Seeking Order in Chaos

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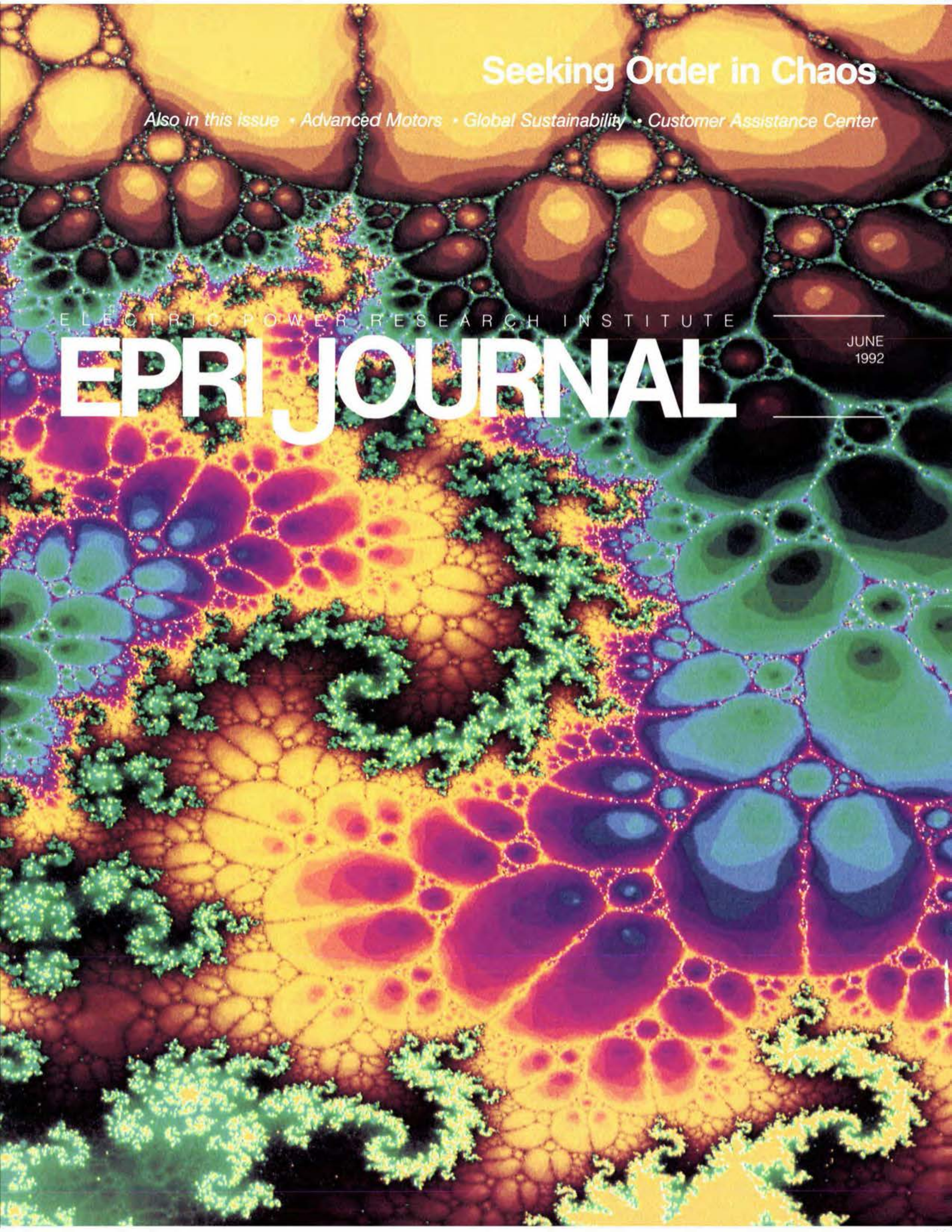

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Cover: While many phenomena in the real world appear to exhibit completely random behavior, chaos theory predicts underlying patterns that may help researchers understand dynamic systems that are basically nonlinear (Photo © 1992 Clif Pickover, *Computers and the Imagination*, New York: St. Martin's Press.)

