Power Quality

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ELECTRIC POWER RESEARCH INSTITUTE

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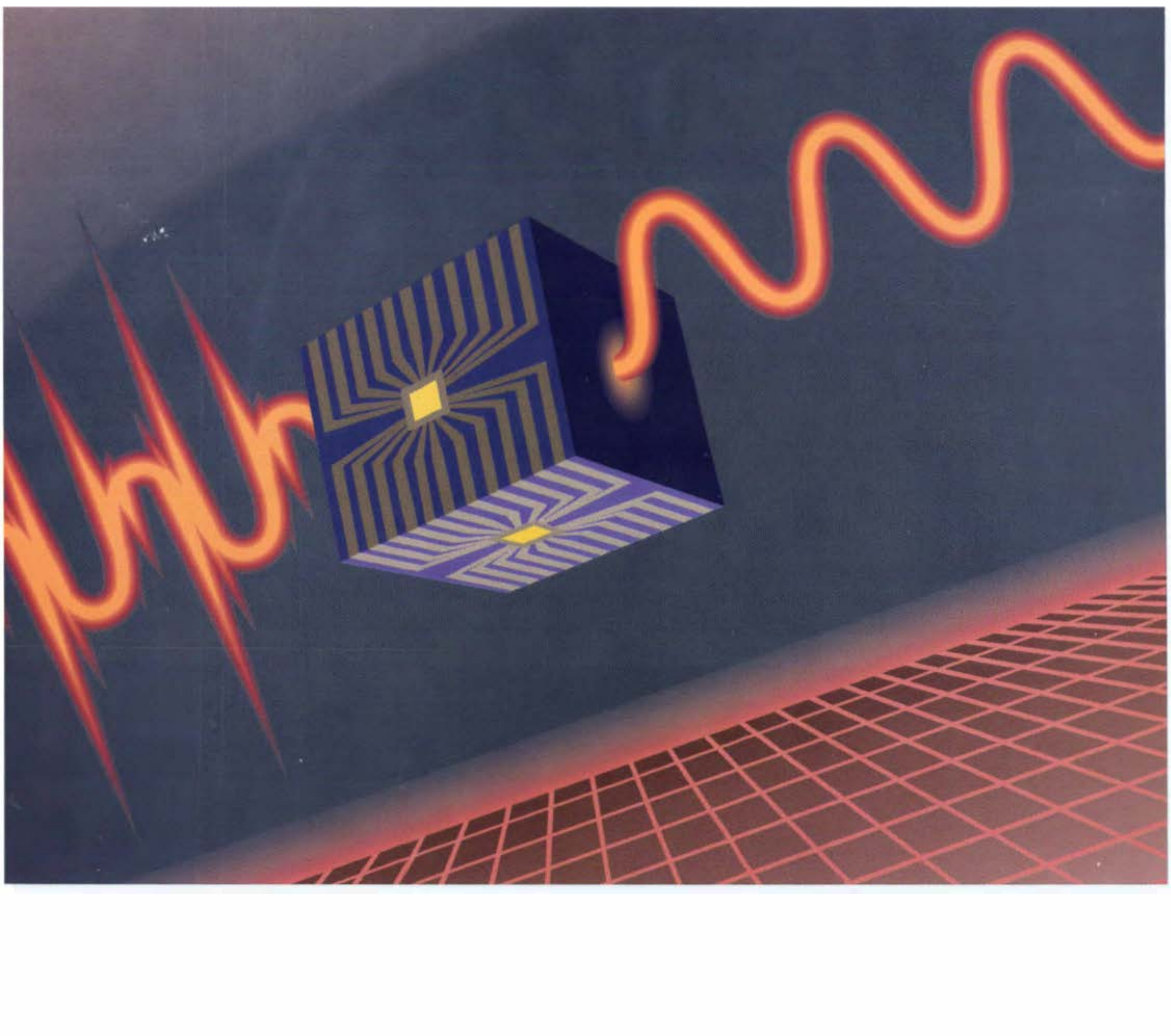

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Cover: Solid-state controllers are at the heart of many devices designed to smooth out power glitches.

EPRI JOURNAL

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COVER STORY

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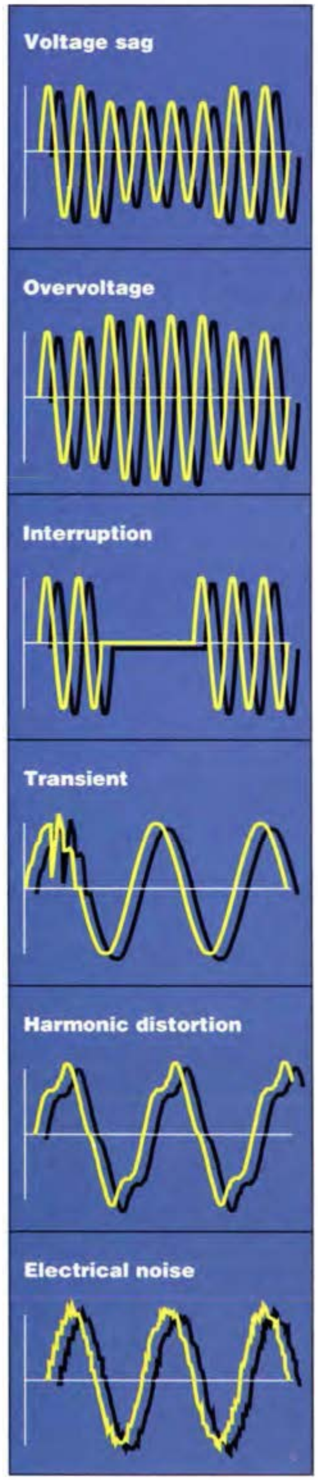
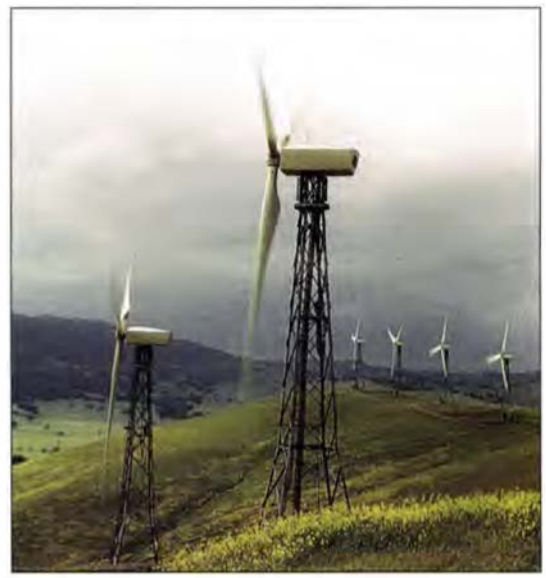


Each year, R&D Magazine's panel of scientific experts selects 100 new products to receive the prestigious R&D 100 Awards. The panel considers these products to be the year's most technologically significant. Presented annually for the past 30 years, the R&D 100 Awards recognize the achievements of inventors and scientists around the world. Past winners include such well-known products as the video recorder, antilock brakes, the automatic teller machine, and the fax machine. This year, four EPRI-sponsored products received R&D 100 Awards.

SureSine for Clean Power

The SureSine™ active power line conditioner solves a variety of power quality problems that cost American businesses, industries, and government agencies billions of dollars each year. This product line, developed by Westinghouse Electric Corporation with support from EPRI and Public Service Electric & Gas Company, is the first integrated electronic package to combine adaptive, active harmonic filtering with sag compensation and instantaneous line voltage regulation. Installed on the customer's premises, it offers two-way protection against power disturbances—against those coming off the utility grid and those produced by the customer's equipment. Whether the problem is a momentary surge, sag, or harmonic distortion, SureSine corrects it to provide clean power. Measuring less than 2 square feet, the 5-kVA single-phase SureSine unit allows for flexibility in terms of mounting. With support from EPRI and PSE&G, Westinghouse plans to add more features, such as ride-through capability and capacitor switching surge suppression.

For more information, contact B. Ben Banerjee, (415) 855-7925. To order, call Robert McCallion at Westinghouse, (410) 584-5979.



Competitive Wind Energy

Until the arrival of the 33M-VS variable-speed turbine, cost-competitive wind power was not widely available. This new turbine, developed by Kenetech/U.S. Windpower in conjunction with EPRI, Niagara Mohawk Power Corporation, and Pacific Gas and Electric Company, offers electricity for 5¢/kWh, which makes it 40% more cost-effective than the best wind machines on the market today. The turbine's variable-speed capability enables it to change rotational speed with the speed of the wind. This feature increases energy capture and prolongs the life of the turbine drivetrain. Relatively light components reduce manufacturing and operating costs. The turbine, which generates 350–400 kW, is available only to utilities and qualified developers; a minimum order of 75 machines is required.

For more information, contact Edgar DeMeo, (415) 855-2159. To order, call Dale Osborn at Kenetech/U.S.Windpower, (415) 398-3825.

Mos-Controlled Thyristor

Harris Corporation packed a lot of power into this little device. Measuring 1.5 by 1 by 0.25 inch, the MOS-controlled thyristor is a semiconductor switch that allows for faster, more efficient control of electric power. Compared with the next best switch on the market, it slices power losses in half and offers the capability to handle roughly 20 times the current level. It also can operate in very high temperature environments that would incapacitate other switches. Moreover, it happens to be the most affordable semiconductor power switch ever developed. Currently it is available in 600-volt (MCTV75P60E1) and 1000-volt (MCTV65P100F1) models only. A full product line is being developed that is expected to range from 200 volts to as high as 5000 volts. *For more information, contact Harshad Mehta, (415) 855-2293. To order, call Fred Lokuta at Harris Corporation, (717) 474-3273.*

Sandsaver 2001

Now metal foundries can meet sand disposal regulations and save money with the Sandsaver 2001 reclamation process. Developed by EPRI's Center for Materials Production in cooperation with Indianapolis Power & Light Company, Navistar International Transportation Corporation, and BGK Finishing Systems, Sandsaver 2001 uses infrared heating and fluidized-bed technologies to clean the spent sand that foundries have used to make molds and cores for metal castings. The product's name reflects the year-2001 deadline set by local, state, and federal mandates requiring a 50% reduction in solid-waste disposal. Reclaiming about 90% of the used sand, Sandsaver 2001 offers the potential for saving millions of dollars in disposal costs annually. Reduced sand transportation also cuts back significantly on oil consumption and carbon dioxide emissions.
For more information, contact Gene Eckhart, (202) 293-7517. To order, call David Bannick at BGK Finishing Systems, Inc., (612) 784-0466.

Ocean Process Could Offset CO_2 Buildup

Although carbon dioxide (CO_2) emissions from human sources (largely energy-related) are the subject of rising concern as a possible contributor to global warming, the amount of carbon thus released is very small in relation to the natural carbon cycle. Much larger amounts of carbon are sequestered and exchanged each year in a cycle involving oceanic, atmospheric, and land-based processes and reservoirs. Even slight changes in the natural exchange or capture mechanisms involved could offset the anthropogenic contribution.

One carbon-fixing process currently being studied as a potential way to counterbalance atmospheric increases in CO_2 involves so-called whitings—white, turbid suspensions of lime mud that form in shallow tropical seas. These cloudy suspensions are composed of very fine grained calcium carbonate ($CaCO_3$) crystals, thought to be precipitated by bacterial activity. The whiting phenomenon is being studied with support from EPRI's Office of Exploratory & Applied Research by scientists at the University of South Florida (USF).

Whiting formations (circled) near Andros Island in the Bahamas

The specific cause of whitings is the subject of considerable debate. Some scientists have attributed the clouds to the resuspension of shallow carbonate sediments as a result of storms or ocean currents, but USF researchers have recently established that whitings are biologically induced. The researchers hypothesize that $CaCO_3$ crystals form on the outer membrane of certain photosynthetic bacteria, such as the genus *Synechocystis*, under specific conditions of light, alkalinity, and carbon concentration.

Laboratory analyses of water samples taken along transects across whitings in Bahamian waters indicate that these formations reduce CO_2 concentrations near the ocean surface and thus drive the increased oceanic absorption of atmospheric CO_2. Whitings generally last from one day to two weeks, after which the precipitated $CaCO_3$ sinks to the bottom of the ocean—effectively sequestering the carbon.

If ways to promote the formation of whitings could be found, the absorption of CO_2 from the atmosphere might be increased significantly. Indeed, there is evidence that biologically induced carbonate precipitation was instrumental in removing CO_2 from the atmosphere at the end of the Cretaceous period—creating such spectacular geologic formations as the white cliffs of Dover. The initial data from the USF research suggest that whitings in the range of 50–100 km^2 could offset the annual CO_2 output of a large fossil power plant.

The USF scientists have cultured *Synechocystis* in the laboratory to verify their field data and to determine how improved cultivation practices could allow natural-strength whitings to be artificially induced. The researchers are also studying satellite images to better evaluate the global occurrence and density of whitings and to determine whether they are increasing naturally in response to higher atmospheric concentrations of CO_2. Understanding the biochemical processes involved in the formation of whitings could also lead to new water purification techniques that induce the precipitation of trace elements and other pollutants.

■ *For more information, contact Robert Goldstein, (415) 855-2593.*

Improving Lamp Design With Nonimaging Optics

Until recently, there was no systematic methodology for determining how to achieve the desired illumination on a surface from an extended source of light, such as a fluorescent tube. Designing reflectors to direct light rays from a source toward a target was essentially a matter of trial and error. Now a new methodology, called nonimaging optics, offers a way to design lighting fixtures that are more efficient, cause less glare, and provide a specified distribution of light on a target.

Traditional optics has used a method of analysis in which rays of light from a point source are focused to reconstruct an image of the point. However, modeling the efficient transfer of light energy from an extended source does not require the consideration of image focusing, with its complex mathematical analysis of the rays from all points on a source. Rather, nonimaging optics can determine target irradiance distribution by considering just those rays emitted at or near the edge of a source.

Nonimaging optics was initially used to develop solar concentrator designs that optimize the conversion of solar radiation to electricity. Now EPRI-sponsored research at the Ecole des Mines, in Paris, is using nonimaging optics to analyze and develop improved reflector designs for fluorescent lamps and other extended sources. Recent results have shown, for example, that light from a fluorescent bulb can theoretically be distributed evenly over a limited target region by using either flat or slightly curved reflectors along both sides of the tube.

Future work will explore the application of nonimaging optics to actual lighting design. Eventually the methodologies developed in this work will be incorporated into software for use by architects and the lighting industry. Research objectives include establishing the theoretical maximum efficiency of fixtures with glare cutoffs and developing the fixture shapes required to achieve uniform illuminance.

■ *For more information, contact Karl Johnson, (415) 855-2183.*

New Coal-Grinding Approach Saves Energy

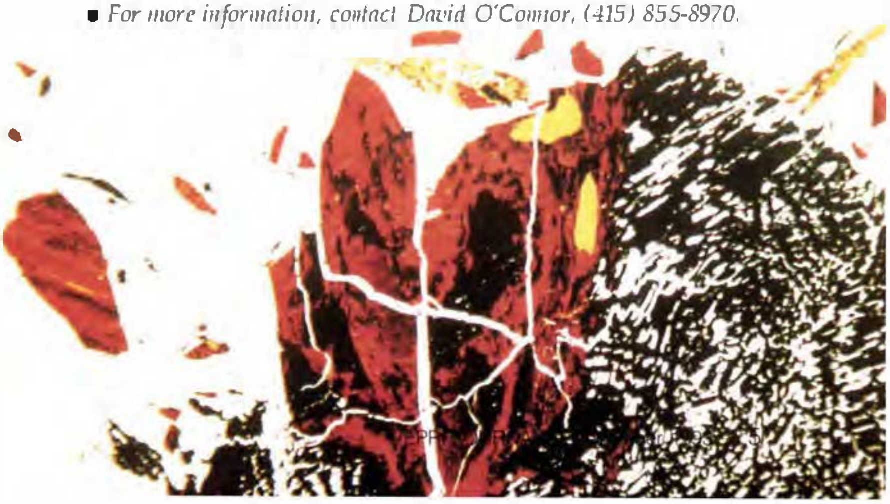
In the conventional grinding mills used to pulverize coal for utility power plants, only about 1% of the energy expended actually goes into reducing the size of the coal particles. Most of the rest is wasted on metal-to-metal contact and friction. The initial results of EPRI-sponsored research at the University of California at Berkeley indicate that a novel, two-stage mill could reduce energy use by 20–50% while producing particles that offer improved combustion performance.

The basic principle of the new mill is that direct compression is the most energy-efficient way to break up pieces of coal. The first stage of the hybrid mill, therefore, features a series of high-pressure rollers that accomplish most of the size reduction. In the second stage, a conventional ball mill (a rotating hollow cylinder with steel balls inside) further breaks up the coal particles to produce fine grains. Oversized particles emerging from the ball mill are recycled back to the high-pressure roll mill. The improvement in the combustion characteristics of the coal may be due to the fact that the particles are finer and more consistent in size.

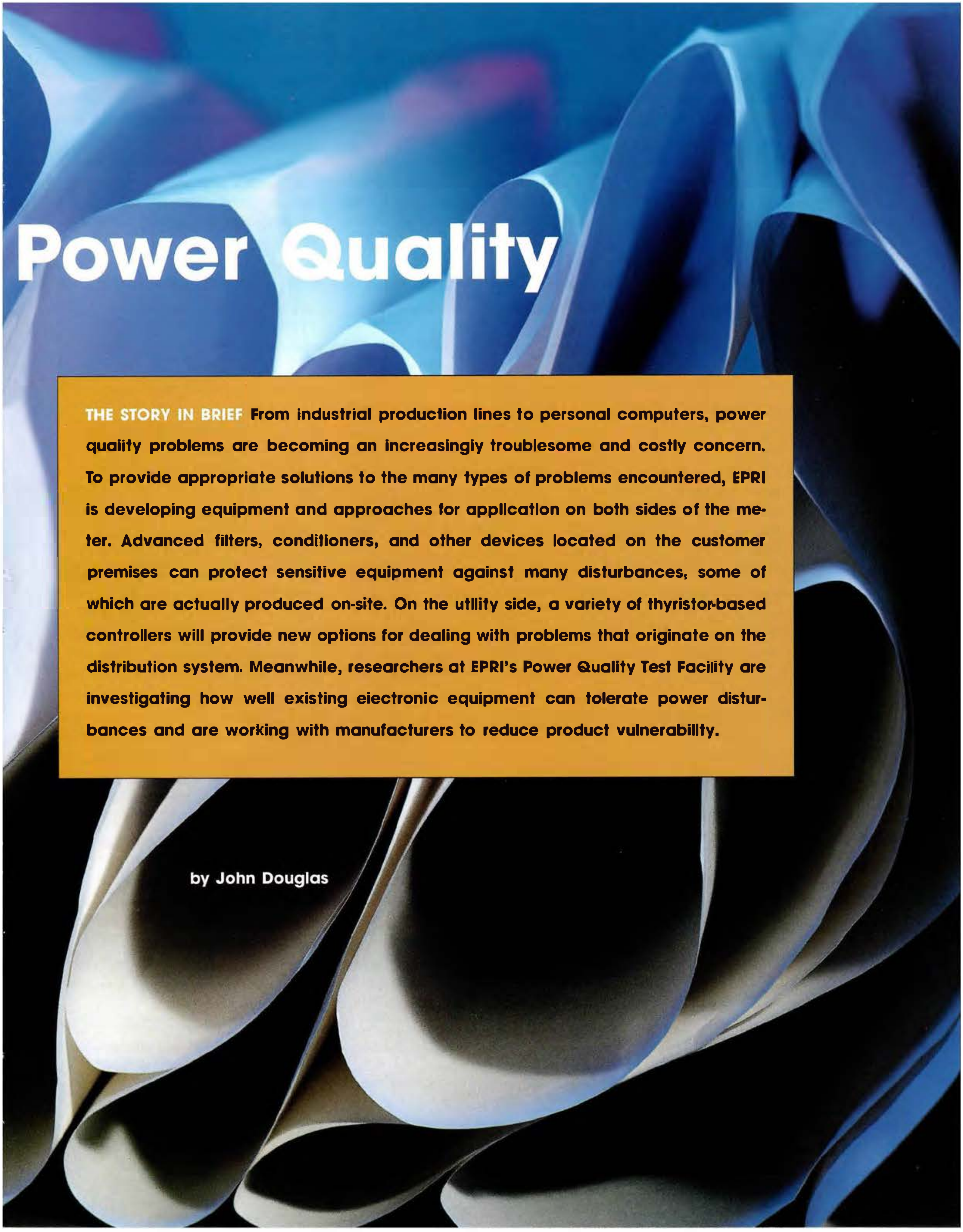
Related research at the University of North Carolina indicates that the increased use of compression during grinding may also make coal cleaning easier. Compression causes coal particles to fracture along grain boundaries—a process that tends to separate carbon grains from grains containing sulfur-bearing minerals. Such separation could potentially facilitate the removal of the sulfur through conventional or advanced coal cleaning.

Tests of the new hybrid mill are continuing, and simulations are being conducted to determine whether it can be retrofitted to existing grinding circuits. If the tests are successful, EPRI will consider putting together a consortium of utilities, vendors, and other interested parties to scale up the grinding technology.

■ *For more information, contact David O'Connor, (415) 855-8970.*



Solving Problems of



Power Quality

THE STORY IN BRIEF **From industrial production lines to personal computers, power quality problems are becoming an increasingly troublesome and costly concern. To provide appropriate solutions to the many types of problems encountered, EPRI is developing equipment and approaches for application on both sides of the meter. Advanced filters, conditioners, and other devices located on the customer premises can protect sensitive equipment against many disturbances, some of which are actually produced on-site. On the utility side, a variety of thyristor-based controllers will provide new options for dealing with problems that originate on the distribution system. Meanwhile, researchers at EPRI's Power Quality Test Facility are investigating how well existing electronic equipment can tolerate power disturbances and are working with manufacturers to reduce product vulnerability.**

by John Douglas

The proliferation of microelectronic processors in a wide range of equipment—from home VCRs and digital clocks to automated industrial assembly lines and hospital diagnostic systems—has increased the vulnerability of such equipment to power quality problems. These problems include a variety of electrical disturbances, which may originate in several ways and have very different effects on various kinds of sensitive loads.

