demonstrating the field performance of the system.

Table 1
PROJECTED SENSITIVITY OF TTFMS TO VARIOUS SMALL MOLECULES

Molecule	Frequency (1/cm)	Wavelength (micrometers)
H_2O_2	1284	7.788
HNO_3	1722	5.807
NH_3	1050	9.524
PAN	1150	8.696
NO_2	1604	6.234
NO	1880	5.319
CH_4	1300	7.692
CO_2	2350	4.255
CO	2120	4.717
N_2O	3492	2.864
HCN	712	14.045
PH_3	992	10 081

New Contracts

Project	Funding/ Duration	Contractor/EPRI Project Manager
Customer Systems		
Energy Lifestyles (RP2979-3)	$40,000 7 months	Lawrence Berkeley Laboratory/*L. Lewis*
Planning Assistance in the Demand-Side Area (RP3084-1)	$25,000 12 months	QEI Inc./*V. Rabl*
Technology Transfer Support for Demand-Side Planning and Information (RP3084-2)	$25,000 12 months	Pacific Consulting Service/ *V. Rabl*
Electrical Systems		
Centrifugal Processing of Superconductors (RP4000-2)	$62,400 7 months	Battelle Memorial Institute/ *D. Sharma*
Development of a Transmission Cable Diagnostic System: Field Evaluation of Insulation Power Factor (RP7910-5)	$151,000 14 months	Power Technologies Inc./ *T. Rodenbaugh*
HTSC Motor Development (RP7911-2)	$875,200 27 months	Reliance Electric Co./ *D. Sharma*
Exploratory Research		
Sulfur Species in Coal (RP8003-19)	$73,000 7 months	Argonne National Laboratory/*H. Lebowitz*
Dry Cleaning of Coal in an Air Fluidized Bed, Phase II (RP8006-14)	$50,000 31 months	Lehigh University/ *C. Harrison*
Prediction of Determination Rate of Utility Cable Insulation (RP8007-1)	$212,600 17 months	Naval Research Laboratory/*T. Rodenbaugh*
Engineering Mathematics and Information Sciences: Problem/Solution Workshops (RP8010-6)	$36,000 11 months	George Fegan Consulting/ *R. Iveson*
Chaotic Dynamics of Fluidized Beds (RP8010-7)	$39,100 7 months	Argonne National Laboratory/*J. Stringer*
Generation and Storage		
Retrofit of Future Advanced Technology to Current Design Combined Cycles (RP2565-17)	$54,000 9 months	Virginia Electric & Power/ *A. Cohn*
Assessment of Seam-Welded Steam Piping in Fossil Power Plants (RP2596-11)	$260,800 24 months	Battelle, Columbus Laboratories/ *R. Viswanathan*
NSP Task Responsibilities for Black Dog Unit #2 AFBC Test Program (RP2628-9)	$49,800 5 months	Northern States Power Co./ *J. Stallings*
Environmental Characterization at CUEA's CFBC Demonstration Unit (RP2683-11)	$238,000 22 months	Radian Corp./*D. O'Connor*
Preliminary Assessment of Coal-Fired Steam Boiler With Air Turbine (RP2819-4)	$46,100 9 months	United Engineers & Constructors/*J. Bartz*
Evaluation of Composite Plastic Materials for CAES Plants (RP2894-4)	$105,600 29 months	Fiberglass Structural Engineering/*B. Mehta*
Wall-Fired Low-NO_x Burner Retrofit Boiler Thermal Performance Evaluation: Phase I, Baseline Tests (RP2916-9)	$177,600 9 months	Foster Wheeler Energy Corp./*D. Eskinazi*
Gas Turbine Blade Measurement by Optical Pyrometer (RP2985-16)	$76,400 35 months	Encotech, Inc./*H. Schreiber*
Improving Reliability of the Putnam Combined-Cycle Plant (RP2989-1)	$224,900 16 months	Florida Power & Light Co./ *R. Frischmuth*