Exploring Chaos

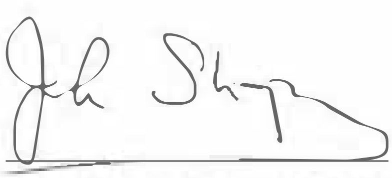
Chaos is all around us in the natural world. Although we often fail to notice its presence, it is a constant influence: in the movement of clouds, the breaking of waves on a shore, the pattern of population growth in a termite colony. As this month's cover story reveals, the current scientific fervor for exploring chaos is beginning to produce remarkable insights about some of the world's most complex dynamic systems.

The modern study of chaos began only a few years ago with computer experiments by Edward Lorenz, who was trying to model convection in the atmosphere—the same phenomenon of fluid motion in response to heat that causes the ever-changing shape of clouds. As Lorenz discovered, once this motion becomes turbulent—that is, chaotic—one can no longer hope to predict its exact behavior. And yet the behavior isn't quite random either. Rather, strange patterns of behavior emerge: bounded, recognizable, never exactly repeating, and extremely sensitive to even slight differences in initial conditions.

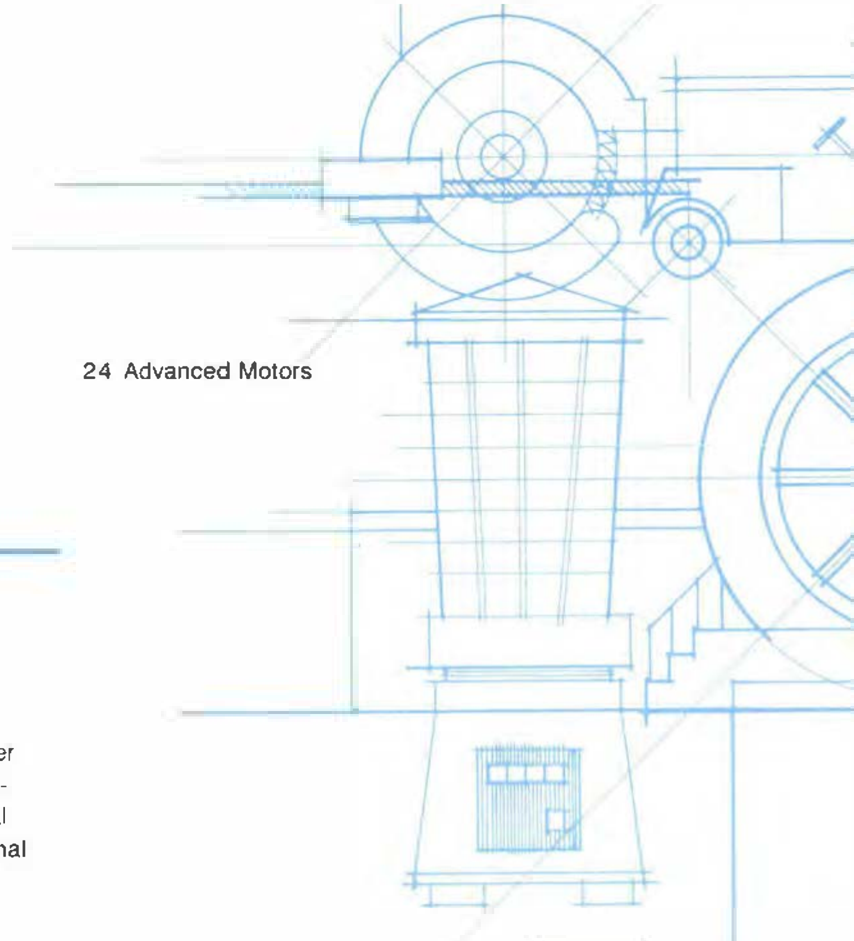
Since Lorenz's pioneering work, similar chaotic behavior has been discovered at the heart of phenomena ranging from market fluctuations and corrosion to heart attacks and fluidized-bed combustion. Until now, most of the research on chaos has been theoretical, with the major visible product being computerized images of such startling beauty and complexity that they virtually constitute a new, fractionally dimensional art form. More practical applications have lagged considerably behind.