What were once considered minor variations in power—usually unnoticed in the operation of conventional equipment, such as lights and constant-speed motors—may now bring whole factories to a standstill. A power interruption or 30% voltage sag lasting mere hundredths of a second, for example, can reset programmable controllers for an assembly line, while adjustable-speed drives for motorized equipment on the assembly line may themselves be sensitive to voltage harmonics and transients. The cost of such interference can be substantial. One glass plant, for instance, estimates that a five-cycle interruption—an outage of less than a tenth of a second—can cost about $200,000, and a major computer center reports that a 2-second outage can cost some $600,000.

As a result of this vulnerability, increasing numbers of industrial and commercial facilities are trying to protect themselves by investing in equipment to improve power quality, such as uninterruptible power supply (UPS) systems, surge suppressors, and isolation transformers. Corporate data processing centers, for example, can justify an increase of as much as 45% in their capital investment for on-site power distribution facilities in order to ensure adequate electricity quality. Products and services related to power quality now represent a multibillion-dollar market in the United States alone.

Which approach to power quality is best, however, depends largely on specific circumstances. Some problems, such as harmonic interference between different electrical loads on the same line inside a building, are often solved most easily on a customer's premises. Others, such as momentary power disruptions caused by lightning strikes or substation switching operations, may be less expensive to correct on the utility's side of the meter. Determining the most cost-effective approach in particular situations requires, first, more information about the causes of power quality problems in general and, second, the development of new analytical tools for utilities to use in advising their customers.

There are also major opportunities, including several based on recent developments in power electronics, to improve power-conditioning equipment for both sides of the meter. More-efficient inverters for on-line UPS systems, for example, will reduce losses from the power that continuously flows through them. Thyristor-based controllers for distribution systems will provide new options for reducing power interruptions that originate on utility lines. Equipment manufacturers are also incorporating power quality protection into their products. Examples include filters to mitigate the effect of harmonics, special circuits to provide power factor correction, and capacitors that provide enough stored energy to enable digital clocks to ride through brief interruptions. EPRI is working with manufacturers in some of these development efforts.

Responding to these needs and opportunities, EPRI is accelerating an already wide-ranging program of research to study and solve power quality problems. Surveys are under way to better understand the causes and effects of power disturbances, as seen both on utility systems and at individual customer sites. The power quality characteristics of important categories of sensitive equipment, such as personal computers, are being measured, and more-advanced power conditioners are being developed for use by customers. EPRI is also developing advanced power electronic controllers for use on utility distribution systems.

Assessing power quality

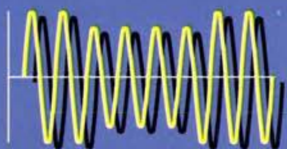
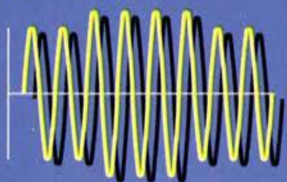
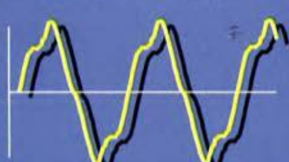
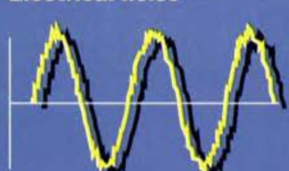
As the need for more information about power quality became apparent over the past few years, EPRI launched two major studies to determine the extent and nature of problems and to identify potential solutions. One effort was aimed at customers and has produced a series of targeted how-to documents for dealing with power quality problems in various end-use situations. A standardized power quality assessment procedure was also produced as part of this effort. The second study, now at its midpoint, involves the use of 300 power quality monitoring nodes on the distribution systems of 24 utilities throughout the United States and is being extended to customer sites. Preliminary results have recently become available and are providing valuable insights into the causes and impacts of various utility system events that affect power quality. Both studies were undertaken by Electrotek Concepts, Inc., of Knoxville, Tennessee.

Several important conclusions emerged from the end-user study. The researchers found that, despite growing concern over power quality, many large industrial customers need to be better educated about how specific problems affect their equipment and about the potential solutions that are available. The three kinds of equipment found to be most susceptible to common disturbances are programmable logic controllers, automated data processors, and adjustable-speed drives (ASDs). The four kinds of disturbance that present the most problems with these types of equipment are voltage sags, momentary interruptions, transients, and harmonics. The cost of losses associated with these problems may exceed the original purchase price of the affected equipment many times over.

The initial phase of the study was followed by 38 detailed case studies at 17 participating utilities. The 32 cases that have been completed have revealed a variety of specific power quality problems facing important industrial and commercial customers.

Automotive plants, for example, are major power consumers; their peak loads are 20 MW or more, typically supplied by two separate distribution lines. While the presence of multiple, redundant lines means that a transmission system fault or the loss of a substation transformer will

SOLUTIONS ON BOTH SIDES OF THE METER

Disturbance	Possible Causes	Utility-Side Solutions	Customer-Side Solutions
Voltage sag 	• Lightning strike • Tree or animal contact with lines	• Dynamic voltage restorer • Static condenser	• Line conditioner • Uninterruptible power supply
Overvoltage 	• Fault on another phase • Load rejection	• Dynamic voltage restorer • Fault current limiter • High-energy surge arrester	• Line conditioner • Voltage regulator • Uninterruptible power supply
Interruption 	• Blown fuse • Breaker operation in response to fault	• Solid-state circuit breaker • Static condenser	• Uninterruptible power supply • Motor-generator set
Transient 	• Lightning strike • Utility switching	• High-energy surge arrester	• Line conditioner • Surge suppressor
Harmonic distortion 	• Nonlinear loads • Ferroresonance	• Filter • Static condenser • Dynamic voltage restorer	• Line conditioner • Filter
Electrical noise 	• Improper customer wiring or grounding		• Grounding and shielding • Line conditioner • Filter

Note: The solutions listed are not inclusive. In a given situation, the ultimate solution will depend on such factors as economic issues, system configuration, the utility-customer relationship, and the customer's electrical environment.

typically cause only a brief voltage sag, even such momentary events may have a significant cost. Following a voltage sag, for example, the restarting of assembly lines may require clearing the lines of damaged work, restarting boilers, and reprogramming automatic controls—for a typical cost of about $50,000 per incident. One automaker estimated that the total losses from momentary power glitches at all its plants run to about $10 million a year. The researchers concluded that most automotive manufacturing equipment could be engineered to withstand small voltage dips and that constant-voltage transformers could help sensitive equipment ride out larger voltage sags.

EPRI's national study of power quality on utility distribution systems began in 1992 and will continue through 1995. Monitoring sites were chosen to produce statistically valid conclusions about how distribution systems in general respond to various power quality problems. Results so far indicate that the most important cause of momentary voltage sags is lightning strikes. In the majority of sags, the voltage drops to about 80% of nominal value. In terms of duration, sags tend to cluster around three values: 4 cycles (the typical clearing time for faults), 30 cycles (the instantaneous reclosing time for breakers), and 120 cycles (the delayed reclosing time for breakers). The effect of a voltage dip on equipment depends on both its magnitude and its duration; about 42% of the sags observed to date were severe enough to exceed the tolerance standard adopted by computer manufacturers.

Another common event that can cause power quality problems is capacitor switching on the distribution system. Although such switching is a long-established practice that usually doesn't affect customer equipment, problems can arise at some large industrial sites that have their own transformers and capacitor banks for power factor correction. In such cases, a resonant oscillation may be set up in the customer's line that magnifies the effect of the utility's switching operation. A momentary overvoltage some three to four times the nominal rating may thus be created, tripping or even damaging protective devices and equipment. Electronically based ASDs for industrial motors are particularly susceptible to these transients. A planned extension of the EPRI distribution power quality project will include simultaneous monitoring of power disturbances on both sides of the meter at affected sites.

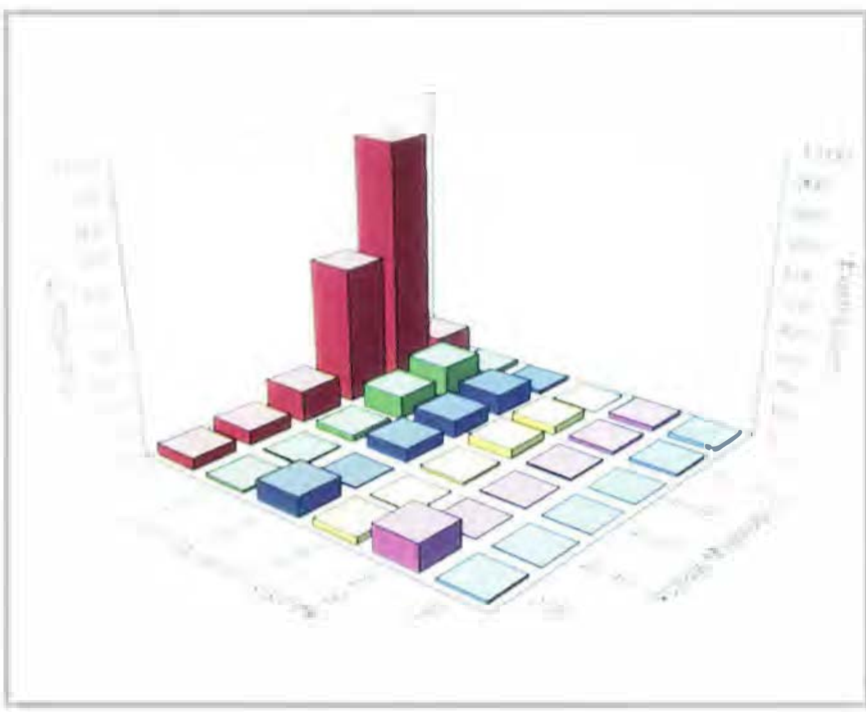
Remedies—customer side of the meter

A variety of technical options are available to correct power quality problems. The choice of which to use—and whether to focus on the customer's or the utility's side of the meter—depends largely on specific circumstances, but research to date has provided some important guidelines.

The majority of minor power disturbances in commercial buildings can be remedied by making improvements in facility wiring and grounding. Sensitive loads and electrically "dirty" loads, for example, can be isolated on dedicated branch circuits to minimize interference. Care must be taken to prevent power anomalies from passing between such dedicated circuits by way of shared neutral wires or ground connections. The National Electrical Code stipulates that the steel frame of a commercial building be bonded to ground at the utility service entrance. Problems can arise, however, if bonds are made inside a building between neutral wires and the grounded frame, creating inadvertent connections between loads and allowing stray currents to cause disruptions.

In many industrial plants, adjustable-speed drives require special consideration, since they are a major source of some power quality problems, especially harmonics, and are particularly susceptible to others, such as voltage surges and sags. ASDs work by first rectifying constant-frequency, constant-voltage ac power to dc and then inverting this dc power to create a variable-frequency, variable-voltage ac output. This process feeds harmonic volt-

ANALYZING VOLTAGE PROBLEMS **Studies of voltage sags and outages on utility distribution lines reveal that the great majority of events involve very brief (<10-cycle) disturbances in which voltage drops by 20–40%. Such information can help engineers design equipment capable of handling the most important power quality concerns.**



age distortions back onto the line, where they can interfere with sensitive electronic loads. In turn, the dc section of an ASD is particularly susceptible to momentary overvoltages coming from the outside.

In general, harmonics caused by ASDs are not a problem unless these devices make up a major part of the load supplied by a customer's transformer. But if the site also has capacitors for power factor correction, the resulting resonant circuit may magnify the effect of a particular harmonic frequency. EPRI research has verified that one cost-effective solution to this problem is the installation of line filters next to large ASDs and motors to reduce the magnitude of harmonic distortion. Conversely, to prevent nuisance tripping of small ASDs in response to transient voltages from the outside, which are also magnified by on-site power-factor-correcting capacitors, a small inductor (choke) can be placed in series on a line to reduce current surges.

Sometimes, however, more-sophisticated technology is needed to solve power quality problems on a customer's premises, and EPRI studies have indicated a particular need for new power-conditioning devices capable of providing integrated protection against multiple kinds of power disturbances. Responding to this need, EPRI has worked with Public Service Electric & Gas Company (PSE&G) and Westinghouse Electric Corporation to develop an active power line conditioner (APLC)—the first device to combine active harmonic filtering, line voltage regulation, and transient voltage surge protection in a single, compact unit. A 5-kVA single-phase version of the APLC was commercialized in late 1992, and 50-kVA and 150-kVA three-phase versions are now also available. Other products in the APLC family will be offered in the near future.

Instead of using conventional passive filter circuits, which remove only specific harmonics from a line, the APLC's power electronic circuits automatically adapt to changes in the harmonic spectrum and actively inject signals onto a line that cancel the disturbances. This approach eliminates the need to calculate what harmonic currents are likely to be present or to retune filters as load conditions change. In addition, the APLC regulates incoming voltage to compensate for sags and surges on the utility line. Since the 5-kVA device is about the size of a personal computer and weighs only 125 pounds, it can easily be installed close to sensitive loads.

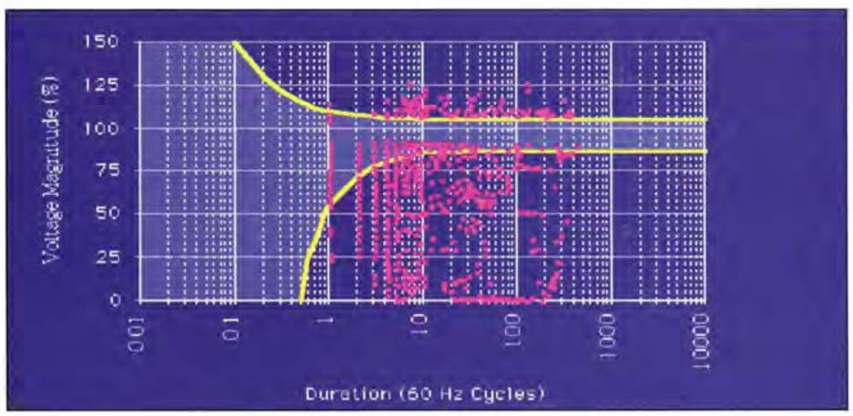
One of the first demonstrations of an APLC took place at a pharmaceutical plant in the PSE&G service territory, where harmonic distortion from ASDs was interfering with the computer-controlled operation of the plant's quality control laboratory. Problems of this kind, which had been interrupting plant operations several times a month, were completely eliminated through the installation of a prototype APLC. During the year-long test, the device also maintained power quality for the lab during a particularly severe thunderstorm.

"The APLC provides a low-cost solution for several kinds of power quality problems," says research manager Ben Banerjee of EPRI's Customer Systems Division. "We estimate that APLC technology could save utility customers many millions of dollars over the next five years. Further development efforts are also under way to incorporate some energy storage capacity into the APLC to enable it to ride through short power outages without affecting the performance of sensitive loads."

The Customer Systems Division is also working on a variety of other power quality devices for end-use applications. One example is a hybrid filter that adds a series active element to an existing passive filter and controls harmonics by actively adjusting series impedance. New England Power Service Company is demonstrating a prototype hybrid filter in an 800-horsepower ASD application at a sewage treatment plant. Another example is an advanced solid-state load center for commercial and industrial facilities, which will integrate a variety of control functions related to power quality, including load monitoring, fast load switching, and protection against fault currents and overvoltages. Also under investigation are advanced UPS concepts that feature novel means of storing energy, such as flywheels and supercapacitors. And a new generation of ASDs is being developed that will reduce harmonics and be more capable of riding through power disturbances.

"This growing array of power quality

VULNERABILITY OUTSIDE THE ENVELOPE Voltage disturbances measured at a single location as part of an EPRI power quality study demonstrate that power glitches frequently lie outside the so-called tolerance envelope used as a design goal by computer manufacturers. Disturbances above the upper line or below the lower line can potentially result in equipment malfunction. Such problems could be reduced by providing higher-grade power or by enlarging the tolerance envelope—that is, designing the equipment to be more robust.



technologies will give utilities and their customers more flexibility in addressing power disturbances," says Wade Malcolm, manager of the Power Electronics & Controls Program in the Customer Systems Division. "In addition, we are working with equipment manufacturers to incorporate power-conditioning capabilities into their products."

Remedies—utility side of the meter

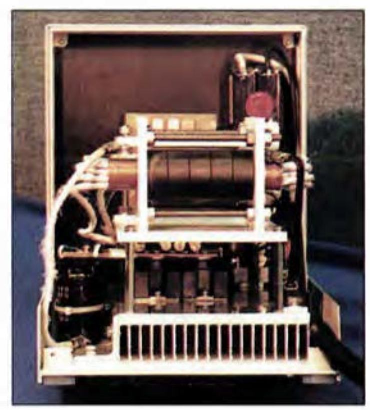
Meanwhile, EPRI is also developing advanced technology for use by utilities to improve overall distribution system reliability and to keep power quality problems that originate on distribution systems from reaching customers. This technology, the basis for a concept EPRI calls Custom Power, involves a combination of power electronic controllers, distribution automation equipment, and an integrated communications protocol, which together will enable utilities to meet the power quality needs of industrial and commercial customers with sensitive loads. Custom Power service would probably be offered initially to large individual customers or to clusters of smaller customers in industrial parks.

"Power quality problems can generally be categorized into two groups," says Vasu Tahiliani, manager of the Custom Power Distribution Program in EPRI's Electrical Systems Division. "One group includes waveform distortions that usually arise on the customer's premises and can best be solved there. The other group includes power interruptions and voltage sags that originate on the distribution system. Custom Power will give utilities new options for overcoming this second group of problems and providing customers with high-quality power. I believe this can sometimes be the lowest-cost approach,

WORKING ON HARMONICS Nonlinear loads—such as adjustable-speed motor drives, electronic ballasts for fluorescent lamps, and power supplies for welding equipment—can inject harmonics onto power lines and interfere with other loads. EPRI is working with equipment manufacturers to create power-quality-hardened equipment that doesn't create harmonics and that can even correct power factor discrepancies, increasing efficiency. Examples are the ballast and welding power supply prototypes shown here.

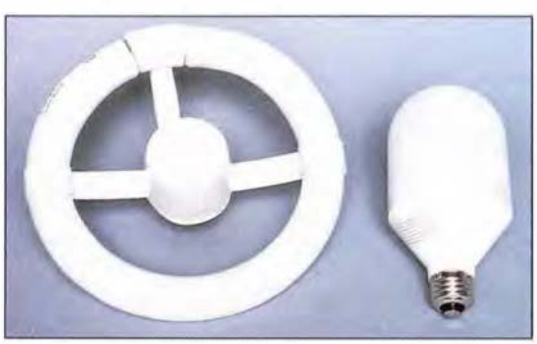
Adjustable-speed drives

Welding equipment

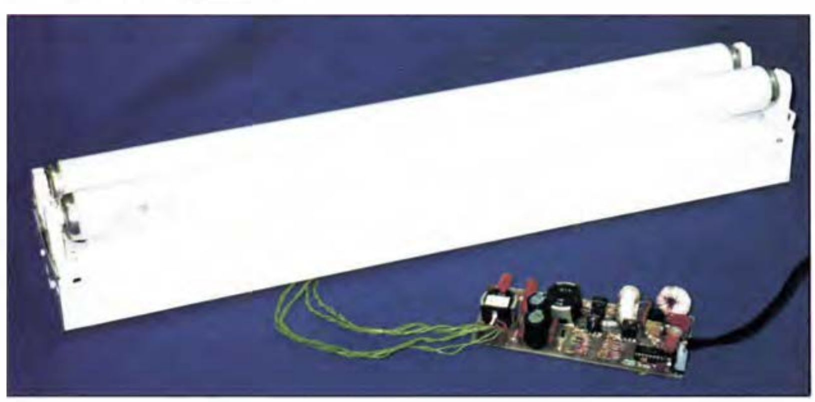


Prototype hardened welding power supply

Electronic lamp ballasts



Prototype hardened ballast



although specific problems have to be handled on a case-by-case basis."

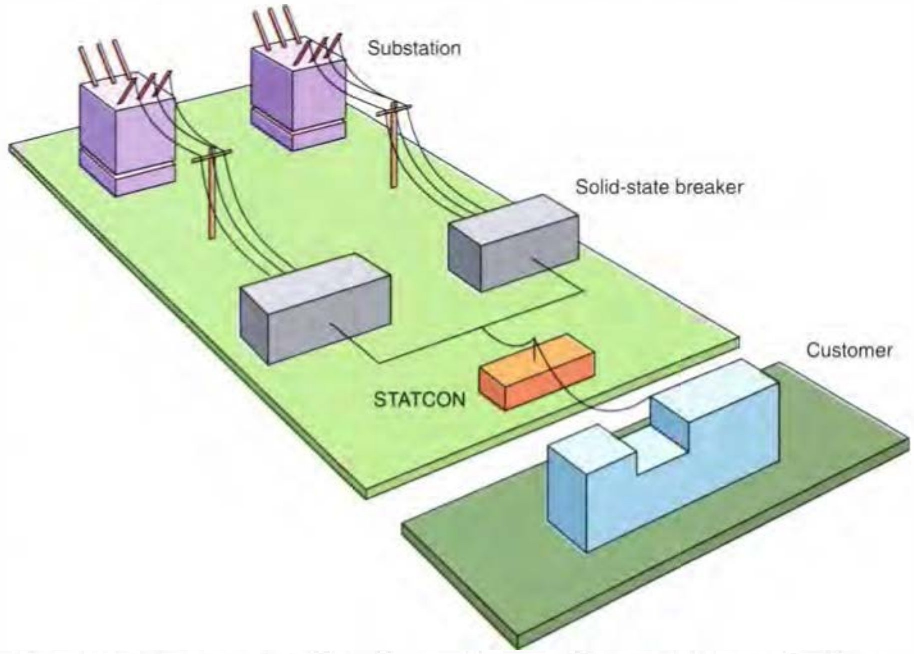
The basic Custom Power configuration would use power electronic controllers at a substation with two independent distribution feeders to provide essentially uninterruptible, robust power to customers. In the event of a power flow interruption on one feeder, a solid-state breaker (SSB) would switch over to the other feeder, reducing the outage time for a fault to one cycle or less. Meanwhile, a static condenser (STATCON) would hold voltage constant and supply momentary power so that the customer load would remain essentially unaffected by the feeder switching.

