Centers for Electrotechnology Application

ELECTRIC POWER RESEARCH INSTITUTE

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Cover: American industry is gearing up for global competition, in part through the use of advanced automation technologies. EPRI has begun seeding a number of electrotechnology application centers to encourage these productivity-enhancing efforts.

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R&D Centers With a Difference

Technologic change holds the key to solving many of the problems that beset today's societies. But although issues such as economic productivity, environmental quality, public health and safety, and the pressures of international competition argue for rapid and extensive change, the costs, risks, and institutional obstacles associated with the development and introduction of beneficial technologies threaten to bar the way. This trend has brought into ever sharper focus the need for collaboration to share these costs and risks and to provide an expeditious route past such traditional barriers as lack of knowledge, resistance to change, and laws designed for the economic environment of the past.

EPRI itself stands as one of the best-known examples of private sector collaboration, focusing R&D for a major industry and expediting the transfer of results into practical use. As cleaner, safer, and more productive technologies for supplying electricity have begun to emerge from EPRI's programs, work on better ways to use the industry's product has been moving to the center of attention. And with this new emphasis, the need has grown to extend the industry's collaborative R&D to include those groups most interested in improved utilization of electricity: the industry's customers and all those stakeholders that stand to gain from the development, marketing, and widespread use of improved or entirely new end-use technologies.

For several years now, EPRI has been seeking and building collaborative end-use R&D projects with utilities, energy users, equipment vendors, and government organizations. But as we intensified our dialogue with electricity users, it became apparent that more was required. The industrial sector in particular—already dependent on a tremendous variety of electricity-based technologies—offered great potential for urgently needed productivity increases if the use of electrotechnologies could be expanded in key industries. Yet the very diversity of technologic opportunities and of the industrial operations into which these technologies could be placed presented a real challenge. Our response was to develop the concept of R&D Application Centers (RDACs) as focal points of collaboration with entire industrial sectors.

Collaboration in R&D through centers of excellence is, of course, not a new idea. Recent examples in the United States include the R&D Center of the Microelectronics and Computer Technology Corp., the Center for Magnetic Recording Research, the centers of the Edison Partnership sponsored by the State of Ohio, and the growing number of engineering centers being established by the National Science Foundation. EPRI's RDACs, however, differ from other joint efforts in a basic way—they focus on the *application* of R&D results.

We felt that a concentration on improved and expanded applications of existing electrotechnologies would lead to important benefits in the near term for utilities and energy users alike. Also, by focusing on early applications of mutual benefit, key stakeholders would be motivated to share the costs and risks and become partners in the transfer of successful applications into actual industrial practice. In addition, we expect the RDAC approach to put important electrotechnology application information into the hands of utilities now, at a time when they are rebuilding closer relationships with some of their most important customers.

Although it is too early to tell to what extent our expectations will be met, there is encouraging evidence that the RDAC concept works. As described in this month's lead article, EPRI's Center for Metals Fabrication, established in late 1983, has already demonstrated an improved electrotechnology application in CADNC, an economical combination of computer-aided design and a numerically controlled laser metal cutter. This productivity-enhancing system is now being transferred by the center to the metals fabrication industry. Our second RDAC, the Center for Metals Production, has attracted the cooperative funding of nearly 20 steel producers for a major project to increase the productivity and reduce the electric noise of electric arc furnaces used for steel making. For both centers, information and technology transfer is becoming an integral aspect of their technical activities.

Beyond what has been achieved so far, we will work to expand the scope and activities of EPRI RDACs to increase their impact and enhance their value. Not only are we planning additional centers, but we will stimulate expansion of the centers' scope, both toward increased technology development and toward systematic technology transfer. Eventually, and with expanding industrial participation, we hope to establish through these centers an integrated set of capabilities that can take technology all the way from R&D to demonstration and into industry application. Our progress to date, the strong interest shown by our member utilities and many of their industrial customers, and the exciting opportunities we see for electric technologies to increase industrial productivity make us optimistic about the future and the value of these unique centers.

Fritz Kalhammer, Vice President
Energy Management and Utilization Division

Authors and Articles

Ever since EPRI came into being, most of its R&D has been market-directed, aimed toward application by electric utilities. A newer twist is R&D aimed toward the applications of major electric utility customers. **Electrotechnology Application Centers: Partnerships in Productivity** (page 6), this month's cover story, describes the newest twist of all, EPRI's cooperative sponsorship of R&D application centers for just such specialized effort. The article is the last one by Nadine Lihach, a senior feature writer who was with the *Journal* for six years. For technical guidance, she turned to three research managers of EPRI's Energy Management and Utilization Division.

I. Leslie Harry, manager of industrial electrification, has worked with research projects in the electrotechnologies since joining EPRI in April 1980 after two years as a consultant at Scientific Applications, Inc. From 1971 to 1978 he was with DOE, becoming a program manager in the Office of Conservation. Harry graduated from Western Kentucky University in physics and mathematics and has an MS in nuclear engineering from Georgia Institute of Technology and an MBA from Stanford University.

Ralph Ferraro, now manager of the Industrial Program, was technical manager for electric interface and control systems until late in 1984. He joined EPRI in December 1977 after four years at Bechtel Power Corp., where he last worked as supervisor of control systems for power plant projects. In the 1960s and early 1970s, Ferraro worked for three other firms in the design and production of power conversion and control equipment. He has a BS in electrical engineering from the New Jersey Institute of Technology.

Thomas Schneider, director of the Energy Utilization and Conservation Technology Department since January 1982, came to EPRI in January 1977 to manage energy storage research projects. He was formerly with New Jersey's Public Service Electric and Gas Co., where he directed R&D in a number of energy conversion, storage, and end-use technologies. Schneider has a PhD in physics from the University of Pennsylvania.

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For most of their history, electric utilities simply pumped out power and concerned themselves mainly with lowering the cost of electricity supply. Now that electricity demand can and must also be taken into account for achieving the lowest-cost service, some fairly complex integration of planning factors is needed. **Testing Load Management Strategies** (page 14) describes the development of a computer model that utilities can tailor to their own service territories. Science writer Stephen Tracy wrote the article in cooperation with Victor Niemeyer of the Energy Analysis and Environment Division.

Niemeyer, a project manager in the Decision Methods and Analysis Program, has been with EPRI since November 1978, part of that time involved in an extensive electric utility rate design study. During 1978 he was with Charles River Associates, and during 1976 and 1977 he was a research associate at the Center for Energy Studies of the University of Texas, in Austin. Earlier, while earning a PhD in economics, Niemeyer was a teaching fellow in economics at Texas. Niemeyer graduated in economics from the University of California at Berkeley.

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Gapless surge arresters were still under development when EPRI's sponsored research was reviewed in the *EPRI Journal* three years ago. They are the universal choice on transmission systems today, and they are preferred for distribution networks where compatibility is not a temporarily limiting factor. **Solid-State Shunt for Overvoltage** (page 18) describes this now-commercial technology and its origins. The article was written by Christine Freeman, science writer, aided by Vasu Tahiliani of EPRI's Electrical Systems Division.

Tahiliani is technology transfer administrator for the division. He was a project manager in the Transmission Substations Program until last year, working mainly with transformers, capacitors, and surge arresters. He was formerly with I–T–E Imperial Corp. (now part of Gould–

Brown Boveri) and McGraw-Edison Co. Tahiliani holds BS and MS degrees in electrical engineering from the University of Baroda (India) and West Virginia University, respectively.

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Technical advice for EPRI's programs comes in about equal parts from the Institute's own R&D staff and its electric utility members. In numbers alone, the edge goes to the advisers, more than 550 of them, organized in committees that parallel EPRI's division and department structure. **EPRI's Industry Advisers** (page 22) describes the makeup, the workings, and something of the atmosphere of this unusual technical resource. Feature editor Ralph Whitaker drew factual background and insight for the article from Louis Elsaesser, assistant to EPRI President Floyd Culler.

Responsible for many aspects of utility industry relations since coming to the Institute in September 1973, Elsaesser is most visible as manager of advisory affairs, coordinating the activities of utility representatives who serve on 25 advisory groups. Between 1970 and 1973 he was with the Edison Electric Institute, becoming director of research. For 23 years before that he was an army officer, at one time serving in the research and engineering office of the Department of Defense. A West Point graduate, Elsaesser has an MS in chemical engineering from Ohio State University.


Ferraro


Schneider

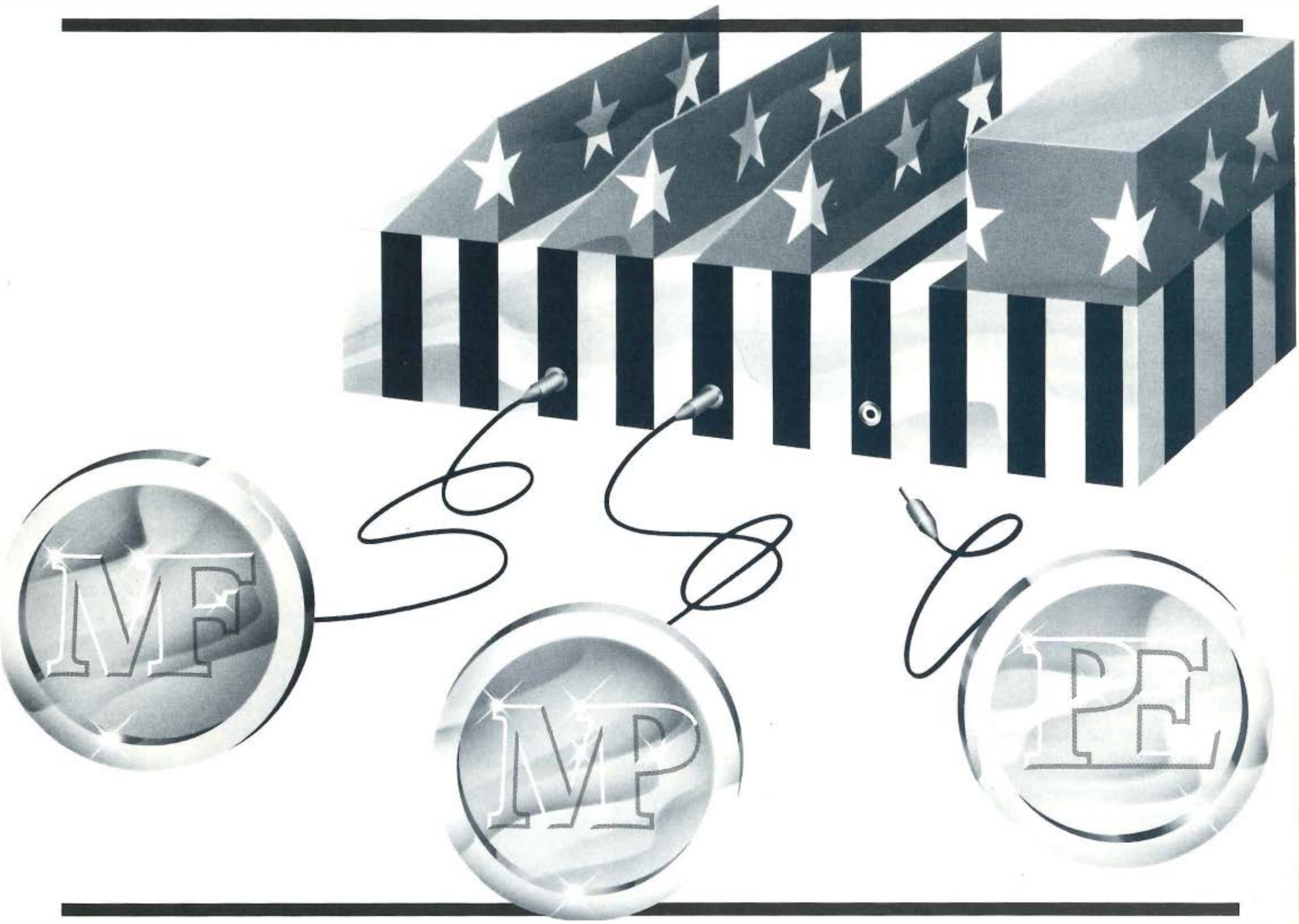

Niemeyer


Harry


Tahiliani


Elsaesser

ELECTROTECHNOLOGY APPLICATION CENTERS
Partnerships in Productivity



Collaborative R&D centers are springing up to speed the diffusion of new technology into critical energy-intensive industries. The Center for Metals Fabrication and the Center for Metals Production are now operating, and a third, the Power Electronics Applications Center, is on the drawing board.

Anyone will tell you: American industry hasn't been keeping up with the competition. Higher overseas energy costs that go back even beyond the turbulent 1970s forced foreign competitors some time ago to pursue new energy-efficient technologies to keep their product prices down. The resulting high productivity, coupled with low overseas labor costs, has left U.S. competitors at a disadvantage, deepened by the recent strength of the dollar.

Simple as it seems, this thumbnail review points to the center of the United States' failure to maintain the competitive edge. Long accustomed to being the leader in technology, U.S. industry largely neglected the imperatives of innovation and productivity development. By not moving ahead fast enough, American industrial products ended up losing ground to foreign imports.

Back on track

One way for U.S. industry to improve its productivity and competitiveness is to turn again to technology development, adopting more-efficient techniques and developing new products for both domestic and foreign markets. To a great extent, productivity advances will key on modern electricity-based techniques that replace older methods of directly combusting oil, gas, or coal to produce the energy to melt, reduce, fabricate, assemble, finish, coat, dry, and otherwise prepare raw materials.

Electricity can give users greater energy value because its every Btu is ready to do the bidding of the user. Even more important, it provides better precision and control by letting users focus energy exactly where it is needed for the precise time needed. It can offer higher production rates and productivity because it can generate intense process heat of 10,000°F (5540°C)—and higher—instead of the 3000°F (1650°C) limit of conventional combustion technologies. Productivity also benefits from the fact that electricity is more convenient for industrial users. By using equipment that runs on electricity instead of oil, gas, or coal, users do not have to worry about fuel transportation and storage or invest in major equipment conversions if their regular fuel supply becomes scarce or expensive, as oil did in recent years. Taken together, electricity's greater energy efficiency, better precision and control, higher productivity, greater convenience, and cleaner use add up to an unbeatable edge in the world market.

Some U.S. industries have already introduced electrotechnologies into their factories and foundries. Electric arc and induction furnaces have been replacing certain combustion furnaces; microwave ovens are starting to do some of the jobs that gas-fueled ovens once did; space-age lasers are gradually taking over from traditional milling and cutting operations; and robots are doing more and more assembly-line work.

But for the most part, American industries have been behind the competition in putting electrotechnologies to work for them. One reason certainly has been a lack of appreciation for the growing competitiveness of the international marketplace. Another has been lack of support—while foreign industries enjoyed government- and/or utility-sponsored electrotechnology programs, U.S. companies were largely left to go it alone. The result was a slow diffusion of technology at home, but foreign industries were spurred on, quick to seize new technology that would allow a stronger toehold in the global marketplace.

By the late 1970s the U.S. electric utility industry began to reevaluate its own role with respect to its industrial customers. Utilities knew that industrial users accounted for about 40% of U.S. electricity consumption, and it did not take weighty economic studies to conclude that what was bad for U.S. industry at large was bad for the utility industry in particular.

EPRI began a series of meetings with leaders in the industrial energy user community in 1980 to explore technologic productivity issues. It became clear that many opportunities were being missed, partly because new electrotechnologies were poorly understood and partly because the lines between different technical disciplines and different economic sectors had stiffened into seemingly insurmountable barriers. Particularly among the mature industries, where energy and electricity use is concentrated, they found that the diffusion and application of technology was frequently a greater problem than technology development. The end result was a renewed commitment to spur the technology application process, and the emergence of the concept of collaborative research to improve the mutual health of utilities and their customers.

A solution

Early insights came from meetings between EPRI and industry representatives as well as such trade associations as the American Society for Metals and the American Iron and Steel Institute. These talks, along with other analyses, led to the conclusion that centers for electrotechnology research, development, and information transfer would be a key way to get needed innovations to needy users and provide the opportunity for industry-utility collaborative projects. "We found a very slow rate of diffusion of new technology in some sectors of U.S. industry," says I. Leslie Harry, organizer of these early sessions and now manager of industrial electrification in EPRI's Energy Management and Utilization Division. "Some companies were familiar with lasers, robots, induction heating, and other innovations, but many others had little or no idea where these technologies belonged in their factories and little understanding about how to introduce them."

By late 1982 EPRI decided to implement the collaborative R&D concept by

ATTRIBUTES OF THE PARTNERSHIP

Manufacturing

- Need for productivity improvement
- Movement toward automated processing
- High-value gain through energy use
- Limited R&D resources

Application Center

- Pooling of resources, information, and expertise
- Collaboration among industrial companies, utilities, universities, government, trade associations, and professional societies
- Focus on specific industrial applications

Technology

- Electricity based
- Existing but not widely accessible or understandable
- Potential for broad-based application
- Potential for productivity gain
- Potential for increasing the value of electricity to customer

providing funding for an initial center—the Center for Metals Fabrication, established at Battelle, Columbus Laboratories in mid 1983 with a budget of $1.6 million over three years. The metals fabrication industry was certainly not the largest U.S. industrial user of electricity—it consumed only about 30% of all energy used by industry—but it was an especially troubled industry, according to Thomas G. Byrer, center director. "They were facing serious competition from abroad, they had antiquated equipment, they lacked application information about the new high-tech products available, and thus they were making incorrect modernization decisions."

This beleaguered industry also had little hope of finding solutions on its own. It was made up of some 150,000 companies that manufactured everything from the simplest soft-drink can to the most sophisticated machine tool. Many of the companies were organizations with fewer than 20 employees and no budget to delve into new technology innovations. And because the industry was so diverse, it had never been possible for small companies to keep up with what others within the industry were doing, much less organize a good-sized R&D effort of their own. Several trade organizations served various segments of the industry, but these were essentially non-R&D groups.

The new center saw an immediate opportunity to make a useful new technology available to industry. "We were able to show metals fabricators that we had a serious commitment to real-world results," says Byrer. The first project CMF settled on was a low-cost, easy-to-use computer-aided design and control software system that could be used to guide such manufacturing equipment as lasers or flame-cutters in cutting two-dimensional components.

Head start

CMF knew that this software would be a boon to the metals fabrication industry. Battelle had recently developed a similar software system for Peerless Saw Co. to custom-design and cut industrial-grade circular saw blades, and the half-century-old Columbus, Ohio, firm was enjoying a surge of new business as a result. Peerless had traditionally designed the blades by hand, then cut them out of sheet metal by either punch-pressing or milling. The process was time-consuming, and because only a few custom blades were ordered at any one time, equipment setup time was often longer than actual production time. Peerless was losing business to modernized competitors until it came to Battelle for help.

Battelle's system enabled Peerless operators to graphically reconstruct the blueprint of a given part on a computer screen. The part's dimensions could be entered and stored on tape, along with cutting-path directions for Peerless's new laser cutting system. With the new system, Peerless was able to cut saw-blades in one-seventh the time it used to take, and Peerless also gained the flexibility to handle smaller, more-customized orders.

Impressed, CMF asked Battelle to design a similar software package for manufacturing custom-designed two-dimensional parts. The result was CADNC—the computer-aided design and numerical control system. The desired part is designed on the graphic display terminal from a blueprint, then CADNC calculates the coordinates and displays the design so it can be examined and edited immediately. The system then generates instructions to direct the manufacturing operation through either direct communication or punched tapes. Design and control information is stored on a disk for easy retrieval. CADNC is easy to learn, shortens design time, reduces errors, creates new designs, and modifies existing designs; it is now offered for sale by an EPRI licensee. Would-be users can receive training on the system from CMF.

Welding is another electrotechnology critical to productivity in the fabrication industries. There are thousands of weld applications in the metals fabrication industry and dozens of different means of welding. Oxyfuel gas welding, shielded metal arc welding, gas metal arc welding, electron beam welding, and laser beam welding are only a few of the choices. But individual fabrication companies, particularly the smaller ones, have had a difficult time getting reliable information on which welding techniques are best for their particular applications.

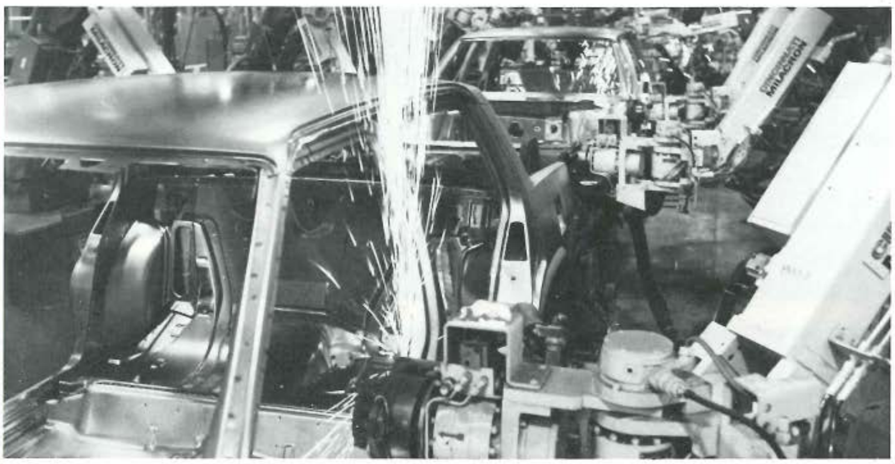
To remedy the situation, CMF has put together two brief and to-the-point welding guides. One describes the different welding processes available and the applications for which they are best suited; the other offers a simple procedure for estimating and comparing the cost of various welding processes. These guides have been enthusiastically received by welding companies, and CMF is now preparing two more guides—one on laser applications and another on visual inspection of nonstructural sheet-metal welds.

Keeping up with robots

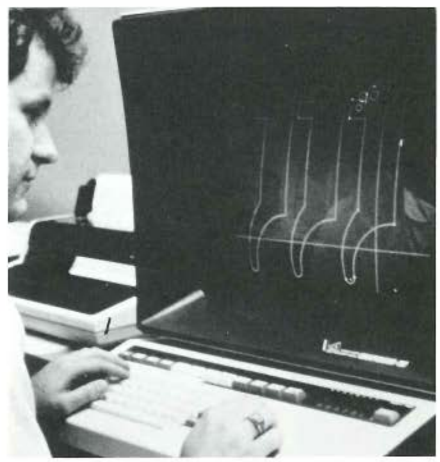
CMF has also been taking a closer look at how to speed up automated electric arc welding. Many manufacturers have invested in automated welding systems in an effort to reduce welding costs. The robots used by these systems could be capable of welding up to 400 in (10 m) a minute of metal. Unfortunately, the welding process itself lags behind the robots—the fastest it can go and still produce sound welds is 20–40 in (0.5–1 m) a minute. CMF has spent several months doing basic exploratory research for speeding up the welding process and recently succeeded in establishing sound welds at an increased welding speed of 180 in (4.6 m) a minute. CMF is now turning the research over to the Edison Welding Institute for further development.

Still another area of CMF research is induction heating. Many fabrication firms heat-treat metal parts, such as gear teeth and drill pipes, in gas-fired furnaces to strengthen them. However, the furnace heats not only metal objects placed in it but its own walls and atmosphere as well. A more efficient way of doing the job is induction heating. The metal object is placed inside a coil through which an electric current flows, and eddy currents produced by the magnetic field generated around the coil produce the necessary heat within the object. The process is extremely

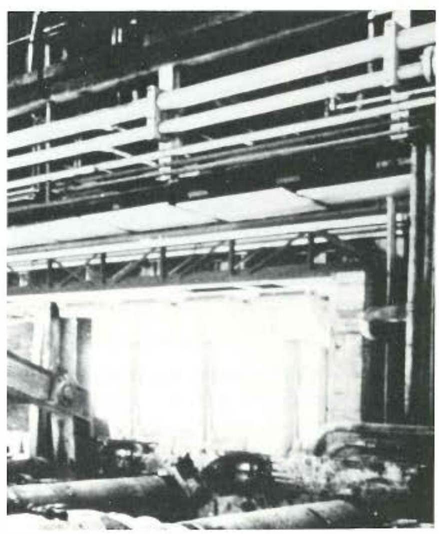
Robotics



Computer-aided design



Laser processing



Induction heating

The Center for Metals Fabrication was established in 1983 at Battelle, Columbus Laboratories with a budget of $1.6 million over three years. Its goal is to adapt new energy-efficient technologies to the metals fabrication industries—an industrial grouping that includes about 150,000 companies, most with less than 20 employees. Many of these companies have the potential for significant productivity gains, but have limited R&D resources and lack communication with suppliers of new technology. Processes being explored at CMF range from automation to heating, welding, cutting, and metal removal.

rapid and energy-efficient, but many potential users shy away from it because they are uncertain about the effects of induction heating on the metal properties. CMF has been investigating induction heating and plans to publish a book this year that will demystify the subject for interested users.

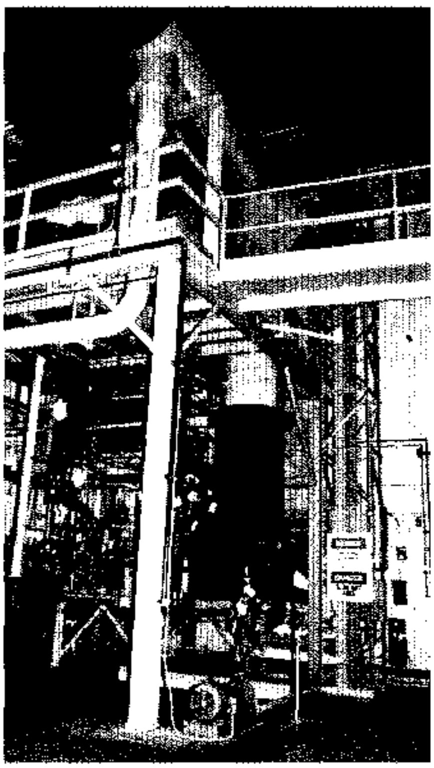
Computerized fabrication, welding advice, and induction heating data are only a few of the products coming out of CMF. Yet just as important as producing products is spreading the word on them, so CMF is pushing to get these results into the hands of companies that can use them. A new CMF program for 1985, called the Utility Subscription Service, is intended to do exactly that. For a yearly fee ($10,000 for EPRI members and $20,000 for non-EPRI members) individual utilities will receive assistance custom-tailored for the companies in their service area. CMF will host a metals fabrication seminar focusing on where electrotechnologies could meet the needs of local industry; provide the utility with an analysis of its metals fabrication customers; and assist the utility in developing industrial marketing programs.

In addition, CMF is establishing a telephone hot-line that participating companies can call for no-nonsense advice on electrotechnologies. "We won't send a big thick report to someone who needs information," pledges Byrer. "Nobody reads reports. We have to tell them what to do, not what to read." So far, the subscription service has about a dozen participating utilities, and more are expected to join soon. CMF is also actively seeking non-EPRI funding for future projects.

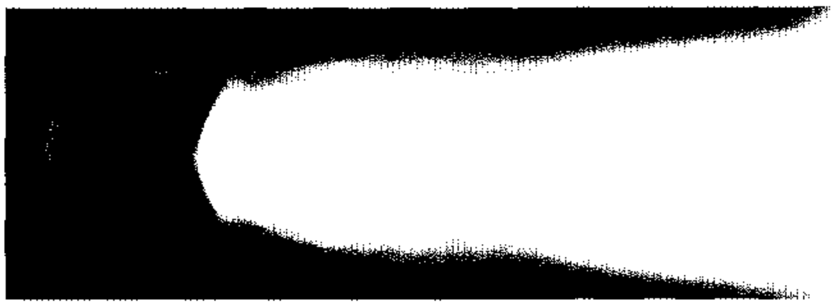
Second center

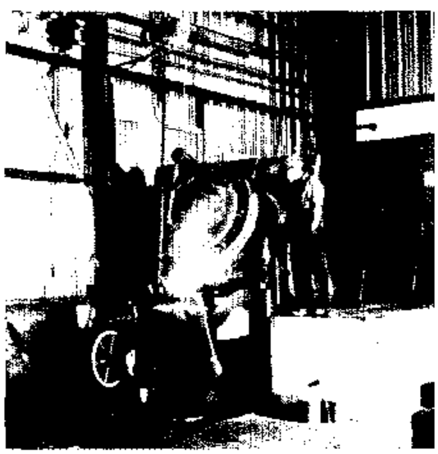
With CMF well on its way, EPRI turned its attention to a second electrotechnology R&D center serving an entirely different industry. The Center for Metals Production (CMP) was established in early 1984 at Mellon Institute, Carnegie-Mellon University, with a total EPRI budget of $1.9 million through 1987. CMP activities are directed at the steel,

Plasma cupola

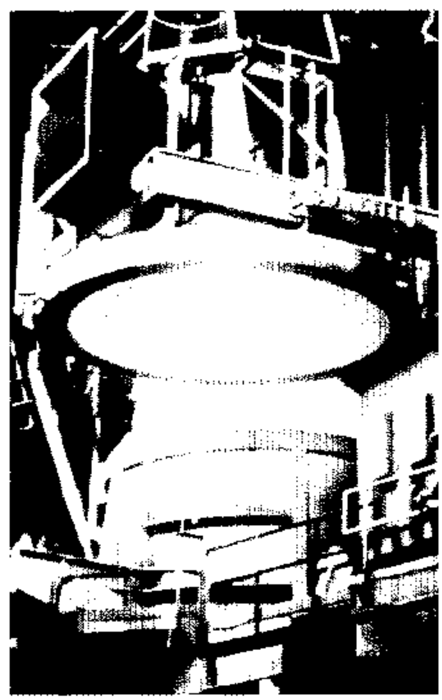


Plasma materials test





Induction melting



Electric arc furnace

The Center for Metals Production was established in 1984 at the Mellon Institute, Carnegie-Mellon University, with a three-year operating budget of $1.9 million. Its goal is to develop and transfer technology that improves the productivity and efficiency of U.S. companies engaged in the production of steel, aluminum, copper, zinc, and other primary metals. These tend to be large companies with aging capital equipment and high labor costs, suffering from worldwide market saturation of their products. Initial CMP target areas include reduction/smelting, refining/remelting, and surface conditioning.