Project	Funding/ Duration	Contractor/EPRI Project Manager
New Dry SO_2/Particulate Control Studies (RP3005-1)	$299,900 13 months	Southern Research Institute/*R. Altman*
Internal Reforming Molten Carbonate Fuel Cell (RP3058-1)	$707,000 12 months	Energy Research Corp./ *R. Goldstein*
Thin-Film High-Temperature Superconductor Heat-Pipe Switch (RP3070-3)	$150,000 14 months	DOE/*L. Atherton*
Gate Code Enhancement and User Support (RP3117-1)	$184,200 18 months	Enter Software Inc./ *H. Schreiber*
Nuclear Power		
Self-Collider U-Catalyzed Fusion Reactor (RP2614-42)	$204,400 12 months	University of Florida/ *D. Worledge*
Electropolishing Qualification Program (RP2758-6)	$138,500 8 months	Westinghouse Electric Corp./*C. Wood*
Laboratory and Computational Iodine Studies for the Advanced Containment Experiments, Phase B (RP2802-16)	$275,000 12 months	Martin Marietta Energy Systems Inc./*R. Ritzman*
Evaluation of Acoustic Emissions for Detection of Crack Initiation in Stainless Steel (RP2812-7)	$75,900 6 months	Battelle Memorial Institute/ *R. Pathania*
Pilot Data Base Management System Development (RP2925-6)	$183,800 8 months	EQE Inc./*R. Kassawara*
Relay Functionality Evaluation Procedures (RP2925-8)	$79,800 10 months	MPR Associates, Inc./ *R. Kassawara*
LWR Set-Point Methodology Demonstration (RP2973-3)	$24,900 5 months	Combustion Engineering, Inc./*G. Srikantiah*
Pilot-Scale Test of UV/Ozone Process for Removal of Organic Contaminants (RP2977-2)	$100,000 8 months	General Electric Co./ *T. Passell*
Evaluation of Fault-Tolerant Digital Control System Architecture (RP3008-1)	$99,100 8 months	Martin Marietta Energy Systems Inc./*K. Sun*
Core Debris Interactions With Containment and Coolability (RP3047-2)	$140,000 11 months	Argonne National Laboratory/*B. Sehgal*
Concrete Cask Storage Demonstration (RP3073-1)	$200,000 22 months	Wisconsin Electric Power Co./ *C.R. Lambert*
Analysis of BWR Fuel Consolidation Considerations (RP3100-1)	$23,700 3 months	Northeast Technology Corp./ *R. Lambert*
Simulator Fidelity Requirements (RP3107-1)	$43,000 1 month	General Physics Corp./ *R. Colley*
Individual Plant Examination Issues Resolution (RP3114-20)	$298,200 12 months	Science Applications International Corp./ *J. Haugh*
Exam of the V.C. Summer Plant Steam Generator Tubes (RPS407-34)	$81,800 6 months	Babcock & Wilcox Co./ *A. Mcilree*
Boric Acid Application Guidelines for Intergranular Corrosion (RPS407-35)	$33,200 5 months	Westinghouse Electric Corp./*P. Paine*
Large Eddy Simulation of Turbulent Flow Fields for Heat Exchanger Tube Vibration Analysis Utilizing Supercomputers (RPS410-12)	$72,500 13 months	Texas Engineering Experiment/*D. Steininger*
Mechanistic Understanding of Nodular Corrosion (RPX102-30)	$21,100 21 months	Atomic Energy of Canada Ltd./*R. Yang*

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

Heat Pumps in Complex Heat and Power Systems
EM-4694 Final Report (RP2220-3); $100
Contractor: ICI-KATALCO (TENSA Services)
EPRI Project Managers: A. Karp, A. Pavone, K. Amarnath

Residential Customer Preference and Behavior: Market Segmentation Using CLASSIFY™
EM-5908 Final Report (RP2671-1); $25
Contractors: National Analysts; Synergic Resources Corp.; QEI, Inc.
EPRI Project Manager: L. Lewis

Photoelectric Control of Daylight-Following Lighting Systems: Daylight-Sensing Photocell Placement
CU-6243 Final Report (RP2285-3); $100
Contractor: Lawrence Berkeley Laboratory
EPRI Project Manager: K. Johnson

Radiant Barrier Applications: Symposium and Workshop Proceedings
CU-6255 Proceedings (RP2034-23); $100
Contractor: Analysis and Control of Energy Systems, Inc.
EPRI Project Manager: J. Kesselring

Radon Control Strategies for Residential Dwellings
CU-6257 Final Report (RP2034-1); $100
Contractor: GEOMET Technologies, Inc.
EPRI Project Managers: P. Joyner, J. Kesselring