Both of the basic Custom Power controllers just described are now being developed for EPRI by Westinghouse Science & Technology Center. SSB and STATCON prototypes are being designed to use currently available gate-turnoff thyristors for 15-kV distribution systems. Laboratory-scale versions of both devices have been constructed and tested to prove concept feasibility. Utility field testing of full-scale prototypes is scheduled to begin in late 1994 or early 1995. Commercial versions of the controllers are expected to be ready for market in 1995 or 1996.

SSBs have several advantages over the mechanical circuit breakers now commonly used in distribution systems. Not only can an SSB react much more quickly than its mechanical counterpart, but it can also be used repeatedly without degrading performance, whereas a conventional circuit breaker has to be refurbished after repeated use. Each SSB has thyristors that conduct normal load current and interrupt excessive fault currents. A surge arrester in parallel with the thyristor switches provides protection against transient overvoltages that develop during faults. In addition to their role in providing premium-quality power to customers with sensitive loads, SSBs will allow utilities to operate their distribution systems at increased short-circuit capacity and to execute automated load management more efficiently.

A STATCON is connected as a shunt between a distribution line and ground; it supports voltage in the line by exchanging power with the line during different parts of a cycle. A thyristor inverter in the STATCON rectifies a portion of the ac power from the line to dc power to charge a large capacitor and then inverts this dc power to ac for reinjection to the line as needed. The capacitor both acts as a source of constant voltage and provides enough energy to supply real power to the line for a few cycles during voltage sags or interruptions.

SOLID-STATE CONTROLLERS FOR CUSTOM POWER EPRI's Custom Power concept involves the use of high-voltage electronic controllers to improve power quality on utility distribution systems. In this configuration, a solid-state breaker can switch between two independent feeders to provide uninterrupted power to a load in the event of a fault on one feeder. A static condenser, or STATCON, helps provide voltage support and supplies momentary power so that the customer load is virtually unaffected by the feeder switching.



Development work has also begun on a variety of other electronic controllers envisioned as part of Custom Power service. A dynamic voltage restorer would be connected in series with a distribution line to override momentary voltage sags and swells by inserting a compensating voltage into the line. Thyristor-switched capacitors would bring distribution system capacitors on-line in smaller increments in order to follow load changes more closely and reduce the transients now associated with large capacitor switching operations.

"Our aim in developing Custom Power technology is to take a cost-competitive approach to improving power quality," says EPRI research manager Harshad Mehta. "Advanced electronic controllers will provide new flexibility to utilities as they implement distribution automation plans and work with customers to find the most expedient and economical way to provide uninterruptible quality power."

Services for members

To be in a better position to advise their customers about the best solutions to power quality problems, utilities need a better understanding of the relationship between distribution systems, customer systems, and a variety of end-use technologies. To address this need, EPRI's Power Electronics Applications Center (PEAC) in Knoxville, Tennessee, has launched a research project on system compatibility. Specifically, this project is aimed at determining how well existing electronic equipment can tolerate power disturbances, what disturbances the equipment generates, and how well it performs its intended function. Equipment is chosen for evaluation by EPRI member utilities participating in the project.

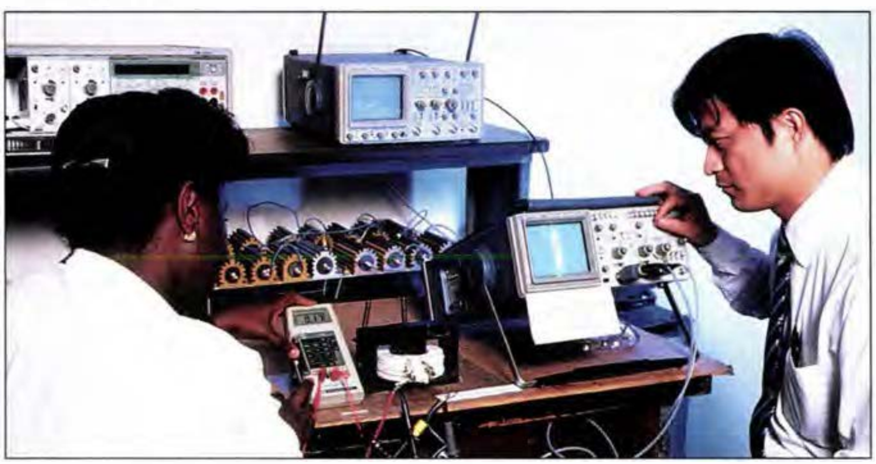
The first two technologies tested under

TESTING AT PQTF The Power Quality Test Facility has been established at EPRI's Power Electronics Applications Center to evaluate how well various equipment tolerates power disturbances and to determine what power quality problems the equipment itself may cause.

The Power Quality Test Facility features a wide variety of measurement and test equipment.

A transient voltage surge suppressor is tested to failure.

An advanced welding power supply is tested for power quality characteristics.



the project were the electronic ballasts used in fluorescent lamps and the transient voltage surge suppressors widely sold to protect sensitive equipment, such as computers. Tests were conducted at the new Power Quality Test Facility (PQTF) at PEAC. The tests showed that, although electronic ballasts produce about 18% more illumination per watt of electric power consumed than conventional magnetic ballasts, they create more than twice as much current distortion and are more vulnerable to transients on the power system. Tests on three brands of transient voltage surge suppressors revealed wide variations among the brands in their response to surges and steady-state overvoltages, and uncovered some deficiencies that were reported to the manufacturers.

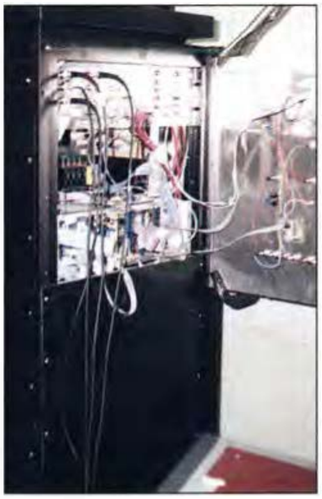
Another PEAC service is the Power Quality Hotline, available to EPRI member utilities. With this service, a utility engineer can obtain immediate, high-level help over the phone to deal with specific power quality problems. Duke Power, for example, recently used the hotline to ask for assistance in finding out why some customers' digital clocks were gaining as much as 2 hours during the night. After Duke faxed a graph of waveforms captured by monitors on the affected circuit, engineers used a simulator at PQTF to reproduce the effect and directed Duke maintenance personnel toward possible causes. Following this lead, the Duke team found that voltage pulses were being sent onto the circuit by substation equipment that was about to fail. Replacing the equipment not only solved the mystery of the speeding clocks but also probably prevented a costly blackout on the circuit.

Two kinds of training courses are provided by PEAC for utility personnel concerned with power quality. The first type is an intensive, hands-on three-day course in which participants use PQTF equipment to simulate a variety of power quality problems and have an opportunity to use some of the commercially available products designed to correct those problems. The second type of course involves customized instruction by PQTF staff on a utility's premises and may be attended by utility customers as well as utility personnel.

To further technology transfer in the power quality area, EPRI has established the North American Power Quality Testing Network and is also setting up regional power quality service centers. The national network includes not only member utilities but also university researchers, public agencies (such as the National Institute of Standards and Technology), and the Canadian Electrical Association. The first regional power quality service center opened recently in the Northwest with half a dozen utility members. The center is currently sponsoring several activities of regional interest, including

ADVANCED PROTECTION DEVICES Improvements in power quality can be achieved by means of new electronic devices now becoming available for use on both sides of the meter. On a customer's premises, an active power line conditioner provides integrated protection against many types of power disturbance, while an active hybrid filter controls harmonics on a line by adjusting series impedance. On utility distribution systems, solid-state breakers react much more quickly to faults than their mechanical counterparts, and STATCON can support voltage in a line by exchanging power with the line during different parts of a cycle.

Hybrid filter



Solid-state breaker

STATCON

Active power line conditioner

power quality workshops, the creation of a database of power quality consultants, and the publication of market-specific power quality brochures.

An integrated approach

Because of the complex nature of power quality problems, an integrated approach is needed in addressing them—in choosing power-conditioning equipment, in deciding whether to use the equipment on the customer's or the utility's side of the meter, and in conducting research to head off future problems as the use of sensitive electronic devices becomes even more widespread. Substantial progress is being made in each of these areas.

A wide variety of power-conditioning equipment is now available for on-site use by utility customers, ranging from small plug-in surge suppressors to multimegawatt uninterruptible power supplies. No single product can solve all the kinds of power quality problems that customers are likely to encounter. PEAC has conducted tests on many of these devices and has published technical commentaries on how each type can be used most effectively to combat various power quality problems. The center is also working with manufacturers to improve product performance.

The optimal placement of power-conditioning equipment eventually comes down to economics. Some cases are clear: a home computer is most easily protected against transient overvoltages by a $20 surge suppressor; a new industrial park might be able to obtain uninterruptible power more cost-effectively through dual-feeder Custom Power service offered by the local utility. Between these extremes, however, the decision about how best to provide premium-quality power depends on a variety of site-specific factors and on continuing technological developments.

Looking to the future, EPRI's Integrated Energy Systems Division (IESD), jointly with the Electrical Systems and Customer Systems divisions, is conducting a market study of power quality that will measure utility and customer attitudes toward power disturbances and their potential solutions. "We want to make sure that EPRI's response to power quality issues is as effective as possible in meeting the demands of the industry," says Vito Longo, a research manager in IESD.

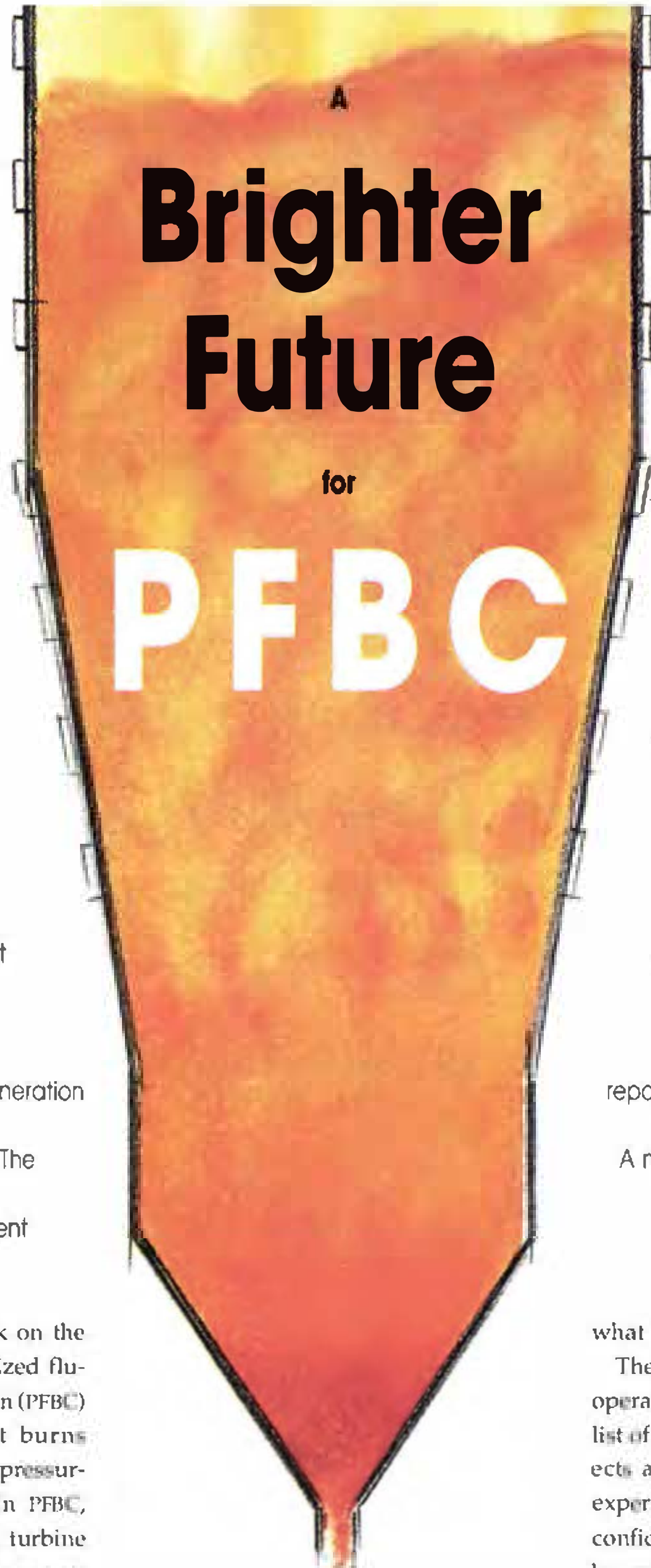
"EPRI is committed to giving member utilities the information and technologies they need to work with customers concerned about power quality," says Marek Samotyj, manager for power electronics end-use systems in EPRI's Customer Systems Division. "Our case studies and the evaluations performed at PEAC are helping to establish much-needed standards in what has been a chaotic field of endeavor."

Vasu Tahiliani of the Electrical Systems Division emphasizes the need for "coordination at all levels—research, development, and application. Particularly as more Custom Power options become available, we expect to work even more closely with the suppliers of this equipment and with member utilities in determining which technologies are most appropriate for a specific application." ■

Background information for this article was provided by Wade Malcolm, Ben Banerjee, and Marek Samotyj, Customer Systems Division; Vasu Tahiliani and Harshad Mehta, Electrical Systems Division; and Vito Longo, Integrated Energy Systems Division.

by Taylor Moore

A Brighter Future for PFBC



THE STORY IN BRIEF

Researchers have new optimism for the commercial prospects of pressurized fluidized-bed combustion (PFBC) among advanced fossil power systems. Recent EPRI studies indicate low capital costs for PFBC and highlight the technology's potential as a competitive source of low-cost generation using low- to medium-sulfur coals. The new perspective is spurred by recent successes at several PFBC projects worldwide, including one in Ohio supported under the federal government's Clean Coal Technology Program. Two other PFBC demonstrations under the federal program are planned in the United States, and some utilities are already considering commercial units for repowering existing generating capacity. A number of larger PFBC units are being planned in Japan and in Europe.

A more positive outlook on the prospects for pressurized fluidized-bed combustion (PFBC) —a technology that burns coal in a chamber enclosed in a pressurized steel vessel—is spreading. In PFBC, steam is raised to power a steam turbine generator while the pressurized flue gases are expanded through a gas turbine. Until recently, EPRI projections of environmental control performance and cost of electricity for PFBC were not among the best for advanced coal technologies.

The latest EPRI engineering and economic analyses, however, suggest that capital costs are lower for PFBC than for other advanced fossil fuel options and also reveal that PFBC operating costs are sensitive to the sulfur content of the feed coal. These studies confirm the potential of PFBC plants, when using low- to medium-sulfur coals, to generate electricity at a lower levelized cost than conventional pulverized-coal plants with flue gas scrubbers, than integrated gasification–combined-cycle (IGCC) plants, or even than natural-gas-fired combined-cycle plants when gas prices are somewhat higher than at present.

The EPRI studies come on the heels of operating success stories from a growing list of demonstration and commercial projects around the world—results that give experts at EPRI and elsewhere increased confidence in the likelihood that PFBC will be commercially available before the end of the decade. The projects include two 80-MW units in Stockholm, Sweden—the first commercial PFBC units—which produce both electricity and steam for district heating; American Electric Power Company's 75-MW Tidd repowering demonstration project in Ohio, supported by the U.S. Department of Energy's (DOE's) Clean Coal Technology Program; and a 79-MW commercial unit in Spain.

"PFBC technology and the market outlook for it are both very exciting. Five commercial-scale units are now operating around the world, and plans are being laid for more than half a dozen others, including three separate design studies for 350-MW commercial units," says Steven Drenker, who manages EPRI's Fluidized-Bed Combustion Program. "Environmental performance is better than expected, and we're seeing companies achieve very good availability factors as they iron out the bugs in the early units."

Adds EPRI's John Wheeldon, a former British Coal engineer with a long involvement in fluidized-bed projects: "Until recently, despite a low relative capital cost, the cost of electricity for PFBC plants seemed relatively high. Recent assessments, however, show that this cost can be reduced appreciably."

Part of the turnaround, explains Wheeldon, is the result of a change in how PFBC is evaluated in comparison with other advanced fossil fuel technologies. The new perspective evolved from EPRI studies of the operating performance of early PFBC plants. "Once we knew something about the capabilities of those plants, we could study where and why the costs were high and determine a set of conditions under which PFBC can be very economical," he says.

"Most of EPRI's earlier comparative studies of advanced fossil technologies were based on the use of high-sulfur coal," Wheeldon continues. "But when you look at PFBC with, say, 0.5–2%-sulfur coal—which is widely available in many parts of the United States—as the design basis, then you have a much lower limestone requirement for 95% sulfur capture and therefore have much less spent sorbent to dispose of. Such factors not only tend to bring down the capital cost of PFBC but markedly reduce its operating cost."

Another part of the turnaround is the result of increasing—through the use of supercritical operating steam conditions—the power generated by the steam cycle. The use of supercritical conditions is growing in Europe and Japan, where fuel costs are higher and a premium is placed on generating efficiency. This interest has resulted in improved turbine designs and more-reliable plant operation.

Straddling the repowering and new-plant markets

Although local or special circumstances could give IGCC the economic advantage over PFBC for new power plants using coals with less than 3% sulfur, the EPRI studies suggest that IGCC is likely to be the better choice for high-sulfur coals and PFBC to be more economical for burning low- to medium-sulfur coals.

The potential operating-cost advantage of PFBC firing the increasingly popular low-sulfur coals, coupled with the fact that PFBC is operationally more like conventional coal combustion than is IGCC, could make PFBC the preferred choice of many traditional coal-burning utilities. These factors and the potential commercial availability of PFBC in a range of unit capacities could give the technology an inside track on a share of both the repowering market for existing fossil fuel units and the green-field market for future capacity.

EPRI recently analyzed the U.S. utility repowering market in detail and conducted a workshop to help utilities chart strategies to use existing assets for maximum competitive advantage. Natural gas-fired combined-cycle plants are typically the economic choice today for new capacity at green-field sites. However, studies for EPRI by Energy Ventures Analysis (EVA)—an Arlington, Virginia, consulting firm—have identified repowering market niches for PFBC, atmospheric fluidized-bed combustion (AFBC), and IGCC systems if natural gas prices rise relative to coal prices, as many experts believe will be the case in the next decade.

By repowering, which makes use of steam cycle equipment and auxiliary and support systems already in place at an existing site, utilities can save 20–40% of the capital cost of new capacity. Those savings and the improved thermal efficiencies and environmental performance of the repowering technologies, compared with conventional fossil fuel boilers, are the key conditions that can allow coal-fired technologies to hold on to some of the fossil fuel generation market currently being lost to natural gas.

According to EVA's Tom Hewson, most decisions today about repowering and generating capacity expansion involve plants intended for peaking or intermediate duty, not baseload service. Those decisions therefore tend to favor fuel-cost-intensive, low-capital-cost solutions like gas-fired capacity over capital-cost-intensive solutions like large coal-fired plants. "With today's relative fuel prices, it's not surprising that we see a lot of gas-fired capacity being built," says Hewson.

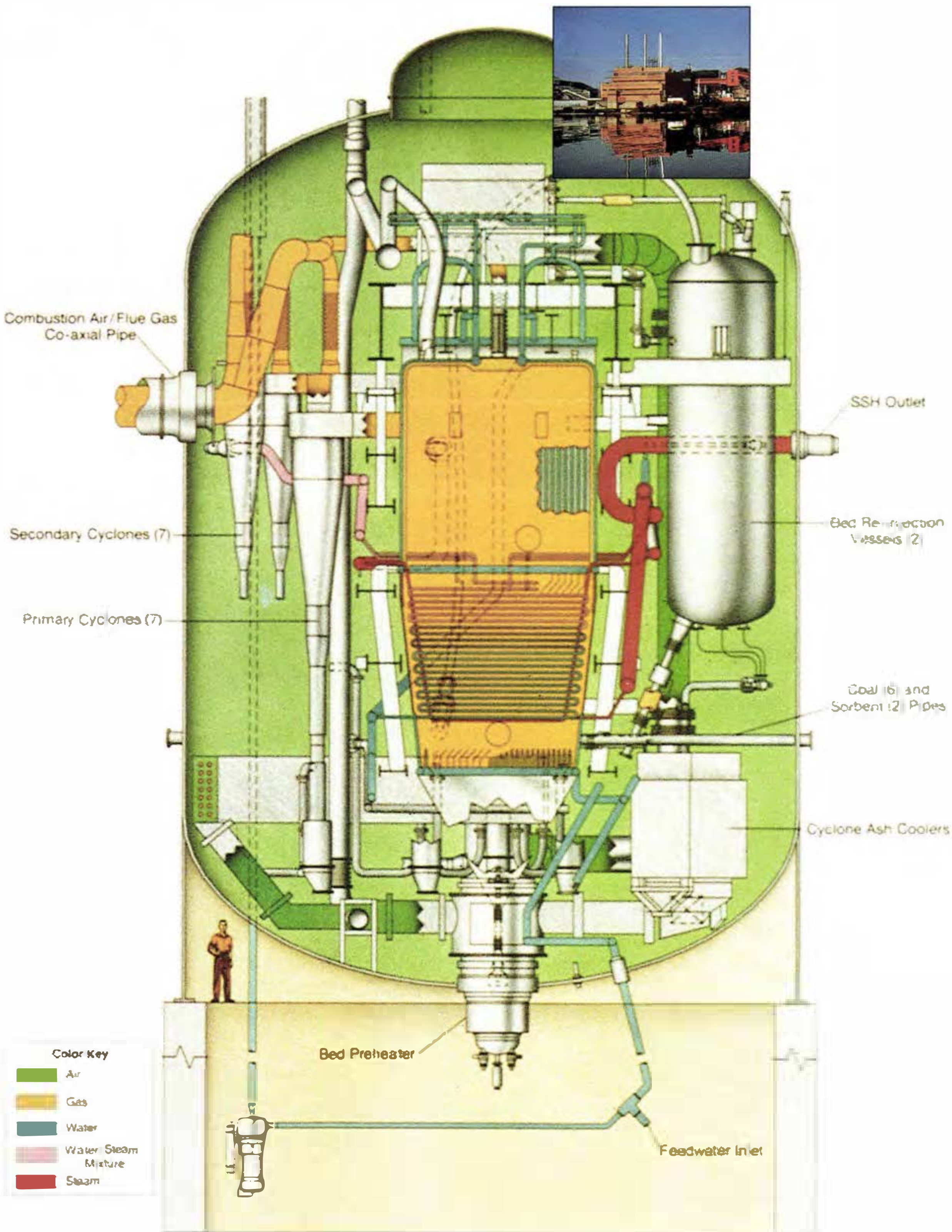
"But looking into the future, we believe that coal prices are going to decline in real terms and that gas prices are going to go up," he adds. The fuel price differential required for advanced coal generation technologies, including PFBC, to offset the capital cost and operating and maintenance cost advantages of natural-gas-fired combined-cycle plants has shrunk from over $3 per million Btu to just over $2 per million Btu. That differential is already within the range of regional variations in some projections of the gap between gas and coal prices by the year 2000.