THE INTERNATIONAL PRECEDENT

Collaborative R&D to advance the state and use of electrotechnologies is already practiced in Europe and Japan. In the United Kingdom the Electricity Council's Capenhurst Research Center was established in 1965 to explore new and improved methods of electricity distribution and utilization. With an annual budget of $10 million and a staff of about 300, the Center focuses on electrochemistry, electrometallurgy, and electrophysical processes.

In France the R&D center concept is embodied in Electricité de France's Les Renardières laboratory. Its development staff of 200 concentrates on the application of high-temperature processes (e.g., plasma and induction heating) to metals and materials, on agricultural and chemical applications, and on such areas as heat pumps and filtration.

In the Federal Republic of Germany much electrotechnology R&D is carried out at the Elektro-Wärmeinstut, which is sponsored by the RWE utility, the federal government, and various manufacturers. The institute has pilot plant capability for developing electric heating applications. R&D is also undertaken for industrial clients by Siemens Research Center.

In Sweden a nonprofit metallurgical and metalworking R&D center known as MEFOS was established in 1963. It has about 30 member organizations from the four Nordic countries; 50% of its financial support comes from the Swedish government.

In Japan the government, companies, and universities have historically worked in concert. Special areas of technology are selected by the Ministry of International Trade and Industry for national attention. □

aluminum, copper, zinc, and other primary metals production industries, which together consume over 40% of the United States' industrial electricity.

Like the metals fabrication industry, the metals production business needs new technologies to keep it competitive. Of particular concern are the steel and aluminum industries, which together make up three-fourths of the total electricity consumption within the primary metals sector. "The steel industry is suffering from aging capital equipment, high labor costs, worldwide market saturation, increasing market penetration of lower-cost imported steel, and increasing demand for higher quality product," explains Richard M. Hurd, center director. "The aluminum industry has been producing aluminum the same way for almost 100 years; the process has been refined a little over time, but it is still low in energy efficiency and high in capital cost. It's time for an overhaul."

But the metals production industry is fundamentally different from the metals fabrication industry, so the new center approaches things somewhat differently. Equipment and capital requirements for metals producers are typically much larger than for metals fabricators, so their research needs are usually more costly and longer-term. Not only that, but because these large corporations have their own R&D departments, even if they have been trimmed in recent years, their engineers have well-defined ideas about the R&D they need done.

As a result, the R&D going on at CMP tends to be on larger, longer-term projects actively pursued by industrial customers. A good example is CMP's first project on electric arc furnace improvements. Concurrent with CMP's formation, an industry trade association, the American Iron and Steel Institute, gathered funds from 20 steel companies to research possible arc furnace stability improvements. CMP provided matching financial support; shortly thereafter, the 20 companies joined with the new center, and the arc furnace study became CMP's first project.

Previous experiments had suggested that by injecting lime and argon through the electrodes, the stability of the arc in the furnace is increased. This in turn would increase productivity by about 10% and reduce furnace operating costs, among other benefits. CMP recently signed a contract with Sidbec-Dosco in Contrecoeur, Quebec, to verify the performance of these hollow electrodes on a 150-ton steel furnace. The project should be completed by April 1986.

Another area that steel companies are intensely interested in is how to dispose of electric arc furnace dust. This furnace by-product often contains the heavy metals zinc, lead, cadmium, and chromium and has been defined by the EPA as hazardous. Steelmakers capture the dust in filter baghouses but are unsure about how to dispose of it properly yet cost-effectively. CMP is conducting a review of current disposal practices and evaluating alternative practices, including treatment at some sort of central plant.

Centers still to come

EPRI is wasting no time planning yet a third center, the Power Electronics Applications Center. Industrial electricity users are beginning to discover that by carefully matching the quantity and quality of electric power (current, voltage, frequency, and phase) to the requirements of the end-use device (motors, lights, for example), they can not only use electricity more efficiently, but save wear and tear on machinery as well. Power electronic devices offer great promise in producing this im-

U.S. CENTERS FOR COLLECTIVE RESEARCH

Jointly funded research centers have become an increasingly popular way in recent years for American industry to remain competitive by speeding the commercial application of new technologies. Generally, such centers involve cooperation between a highly respected university, where innovation abounds, and several otherwise competing companies of the same industry, which have identified specific areas of research where cooperative effort is needed. Sometimes, various government agencies also played a key role in establishing centers for collective research, but such centers now often find themselves trying to make up for reductions in government R&D funds.

Some of the first centers were established as part of the National Science Foundation's Industry-University Cooperative Research Centers Program, which began in 1973. "There was lots of science and technology coming out of universities with no place to go," explains Robert Colton, an NSF spokesman. "Most of it was ending up in library stacks."

The purpose of the NSF program is to seed the establishment of collective research centers by providing approximately half the funds needed by each new facility, with the remaining support coming from private sources. After an initial startup period, which may last as long as five years, NSF funds are expected to cease and each center will then survive or fail on the basis of funding from the industry it serves. The Polymer Processing Center at the Massachusetts Institute of Technology, for example, is now well over a decade old and is entirely supported by private contributions. On the other hand, another of the early centers, devoted to research on making furniture, is now defunct.

Since the program's beginning, NSF has provided funds for about 20 centers, several of which are still in the planning stages. The fields of research range from telecommunications, signal processing, and computer graphics to biotechnology and materials handling.

Some cooperative centers have been established without the need for government initiative. Stanford University, for example, solicited funds from 18 corporate sponsors to start the Center for Integrated Systems. Later, however, the center was able to attract major government funding, including an equipment grant from the Department of Defense. Although CIS research concentrates on integrated circuits and artificial intelligence, the center's presence has helped provide its university home with substantial side-benefits, including eight new faculty positions and a 40% increase in graduate applications to the electrical engineering department.

Several states have also provided funds to establish research centers and related facilities that will draw universities and private companies into joint work. In the early 1960s North Carolina's Research Triangle Park was created with joint state and corporate support to attract companies into an area surrounded by three universities. After a few years of slow growth, the park began attracting investment from major high-technology companies. More recently, state funds have been used for the construction of a microelectronics research center at the park.

Not all state-funded research centers work alike. Some, rather than sponsoring research directly, act more as facilitators. The Wisconsin Innovation Service Center, for example, conducts surveys of technology innovations needed by the state's companies and then uses this information to evaluate the feasibility of ideas submitted by independent inventors. Using a somewhat different approach to a similar end, Virginia's Center for Innovative Technology surveys industry needs and then tries to match companies with the appropriate university researchers. The state also provides some direct funds for university-industry research.

Some industry-sponsored research centers do not involve direct university participation, but the availability of highly trained specialists is always a major factor in determining the location of such a center. For instance, when a group of 18 companies formed the Microelectronics and Computer Technology Corp. in 1983 to conduct collectively funded R&D, an extensive search was launched to find an appropriate site. Austin, Texas, was finally chosen, in part because the state promised to expand both faculty and facilities in microelectronics and computer science at the University of Texas and Texas A&M, as well as provide $20 million to build an office and laboratory for the center on university land.

Cooperation among universities, industry, and government agencies on collective research is by no means an exclusively American phenomenon. One of the reasons for Japan's preeminence in some technical fields is the collaborative effort directed by the Ministry of International Trade and Industry. Although MITI itself has sponsored relatively few research centers, its funding has served to strengthen other ties between private companies and various university departments. As international competition in high technology increases, more countries are likely to find collective research centers a promising way to help their industries get ahead. □

EPRI is now preparing groundwork for the **Power Electronics Applications Center,** which unlike CMF and CMP will focus on a particular set of technologies rather than a particular set of industries. The initial effort will be to explore the range of applications for electronic adjustable-speed drives for industrial energy savings and productivity enhancement. Further out, the application of power electronics will be extended to switching and precision control. The center's location, schedule, and budget have not yet been finalized, but the target date for opening is currently set for 1986.

Home appliances

Assembly line conveyor

Electric transportation

Escalator

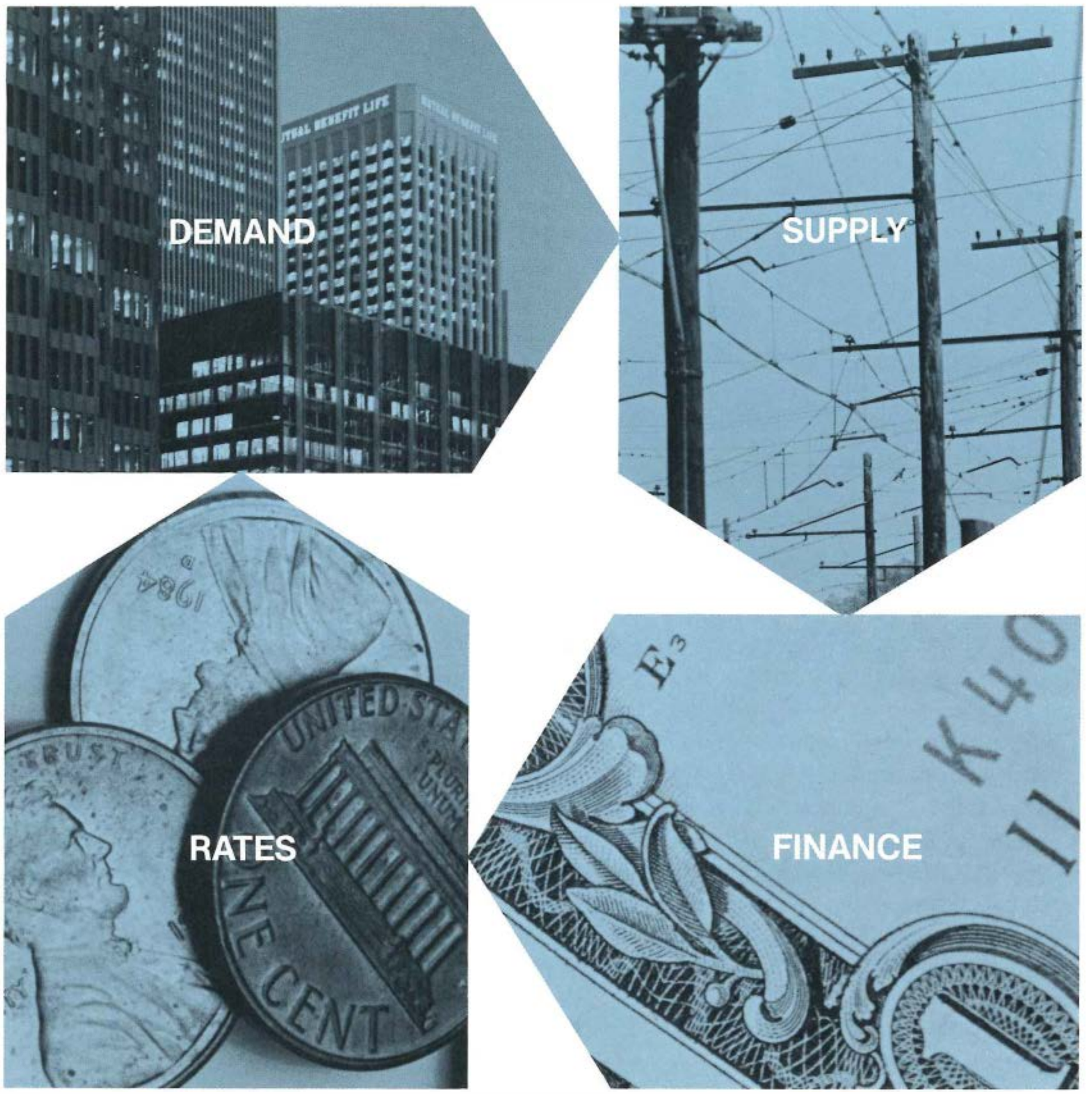
proved match between the electricity grid and the end-use device. But until recently, information on power electronics has been difficult to find; EPRI has intensified its work in the field in the past few years and is now making preparations for this center, which may open as soon as 1986.

Center location, schedule, and budget have yet to be finalized, but one of the first tasks of the center will be to more fully explore the benefits of electronic adjustable-speed drives (ASDs). Unlike other electrotechnologies, ASDs do not replace conventional processes; instead, they smoothly shift motor speed up or down to optimize power requirements of processes driven by fans, pumps, conveyors, and similar industrial equipment. Properly integrated with other controls into these motor-driven processes, ASDs can also enhance productivity and product quality. Motors account for about 60% of industrial energy use; energy savings of 20–30% are commonly found with ASDs, and up to 50% are possible in some applications, so ASDs should offer another option to industrial managers to leverage economic productivity. The center will address ASD applications for all kinds of industries, but ASDs are only a jumping-off point for the much larger world of power electronics, including switching and precision control.

Even with two electrotechnology centers ongoing and a third on the drawing board, EPRI is not slowing the effort to get new and improved technologies out into industry. "EPRI will be watching to see if other industries need centers like these," says Ralph Ferraro, head of EPRI's industrial program. To keep both American industry and the utility industry that supports it strong, it is important to develop up-to-the-minute technology—and use it. ■

This article was written by Nadine Lihach. Technical background information was provided by Ralph Ferraro, I. Leslie Harry, and Thomas Schneider, Energy Management and Utilization Division.

Testing Load Management Strategies



The integrated structure of the LMSTM code allows utilities to test the effectiveness of a full range of demand-side and supply-side alternatives and determine which strategy best fits their needs. Nearly 90 utilities have now acquired the code to assist in decision making.

Utility planning for growth in customer demand has undergone a dramatic shift in the past decade. Utility planners are increasingly looking into alternatives that will allow them to choose a portfolio of demand- and supply-side options to meet the customer's demand for low-cost, reliable service. The approach is called integrated planning, and it involves a number of possibilities. On the demand side the options are marketing programs, new rate structures, conservation programs, and even direct control of customer loads; on the supply side are pumped storage, new modular plants, bulk power purchases, and cogeneration.

Demand-side options can definitely influence the consumption patterns of a service area. But because the effectiveness of such management strategies are both utility- and customer-specific, utility decision makers are facing subtle and complicated problems in choosing among demand-side options and between a demand and a supply approach. Planners need tools to help them decide which of these strategies make sense for their particular situations.

To address the problem of evaluating integrated planning options, EPRI sponsored a project conducted by Decision Focus, Inc. DFI designed the load management strategy testing model (LMSTM) to efficiently and economically screen a full range of demand-side planning alternatives in the context of alternative supply plans. Among these are promotion of electric space heat, time-of-use rates, direct control of appliances, thermal energy storage, interruptible rates, and electrification of industrial processes. Teams of specialists from three utilities supplied technical advice and trial data. Later, two workshops with industry representatives ensured that the production version of the computer model would address the industry's needs. The final version of the model was tested with Public Service Co. of Oklahoma in an evaluation of four hypothetical demand-side planning strategies.

The most significant feature of LMSTM is its integrated structure, which is achieved by combining four different submodels—demand, supply, rate, and financial—into a single system simulation model. In addition to these four submodels, there is a fifth evaluation submodel to perform a cost-benefit analysis based on the forecasts of the four other simulations. Combined in a single package, the submodels provide a comprehensive view of the effect of a large number of integrated planning options.

The four basic submodels work together to represent a utility system and produce detailed simulations of alternative strategies in the following way. The demand submodel projects system loads in terms of customer class, end use (e.g., space heating or air conditioning), and various technologies within end-use categories (e.g., heat pumps, resistance heat). The submodel then simulates the effect of any pricing change on the demand for energy and daily load shapes. The detail and articulation of end uses make this submodel flexible enough to consider virtually any change in the daily load pattern. LMSTM's demand component also clearly differentiates between short- and long-range demand responses to rate changes. For the short run, the model shows changes in daily energy consumption and changes in the timing of the consumption. For the long run, the model shows demand changes that result from changes in appliance stocks, building stocks, and industry.

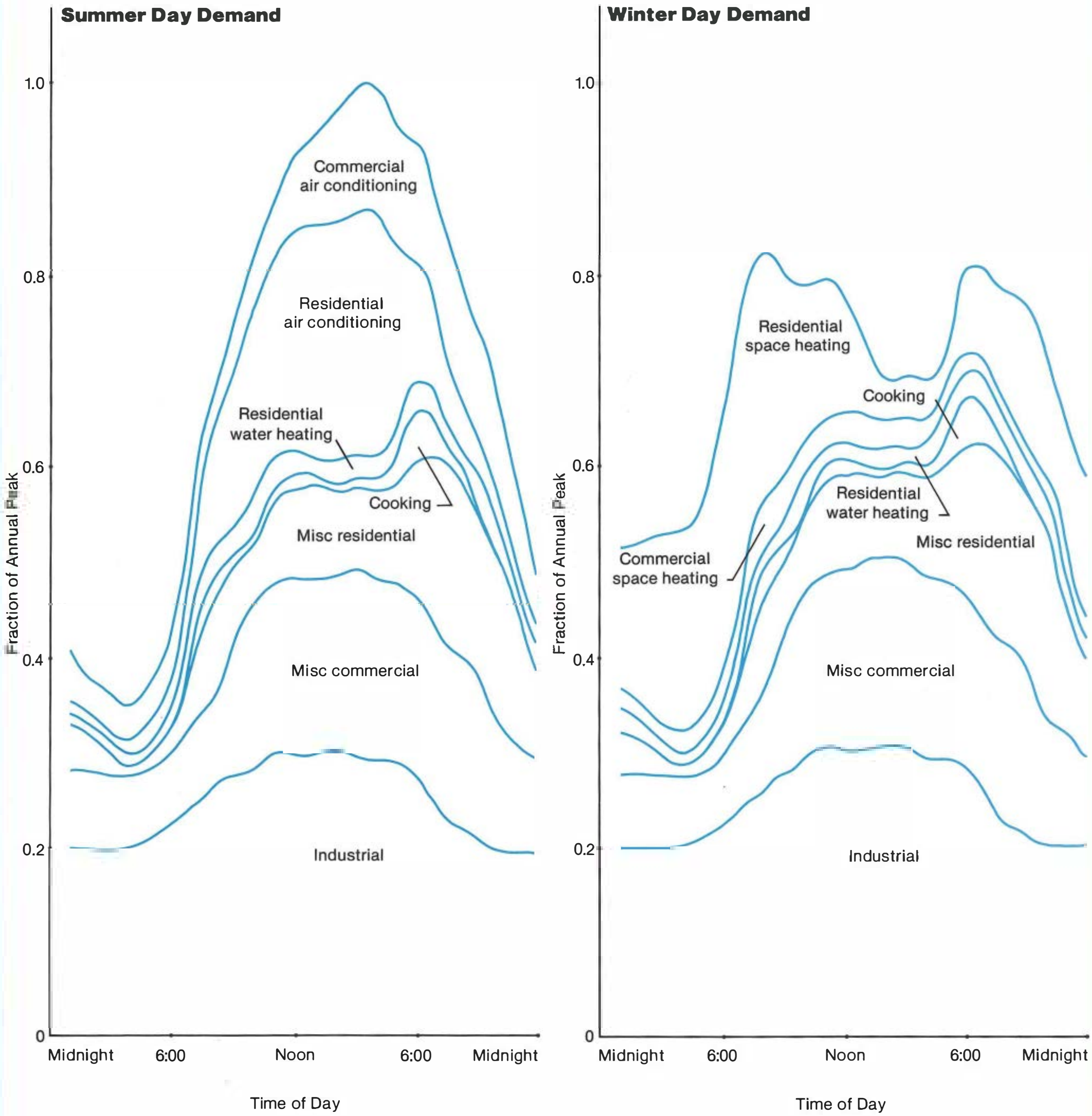
The supply submodel projects power plant operating costs but has been specially developed to account for the effects of load management strategies and devices. Direct load control devices and storage devices with a 24-hour cycle, such as water heaters, space heaters, and air conditioners, make an hour-by-hour simulation of demand and generation dispatch necessary. Previously available models were not considered adequate to evaluate such effects. LMSTM's supply submodel simultaneously dispatches thermal power plants, energy-limited hydro plants, pumped-storage units, and direct load control devices. In this way the interactions between load management options, thermal-unit availability, and central station storage are adequately simulated. With this innovative detailing of supply parameters, the submodel can include hourly operating costs, fuel use, environmental emissions, emergency actions, and operation of direct load control devices.

The rate submodel calculates prices and demand charges for each customer class on the basis of class demands, fixed and variable costs, and the rate design method selected by the model user. It is in the rate submodel that such load management rate options as time-of-day pricing are characterized. It allows the model user to examine different approaches to ratemaking, including the offer of rebates and credits for participation in load management programs.

The financial submodel tracks the effects of alternative demand/supply strategies on the utility's revenues, investment, and depreciation. This submodel is executed once during each annual cycle of the other submodels and generates a full set of income and balance sheets. The detailing of the financial submodel was considered necessary because adoption of demand- and supply-side options can involve patterns of investment, depreciation, and financing very different from those appropriate for supply-side strategies alone.

Once the simulation submodels have been run, the cost-benefit evaluation submodel takes the effects of the system predicted by those submodels and calculates the net benefits. The calculation includes a means of translating changes in hourly prices and consumption to changes in customer well-being, measured as customer surplus (the difference between what customers would be willing to pay for energy and services and the amount that they actually pay). Also included in the calculation are explicit trade-offs between monetary outcomes, such as cost of service, and nonmonetary

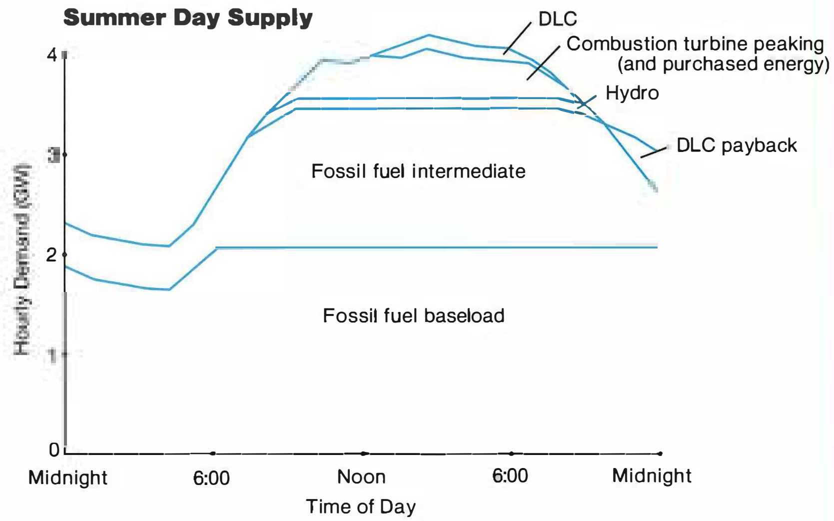
LMSTM generates the overall utility system load shape, as well as the layered components of daily demand shown in these summer and winter peaking examples. From such displays utilities can gather insight about the potential benefits of managing particular loads. In the North Central region, shown here, the single hump of summer peak day demand is driven by air conditioning; the characteristic double spike of winter weekday load, by space heating.



outcomes, such as outages. These benefit calculations are performed for each customer class as well as for the whole system. Comparison of the results with those of a base case provides a bottom-line evaluation of alternative strategies. The estimates are calculated for each year of the simulation period, typically 5–15 years.

Together, the system simulation model and the cost-benefit evaluation submodel constitute LMSTM. The flow of inputs, outputs, and data between the various submodels allows a comprehensive treatment of the effects of integrated planning options. The level of detail in evaluating strategies is adjustable and can be changed in response to data availability and the problem at hand. Most important, the model's integrated structure gives users an accurate and efficient means of exploring a wide spectrum of alternatives.

LMSTM calculates the hour-by-hour dispatch of power plants, taking into account minimum unit loads and startup costs in order to produce a realistic estimate of how much the costs of system operation can be reduced by direct load control (DLC) and storage. DLC yields economy because operating costs during peak hours are higher than during off-peak hours, when the energy is "paid back." DLC also improves the operating margin (and thus reliability) during peak periods.



After its development, LMSTM was reviewed extensively and tested by 10 companies. In one of the first uses, The Cincinnati Gas and Electric Co. put together a task force made up of representatives from its planning, engineering, production, and rate departments to do a load management evaluation based on direct load control of air conditioning and water heating, time-of-day pricing, and thermal storage. The model allowed the utility to observe the effects of simultaneous combination of direct controls and time-of-use metering. CG&E estimated that LMSTM saved them $750,000 in consultants, analysts, and programming time.

Perhaps the most significant savings, however, result from improved forecasts of program costs and benefits. In one instance, a water heater timing program was redesigned when LMSTM showed the timers were contributing to rather than reducing peak demand.

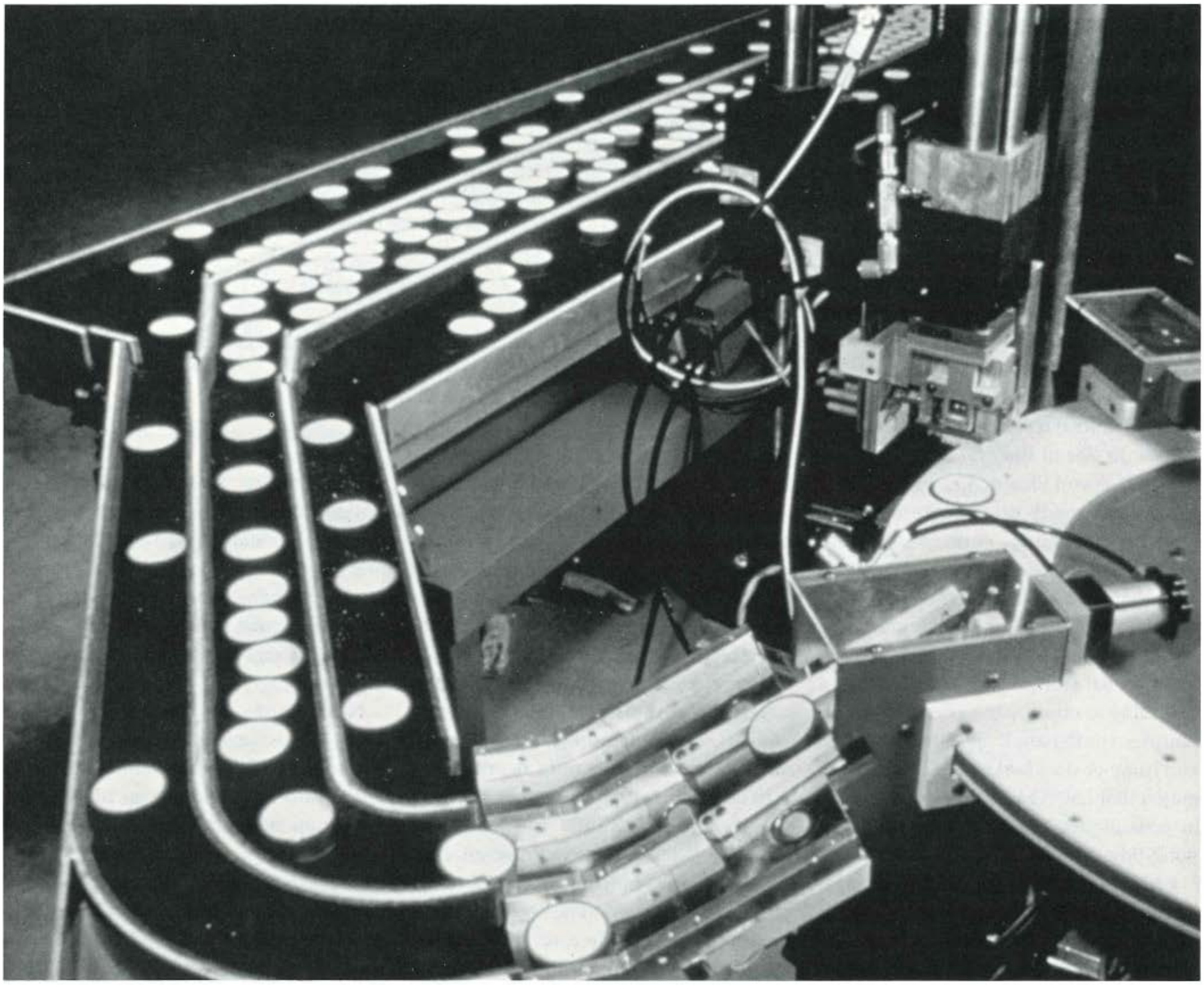
Currently, over 70 organizations are licensed to use LMSTM. One company has recently completed an analysis of company-sponsored appliance rebate programs designed to increase the penetration of efficient residential air conditioners, refrigerators, and electric water heaters. The company is now evaluating add-on heat pump programs with LMSTM. A second company used a customized version of LMSTM to evaluate the effects of price increases caused by adding nuclear construction costs to the rate base. Another utility is using LMSTM to evaluate demand-side planning options for regulatory hearings.