Recently, however, the study of chaos has begun to move from the realm of theoretical science to that of practical engineering. Although changes in chaotic systems may not be predictable in detail, the recognizable patterns of their overall behavior can reveal new ways of exerting control. The operating conditions of electric power delivery systems, for example, may someday be tuned to prevent the onset of chaos and probable collapse, while those of power plant boilers may be adjusted to maximize chaos and thus the mixing of air and fuel.

In the field of electric power, much of this theory-into-practice research is being sponsored by EPRI's Office of Exploratory & Applied Research. Indeed, the effort exemplifies the reason why this office was created: to fund the exploration of fields that are not yet fully defined and whose boundaries are not yet confined by traditional academic fiefdoms. It is in such emerging fields that surprising discoveries are most likely to occur, bringing the hope for unexpected benefits for humanity—for research itself can be chaotic, in sometimes exciting ways!



John Stringer, Director of Applied Research
Office of Exploratory & Applied Research



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THE STORY IN BRIEF

Is chaotic behavior impossible to understand? Not necessarily, according to current theory, which describes an underlying order in seemingly random phenomena. Using the tenets of deterministic chaos, EPRI is doing exploratory research on several dynamic processes of importance to the utility industry—searching for points of departure from linear behavior and for the reasons that predictable dynamics become chaotic. For power delivery systems, this research may help define the difference between a stable network and a system failure. For combustion processes, on the other hand, chaotic behavior may actually be encouraged in order to optimize the turbulent mixing of fuel and air that leads to higher combustion efficiency. Convection and metal passivation may also have chaotic aspects. Understanding chaotic behavior in such processes—learning how to control it and, if desirable, reverse it—could lead researchers to a better grasp of complex natural phenomena and to very practical technical fixes as well.

The sudden onset of chaotic behavior can be seen in the smoke from a cigarette. The smoke rises in a typically laminar flow pattern for several inches but then—even in completely still air—breaks into what appears to be turbulence.

Seeking Order in CHAOS

by John Douglas

FOR HUNDREDS OF YEARS, a fundamental notion of science and engineering has been that the behavior of complex systems could be predicted accurately if only one had enough information and intelligence. This critical assumption was first challenged at the atomic level by quantum mechanics and has now received another blow from the emergence of chaos theory. This theory holds that even for macroscopic systems, tiny variations in initial conditions may sometimes create radically different outcomes, making accurate prediction impossible. Perhaps most startling of all, such chaotic behavior can also arise in relatively simple systems governed by a few uncomplicated equations.

The implications of this discovery for electric power equipment and networks are both disturbing and exciting. On the one hand, an unsuspected potential for instability may lurk among the operating conditions of systems thought to be well understood. Sudden voltage collapses on power grids, for example, may indicate the presence of underlying chaotic dynamics. On the other hand, understanding chaos may provide unprecedented control over some of the most complex and elusive natural processes, such as combustion, corrosion, and superconductivity.

Although chaos theory has been generating considerable excitement in the academic community, few practical uses have so far been achieved. To begin bridging the gap between theory and practice, EPRI sponsored a workshop, "Applications of Chaos," in San Francisco in December 1990. Organized by John Stringer of the Office of Exploratory & Applied Research and Jong Kim of the Nuclear Power Division, the workshop brought together specialists from a wide variety of disciplines—ranging from physics and engineering to physiology and computer science. Presentations included progress reports on chaos-related projects already being sponsored by EPRI, as well as reports on other attempts to bring chaos theory to bear

THE TENDENCY OF DIVERGENCE **Dynamics in a chaotic system are exquisitely sensitive to starting conditions. Consider two particles that are driven by the wind. Starting from *almost* exactly the same position, the particles are blown along the same path for some distance. But nonlinear systems significantly magnify small changes, and the particles soon diverge—not just slightly, but radically. Such huge end effects from minute differences in initial conditions point up the hopelessness of trying to predict the long-range behavior of nonlinear systems, such as the weather, by using classical deterministic approaches.**