"We think that the fuel price differential—and less so the capital cost differential—will be the factor driving more coal-fired-capacity decisions in the future," says Hewson. "And as the generation market turns more to baseload in the future, the market share for coal-based technologies, such as IGCC and PFBC, will increase. The costs and performance of those technologies are improving, reducing the capital cost and performance advantages of gas-fired capacity. That will increasingly favor a return to coal."

If PFBC is to play a role in the fossil repowering market, says Hewson, the keys may be the successful demonstration of the next scale of capacity beyond the 80-MW commercial plants and the commercial availability of proven designs at unit sizes closely matching those of the units to be repowered.

In the United States, according to EVA, about 87,000 MW of fossil fuel steam generating capacity will be over 45 years of age by 2000, almost all of it in units of 150 MW or less. PFBC could play a major

TIDD PIONEERS PFBC IN UNITED STATES American Electric Power Company's demonstration of PFBC for repowering at its Ohio Power subsidiary's Tidd plant features one of five nominal 80-MW units around the world based on ABB Carbon's initial design. The PFBC system—which consists of a fluidized-bed boiler, ash removal cyclones, and bed reinjection vessels, all contained in a steel vessel pressurized at about 12 atmospheres—replaced the boiler at one of Tidd's two units while most of the balance-of-plant equipment was retained. The pioneering Tidd demonstration unit was built by Babcock & Wilcox in a partnership with ABB Carbon and was cofunded by Ohio Power, the U.S. Department of Energy's Clean Coal Technology Program, and the Ohio Coal Development Office.



role in repowering many of those units. "From 2005 to 2010," predicts Hewson, "we will see new U.S. coal-fired capacity taking off, with some 20,000 MW of new capacity." Before then, PFBC needs to be commercially demonstrated at the 150–350-MW scale "in order to be seriously considered and built in significant numbers," he says. "So the timing and status of large-scale projects worldwide are critical to PFBC's future. If they are successful, PFBC could capture a significant portion of the new-capacity market, as well as the nearer-term repowering market."

CLEAN COAL POWER FOR STOCKHOLM **Stockholm Energi's Värtan plant uses two 80-MW PFBC units from ABB Carbon to generate electricity as well as to supply steam for district heating. The PFBC boilers, which burn low-sulfur coal, replaced oil-fired boilers and produce low enough emissions to be operated in an urban area.**

Technology contenders around the globe

As reported in the latest version of EPRI's *Technical Assessment Guide*, PFBC systems offer not only lower capital costs and a lower cost of electricity than conventional coal-fired plants, but also a generating efficiency that is at least 12% better. PFBC plants are coal-fired combined-cycle plants, raising steam in a boiler to drive a steam turbine and sending the hot combustion gas on to drive a gas turbine. Since emissions control is an inherent part of the combustion process, there is no need for postboiler scrubbers to control sulfur dioxide emissions or other systems to control emissions of nitrogen oxides (NO_x). A sulfur capture of 95% has recently been demonstrated for PFBC. NO_x emissions are inherently lower than in other technologies because of the lower combustion temperature, and ammonia can be injected ahead of the cyclones inside the PFBC vessel to further reduce NO_x. The cyclones extract most of the ash and spent sorbent from the hot combustion products.

ABB Carbon is the current PFBC market leader and has licensed its bubbling-bed technology to companies in the United States, Japan, Spain, and the Czech Republic. Now ABB Carbon's 350-MW design is being licensed in Japan for what could be the first large-scale commercial plant, the Karita unit of Kyushu Electric, planned for startup in 1996. An ABB STAL gas turbine is being built for the unit. Another 350-MW PFBC unit of ABB design is being studied for Taiwan.

Over 30,000 hours of operation have been logged by the four bubbling-bed PFBC units in Ohio, Spain, and Sweden. These first-generation units are similar in many key respects. In each of them, for example, the majority of the dust in the flue gas leaving the boiler is removed by cyclones. And each unit's gas turbine has been ruggedized with special blade coatings and other design features to handle the remaining dust in the gas.

Such use of partially cleaned high-temperature flue gas in a ruggedized turbine, however, will not be acceptable for higher-efficiency advanced PFBC systems. Those systems will depend on the availability of hot-gas cleanup (HGCU) technology, in which the gas is directed through large ceramic filter units before it enters the gas turbine. HGCU has been a major focus of EPRI's R&D activity in PFBC over the years, and achieving the effective removal of solids from the flue gas by means of ceramic elements (themselves operating at a high temperature) has proved challenging. Although not essential for PFBC systems such as ABB Carbon's, the successful implementation of HGCU technology would allow other PFBC developers to use conventional gas turbines, which are available in a wider range of generating capacities.

Because of the dependence of advanced PFBC on reliable HGCU technology, observers are closely following developments at the world's fifth bubbling-bed PFBC unit—the 71-MW Wakamatsu demonstration by Japan's Electric Power Development Company (EPDC)—which began operating in September. The unit has as an integral component a full-scale, tube-type ceramic filter, although it also features a ruggedized ABB gas turbine in case the filter does not perform as expected. In addition, this is the first project to incorporate some of ABB Carbon's design concepts for the 350-MW-scale unit. ABB Carbon licensed the PFBC design and supplied the gas turbine for Wakamatsu. The boiler and pressure vessel were manufactured by Ishikawajima-Harima Heavy Industries, a licensee of ABB's PFBC technology in Japan.

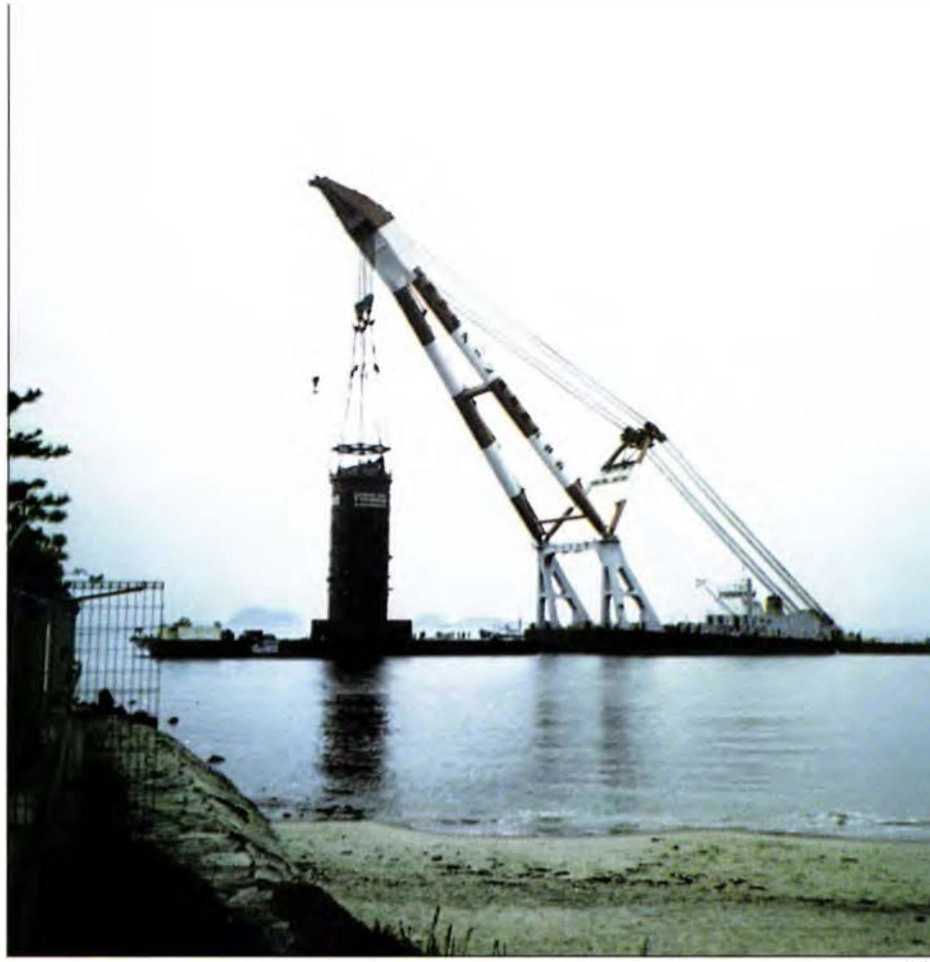
Meanwhile, half a dozen other PFBC projects are on the drawing board in Japan. The industrial heavyweights Hitachi and Mitsubishi Heavy Industries (MHI) also have developed PFBC designs based on their own test units. MHI is set to build an 80-MW plant for Hokkaido Electric that is planned for 1996 startup. Hitachi is the vendor for two proposed 250-MW units for Chugoku Electric that could be operating by 1999. Elsewhere in Japan, EPDC is considering two 350-MW units based on ABB Carbon's design for startup at Isogo in 2002, while Okinawa Electric is studying a 150–250-MW unit that could be operating by 2000. And Chubu Electric is evaluating a 300–400-MW unit for startup around 2001; it is based on the Ahlstrom Pyropower circulating-bed PFBC design that is one of the commercial challengers to ABB Carbon's technology.

"The Japanese utilities are very attracted to coal technology and regard PFBC as the most advanced coal-burning technology for power plants," says EPRI's Wheeldon. "They don't have ready access to an assured supply of low-cost natural gas; what they do get is mainly high-cost, liquefied natural gas. But they can and will be importing a lot of low-sulfur (0.5%) coal from Australia for the PFBC units they're building and planning."

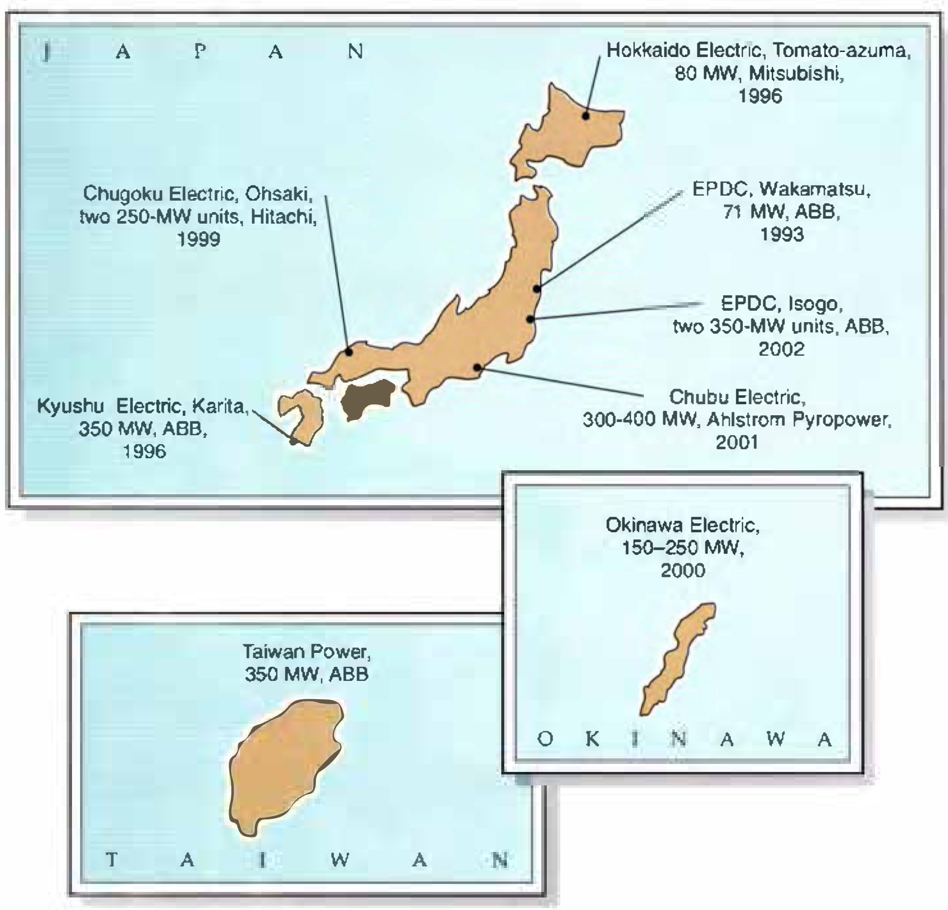
In Europe too, developments with PFBC technology continue apace. Designs are being prepared for the first of two 75-MW commercial-scale units in the Czech Republic, and studies for 350-MW commercial plants are under way in Germany and Spain. EPRI research managers point out that for Europe as well as Japan, a large price differential between coal and natural gas goes far in explaining the more immediate commercial interest in PFBC than is seen in this country.

The circulating-bed PFBC system being developed by the Finnish boiler manufacturer Ahlstrom Pyropower—an established name in the world of AFBC with a circulating-bed design—promises to match the 95% sulfur removal of bubbling-bed PFBC while consuming less limestone sorbent. This is to be achieved through the use of finer sorbent particles and a sorbent-recycling system. Lurgi-Lentjes-Babcock (LLB), a new German joint venture formed by Lurgi, Lentjes, and Deutsche Babcock, also has a circulating-bed PFBC design that it expects to supply to a European customer in the near future. (LLB also offers a bubbling-bed PFBC design but believes that circulating-bed PFBC is more commercially attractive.)

Pyropower has operated a circulating-



Wakamatsu pressure vessel shipment and installation



PENETRATING MARKETS IN THE PACIFIC RIM PFBC technology is making inroads into Asian and European power plant markets faster than into the U.S. market as a result of two factors: differences in coal prices relative to gas prices and the greater need for new baseload and intermediate capacity overseas. Plans and studies for a number of projects are being made by utilities in Japan and Taiwan, which have access to low-cost, low-sulfur Australian coal. A nominal 80-MW unit based on ABB Carbon's bubbling-bed PFBC design began operating in September at Wakamatsu in a project funded by Japan's Electric Power Development Company (EPDC), and half a dozen other Japanese PFBC projects are on the drawing board. The map identifies projects by utility and—where available—plant name, rating, vendor, and projected startup date.

bed pilot plant in Finland, and LLB has operated one in Germany. Proponents of the circulating-type PFBC believe that it promises lower operating and capital costs than bubbling-bed technology, as well as simpler operation. Its reduced sorbent consumption, compared with the bubbling version, is a major advantage and is expected to increase PFBC's competitiveness in using high-sulfur coal. EPRI has been conducting its own engineering and economic evaluation of circulating-bed PFBC and expects to issue reports this month.

Under the DOE Clean Coal Technology Program, Midwest Power Company is planning to build a 75-MW circulating-type PFBC unit of the Pyropower design at its Des Moines Energy Center in Iowa. Plant startup is scheduled for 1997. EPRI is supporting this demonstration project with a dynamic simulation, testing, and documentation program.

Advanced technologies for higher efficiency

In conventional PFBC plants, the overall cycle efficiency is limited to less than 42%. That's because the combustor's operating temperature—which must be held to 1650°F (900°C) or less to avoid sintering the ash and releasing alkali metals that could foul or corrode the gas turbine—in effect sets the gas turbine inlet temperature far below the 2350°F (1290°C) or so featured in the most efficient heavy-frame machines currently in use firing natural gas or oil. Advanced gas turbines in the future may be capable of even higher firing temperatures.

Increasing the inlet temperature of the gas turbine, which typically provides 20–25% of the power in a PFBC plant, could raise the overall cycle efficiency to more than 45%. A simple means of boosting the flue gas temperature would be to fire a topping fuel, such as natural gas, ahead of the gas turbine. But 2350°F would be well above the ash-softening temperature, so high-temperature, high-pressure filtration systems would be essential to remove all particulate matter before firing the natural gas.

Truly advanced PFBC systems would use gas from coal rather than natural gas as the topping fuel. The coal would be pyrolyzed in a low-oxygen environment under pressure to produce both a low-Btu fuel gas and a residual char. The fuel gas would be passed through its own HGCU filters before being fired in a topping combustor ahead of the gas turbine; the char would be burned in a circulating-bed PFBC, from which the flue gas would also be filtered and then combined with the topping-cycle gas stream. (Or the char could be simply fired in an atmospheric fluidized-bed combustor.) With net heat rates below 7600 Btu/kWh (45% efficiency), carbon dioxide emissions would be correspondingly low.

Such advanced systems are in the early stages of development by two groups: one in Britain, led by British Coal in conjunction with PowerGen and the Anglo-French manufacturing consortium GEC Alsthom; and one in this country, which is led by Foster Wheeler, is funded by DOE, and includes LLB and Air Products and Chemicals.

DOE selected a proposal from the Foster Wheeler team for cost sharing under the fifth round of the Clean Coal Technology Program. This effort, the Four Rivers Energy Modernization Project, involves building a 95-MW advanced circulating-type PFBC unit at Air Products' Calvert City, Kentucky, chemical manufacturing facility. Steam from the unit, which will feature a coal-gas-fired topping combustor and an HGCU system, will be used in chemical production, and the power will be sold to the Tennessee Valley Authority. The project is scheduled to begin commercial operation in December 1997.

Two utility perspectives

No review of the prospects for PFBC in the United States would be complete without the perspective of American Electric

Power (AEP), the Columbus, Ohio, holding company for several largely coal-based utilities that has long championed PFBC as a clean coal technology. With the Tidd repowering project approaching the final quarter in a successful three-year demonstration program, AEP is reconsidering its business plans to deploy PFBC, despite its decidedly positive outlook on the technology.

"The more experience we gain with Tidd, the more encouraged and enthusiastic we are about the technology," says James Markowsky, executive vice president for engineering and construction at AEP Service Corporation. "We believe PFBC technology is ready now for commercial demonstration at the 330–350-MW scale. But the issue for us is the need for capacity." AEP initially proposed, in 1989, to follow a success at the Tidd unit with the repowering of a coal-fired unit at its Sporn station. The focus later shifted to a design study for a 350-MW green-field plant at its Mountaineer station in West Virginia.

But significant changes in load growth forecasts and in the projected need for new baseload capacity on the AEP system have eliminated the utility's need for new coal-fired baseload generation until 2005 or later, notes Markowsky. He says that AEP is now evaluating options for its DOE-supported design study of a 350-MW unit, "including exploring whether there may be other utilities or independent power producers that want to participate in the commercialization of PFBC."

Meanwhile, the Tidd unit has recently been running well on 3–3.5%-sulfur Ohio coal, after resolving initial startup difficulties with the coal-feeding and ash removal systems. (Such difficulties have been experienced at all the demonstration units.) The Tidd unit also made a swift four-month recovery from a failure of the gas turbine last February that, says Markowsky, was unrelated to PFBC operation. "We are extremely pleased with the PFBC process at Tidd, although it took a while to get here. We had to address some development issues with systems and components, like you have with any new technology."

Markowsky says that AEP is seeking government funding to extend the Tidd demonstration to a fourth year in order to upgrade the plant's sulfur removal efficiency. Currently, 90% removal is achieved at a calcium-to-sulfur ratio of 1.8–2 to 1. The goal is to achieve 95% removal at a ratio of 1.6–1.8 to 1. "We want to examine ways to get the best environmental performance with the lowest sorbent demand. That means looking at additional sorbent feed points, other particle-size distributions, different feeding methods, and the recycling of cyclone ash," Markowsky explains.

"Although there is a strong likelihood that a larger unit will not be planned for our system at this point, we would like to participate in the continued development of the technology because we want it to be available when we select an advanced coal technology in the future," adds Markowsky, whose involvement with PFBC at AEP dates back 17 years, to the very beginning. "To appreciate PFBC, you first have to see a conventional coal plant with a scrubber on it. Then you come to Tidd, and you ask, 'Where's the sulfur removal device, the dewatering vessels, the solids-handling building?' Tidd looks just like a power plant—without a chemical facility added on."