In addition to the companies licensed to use LMSTM, EPRI has sponsored several bellwether projects in an effort to accelerate the transfer of LMSTM to other industry users. The object of these projects is to provide a set of examples for planners throughout the industry. Four utilities participated: Boston Edison Co., Commonwealth Electric Co., Niagara-Mohawk Power Corp., and San Diego Gas & Electric Co. Integrated planning applications included a cost-benefit evaluation of residential and commercial load management and conservation programs; an evaluation of a capacity expansion plan that included demand-side options; the evaluation of marketing programs that included add-on heat pumps and special rate incentives to promote electricity sales; and the development of an expansion plan that included time-of-day pricing, interruptible service, and cogeneration.

Now firmly in the transfer phase, LMSTM has several support programs. Knowledgeable experts are available to answer users' questions; an LMSTM users group meets periodically to discuss applications; a newsletter is regularly published; and an electronic bulletin board is being used to distribute technical information and data. After extensive review and testing, LMSTM has proved to be a flexible, efficient, and powerful tool in helping utilities plan for an increasingly complex and challenging future. ■

This article was written by Stephen Tracy, science writer. Technical background information was provided by Victor Niemeyer, Energy Analysis and Environment Division.

SOLID-STATE SHUNT FOR OVERVOLTAGE



Metal oxide disks are the heart of gapless surge arresters, which switch faster, more reliably, and at consistently lower levels of overvoltage than gapped arresters. Originated under EPRI sponsorship 10 years ago, this new technology is now the commercial standard.

Thunder in the distance. Then rising wind and a gentle rain. Suddenly, lightning hits a power line and the lights go out. The lightning bolt has created a surge of voltage far exceeding what the line or any nearby circuit breaker or transformer can tolerate. This is one common scenario for a power failure.

Spectacular overvoltage like this does its damage noticeably and immediately. But even modest overvoltage can cut away at electrical equipment performance or life. And most utility apparatus undergoes some such stress whenever it is switched on or off in response to a change in electricity supply or demand. Whatever the cause of these electrical stresses, the results are reflected in maintenance and repair costs and, eventually, in electricity rates.

To reduce damage, utilities install surge arresters between potential overvoltage sources (mainly switching equipment) or carriers (power lines) and the equipment that is vulnerable to surges (transformers, inductive reactors, and gas-insulated substations). Arresters are connected so as to shunt high-voltage energy directly to ground.

Until recently the conventional arrester was made up of silicon carbide (SiC) blocks separated by gaps filled with dry air or nitrogen. The gaps hold off normal voltage (and even considerable momentary overvoltage); but beyond some design threshold, electric arcs bridge the gaps and the accompanying burst of excess energy is diverted to ground, dissipated as a large flow of current through the SiC blocks. SiC alone is called a varistor (for variable resistance), and the abrupt change of resistance with voltage is called nonlinearity.

Gapped arresters offer significant protection, but they have limitations. Their sparkover level is high compared with normal voltage, and they do not always respond quickly enough to such very fast transients as direct lightning strikes. Even during the fraction of a microsecond before sparkover occurs, the system can experience potentially damaging overvoltage.

Inconsistent operation is another problem. When current flows across the gaps of an arrester, it melts a portion of the electrodes, which thus erode over time and eventually become unreliable, switching over at different voltages or even ceasing to function. Moisture in the arrester housing produces the same effect—changing the voltage at which the arrester operates.

The switch to solid state

In their manner of operation, surge arresters are like the semiconductors that have become so familiar during the last 25 years. Indeed, by the mid 1970s manufacturers of televisions, stereos, and other electronic appliances and instruments were beginning to use metal oxide devices to protect their delicate equipment. Such solid-state materials seemed to offer the greater sensitivity and reliability that utilities needed in surge arresters.

However, metal oxides had never been molded into blocks large enough for utility application. No one knew whether they would exhibit the needed nonlinearity at the current and voltage levels of utility power systems. Also, would they tolerate repeated high-current surges? To answer these questions, 10 years ago EPRI selected two power equipment manufacturers, McGraw-Edison Co. and Westinghouse Electric Corp., to channel their knowledge and research talent into creating the largest metal oxide varistor (MOV) devices ever developed.

Today, nearly all U.S. utilities are buying the new generation of surge arresters that resulted. Manufacturers offer them in a full range of sizes and shapes; in fact, they no longer make gapped arresters for high-voltage (>69 kV) application. Gapped arresters are still available for distribution voltages, mainly as a matter of compatibility with extensive systems already in place and also because manufacturing capacity for metal oxide arresters does not yet equal the demand for them.

The drive for what became the MOV arrester sprang from a need for lower thresholds of response to overvoltage, faster operation, and greater reliability, all seen as ways to reduce maintenance and replacement expenses for utility transmission and distribution equipment. As researchers began to examine semiconducting materials, they found that metal oxides, in particular, exhibited the pronounced nonlinearity between nonconductive and conductive states that was needed for a utility surge arrester that would function without air gaps.

The keys to this advantageous property are the composition of the semiconducting material and how it is made. Zinc oxide (ZnO) is ground up with small amounts of other metals (e.g., bismuth, antimony, chromium, nickel, aluminum); this combination is referred to as metal oxide. After molding into cylindrical blocks, kiln firing at about 1200°C, and cooling, the metal oxide contains millions of tiny grains (primarily ZnO) surrounded by insulating layers (other metals). The insulating layers hold off voltage up to a certain level, but at and above that level they permit current to flow through to the ZnO grains and thus through the device.

Several projects, including two sponsored by EPRI, turned to the challenge of maintaining the necessary uniform firing and shrinkage while creating blocks large enough to handle high voltage. Many new formulations and firing techniques were the subject of experimentation, and even as early as 1976 General Electric Co. independently introduced a new series of gapped surge arresters in which the varistor element was ZnO instead of SiC.

Commercial introduction

In 1981 EPRI-sponsored researchers began field tests of prototype gapless ZnO blocks encased in insulating ceramic porcelain. Evaluations of 1200-kV MOV surge arresters by the Bonneville Power Administration and of 550-kV devices by the Tennessee Valley Authority conclusively demonstrated device capabilities. Soon thereafter, gapless MOV surge arresters became commercially available from both Westinghouse and McGraw-Edison.

It was apparent at the outset that the new generation of surge arresters would have to recover substantial investments in R&D and production tooling, yet their prices would have to be competitive if utilities were to accept them. Now, because of the lower labor content and reduced rejection rates of automated production, MOV surge arresters are being sold at prices no higher than the older devices. Shipping and installation also cost less because the gapless arresters are smaller and weigh less.

As desired, MOV arresters react to overvoltage faster than gapped arresters. There is less delay because there is no sparkover. Instead, the metal oxide insulating layers in the blocks sense the voltage rise almost immediately and they change to the conductive state more quickly and at a lower voltage level. MOV arresters typically begin conducting electricity at about 1.25–1.30 times normal voltage, rather than at 1.50–2.00 times normal as do gapped arresters. Protected electrical equipment therefore experiences overvoltage for a shorter time and at a lower level. This means that the basic insulation level (BIL) of other apparatus can be lower, yielding economies in the initial cost of equipment.

MOV arresters have proved to have much more pronounced nonlinearity than gapped arresters. Current leakage at normal operating voltage is negligible, a matter of only a few milliamperes; but at a predetermined voltage threshold the discharge rises quite steeply to thousands of amperes. The devices are also extremely consistent, responding at the same level of overvoltage every time and later ceasing to conduct at almost exactly that value.

EPRI and the manufacturers of MOV arresters expect significantly better long-term reliability from the devices than from their forerunners. The production sequence itself contributes to product reliability, as the metal oxide material must be scrupulously formulated and processed for uniformity, avoiding even the slightest impurity that might affect semiconductor performance. Machinery automatically tests, stamps, and sorts all devices.

The nature of the MOV material and the gapless design of the arrester eliminate erosion and degradation. And because a gapless arrester does not depend on a spark, only extreme amounts of water leaking into the molded casing can affect its ability to operate.

Payoff in practice

Some utilities have installed the new devices on a trial basis first. Thus, Alabama Power Co. established a project specifically to evaluate MOV arrester performance. One 34.5-kV substation feeder was fitted with conventional gapped SiC arresters, a similar feeder was equipped with MOV arresters, and their operation was compared through two lightning seasons. The data are not yet completely compiled and analyzed (the second lightning season ended in the fall of 1984), but William Dow, the utility's assistant manager of distribution, has sized up field opinion. "Our operating people feel the metal oxide arresters have done a great job of holding down system outages and equipment failures."

Alabama Power also gained an unexpected bonus, hitting on an attribute of MOV arresters that should be welcomed by utilities everywhere. The considerable radio interference often generated on the utility's 34.5-kV lines is absent from the line with metal oxide arresters.

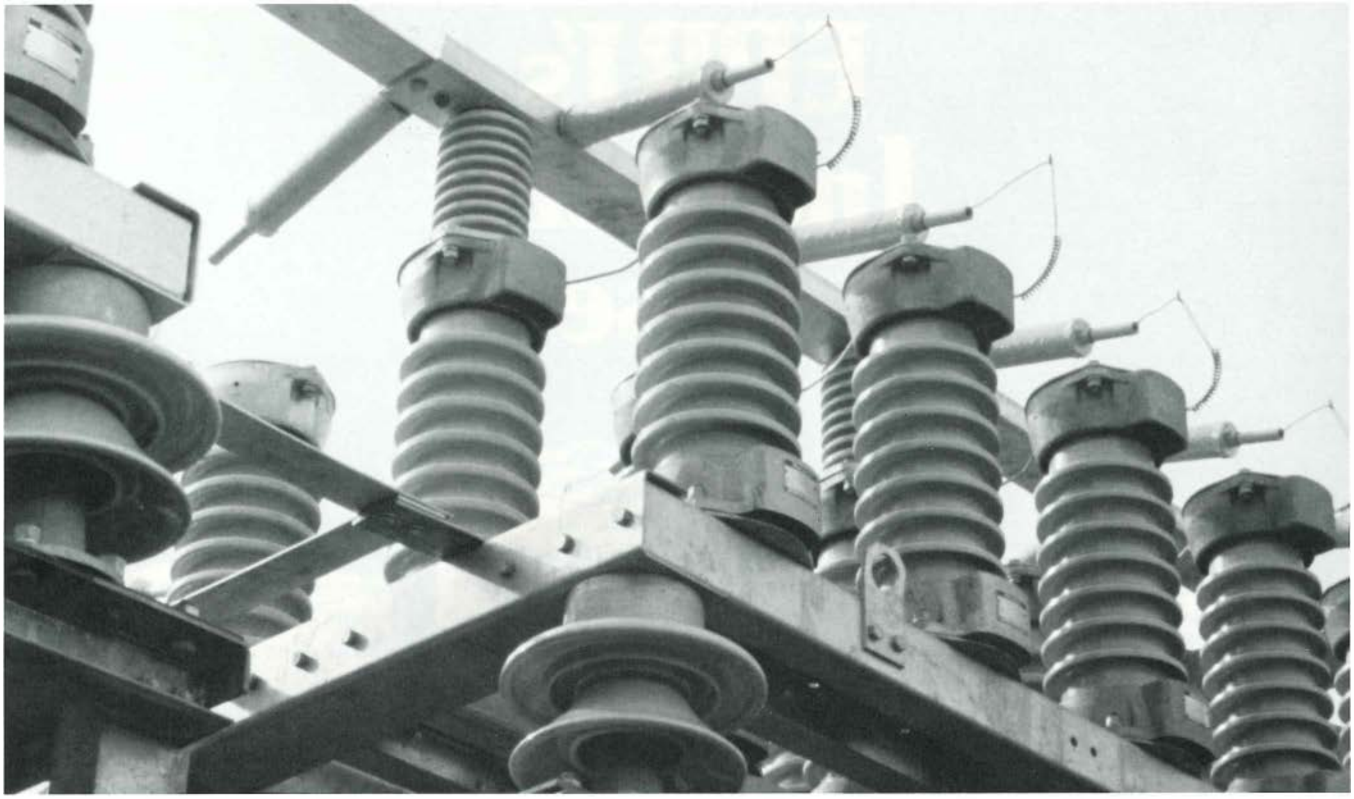
The utility had tried unsuccessfully to eliminate the problem (about which many customers had complained), even rebuilding sections of circuit, but without success. Now it can be deduced that minor sparking in the gaps of a few surge arresters somewhere (virtually impossible to isolate) was causing electrical noise to propagate throughout the nearby network, which thereby acted as an antenna. With MOV arresters: no gaps, no sparks, no noise.

Other utilities have avoided the cost of investments in other new equipment by installing MOV arresters. William Lannes, substation engineering manager for Louisiana Power & Light Co., explains that they were able to upgrade part of a substation from 115 kV to 230 kV without having to upgrade the BIL values from 550 kV to 900 kV. The upgrading was possible because of greater MOV sensitivity, precision, and reliability: faster response at a consistently lower level of overvoltage. Says Lannes, "We estimate that metal oxide arresters saved us approximately 40% on that project. We've had no problems with them, even after many lightning storms."

MOV surge arresters provide special economic benefits in underground and gas-insulated substations. For example, gapped arresters on underground circuits require a separate pad and enclosure to isolate and shield them. But gapless MOV arresters, insulated with epoxy and a carbon-painted grounded exterior, can be safely installed directly to the terminal connector of the transformer. Virginia Power is one utility taking advantage of this point. The utility estimates its levelized annual saving in revenue requirement to be approximately half a million dollars.

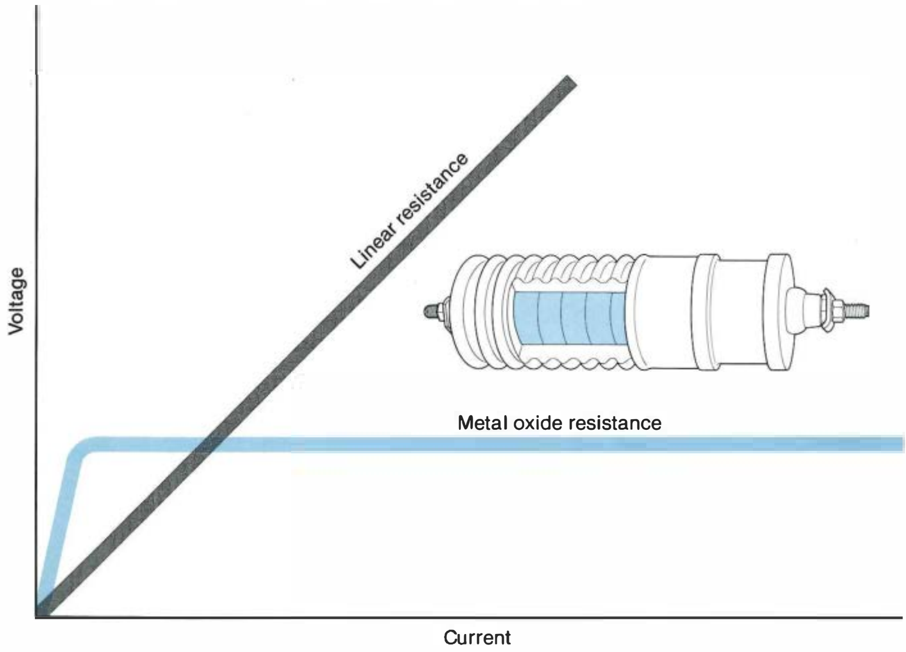
New frontiers of use

Utility use of metal oxide semiconductors is not ending with surge arresters. Manufacturers have already applied the technology to other transient energy absorption devices, such as series capacitor protection equipment, motor starter capacitors, vacuum interrupter switchgear, and capacitor voltage transformers. At this point, applications requiring high energy absorption capability need many metal oxide blocks arranged in parallel. EPRI will soon be supporting research to triple or quadruple the energy-handling



This application by the Bonneville Power Administration involves 96 metal oxide units connected in parallel for the protection of a series capacitor bank. The installation has a 15-MJ energy rating.

The novel feature of a metal oxide surge arrester is its variable resistance. Like other semiconductors, it holds off current flow as voltage rises up to a predetermined point; then it "avalanches," offering negligible resistance to current flow and thereby limiting (arresting) the voltage surge. The new slope of the curve is virtually flat.

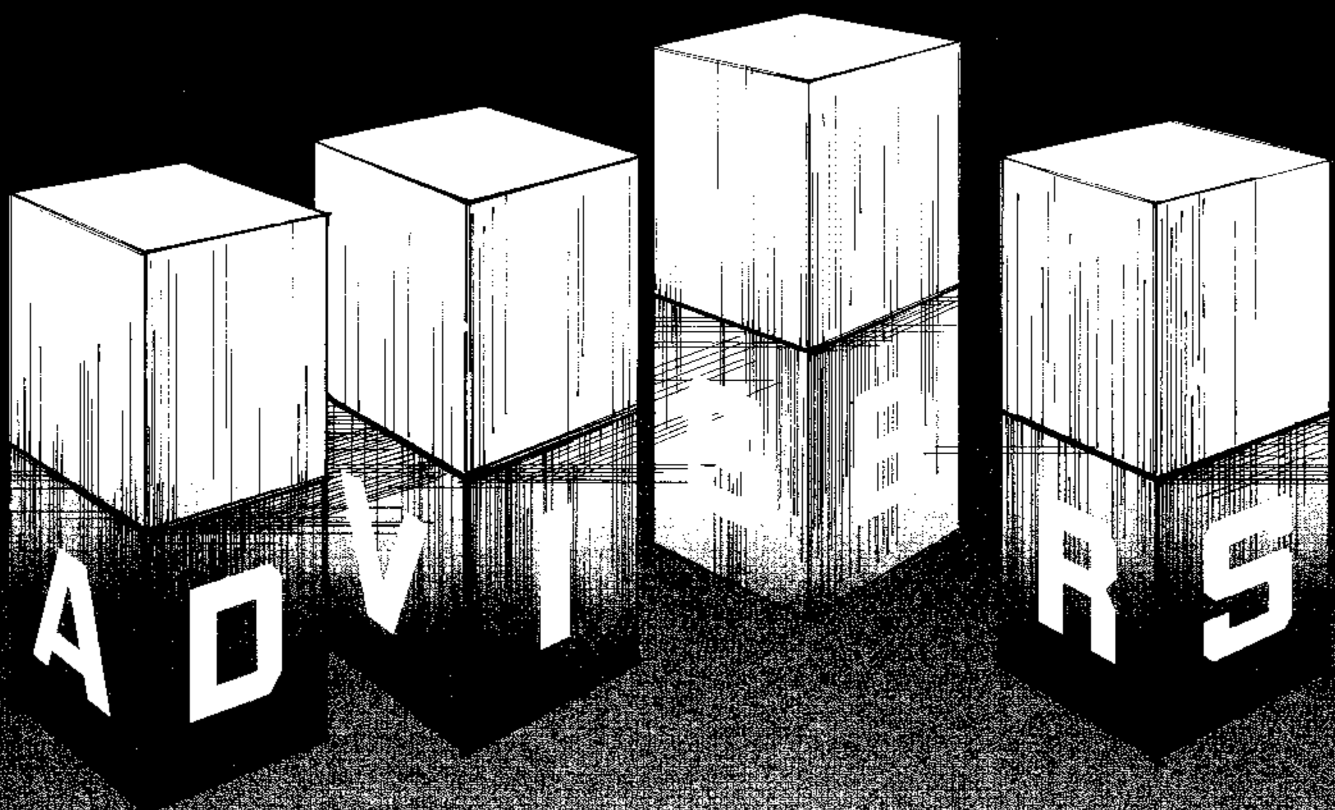


capability of metal oxide materials and thus make possible more-efficient device designs.

Vasu Tahiliani is EPRI's project manager for metal oxide technology. He predicts that if this endeavor is successful, it may open a new age of large-scale semiconductor-based protection devices during the next 10 years. He finds this prospect exhilarating. "It's a perfect example of how a small up-front investment by EPRI can stimulate the commitment of much greater resources by manufacturers and also arouse interest that carries the R&D concepts well beyond the scope of the original project. In the end, our seed money is repaid many times over." ■

This article was written by Christine Freeman, science writer. Technical background information was provided by Vasu Tahiliani, Electrical Systems Division.

EPRI's Industry Advisers



More than 550 representatives of 100 utilities are members of an advisory structure that directly reflects EPRI's management, division, and department organization. Their wide-ranging technical expertise and industry insight are essential in establishing R&D plans and priorities, monitoring the conduct of projects, and putting the results into utility practice.

The best thing I can say to a new member of an advisory committee or task force is, 'Get as smart as you can about EPRI—about its overall structure, its processes, its individual programs—get as smart as you can as fast as you can. Don't be afraid to speak up or to ask questions. Take an active part, because the reason you were selected is to provide advice and counsel.'"

That's advice from an adviser. You might even say an adviser's adviser, because Lawrence Papay has been a member of EPRI's Research Advisory Committee, its senior body of technical advisers, for all but two of the Institute's twelve-plus years of R&D operations. Formerly director of R&D for Southern California Edison Co. and now a senior vice president of the utility, Papay has been chairman of RAC, as it is called, since January 1983.

From start to finish, the spirit of Papay's advice is unassailable. The substance of it, however, can be looked at more critically. Because EPRI has three official tiers of utility advisers (and at least one unofficial one), Papay's call for detailed knowledge of EPRI and all its processes seems a little sweeping. By far the majority of some 550 officially organized advisers target their energies and attention on fairly narrow areas of R&D where their personal expertise is the key resource.

But Papay is insistent, and he draws the parallel of research planning in his own utility. "It comes down to the individual who proposes a project and argues for it with conviction, only to see it dropped from the final budget. The more that person knows and understands Edison's entire operation, the easier it is to accept what otherwise would be a personal defeat and still play an interested, effective part in the company's planning."

Papay's advice also emphasizes the manner in which expertise is delivered. He urges a dynamic process of lively listening, open questioning, and candid expression. His major concern may be that utility advisers get their messages across, but the process thus influenced is an exchange. It involves EPRI research managers and department and division directors just as much as it does their advisers. Two-way communication establishes authenticity. It builds acceptance for the advisers' input before research begins and while it is under way, and it builds credibility for EPRI's output when it shows up for adoption by those same advisers and their colleagues in utilities all over the country.

Advisory organization

EPRI's industry advisory structure is designed to parallel the Institute's own organization. RAC corresponds to and works most closely with EPRI's top management and Board of Directors. In turn, 6 advisory committees counsel EPRI's 6 technical division directors and their key staffs, and 18 advisory task forces help to shape the R&D conducted by individual research departments and programs.

Numbers are one thing that distinguish EPRI's body of industry advisers from that of any other industry or single institution. Among them, the 18 task forces total about 410 individuals, all selected for their expertise in one or another technical area of EPRI's overall program. Collectively, the approximately 550 industry advisers at all levels come from about 100 utilities, a solid 20% of EPRI's overall roster of members. This intentional breadth and depth of representation is without precedent.

Selected from candidates nominated annually by the chief executives of member utilities, advisers serve staggered three-year terms. There is no shortage of candidates; at least twice the needed number is proposed each year. Letters calling for nominations list the needed expertise, and nominations are for specific assignments—RAC, a particular divisional committee, or a named task force. That some specialties are hard to fill is indicative of functions only lately coming into utility organizations. Occupational health and industrial hygiene are recent examples; advisers were urgently sought last year for the Environment Task Force.

Selections for each group are made by the next higher group, and RAC members are chosen by the Board of Directors. Similarly, each chairman is appointed by the chairman of the next senior body and, if not already a member of that senior body, becomes one ex officio. The dual membership role of chairmen was intended to act as built-in piping for vertical communication between groups, but this has come to depend also on the temperaments of the individuals involved.

An early concern that small utilities could not compete in the technical qualifications of their advisers has been dispelled, replaced by the realization that representation from different types and sizes of utility is more important to a group's useful, credible function than expertise. It is increasingly apparent that heterogeneous membership is the first priority of committees as they select new advisers.

The professional makeup of the three advisory tiers is largely a matter of professional maturity and technologic breadth; the differences match those of the counterpart EPRI staff bodies they serve. RAC identifies industry R&D needs in broadest terms and monitors EPRI's overall program to ensure that its balance and priorities serve those needs. Its lines of communication are mainly with the Institute president and vice presidents, including the technical division directors, and, of course, with the Board of Directors.

RAC also considers technical policy issues, as necessary, and manages the subordinate tiers of the advisory committee structure. Two standing subcommittees, Planning and Evaluation and Membership and Procedures, lend continuity to RAC's efforts; and a third, Exploratory Research, was recently named for advisory service to a new program organized apart from any single division responsibility.

The divisional committee composition closely parallels that of RAC but with a narrower purview. Each committee works most closely with an EPRI division director and his key staff, and it is concerned with identifying and meeting R&D needs within that division's responsibility, as well as dealing with related technical policy matters. Major communication links are upward with RAC and downward with two or more task forces.

Task forces differ sharply from the other advisory groups; they embody much more specific technical expertise. It is their strong point and purpose in counseling EPRI staff. Their members may be in on the formulation of research program plans, the recommendation of funding, and the subsequent conduct and results of the work—at least, in a summary fashion. Task forces also are the point of interface between EPRI's official advisory structure and another, unofficial hierarchy of some 1200 individuals (also mostly from utilities) who work still further down and whose loyalties are to even more specialized activities.

Meetings and schedules

As an ideal, EPRI's advisory groups were foreseen by RAC to have no more than 20 members each. But the pressure and diversity of EPRI's program workload today have pushed the membership a little higher on all but three groups. It is not a case of allowing numbers to compensate for absences. Committees meet three times annually on a strict schedule, and advisers who miss two meetings in succession can be asked to reconsider their commitments.

Meeting agendas, as well as dates, must accommodate the annual cycle of EPRI program and budget planning, a process that produces a specific overall program for the ensuing calendar year and simultaneously updates a rolling five-year plan. Thus, between January and March task forces and divisional committees begin a new cycle, working with their counterpart EPRI groups on preliminary R&D strategy and program content for the following year. RAC formulates strategy at its March meeting, providing additional guidance for Institute management, R&D planners, program managers, and their advisers during the ensuing months.

A round of advisory group meetings begins in May with task force consideration of program proposals. These go on to the divisional committees, which consolidate and trade off recommendations received from staff and task forces. Action by RAC in July produces a preliminary R&D program plan, the basis for detailed plans and budgets. Another advisory round in the fall yields the final recommendations that are sent jointly by management and RAC to the December meeting of EPRI's Board of Directors.

As was particularly noted for task forces, EPRI's industry committee members advise staff research managers on the selection of R&D projects. Their degree of approval authority is a subject of recurring misunderstanding. Projects are endorsed by the task forces, but approval authority for the most part rests with EPRI's president, delegated there by the Board.

However, if a proposed project is not in the current year's plan, has a lifetime price tag of more than $5 million, or has a seemingly unresolvable issue, it must undergo divisional committee review and then be submitted to RAC. If the only irregularity is a project's absence from the plan, RAC has the final word. However, projects above $5 million or with still-unresolved aspects must also go to the Board.

Despite the seeming lockstep of advisers' meeting dates and agendas, and despite the necessary limits on their authority, advisory groups exhibit great variety in their makeup, work mode, and spirit. This variety is traceable partly to the personal styles of chairmen and division directors and partly to technical practices and industry traditions. EPRI's Electrical Systems Division, for example, has an advisory committee and six advisory task forces—one for each of six programs (instead of one for each of two departments). Going back to the organization of cooperative utility research before EPRI existed, this arrangement reflects the long-standing specialization of R&D in transmission and distribution.

Two-way technology

When EPRI's organizers conceived the idea of an advisory structure to be drawn from its utility membership, technology needs were topmost in mind. Technology input and technology output were the advisers' purposes. Men and women would be the messengers, but technology, pristine and self-evident, would be their message.

EPRI urgently needed authentic information from utilities about what technology they needed, in what priority, according to what criteria, in what regional or other variations, according to what economic rationale. Unmistakably, industry input was not to be an incidental; EPRI would rely on it and was organized accordingly.

Along with the size of the industry advisory structure, EPRI's intentional, purposeful use of it was and is unique. *Reliance* is no figure of speech. EPRI needed specific expertise for each technology under consideration. The advisers make for authenticity in R&D activities, and they give first-line credibility to the results. EPRI's advisory structure thus is a far cry from an optional consumer advisory panel or occasional market consultant.

Although technology output was acknowledged to be a matter for advisers, the manner and ramifications of their messenger service were not as completely thought out. The process nuances of technology transfer were not anticipated. EPRI was envisioned mainly as a wellspring of options. Research results would issue forth in report form for utilities to draw upon, selecting according to their needs and interests. This vision of a library of technology options is changing.