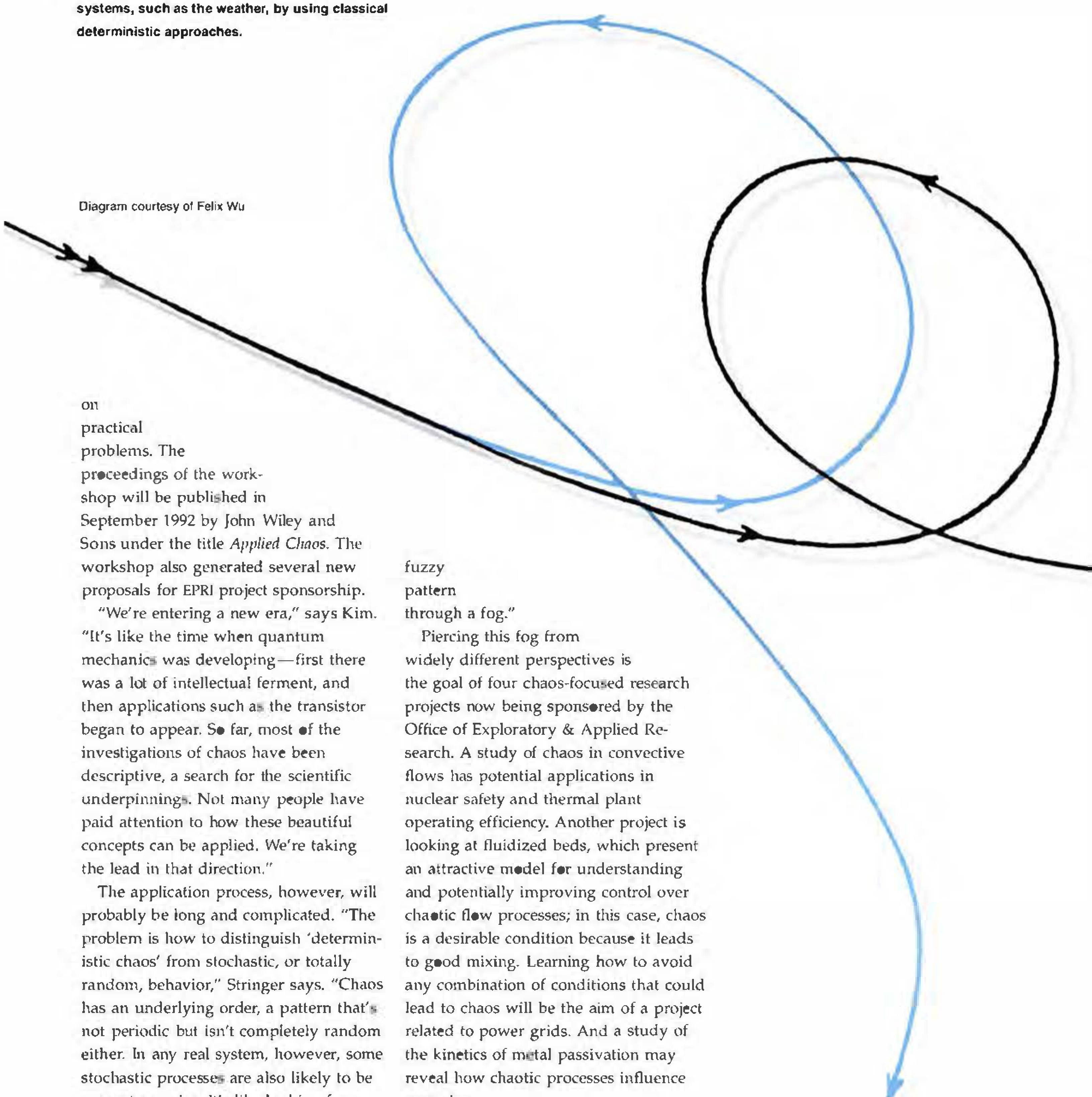


Diagram courtesy of Felix Wu

on practical problems. The proceedings of the workshop will be published in September 1992 by John Wiley and Sons under the title *Applied Chaos*. The workshop also generated several new proposals for EPRI project sponsorship.

"We're entering a new era," says Kim. "It's like the time when quantum mechanics was developing—first there was a lot of intellectual ferment, and then applications such as the transistor began to appear. So far, most of the investigations of chaos have been descriptive, a search for the scientific underpinnings. Not many people have paid attention to how these beautiful concepts can be applied. We're taking the lead in that direction."