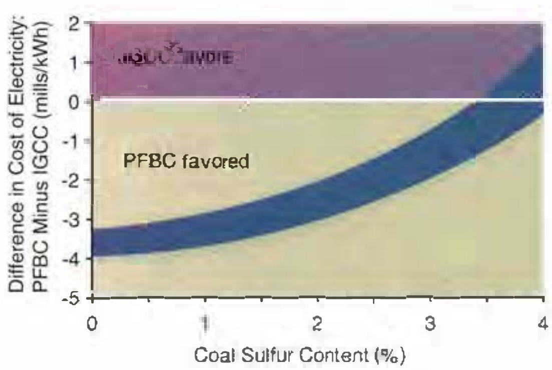
Another heavily coal-based utility that would like to see PFBC commercially available today and that may be a candidate to adopt the technology is the Southern Company, the Atlanta-based holding company. Its engineering organization, Southern Company Services, is currently evaluating 80-MW and 350-MW PFBC plants for repowering and possible cogeneration applications, according to Tom Newton, manager of power engineering.

"We're excited about how PFBC could fit into some of our baseload repowering projects," says Newton. "We are now evaluating the engineering economics of the technology on a commercial basis, looking at it as a planning option for the 1998–2005 time frame at whatever unit scale gives us the lowest-cost electricity. We're probably most interested in the larger scale, but we're also looking at some cogeneration project scenarios where 80-MW PFBC units could fit neatly. As a repowering option, PFBC units of that scale offer a greater advantage of lowering the cost of production than IGCC does."

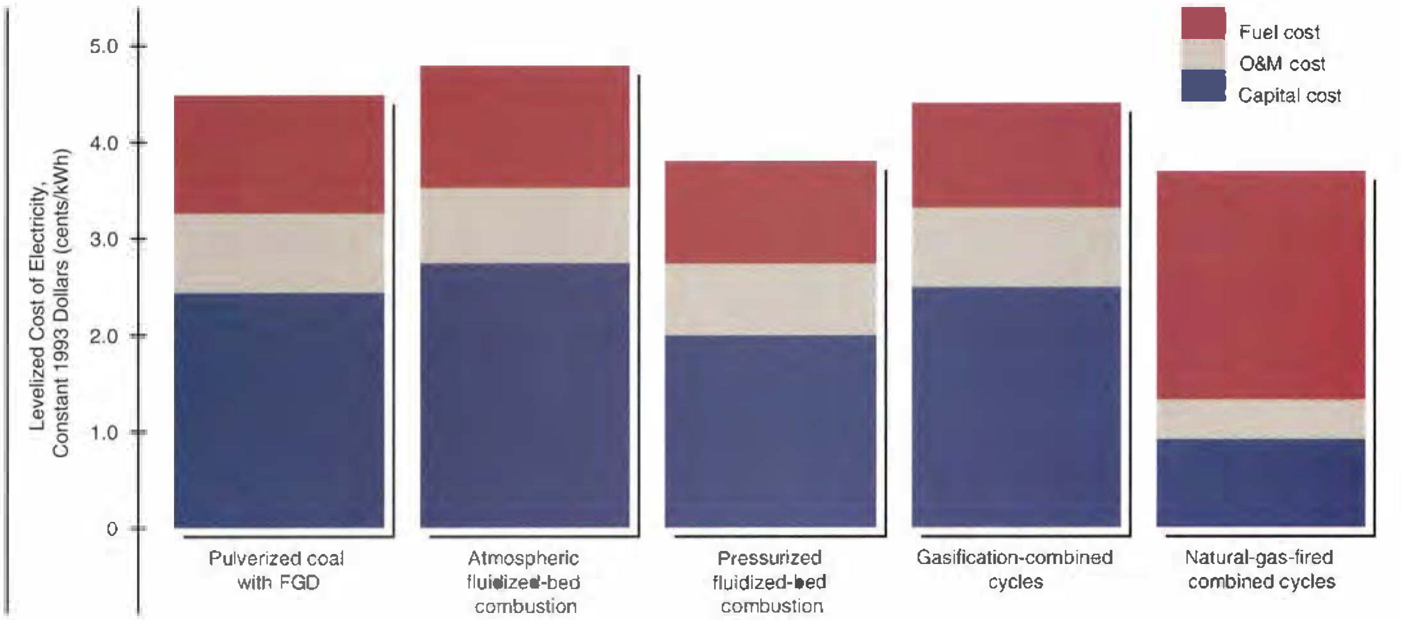
Newton says that, like most utilities, Southern's operating subsidiaries probably won't need new baseload capacity until after 2005. "But if we're talking about repowering existing baseload capacity to reduce our cost of generation, then in our case we'd be talking about needing something earlier than 2005." He adds, however, that for Southern or another utility to proceed with a commercial PFBC project in the 1990s, "it's probably going to require some cost sharing by the government. It's still a little early for this technology, and most utilities don't want to take a risk with new technology until they see several units running well."

Acknowledging that gas-fired combined-cycle technology is in most cases

ECONOMICS SENSITIVE TO SULFUR CONTENT **PFBC operating costs and, to a lesser extent, capital costs are sensitive to the amount of sulfur in the coal to be burned. A higher sulfur content means higher ash and sorbent flow rates and disposal volumes and, in turn, larger plant equipment—factors that translate into an increased cost of electricity. Variations in cost with coal sulfur content have been compared for similarly sized PFBC and integrated gasification–combined-cycle (IGCC) power plants operating at 80% capacity factor. Since the comparison is based on differential costs, the results are independent of the price of individual coals.**



HOW PFBC'S COST OF ELECTRICITY STACKS UP **Comparative analyses by EPRI's Integrated Energy Systems Division of the cost of electricity from several fossil power generating options—both current systems and advanced systems likely to be available in the near term—indicate PFBC's competitive position. PFBC's low capital cost and its expected low operating cost when firing low- to medium-sulfur coals make it a strong competitor with conventional coal plants using flue gas desulfurization (FGD), with integrated coal gasification–combined-cycle plants, or even with natural-gas-fired combined-cycle plants at gas prices of $3.25 per million Btu or higher. The analyses are based on EPRI's average cost-of-electricity parameters for each technology and on the use of 2.1%-sulfur bituminous coal.**



the lowest-cost choice for repowering intermediate-load capacity today, Newton notes that the future outlook for gas prices plays a significant role in his company's perspective on PFBC. "We consider PFBC technology, with its flexibility to burn a variety of low-cost fuels, an important hedge against gas prices. We're looking at scenarios in which PFBC could generate power even more economically than our existing coal-fired plants that do not have flue gas scrubbers. So in our analyses, PFBC competes directly against the gas-fired combined-cycle option, and we see the two technologies as a hedge against each other. Personally, I think coal is the real hedge and that gas prices will go higher."

Meanwhile, Southern is in the process of creating the Power Systems Development Facility (PSDF) at its Wilsonville, Alabama, R&D center, where DOE and EPRI have supported coal liquefaction and other fossil fuel process development work for more than a decade. Testing at PSDF will focus on PFBC-related technologies, such as HGCU systems and topping-cycle combustors. The new $160 million facility, some 80% of which is being funded by DOE, is expected to play an important supporting role in future PFBC demonstration projects.

A market niche for PFBC

Ron Wolk, director of EPRI's Advanced Fossil Power Systems Department, echoes the sentiment of the Southern Company's Newton on the need for technology hedges with respect to gas-fired generation. And he says that PFBC provides a further technology hedge with respect to the price and availability of low- versus high-sulfur coal.

"A starting point is the question of just how big the market is for advanced coal technologies. Over the last year we've begun to think there is a real market niche for PFBC. Our studies indicate that PFBC has lower capital costs than IGCC and similar cycle efficiencies and NO_x emissions, but that its sulfur removal is not quite as good. The big thing PFBC has going for it is that it's a coal combustion technology and is therefore more familiar to utilities than IGCC. Although its solids discharge stream may be too high when high-sulfur coals are used, the amount of solids is far less of a problem with low- to medium-sulfur coals," Wolk explains.

"When you put all these factors together, PFBC looks like a technology that will find a market niche for repowering and for new capacity," he goes on. "But no single technology is going to get all of the market. To me the real question is, how big will the market be over the next 15 years? The answer really depends on natural gas—specifically, gas supply in North America and what happens to gas prices over that time.

"Among the utilities that will continue to rely heavily on coal-fired generation, some will favor PFBC and others will not. So it's good to have both intertechnology competition and intervendor competition. Worldwide, there is a market for more than one advanced coal technology." ■

Background information for this article was provided by Steven Drenker, John Wheeldon, and Ron Wolk, Generation & Storage Division.

BONDS OF SCIENCE

Strengthening Ties With the CIS

by Leslie Lamarre

Detailed news reports have made it clear that times are tough in the former Soviet Union. Soaring inflation pushed Russian prices up 2000% in 1992 alone; government funds have dwindled; and scientists with PhDs typically make less than bus drivers.

But just because residents of what is now the Commonwealth of Independent States are struggling doesn't mean that they have nothing to offer. In fact, where many see a bitter stew of political, economic, and social turmoil, EPRI—among other scientific organizations worldwide—sees a cask of precious skills waiting to be tapped. And scientists in the commonwealth are ready to let their talents flow.

"They are willing and even eager to negotiate contracts with us," says EPRI's Tony Armor, director, fossil power plants, who in 1992 visited utility industry facilities in Russia and Uzbekistan. "The driving factor is the need for Russia to attract foreign currency to ensure the viability of the country and the continuation of its R&D activities." The intent of Armor's two-week mission in August 1992—a follow-up to a visit he made in 1989—was to scope out potential research projects that could offer significant benefits to EPRI member utilities.

Armor returned with a list of more than two dozen areas for potential collaboration with scientists from Russia and other ex-Soviet republics. They include tests on 300-MW superconducting generators, supercritical boilers featuring full variable-pressure operation, low-slagging lignite-fired boilers that emit low levels of nitrogen oxides, water-cooled gas turbine blades, and steam turbines employing thyristor-controlled startup techniques. Two of the research areas that were identified—hydraulic recirculation pumps and advanced district-heating turbines—have been selected for the initial projects, and EPRI has drawn up contracts with scientists from Russia and Lithuania to perform the work.

Walter Piulle, the Russian-speaking technical expert in Armor's group who is managing the projects, explains that they are relatively short term efforts that will offer insight into the potential for contractual working relationships with scientists from the Commonwealth of Independent States. If they are successful, then other, more extensive projects from Armor's list may be initiated. "These are among the first actual contracts EPRI has had with scientists from Russia and the other republics," notes Piulle. "Past relationships have involved informational exchanges with the Soviets but never a funded contract."

Russian strengths

EPRI's interest in the scientific talents of the former Soviet Union isn't unique. Russia has been known for its strength in the basic sciences since long before the communist era. High-energy physics, spectroscopy, plasma physics, high-temperature materials, and electrochemistry are just some of the areas in which Russian scientists excel. Another is steam chemistry: two scientists from the world-renowned Moscow Power Institute developed the scientific basis for the so-called ray diagram, which provides the foundation for steam plant cycle chemistry around the world.

Nor is EPRI's interest in Russia a recent phenomenon. Individual EPRI staff members have maintained long-term working relationships with Soviet scientists, in some cases dating back 20 years to the time EPRI was established. Many of these relationships have been nurtured over the years through such professional organizations as the International Conference on Large High-Voltage Electric Systems and the International Association for the Properties of Water and Steam (IAPWS).

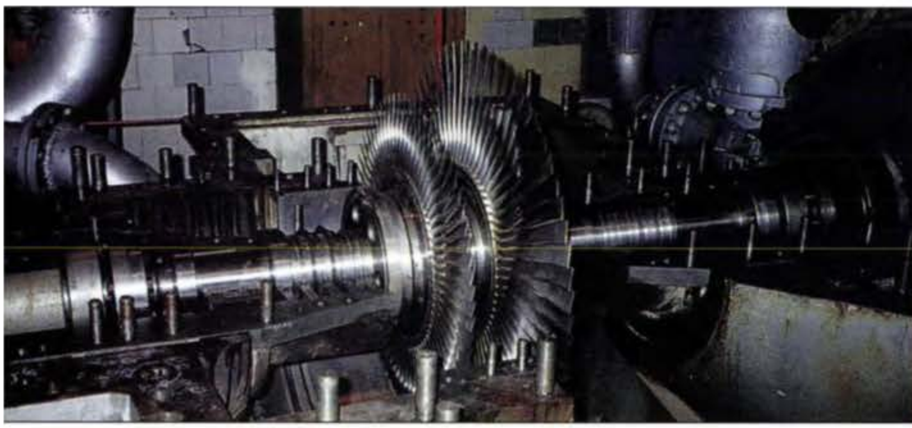
It is no secret that foreign organizations like EPRI that have initiated contracts in the Commonwealth of Independent States are getting a good deal on scientific talent. But, as Armor points out, "the real carrot is the possibility of acquiring their advanced technology—technology that has been developed largely without Western influence and hence is often significantly different from that of the West." This is the kind of technology that Armor sought during his visit to Russia and Uzbekistan last year.

THE STORY IN BRIEF Tough times in the Commonwealth of Independent States (CIS) have not diminished opportunities for international scientific collaboration. In fact, according to EPRI researchers who have maintained long-term working relationships with scientists in Russia and the other republics, interest in working with the Institute has only increased since the troubles began. Recently EPRI entered a new phase in its relationship with scientists there, going beyond the traditional information-exchange agreements to initiate funded contracts. Both types of arrangement are advantageous for EPRI member utilities, who benefit from the state-of-the-art technology, world-class experimental facilities, and top-notch scientific skills available in the CIS.

Moscow Power Institute

Tony Armor of EPRI (foreground) inspects a 300-MW superconducting rotor in St. Petersburg.

LEARNING FROM THEM Through long-term working relationships and frequent visits, EPRI staff members have become quite familiar with the electric power industry in the former Soviet Union. As a result, EPRI member utilities have benefited from the special skills and facilities available there. EPRI is continuing its efforts to identify technologies of potential interest to U.S. utilities, and some of these technologies have already become the focus of joint research projects.



A fully instrumented test turbine at the Moscow Power Institute offers unique opportunities for in-depth analysis.

A technician at a Moscow power plant performs a chemical analysis of turbine steam.

Russian scientists have used these advanced probes to measure moisture in turbine steam.

Suiting up for a tour of a nuclear plant in St. Petersburg.

Improved turbines for district heating and hydraulic recirculation pumps—the focus of the two initial projects resulting from Armor's visit—are among the key technical advances that the Russians have installed in operating power plants. District heating—in which steam from the generating process is used to heat water that is piped to utility customers for direct use and for space heating—originated in Europe as a means of conserving fuel. Implemented in cogeneration plants, this technology offers the potential to significantly enhance overall cycle performance and to improve (i.e., reduce) effective plant heat rate by as much as 50%. U.S. utilities are expressing increased interest in district heating as a means of improving total plant utilization. The efficiency improvement also offers an attractive option for significantly lowering carbon dioxide emissions levels.

EPRI has initiated a nine-month contract with Lithuanian scientists for a series of well-documented tests on an advanced district-heating turbine. The goal is to demonstrate the performance and unique technical features of the turbine, a 180-MW machine located at a power plant in Vilnius, Lithuania. "The Lithuanian plant offers us a unique opportunity to conduct—at full scale, with zero development costs—a project of great interest to U.S. utilities," Piulle points out, noting that the establishment of even a pilot-scale unit for testing in the United States would involve considerable expense. The project will be completed in February.

Similarly, the project on operating, full-scale hydraulic recirculation pumps will involve no development costs. The hydraulic pump, which utilizes the energy potential offered by a power plant's water streams, was developed by engineers at the Central Boiler and Turbine Institute in St. Petersburg. Users in the former Soviet Union have found it to be reliable and efficient in all boiler operating modes, including startup and partial-load operation. The project will explore whether the Russian pump is a good alternative to the electricity-driven hermetic pumps used in U.S. plants, which frequently suffer from reliability problems, particularly at partial load. The Russian pump offers several potential advantages, including simplified operation and maintenance, the capability for variable-speed operation, and significantly reduced size and weight. This seven-month project, initiated at the end of September, involves the demonstration of a hydraulic pump at a 250-MW supercritical cogeneration unit at a power station in St. Petersburg. The Russian contractors will perform technical and power usage comparisons of electricity-driven and hydraulic pumps.

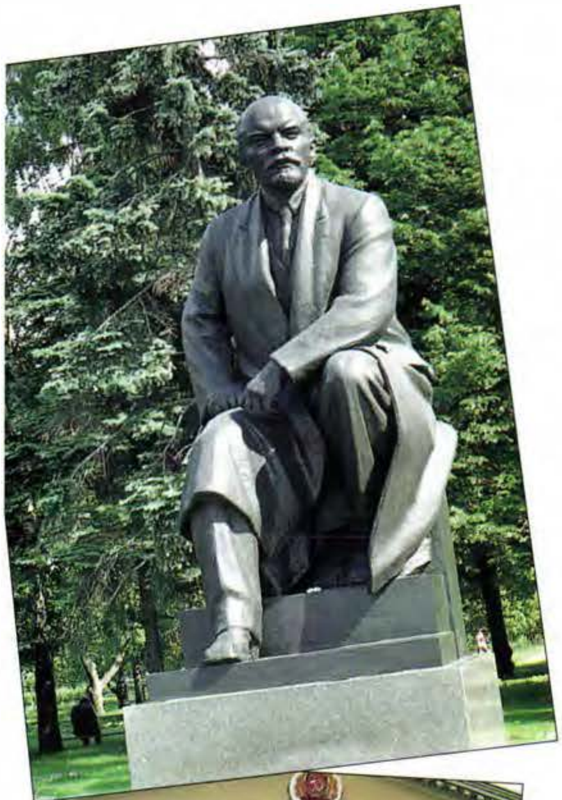
EPRI will closely monitor the progress of both projects through an American contractor, Joseph Technology Corporation. Joseph Technology also will perform economic evaluations in accordance with EPRI criteria. "We want to get a good idea of the quality of the products coming out of these contracts before we invest in other contracts with the Russians," Piulle says, referring to Armor's list. "However, we anticipate very significant benefits for a very modest investment."

State-of-the-art facilities

Scientific genius is not the only useful resource EPRI is tapping in the Commonwealth of Independent States. Some of the republics own state-of-the-art facilities for power plant research. Among them is the Moscow Power Institute (MEI), the training ground for most of the technical experts that run the power plants of the former Soviet Union.

MEI, which currently has a student body of 12,000, has churned out numerous top-notch scientists. Observers note that the economic plight of the Commonwealth of Independent States has hit the technical institutions hard, as it has other scientific organizations supported by the government. It is estimated that some 25–30% of all scientists in the commonwealth have either lost or left their jobs.

But tough times have not yet spoiled MEI's state-of-the-art facilities. The organization has its own power plant and a large, fully instrumented test turbine that runs on steam diverted from one of the power plant's turbines. This offers a unique opportunity for in-depth study of the serious global problem of corrosion



and erosion of turbine blades. The test turbine is configured to allow the insertion of probes between stationary and rotating blades during operation so that realistic steam samples can be taken. Other instrumentation allows for the monitoring of chemical and physical conditions before and after each row of blades and at various points along each blade length.

"There is nothing like this available outside Russia," says Barry Dooley, manager of boiler and cycle chemistry in EPRI's Office of Exploratory & Applied Research. Dooley oversees a project on steam chemistry that employs the test turbine at MEI. The aim is to explore the formation of chemical species in steam that contribute to the corrosion of turbine components. In this effort, MEI scientists will divert steam into the test turbine for detailed analysis. The resulting data will be part of EPRI's contribution to a broad international collaborative study of steam turbine chemistry and corrosion.

Dooley also manages EPRI's participation in the international effort, which involves 23 industrial organizations from 13 countries, including Australia, Denmark, England, and Japan. Like MEI, these organizations will gather data on steam chemistries. To help ensure that the data are comparable and comprehensive, EPRI is supplying the participating organizations with special monitoring instrumentation it has developed. When the project is completed—in two years—EPRI will collect and publish the results.

So far, the international collaboration has led to a solid overall understanding of worldwide experience in steam chemistry and to the identification of specific areas that are not well understood. The project's objectives are to develop a computer model for predicting salt deposition in the turbine steam path, to create a new design code for turbine blades, and to establish operating guidelines for controlling steam purity. These products, notes Dooley, will be of direct benefit to EPRI member utilities. "This is the first time that such a comprehensive, international perspective has been taken on this topic," says Dooley. "It's not surprising that so many groups are interested in cooperating. Steam chemistry is not a special phenomenon that affects a few facilities here and there. It affects everybody everywhere."

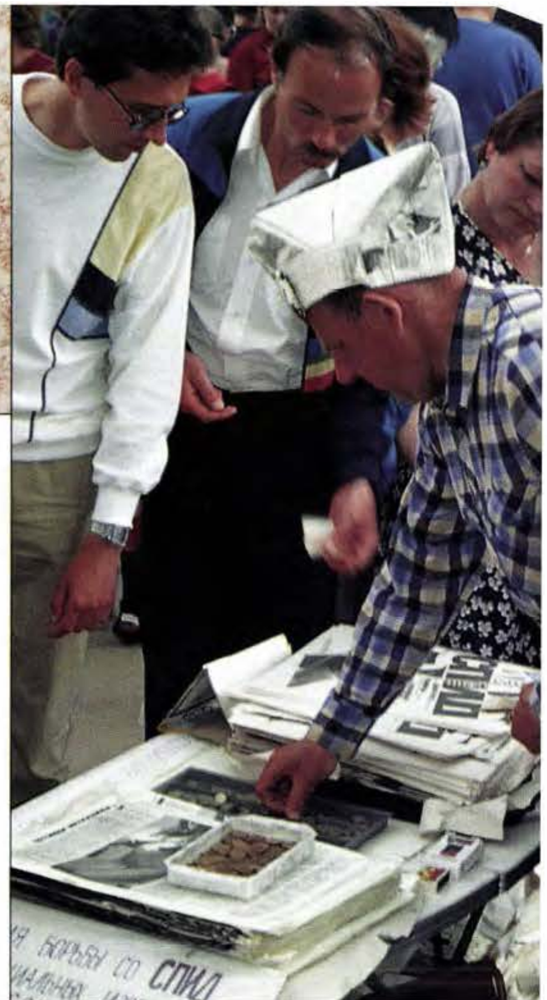
Long-term ties

Like the projects that Piulle manages, Dooley's work with MEI involves a contract with Russian scientists and is the outgrowth of a long-term relationship with Russian colleagues. Dooley has been working on steam chemistry issues with Russian scientists for the past decade, largely through IAPWS. "In the communist days, the IAPWS meetings were our only chance to get together," says Dooley. But while meetings may have been restricted, the information flowed just as freely between Russian and U.S. scientists in the communist era as it does today, he says.