Today the need is growing for more and better means of technology transfer —from the pages of EPRI reports into the minds and practices of utility people. The one-on-one credibility of individuals is becoming recognized as fastest and most authoritative, and teams of EPRI staff members and EPRI advisers—past and present—are thus the principal technology transfer channels.

EPRI's advisory structure is easily seen in terms of boxes on an organization chart. But more important today is a continuous, multidirectional human endeavor, an advisory process. And this is not too easily seen by advisers, even by some experienced ones, or by their utility colleagues who know EPRI only from a greater distance.

Even today, "EPRI? What's that?" is not an uncommon query. It is a consequence of EPRI's being a wholesale entity, one that does not deal with the general public. In fact, EPRI is not automatically or easily seen even by employees of electric utilities, which range from local enterprises of as few as 10 people to holding companies with a half dozen or more operating and service companies that generate and distribute electricity to millions of customers scattered over several states.

The situation provokes comment from Louis Elsaesser, assistant to EPRI President Floyd Culler and manager of advisory affairs (self-termed "mother hen" to all the groups). Elsaesser endorses the sense of involvement and cooperation that pervades EPRI's advisory groups while they are at work. He acknowledges that these attributes of mood and spirit, more qualitative than functional, are the foundation of trust and integrity.

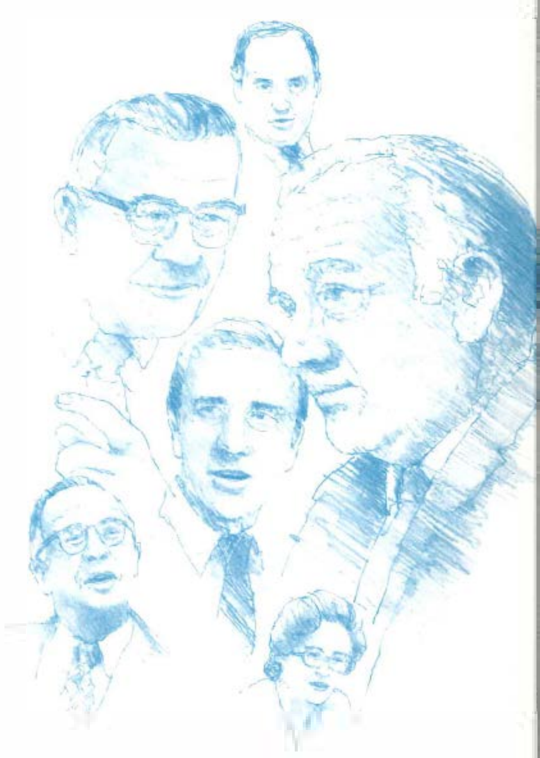
"But," he adds, "it's still too often the case that advisers begin and end their roles with the opening and closing of each committee meeting. They seem to forget that they know things that people in their utilities don't know, yet need to know. It's as if there were two different worlds. Too often they don't see their role as emissaries."

Help is on its way. EPRI's avowed reliance on its industry advisers is gradually being matched by the utilities' equally purposeful reliance on them. Although utilities in the past did not systematically debrief their EPRI advisers, more are doing so today. Partly, the motivation is to know and guide their advisers' contributions. But in the main, it is to extract technology insights and decide their own next moves toward adoption of new technology or practice.

Also, the view of advisory responsibility as simply incidental to an individual's technical duties is coming to be less frequent. Utilities are starting to see advisory performance as a part of professional duty and subject to evaluation accordingly.

All this is an evolution in industry thinking. One EPRI research manager, himself a former utility employee, recalls the traditional sequence in which his utility sought new information in technology. "The very first thought was to look inside, even if this meant throwing the question to a junior engineer and turning him loose in the library.

"Second would be to go to equipment vendors, and next would be a system supplier like General Electric or Westinghouse. Then, if the problem still didn't yield, a call would go to a local university engineering professor. In this chain of thinking, it would be a long, long time before we thought of going to another utility or, in today's terms, to EPRI."



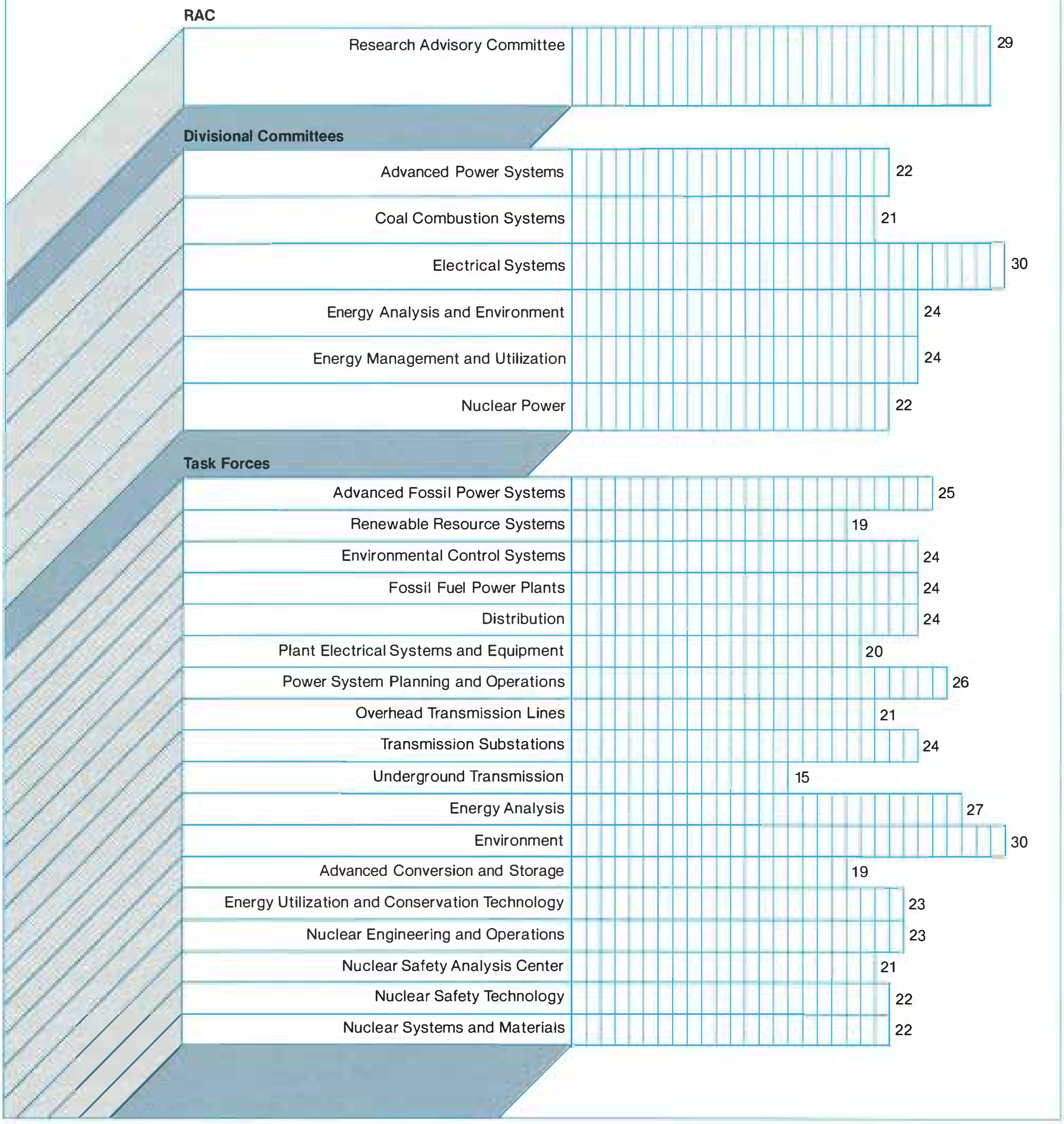
Another evolving value is appreciation of the research process, especially its dependence on the collection, analysis, and dissemination of data. As utilities themselves, through EPRI, become more involved in the R&D that unlocks new technologies, they are finding it easier to understand and value the laborious and voluminous prominence of data in the effort.

The adviser-EPRI relationship

Elsaesser's work with advisers goes back well before EPRI's beginning. In the early 1970s he was with the Edison Electric Institute, trade association of the investor-owned utilities, as director of research. He thus held responsibility for liaison with utility representatives on several power research projects then being funded by EEI or by an industrywide group, the Electric Research Council. Elsaesser specifically recalls the misunderstand-

THE INDUSTRY ADVISORY STRUCTURE

Two-way communication flows between EPRI and its member utilities via the utility advisers on these 25 committees and task forces, who work closely with research managers at each level of EPRI's organization—the executive office, technical divisions, and departments and major programs. Numbers vary as advisers come and go according to their three-year terms, but in the spring of 1985 there were 557 individuals in 581 positions. (Each advisory group chairman, except the RAC chairman, is an ex officio member of the next-senior group.)



ings that arose when EPRI assumed responsibility for that ongoing program and instituted a different definition of the advisory role.

Utility representatives for EEI and ERC had actually been responsible for managing their research projects. Advisers for EPRI (often the same individuals to begin with) would conform to a more literal interpretation. Some early relationships were stormy, the advisers clearly being senior but needing to relinquish control as EPRI staff members took charge in their stead.

If there ever was a time when cosmetic factors played a part between EPRI and its advisers, it was then. EPRI, after all, was unfamiliar with many utility practices, among them the economic and reliability analyses on which R&D feasibility hinged. Unintentionally (but understandably) defensive on occasion, some research managers were seen as impatient, even arrogant—"as though we weren't really convinced we needed advisers," Elsaesser recalls. In trying to ease the tension, other staff members were sometimes overly indulgent of advisers. But the necessary learning took place on both sides, so that mutual respect and candor are the rule today.

Other practices of EPRI's earliest days have been tenaciously retained by its advisers. Elsaesser points, for example, to the review of proposed projects. "We were trying to staff up and commit funds at the same time. It was easier to pick research when you had more money than you could effectively commit. I think it's to our credit that neither EPRI nor its advisers tried to see how much they could commit without seeing that it was done well. In fact, we were seen by some as stashing money away, which was a problem all its own!"

Elsaesser contrasts that time to recent years, when EPRI's R&D budget has been virtually flat (in constant-dollar terms), forcing advisers, as well as research planners and managers, to sharpen their pencils and make many more hard choices. "I think advisers are even more valuable today—and they have a tougher job—because there is much more research to do than there is money to support it."

Hard advisory choices are not matters of money alone. There is inevitable competition among projects and technologies. An R&D topic may indeed be of more value in one or another region of the country, or of value only to large utilities (or small ones), to utilities in growth areas, or to utilities having relatively heavy plant investment in transmission and distribution. Because there are so many factors by which to categorize utilities, very few of them are truly alike in their R&D needs, and there isn't evidence of bloc advisory action. Instead, technical expertise and individual judgments prevail.

If there is any institutional influence on any adviser, it is likely to be that of his or her own utility, not of the utility's category. One utility, for example, has more than a dozen advisers on various EPRI committees and task forces. Periodically, those advisers convene for their own review of EPRI's progress in their respective areas of interest. Each adviser gets input and insight from the perceptions of the others. To some extent, then, the result of their sharing is a consensus in the value and interest of a technology to the utility.

The number of a utility's advisers also reflects its desire to get its money's worth from EPRI membership. Such a utility methodically reviews EPRI's entire program to pick out the technologies in which it most needs improved capability. It then nominates its best people in all those specialties for advisory service. Their competence fulfills the Institute's purpose of cooperative value, and their participation gives the utility direct, timely, and thorough access to the results.

How advisers advise

Competence may account for an adviser's selection, but how, in fact, does the advisory process take place? What encourages it? What threatens it? The answers are probably no different from those for other deliberative bodies, professional groups, or even neighborhood gatherings.

Acquaintance and (often) friendship initially generate permission and eventually produce candor. The same factors of acquaintance and friendship can also inhibit, should advisers fall into patterns of personal or professional protection. But nearly everyone to some extent fits the joking description of a consultant—that is, an ordinary person away from home—with the consequent sense of detachment that produces free expression of opinion. Advisers' opinions are frequently and explicitly from "our plants," "our managers," "our service territory," or "our state" (and sometimes from "the economy") but not obviously from an adviser's personal bias.

EPRI advisory groups function for the most part on a nominally parliamentary basis, requiring at least a simple majority vote for official expression or a course of action. But it is a toss-up whether the advisers or their counterpart EPRI research managers are quicker to withdraw a contended issue for reconsideration, rather than proceed on the strength of a narrowly won vote. As a rule, a near-consensus is achieved.

Because advisers meet as a body only three times a year, they have a continuous burden of homework, especially in preparation for meetings. Even so, meeting agendas include presentations by EPRI staff as a common and current basis for the give-and-take that produces advisory action. An observer would question whether everyone listens attentively at all times or needs to. But let the speaker inject a funny remark and there is a universal chuckle in response. They listen!

An EPRI adviser's assignment, although it may be a sideline, is not a small duty. Simply attending meetings accounts for nearly three weeks annually, travel included. Then there is homework, plus whatever interim EPRI contact may arise. For some individuals, there are advisory subcommittee duties; and for chairmen there is participation as a member of the next senior group. The direct advisory involvement with and for EPRI can easily account for 10% of an adviser's time; and that says nothing of the time devoted to helping others in his or her utility.

Advisory meetings were cut from four to three per year in 1982, for travel cost economy and efficiency. At the same time, however, they were lengthened from 1½ days to 2½ or even 3 days each. This change dealt successfully with a complaint that meetings were too short. Now, in addition to the inevitable action agenda required to move the annual planning process along, the groups have time for open discussion and original thought.

Absences are not a problem, at least not repeated absences of the same advisers. In general, attendance runs about 85%, which means 17 of 20 advisers. And the advisers quite routinely complete their terms. According to Elsaesser, practically all resignations result from individuals' leaving their utilities or being assigned to utility duties that have no connection with the advisory assignment.

Such loyalty might encourage low turnover of advisers—the same interested people being selected to succeed themselves. But the RAC all but prohibits reappointments and, accordingly, they are infrequent. What is becoming more frequent is the progression of advisers through successive task force and division advisory capacities, perhaps to a post on RAC. This is possible because of past turnover and the consequent availability of candidates with advisory experience. All else being equal, a selection group will go for such experience, but it is not a prerequisite. For example, an unusual viewpoint may be more useful than conventional credentials.

Whatever may be the days, hours, and duties of an EPRI industry adviser, the pay is terrible. Zero. Each adviser's utility incurs essentially all the costs of participation. EPRI pay for advisers has never been an issue, but on at least two occasions the question of expense-sharing has been considered. Both times it came before EPRI's Board of Directors, and both times the Board said no. It is important that no member utility have any basis to doubt the loyalty of an adviser. There must be no possible sense that EPRI and a utility are competing for an adviser's services and viewpoint.

The occasional headaches

There are what Elsaesser gingerly calls areas of turbulence in the relationships of EPRI and its advisers. By and large, they are inevitable eddies, which recede before special attention and then form again with the replacement of individuals in the advisory structure.

For example, "It doesn't matter what we do, because EPRI staff will override us anyway." This sentiment is always present somewhere among the advisers, according to Elsaesser, and its converse sometimes arises in the research staff. Both result from the difficulty of clearly distinguishing between advisers' endorsement and approval of proposed research. A 1984 Board-sponsored review of EPRI's effectiveness took firm hold of this point, stating " . . . advisory groups should recognize that their role is as the term implies—advisory. . . . The Board of Directors holds the EPRI staff responsible. . . ."

Then there is the length of an adviser's term. "It's too short. Should be four, even five years. There isn't time to follow through with a project that you've helped initiate." There is no satisfactory answer for an individual here. EPRI's 1984 effectiveness review concluded that (for the next several years, at least) the term must continue to be based on the needs of the process and the industry, such as wide participation, fresh viewpoints, and freedom from advisers who were not good choices.

Questions occasionally arise about EPRI's unofficial advisory groups, too. This lower tier of technical aid (also entirely volunteer) was foreseen when EPRI began, but its organization and conduct were not prescribed by RAC. It was thought that most groups would be ad hoc, brought into being only occasionally and for short assignments. Also, it was anticipated that they would make a point of including the nonutility expertise—universities, manufacturers, other research bodies—that was precluded from the official industry advisory structure.

Today, however, unofficial advisory activity involves its own 1200 individuals, most of them permanently organized in a well-defined hierarchy (program committees, subprogram committees, and working groups) that is regularly convened and accorded considerable authority. Some task forces (the governing bodies in most cases) restrict participation in these subgroups to member utility personnel, even to members of the task forces.

Elsaesser has watched the evolution with mixed feelings. He regrets the inflexibility, especially where nonutility advisers are prohibited. "They're missing the whole point," he says. On the other hand, he admits that the nonuniformity of the groups and how they are used may be less of a problem than is sometimes seen. "The question is, do they get the job done? That's what counts most, after all."

Credibility is success

The fits and starts of EPRI's advisory groups are minor in the context of what they are and do. Counting all levels, including the unofficial hierarchy, they total nearly 1700 individuals. They bring an awesome range of electric utility interest and expertise to bear on the industry's R&D agenda. By and large, they are effectively organized. And they are learning to communicate more thoroughly upward and downward in their own ranks.

What Elsaesser calls the emissary role of advisers must be seen more clearly, both by the individuals concerned and by their utilities. There is an expanding body of R&D output from EPRI, bought and paid for by its members, that will take its application momentum from the personal authority of enthusiastic, inquisitive, and talkative advisers far more than from the weight or thickness of any published report.

The extra length of advisory meetings since 1982 is a timely and valuable move. Because there is so much that could be done with available funds, programs are being ever more structured, organized, analyzed, and prioritized at each EPRI staff level. In such a well-defined context, it is easy for an advisory group simply to react to the documents on the agenda of a given meeting in the planning cycle. However, with scheduling so that task forces and divisional committees meet back-to-back or have a day of overlap with each other, there is opportunity for initiative, conversations on new topics, and new approaches to the R&D task.

RAC, for example, has convened twice in recent years in workshops that featured facilitated discussion (virtually brainstorming on one occasion) as a means of quickly bringing perceptions of strategic issues to the fore. Without enshrining the technique, RAC Chairman Papay has welcomed the experiments for their value in stimulating RAC, encouraging what he calls proactive participation. "It's valuable to get into the process at the front end," he says. "Otherwise, there is easily a feeling of seeing things only after they're all done and cast in concrete or, these days, in hard plastic," he adds with a smile.

From Papay's vantage point of a dozen years as an EPRI adviser (plus service on the interim Research Priorities Committee that preceded RAC), he concludes that the venture is a success. He feels personally rewarded by EPRI's advancement and maturation from a time when, he says, "All of us were clumsy—advisers and staff members alike." For Papay, the number one evidence of EPRI's success is its credibility with the utility community.

As one looks ahead, whether a day or a decade, it is easy to agree that credibility has opened a door and is holding it open. But a trained troop of dedicated emissaries is now required to pour through the door and put the new technology to work. ■

This article was written by Ralph Whitaker. Background was furnished by Louis Elsaesser, Assistant to the President.

New Method to Assess Weather Effects on Electricity Sales

A new method is available to help utility analysts build more-precise models for assessing the effect of weather on utility sales. Weather normalization is a recurring problem for utility analysts—regulatory agencies often require normalized data for test years in rate cases, and financial analyses depend on normalized data to filter out the effects of weather on a company's financial status. Under EPRI contract, Cambridge Systematics, Inc., and Queri surveyed and tested normalizing techniques used by several utilities. From this experience the contractors developed a five-step approach to constructing normalization models that involves an advanced new technique for detecting time-variation in weather sensitivity. Several utilities have already used the method with success; one, Puget Sound Power & Light Co., reports saving at least $67,000 by avoiding the need to perform such a study on its own. ■ *EPRI Contact: Ahmad Faruqui (415) 855-2630*

PCB Screening Kit Saves Virginia Power Time and Money

Every time transformer oil hits the ground we have to treat it as PCB-contaminated oil no matter how large or small the spill is." So said Albert N. Kirksey of Virginia Power. But now a new test kit allows field crews to test spilled oil for PCBs on the spot, saving time and money. The test kit is named Clor-N-Oil, and it was developed by General Electric Co. under an EPRI contract. The test is easy and cheap to use—effective enough that after experience with it in the field, Virginia Power estimates it will save $124,000 per year in laboratory time, work hours, disposal costs, and paper work. ■ *EPRI Contact: Vasu Tahiliani (415) 855-2315*

Btu Recovery Boosted 12% Through Better Coal-Cleaning Circuit

The group of utilities that owns the Conemaugh generating station in Pennsylvania became concerned that its coal-cleaning plant was rejecting material that still contained economically recoverable energy. At the Florence Mining Co., which provides coal for the Conemaugh plant, a study of the existing air table cleaning apparatus revealed that considerable fuel could be recovered by redesigning the coal-cleaning circuit. To determine how much additional energy was recoverable, the proposed circuit was tested at EPRI's Coal Cleaning Test Facility in Homer City, Pennsylvania. These tests established engineering tolerances for improving Btu recovery from the previous 60% to an expected 72%. The total saving represented by this new fuel recovery and coal-blending capability will be on the order of $5 million per year. ■ *EPRI Contact: Clark Harrison (412) 856-7120*

Guidelines Identify Best Wind Turbine Sites

Guidelines developed by EPRI to aid in selecting sites for wind turbines can help utilities avoid some of the problems that arise from site-specific studies. After conducting a number of such studies, Seattle City Light (SCL) found it had to take a more broad-based approach that would employ widely recognized assessment methods. "We wanted to use the EPRI guidelines because we realized they would give us a valid data base that would be acceptable to everyone involved," says SCL's director of energy resources planning, Al Yamagiwa. The guidelines, based on research by Battelle, Pacific Northwest Laboratories, include methods for identifying the best wind resources of an area, selecting potential sites, screening sites in terms of development costs, and narrowing selection of preferred sites by detailed economic analysis. SCL estimates that it has saved about $40,000 by using the guidelines. ■ *EPRI Contact: Frank R. Goodman, Jr. (415) 855-2872*

Boston Edison Saves $1.2 Million With Boiler Tube Program

New instruments and measurement techniques are helping Boston Edison Co. make dramatic improvements in boiler performance at its New Boston generating station. Recurring tube failures in the once-through subcritical boilers at the station prompted a detailed failure analysis of the tube system. Sponsored by EPRI and conducted by Delian Corp., the study led to two operational changes: the present chordal thermocouple system was expanded to permit accurate monitoring of temperature changes and gradients within the boiler tube system; and a new tube failure mapping program was initiated, using a minicomputer to keep track of tube failures, locations, and causes. With increased monitoring capability, Boston Edison operators were able to establish new startup procedures, minimizing thermal stresses and reducing tube failures in boiler tubes. The failure-tracking program, which made the failure analysis study possible, allows Boston Edison to carry out preventive maintenance by pinpointing known problem areas and weak spots from earlier tube failures. Together, the programs are saving Boston Edison an estimated $1.25 million annually in maintenance and replacement power costs. ■ *EPRI Contact: Anthony Armor (415) 855-2961*

IPS Restores Precipitator Performance With Sodium Conditioning

Soon after the George Neal station, Unit 4, of Iowa Public Service Co. (IPS) began operation, performance of its hot-side electrostatic precipitator deteriorated to well below its design level. As a result the plant had difficulty meeting the federal New Source Performance Standards (NSPS), and IPS was faced with the possibility of having to convert to a cold-side precipitator at an estimated cost of $10 million. To avoid this contingency, the utility considered the experience of Gulf Power Co., which was cooperating with Southern Research Institute in an EPRI-sponsored test of sodium conditioning to improve precipitator performance. On the basis of this experience, IPS found that adding sodium sulfate or sodium carbonate to the coal at Neal-4 would bring operation of the unit's precipitator well within NSPS and thus avoid the expensive conversion. ■ *EPRI Contact: Ralph Altman (415) 856-7120*

Regional Study Reduces Fuel Market Uncertainties

The usefulness of most fuel market studies for the utility industry has been limited by their national viewpoint or fragmented information. Now a regionally based study of interfuel competition, sponsored by EPRI, reduces many of the uncertainties in fuel market forecasting. Conducted by Charles River Associates, Inc., the study focuses primarily on competition between oil and gas in the Gulf, Central South, and Southeast states. In addition to identifying critical national fuel trends, the study takes into account such local characteristics as generation facilities, transportation, and demand growth. System Fuels, Inc., the fuel subsidiary of the operating companies of Middle South Utilities, Inc., used the study to gain insight in developing its 10-year fuel strategy. Besides the potential long-range benefits resulting from the study, the company estimates that it has been able to avoid the additional time and consultant fees that might have been needed to reinforce in-house studies and conclusions. ■ *EPRI Contact: Jeremy Platt (415) 855-2628*

Better Cable Insulation Cuts $70,000 in Repairs at APS

Arizona Public Service Co. (APS) keeps close watch on cable insulation quality and is ready to confirm that a new technique for controlling contamination in insulation materials has dramatically improved insulation quality and saved APS $70,000 in repair costs in 1983 alone. The new method, developed by Reynolds Metals Co. and subcontractor Food Technology Corp., uses an electro-optical device to spot contaminated polyethylene pellets during cable insulation production. The detector triggers an air-jet system that blows the bad pellets out of the process stream. Result: higher-quality cable insulation, fewer cable faults, and less money spent replacing cable in the field. APS estimates even higher savings to come as the new better-quality stock replaces the old cable. The new equipment is currently in use at two of the Reynolds cable plants. Union Carbide Corp. uses it for quality control in polymer pellet production. ■ *EPRI Contact: Bruce Bernstein (202) 872-9222*

KCP&L Extends Pole Life by One-Third; Saves $1.6 Million

Detecting and controlling fungus-induced decay in wood poles is no small matter for utilities. For Kansas City Power & Light Co. (KCP&L), reliable information on detection and treatment methods is worth $1.6 million per year. That's what KCP&L estimates it will save by extending pole life by one-third, to an average 40 years. KCP&L is launching a new testing and treatment program based on information gathered in two EPRI-supported projects. The first, carried out at Oregon State University, studied decay patterns and fungicide effectiveness for Douglas fir and western red cedar poles. The second, with State University of New York at Syracuse, extended the project to include poles made of southern pine. Together the studies provide maintenance data for three of the most common wood poles used in utility transmission and distribution systems—a real benefit to KCP&L, which has all three types in its 200,000-pole network. ■ *EPRI Contact: Robert Tackaberry (415) 855-2301*

Nationwide Standards Help Electric Utilities

The National Bureau of Standards' Center for Electronics and Electrical Engineering provides measurement services to help utilities meter power accurately, improve operating efficiency, and minimize equipment and system failure.

Established by an act of Congress in March 1901, the National Bureau of Standards (NBS) is the nation's measuring stick. The bureau not only defines the basis for this country's physical measurement system but also provides measurement-related scientific and technologic services for government and industry and ensures U.S. involvement in domestic and international standardization.

An agency of the Department of Commerce, NBS comprises a variety of centers performing specialized testing and design functions. Standards and measurements for electric utility power equipment are developed in the Center for Electronics and Electrical Engineering (CEEE). Of the five divisions within CEEE, two are located in Boulder, Colorado, and three are at the bureau's headquarters in Gaithersburg, Maryland. Utility-specific research is carried out in the Electrosystems Division at the headquarters location. There, researchers seek improved techniques for measuring electric power and energy, study fast high-energy transients, and determine the quality of electrical insulation. Robert E. Hebner, a physicist by training, manages the Electrosystems Division's high-voltage test facility where these power equipment test standards are evaluated.

Hebner explains that high-voltage research has been a focus of CEEE for some time, but when NBS moved to Gaithersburg in the late 1960s, the old high-voltage laboratory closed. However, in the early 1980s a leaner high-voltage test facility opened to address a wide range of electrical measurement needs, including those of utilities. Says Hebner, "It is a small laboratory—intended primarily for NBS use—where utility equipment tests and measurements can be qualified."

A group of 20 researchers work under Hebner at the laboratory. Currently, his budget is $1.5 million. Although acknowledging that the NBS allocation for this program has decreased, Hebner explains that his facility gets other support. "The Department of Energy has always had an active program in electric energy systems, and it has provided us with some additional funding for the past several years. This is not an unusual situation, as NBS gets 40–50% of its funding from other agencies. We have also had an ongoing project to develop a system for calibrating capacitive voltage transformers that is jointly funded by NBS and EPRI."

Hebner notes that much of the research at CEEE directly supports the utilities, their equipment manufacturers, and—ultimately—the consumer. "In fact," he comments, "some of the oldest records we have found here are in the area of meter reading. NBS wanted to make sure that utilities were metering the use of electricity fairly." As a result, NBS calibrates all types of meters to be certain that the measurements are accurate. Utilities, in turn, calibrate their customers' meters, using standards calibrated at NBS.

NBS also sets the standards and calibration measures for the large-scale voltage and current transformers that utilities use in power plants and substations. "The calibration of meters may be the simplest and most visible service to the utilities and their customers that we perform," says Hebner, but adds, "We also have a great deal of other research going on that is more complex." As an example, he points out that another aspect of the center's work is to provide the measurement support needed to assess the effect of lightning on a utility system.