Supermarket Refrigeration Modeling and Field Demonstration
CU-6268 Interim Report (RP2569-2); $150
Contractor: Foster-Miller, Inc.
EPRI Project Manager: M. Blatt

Proceedings: Advanced Adjustable Speed Drive R&D Planning Forum
CU-6279 Proceedings (RP2918-1); $100
Contractors: TEM Associates, Inc.; McCleer J. Power, Inc.
EPRI Project Manager: B. Banerjee

Freeze Concentration of Dairy Products: Phase 1
CU-6292 Final Report (RP2782-1); $100
Contractor: Dairy Research, Inc.
EPRI Project Managers: K. Amarnath, A. Karp

1987 Survey of Commercial-Sector Demand-Side Management Programs
CU-6294 Final Report (RP2884-1); $100
Contractor: Battelle, Columbus Division
EPRI Project Managers: P. Hanser, W. Smith

New Dimensions in Pricing Electricity: Proceedings
CU-6300 Proceedings (RP2343); $100
EPRI Project Manager: W. LeBlanc

A Design for a Lighting Demonstration Module
CU-6320 Final Report (RP2285-12); $100
Contractor: Lighting Research Institute
EPRI Project Managers: K. Johnson, G. Purcell

Analysis of Building Codes for Commercial Kitchen Ventilation Systems
CU-6321 Final Report (RP2033-21); $100
Contractor: National Conference of States on Building Codes and Standards, Inc.
EPRI Project Manager: K. Johnson

Design of Industrial Process Refrigeration Systems
CU-6334 Final Report (RP2783-4); $100
Contractor: Union Carbide Corp.
EPRI Project Managers: A. Pavone, K. Amarnath

Commercial Unitary Heat Pumps: An Assessment Study
CU-6371 Final Report (RP2480-2); $100
Contractor: Joseph A. Pietsch, P.E.
EPRI Project Manager: Morton Blatt

ELECTRICAL SYSTEMS

Application of Microprocessors to Control HVDC Converters
EL-6274 Final Report (RP1942-1); $25
Contractor: General Electric Co.
EPRI Project Manager: S. Nilsson

AC Losses in the New High-Temperature Superconductors
EL-6277 Final Report (RP7898-13); $25
Contractor: Iowa State University
EPRI Project Manager: M. Rabinowitz

Advanced Current and Voltage Transducers for Power Distribution Systems, Vols. 1 and 2
EL-6289 Final Report (RP2734-1, -2); Vol. 1, $32.50; Vol. 2, $25
Contractors: Westinghouse R&D Center; McGraw-Edison Power Systems
EPRI Project Managers: J. Porter, W. Shula

Direct Embedment Foundation Research
EL-6309, Final Report (RP1280-3); $32.50
Contractor: GAI Consultants, Inc.
EPRI Project Manager: Vito Longo

ENVIRONMENT

FASTCHEM™ Package, Vol. 1: Overview and Application to a Chemical Transport Problem
EA-5870 Final Report (RP2485-2); $32.50
Contractor: Battelle, Pacific Northwest Laboratories
EPRI Project Manager: D. McIntosh

FASTCHEM™ Package, Vol. 5: User's Guide to the EICM Coupled Geohydrochemical Transport Code
EA-5870 Computer Code (RP2485-2); $32.50
Contractor: Battelle, Pacific Northwest Laboratories
EPRI Project Manager: D. McIntosh

The FASTCHEM™ Workstation for Integrating Pre- and Postprocessing Functions
EA-5871 Final Report (RP2485-2); $32.50
Contractor: Battelle, Pacific Northwest Laboratories
EPRI Project Manager: D. McIntosh

An Optical Particle Counter for Measuring Small-Particle Flux
EN-6188 Final Report (RP2584-1); $40
Contractor: Battelle, Pacific Northwest Laboratories
EPRI Project Manager: L. Levin

Human Activity Patterns in Cincinnati, Ohio
EN-6204 Final Report (RP940-6); $40
Contractor: PEI Associates, Inc.
EPRI Project Manager: R. Wyzga

Screening of Contamination Potential and Site Cleanup at Manufactured-Gas Plant and Pole Treatment Sites
EN-6213 Final Report (RP2634-1); $25
Contractor: CH2M Hill
EPRI Project Manager: A. Silvers