The past exchanges did involve some daunting logistics, however. Visits by Russian scientists to EPRI typically spurred frequent calls from the U.S. State Department. Some of the Soviet scientists did not dare to venture into the homes of Americans who extended invitations. By the same token, these Soviets were afraid to invite visiting U.S. scientists into their own homes. "Although there was no written regulation against these visits, I was afraid that my right to travel would be restricted," says Gennadi Vasilenko, a scientist from the Central Boiler and Turbine Institute (CKTI) in St. Petersburg who is a consultant for EPRI's project with MEI.

Former Soviet president Gorbachev's program of glasnost and perestroika did much to quell these fears. By 1989, when Armor and a consultant from Joseph Technology, Ishai Oliker, traveled to the Soviet Union, they received many invitations to the homes of Russian scientists, including those at CKTI. Vasilenko, a visiting scientist at EPRI for two months this summer, says that he is no longer afraid to invite foreign guests to his home. In fact, he did just that when Dooley was in Russia in September 1992, taking the EPRI visitor to his St. Petersburg flat to meet his wife and sons. Likewise, Vasilenko visited Dooley's family during his stay at EPRI. Other advantages have come with the fall of communism; for example, the arrival of Russian scientists at EPRI no longer prompts

The son of a Russian scientist tries out the laptop computer of a visiting EPRI employee (1992).



BEHIND—AND BEYOND—THE IRON CURTAIN Life in the former Soviet Union has changed considcrably over the course of EPRI's relationships with scientists from the various republics. Where once the KGB had a high profile, small-scale entrepreneurs have now set up shop. Throughout the political and economic chaos of recent years, science has remained a key strength.

Street scene, Moscow (1990).

A Moscow entrepreneur sells newspapers

Visitors tour a popular space museum in I

calls from the U.S. State Department.

Still, however, many things have not changed. For instance, a meeting between Dooley and Vasilenko at CKTI still requires the presence of a department director and numerous associates. "Before you know it, I'm sitting on one side of the table with 15 people across from me," Dooley says.

Common goals

Vasilenko's main purpose at EPRI this summer was to serve as a consultant for another project that Dooley oversees—a study of the volatility of salts in turbine steam. Funded through EPRI's Office of Exploratory & Applied Research, the project has been under way at Oak Ridge National Laboratory for the past three years. Recently, utilities from Australia, Canada, Italy, South Africa, and Denmark joined as cosponsors.

CKTI, where Vasilenko is employed, has developed a theoretical methodology to explain the volatility of salts in steam. Dooley says the hope is that the experimental approach at Oak Ridge will yield results that are consistent with CKTI's theoretical results. The goal of the project is to provide information for modifying the existing ray diagram to more accurately guide steam plant operations.

Another project involving CKTI is aimed at improving the thermodynamic performance of steam turbines. This project is a result of Armor's 1992 visits to turbine test facilities at both CKTI and the turbine manufacturer LMZ. Tom McCloskey, manager of the project, says that researchers will use the 40-MW test turbine at CKTI to try out a new design for turbine flow paths. The new design, to be developed next year, has the potential to increase turbine efficiency 3–5%. McCloskey cites CKTI's unique facility as the main reason it was selected as the test site. "Right now there is no comparable facility in the United States," he says. McCloskey's project is another effort involving a contract with Russian scientists—an arrangement that would have been far more difficult to establish three years ago, he notes.

Other projects with Russia involve the exchange of information and technology. EPRI recently initiated such a project on adjustable-speed drives with the All-Russian Electric Power Research Institute (VNIIE). Since 1981, EPRI has successfully retrofitted adjustable-speed drives in U.S. power plants for boiler feedpump and forced-draft-fan applications. Advantages of the electronic drives include energy savings, improved process control, and reduced emissions. Now, through a memorandum of understanding expected to be signed by the end of the year, EPRI's Power Electronics & Controls Program will provide VNIIE with information on the U.S. retrofits. In return, the agreement states, the Russians will implement an advanced adjustable-speed drive that has been on the market for over two years but has never been installed in the United States. They will collect extensive data on the drive's performance—data that will give U.S. utilities valuable insight into this new technology.

EPRI researchers believe that member utilities can benefit equally from both types of exchanges—those that involve work under contract and those that involve the exchange of information and technology. One new idea under consideration could very well combine both types. The idea was proposed by Jouni Keronen, who is on loan to EPRI for two years from Imatran Voima (IVO Group), a utility holding company in Finland. It calls for the establishment of a center for technology exchange in Finland, the only Western country that has a common border with Russia. The purpose of the center would be to facilitate the introduction of EPRI technologies and services in the former Soviet Union and in Eastern Europe. "The concept is good. The key questions are what kind of investment we would have to make and what the paybacks would be," Armor says. "We have been working with IVO Group to see what the opportunities might be in both Russia and Eastern Europe." Of interest, for example, is a large combined-cycle plant at Lenenergo, the utility in St. Petersburg. IVO Group is currently engineering this plant and could provide EPRI with insights into state-of-the-art Russian and European designs. In return, the facility could benefit from EPRI's combustion turbine technology.

For their part, scientists from Russia and the other republics are equally interested in new initiatives with EPRI. As Gennadi Vasilenko points out, "Collaborating with EPRI gives us an idea of where we stand, compared with the rest of the world. Also, together we can resolve problems faster and more cheaply than either of us could if we were competing with each other." Vasilenko cites a famous Russian physiologist whose connections to the outside world were severed after the revolution of 1917. "I remember learning that he said he would die as a scientist if he did not have contact with his foreign colleagues," Vasilenko recalls. "Those words impressed me." ■

Background information for this article was provided by Tony Armor and Walter Piulle, Generation & Storage Division, and Barry Dooley, Office of Exploratory & Applied Research. The architectural photographs are by Barry Dooley.

CONTRIBUTORS

Technical sources for Journal feature articles

MALCOLM

TAHILIANI

DRENKER

WHEELDON

ARMOR

DOOLEY

PIULLE

Solving Problems of Power Quality (page 6) was written by science writer John Douglas, with background information from members of EPRI's Customer Systems and Electrical Systems divisions.

Wade Malcolm has been manager of the Power Electronics & Controls Program of the Customer Systems Division since July 1991. Earlier he was a project manager in the Electrical Systems Division's Distribution Program, on loan from Philadelphia Electric Company. At Philadelphia Electric, Malcolm was an engineer in the Research Division and the Electric Transmission and Distribution Department. He has BS and MS degrees in electrical engineering from Drexel University.

Vasu Tahiliani, who heads the Custom Power Distribution Program in the Electrical Systems Division, joined EPRI in 1977 as a senior project manager for transmission substations. He became the division's technology transfer administrator in 1984 and program manager for technology transfer the following year. He assumed his current position in 1991. Before coming to the Institute, Tahiliani spent five years at ITE Imperial Corporation and five years at McGraw-Edison Company. He holds two electrical engineering degrees—a BS from the University of Baroda (India) and an MS from West Virginia University. ■

A Brighter Future for PFBC (page 16) was written by Taylor Moore, *Journal* senior feature writer, with principal guidance from two members of EPRI's Generation & Storage Division staff.

Steven Drenker has been manager of the Fluidized-Bed Combustion Program since 1991. He joined EPRI in 1978 as a project manager in the program. Earlier Drenker was a field service engineer with Babcock & Wilcox Company. He received a BS degree in mechanical engineering from the University of Missouri and an MBA from the University of Santa Clara.

John Wheeldon manages projects on pressurized fluidized-bed combustion (PFBC) technologies. He joined the Institute in 1990 after three years as an EPRI contract employee at the Tennessee Valley Authority's 160-MW atmospheric fluidized-bed combustion demonstration project in Kentucky. Wheeldon previously was with British Coal Corporation for 13 years as a research engineer in various coal technologies; he spent part of that time at the International Energy Agency's Grimethorpe PFBC test facility in England. He received BS and MS degrees in chemical engineering from the University of Bradford (England). ■

Bonds of Science: Strengthening Ties With the CIS (page 24) was written by Leslie Lamarre, *Journal* senior feature writer, with guidance from three EPRI staff members.

Tony Armor, director of the Fossil Power Plants Department in the Generation & Storage Division, came to EPRI in 1979. Before that, he was with General Electric for 11 years, first in the Large Steam Turbine-Generator Division and then in the Energy Systems Division, where he served as program manager for superconducting generators. Armor has a BS in mathematics and an MS in mining engineering from the University of Nottingham (England).

Barry Dooley, manager of boiler and cycle chemistry in the Office of Exploratory & Applied Research, joined the Institute in 1984. Previously he spent nine years with Ontario Hydro, ultimately serving as manager of the Chemistry and Metallurgy Department. Earlier he was a research officer with the Materials Division of the Central Electricity Research Laboratories in England for three years. Dooley has BS and PhD degrees in engineering metallurgy from the University of Liverpool (England).

Walter Piulle, a combustion turbine process manager in the Generation & Storage Division, came to EPRI in 1976. Earlier he was a regional manager at Envirotech Corporation, where he worked for 18 years, and a development engineer at Curtiss-Wright Corporation for two years. He has a BS in electrical engineering from Pratt Institute. ■

Curbside-Charging Winners Bring EVs Closer to Reality

Four companies were winners in EPRI's recent design competition on technologies for curbside charging, a basic element of the infrastructure necessary to support the use of electric vehicles (EVs). The winners were presented awards, and their entries were exhibited, at the Second National Conference on Electric Vehicle Infrastructure in early December in Scottsdale, Arizona.

"We wanted to reward the designers of innovative ideas that make EV charging convenient and easy," explains Ed Riddell, EPRI's transportation program manager. The contest rules required the chargers to be safe and easy to use in any weather. "We also wanted the technology to be commercially available as soon as possible to anyone who buys an EV," Riddell continues. "EPRI has been a leading force in EV research for more than a decade. The charger competition is a natural extension of that effort."

The entries were judged by technical and product-development experts from the utility and automotive industries. "We were pleasantly surprised at the range of complex problems solved by the entrants," notes EPRI's Gary Purcell, manager of EV systems technology. The competition had three categories: "market ready," for charging products that are ready for use today; "innovative," for devices using new technology; and "leading edge," for ideas that offer something new but must overcome technical or development obstacles.

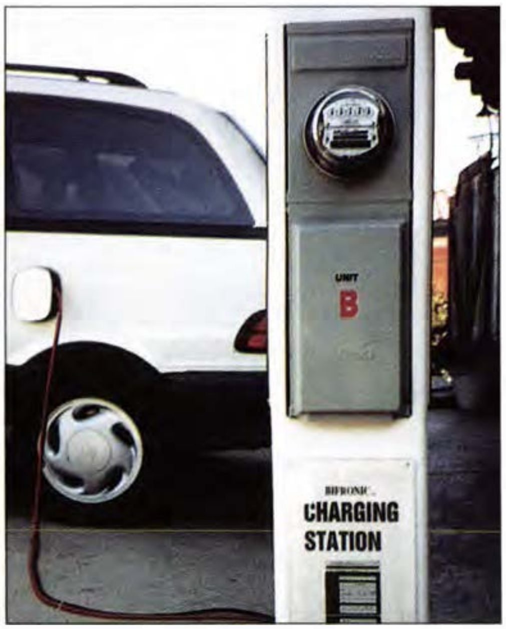
EHV Corporation of Manhattan, Kansas, and Moerman, Inc., of San Luis Obispo, California, were winners in the market-ready category. EHV won for its EDD-7 charger, a durable system that uses circuitry with such safety features as overcurrent protection and ground-fault interruption. Moerman won for its Bifronic Power Pedestal, a compact charger that can charge up to four vehicles at a time and does not impede sidewalk foot traffic.

Innovative Systems, Inc., of Santa Monica, California, received the innovative category award for its EV Smart Card, which has an embedded computer chip and can be used like a credit card at charging stations.

NuSun, Inc., of West Jefferson, North Carolina, won in the leading-edge category for its EV Autocharge system, which allows EV users to charge vehicles with a remote, hands-free coupling system.

Honorable mention went to ACT International of Saratoga, California, for its Combometer charging concept, which remotely signals EV users upon completion of vehicle charging.

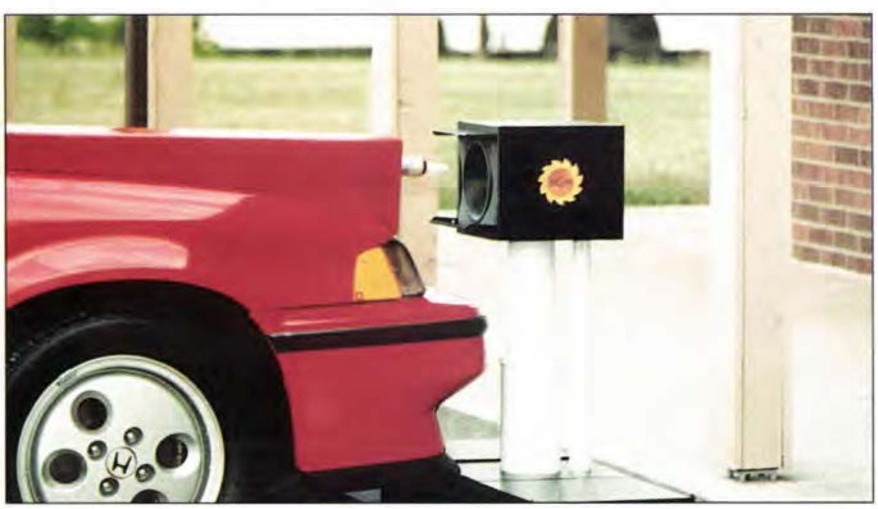
■ *For more information, contact Gary Purcell, (415) 855-2168.*



Moerman's Bifronic Power Pedestal

EHV's EDD-7

NuSun's EV Autocharge



Motor Challenge Promotes Efficient Industrial Systems

After several years of successful development and technology transfer work on advanced motor systems, EPRI has formed a partnership with the Department of Energy (DOE) and the users and suppliers of electric motors and drive systems to promote energy-efficient motor systems for their economic and environmental benefits. The result—the Motor Challenge program—targets industrial end users and adds another dimension to EPRI's efforts.

"EPRI's work on advanced motors focuses on achieving higher energy efficiency and enhanced productivity at lower costs. The government's involvement in the Motor Challenge program will help all of us achieve our objectives much faster," says Richard Balzhiser, EPRI's president and CEO. He notes that motors are the largest energy load on most electric utility systems and that they account for about one-half of the country's total electricity consumption.

High-efficiency motors and related systems are expected to use 2–7% less energy, depending on the motor type and size. And the addition of an electronic adjustable-speed drive (ASD) to a motor can slash its energy consumption by as much as half, depending on the application. Such lowered energy consumption could play a significant part in achieving the voluntary reductions in greenhouse gas emissions from fossil fuel combustion that have been called for by the Clinton administration.

Currently, the three principal elements of the Motor Challenge program are activities whereby private companies, associations, institutions, and the public sector exchange information; demonstrations that showcase efficient electric motor systems; and the development of the National Electric Motor Systems Database for exchanging data and reporting progress on demonstrations and other activities. Future efforts will include the recognition of individual excellence in implementing and managing efficient electric motor systems in industrial settings.

"EPRI has established a technology transfer program with its member utilities and their customers on motor research and has been successful in technology development with manufacturers. Our work spans all customer sectors and will complement the DOE effort in making the Motor Challenge program a success," says Wade Malcolm, power electronics and controls program manager in EPRI's Customer Systems Division.

In 1991 EPRI established the National Motors and Drives Steering Committee, which provides a forum for the discussion of development and applications activities in advanced motor drives by private and public R&D institutions. In 1986 the Institute opened the Power Electronics Applications Center (PEAC), which conducts power quality investigations and research on ASDs. This year PEAC opened the ASD Office to provide applications expertise for utilities and their customers. In addition, EPRI has several advanced motor technologies in development and has conducted technology demonstrations and assessments related to the textile, petrochemical, utility power plant, and municipal water management markets.

■ *For more information, contact Wade Malcolm, (415) 855-1031.*

First CCT Commercial Sale Is Low-NO_x Burner

The first domestic commercial sale of clean coal technology developed under the Department of Energy's CCT demonstration program involves an advanced low-NO_x burner system developed by Babcock & Wilcox with support from EPRI. B&W, DOE, and the Ohio Coal Development Office announced that Allegheny Power System will use B&W's burners in two of the 555-MW coal-fired boilers at the Hatfield Ferry plant in Pennsylvania, which is jointly owned by Allegheny's operating companies and is run by West Penn Power Company.

B&W's low-NO_x cell burner (LNCB) is a retrofit for the original B&W cell burner, which was created to burn coal efficiently in a compact utility boiler. The LNCB limits NO_x emissions by staging the secondary air with the fuel during combustion; the design replaces the top of a pair of coal nozzles in each burner cell compartment with an air port for staging. B&W says that the burner has a typical retrofit cost of approximately $5.50–$8.00/kW. To order the LNCB, contact Jane Piepho, B&W manager of business development, at (216) 860-6246.

■ *For more information, contact Tony Facchiano, (415) 855-2494.*

EHV Cable Lab Upgraded

As EPRI's world-class extra-high-voltage (EHV) cable laboratory approaches its quarter-century mark, it is undergoing a multiyear upgrading for its future roles, which will include testing superconducting transmission cable. Located on the Hudson River in Yonkers, New York, the facility was built in 1969 by Phelps Dodge Cable & Wire Company and was purchased for EPRI in 1984 with funds provided by Consolidated Edison Company of New York.

The principal test equipment at the EHV laboratory, now operated for EPRI by Westinghouse Electric Corporation, was designed specifically for the development of high-voltage underground transmission cables. It consists of a 1500-kV, 3-A, 60-Hz series-resonant transformer; a 2000-kV, 20-mA reversible-polarity dc voltage supply; and a 4600-kV, 345-kJ, 23-stage impulse generator.

The upgrading of the impulse generator is scheduled for completion this year. The work includes reimpregnating, resealing, and testing the stage capacitors. In addition, the triggered gap systems will be replaced with a new pressurized system developed by Hipotronics, Inc.

During its lifetime, the Yonkers laboratory has been instrumental in several important developments in underground transmission cable. Notable among these developments are PPP-insulated cable and high-pressure fluid-filled cables rated at 138, 230, 345, and 765 kV. Much of the work at the laboratory has been done in conjunction with EPRI's outdoor cable test facility at Waltz Mill, Pennsylvania.

■ *For more information, contact Phil Garcia, (914) 964-2976.*

Utilities Demonstrate Magnetic Bearings

Magnetic bearings have been used in small machines for some 20 years. Now, recent advances in magnets, materials, and control technology have opened the door for the use of these bearings in larger-shaft systems with higher bearing-load capacity. EPRI and Empire State Electric Energy Research Corporation (ESEERCO) are applying this new technology in utility field demonstrations to show how magnetic bearings behave in large pumps and fans. Active magnetic bearings use electromagnets and electronic sensors to levitate and precisely position rotating shafts; as a result, vibration—which increases maintenance costs and reduces equipment availability—is virtually eliminated.

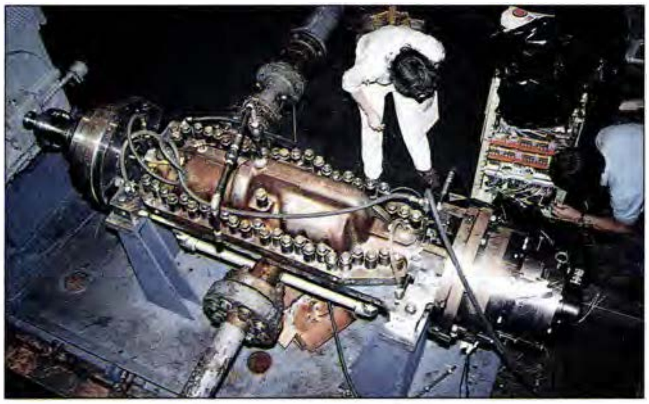
The first utility magnetic-bearing system, in a 600-hp boiler feedpump at New York State Electric & Gas Corporation's Greenidge plant, has operated successfully since late 1990. The second system, in a 3500-hp gas recirculation fan at the Bowline plant of Orange and Rockland Utilities (O&R), began operation last winter. The fan's 23,000-lb rotor is the heaviest ever suspended by magnetic bearings anywhere in the world. Encouraged by the performance of these bearings, EPRI and ESEERCO are looking for other utilities to host further demonstrations on large power plant pumps, fans, and turbine generators.

EPRI and ESEERCO began exploring magnetic bearings with a survey of applications in other industries. The results indicated that the technology could offer the utility industry significant reductions in operating costs and power requirements. In addition to reducing vibration and friction, the bearings eliminate the potential for catastrophic oil fires and bearing-oil contamination.

The system in the boiler feedpump at Greenidge convincingly demonstrated bearing operability and capability in a utility environment over a two-year period. Shaft position control was excellent—within 1 mil of design position. The bearings maintained full control, without any contact with backup bearings, through all transients. The Greenidge bearing system was manufactured by Magnetic Bearings, Inc. (MBI).

Encouraged by the positive results at Greenidge, EPRI and ESEERCO decided to demonstrate magnetic bearings on a significantly larger scale at the 3500-hp, 890-rpm gas recirculation fan at O&R's Bowline plant. Bearings for the fan and its motor were manufactured by MBI. Since startup last February, the bearings have performed flawlessly, cutting fan vibration to one-fiftieth of usual.