Hebner

Lightning Impulses

"Lightning is a very strange creature with no set habits. It can produce very high currents in an extremely short time or can just as easily produce a low current over a longer time," Hebner explains. Utility managers know that lightning is going to strike their lines at some point and that voltage and current impulses will be introduced into their systems. Because utilities need to know how their equipment will respond to such a shock, researchers in the high-voltage laboratory simulate the effect of lightning on utility equipment.

Because it would be impossible to test for the entire range of voltages that can be introduced by lightning, national and international standards specify a single test waveform (the standard lightning impulse)—a voltage pulse that rises in about 1.2 μs and is about 50 μs to half value. Using it, manufacturers can perform laboratory tests on the transformers, capacitors, and lightning arresters that utilities buy to install on their systems. To ensure quality, each piece of apparatus is tested according to its own standard to determine what its failure criteria are. Special care is taken so that the life of a device is not degraded by the testing.

It is also not uncommon for manufacturers to call on the high-voltage laboratory to perform corroborating measurements, Hebner reports. "We can go there and calibrate in situ up to a million volts on a standard lightning impulse." He tells of an incident when the laboratory was asked to confirm manufacturer results. "When lightning arresters were changed from gap arresters to zinc oxide arresters, the performance characteristics also changed. As a result, the voltage wave shape that was formerly used as a measurement for gap arresters took on a different form. This caused the manufacturers to question their own measurement systems, and they asked the laboratory to help them verify their measurements."

The development and maintenance of an accurate base for measuring utility power equipment allows lightning's effect on equipment to be predicted before the devices are put into use; this prevents possible failures and blackouts and saves time and money for utilities and their customers.

Transient Voltage

CEEE is also investigating reliable ways to measure transformer insulating materials to see how they withstand rapid voltage rises, such as those caused by a lightning strike. Insulating materials can be solids (paper), liquids (oil), or gases (air), or any combination of these. By creating a transient voltage with a standard lightning impulse generator, NBS researchers can test insulating materials with as much as a half-million volts. As a result of these tests, researchers are able to evaluate insulator performance, as well as the accuracy of the test equipment.

Hebner explains that utilities have a keen interest in how well gas insulation performs because of the many gas-insulated substations recently built or being considered. These substations use a gas, such as sulfur hexafluoride, to insulate transformers, high-voltage cables, and switches. "The study of gas insulators is really fascinating," Hebner says. "We use a nanosecond-range transmission line, which is a long, tubular device that allows transient voltage to be studied under controlled situations. This new device is an order-of-magnitude improvement in the testing of high-voltage dividers used in pulse power systems." Hebner expects that this research will result in more-effective insulation, as well as an understanding of how existing insulation can perform more reliably.

The CEEE staff conducts research on liquid insulations as well, measuring the electric fields in insulating oils to determine which oil samples are going to fail at what stress levels. A complete understanding of the effects of such parameters as temperature and space charge has not yet been achieved. The laboratory staff is also examining new techniques for comparing voltage and current measurements, techniques that employ new fiber-optic equipment like electro-optical and magneto-optical devices.

"It would not surprise me if, within the next 5 to 10 years, optical sensors or fiber-optic communications became the norm in gas-insulated substations," Hebner predicts. "The development of fiber-optic technology has just exploded, and it will almost certainly have some application to utility systems. Utilities are now using electrons and wires, but before long, their measurement equipment will rely on photons and fiber optics."

In addition to its work in fiber optics, the CEEE electrosystems staff is also researching system performance problems caused by low-frequency electromagnetic interference and is involved in measuring electromagnetic field emissions.

Electromagnetic Fields Measurement

Using funds provided by DOE, over the last nine years NBS has maintained a program to measure electromagnetic fields and ions from high-voltage transmission lines. The program also provides technical support to biologists who are working on the question of whether biologic health effects may result from contact with these fields. NBS staff has played an important role in this research, developing standards to ensure that measurements are made consistently across the country.

By initiating a modeling program that determines how these measurements should be used, CEEE researchers have also helped to stabilize the measurement process. "As a result, we participated in the development of voluntary standards, published articles, and held tutorials to explain to those involved in the research process exactly how these measurements should be taken. And we published a primer for biologists to give them the information they need for actually taking these measurements." An international standard is now being developed, Hebner continues, that will ensure that people worldwide are measuring electromagnetic fields in the same way.

"I believe there are approximately 10 million research dollars a year being spent by DOE, EPRI, and New York State on the biologic effects of electromagnetic fields, and we work with all these groups to make sure they measure the electric fields properly. That is our only role; we are not involved in any biologic research or in the preparation of any regulations."

Also as part of the electromagnetic fields program, NBS is preparing measurements on direct current. Direct current transmission produces ions, a phenomenon that does not occur in ac transmission. Thus, standards are needed to measure these ions, and there is a CEEE program to provide the standards. This research is especially necessary because of the increasing number of dc transmission lines being built in this country to carry high voltages more efficiently for long distances.

To test the accuracy of the equipment used for dc transmission readings, CEEE researchers have erected a scaled-down version of a dc power line. The instruments now under study include electric field meters, Wilson plates (for measuring current), and ion counters. Ion counters, which measure the ion density in air, are used by scientists studying the biologic effects of ions, as well as by industries interested in controlling ion density to prevent static electricity in their industrial processes.

Others Use CEEE Laboratory

A test facility like the measurement laboratory is a valuable resource for utilities, equipment manufacturers, and federal agencies. NBS receives many requests from outside organizations to accept guest workers at its laboratory. To meet these requests, NBS has set up an industrial research associate program, where industry representatives spend time at the bureau to work on projects of mutual interest. At the present time, NBS is host to 155 research associates, who work alongside the NBS staff.

"Currently, we have four research associates at the high-voltage laboratory," Hebner states. "Two representatives from Exxon Research and Engineering Co. and two from ASEA Electric in Waukesha, Wisconsin. We would welcome applications from utility personnel who wish to work with us in the laboratory."

There is a good deal of interest from equipment manufacturers in sending their personnel to the NBS facility as well, because even though there are other electrical test laboratories in the country, NBS is the leader in exploring the fundamentals of electrical measurements. And the NBS fundamental measurements become the standards that other laboratories and equipment manufacturers ultimately adopt. As Hebner notes, "It is our job to develop the best measurements possible because our standards will be the yardstick against which all others will be measured." ■

This article was written by Christine Lawrence, Washington Office.

EPRI Board Names New Officers

The head of a metropolitan utility and the president of a rural cooperative are elected to top positions on EPRI's Board of Directors.

Hauspurg

Cleveland

Baker

Arthur Hauspurg, chairman and president of Consolidated Edison Co. of New York, Inc., was elected chairman of EPRI during the annual Board of Directors meeting held April 9, 1985, in Washington, D.C. Named as EPRI's vice chairman was Robert N. Cleveland, president of Buckeye Power, Inc.

Hauspurg began his career with Consolidated Edison in 1969 as a vice president and was later named a senior vice president before being appointed executive vice president and chief operating officer in mid 1975. He became president in October 1975 and assumed the title of chairman in 1982. Hauspurg has served as vice chairman of EPRI since April 1983, when EPRI members elected him to a second four-year term.

President of Ohio Rural Electric Cooperatives and Buckeye Power since 1977, Cleveland is also their chief operating officer. The two groups act as service organizations for Ohio's rural electric cooperatives. Previously, Cleveland was executive vice president and general manager of the North Carolina Electric Membership Corp.

Another utility executive, James O. Baker, was newly elected to the Board to represent EPRI member municipal utilities and rural electric cooperatives. Baker, general manager of The Middle Tennessee Electric Corp. of Murfreesboro, succeeds George H. Usry III, general manager of the Athens (Tennessee) Utilities Board.

Baker started as an electrical engineer with Middle Tennessee Electric in 1965. He was later appointed director of operations in 1975, assistant manager in 1979, and general manager in 1980. He is actively involved in the electric utility industry at the local, state, and national levels.

In addition to Baker, EPRI members also reelected four other Board members to four-year terms: Theodore J. Carlson, chairman of the board and principal officer of the Central Hudson Gas & Electric Corp.; John W. Ellis, president and chief executive officer of Puget Sound Power & Light Co.; John J. Hudiburg, president and chief executive officer of Florida Power & Light Co.; and Sherwood H.

Smith, Jr., chairman of the board and chief executive officer of Carolina Power & Light Co. EPRI's Board of 15 directors represents investor-owned utilities; rural electric cooperatives; and municipal, regional, and federal public-power agencies. ■

Technical Information Center Offers Access to EPRI Data Base

EPRI's Technical Information Center maintains a telephone service to assist those seeking information about EPRI activities and research programs. Dialing (415) 855-2411 between 6:30 a.m. and 4:45 p.m. (Pacific time), Monday through Friday, puts callers in touch with EPRI information specialists who answer specific technical questions on EPRI research projects.

Fielding nearly 800 inquiries a month, the information specialists help callers search the Electric Power Database, the EPRI Publications Database, and other special public files. They provide information on EPRI-sponsored workshops or seminars, on published EPRI reports, and on publication dates for EPRI technical reports. The specialists can also connect callers to EPRI project managers and to the order desk at the Research Reports Center, and they can forward mailing lists or technical interest profile changes to staff members within EPRI.

To carry out their assignments, the information staff maintains a variety of computer data bases and special files for storing and retrieving this information. For example, the Publications Database is available on-line for all technical reports, computer codes, and other selected publications issued by EPRI. It provides a descriptive record that includes the title, abstract, project manager's name, publication date, research project number, and keywords for each publication or code. And since August 1983, the one-page summaries that EPRI publishes to highlight the major information contained in each technical report have been input directly into the data base, making it an on-line file for all report summaries. The Technical Information Center also keeps a data base of speech citations and seminar papers presented by EPRI staff. Copies of the full speech or paper, which are retained in the technical library, are available on request.

Of major importance to information seekers is the Electric Power Database (EPD), which contains summaries of both ongoing and completed research projects conducted by EPRI, the Canadian Electric Association, U.S. and Canadian electric utilities, and various research organizations concerned with developing electric power. An EPD record includes a project's title; its contractor; its current, past, and future funding status; a project description; subject headings and classifications identifying which research areas are emphasized; and any publications resulting from the work.

On-line access is available to users outside EPRI through the U.S. Department of Energy's RECON system, through Dialog Information Services, Inc., and through the National Research Council of Canada's CAN/OLE System. For information about accessing EPD or to request a data base search, call the Technical Information Center hotline number. ■

International Source-Term Experiments to Be Performed in Washington State

Representatives of seven foreign nuclear research institutes have joined EPRI and two other U.S participants in an $8 million project to study the release of radioactive aerosols during postulated accidents in nuclear power plants. The project, named LACE (LWR aerosol containment experiments), is one of a number of international experiments being conducted on source-term reductions and will provide data needed to verify the modeling codes used in nuclear accident studies.

International participation in the research consortium was agreed on earlier this year when representatives from the Technical Research Center of Finland, the Commissariat à l'Energie Atomique of France, the Comitato Nazionale per la Ricerca e per lo Sviluppo dell' Energia Nucleare e delle Energie Alternative of Italy, the Statens Karnkraftinspektion of Sweden, the Eidgenössisches Institut für Reaktorforschung of Switzerland, the Atomic Energy Authority of the United Kingdom, and the European Community met in Tampa, Florida, with their counterparts from EPRI, NRC, and DOE. The Japan Atomic Energy Research Institute will also participate in the program.

LACE research will be conducted at the 30,000 ft^3 (850 m^3) aerosol research facility at the Hanford Engineering Development Laboratory in Richland, Washington. The facility, capable of simulating a nuclear power plant's reactor containment and auxiliary buildings, will be used to show how thermal-hydraulic effects that exist during an accident reduce radioactivity. Jet impingement and aerosol species solubility are two examples of thermal-hydraulic effects that were found to be important during scoping tests for the experiments.

Researchers will concentrate on nuclear accident scenarios believed to have potentially serious consequences for the public—for example, the breaching or bypassing of the reactor containment building. Test results from the Hanford experiments will help establish the size of emergency planning zones needed around nuclear generating stations. In addition to the LACE work at Hanford, supporting research is to be carried out by individual cosponsors in their home laboratories.

Three full-scale scoping tests, sponsored by EPRI before the consortium was formed, helped demonstrate the feasibility of the experiments and established a budget and schedule for the project. These tests confirmed the importance of thermal-hydraulic conditions on aerosol behavior and showed that releases would be smaller than had been thought. If LACE can substantiate these early results, the experiments will help promote confidence in the safety of nuclear power plants. The experimental program will conclude at the end of 1986. ■

Health, Safety, Environment Viewed as Top Concerns in Industry Survey

Results of EPRI's eighth Industry Advisory Committee Survey show an increased interest in Institute environmental programs, reflecting utility concerns about health, safety, and environmental issues. Sixty-five utilities, representing about 60% of the nation's electricity generation, responded to the survey.

The results showed that environmental issues embedded in EPRI strategic program areas were judged most important. Respondents ranked advanced fossil fuel plant technologies as having the highest R&D priority, followed by environmental control technology, fossil fuels, fossil fuel power plants, and environmental assessment.

To learn how the industry perceives its own future, the survey asked respondents to indicate the most significant challenges confronting their utilities. Overall, the problems seen as most challenging were maintaining financial health, reducing electricity costs, constructing and licensing nuclear plants, building public credibility, planning, and commercializing new technologies. Respondents saw research and development as major aids to reducing costs and addressing environmental issues.

The survey addressed other topics, including demand-side management, independent power producers, the addition of new transmission facilities, financial strategy, and forecasting techniques. The respondents also showed great interest in technologies that extend the life of power plants and transmission and distribution facilities.

EPRI periodically conducts the industry survey as part of its strategic planning process to assist in determining its program emphasis. For further information, contact Sherman Feher of EPRI's Planning and Evaluation Division. ■

CALENDAR

For additional information on the EPRI-sponsored/cosponsored meetings listed below, please contact the person indicated.

MAY

6–9
1985 Joint Symposium on Stationary Combustion NO_x Control
Boston, Massachusetts
Contact: Michael McElroy (415) 855-2471

7–8
Seminar: Maintaining Equipment Qualification
Chicago, Illinois
Contact: Robert Kubik (415) 855-8905

8–9
EPRI Reactor Physics Software Users Group Meeting
Houston, Texas
Contact: Walter Eich (415) 855-2090

14–15
Regional Conference: Compressed-Air Energy Storage
Chicago, Illinois
Contact: Robert Schainker (415) 855-2549

14–15
Seminar: Investigation and Correction of Boiler Tube Failure
San Antonio, Texas
Contact: Barry Dooley (415) 855-2458

14–16
Annual Review of Demand and Conservation Program
Tampa, Florida
Contact: Joseph Wharton (415) 855-2924

JUNE

4–5
EPRI Coal-Water-Slurry Project Review
Hartford, Connecticut
Contact: Craig Derbidge (415) 855-2427

4–6
Artificial Intelligence Application to Nuclear Power
Palo Alto, California
Contact: David Cain (415) 855-2112
or Bill Sun (415) 855-2119

4–7
9th FGD Symposium
Cincinnati, Ohio
Contact: Stuart Dalton (415) 855-2467

10–12
Symposium: Fossil Plant Cycle Water Chemistry
Atlanta, Georgia
Contact: Roland Coit (415) 855-2220
or Barry Dooley (415) 855-2458

11–14
Seminar: Electrical Design of Transmission Lines
Lenox, Massachusetts
Contact: John Dunlap (415) 855-2305

18–21
Symposium: Condenser Biofouling Control
Orlando, Florida
Contact: Winston Chow (415) 855-2868

26–27
Seminar: Maintaining Equipment Qualification
Palo Alto, California
Contact: Robert Kubik (415) 855-8905

R&D Status Report
ADVANCED POWER SYSTEMS DIVISION

Dwain Spencer, Vice President

SYSTEM BENEFITS OF USING GCC UNITS FOR CAPACITY EXPANSION

EPRI has sponsored a study by Zaininger Engineering Co. to compare the value of coal gasification–combined-cycle (GCC) power plants with conventional coal fired plants (RP2029-11). The comparison was based on system expansion analyses, in which the capacity of a regional system (the EPRI West Central system) was expanded over a 30-year period by using 500-MW GCC units or, alternatively, 500-MW conventional coal units. Total system busbar revenue requirements were calculated for each expansion alternative. The system saving per kWh of GCC generation was found to be considerably greater than the saving calculated by the commonly used cost comparison method. This study is reported in EPRI AP-3551.

Study approach

When different types of power plants are compared, the cost of electricity produced by each type is commonly determined by the busbar costing method. This entails calculating the levelized busbar revenue requirements of a single unit by (1) multiplying plant investment by a levelized fixed-charge rate; (2) adding to this product levelized fuel costs and levelized operating and maintenance costs; and (3) dividing the total by annual production at a fixed annual capacity factor (ACF). Although this calculation seems rigorous, it suffers from several deficiencies that can result in poor decision making, particularly in planning R&D for new generating technologies. These deficiencies can be summarized as follows.

▫ The calculation does not account for the inherent differences in reliability between technologies.

▫ In applying the busbar costing method, it is common practice to use a constant ACF throughout the life of a facility. Actually, the ACF will vary from year to year. Further, the ACFs of different unit types can vary, depending on their load duty and dispatch priority as determined by their relative costs.

▫ The method does not allow for changes in plant capacity due to ambient temperature changes. This is particularly important in the case of GCC plants. For example, the capacity of a Texaco-gasifier-based GCC plant varies with ambient temperature as follows: 500 MW at 88°F (31.1°C), 550 MW at 60°F (15.6°C), and 622 MW at 20°F (−6.7°C). The significance of the increased capacity at lower temperatures is that GCC units can displace higher-cost generation (e.g., oil generation) at these temperatures. The common calculation method does not provide a credit for this ability.

▫ It is conceivable that two technologies can operate at the same ACF, but using the busbar costing method to compare the two may reveal only a fraction of the advantage of the lower-cost technology. The reason this calculation may underestimate the advantage is that it does not take into account how units added to a system can displace other generation and change the dispatch order.

Thus, because the common calculation method does not account for the full system economic benefits that result from GCC plant characteristics, system expansion analyses were conducted in order to more realistically evaluate GCC plants against conventional coal-steam plants. One of the six systems in EPRI's regional systems methodology—the West Central system, with 20,000 MW of capacity in 1990—was used for these analyses. System load growth was assumed to be 3.2% per year from 1990 to 2000 and 2.33% per year after 2000. Financial and coal cost criteria were based on the EPRI *Technical Assessment Guide*.

Several cases were studied to address several questions, but only the base case will be reported here. Its purpose was to compare GCC plants with conventional coal-steam plants in terms of full system benefits by using the most current cost and performance data on the two technologies. (The changes in GCC plant capacity with temperature noted above were included in the evaluation.) System economic benefits were determined by expanding capacity alternatively with 500-MW conventional coal units and with 500-MW (nominal) GCC units and comparing the results. This case used a set of relatively low oil prices to reflect the depressed market for oil fuels that prevailed at the time the study began.

The required reserve capacity was fixed at 22% when using coal-steam plants for expansion. When using GCC units, the reserve capacity was calculated as that required to yield the same loss-of-load probability as in the coal expansion with its 22% reserve.

Base-case results

Before reviewing the results of the base-case expansion analysis, it should be noted that when busbar electricity costs were calculated for GCC and conventional coal plants by the common method summarized above, the economic benefit of using GCC units appeared to be marginal: assuming an ACF of 0.7, the advantage of GCC units over coal units was only 1.5 mills/kWh (in levelized mid-1983 dollars). As will be shown below, however, the actual benefit of using GCC units—as calculated by system expansion analysis—is substantially greater.

ACFs produced by the base-case system expansion analysis are shown in Figure 1. When these values are levelized, the resulting ACFs are 0.7156 for new conventional coal units and 0.7045 for GCC units (rated at 60°F [15.6°C]). Using these levelized ACFs in the common method of calculating electricity costs would yield results similar to those cited

Figure 1 Annual capacity factors from the base-case system expansion analysis. Levelized values are 0.7156 for new conventional coal units and 0.7045 for GCC units. The near equality of these factors seems to support the results of the common costing method and tends to obscure the advantages offered by GCC units.

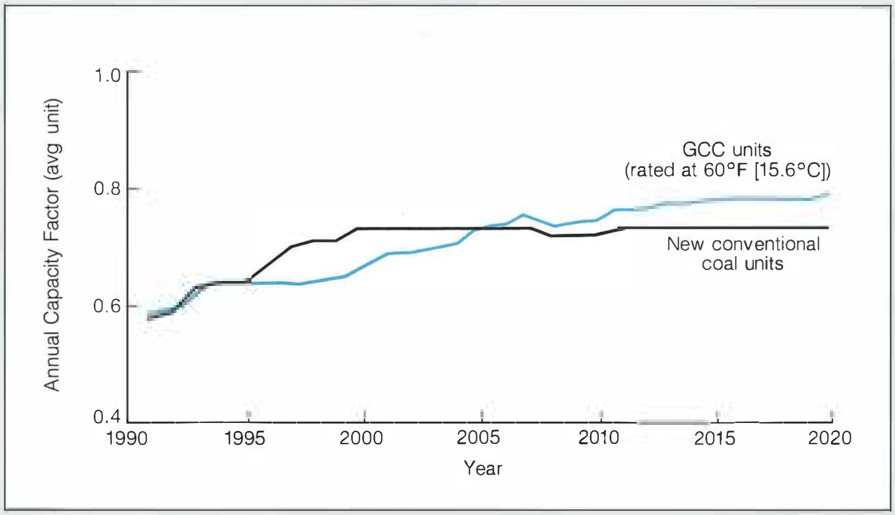


Table 1
CAPACITY ADDITIONS AND SYSTEM RESERVE REQUIREMENTS

	Conventional Coal Expansion	GCC Expansion
New capacity additions (MW)		
Conventional coal units	17,500	—
GCC units	—	19,500
Oil units	22,400	18,100
Total	39,900	37,600
System reserve requirements (%)		
In 2000	22.0	21.9
In 2010	22.0	18.2
In 2020	22.0	15.8

above—that is, GCC units would appear to have only a marginal advantage. Thus, ACFs produced by system expansion analysis are not sufficient in themselves to allow the entire benefit of one technology over another to be accounted for.

Table 1 shows the capacity added during each system expansion. Two important points should be noted: more GCC capacity is added than conventional coal capacity, and less total capacity is required in the GCC expansion. The significance of the first point is that the additional GCC capacity will displace higher-cost oil generation—generation that is not displaced by conventional coal units in the other expansion. The lower total capacity required when GCC units are used for expansion results from the higher postulated reliability of the GCC units. System reserve requirements at the same loss-of-load probability are also summarized in Table 1.

Neither of these advantages is taken into account when the common method of calculating comparative electricity costs is used. Thus, the data in Table 1 are beginning to indicate how system expansion analysis enables technologies to be compared more realistically.

Further GCC advantages are shown in Figure 2, which breaks down electricity production by type of generation for both the con-

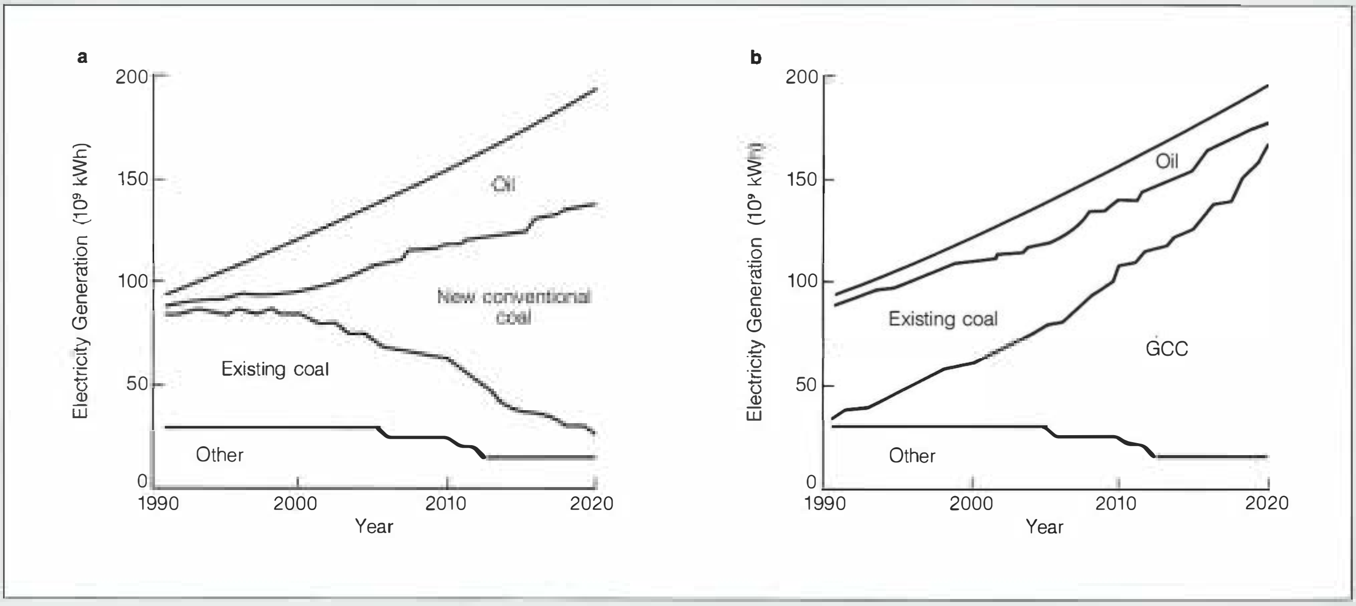


Figure 2 Electricity production by generation type for system expansion (**a**) with conventional coal units and (**b**) with GCC units. (*Other* is mostly nuclear generation, with some hydro, pumped-storage hydro, and purchased power.) The GCC units produce more baseload power than the new conventional coal units, which increases their annual capacity factor, but they also displace considerable intermediate-load oil generation, which lowers their ACF. As a result of the different effects of these two types of duty, the ACF of the GCC units is nearly the same as that of the new conventional coal units in the other expansion.

ventional coal and GCC expansion alternatives. It can be seen that the GCC units produce considerably more electricity than the new coal units, albeit at essentially the same levelized ACF (when rated at 60°F [15.6°C]). More baseload power is generated by the GCC units because of their higher availability and because they are dispatched preferentially to existing coal units. More important, the use of GCC units results in the displacement of a considerable quantity of expensive oil generation. Together the additional baseload generation and the intermediate-load oil displacement result in a capacity factor similar to that of conventional coal units (when both types are rated at 60°F).

A portion of the oil displacement can be attributed to the unique ability of GCC units to produce additional quantities of electricity at ambient temperatures lower than the 88°F (31.1°C) peak temperature assumed for this study. When temperatures are lower, the additional capability of GCC units serves to displace some existing coal-steam and oil capacity—capacity that would be required if GCC units were held to their 500-MW capability at 88°F.

Table 2
LEVELIZED PRODUCTION
(GWh/yr)

	Conventional Coal Expansion	GCC Expansion
Nuclear units	26,313	26,311
Existing coal units	51,980	50,368
New conventional coal units	16,173	--
GCC units		28,943
Oil units	19,687	8,546
Other	1,760	1,746
Total	115,913	115,914

Table 2 shows levelized production for both the conventional coal and GCC expansion alternatives. For existing coal units the levelized production is essentially the same in both situations. It was assumed that larger existing coal units were committed to meet daily peaks and could not be shut down at night in response to reduced loads. Instead, on-line GCC units were assumed to be backed off because of their higher incremental heat rates. If existing coal units could be shut off at night, it is likely that GCC unit production and capacity factors would have been significantly higher than indicated in this study, making GCC units look even more attractive.

The total system costs were calculated to be $174.411 billion for expansion with conventional coal units and $161.156 billion for expansion with GCC units (present values as of January 1, 1991). Thus, deploying GCC units resulted in a saving to the system of $13.255 billion. This amount was de-escalated to mid 1983 dollars and then levelized, and the result was divided by the levelized production of the GCC units. This calculation indicated the system saving per kWh generated by the GCC units to be 7.99 mills (in constant mid 1983 dollars)—considerably higher than the saving of approximately 1.5 mills/kWh calculated by using the busbar costing method. The results clearly indicate the need to perform system analysis to properly evaluate and compare these two coal-fired alternatives. *Project Manager: Bert M. Louks*

R&D Status Report
COAL COMBUSTION SYSTEMS DIVISION

Kurt Yeager, Vice President

FLUE GAS DESULFURIZATION: CHEMICAL PROCESS PROBLEMS

Many flue gas desulfurization (FGD) systems currently installed at coal-fired generating plants have problems that result in high operating and maintenance costs and, in some cases, poor reliability. Although construction materials failures result in lost operating time, chemical process problems cause the more persistent and troublesome maintenance difficulties, such as scaling, inadequate SO_2 removal, and poor reagent utilization. Defining and solving these chemical problems are the objectives of RP2248-1 and RP1031-4.