The Wisconsin Regional Integrated Lake-Watershed Acidification Study (RILWAS): 1981–1983
EA-6214 Interim Report (RP2174-2); $47.50
Contractor: Wisconsin Department of Natural Resources
EPRI Project Manager: R. Goldstein

Physiologic, Toxicologic, and Population Responses of Brook Trout to Acidification: Interim Report of the Lake Acidification and Fisheries Project
EN-6238 Final Report (RP2346); $32.50
Contractors: University of Wyoming; Oak Ridge National Laboratory; Western Aquatics, Inc.; McMaster University
EPRI Project Manager: J. Mattice

Potential Impacts of Climate Change on Electric Utilities
EN-6249 Final Report (RP2141-11); $32.50
Contractor: ICF Inc.
EPRI Project Manager: T. Wilson

Chemical Spill Uncertainty Analysis
EN-6284 Final Report (RP2634-1); $25
Contractors: CH2M Hill; Woodward-Clyde Consultants
EPRI Project Manager: A. Silvers

GENERATION AND STORAGE

AFBC Conversion at Northern States Power Company, Vol. 2: Black Dog Unit 2 Equipment Design
CS-5501 Final Report (RP2628-3); $40
Contractor: Stone & Webster Engineering Corp.
EPRI Project Manager: S. Tavoulareas

Colorado-Ute's Nucla Circulating AFBC Demonstration Project, Vol. 2: Plant Equipment and Systems Design
CS-5831 Final Report (RP2683-2); $32.50
Contractor: United Engineers & Constructors, Inc.
EPRI Project Manager: S. Tavoulareas

Heat Exchanger Tube Coatings and Liners
GS-6203 Final Report (RP1689-18); $32.50
Contractor: Stone & Webster Engineering Corp.
EPRI Project Manager: J. Tsou

Experiences With Commercial Wind Turbine Design, Vols. 1 and 2
GS-6245 Final Report (RP1590-12); Vol. 1, $40; Vol. 2, $25
Contractor: R. Lynette & Associates, Inc.
EPRI Project Manager: J. Schaefer

Photovoltaic Field Test Performance Assessment: 1987
GS-6251 Final Report (RP1607-6); $32.50
Contractor: Southwest Technology Development Institute
EPRI Project Manager: J. Schaefer

Survey of Water-Conserving Heat Rejection Systems
GS-6252 Final Report (RP1260-59); $40
Contractor: Robert D. Mitchell, P.E.
EPRI Project Manager: J. Bartz

Assessment of Wind Power Station Performance and Reliability
GS-6256 Final Report (RP1590-10); $32.50
Contractor: R. Lynette & Associates, Inc.
EPRI Project Manager: J. Schaefer

Quality Assurance and Quality Control for Environmental Laboratories: Design Guidelines
GS-6258 Final Report (RP1851-1); $40
Contractor: TRW, Inc.
EPRI Project Manager: W. Chow

Demonstration of an Availability Optimization Method
GS-6266 Final Report (RP2462-1); $32.50
Contractor: ARINC Research Corp.
EPRI Project Manager: J. Weiss

Development of Improved Boiler Startup Valves
GS-6280 Topical Report (RP1403-19); $32.50
Contractors: Foster Wheeler Development Corp.; Ishikawajima-Harima Heavy Industries Co., Ltd.; Bailey Japan Co., Ltd.
EPRI Project Manager: W. Bakker

Electrostatic Precipitator Upgrades for Furnace Sorbent Injection
GS-6282 Final Report (RP1402-27); $25
Contractor: Cottrell Environmental Sciences, Inc.
EPRI Project Manager: M. McElroy

Baltimore Gas and Electric Company's Study of a Shell-Based GCC Power Plant
GS-6283 Final Report (RP2773-3); $40
Contractor: Baltimore Gas & Electric Co.
EPRI Project Manager: J. Fortune

The 20-MW TVA Atmospheric Fluidized-Bed Boiler
GS-6287 Interim Report (RP1860-1); $32.50
Contractor: Tennessee Valley Authority
EPRI Project Managers: T. Boyd, W. Howe