Despite the demonstrated reliability and benefits of



magnetic bearings, their high cost must be reduced before they can be widely used in power plants. "Magnetic bearings can cost twice as much as oil-lubricated bearings; however, most of that cost is for the engineering required for each application," explains Tom McCloskey, manager of turbomachinery projects in EPRI's Generation & Storage Division.

EPRI will use the results of the demonstrations to develop standardized procurement specifications that will significantly lower the cost of magnetic bearings; operation and maintenance specifications will also be developed. These should be available in 1995. Meanwhile, utility interest reportedly is high, and a users group of utilities, equipment suppliers, and magnetic-bearing suppliers is being formed.

■ *For more information, contact Tom McCloskey, (415) 855-2655.*

Keeping Frozen Foods Cold With Non-CFC Refrigerants

Paced by international agreements for the accelerated phaseout of chlorofluorocarbons (CFCs), manufacturers and users of all types of vapor-compression cooling and refrigeration systems are scrambling to replace CFCs with chlorine-free, ozone-friendly alternatives. Chemical producers have recently introduced several new refrigerants that are expected to become the favored substitutes in many key applications. Some equipment, such as air conditioners for new automobiles, has already been redesigned to accept new refrigerants. But finding non-CFC substitutes for most refrigeration and air conditioning equipment is trickier, leading in some cases to the exploration of untried refrigerant blends with unknown performance.

EPRI is working with refrigerant producers, equipment manufacturers, the Environmental Protection Agency (EPA), and end-user industries on a broad front to identify and evaluate candidate compounds as CFC substitutes. Several projects are focused on refrigeration systems for food and other frozen products. For example, EPRI has cosponsored the installation of an advanced medium-temperature refrigeration system using the hydrofluorocarbon (HFC) 134a at a Hannaford Brothers supermarket in Glen Falls, New York. And field tests of two new refrigerant blends for low-temperature (frozen-food) refrigeration recently began at a Safeway store in Menlo Park, California, where EPRI had previously demonstrated new energy-efficient refrigeration systems.

The refrigeration systems that chill frozen cases along two aisles at the Menlo Park Safeway were retrofit last summer with about 270 pounds of either Allied-Signal's binary blend AZ-50 or DuPont's ternary blend SUVA HP-62. These refrigerants were recently approved for public testing as substitutes for R-502, a hydrochlorofluorocarbon that is widely used in low-temperature refrigeration systems. Although R-502 is being phased out, until recently there were no substitutes for it.

In connection with the field tests, the equipment's internal mineral-oil lubricant was replaced with a new ester-based oil that is compatible with the refrigerant blends. It was found that a minimum of three oil changes three to four days apart were required to fully exchange the lubricants. Research managers say that the refrigerant blends appear to be performing well with no noticeable impact on overall energy efficiency. Continuing efforts are focused on possible improvements in energy efficiency through the optimization of control setpoints. When the work is completed in mid-1994, users of commercial low-temperature refrigeration systems will have access to full technical documentation describing how to carry out such a retrofit with minimum expense and downtime and how to reoptimize systems for efficient operation. The results will also help in the design of new refrigeration systems.

EPRI's previous work demonstrating advanced refrigeration systems at the Menlo Park Safeway was recognized in a 1992 Renew America Award by the National Environmental Awards Council. This year, for its cosponsorship of the field demonstration at the Hannaford Brothers supermarket, EPRI was recognized in a Stratospheric Ozone Protection Award by the EPA.

■ *For more information, contact Mukesh Khattar, (415) 855-2699.*

New Contracts

Project	Funding/ Duration	Contractor/EPRI Project Manager
Customer Systems		
Commercialization of the Nonintrusive Appliance-Load-Monitoring System (RP2568-30)	$749,000 30 months	Telog Instruments/ *L. Carmichael*
Knowledge-Based Energy Management System for Water Distribution Pumping Control (RP2662-38)	$181,300 12 months	Texas Engineering Experiment Station/ *M. Jones*
Implementation of Industrial Heat Pump Technology Using Low-Temperature Effluent at a Wastewater Treatment Plant (RP2662-45)	$672,400 22 months	City of Topeka/ *M. Jones*
Advanced Commercial Unitary Air Source Heat Pump Development (RP2891-12)	$900,000 27 months	Lennox Industries/ *W. Krill*
Commercial Lighting Retrofit Data Collection and Analysis (RP2980-44)	$101,800 17 months	Fleming Group/ *R. Gillman*
Development of Large Industrial Microwave and Radio-Frequency Systems for Process Industries (RP3245-18)	$67,000 9 months	Thermo Energy Corp./ *A. Amarnath*
Design and Manufacture of Prototype EV Charging Station for Parking/Commercial Facilities, Phase 1 (RP3304-13)	$100,000 8 months	Sundberg-Ferar/ *G. Purcell*
Design and Manufacture of Prototype EV Charging Station for Parking/Commercial Facilities, Phase 1 (RP3304-16)	$100,000 8 months	Walter Dorwin Teague Associates/*G. Purcell*
Integrated Value-Based Planning: Customer Service Improvement (RP3310-7)	$99,500 6 months	Putnam, Hayes & Bartlett/ *T. Henneberger*
Use of Ozone to Renovate Dye-Bath Water (RP3329-4)	$57,000 19 months	Southern Company Services/*A. Amarnath*
Load Control for Transmission and Distribution Benefits (RP3337-9)	$65,000 19 months	Analysis & Control of Energy Systems/*G. Heffner*
Photovoltaic Decision Model (RP3337-12)	$377,600 18 months	Energy and Environmental Economics/*G. Heffner*
Airport Electrification Study (RP3536-1)	$400,000 12 months	Energy Research Group/ *G. Purcell*
Development of Enhanced Thermal Storage System (RP3801-1)	$514,400 27 months	Florida Power Corp./ *J. Kesselring*
Thermal Storage Systems Development and Demonstration (RP3[illegible]20-2)	$431,000 24 months	Northern States Power Co./*R. Wendland*
Electrical Systems		
TOMCAT 2000: Substation Demonstration (RP1497-6)	$50,000 6 months	Consolidated Edison Co. of New York/*H. Mehta*
Improved Dynamic Equivalencing (RP2447-2)	$[illegible]20,600 24 months	General Electric Co./ *P. Hirsch*
Steady-State Voltage Monitoring and Control (RP2473-70)	$50,000 10 months	Massachusetts Institute of Technology/*D. Maratukulam*
Power Circuit Breaker Diagnostics (RP2747-10)	$288,200 8 months	UB Foundation Services/ *J. Porter*
Power Grid Maintenance Scheduling Under Increased Asset Utilization (RP2944-9)	$312,400 13 months	Australian Artificial Intelligence Institute/ *A. Vojdani*
Study of System Operating Impacts of FACTS Technologies (RP3022-29)	$124,000 11 months	New York Power Authority/ *A. Vojdani*
Characterization and Detection of Low-Current Faults on Low-Voltage Systems (RP3127-11)	$50,000 9 months	Texas Engineering Experiment Station/ *T. Kendrew*
Performance Enhancements for the Long-Term Stability Program and the Extended Transient-Midterm Stability Program (RP3144-3)	$197,700 16 months	Battelle Memorial Institute/*P. Hirsch*
Laser-Induced Lightning Research: Discharge of Lightning With Ultrashort Pulses (RP3556-2)	$150,000 23 months	University of New Mexico/ *R. Bernstein*
Hourly Load Forecasting Using Neural Networks (RP3573-4)	$151,100 14 months	Southern Methodist University/*D. Maratukulam*
Distribution Automation Demonstration (RP3674-1)	$1,794,900 31 months	Oglethorpe Power Corp./ *B. Blair*
Distribution Automation/Demand-Side Management Demonstration (RP3[illegible]74-[illegible])	$483,200 30 months	Union Electric Co./*B. Blair*
Geomagnetic Disturbance Investigation (RP367[illegible]-1)	$775,200 25 months	Electric Research & Management/*J. Porter*
Advanced Power Transformer: TVA Prototype (RP3697-1)	$624,500 7 months	ABB Power T&D Co./ *S. Lindgren*
Low-Cost-Radio Project (RP3759-1)	$951,700 18 months	Southern California Edison Co./*V. Tahiliani*
Nuclear Magnetic Resonance Earth Probe for Subsurface Imaging of Buried Cable and Pipe: Feasibility Study (RP7910-25)	$1[illegible]0,200 19 months	Electrascan/*T. Kendrew*
Development of Rock Steering Head for Small-Diameter Horizontal Boring Tool (RP7[illegible]10-26)	$100,200 12 months	Underground Research/ *T. Kendrew*
Demonstration of Advanced Underground Construction Technology for Installing Transmission Cable (RP7[illegible]22-1)	$388,300 4 months	Underground Research/ *T. Rodenbaugh*
Environment		
Influence of Global Climate Change on the Distribution and Population Dynamics of Selected Wildlife Species (RP3316-3)	$104,700 18 months	Yale University/ *L. Pitelka*
Carbon-Cycle Model Linkage Project (RP3416-1)	$1,594,000 59 months	Max Planck Institut für Meteorologie/*L. Pitelka*
Mechanisms of Mercury and Mercuric Chloride Absorption (RP3470-2)	$145,100 30 months	University of Texas, Austin/*D. Owens*
Demonstration of Selective Noncatalytic Reduction on a Cyclone Boiler (RP3619-1)	$[illegible]82,000 15 months	Atlantic Electric Co./ *J. Stallings*
Pulmonary Disorders and Asbestos Exposure Management (RP3627-2)	$[illegible]1,800 44 months	Daniel H. Roth Associates/ *L. Goldstein*
Evaluating the Impact of Mine Injection of FGD Sludges (RP9010-1)	$55[illegible],200 28 months	GAI Consultants/ *D. Golden*
Placement of Fixated Scrubber Sludge Fluid in Mines (RP9010-2)	$297,400 15 months	Conversion Systems/ *D. Golden*
Development of a Utilitywide Waste Accounting System (RP9011-1)	$430,000 43 months	Precor Corp./*M. McLearn*
Evaluation of a Wet Electrostatic Precipitator for Fine Particulate Control (RP9013-1)	$2,398,100 32 months	Northern States Power Co./*R. Altman*
Extraction and Treatment of Groundwater From the Toms River Manufactured Gas Plant Site (RP9015-1)	$550,000 17 months	Ebasco Environmental/ *I. Murarka*
Thermal Remediation of Petroleum-Contaminated Soils (RP9015-7)	$810,000 8 months	Puget Sound Power & Light Co./*I. Murarka*
PISCES Field Chemical Emissions Monitoring at Niagara Mohawk's Oswego Unit 6 (RP9016-19)	$500,000 11 months	Carnot/*B. Toole-O'Neil*
Modeling for Basin Closure Study (RP9020-1)	$93,500 11 months	Tetra Tech/*I. Murarka*
Assessment of Chemical Treatment of an Active Coal Storage Pile to Control Acid Leachate (RP9021-1)	$274,500 18 months	Atlantic Environmental Services/*I. Murarka*
Coal Pile Site Field Investigation (RP9021-3)	$143,100 10 months	Tetra Tech/*I. Murarka*

Exploratory & Applied Research

Project	Funding/ Duration	Contractor/EPRI Project Manager
Computational Algorithms for the Multirate Simulation of Electric Power System Dynamics (RP8014-3)	$187,500 56 months	University of Missouri, Rolla/*A. Wildberger*
Neural Networks With Internal Structure in the Analysis of Complex Systems (RP8017-4)	$98,100 15 months	Northwestern University/ *A. Wildberger*
Removal of Nitrogen From Coal by Thermal Oxidation (RP8022-5)	$148,800 12 months	Babcock & Wilcox Co./ *C. Kulik*
Sulfur Forms Analysis of Coals and Treated Coals (RP8022-6)	$96,400 9 months	ViRoLac Industries/ *C. Kulik*
Removal of Trace Elements From Coal by Means of a Multiple-Property Processing Circuit (RP8022-7)	$138,900 8 months	Virginia Polytechnic Institute and State University/*C. Kulik*
Generic Architecture for Multiple-Agent Process Control (RP8030-3)	$100,000 36 months	North Carolina State University/*J. Naser*
Experimental Development of Power Reactor Intelligent Control (RP8030-4)	$100,000 28 months	Pennsylvania State University/*C. Lin*
Intelligent Control of Power Plants (RP8030-5)	$100,000 36 months	Pennsylvania State University/*G. Pflasterer*
Interpreting Hippocampal Function and Developing Artificial Neural Networks for Prediction in Spatial Control (RP8030-8)	$100,000 33 months	University of Virginia/ *A. Wildberger*
Generic Framework for Flexible-Agent-Based Intelligent Control (RP8030-9)	$100,000 31 months	University of Texas/ *A. Wildberger*
Intelligent Feedback Systems (RP8030-10)	$100,000 36 months	Massachusetts Institute of Technology/*J. Naser*
Effects of Refractory Metals on Scaling of Fe-Ni-Cr Alloys in Mixed Oxidants (RP8041-1)	$360,400 20 months	Lockheed Missiles & Space Co./*W. Bakker*
Advanced Ni-Al Shape-Memory Alloys (RP8043-2)	$224,700 24 months	University of Illinois/ *J. Stringer*
Harmonic Instabilities in Power Systems (RP8050-4)	$242,100 29 months	University of Wisconsin, Madison/*A. Edris*

Generation & Storage

Project	Funding/ Duration	Contractor/EPRI Project Manager
Fabrication of Alloy 28 Waterwalls for Syngas Coolers (RP2048-12)	$90,600 12 months	NV KEMA/*W. Bakker*
AC Battery Module Intensive Monitoring (RP2123-24)	$120,100 10 months	Omnion Power Engineering Corp./*S. Eckroad*
Zebra Mussel Control Device Development (RP2504-15)	$76,400 9 months	Gilbert/Commonwealth/ *J. Tsou*
Development of Advanced Weather Technologies for Electric Utility Applications (RP2917-44)	$450,000 33 months	National Severe Storms Laboratory/*D. Morris*
Fossil Power Plant Performance Improvement (RP3151-14)	$229,000 11 months	Organizational Learning Center/*G. Pflasterer*
Training Simulator Model for Power Plant Emissions Control (RP3152-22)	$300,000 6 months	Power Safety International/ *R. Fray*
Siemens Control Logic Translator Development (RP3152-24)	$58,600 11 months	Trax Corp./*R. Fray*
Magnetic Bearings Procurement and Operating Guidelines (RP3319-3)	$425,300 43 months	Technology Insights/ *T. McCloskey*
Header Feedwater Heater Retrofit and Evaluation (RP3652-2)	$409,700 37 months	Encor-America/*J. Bartz*
Evaluation of the Impacts of Powder River Basin Coal Blends on Plant Performance and Emissions (RP3667-1)	$4,000,000 36 months	PSI Energy/*A. Mehta*
Modular Inclined Fish Screen Evaluation at Green Island Hydro Project (RP3672-1)	$1,394,000 13 months	Stone & Webster Engineering Corp./*C. Sullivan*
Photovoltaic Distributed Generation Project (RP3766-1)	$2,000,000 48 months	Southern California Edison Co./*E. DeMeo*
Solar Energy Balance-of-System Project (RP3766-2)	$1,000,000 18 months	Southern California Edison Co./*E. DeMeo*

Integrated Energy Systems

Project	Funding/ Duration	Contractor/EPRI Project Manager
Stochastic Programming: Decomposition, Importance Sampling, and Parallel Processors (RP2767-7)	$75,000 12 months	Stanford University/ *J. Bloom*
Bayesian Belief Network Solver (RP3581-4)	$100,000 11 months	SRI International/*R. Siddiqi*
Ecosystem Valuation Project, Phase 1 (RP3676-1)	$70,000 3 months	Decision Focus/*T. Wilson*
Operating and Maintenance Cost Management (RP3678-1)	$180,000 12 months	Strategic Decisions Group/ *L. Rubin*

Nuclear Power

Project	Funding/ Duration	Contractor/EPRI Project Manager
Demonstration of PWR Control Rod Guide Card Inspection Capability (RP3428-1)	$241,200 12 months	B&W Fuel Co./*O. Ozer*
Role of Grain Orientation on Carbide Morphology, IGSCC Deformation Mechanisms, and Grain Boundary Depletion (RP3468-2)	$161,500 18 months	Rutgers University/ *L. Nelson*
Operation and Maintenance Cost Evaluations for Risk-Based Prioritizations (RP3477-4)	$612,300 36 months	Scientech/*F. Rahn*
Development of Macrocycle Purification System (RP3500-21)	$50,000 8 months	IBC Advanced Technologies/*P. Paine*
Welding Repair Technology for Steam Generator Tubing (RP3500-22)	$199,500 10 months	J. A. Jones Applied Research Co./*W. Childs*
Feasibility of Adaptation and Transfer of NASA's Advanced Scheduling Technology to the Nuclear Utility Industry: Exploratory Evaluation (RP3500-23)	$96,300 10 months	Kaman Sciences Corp./ *R. Oehlberg*
Digital Safety and Control System Replacement Activities (RP3549-4)	$98,500 17 months	Entor Corp./*J. Naser*
French Steam Generator Database (RP3580-3)	$56,600 29 months	Chanhassen Associates/ *P. Paine*
Preventive Maintenance Program (RP3590-1)	$597,100 48 months	Quadrex Energy Services Corp./*D. Worledge*
Storage and Disposal of Low-Level Radioactive Waste (RP3801-5)	$595,700 16 months	Public Service Electric & Gas Co./*C. Hornibrook*
Demonstration of Inspection Capability for Alloy 600 Closure Head Penetrations (RP4223-4)	$499,900 24 months	J. A. Jones Applied Research Co./*J. Lance*
Characterization of NDE-Irradiated Materials (RP5365-7)	$202,100 22 months	Materials Engineering Associates/*M. Lapides*
Steam Generator Tube Examination (RPS413-9)	$298,200 7 months	Westinghouse Electric Corp./*A. McIlree*
Inhibitor Application Guidelines (RPS510-3)	$87,500 8 months	Dominion Engineering/ *P. Paine*
Steam Generator Tube Fatigue Analysis (RPS540-1)	$387,100 13 months	Foster Wheeler Development Corp./*G. Srikantiah*
Technical Support for Tube Support Plate/Tube Plugging Criteria Limits (RPS550-3)	$57,300 12 months	Westinghouse Electric Corp./*C. Williams*
Development of Standardized Data Management Reporting Formats in Support of Steam Generator Alternative Repair Criteria (RPS550-8)	$70,000 3 months	Steve Brown/*D. Steininger*

New Technical Reports

Requests for copies of reports should be directed to the EPRI Distribution Center, 207 Coggins Drive, P.O. Box 23205, Pleasant Hill, California 94523; (510) 934-4212. There is no charge for reports requested by EPRI member utilities. Reports will be provided to others in the United States for the price listed or, in some cases, under the terms of a license agreement. Those outside the United States should contact the Distribution Center for price information.