A field study of the effects of zero discharge operation on wet-scrubbing FGD systems at cost-fired plants identified several process problems not related to zero discharge. (*Zero discharge* refers to those plants that do not discharge wastewater.) Because of the necessity of decreasing freshwater use, the wet-scrubbing systems must recycle liquor, resulting in higher impurity levels in the scrubber system. In this project (RP1031-4), the EPRI contractor, Radian Corp., studied three wet scrubbers at three plants: South Mississippi Electric Power Association's R. D. Morrow station, Central Illinois Light Co.'s Duck Creek station, and Colorado-Ute Electric Association's Craig station. EPRI CS-3796 reports the results.

R. D. Morrow station

The R. D. Morrow station is relatively free of chemical problems even though the FGD system operates with liquors containing the highest impurity levels of the three plants studied. Analyses indicated chloride concentrations of 10,000–15,000 parts per million (ppm) at this plant, but these levels had no noticeable effects on SO_2 removal. The Morrow plant has two identical 200-MW coal-fired boilers. The FGD systems are identical absorber modules (one per unit, each with four rod decks) that use limestone as reagent. The limestone contains 85–90% calcium carbonate ($CaCO_3$), 8–12% magnesium carbonate ($MgCO_3$), and 1–3% inert materials. This limestone is ground in a wet ball mill with recycle to 92–98% through 325 mesh. A reagent ratio of 1.1–1.4 mole $CaCO_3$/mole SO_2 absorbed is added to the scrubbers as a slurry of 45–60% solids. A small portion of the $MgCO_3$ in the limestone dissolves to maintain a concentration of 3000–5000 ppm magnesium ion (Mg^{++}) in the scrubber liquor.

Plant personnel have developed an excellent program to follow FGD chemistry. They use a version of the EPRI chemical equilibrium computer program (FGDLIQEQ) to calculate important chemical factors, such as ion balance, alkalinity, SO_2 vapor pressure, and saturation of calcium sulfite ($CaSO_3 \cdot \frac{1}{2}H_2O$) and calcium sulfate, or gypsum ($CaSO_4 \cdot 2H_2O$). The solids produced are gypsum and are separated by thickening and filtering to produce a wet sludge containing 90% solids. The wet filter cake is discarded in a landfill. The system has had few gypsum scaling problems because the liquor is maintained below gypsum saturation. An SO_2 removal level of 80% (inlet 600–800 ppm SO_2) can be easily maintained and is adequate for meeting emission regulations.

The major problem observed was the relatively poor use of $CaCO_3$ in the limestone. Because $MgCO_3$ is present as dolomite ($CaCO_3 \cdot MgCO_3$), some of the $CaCO_3$ is bound up as this relatively insoluble compound. The data indicated that only about 10% of the dolomite dissolves in the scrubbers. As dolomite accounts for 10–26% of the limestone, total $CaCO_3$ utilization was as low as 60%. It was recommended that the utility investigate the use of high-calcium limestones to decrease reagent costs. The utility is currently testing alternative limestones.

Duck Creek station

The Duck Creek FGD system had several operating problems that resulted in inadequate SO_2 removal when the unit operated at full load. Central Illinois Light Co. (CILCo) had started investigating the use of adipic acid as an additive to increase SO_2 removal when EPRI requested the utility's participation in this study of Duck Creek as a zero discharge plant. This gave EPRI the opportunity to compare magnesium oxide as an alternative to adipic acid for increasing SO_2 removal. Other recommended changes in operating procedures and equipment were made by CILCo so that EPRI could document the effects of these changes as well.

The Duck Creek station is a 400-MW unit that burns high-sulfur (3–4%) bituminous coal. Regulations limit SO_2 emissions to 1.2 lb/million Btu heat input. To meet these limits, the scrubbers must remove 82–85% of the SO_2 in the flue gas. The FGD system consists of four modules with each absorber having seven rod decks. Limestone is the reagent, which is fed to the reaction tanks as a slurry. The solids circulating in the system are maintained at 10% and are purged from the system to a disposal pond for all plant waste. The solids are not dewatered before disposal.

An initial investigation of the Duck Creek FGD system showed the major problems to be inadequate SO_2 removal, mist eliminator scaling, and poor reagent utilization. Because all the causes of these problems interact to increase problem severity, changes were made simultaneously. The mist eliminator suffered severe scaling caused by washing with water nearly saturated with gypsum and by allowing unreacted limestone to carry over to the mist eliminators from the scrubber. Changing the wash water to one containing less dissolved sulfate, changing the wash sequence, and increasing the limestone utilization to >85% solved this problem.

To increase FGD limestone utilization, CILCo altered the ball mill grinding circuit according to previous studies of limestone preparation (RP1877) so that the particle size was decreased from 86% passing 200 mesh to 99% passing 200 mesh with 90% through 325 mesh. Smaller particle sizes improved limestone utilization from 55–60% to >90%. An added benefit was improved SO_2 removal.

Tests with dibasic acid (DBA), a by-product of adipic acid manufacture that is less expensive than adipic acid, and magnesium oxide added as dolomitic lime showed that both additives will increase SO_2 removal. Although both additives were feasible, CILCo chose DBA for two reasons: SO_2 removal responds rapidly to DBA addition, and SO_2 removal can be maintained in compliance by adding DBA only when operating the unit at full load. With a fine limestone (90% through 325 mesh), the DBA necessary to achieve adequate SO_2 removal is 200 ppm in solution, one-half that required with coarse limestone.

When all these changes were made, system reliability increased to >95%, while meeting SO_2 removal requirements and decreasing operating costs by about $300,000/yr. CILCo estimated that using only DBA without the other process changes would have increased the operating costs, including purchased power during downtime, by as much as $2.5 million/yr. Later tests on alternative limestone supplies showed that an additional saving of $150,000/yr in reagent costs is possible by changing limestone supplier.

Craig station

The Craig station has two 400-MW units each with an FGD system. This plant operates at zero discharge and uses cooling-tower blowdown as makeup to the FGD systems. The plant burns low-sulfur western coal, which results in a flue gas containing 250–300 ppm SO_2. Each unit has four spray towers that use limestone as reagent. Solids are dewatered in a thickener and then in horizontal centrifuges before disposal into a landfill. Initial investigation of the FGD systems indicated that the scrubbers achieved excellent SO_2 removal with three of the modules per unit. Scrubber liquors contained up to 44,000 mg/L of dissolved solids, but calculations of material balance at steady-state operation indicated that dissolved solids could reach 120,000 mg/L. The problems observed at Craig were mist eliminator scaling and poor sludge-handling characteristics after dewatering.

The mist eliminator scaling resulted from inadequate coverage by some spray nozzles and by washing with water that contained solids from the scrubber. The wash water was a combination of cooling-tower blowdown and liquor plus fine solids produced by separating scrubber solids in a hydroclone. It was recommended that Colorado-Ute increase the number of spray nozzles for mist eliminator wash and use water of higher purity, such as only cooling-tower blowdown, for washing. The utility has made these changes and has drastically reduced the mist eliminator plugging that resulted from scale formation.

The sludge-handling problem, a result of thixotropic behavior, appears to be caused by segregation and dewatering of the smaller gypsum crystals. The Craig FGD system produces gypsum, which generally grows to rather large crystals that dewater easily and are not thixotropic. At Craig, the solids going to the thickener are taken from behind a baffle in the reaction tank. The overflow from the hydroclone is returned to this area, resulting in withdrawal of the smallest crystals from the system. The hydroclone underflow returns to the open section of the reaction tank, and the solids in this stream are large, rounded gypsum crystals. Their rounded shape indicates that these crystals have remained in the system for long periods and are rounded by attrition.

Following recommendations, the utility changed the process on one of the units, which now returns both the underflow and overflow of the hydroclone to the open section of the reaction tank. However, the product has not improved noticeably. Further work is being done at this site in an effort to improve the product so that it can be transported in ash trucks rather than in the cement trucks now being used. One test in progress is to compare the product from a rotary vacuum filter and a vacuum belt filter with that from the centrifuges now used at Craig.

Because each station studied had operating problems, EPRI initiated another research project to investigate additional problems associated with wet scrubbing systems (RP2248). The goal of this project is to define and solve problems in sufficient number so a troubleshooting computer model can be developed. To accomplish this goal, EPRI is investigating problems in as many different types of FGD processes as possible. Many of the following investigations are not yet complete but are included in this report to indicate the range of problems encountered.

Martin Lake station

Texas Utilities Generating Co.'s Martin Lake station has three identical 750-MW units. The FGD systems have eight towers per unit with a common reaction tank for each set of two towers. These towers are dual loop, each with a quencher, where forced oxidation takes place, followed by an absorber, where SO_2 removal is completed. The absorber sections have packing to increase mass transfer.

Initial investigation of the system chemistry defined many of the problems previously observed in other operating scrubbers (e.g., absorber scaling, poor limestone utilization, and mist eliminator scaling). Absorber scaling resulted from oxidation of enough of the sulfite to increase the $CaSO_4$ concentration to above gypsum saturation. Because the solid phase is mostly $CaSO_3 \cdot ½H_2O$, which does not act as seed crystals for gypsum, the gypsum precipitates on the packing and surfaces of the absorber. Limestone utilization was poor, which resulted in excess unreacted limestone that contributed to the scaling in the absorber packing and in the mist eliminator.

It was recommended that gypsum crystals from the quencher be recycled to the absorber to act as seed for gypsum precipitation to inhibit scaling and plugging of the absorber packing. To maintain adequate SO_2 removal while reducing limestone utilization, it was recommended that the limestone feed to both the quencher and the absorber be of a finer particle size and be controlled by pH.

The utility altered two of the towers, as recommended, for a test. After operation of up to 84 days on one of the towers, inspection showed no scaling on the absorber packing. Under previous operating conditions, the packing would have been at least 75% plugged and would have had to be replaced about three times a year because of plugging.

Mist eliminator scaling (~30% of eliminators) was still apparent in these towers, but this was at least partially caused by an inadequate flow of wash water. High-flow nozzles were installed in one tower. After 37 days of further operation, ~5% of the mist eliminator had scale, which indicates that additional improvements in the spray can eliminate mist eliminator scaling.

Limestone utilization was ~75% before the test program. Some improvement in the ball mill circuit was achieved on one unit, which improved limestone utilization to 80%. Further decrease in limestone particle size should result in >90% limestone utilization.

Martin Lake cannot discharge wastewater containing greater concentrations of impurities than the raw water. Because the plant produces a waste stream, treatment is necessary. A water balance was prepared, assuming an average rainfall runoff at the plant. With normal use of water for pump seal flush, mist eliminator wash, and ball mill water for wet grinding, the plant produces 1900 gal/min (7200 L/min) of wastewater. Recommendations to reduce this wastewater quantity are to use thickener overflow for limestone grinding, optimize mist eliminator wash, and eliminate seal water by using mechanical seals on pumps. These recommendations are being tested currently with good results. The utility will consider changing the entire system if no problems develop during the test period.

The utility has implemented the changes to prevent scaling of the absorber packing and estimates that they will result in savings of $1.2 to $2.0 million/yr in operating and maintenance costs. It has also improved limestone utilization and estimates that reagent costs will be reduced by about $500,000/yr. The recommendations for preventing mist eliminator scaling and for improving water balance are under investigation by Martin Lake personnel. Cost savings associated with these improvements have not yet been estimated.

Dallman station

City Water, Light, & Power of Springfield, Illinois, has an FGD system at its Dallman plant that is almost identical to the Martin Lake FGD systems. Dallman had the same problems of scaling and plugging in absorber packing and mist eliminators, poor limestone utilization, poor water balance, and variable oxidation in the quencher. Many of the Martin Lake recommendations applied to this plant, except the recycle of gypsum from the quencher to the absorber to supply seed crystals. Unlike Martin Lake, the Dallman absorber was not protected with a resin coating. A recycle from the quencher into the absorber might have resulted in accelerated corrosion because of increased chloride concentrations.

The utility added limestone feed to both the quencher and the absorber (rather than all to the absorber) to reduce excess limestone in the absorber. The pH control system in both the quencher and the absorber was improved. Limestone grind was optimized to produce finer particles. These changes improved control of the FGD system and marginally decreased the scaling in the system. With decreased scaling and improved preventive maintenance, the unit generally remained in compliance without reducing load. The utility is considering recommendations to further improve operation and reduce operating and maintenance costs.

Mitchell station

Operation of the FGD system on West Penn Power Co.'s Mitchell station is relatively trouble free. The absorber is an open spray tower using lime that contains some MgO as reagent. The major problem investigated was the formation of hydrogen sulfide (H_2S) in the solids separation section. Sulfur-reducing bacteria are a probable cause of H_2S formation. Cultures under aerobic and anaerobic conditions were made with thickener overflow and underflow samples. Only anaerobic conditions in the thickener underflow produced bacterial growth. The bacteria had properties indicative of the *Desulfovibrio* genera. To prevent H_2S formation, the utility can reduce the slurry's organic content to inhibit bacterial growth or investigate the use of nonoxidizing biocides.

Several other utilities are participating in this study of chemical process problems, but data analysis or recommended changes are not yet complete. The stations being investigated are Utah Power & Light Co.'s Hunter station, Houston Lighting & Power Co.'s Parish station, Arizona Public Service Co.'s Cholla station, Minnesota Power & Light Co.'s Clay Boswell station, Duquesne Light Co.'s Elrama and Phillips stations, Indianapolis Power & Light Co.'s Petersburg station, and Associated Electric Cooperative's Thomas Hill station. This project will continue until sufficient data are collected to complete a troubleshooting computer model. The completed model will be field-tested to determine its applicability to FGD systems at commercial plants. *Project Manager: Dorothy Stewart*

R&D Status Report
ELECTRICAL SYSTEMS DIVISION

John J. Dougherty, Vice President

UNDERGROUND TRANSMISSION

Cryogenic cable insulation

Although much work has been done to develop a conductor for superconducting cables, little success has been achieved in the development of insulation. The insulation has turned out to be an even more difficult problem to solve than the conductor in such cable. In a laminar taped insulation, for example, the cryogen is present in the butt gaps between the tape layers, and this reduces the dielectric strength of the cable. A project was undertaken to develop a novel insulation system that would facilitate development of higher-voltage superconducting and cryoresistive cables with higher reliability and lower costs than other approaches (RP7892).

Bulk cross-linked polyethylene (XLPE) insulation was preexpanded so that on shrinking during cooldown it would not be stressed by the conductor. A test cryostat was constructed, and many tests were conducted on model cables rated from 69 kV through 230 kV.

The result was that bulk XLPE was demonstrated as a viable cryogenic insulation across these voltages; it also withstood the required test voltages (both 60 Hz and impulse) and accelerated aging. Cost estimates were made, and such a cable would be significantly less expensive than other superconducting or cryoresistive cables. *Project Manager: Mario Rabinowitz*

Solubility of gases in HPOF cable oil

High-pressure oil-filled (HPOF) cables are used extensively in this country for underground transmission of bulk power; as such, they are important arteries in our metropolitan areas. Because they are difficult to replace, they are in service for many years, and utilities have to know their condition on a regular basis.

Aging of paper cable depends on the electrical and thermal history of each cable, but this aging process leaves behind its fingerprints in the form of dissolved gases. A systematic, basic materials research project was therefore undertaken to fully characterize gas generation, gas solubility, and gas diffusion in HPOF fluids (RP7895). The contract was placed with Detroit Edison Co.'s research laboratory.

This project should result in procedures for analyzing dissolved gases in operating cables and correlating gaseous concentration with any abnormal condition (arcing, corona, high temperature) that might have occurred.

Thus far, the solubility and rate of diffusion of certain gases have been measured in typical pipe and insulation impregnating oils. Figure 1 shows a typical data curve for CO_2 in Cosden insulating oil; hundreds of tests like this must be completed before diffusion of gases under electrical and thermal influence can be evaluated. A future effort will separate the effect of paper degradation and determine maximum deterioration (mechanical, chemical, polymerization) under thermal conditions. Gases from paper degradation should be different from gases from oil aging and therefore can be measured. This project runs through April 1986, at which time a phase 2 field analysis may begin. *Project Manager: Thomas Rodenbaugh*

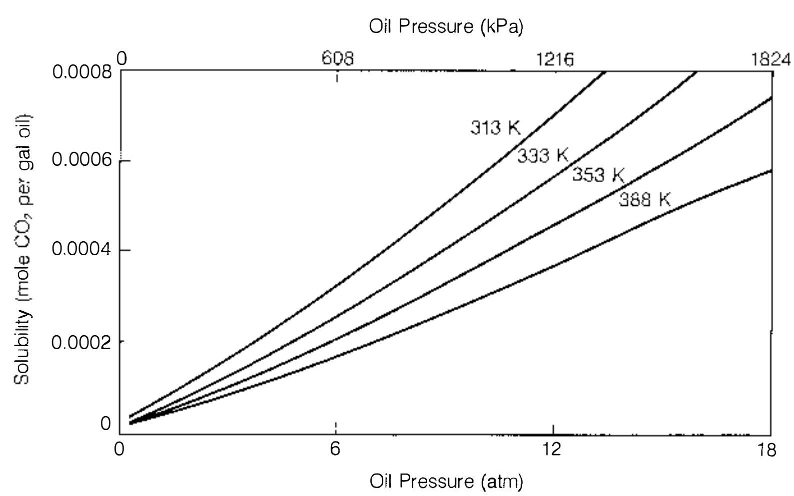


Figure 1 The first data ever published on solubility of gases (e.g., CO_2) in underground transmission cable oil shows the effect of temperature and pressure on Cosden insulating oil.

POWER SYSTEM PLANNING AND OPERATIONS

Multiterminal HVDC links in large ac systems

High-voltage direct-current (HVDC) transmission has become an attractive alternative to ac transmission in situations where its specific advantages outweigh its higher cost and the greater complexity of converter stations. Successful tests completed recently on prototype HVDC breakers make the operation of multiterminal (three or more) HVDC networks more viable than ever. But very little information is available on multiterminal HVDC systems because all existing installations are limited to two-terminal HVDC links.

In September 1981 EPRI contracted a project with the Institut de Recherche de l'Hydro-Québec to focus on the development of digital models of multiterminal HVDC controls and the integration of those models in EPRI large-scale load flow and stability programs (RP1964-2). This project will also evaluate the effectiveness of multiterminal HVDC links in transmission system expansion.

The contractor has completed the development and testing of the models of multiterminal HVDC controls and HVDC networks, included these models in ac-HVDC load flow and stability programs, and validated these programs with actual utility system data. The evaluation of ac-HVDC system performance under various system conditions is in progress. The project is scheduled to be completed in July 1985. *Project Manager: Neal Balu*

Component outage data analysis methods

To evaluate bulk power system reliability, one needs statistics on the behavior of individual components. However, two major difficulties confront the utility engineer: the imprecision or lack of outage data, and the inaccuracy of models.

The objectives of this project were to (1) identify and develop statistical methods for analyzing severely limited outage data on major power system components, such as generating units, transmission lines, and transformers (RP1468-1), and (2) develop reliable models for predicting the forced-outage performance of single and multiple transmission lines. These methods will be validated by comparison with the historical performance on an existing transmission system, that of Commonwealth Edison Co.'s 345-kV system (RP1468-2).

In this project a transmission unit is defined as a facility that transfers power between two or more points in a transmission system. A single transmission unit could include the physical components, such as a transmission line, the circuit breakers and buses at each end, and the line-protective relays. Some components may be involved in the operation of more than one transmission unit. Examples of transmission units are an overhead unit, a transformation unit, and an underground unit.

A component is defined as a physical facility that performs a major operating function in a transmission system; it is regarded as an operating entity at which both outage and exposure data can be recorded. Examples of components are power transfer components (e.g., transmission lines, transformers, and cables); switching components (e.g., circuit breakers); termination components (e.g., buses); power conditioning components (e.g., condensers and reactors); and protection components (e.g., line or bus protection).

Outage data can be collected either at the individual component level or at the unit level (made up of several components). Outage data were collected at the unit level on the host utility's system in this project; these were expanded to the component level to fully test the statistical methods of analyzing severely limited outage data and to develop more-reliable models for predicting forced outages. Then predicted outage performance models were developed for both individual lines (components) and units. These were later used to develop multiple outage performance models.

Phase 1 of this project (RP1468-1) identified three problem areas that limit the analysis: (1) the limited experience that some utilities have with many types of outages on diverse types of equipment, (2) the impracticality of collecting outage data and the difficulty in maintaining adequate exposure data, and (3) the lack of match-up between failure models and actual outage data. Ways of improving outage data collection are proposed in the final report (EL-1980).

In phase 2 of this project (RP1468-2) the principal factors that contributed to unit outages were found to be substation arrangements, transmission line layout, transmission tower design, major storms, and loss of major components included in a unit (e.g., a circuit breaker).

The mathematical models developed in this project tended to predict considerably fewer outages than actually occurred on the Commonwealth Edison system; however, when these models were combined with more complex combinations of models, the prediction rate reached 59% of actual observed outages—still an unacceptable rate (EL-3880).

The project demonstrated that regression analysis is a potentially effective tool in indicating the precision of predicted outage rates. Selection of a specific data collection system (unit or component) must recognize the trade-off between the completeness of the data gathered and the precision of the outage predictions.

A two-weather (normal and adverse) model added to the basic model provides only a marginal increase over the precision of the unaided model. However, an improved weather model that takes into account the variations in weather intensity, the exposure of the lines, the geographic juxtaposition of lines, and the electrical closeness of lines is recommended for further research. *Project Manager: Neal Balu*

PLANT ELECTRICAL SYSTEMS AND EQUIPMENT

Detection of open rotor bars in motors

The vast majority of drives used by industry and utilities are induction motors. The relatively simple and rugged construction of the rotating parts has a slotted rotor core with embedded electric conductors or bars. The copper or aluminum bars are interconnected by two circular end rings, forming a complete electric circuit (commonly called a squirrel cage) carrying induced current. This rotor current, together with the magnetic field, produces the desired motor torque. It is essential to maintain discontinuity-free current passage in the rotor cage. Cracks in the bars or end rings can cause an array of abnormalities, ranging from a relatively minor change in the torque-speed characteristic to severe arcing and a catastrophic large-motor failure.

An EPRI-sponsored survey of some 4800 induction motors revealed that about 5% (52 failures) of the motor failures originated in the squirrel cage (EL-2678). Primary causes are unnoticed imperfections during manufacturing (end ring brazing or casting porosity) and application abuse (too many or too frequent starts).

The objective of a project with General Electric Co. on the detection of open rotor bars in motors is to provide an inexpensive system that is able to detect squirrel cage discontinuities, preferably under normal motor operation (RP2331-1). A crack in a rotor bar or end ring changes the normal pattern of rotor current distribution. To a varying degree, this change affects the magnetic flux, line current, speed, and torque. Broken bars introduce harmonics into the line current spectrum. Because of current and flux asymmetry, the normally steady torque and speed exhibit an oscillating component at twice the slip frequency. Broken end rings cause variations in magnetic spatial distribution of flux. These changes in current, flux, torque, and speed can be monitored to indicate broken bars; however, the measurements are also susceptible to imperfections not associated with cage discontinuities, such as rotor eccentricity and magnetic orientation.

An effective and reliable broken-bar detector should be a simple, low-cost device that can be used without extensive motor modification. The monitor should be highly sensitive to disturbances caused by broken rotor bars, but unaffected by other signals. The difference can be enhanced through a signal processor.

In the course of the project, computer modeling will be used to analyze the effect of bar discontinuities on various motor characteristics, such as current, speed, and torque. The motor operating characteristics most affected by broken rotor bars will be identified, and those that are easily measured will be studied.

The computer-simulated response will also be used to select a suitable signal processing algorithm. A laboratory prototype detector will be developed, using the knowledge obtained from computer simulation and actual motor testing.

The prototype's ability to detect true cage discontinuities will be verified in the laboratory as well as in the field, or as a part of final production or repair testing. The contractor will also develop a plan to make the open bar detector commercially available. The project is scheduled for completion during the fourth quarter of 1985. *Project Manager: Jan Stein*

OVERHEAD TRANSMISSION

Transmission Line Mechanical Research Facility

The testing activities at the Transmission Line Mechanical Research Facility (TLMRF) at Haslet, Texas, and research activities under the companion structural research project have been under way for more than one year (RP1717; RP2016).

Thirteen cosponsored tests and three major retests of the subject structures were conducted during this period. Cosponsored tests at TLMRF are on structures brought to TLMRF by utilities for testing in support of new transmission line construction, transmission line upgrade, or utility in-house research (Figure 2). To date, the cosponsored tests have covered the range of freestanding structural types now being used in the United States. These tests, plus EPRI research, provide the structural development project with the basic data for research initiatives and the structural software development effort.

The TLWorkstation* software package is now available in a microcomputer version (M68000 series machines), a VAX computer version, and an IBM/TSO mainframe version. Each version of this highly interactive software is identical, and users can easily move from one version of the software to another. This first release contains an interactive structure analysis generator with postprocessing capability (TAG), a finite element structural analysis program (ETAP), an interactive version of the pole design and analysis program (POLEDA-80), an interactive version of a pier analysis and design procedure for lateral loads (PADLL), and an interactive version of a procedure to analyze the effect of broken wires on transmission structures (BRODIFLX). The package will soon contain GATL, grounding analysis of transmission lines; ACPIPE, induced ac potential on pipelines; MULTIFLASH, multiple-phase lightning flashover of transmission towers; TLOP, transmission line design optimization; and SGA, substation grounding analysis.

In addition, the TLWorkstation software contains an integral plot package (PLOT10 compatible), which permits use of the software on systems that do not now have graphics software installed and provides uniform graphics capability for all versions of the software. The present version is the first step in the development of a comprehensive transmission line design software package.

Building a probabilistic data base for lattice-type structures has been one of the major efforts associated with the TLMRF project to date. Tower members are gauged to determine the actual bending and axial loads. These are compared with the theoretical values of bending and axial load, and a difference histogram is generated for a particular tower. These tower error histograms have proved to be repeatable for the various lattice towers tested at TLMRF. This result implies that the differences between the test and predicted data are from specific assumptions inherent in the prediction techniques. A research effort is continuing to expand the present data base, to experiment with different analysis techniques, and to improve the simulation software.

One of the goals of the TLMRF research project is to be able to numerically simulate the collapse response of transmission structures subjected to both static and dynamic loading environments. An elastic-plastic geometrically nonlinear beam element is being developed as part of the structural development project. This new element will be particularly useful in simulating the behavior of steel poles, steel pole H-frames, and substation takeoff structures. The data gathered during TLMRF full-scale tests will be used to help validate the analytic elements being developed for the software.

In late 1984 construction and erection of research test line No. 1 at TLMRF began. Construction of this line will be completed in early 1985, with the first cosponsored test using the test line scheduled for the second quarter of 1985. Instrumentation capabilities similar to those in the test pad area will be available for recording test data on the test line.

Research test line No. 1 will provide the TLMRF program with a valuable new research

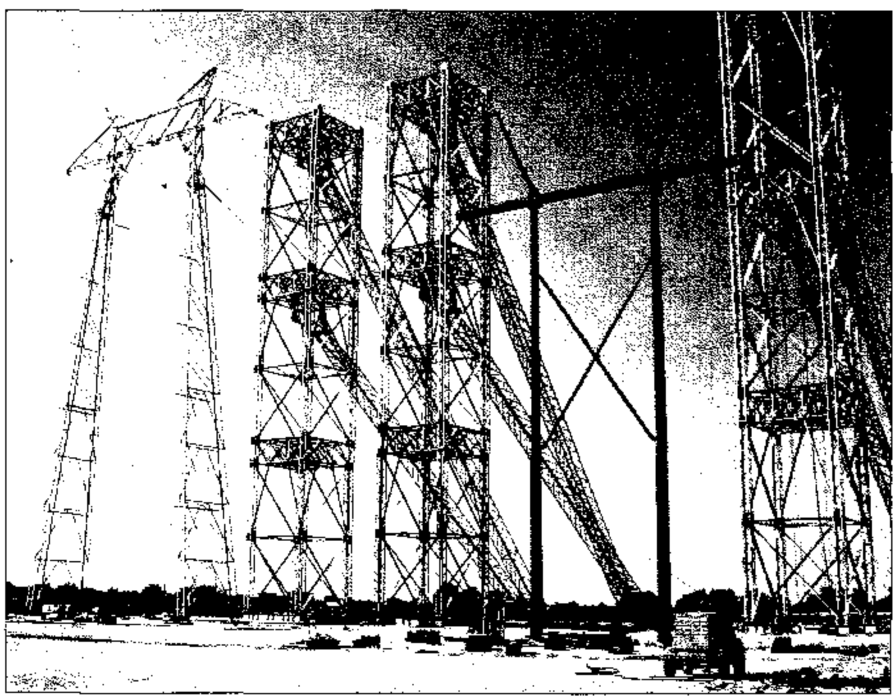


Figure 2 A 500-kV internally guyed lattice structure and a 345-kV steel pole H-frame being readied for testing at TLMRF.

*TLWorkstation is a registered EPRI trademark.

tool. Data collected from the test line will be used to determine the validity of the structural response predicted by analytic methods and to make appropriate comparisons with static and dynamic tests conducted on the test pad. An existing tower design is being used on the test line; however, the line conductor and the grillage foundations were sized by using a return period of three years for the conditions at the TLMRF site. (This means that there is a high probability of loads that exceed the design loads within a three-year period because of local atmospheric conditions.) Significant loads can be expected on the lines from local weather conditions, in addition to the artificially induced loads during individual line tests.