Intake Technologies: Research Status
GS-6293 Final Report (RP2214-4); $25
Contractors: Lawler, Matusky & Skelly Engineers
EPRI Project Manager: W. Micheletti

Simulator-Analyzer for Modular Wellhead Binary-Cycle Power Systems, Vols. 1 and 2
GS-6302 Final Report (RP1197-22); Vol. 1, $40; Vol. 2, $25
Contractor: ESSCOR, Inc.
EPRI Project Manager: J. Berning

Survey of U.S. Line-Connected Photovoltaic Systems
GS-6306 Special Report; $25
EPRI Project Manager: J. Schaefer

Proceedings: First Combined Flue Gas Desulfurization and Dry SO_2 Control Symposium, Vols. 1 and 2
GS-6307 Proceedings (RP982-41); $170 for two-volume set
Contractor: Radian Corp.
EPRI Project Manager: P. Radcliffe

Gas Turbine Procurement: 1988 Workshop
GS-6312 Final Report (RP2565-6); $500
Contractor: Energy Systems Associates
EPRI Project Manager: H. Schreiber

Proceedings: International Cooling-Tower Conference
GS-6317 Proceedings; $70
Contractors: ENEL (Italian Power Authority); CRTN (Thermal and Nuclear Research Center)
EPRI Project Manager: J. Bartz

NUCLEAR POWER

Below Regulatory Concern Owners Group: Evaluation of Candidate Waste Types, Revision 1
NP-5670 (Rev. 1) Final Report (RPB101-26); $1000
Contractor: Analytical Resources, Inc.
EPRI Project Manager: P. Robinson

Below Regulatory Concern Owners Group: Radionuclide Prioritization Study, Revision 1
NP-5671 (Rev. 1) Final Report (RPB101-9); $1000
Contractor: Science Applications International Corp.
EPRI Project Manager: P. Robinson

Below Regulatory Concern Owners Group: Nonradiologic Characterization and Environmental Assessment of BRC Waste
NP-5674 Final Report (RPB101-19); $25
Contractor: Science Applications International Corp.
EPRI Project Manager: P. Robinson

Below Regulatory Concern Owners Group: An Evaluation of Dry Active Waste Sorting
NP-5676 Final Report (RPB101-14); $1000
Contractor: Anacapa Sciences, Inc.
EPRI Project Managers: P. Robinson, E. Bradley

Below Regulatory Concern Owners Group: Radionuclide Characterization of Potential BRC Waste Types From Nuclear Power Stations
NP-5677 Final Report (RPB101-15); $1000
Contractor: Battelle, Pacific Northwest Laboratories
EPRI Project Manager: P. Robinson

Below Regulatory Concern Owners Group: Cost-Benefit Analysis of BRC Waste Disposal
NP-5681 Final Report (RPB101-18); $1000
Contractor: Sargent & Lundy
EPRI Project Manager: P. Robinson

Below Regulatory Concern Owners Group: Evaluation of Dry Active Waste Monitoring Instruments and Techniques
NP-5682 Final Report (RPB101-20); $1000
Contractor: Battelle, Pacific Northwest Laboratories
EPRI Project Manager: P. Robinson

Seismic Analysis of Multiply Supported Piping Systems
NP-6153 Final Report (RP964-10); $32.50
Contractor: Westinghouse Electric Corp.
EPRI Project Manager: Y. Tang

Proceedings: EPRI/NRC/TPC Workshop on Seismic Soil-Structure Interaction Analysis Techniques Using Data From Lotung, Taiwan, Vols. 1 and 2
NP-6154 Proceedings (RP2225); $100 for two-volume set
EPRI Project Manager: Y. Tang

Concrete Containment Tests, Phase 3: Structural Elements With Penetration Sleeves
NP-6259-M Final Report (RP2172-2); $25
Contractor: Construction Technology Laboratories, Inc.
EPRI Project Manager: H. Tang

Criteria and Guidelines for Predicting Concrete Containment Leakage
NP-6260-M Interim Report (RP2172-1); $32.50
Contractor: ANATECH Research Corp.
EPRI Project Manager: H. Tang

CALENDAR

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

JULY

25–27
Power Quality Training for Utilities
Boston, Massachusetts
Contact: Marek Samotyj, (415) 855-2980