CUSTOMER SYSTEMS

User's Guide: HOTCALC 2.0 Commercial Water Heating Performance Simulation Tool
CM-100211 (R1) Final Report (RP3169-1); $295
Contractor: D. W. Abrams, P.E., & Associates
EPRI Project Manager: K. Johnson

Engineering Methods for Estimating the Impacts of Demand-Side Management Programs, Vol. 2: Fundamental Equations for Residential and Commercial End Uses
TR-100984 Final Report (RP3269-3); Vol. 2, $200
Contractors: Architectural Energy Corp.; RCG/Hagler, Bailly, Inc.
EPRI Project Manager: P. Hummel

Development of a Microwave Clothes Dryer: Interim Report I
TR-102114 Interim Report (RP2034-39); $200
Contractors: Thermo Energy Corp.; JG Microwave
EPRI Project Manager: J. Kesselring

Guide to Energy-Efficient Office Equipment
TR-102545 Final Report (RP2890-20); $200
Contractor: American Council for an Energy-Efficient Economy
EPRI Project Manager: M. Blatt

Air Conditioning Systems for Electric Vehicles
TR-102657 Final Report (RP2861-3); $200
Contractor: Arthur D. Little, Inc.
EPRI Project Managers: G. Purcell, B. Banerjee

Pulp and Paper Mill Effluent Treatment Using Advanced Oxidation Processes
TR-102667 Final Report (RP3328-1); $200
Contractor: Black & Veatch
EPRI Project Manager: A. Amarnath

Electric Commercial Cooking Appliance Development Needs
TR-102743 Final Report (RP2890-21); $200
Contractor: Tecogen
EPRI Project Manager: W. Krill

The Transportation Program: Transportation Infrastructure Research Plan, 1993–1997
TR-102770 Final Report (RP3272-2); $200
Contractor: Hart, McMurphy & Parks
EPRI Project Manager: G. Purcell

Guidebook of Environmental Solutions for Small Businesses
TR-102843 Final Report (RP2890-13); $200
Contractor: Resource Dynamics Corp.
EPRI Project Manager: W. Krill

ELECTRICAL SYSTEMS

Production Methods for Amorphous Alloy for Transformer Cores
TR-101978 Final Report (RP1290-1); $5000
Contractor: Allied Corp.
EPRI Project Managers: E. Norton, B. Damsky

Amorphous Metal for Transformers
TR-102264 Final Report (RP1290-3); $5000
Contractor: Allied-Signal Corp.
EPRI Project Manager: B. Damsky

Transmission Limitation Program, Version 1.0, Vols. 1–4
TR-102416 Final Report (RP2746-2); Vol. 1, $5000; Vols. 2–4, license required
Contractor: Ontario Hydro
EPRI Project Manager: P. Hirsch

Proceedings: Dynamic Security Assessment and Voltage Stability (Two Coordinated Workshops), Vols. 1 and 2
TR-102444 Proceedings (RP2473-60); Vols. 1 and 2, $200 each volume
Contractor: Decision Systems International
EPRI Project Managers: G. Cauley, D. Maratukulam

Proceedings: Static Electrification in Power Transformers
TR-102480 Final Report (RP1499-99); $200
EPRI Project Manager: S. Lindgren

Solar Magnetic Disturbances/Geomagnetically Induced Current and Protective Relaying
TR-102621 Final Report (RP3211-4); $5000
Contractor: Electric Research and Management, Inc.
EPRI Project Managers: M. Wilhelm, F. Phillips

Interfacial Bond Strength of Paper-Polypropylene-Paper Laminates
TR-102777 Interim Report (RP7880-12); $5000
Contractor: University of Akron
EPRI Project Manager: B. Bernstein

ENVIRONMENT

Field Pan Studies on Treatment of Manufactured-Gas Plant (MGP) Soils Using Commercially Grown Fungus
TR-102185 Final Report (RP2879-12); $200
Contractors: Atlantic Environmental Services, Inc.; META Environmental, Inc.
EPRI Project Manager: I. Murarka

Condenser Microbiofouling Control Handbook
TR-102507 Final Report (RP2300-16); $200
Contractor: Fourth Floor Databases, Inc.
EPRI Project Managers: W. Micheletti, M. Miller

On-line Corrosion Monitoring at the High-Sulfur Test Center
TR-102538 Final Report (RP1871-14); $200
Contractor: CAPCIS MARCH, Ltd.
EPRI Project Manager: B. Syrett

Fly Ash Exposure in Coal-Fired Power Plants
TR-102576 Final Report (RP2222-2); $200
Contractor: Radian Corp.
EPRI Project Managers: W. Weyzen, R. Wyzga

Limestone Selection Methodology for Wet Flue Gas Desulfurization Systems
TR-102660 Final Report (RP1877-1); license required
Contractor: Radian Corp.
EPRI Project Manager: D. Owens

Retrofit NO_x Controls for Coal-Fired Utility Boilers: Technology Assessment Guide for Meeting Requirements of the 1990 Clean Air Act Amendments
TR-102906 Final Report (RP2916-7); license required
EPRI Project Manager: D. Eskinazi

EXPLORATORY & APPLIED RESEARCH

Feasibility of On-line Monitoring of Stress Corrosion Cracking in Rotating Components
TR-102537 Final Report (RP8002-35); $200
Contractor: CAPCIS MARCH, Ltd.
EPRI Project Manager: B. Syrett

Measuring Precrack Initiation Fatigue State in Reactor Pressure Vessel Steels
TR-102761 Topical Report (RP2426-19); $200
Contractor: IHI Research Institute
EPRI Project Manager: M. Lapides

Oxidation Phenomena in Water Treeing
TR-102769 Final Report (RP8000-3); $200
Contractor: Institut de Recherche d'Hydro-Québec
EPRI Project Manager: B. Bernstein

GENERATION & STORAGE

Shell Coal Gasification Project: Final Report on Eighteen Diverse Feeds
TR-100687 Final Report (RP2695-1); $200
Contractor: Shell Development Co.
EPRI Project Manager: N. Stewart

Probable Maximum Precipitation Study for Wisconsin and Michigan, Vols. 1 and 2
TR-101554 Final Report (RP2917-29); Vols. 1 and 2, $200 each volume
Contractor: North American Weather Consultants
EPRI Project Manager: D. Morris

Gas Turbine Overhaul Plan for General Electric MS5001 Simple-Cycle Power Plants (GTOP-5), Vols. 1 and 2
TR-101687 Final Report (RP2831-2); Vols. 1 and 2, license required
Contractor: Operational Services, Inc.
EPRI Project Managers: R. Frischmuth, J. Stover

Preliminary Guidelines for Fossil Plant Simulator Training Programs
TR-101854 Final Report (RP3384); $200
Contractor: American Systems Engineering Corp.
EPRI Project Manager: R. Fray

Proceedings: Combustion Turbine Associates Group (CTAG) Technical Exchange Meeting, February 1993
TR-101977 Proceedings (RPCTAG-78); $200
Contractors: EPRI Combustion Turbine Center; Scofield Communications
EPRI Project Manager: R. Frischmuth

Proceedings: Third International Zebra Mussel Conference, 1993
TR-102077 Proceedings (RP2504-13); $200
Contractor: Stone & Webster Environmental Technology & Services
EPRI Project Manager: J. Tsou

Field Experience With Photovoltaic Systems: Ten-Year Assessment
TR-102138 Final Report (RP1607-6); $200
Contractor: Southwest Technology Development Institute
EPRI Project Managers: J. Berning, F. Goodman

Landfill Characteristics of Circulating-Fluidized-Bed Combustion Ash
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EPRI Project Manager: T. Boyd

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TR-102392 Final Report (RP1266-46); $200
Contractor: Brigham Young University
EPRI Project Managers: D. Broske, B. Dooley

Proceedings: 1993 EPRI Workshop on Power Plant Cable Condition Monitoring
TR-102399 Proceedings (RP2895); $200
EPRI Project Managers: J. Stein, J. Carey, B. Bernstein

Gas Turbine and Combined-Cycle Capacity Enhancement
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EPRI Project Manager: H. Schreiber

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Development of a Rotor-Mounted Scanner for Hydrogenerators
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Workshop Proceedings: State-of-the-Art Review of Microbubble Froth Flotation
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EPRI Project Manager: C. Kulik

Advanced Physical Fine-Coal Cleaning: Spherical Agglomeration
TR-102633 Final Report (RP2704-1); $200
Contractor: Bechtel National, Inc.
EPRI Project Managers: C. Kulik, H. Lebowitz

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Contractor: Bechtel National, Inc.
EPRI Project Managers: C. Kulik, C. Harrison, J. Hervol, H. Lebowitz

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Contractors: Rochester Institute of Technology; Jerry Taborek Consulting Services
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Proceedings: Low-Rank Coal Upgrade Technology Workshop
TR-102700 Proceedings (RP1895-36); $200
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EPRI Project Manager: B. Weber

Coal Log Fuel Handling and Treatment at Power Plants
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Contractor: University of Missouri
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Turbine Efficiency Improvement Investigation
TR-102729 Final Report (RP2818-7); $200
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EPRI Project Manager: R. Leyse

Clean Coal by Agglomeration: Part 1, Agflotherm Process for Low-Rank Coals; Part 2, Aglofloat Process for Bituminous Coals
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EPRI Project Manager: C. Kulik

Proceedings: Conference on Asbestos Control and Replacement for Electric Utilities
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Generator Retaining Ring Moisture Protection Guide
TR-102949 Final Report (RP2719); $200
Contractor: EPRI Nondestructive Evaluation Center
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INTEGRATED ENERGY SYSTEMS

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TR-102898 Final Report (RP2359-20); $200
Contractor: Decision Focus, Inc.
EPRI Project Manager: R. Goldberg

Overview of the EPRI CONTRACTMIX Model for Coal, Uranium, and Fuel Oil Applications
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The Analyst's Guide to Fuel Contracting With the EPRI CONTRACTMIX Model
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EPRI Project Manager: R. Goldberg

NUCLEAR POWER

Evaluation of Discrepancies in Assembly Cross-Section Generator Codes, Vol. 4: Doppler Evaluation
NP-6147 Final Report (RP2803-2), Vol. 4; $200
Contractor: Utility Resource Associates
EPRI Project Manager: R. Breen

Seismic Ruggedness of Relays, Vol. 2, Addendum 1
NP-7147-SL Final Report (RP2925-2), Vol. 2; license required
Contractor: ANCO Engineers, Inc.
EPRI Project Manager: R. Kassawara

Procedure for Evaluating Nuclear Power Plant Relay Seismic Functionality, Vol. 2, Addendum
NP-7148-SL Final Report (RP2925-8), Vol. 2; license required
Contractor: MPR Associates, Inc.
EPRI Project Manager: R. Kassawara

VTESTER Analysts Manual
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Contractors: Westinghouse Electric Corp.; Decision Focus, Inc.
EPRI Project Manager: R. Carter

Electric Utility Service Water System Reliability Improvement: A Compendium of Presentations
TR-101541 Application Report (RP3232-1, RP4242-1); $200
EPRI Project Manager: N. Hirota

EPRI Motor-Operated-Valve Performance Prediction Program: Stem/Stem-Nut Lubrication Test Report
TR-102135 Topical Report (RP3433-4, -10, -26); $20,000
Contractors: Bolt & Associates; Liberty Technologies
EPRI Project Manager: L. Dorfman

Evaluation of the Safety Benefits and Costs of Proposed Revisions to In-service Testing Requirements for Pumps and Valves
TR-102240 Final Report (RP3186-13, -14); $200
Contractors: Sequoia Consulting Group, Inc.; Rowley Consultants
EPRI Project Manager: W. Houston

Calvert Cliffs Nuclear Power Plant Life-Cycle Management/License Renewal Program: Integrated Plant Assessment
TR-102267 Final Report (RP2643-35); $200
Contractors: Baltimore Gas & Electric Co.; Grove Engineering, Inc.
EPRI Project Manager: M. Lapides

CHIRON, a Fuel Failure Prediction Code: Revised User's Manual for Version 2.1
TR-102297 Computer Code Manual (RP2229-6); license required
Contractor: S. Levy, Inc.
EPRI Project Manager: O. Ozer

Geotechnical Synthesis for the Lotung Large-Scale Seismic Experiment
TR-102362 Final Report (RP2225-23); $200
Contractor: CH2M Hill
EPRI Project Manager: Y. Tang

Evaluation of Snubber Functional Test Methods
TR-102363 Final Report (RP3182-1); Tier 1, $200, Tier 2, $600
Contractor: Lake Engineering Co.
EPRI Project Manager: Y. Tang

Reactor Coolant System Heat-up/Cooldown Curve Calculator: P-T Limit Curve Calculator, Version 2.0
TR-102552 Final Report (RP1757-72); $200
Contractor: Structural Integrity Associates, Inc.
EPRI Project Manager: R. Carter

STARRS-EPRIGEMS.02 Code: An Expert Analytical Tool for Assessing PWR Steam Generator Tube Rupture Events—Vols. 1–3
TR-102623 Final Report (RP2453-4); Vols. 1–3; license required
Contractor: Science Applications International Corp.
EPRI Project Manager: S. Kalra

Refueling Outage Data Collection and Analysis
TR-102624 Final Report (RP3333-8); $200
Contractor: Tenera, LP
EPRI Project Manager: B. Chu

Destruction of Organics in Steam Cycle Water Samples
TR-102626 Final Report (RP3500-1); $200
Contractor: GEBCO Engineering, Inc.
EPRI Project Manager: D. Cubicciotti

Proceedings: Utility Workshop on the Life Cycle Management/License Renewal Program at Calvert Cliffs Nuclear Power Plant
TR-102627 Proceedings (RP2643-35); $200
Contractor: Grove Engineering, Inc.
EPRI Project Manager: M. Lapides

GAPPIPE 2.0: Computer Software for Analysis of Piping Systems With Seismic Limit Stops or Large Support Gaps—User's Manual
TR-102651 Final Report (RP2349-1); license required
Contractor: Robert L. Cloud & Associates, Inc.
EPRI Project Manager: Y. Tang

Residual Stresses in Stainless-Steel-Clad Pressure Vessel Steel
TR-102692 Final Report (RPC102-8); $1000
Contractor: AECL Research
EPRI Project Manager: R. Pathania

Application of the Cylindrically Guided Wave Technique (CGWT) for Bolt and Pump Shaft Inspection
TR-102703 Final Report (RP2179-6); $500
Contractor: Southwest Research Institute
EPRI Project Manager: S. Liu

Proceedings: 1991 Symposium on Chemistry in High-Temperature Aqueous Solutions
TR-102706 Proceedings (RPS407-43); $200
Contractor: Brigham Young University
EPRI Project Manager: P. Millett

Horizontal Above-Rack Pool Storage
TR-102732 Final Report (RP2062-16); $200
Contractor: U.S. Tool & Die, Inc.
EPRI Project Manager: R. Lambert

Design and Operation of the Westinghouse MC-10 Spent-Fuel Storage Cask
TR-102735 Interim Report (RP2406-4); $200
Contractor: Virginia Power
EPRI Project Manager: R. Lambert

Chromium Coatings to Reduce Recontamination: Preparation and Characterization of Chromium-Coated Residual Heat Removal System Piping
TR-102746 Interim Report (RP2758-2); $200
Contractor: Radiological & Chemical Technology, Inc.
EPRI Project Manager: H. Ocken

Common-Cause Data Analysis Tool (CCDAT) User's Manual
TR-102747 Final Report (RP3200-20); $500
Contractors: FRH, Inc., University of Maryland
EPRI Project Manager: B. Chu

Environmentally Assisted Fatigue Crack Initiation in Low-Alloy Steels: A Review of the Literature and the ASME Code Design Requirements
TR-102765 Final Report (RPC102-10); $1000
Contractor: GE Nuclear Energy
EPRI Project Manager: R. Pathania

Prediction of Electrochemical Potentials in BWR Primary Systems, Vol. 1: Evaluation of Water Chemistry and ECP Measurements Under Hydrogen Water Chemistry
TR-102766 Final Report (RPC101-20); Vol. 1, $1000
Contractor: GE Nuclear Energy
EPRI Project Manager: R. Pathania

NAUAHYGROS 1.0: A Code for Calculating the Behavior of Aerosols in Nuclear Plant Containments Following a Severe Accident
TR-102775 Final Report (RP1933-90); $200
Contractors: Rudolph Sher Associates, Technical Research Centre of Finland
EPRI Project Managers: A. Machiels, F. Rahn

The Role of Trace Impurities in Classification of In-Core Reactor Components
TR-102800 Final Report (RP2813-32); $200
Contractor: Battelle, Pacific Northwest Laboratories
EPRI Project Manager: R. Lambert

A Methodology for Determining an EDG's Capability to Start Its Emergency Loads
TR-102814 Final Report (RP4114-7); $200
Contractors: Rochester Gas & Electric Corp.; Roettger Engineering
EPRI Project Manager: H. Wyckoff

Natural Circulation Experiments for PWR High-Pressure Accidents
TR-102815 Final Report (RP2177-5); $50,000
Contractor: Westinghouse Electric Corp.
EPRI Project Managers: B. Sehgal, M. Merilo

Thermal Hydraulic and Fission Product Release Behavior During Core/Concrete Interactions
TR-102816 Final Report (RP1933-3); $200
Contractor: Massachusetts Institute of Technology
EPRI Project Manager: B. Sehgal

A Comparison of Zircaloy Oxide Thicknesses on Millstone-3 and North Anna-1 PWR Fuel Cladding
TR-102826 Final Report (RP2493-5); $200
Contractor: Nuclear Electric PLC
EPRI Project Manager: S. Yagnik

Evaluation of Limits on BWR Pressure Vessel Hydrotest Temperature and PWR Low-Temperature Overpressurization Protection System
TR-102850 Final Report (RP1757-57, -92); $200
Contractor: Sartrex Corp.
EPRI Project Manager: R. Carter

A Review of the Design Basis of the K_{IR} Fracture Toughness Curve
TR-102852 Final Report (RP2975-5); $200
Contractor: Westinghouse Electric Corp.
EPRI Project Manager: R. Carter

Advanced Amine Application Guidelines (Revision 0)
TR-102952 Final Report (RP2977); $200
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APLUS™: Analysis of Plant Utility Systems
Version 2.0 (PC-DOS)
Developer: Tensa Services, Inc.
EPRI Project Manager: Ammi Amarnath

CEM RW™: Continuous Emissions Monitoring Reporting Workstation
Version 1.1 (PC-DOS)
Developer: Electric Software Products, Inc.
EPRI Project Manager: Chuck Dene

COGENMASTER: Evaluation of Cogeneration Projects
Version 1.11 (PC-DOS)
Developer: Synergic Resources Corp.
EPRI Project Manager: Michael Evans

COOLAID: Thermal Energy Storage/Demand-Side Planning/Load and Market Research
Version 3.1 (PC-DOS)
Developer: Regional Economic Research
EPRI Project Manager: Ron Wendland

DYNAMICS
Version 2.0 (RS6000-AIX)
Developer: Decision Focus, Inc.
EPRI Project Manager: James Fortune

EMTP Workstation: Electromagnetic Transients Program
Version 2.1 (HP-UNIX)
Developer: Electrotek Concepts, Inc.
EPRI Project Manager: Rambabu Adapa

INFORM: Industrial End-Use Forecasting Model
Version 1.2 (PC-DOS)
Developer: Regional Economic Research
EPRI Project Manager: Paul Meagher

PTLOAD™: Power Transformer Load Planning
Version 4.0 (PC-DOS)
Developer: Power Computing Co.
EPRI Project Manager: Gil Addis

TRELSS: Transmission Reliability Evaluation for Large-Scale Systems
Version 1.2 (RS6000-AIX)
Developer: Southern Company Services
EPRI Project Manager: Ali Vojdani

EPRI Events

JANUARY 1994

18–20
Fossil Plant Inspections
San Antonio, Texas
Contact: Lori Adams, (415) 855-8763

31–February 4
Fireside Performance of Coal-Fired Boilers
Irving, Texas
Contact: Ursla Rosenblum, (215) 758-4090

FEBRUARY

7–8
Workshop on Rate Design in the 1990s
Tampa, Florida
Contact: Pam Turner, (415) 855-2010

9–11
Innovative Electricity Pricing Conference
Tampa, Florida
Contact: Pam Turner, (415) 855-2010

9–11
Outage Risk Assessment and Management (ORAM) Workshop
Orlando, Florida
Contact: Jeff Mitman, (415) 855-2564

15–16
Customer Value Deployment
Dallas, Texas
Contact: Lynn Stone, (214) 556-6529

MARCH

1–2
Needs-Driven Program Design
Dallas, Texas
Contact: Lynn Stone, (214) 556-6529

3–4
Clean Air Response: Achieving Compliance in an Evolving Market
Baltimore, Maryland
Contact: Jeremy Platt, (415) 855-2628

3–4
Continuous Emissions Monitoring Quality Assurance
Dallas, Texas
Contact: Lynn Stone, (214) 556-6529

14–16
EMF Science and Communication Seminar
Santa Clara, California
Contact: Amelia Birney, (612) 623-4600

15–16
Distributed Utility Workshop
Baltimore, Maryland
Contact: Susan Marsland, (415) 855-2946

16–17
Asbestos Control and Replacement
San Diego, California
Contact: Linda Nelson, (415) 855-2127

22–23
4th Annual NMAC Conference and Technical Workshop
Charlotte, North Carolina
Contact: Jayne Adkisson, (704) 547-6141

23–25
Fossil Plant Cycling
New Orleans, Louisiana
Contact: Lori Adams, (415) 855-8763

23–25
Weld and Repair Technology for Fossil Power Plants
Williamsburg, Virginia
Contact: Susan Bisetti, (415) 855-7919

29–31
Nondestructive Evaluation of Fossil Plants
Dallas, Texas
Contact: Lynn Stone, (214) 556-6529

APRIL

5–6
Global Warming: A Call for International Coordination
San Francisco, California
Contact: Colleen Hyams, (415) 855-2143

5–7
Direct Demand-Side Management Marketing
Dallas, Texas
Contact: Lynn Stone, (214) 556-6529

26–29
Transformer Performance Monitoring and Diagnostics
Eddystone, Pennsylvania
Contact: John Niemkiewicz, (215) 595-8871

MAY

3–5
Heat Rate Improvement
Baltimore, Maryland
Contact: Susan Bisetti, (415) 855-7919

10–13
Decision Quality/Decision Analysis Seminar and Workshop
Newport, Rhode Island
Contact: Susan Marsland, (415) 855-2946

11–13
NO_x Controls for Utility Boilers
Scottsdale, Arizona
Contact: Pam Turner, (415) 855-2010

16–20
Applications of Static Compensators and Other FACTS Power Flow Controllers
Madison, Wisconsin
Contact: Bill Long, (608) 262-2061

17–19
Fluidized-Bed Combustion for Power Generation
Atlanta, Georgia
Contact: Linda Nelson, (415) 855-2127

17–19
6th Predictive Maintenance Conference
Philadelphia, Pennsylvania
Contact: Lori Adams, (415) 855-8763

19–20
Improving Building Systems in Hot and Humid Climates
Arlington, Texas
Contact: Susan Swanson, (409) 862-2291

JUNE

1–2
Customer Value Deployment
Dallas, Texas
Contact: Lynn Stone, (214) 556-6529

6–8
ISA POWID/EPRI Controls and Instrumentation Conference
Orlando, Florida
Contact: Lori Adams, (415) 855-8763

29–July 1
Service Water Systems Reliability Improvement
St. Louis, Missouri
Contact: Susan Otto, (704) 547-6072

JULY

10–14
Mercury as a Global Pollutant
Whistler, British Columbia
Contact: Pam Turner, (415) 855-2010

12–13
Needs-Driven Program Design
Dallas, Texas
Contact: Lynn Stone, (214) 556-6529

24–26
International Conference on Low-Level Waste
Norfolk, Virginia
Contact: Linda Nelson, (415) 855-2127

26–29
ASME/EPRI Radwaste Workshop
Norfolk, Virginia
Contact: Linda Nelson, (415) 855-2127

AUGUST

1–2
Rate Design in the 1990s
Boston, Massachusetts
Contact: Phyllis Firebaugh, (214) 556-9545

2–4
Direct Demand-Side Management Marketing
Dallas, Texas
Contact: Lynn Stone, (214) 556-6529

17–19
Effects of Coal Quality on Power Plants
Charleston, South Carolina
Contact: Susan Bisetti, (415) 855-7919

30–September 1
Cooling Towers and Advanced Cooling Systems
St. Petersburg, Florida
Contact: Lori Adams, (415) 855-8763

SEPTEMBER

7–9
4th Conference on Cycle Chemistry in Fossil Plants
Atlanta, Georgia
Contact: Linda Nelson, (415) 855-2127

20–22
International Conference on Advanced Turbines
Portland, Oregon
Contact: Susan Bisetti, (415) 855-7919

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