Over the past year TLMRF has been a valuable tool for the EPRI research efforts and for individual utility design and research tasks. Proof testing, research testing, and structural analytic research have been integrated to provide immediate useful results, while also advancing the state of the art of transmission line structural design. *Project Manager: Paul Lyons*

TRANSMISSION SUBSTATIONS

Advanced thyristor valve

The June 1983 R&D status report on this subject discussed the problems encountered in scaling up an advanced thyristor valve for commercial operation. General Electric Co., the contractor for RP1291-5, has found solutions for these and other questions that have arisen. For example, the cesium lamp light source has been redesigned to reduce light emission between pulses by a factor of 4, significantly reducing the heating of the separate light-triggered thyristors (SLTTs); a reflector also has been designed for the lamp.

Numerous other components have been incorporated to optimize valve operation. A quartz optical mixer has been developed to combine the outputs of two redundant light sources, and electric filters have been added to the cesium arc power supplies. Redundant Freon cooling systems have been tested by using resistance heaters as surrogates for thyristor heat loss, and software has been developed to permit use of three independent controllers, with a two-out-of-three vote required for controlling operation of the cooling system. Sixty-six thyristors with 4700-V forward and 5200-V reverse minimum blocking ratings have been supplied, and individual thyristors have been type-tested for short-circuit current.

Another test series was run to check the scatter of individual thyristor delay times at both minimum and typical light levels. The thermal status of the SLTTs was measured in the presence of the remaining background light (after the 4:1 light reduction mentioned earlier).

Eleven power modules, each containing six thyristor levels, were fabricated and assembled into the valve structure. The structure matches the dimensions and terminations of the existing mercury arc valve, which it will replace both electrically and physically, and meets the rigid seismic requirements of Los Angeles Dept. of Water & Power's (LADWP's) Sylmar converter station.

All equipment external to the high-voltage cage has been installed at the Sylmar station, and a shutdown of the dc line to permit installation of the experimental valve is awaited. The valve will then undergo two years of field trials, during which LADWP will monitor details of performance. *Project Manager: Gilbert Addis*

DISTRIBUTION

Effects of voltage impulses on solid dielectric cable life

Cables that utilities have been installing for underground residential distribution lines were intended to have a life of 30 years or more. However, the actual life of the cables is expected to be much less. Utilities have replaced cables that have failed after as little as 5 years.

To gain insights into the problem of premature cable failure, EPRI started a major research effort into understanding the possible causes (RP2284). This project will look at the relationship between surges and degradation of cable insulation. Specifically, it will determine the effects of lightning discharge surges and fault-locating equipment (thumper) surges. These surges will be applied to full-size 15-kV cables with five different kinds of insulation material and two insulation thicknesses.

It is hoped that this project will provide information related to the following.

- Effects of surges on insulation degradation
- Types of surges that are most damaging
- Cumulative effects of a number of surges
- Performance of different thicknesses of cable insulation

Georgia Power Co., the contractor for this project, is currently subjecting the first group of cables to surges. Results from this project are expected to be available in early 1988. *Project Manager: Harry Ng*

R&D Status Report
ENERGY ANALYSIS AND ENVIRONMENT DIVISION

René Malès, Vice President

ASSESSING THE IMPACT OF POWER LINES ON BIRDS

A lack of data, together with much speculation, about the impact of electric power transmission lines on birds has in some cases resulted in costly delays, route changes, and the refusal of permits for power line construction projects. Thus utilities need a detailed, generic research method for assessing the effects of overhead lines on bird flight behavior and collision mortality. To help meet this need, in 1979 EPRI initiated a two-phase study of avian interactions with transmission lines (RP1636).

In phase 1 of the project, researchers tested a mobile laboratory equipped with fixed-beam radar, night vision devices, closed-circuit television, and other visual observation techniques for studying bird behavior in the vicinity of transmission lines. This initial testing was completed in mid 1981. Phase 2, which began in the fall of 1981 and was completed in the spring of 1984, involved further modification, application, and evaluation of the equipment and techniques developed in phase 1. Also, another (marine) radar was installed in the mobile laboratory, and the usefulness of fixed-beam and rotating-beam configurations was evaluated. Much of the phase 2 work was conducted in the field—at transmission lines in different places with different ecosystems.

Laboratory equipment

The two radar systems in the mobile laboratory are operated in totally different modes. The first is a fixed-beam system that is used primarily as a narrow-beam radar range finder; it can be directed horizontally or vertically. The second system, an unmodified (off-the-shelf) Decca 150 marine radar, is used in a conventional surveillance, or rotating-beam, mode. Having both fixed-beam and surveillance units greatly enhances the gathering of precise data on the characteristics of bird movements in all three spatial dimensions.

The major electro-optical systems in the mobile laboratory are an image intensifier that is used in observing the flight behavior of birds at night; a closed-circuit video system that combines, displays, and records data from the fixed-beam radar and the image intensifier; and an automatic cinefilming system that records the display of the surveillance radar.

A critically important factor in the mobile laboratory concept is the ability to monitor bird movements at night, when ordinary visual techniques cannot be used. This was achieved by means of the image intensifier. The intensifier and the television camera are used together for observations at night in the same way as the camera and a zoom lens are used during the daytime. They can be directed horizontally to observe the flight behavior of birds near a transmission line, or they can be directed vertically to monitor the passage of nocturnal migrants overhead. In situations when there is insufficient ambient lighting, a 500-W spotlight is used for illumination.

The mobile laboratory's closed-circuit video system enables observations of bird movements to be made automatically. A video tape provides a record of observations by the fixed-beam radar and the television camera, as well as a simultaneous audio record of bird flight calls and observer commentary.

Viewing bird movements directly on the screen of the Decca 150 surveillance radar is difficult because the echoes fade rapidly. When time-lapse cinefilms of the screen are made, the movements are much more obvious, and careful study with a motion analyzer is possible. To make a film record of the bird movements on the display, an automatic cinefilming system was developed.

Test results

The performance of the electro-optical and radar systems was evaluated in the field under diverse weather conditions at several locations. It was found that the fixed-beam radar system could detect birds at greater distances than could the television camera with a 150-mm lens or an observer using 10 × 50 binoculars. When the radar unit was properly tuned, it could detect even small birds, such as warblers, at ranges of up to 1200–1500 ft (370–460 m); birds the size of geese were detectable at ranges of 1–1.5 miles (1.6–2.4 km).

When directed horizontally, the fixed-beam radar readily detected birds flying near transmission lines. It could not detect the lines, however, only the supporting towers. The television and direct visual observations provided detailed, high-resolution information on the behavior of the birds near the lines. Thus the visual techniques and the fixed-beam radar are complementary: the visual techniques provide detailed information on the types and numbers of birds and their flight behavior near transmission lines, and the radar provides accurate range information and verification of sightings.

An evaluation of the Decca 150 surveillance unit's performance showed that a small marine radar is capable of monitoring the distribution of birds in relation to power lines and topographic features. The radar could detect birds flying just above the ground; in many instances water fowl sitting on the surface of water could be detected. Although ground objects are readily detected by the surveillance radar, they pose no real problem and are in fact useful when cinefilms are analyzed.

Single gulls could be detected at a range of 1 nautical mile (1.9 km) by the surveillance system, and single songbirds could be detected out to 0.5 nautical mile (0.9 km). When birds were flying perpendicular to the beam, they were detectable at greater distances than when they were flying toward or away from the radar antenna.

When ground fog made visual observations impossible, both radar systems continued to detect bird movements. Even in misty rain the radars were able to detect birds; when hard rain was falling, however, the radar beams were saturated with echoes from the rain.

The observation techniques used in the mobile laboratory will undoubtedly be improved as more data are gathered and more testing is completed, but it can be said with confidence that the systems are capable of gathering detailed, accurate data on the movements of birds near transmission lines. Moreover, the techniques evaluated have much wider applicability beyond the specific focus of this project. They can be used at other sites where similar data on birds are required (e.g., near tall towers, bright flares, and magnetic disturbances) and also to study many basic aspects of the local and migratory movements of birds (e.g., the orientation of flight behavior, the timing of movements, and the influences of weather). *Project Manager: John Huckabee*

END-USE PLANNING FOR THE COMMERCIAL SECTOR

The transformation from an industrial to an information and service society has been identified by futurists as the foremost trend in U.S. society. Technicians, programmers, clerks, and others whose primary job is producing, distributing, and storing information have grown from 17% of the labor force in 1950 to over 65% today. Utilities see this transformation as a steady increase in the importance of the electric loads (particularly peak loads) of new commercial buildings, such as offices and medical facilities. Moreover, noninformation service loads, such as restaurants and stores, are growing as well. There is clearly a great potential for demand-side management programs to shape new and existing commercial loads in order to reduce utility and customer costs and simultaneously increase customer satisfaction. To realize this potential, utilities need information and tools to target specific end uses (e.g., lighting, cooling, heating) for change. EPRI has funded an integrated research effort under RP1216 to develop such tools and to demonstrate their applicability. The focus of this effort has been the development of a commercial end-use planning system.

COMMEND model

EPRI has developed a state-of-the-art commercial end-use model called COMMEND. COMMEND has several features not offered by other commercial-sector models—in particular, a module for forecasting summer and winter peak day load shapes and a module for choosing heating, ventilating, and air conditioning systems on the basis of life-cycle costs.

In the model commercial buildings are disaggregated into 11 types: small office buildings, large office buildings, retail stores, grocery stores, restaurants, health facilities, lodgings, elementary and secondary schools, colleges, warehouses, and miscellaneous. To capture changes over time in building design and equipment efficiency, the year of construction (or vintage) is also considered. Electricity consumption in each building type is broken down into eight end uses: heating, ventilation, air conditioning, lighting, water heating, refrigeration, cooking, and miscellaneous. As well as electricity, COMMEND can consider up to four other fuels, including natural gas and oil.

Thus the COMMEND model structure contains many building type–end use combinations. Electricity consumption for each combination is the straightforward product of four simple terms.

- The amount of floor space
- The average design energy use per square foot
- The choice of fuel type (when options exist, such as for space heating)
- The changing utilization rate for equipment and systems

COMMEND produces forecasts of annual kWh consumption by building type and end use and also determines the peak day load shape of each end-use component (Figure 1). The model explicitly shows the three ways that changes in relative fuel prices can affect electric loads: they can result in switches in fuel, particularly for space and water heating; the use of new, more efficient equipment; and changes in the utilization of existing equipment.

Georgia Power Co. and Long Island Lighting Co. participated in the initial COMMEND case studies. In an EPRI *First Use* sheet (4105E), a spokesman for Georgia Power points out that one of the great benefits of using COMMEND was the strong channel of communication established between the forecasting and marketing departments. End-use analysis makes this possible.

In the summer of 1983, COMMEND was released to 15 utilities under a prerelease agreement. These early users helped make many refinements to COMMEND. The code was released through the Electric Power Software Center in the spring of 1984. Today there are 28 COMMEND users. With EPRI's support a users

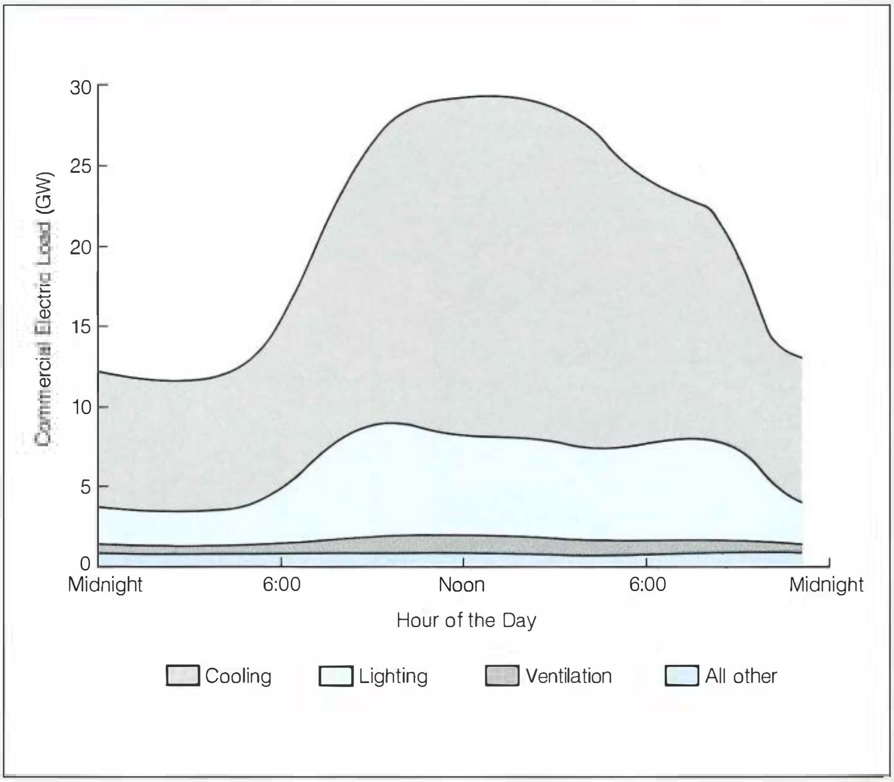


Figure 1 This sample COMMEND commercial-sector load profile shows the expected contribution of different end uses to the summer 1985 peak day load in the Southeast (DOE Region 4). As well as producing summer and winter peak day load profiles, this EPRI-developed model forecasts annual kWh use by commercial building type and end use.

group has formed, which meets several times a year to discuss issues in model development and application.

Data development

The use of COMMEND for demand-side management rests on the foundation of good data. Applying COMMEND to a utility's service territory requires two types of new information: data on the composition of the commercial customer class (e.g., business activity, building size and vintage) and end-use data on the patterns of electricity consumption. Compositional information is available from public sources, such as government employment statistics, or from a survey of the utility's own commercial class. End-use data have been developed in three basic ways: simulating building energy use with computer models, breaking down utility bills by using engineering data and statistical analysis, and metering individual end-use circuits.

The initial applications of COMMEND have primarily used data from public sources, existing utility surveys, and computer simulations. This data development process is laid out in the COMMEND implementation guide (EPRI EA-4049-CCM, two vols., forthcoming). For accuracy, end-use aggregates are systematically calibrated to building totals developed from utility billing records.

To improve commercial end-use analysis, EPRI's Demand and Conservation Program is focusing on ways to simplify data development and to improve its accuracy. This research involves the following three efforts.

- Analyzing public data, particularly from DOE, and delivering them in COMMEND input format

- Developing a packaged methodology for commercial-sector mail surveys

- Developing a guidebook on how to effectively and efficiently conduct an end-use metering project

In 1983 DOE released a major data base containing the results of its Nonresidential Building Energy Consumption Survey (NBECS), which covered over 6000 commercial buildings across the country. EPRI has undertaken a project to use the NBECS data in developing a national version of COMMEND. This work has produced several benefits.

One major benefit is the use of the data with COMMEND to simulate the impacts of new commercial-sector demand-side technologies being developed by EPRI, such as thermal energy storage systems. Figure 2 shows a simulation of the possible summer peak reduction resulting from cool storage systems in the United States in 2000.

Another major benefit is a series of 10 regional input data sets produced for COMMEND, which utilities can use in developing versions of the model for their own service territories. All COMMEND users have been sent these data.

A third major benefit of the data analysis effort is to dispel the popular misconception that the commercial sector is too heterogeneous, complex, and utility-specific to be understood without a huge commitment of resources. From the NBECS data emerges a picture of the commercial sector at the national and regional levels that has a basic unity and simplicity. The commercial sector in every utility service territory is a partial reflection of this national picture, which can be summarized in six basic facts.

- When national and regional data on commercial floor space are broken down into building types, there is significant variation in total area from type to type; however, the percentage distribution of floor space by building types is uniform across regions.

- The intensity of electricity use in the commercial sector, defined as annual kWh consumption per square foot of floor space, is increasing over time in all regions.

- The intensity of electricity use varies significantly across building types.

- The space-heating fuel shares of electricity, natural gas, and fuel oil show great variation across regions because of differences in relative prices and availability.

- Of greatest significance, the penetration of electric space heating is increasing with time in every region of the country (Figure 3).

- In general (with some regional variation), when annual electricity consumption is broken down by end use, lighting has the largest share, followed by cooling, space heating, and ventilation.

Another current EPRI research effort is to develop and test a packaged methodology for surveying the commercial sector. This will provide utilities with an economical means of getting information on their own customers for comparison with national patterns.

A survey consists of five steps: overall design, sample design, preparing the survey instrument, fielding the survey, and preparing the data base. Sample design for the commercial sector is discussed in a 1984 EPRI report (EA-3688) based on the experience of California utilities. To identify remaining survey problems, 30 utilities who had recently conducted commercial surveys were interviewed. Three key issues emerged: (1) avoiding biased values when there is substantial nonresponse; (2) given that many commercial buildings have multiple meters, determining that all the accounts are matched with a building; and (3) determining what, if any, benefits would result from tailoring questionnaires to specific building types.

A research project on these issues has been developed in cooperation with three utilities now doing commercial surveys: New York State Electric & Gas Corp., Potomac Electric Power Co., and Virginia Power. Alternative approaches to each of the issues will be tested in

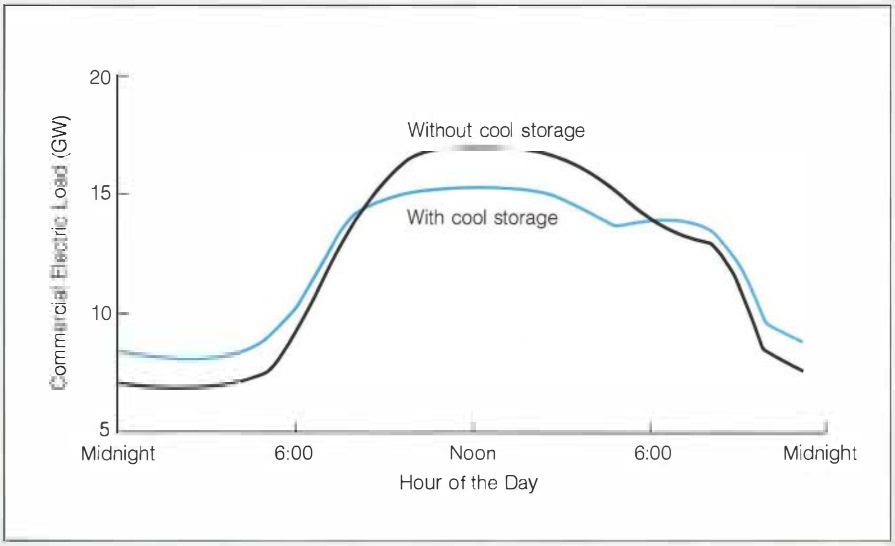
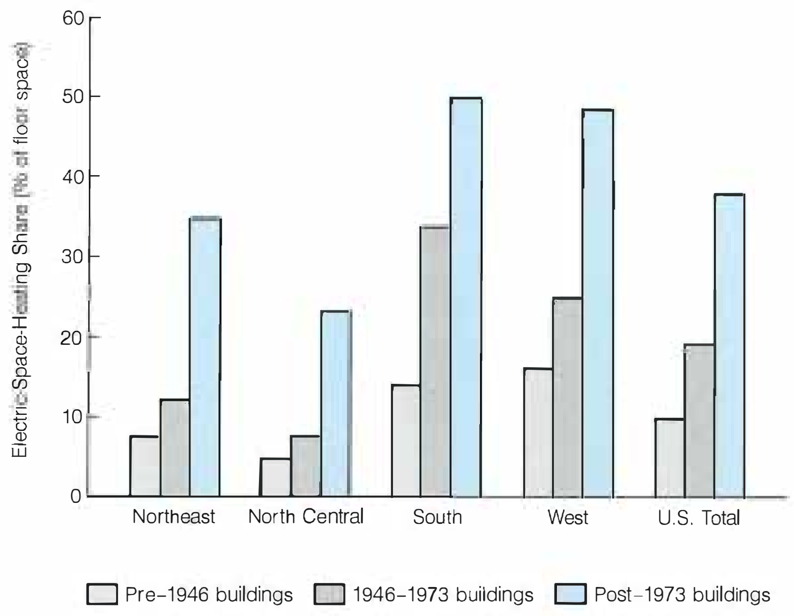


Figure 2 COMMEND can simulate the effects of new demand-side technologies on electricity use in the commercial sector, as illustrated by these projected summer peak day load profiles with and without cool storage for the year 2000. Estimates for the 10 DOE regions were averaged to produce these profiles.

Figure 3 Electricity's share of commercial space heating in terms of floor space served is growing in all regions of the country, as indicated by these data from DOE's Nonresidential Building Energy Consumption Survey.



the most practical setting—an actual utility survey—and a guidebook will be prepared.

The third current EPRI research effort in commercial-sector data development involves end-use metering of loads in commercial buildings. The COMMEND data on the load shapes of individual end uses, such as lighting and air conditioning, are based on computer simulations. EPRI is working to validate and improve this information, which is important in identifying targets of opportunity for demand-side management.

End-use metering is expensive, and only a handful of utilities have conducted such projects. The approaches and experiences of three—Seattle City Light, the Bonneville Power Administration, and Sierra Pacific Power Co.—were discussed at an EPRI workshop in Seattle in January 1985. Data coming from these end-use metering projects are being used to cross-check and validate the statistical and computer simulation data development methods. The lessons of this experience will be developed into a reference guidebook.

In summary, the commercial sector deserves the utility industry's attention because it is dynamic and offers untapped demand-side management opportunities. COMMEND provides a flexible set of tools, data, and data development methods for utilities to use in analyzing this sector. *Project Manager: J. B. Wharton*

R&D Status Report
ENERGY MANAGEMENT AND UTILIZATION DIVISION

Fritz Kalhammer, Vice President

LOW-COST HEAT STORAGE FURNACE

Heat storage systems, which shift daytime space heating loads to late night hours, represent a promising load management technology that utilities can use to defer new capacity, build off-peak load, and establish a controllable block of loads for the future. Heat storage furnaces, well known in Europe, use off-peak electricity to heat ceramic bricks to 1200–1500°F (650–820°C). During the day the stored heat is supplied as needed. Although a number of room and central systems have been installed in the United States, primarily in areas with severe heating requirements, wider use is hampered by high system cost. To overcome that disadvantage, EPRI is pursuing a program to develop a low-cost heat storage furnace that would be economical compared with conventional electric heating and would challenge oil or gas heat in some regions.

Current heat storage systems use large quantities of ceramic (magnesite and olivine) bricks that can withstand repeated heating to the required high operating temperatures. The bricks are shaped to allow embedding of electrical resistance elements and to provide channels for air circulation through the brick stack. These special bricks are expensive ($500/t) and contribute approximately 40% to central system cost. Substituting less-expensive ($10/t) common rocks offers an excellent opportunity for reducing system costs.

Tests carried out in the compressed-air energy storage projects sponsored by EPRI and DOE first demonstrated the potential of rocks as a heat storage medium at elevated temperatures (EPRI EM-2999). In these tests, off peak electric energy drove air compressors, which filled large underground caverns with heated compressed air. This stored air then drove expansion turbines when required by electricity demand. The rocks stored the heat (900°F; 485°C) of the air leaving the compressors and later returned it to the air during decompression. Repeated tests demonstrated that basalt, a quartz-free rock widely used as railroad ballast, could be heated to 900°F without any degradation.

On the basis of the promising results of this work, EPRI contracted with Fluidyne Engineering Corp. to explore rock's potential in heat storage furnaces (RP2036-8). Researchers selected samples of generally available rock from locations throughout the United States. They then examined these samples before and after tests under simulated furnace conditions to determine rock behavior during thermal cycling and to identify the most promising candidates. In addition, investigators designed three conceptual heat storage furnaces for operation at three different storage temperatures. They then evaluated these designs to predict each concept's cost.

Heat storage furnace design

A heat storage furnace using crushed rock will operate somewhat differently than will a conventional unit using bricks. The brick stack is heated directly by radiation and free convection from resistance heaters and cooled by air passing through the air channels. The surface area for heat injection and removal is limited in relation to the volume, so much of the heat must be conducted through long paths in the bricks during both heating and cooling. Crushed rock has a greater surface area than brick through which to transfer heat and shorter conduction paths from surfaces to the center of the rock. Rock is also heated and cooled from the same surface by forced convection. Hence, crushed rock is easier to heat to a uniform temperature, and it relinquishes much more of its stored heat. This feature is unique to crushed rock storage media, and the furnace design takes full advantage of it.

Researchers compared designs to estimate differences in installed costs between a conventional brick furnace and a crushed-rock storage furnace. They evaluated three crushed-rock furnace designs of 120-kWh capacity, each with a different maximum temperature: 850°F (455°C), 1150°F (620°C), and 1800°F (980°C). Project personnel selected these temperature limits because they are breakpoints in storage furnace construction materials (cabinet and insulation).

The 850°F temperature is near the upper limit for two relatively inexpensive construction materials: low-alloy carbon steel, which oxidizes rapidly above 900°F (480°C), and fiberglass insulation, which is limited to service below 850°F. A furnace that operates at 850°F requires more rock to store a given amount of heat than a furnace that operates at higher temperatures. However, it also needs less insulation and may be more simply configured than higher-temperature designs.

The 1150°F furnace operates just below the temperature limit of both 400-series stainless steel and mineral wool blanket insulation. With this temperature limit and these better-quality, more-expensive construction materials, furnace design is more complex than it is at 850°F. It requires less rock but more insulation.

The 1800°F furnace requires best-quality and highest-cost construction materials and results in a more complex configuration than either of the lower-temperature furnaces. In addition, the high temperature makes internal insulation necessary.

The cost comparison favored the low-temperature design. The estimated installed cost for the 850°F design ($2700) is about 45% less than for a conventional storage furnace ($4800). The 1150°F design is about 30% less than a conventional one, and the 1800°F design is about 20% more. The low-temperature design uses only a slightly larger floor area than a conventional furnace of the same capacity because the crushed rock is more efficient. Additional design studies showed that the performance of a crushed-rock furnace was scarcely affected by rock size.

Findings

This research shows that low-cost, commonly available rocks will perform well in heat storage furnaces. These furnaces can accommodate a wide range of rock sizes, which will further improve the potential for local use of this storage medium.

Low-temperature (850°F) rock storage furnaces are the least expensive, saving about 45% of conventional heat storage furnace cost and approaching conventional fuel oil and propane central heating system costs. On the basis of promising test results and preliminary design studies, EPRI proceeded with prototype development. Two furnaces were tested in the laboratory, and two were installed for testing in residences in the Minneapolis area. All have performed satisfactorily. A pilot test of 10 furnaces, to be carried out in cooperation with several utilities, is planned for the winter of 1985–1986. *Project Manager: Veronika A. Rabl*

FIRST-GENERATION FUEL CELLS

The primary objective of EPRI's fuel cell research is to expedite the commercial introduction of first-generation phosphoric acid fuel cells for dispersed power plant applications. Using natural gas, petroleum distillate, and coal-derived fuels in an environmentally acceptable manner, these power plants will achieve heat rates near 8000 Btu/kWh. EPRI's activities are part of a much larger, nationally funded effort to make first-generation fuel cells available for utility applications by the early 1990s. Previous EPRI Journal *articles have discussed EPRI's role in this national program (June 1984, p. 55; September 1984, p. 6).*

EPRI is supporting three major efforts to expedite the commercialization of first-generation phosphoric acid fuel cells.

- Installing and operating a United Technologies Corp. (UTC) 4.5-MW net ac fuel cell module on the system of Consolidated Edison Co. of New York, Inc. (RP842). This utility-oriented effort is designed to demonstrate that utility personnel can install, operate, and maintain fuel cells and that the technology is technically ready for first-generation commercial applications.

- Upgrading the 4.5-MW UTC demonstrator design to a configuration more commercially viable for utility applications (RP1777). Efforts in this area are aimed at reducing capital costs and improving plant reliability, maintainability, and durability. Emphasis is on the development and verification of key power plant components.

- Defining a 7.5-MW gross dc power plant based on Westinghouse Electric Corp.'s air-cooled fuel cell technology (RP2192). EPRI's role includes the definition of power plant and system design requirements, with emphasis on the development and verification of the plant's steam reformer and fuel-processing system.

Demonstration plants

After achieving nearly all the initial project objectives, operations at the Con Edison 4.5-MW fuel cell plant were stopped in the fall of 1984. Key accomplishments included the siting, installation, and licensing of this new technology on a utility system in a dense urban area and the integrated operation of all subsystems under simulated load conditions.

Operation under actual load conditions was attempted in the spring of 1984; however, the plant was found to be inoperable because of high levels of reactant gas crossover leakage within the fuel cells. Diagnostic tests confirmed that the shelf life of the 1976-vintage fuel cell stacks had been exceeded. The phosphoric acid electrolyte had migrated out of the active fuel cell area, thus rendering the stack assemblies unable to operate electrochemically.