AUGUST

1
Power Plant Water Management
Location to be determined
Contact: Wayne Micheletti, (415) 855-2469

6–10
4th International Symposium on Environmental Degradation of Materials in Nuclear Power Systems—Water Reactors
Jekyll Island, Georgia
Contact: Dan Cubicciotti, (415) 855-2069

14–18
Structural Mechanics in Reactor Technology (SMIRT)
Anaheim, California
Contact: Gary Dau, (415) 855-2051

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 the Release, Transport, and Fate of 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
4th Annual EPRI Conference on 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
International 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

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

13–17
Conference: Marketing Electric Vans
Washington, D.C.
Contact: Jim Janasik, (415) 855-2486

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

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Contact: Murthy Divakaruni, (415) 855-2409

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St. Louis, Missouri
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Contact: Paul Lyons, (817) 439-5900

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Atlanta, Georgia
Contact: Neal Balu, (415) 855-2834

3–5
FASTCHEM, FOWL, and MYGRT: Codes for Modeling the Release, Transport, and Fate of 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
4th Annual EPRI Conference on 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
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On-Line Coal Analysis Applications
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Palo Alto, California
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26-27
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Contact: Glenn Cook, (415) 855-2797

13–17
Conference: Marketing Electric Vans
Washington, D.C.
Contact: Jim Janasik, (415) 855-2486

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

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Atlanta, Georgia
Contact: Mort Blatt, (415) 855-2457

Authors and Articles

Iveson

Young

Hakkarinen

Mueller

Kassawara

Wall

The Future of Transmission: Switching to Silicon (page 4) was written by John Douglas, science writer, with technical guidance from two staff members of EPRI's Electrical Systems Division.

Bob Iveson has a special interest in equipment and techniques for transmission system control. Now a staff technical adviser, he previously managed the Power System Planning and Operations Program for nine years. Before coming to EPRI in 1979, he was with New York State Electric & Gas Corp. for 20 years, including 9 years as supervisor of transmission planning for the New York Power Pool. Iveson has BS and MS degrees in electrical engineering from Rensselaer Polytechnic Institute and Syracuse University, respectively.

Frank Young, associate division director since 1987, was previously EPRI's manager of strategic planning for six years. He came to the Institute in 1975 after 20 years with Westinghouse Electric, where he became manager of UHV transmission research. Young graduated in electrical engineering from Stanford and earned an MS in the same field at the University of Pittsburgh. ■

Concern Over Ozone (page 14) was written by Taylor Moore, senior feature writer, with information from two research managers in EPRI's Environment Division.

Chuck Hakkarinen, division technical manager, has been with EPRI since 1974. Starting as a project manager for environmental assessment, he became assistant to the division director in 1979 and then was manager of environmental data analysis until early this year. Hakkarinen has BS and MS degrees in mathematics and meteorology, respectively, from the University of Maryland and a doctorate in environmental engineering from UCLA.

Peter Mueller, a program manager since 1987, heads the Atmospheric Sciences Program. He came to EPRI in 1980 from Environmental Research & Technology, where he managed an environmental chemistry center. Prior to that, he had worked briefly at the EPA and for 16 years with California's Department of Health, becoming director of its air and industrial hygiene laboratory. Mueller earned a BS in chemistry at George Washington University and an MS and a PhD in environmental science at Rutgers. ■

Real-World Lessons in Seismic Safety (page 22) was written by Dave Boutacoff, feature writer, aided by two research managers in EPRI's Nuclear Power Division.

Bob Kassawara, a specialist in seismic analysis, manages postearthquake investigations. He joined EPRI in 1985 after four years with Impell Corp., much of that time as manager of engineering analysis, mostly for nuclear power industry clients. From 1970 to 1981 he was with Combustion Engineering, where he became a group supervisor for the dynamic analysis of reactor coolant systems. Kassawara is a civil engineering graduate of Polytechnic University in Brooklyn; he earned an MS and a PhD at the University of Illinois.

Ian Wall heads the Severe Accident Program, continuing career work in risk analysis begun when he was with the NRC Office of Regulatory Research from 1974 to 1979. Earlier, beginning in 1964, he worked for ten years with the nuclear energy division of General Electric, initially in engineering but eventually in marketing. An engineering honors graduate of Imperial College of Science and Technology (London), Wall later earned an ScD in nuclear engineering at MIT. ■

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