The project participants considered correcting the Con Edison situation either by replenishing the phosphoric acid electrolyte or by replacing the inoperable stacks with new modules based on an improved cell design that has virtually unlimited shelf life. In view of the cost and time to implement either alternative, however, and given the successful operation of a nearly identical 4.5-MW unit in Japan by Tokyo Electric Power Co. (Tepco), it was decided to terminate all operations at the Con Edison site. Efforts in 1985 will consist of preparing the final report, removing the plant equipment, and restoring the site to Con Edison's specifications.

Although the Con Edison demonstrator did not produce power, the Tepco unit (Figure 1), which was not sponsored by EPRI but which built on the experiences at Con Edison, has operated successfully. As of March 7, 1985, the unit had accumulated over 1900 load hours (4200 MWh); the longest continuous run was 21 days. Tepco reports operation to be very stable, and performance is very close to UTC's design goal (Figure 2). The unit's environmental characteristics also appear to be satis-

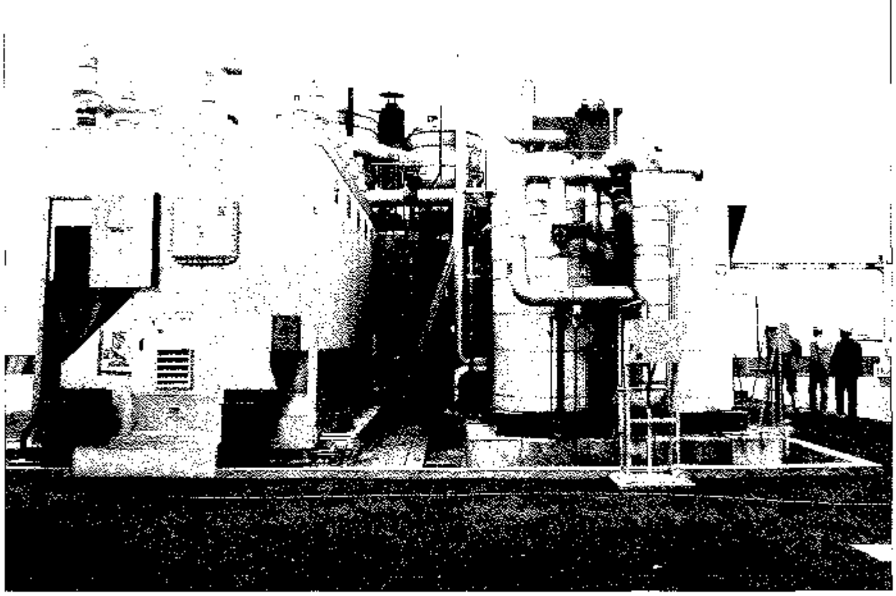
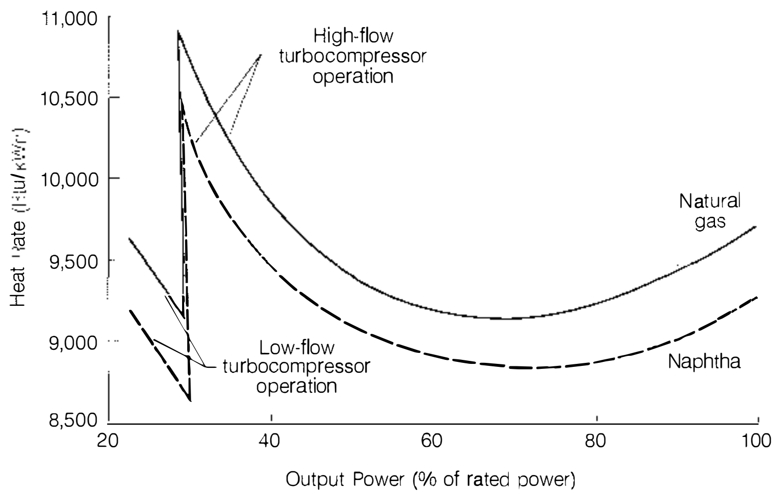


Figure 1 Tepco's 4.5-MW fuel cell demonstration unit at the Goi power station near Tokyo. This unit's initial operating success, together with accomplishments at a similar unit in New York City, represents an important step toward the commercialization of first-generation phosphoric acid fuel cells based on UTC technology.

Figure 2 Heat rate data from Tepco's fuel cell demonstrator during natural gas operation (colored points) versus UTC's design goal (solid curve). Naphtha operation, for which the design heat rate is lower, has not yet been tested at the plant. (All heat rates are based on the higher heating value of the fuel.)



factory: emissions of nitrogen oxides are less than 10 ppm, and noise at the site boundary is 60 db(A).

In Tepco's ongoing Phase 2 endurance test program, which was begun in June 1984 after a thorough three-month inspection and maintenance outage, the unit's performance and endurance characteristics will be evaluated through the first half of 1985. These data, together with the data already obtained, should show that UTC's fuel cell technology is technically ready for the next step toward commercialization.

Commercialization

EPRI funding and electric utility input have helped UTC upgrade the design of the 4.5-MW demonstrator into a commercially viable 11-MW (8300 Btu/kWh) fuel cell power plant configuration. UTC has formed a joint venture company with Toshiba Corp. of Japan to develop, manufacture, and market fuel cell power plants on a worldwide basis. The equally owned company, called International Fuel Cells, began formal operations in early

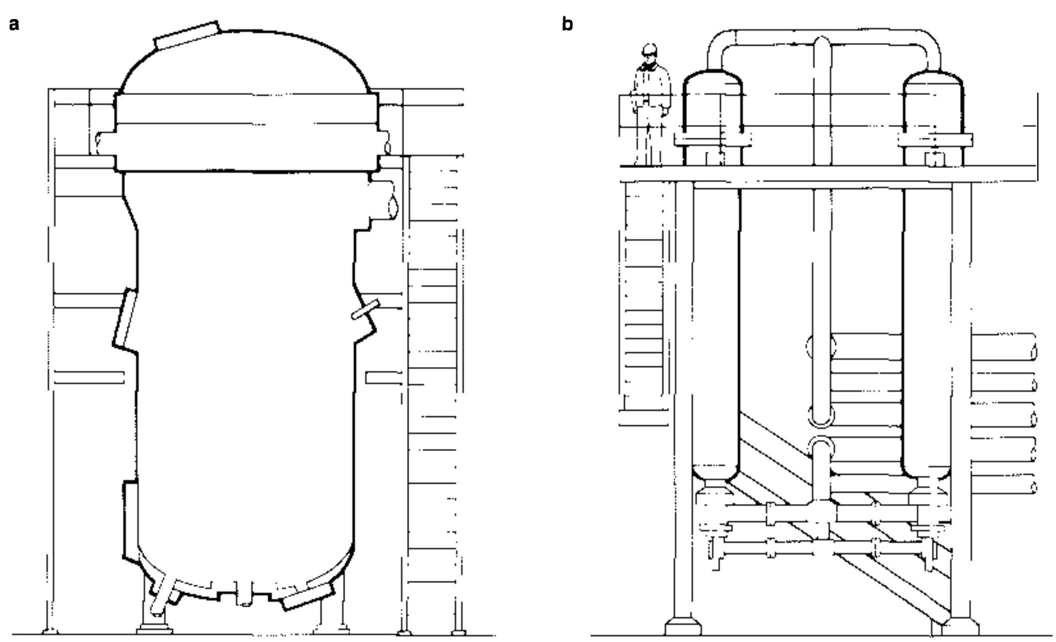


Figure 3 Two steam reformer designs are being investigated for a 7.5-MW Westinghouse prototype fuel cell power plant: (**a**) a pressurized fluidized-bed concept by Mitsubishi Heavy Industries, and (**b**) a modular concept by Haldor Topsoe. MHI's fluidized-bed concept features 54 reformer tubes contained in a pressure vessel 12.5 ft (3.8 m) in diameter and 28.7 ft (8.7 m) tall; a single burner; and an assembled weight of 145 t. Haldor Topsoe's modular reformer concept features six individual tubes, each 3 ft (0.9 m) in diameter; one burner per tube; a footprint of about 20 by 30 ft (6 by 9 m); and an assembled weight of 50 t.

1985 and will solicit orders for as many as 23 power plants during the first phase of its commercialization activities. The first commercial prototype plant could be operational as early as 1988.

Meanwhile, Westinghouse and Mitsubishi Heavy Industries (MHI) are working together to supply a 400-kW dc air-cooled fuel cell demonstration plant to Kyushu Electric Co. of Japan. That plant, which will demonstrate the Westinghouse fuel cell characteristics, is expected to be operable in 1986. Westinghouse has also signed an agreement with Southern California Edison Co. that could lead to a 7.5-MW dc prototype fuel cell power plant if 100-kW and 400-kW fuel cell stack modules can be shown to operate satisfactorily. That first commercial Westinghouse prototype could be operable by 1988.

Steam reformer development

EPRI is supporting both UTC and Westinghouse in the development of a steam reformer and fuel-processing system. The UTC work was highlighted in a report in the June 1984 *EPRI Journal* (p. 55); the Westinghouse efforts are highlighted here.

The development of the Westinghouse fuel-processing system is being pursued in two parallel programs with contractors experienced in chemical process technology. In one program Westinghouse and MHI have entered into a cooperative agreement whereby MHI is developing a steam reformer and fuel-processing system design according to Westinghouse's fuel cell plant specifications. EPRI is providing funds for Westinghouse to monitor the MHI development activities and to perform the necessary system integration.

The MHI steam reformer concept (Figure 3a) uses a pressurized fluidized-bed furnace to provide the necessary heat of reaction for the endothermic steam-reforming process. In an attempt to increase tube durability and provide for maximum safety, the fluidized bed maintains a constant, moderate-temperature environment for the reformer tubes. To verify steam reformer performance and operational characteristics, MHI has built a 400-kW reformer with three full-length tubes (54 similar tubes will be required for the 7.5-MW plant). Efforts in 1985 will involve monitoring and assessing the performance of this 400-kW reformer.

EPRI is supporting a parallel steam reformer development effort through a joint agreement with Haldor Topsoe, Inc. Haldor Topsoe's reformer design (Figure 3b), which is based on a proprietary heat transfer and chemical reaction concept, features a novel modular approach. Each reformer module will deliver hydrogen approximately equivalent to 1.25 MW (assuming the conditions specified by Westinghouse). Efforts in 1985 will focus on the fabrication and testing of a full-scale module at Haldor Topsoe's Houston, Texas, facility.

Both the MHI and Haldor Topsoe designs are aimed at improving maintainability, reliability, and performance; if development efforts are successful, both concepts appear to be attractive for electric utility fuel cell system applications. In addition, the Haldor Topsoe modular concept promises improved operational flexibility and presents virtually no scale-up issues for multimegawatt fuel cell applications. *Project Manager: D. M. Rastler*

R&D Status Report
NUCLEAR POWER DIVISION

John J. Taylor, Vice President

OCONEE PRA SUPPORTS COST-EFFECTIVE IMPROVEMENTS

In early 1980 the Nuclear Safety Analysis Center (NSAC) suggested that the nuclear industry undertake probabilistic risk assessments (PRAs) of specific plants for several reasons: (1) to provide additional insights into nuclear plant safety, (2) to take the initiative in plant safety analysis, and (3) to develop PRA methods that could help in plant design, operation, and licensing decisions. Duke Power Co. agreed to host a PRA of its Oconee Unit 3 (RP2354). The analysis has been completed and the final report published. The summary report contains a concise but complete description of the methods used and the project's major technical findings (NSAC-60-SY). The main report is a comprehensive reference document that describes in detail the analysis process and techniques and presents the models and their results (NSAC-60, Vols. 1–4). Analysts should be able to follow the step-by-step procedure from this documentation.

In addition to quantifying plant safety, the study results have been useful in a number of practical ways. When the analysts had initially completed the work, results focused on accidents caused by flooding of the turbine building basement that would disable much of the equipment required for removing decay heat from the reactor core. These analytic results were refined over several months to ensure that flood sources, flood frequency, postflood sequence of events, and operations staff postflood recovery had all been treated as realistically as possible.

Low-cost improvements

Several iterations of the analysis process not only made the sequence of flood events and their frequencies more realistic but also identified a number of modifications to plant design and operations that would significantly improve the plant's ability to cope with turbine building floods. Duke Power selected and implemented a set of these modifications, which reduced the estimated frequency of core-damaging accidents by more than an order of magnitude and were relatively inexpensive to carry out. Examples of these modifications are described below.

All openings in the basement walls of the turbine and auxiliary buildings, including doorways, were sealed to a height of 6 ft (1.8 m). A major complication of turbine building floods was that water could spill over into the auxiliary building. This flow could flood the electrically driven pumps necessary for reactor core cooling. Sealing wall openings eliminated this problem for all but the very largest floods.

Another modification Duke Power chose was to close two cross-connect valves between the condenser circulating water (CCW) systems of the three Oconee units. Closing the valves increased the time available to isolate a flood.

Lake Keowee, which lies above the plant site, provides water for both normal and emergency cooling. Valves in the condensate cooler flow path were modified to limit water flowing from the lake back to a CCW system pipe break but still allow enough water for essential-service water pumps. Decreasing the water flow to the flood gives operators more time to take corrective action.

However, a limited amount of backflow during a flood is necessary to provide suction for service water pumps. Backflow also provides a water source that the independent standby shutdown facility can use to remove heat from the steam generators if the flood has disabled all other systems. To provide a path for this limited backflow, Duke Power has fully opened the temperature control valves on selected condensate coolers.

One major source of water to feed a turbine building flood would be water forced by gravity from Lake Keowee through the CCW pump discharge valves and out through a pipe break. Previous CCW pump control logic left open the discharge valve on the last CCW pump to be stopped on that unit. The valve had to be closed locally. Installation of override switches allows operators to close all CCW pump discharge valves from the control room, which could rapidly isolate a flood.

Duke Power has also modified the large drain in the turbine building basement. During a flood, debris could clog the security grating in front of the drain. A trash screen with a very large surface area was installed to prevent this problem.

One key to rapid response to an accident is early, correct diagnosis of the problem. To this end, Duke Power installed a flood alarm system in the turbine building basement. This alarm will alert operators to early indications of abnormal water levels.

Plant operating and emergency procedures were reviewed and modified, where appropriate, to account for these hardware and configuration changes. For example, the utility revised the turbine building flood emergency procedure to include the flood alarm and to reflect the new valve positions.

These examples demonstrate the effectiveness of the PRA models, which identify specific operating and design features that affect a plant's ability to cope with accident event sequences. In addition to the modifications to control turbine building floods, PRA and the system reliability models have resulted in other useful findings and applications.

System analysis called for isolation of the integrated control system (ICS) simulator—a device used to tune the ICS after maintenance—from the actual ICS during normal operation. The practice of leaving the simulator connected at all times was discontinued to preclude the possibility that a fault in the simulator would cause a transient in the plant.

The operating procedures were improved to warn operators not to run low-pressure injection (LPI) pumps at low-flow levels for long periods, which might overheat pumps in the event of certain small loss-of-coolant accidents (LOCAs). System analysis also identified throttling of the reactor building spray pump discharge during post-LOCA recirculation to prevent pump runout. Analysis suggested ways for the operating staff to maintain suction flow to the emergency feedwater pumps during various types of transients.

Follow-on applications

PRA models and results have other applications. Duke Power used some results while the study was in progress to demonstrate that the continued operation of the Oconee units until the primary safety-relief valve settings could be adjusted was not unduly risky. The study evaluation formed a part of the justification that helped Duke Power obtain an emergency technical-specification authorization to continue operating one of the two available Oconee units for two weeks while the third unit was shut down to make the necessary adjustment. The PRA played an important role in saving the utility several million dollars for replacement power without compromising safety.

In another case, Duke Power modified the system models under development in the PRA to estimate the frequency of a transient that would result in rapid cooling of the reactor coolant system. The utility provided NRC with the results to show that it had sufficiently analyzed the pressurized thermal shock issue.

Duke Power has recently used the plant and system models to evaluate the cost-effectiveness of reactor vessel level instrumentation. As a participant in RP2142-1, the utility will use these models to evaluate selected plant technical specifications for possible relaxation of allowed outage time or test frequency.

Current program direction

Experience to date shows that utility use of PRA and system reliability analysis techniques can go far beyond quantifying public risk and estimating accident frequency. As a result, a major thrust of the Safety Technology Department's development programs in this area is use of these techniques to provide information that will aid plant management. One example of such an application is the project to optimize technical specifications. A reliability-centered maintenance technique is being tested for development of effective preventive maintenance programs that eliminate unnecessary and unproductive tasks (RP2508-2). A software system called RAPID (reliability analysis program with integral data) is being developed in RP2508-1 to help operations personnel quickly evaluate the impact on overall plant reliability of removal of specific equipment from service, to evaluate alternative technical specification strategies, and to perform other system reliability analyses efficiently. EPRI expects that projects such as these will result in productive applications that can easily offset the costs of the associated system reliability analysis and modeling. *Project Manager: W. R. Sugnet*

New Technical Reports

Each issue of the *Journal* includes information on EPRI's recently published reports.

Inquiries on technical content may be directed to the EPRI project manager named at the end of each entry: P.O. Box 10412, Palo Alto, California 94303; (415) 855-2000.

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Guidebook for the Use of Synfuels in Electric Utility Combustion Systems: Coal-Derived Gases
AP-3348 Final Report (RP2106-1), Vol. 2; $17.50
Contractor: KVB, Inc.
EPRI Project Manager: W. Rovesti

Laser Recrystallization of Compound Semiconductor Films
AP-3533 Final Report (RP1193-2); $10.00
Contractor: Poly Solar, Inc.
EPRI Project Manager: R. Taylor

Wind Turbine Operation and Maintenance Experience
AP-3735 Interim Report (RP1996-2); $16.00
Contractor: R. Lynette & Associates, Inc.
EPRI Project Manager: F. Goodman

Methanol Catalyst Preparation
AP-3798 Final Report (RP1656-1); $13.00
Contractor: United Catalysts, Inc.
EPRI Project Manager: N. Hertz

Experimental Control Analysis of a Fuel Gas Saturator
AP-3799 Final Report (RP2389-1); $14.50
Contractor: General Electric Co.
EPRI Project Manager: G. Quentin

Water-Steam Rankine-Cycle Solar Central Receiver Power Plant: Cost Estimates
AP-3801 Final Report (RP1990-1); $23.50
Contractor: Bechtel Group, Inc.
EPRI Project Manager: S. Kohan

Proceedings: Ninth Annual EPRI Contractors' Conference on Coal Liquefaction
AP-3825-SR Special Report; $64.00
EPRI Project Manager: H. Lebowitz

Light Ion System Analysis and Design
AP-3853 Final Report (RP1527); Vol. 1, $17.50; Vol. 2, $11.50
Contractors: Bechtel Group, Inc.; Physics International Co.
EPRI Project Managers: K. Billman, R. Scott

Biomass Gasification for Electric Utility Diesel Generating Units
AP-3865 Final Report (RP1348-16); $13.00
Contractor: Burns & McDonnell Engineering Co.
EPRI Project Managers: S. Kohan, M. Gluckman

Cool Water Coal Gasification Program: Third Annual Progress Report
AP-3876 Interim Report (RP1459); $13.00
Contractors: Cool Water Coal Gasification Program; Bechtel Power Corp.
EPRI Project Manager: T. O'Shea

Acid Corrosion in a Simulated Clean-Gas Saturator of a Coal Gasifier
AP-3879 Final Report (RP2048-3); $16.00
Contractor: Ohio State University
EPRI Project Managers: W. Bakker, B. Syrett

Technical Risks and R&D Requirements for Inertial Confinement Fusion
AP-3883 Final Report (RP1972-1); Vol. 1, $8.50; Vol. 2, $19.00
Contractors: TRW, Inc.; Woodward-Clyde Consultants; Burns and Roe, Inc.
EPRI Project Manager: K. Billman

Influence of Hydrogen Bonding and Structural Features of Coal on Its Liquefaction
AP-3889 Interim Report (RP2147-4); $10.00
Contractor: Rockwell International Corp.
EPRI Project Manager: L. Atherton

Laboratory Combustion Study of EDS Coal-Derived Liquids
AP-3910 Final Report (RP1412-90); $11.50
EPRI Project Manager: W. Rovesti

COAL COMBUSTION SYSTEMS

Coal Cleaning Test Facility Campaign Report Number 1: Freeport Seam Coal
CS-3808 Interim Report (RP1400-6, -11); $17.50
Contractors: Raymond Kaiser Engineers, Inc.; Science Applications, Inc.
EPRI Project Managers: C. Harrison, J. Hervol

Gas-Cleaning Technology for High-Temperature, High-Pressure Gas Streams
CS-3812 Annual Report (RP1336-1); $16.00
Contractor: Westinghouse Electric Corp.
EPRI Project Managers: S. Drenker, O. Tassicker

Water Management Assessment Using Flow and Mass Balances
CS-3845 Final Report (RP2114-1); $20.50
Contractor: CH2M-Hill, Inc.
EPRI Project Manager: W. Chow

Combined Makeup and Sidestream Softening Field Test for a Proposed Closed-Cycle Cooling-System Design
CS-3852 Final Report (RP1261-6); $13.00
Contractors: Stearns Catalytic Corp.; Radian Corp.
EPRI Project Managers: W. Chow, W. Micheletti

Arapahoe Low-Sulfur-Coal Fabric Filter Pilot Plant: Fluid Dynamics Testing, May–September 1980
CS-3862 Final Report (RP1129-8), Vol. 1; $14.50
Contractor: Southern Research Institute
EPRI Project Manager: R. Carr

Survey of Steam Turbine Blade Failures
CS-3891 Final Report (RP1856-1); $13.00
Contractor: Stress Technology, Inc.
EPRI Project Manager: T. McCloskey

Groundwater Manual for the Electric Utility Industry
CS-3901 Final Report (RP2301-1), Vols. 1–3; $200.00 per volume
Contractor: Southern Company Services, Inc.
EPRI Project Manager: D. Golden

Pilot Plant Evaluation of Chemical Coal Cleaning by Promoted Oxydesulfurization
CS-3902 Final Report (RP833-2); $20.50
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EPRI Project Managers: W. Slaughter, R. Row

ELECTRICAL SYSTEMS

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EPRI Project Manager: G. Addis

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EPRI Project Manager: J. Lamont

Long-Term System Dynamics Simulation Methods
EL-3894 Final Report (RP1469-1); $19.00
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EPRI Project Manager: J. Lamont

Development of Cross-Linked Polyethylene Insulated Cable for Cryogenic Operation
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Contractor: Cable Technology Laboratories, Inc.
EPRI Project Manager: M. Rabinowitz

ENERGY ANALYSIS AND ENVIRONMENT

Case Studies in Technology Choice
EA-3619 Final Report (RP1433-1); Vol. 1, $16.00; Vol. 2, $14.50
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EPRI Project Manager: L. Rubin

Utility Planning Tools Catalog
EA-3793 Final Report (RP1634); $14.50
Contractor: Booz, Allen & Hamilton, Inc.
EPRI Project Manager: D. Geraghty

Market Analysis Methodology: A Utility Case Study
EA-3794 Final Report (RP1634); $10.00
Contractor: Booz, Allen & Hamilton, Inc.
EPRI Project Manager: D. Geraghty

Residential Load Forecasting for Small Utilities: Reference Guide
EA-3805 Final Report (RP1985-1), Vol. 1; $17.50
Contractor: Burns & McDonnell Engineering Co.
EPRI Project Manager: J. Wharton

Evaluation of EPRI Options for the Development and Commercialization of Modular Small Hydroelectric Power Plants
EA/EM-3820 Final Report (RP1432-1-1, -3-1); $13.00
Contractors: Applied Decision Analysis, Inc.; Decision Focus, Inc.
EPRI Project Managers: S. Chapel, C. Sullivan

Innovative Rate Design Survey
EA-3830 Final Report (RP2381-5); $23.50
Contractor: Ebasco Business Consulting Co.
EPRI Project Manager: J. Chamberlin

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EA-3890 Final Report (RP2074-1); Vol. 1, $8.50; Vol. 2, $14.00
Contractor: Temple, Barker & Sloane, Inc.
EPRI Project Manager: D. Geraghty

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EA-3917 Final Report (RP679-6); $11.50
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EPRI Project Manager: R. Patterson

Toxicology of Fossil Fuel Combustion Products
EA-3920 Final Report (RP1596-1); Vol. 1, $19.00; Vol. 2, $25.00
Contractor: Systems Applications, Inc.
EPRI Project Manager: G. Newell

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Solar Residential Heating and Cooling Field Test Program
EM-3817 Final Report (RP549-3); Vol. 1, $14.50; Vol. 2, $22.00
Contractor: Arthur D. Little, Inc.
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Baseline Cycle Testing of a 500-kWh Zinc Chloride Battery at the Battery Energy Storage Test Facility
EM-3836 Interim Report (RP255-2); $10.00
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EPRI Project Manager: W. Spindler

Residential Load Management Technology Review
EM-3861 Final Report (RP1940-6); $26.50
Contractor: Analysis and Control of Energy Systems, Inc.
EPRI Project Manager: V. Rabl

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EM-3866 Proceedings (RP2285-7); $13.00
Contractor: Government Institutes, Inc.
EPRI Project Manager: S. Pertusiello

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EM-3867 Final Report (RP1276-5); Vol. 1, $8.50; Vol. 2, $11.50; Vol. 3, $14.50; Vol. 4, $13.00
Contractor: Burns and Roe, Inc.
EPRI Project Manager: D. Hu

Evaluation of Dual Energy Use Systems (DEUS): Distillation Applications
EM-3868 Final Report (RP1276-13); Vol. 1, $8.50; Vol. 3, $26.50; Vol. 2, forthcoming
Contractors: Procon International, Inc.; Black & Veatch Engineers-Architects
EPRI Project Manager: D. Hu

Updated Cost Estimate and Benefit Analysis of Customer-Owned Battery Energy Storage
EM-3872 Interim Report (RP1275-12); $16.00
Contractor: Bechtel Group, Inc.
EPRI Project Manager: D. Douglas

NUCLEAR POWER

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NP-3497 Interim Report (RP959-1); $43.00
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EPRI Project Manager: A Singh

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NP-3772 Final Report (RP1068-4); $10.00
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NP-3773 Topical Report (RP966-2); $8.50
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EPRI Project Manager: C. Wood

Proceedings: Third International RETRAN Conference
NP-3803-SR Proceedings; $70.00
EPRI Project Manager: L. Agee

Joint TMI-2 Information and Examination Program: EPRI Participation and Support
NP-3810-SR Special Report; $13.00
EPRI Project Manager: A. Roberts

Influence of Induction Heating Stress Improvement Treatment on Ultrasonic Reflectivity of IGSCC
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IGSCC Detection in BWR Piping Using the Minac
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Diagnostic Training for Nuclear Plant Personnel: Courseware Development
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Microchemistry of Corroded Intergranular Surfaces
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Use of the HITCH Code to Evaluate Amines as Neutralizers of Crevice Acidity in Nuclear Steam Generators
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Steam-Water Flooding in Debris Beds and Its Role in Dryout
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Combined Convection and Radiation Heat Transfer Under Conditions Simulating Uncovered Reactor Fuel Rods
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NP-3887 Final Report (RP1707-1, -10); $14.50
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EPRI Project Manager: G. Sliter

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NP-3906 Interim Report (RP2406-1); $10.00
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EPRI Project Manager: R. Lambert

Proceedings: International Topical Meeting on Probabilistic Safety Methods and Applications
NP-3912-SR Special Report, Vols.1–3; $125.00 per set
EPRI Project Manager: I. Wall

In Situ Application of Hard-Facing Materials in Main Steam Isolation Valves
NP-3926 Final Report (RP2186-1, -2, -4); $16.00
Contractors: J. A. Jones Applied Research Co.; ESD Corp.; Hobart Brothers Co.
EPRI Project Manager: B. Brooks

R&D STAFF

Grain Boundary Composition and Intergranular Fracture of Steels: Detection of Grain Boundary Segregation in Steels
RD-3859 Final Report (RP2257-1), Vol. 1; $11.50
Contractor: Battelle, Pacific Northwest Laboratories
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Version 1.0 (IBM–PC)
Contractor: Woodward-Clyde Consultants
EPRI Project Manager: D. Fromholzer

EGEAS: Electric Generation Expansion Analysis System
Version 2.0 (IBM); EL-2561
Contractor: Stone & Webster Engineering Corp.
EPRI Project Manager: N. Balu

FAST: Decision Framework for Ambient Air Quality Standards
Version 1.1 (generic use); EA-3193
Contractor: Decision Focus, Inc.
EPRI Project Manager: D. Fromholzer

ILWAS: Integrated Lake-Watershed Acidification Study
Version 1.1 (IBM); EA-3221
Contractor: Tetra Tech, Inc.
EPRI Project Manager: R. Goldstein

REEPS: Residential End-Use Energy Planning System
Version 1.0 (IBM); EA-2512 and EA-3409
Contractor: Cambridge Systematics, Inc.
EPRI Project Manager: S. Braithwait

SHORT: Transient Temperature of URD Cables
Version 1.0 (IBM–PC); EL-3102 CCM
Contractor: Pirelli Cable Corp.; Georgia Power Co.
EPRI Project Manager: H. Songster

STEALTH–SEISMIC
Version 4-1A (CDC, IBM); NP-2080 CCM, Vols. 5, 9
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