The application process, however, will probably be long and complicated. "The problem is how to distinguish 'deterministic chaos' from stochastic, or totally random, behavior," Stringer says. "Chaos has an underlying order, a pattern that's not periodic but isn't completely random either. In any real system, however, some stochastic processes are also likely to be present as noise. It's like looking for a fuzzy pattern through a fog."

Piercing this fog from widely different perspectives is the goal of four chaos-focused research projects now being sponsored by the Office of Exploratory & Applied Research. A study of chaos in convective flows has potential applications in nuclear safety and thermal plant operating efficiency. Another project is looking at fluidized beds, which present an attractive model for understanding and potentially improving control over chaotic flow processes; in this case, chaos is a desirable condition because it leads to good mixing. Learning how to avoid any combination of conditions that could lead to chaos will be the aim of a project related to power grids. And a study of the kinetics of metal passivation may reveal how chaotic processes influence corrosion.

Convection: the problem of nonlinearity

Although the possibility for chaotic behavior in dynamic systems was first recognized by the French mathematician Jules-Henri Poincaré near the turn of this century, it was first observed in 1961 by a meteorologist, Edward Lorenz, as he tried to develop a simple computer model of weather on the basis of convection currents in the atmosphere. Puzzled by the sensitivity of his model to what seemed to be insignificant differences in starting conditions, Lorenz simplified the problem even further. He described a very abstract version of convection with just three variables and three equations, but still he found unexpectedly complex behavior. The variables changed in a complicated way, so it was impossible to predict their values with any degree of certainty over long time periods. Nevertheless, as Lorenz mapped their long-term trends, he noticed that the variables produced a three-dimensional pattern that vaguely resembled the outstretched wings of a butterfly. The pattern was not stochastic—purely random variation would have produced only a smear—but it wasn't periodic either. No two lines ever quite intersected, giving the "Lorenz butterfly" an infinitely complex microstructure.

It took more than a decade and a half for this kind of phenomenological pattern—globally organized but locally unpredictable—to gain enough recognition to be named, and it took even longer for investigations of chaos to earn scientific respectability. Indeed, what eventually led to the current revolution in the science of dynamic systems was the slow realization that chaotic behavior is ubiquitous. Fluctuations in predator-prey populations, fibrillation of the heart, the dripping of a faucet, trends in the price of cotton—all show telltale signs of chaotic behavior and are thus amenable to study through the same mathematical formalism.

The equations that describe potentially chaotic systems usually have at least one thing in common, nonlinearity. In a linear equation, an increase in one variable produces a proportional increase in another, making the equation easy to solve. Push twice as hard on a car and it will accelerate twice as fast. But in nonlinear equations—which generally cannot be solved—not only do changes lack proportionality, they may differ qualitatively as conditions change. Convection, for example, starts out as a smooth flow that speeds up as the temperature difference between the top and the bottom of a fluid increases. But beyond a certain point, instabilities begin to appear, and at great enough temperature differences, the flow becomes turbulent—that is, chaotic.

EPRI's project on chaos in convective systems, being conducted at the University of Virginia, aims to develop a generic model of nonlinear flow in critical electric power devices, such as transformers, heat exchangers, and boiling water reactors. Using the three original Lorenz equations as a starting point, researchers are attempting to determine what conditions lead to chaotic flow and what effect this transition has on the heat removal efficiency of the devices in question. They will also explore the feasibility of reversing this process, driving the system back from chaotic to periodic flow.

The potential importance of such work was underscored recently by an incident at the LaSalle-2 BWR, near Chicago. After an operator's valve-setting error, the reactor apparently made a transition from stable equilibrium to rapid power surges. Such surges result from nonlinearities in both the convective and the nuclear properties of a BWR. Although the incident never represented a hazard to either power plant personnel or the public, it reinforced the importance of better understanding the nonlinear dynamics of reactors.

"We need to understand what conditions can result in chaotic behavior in major power systems," says Jong Kim, who is project manager for the convection research. "It's not always to be avoided, of course; chaotic flow is an aid when you want more fluid mixing, for example. But we do need to learn how to control chaos, including how to reverse it. Such research will be particularly important for ensuring the stability of the next generation of so-called passively safe reactors, which rely on natural convection to provide emergency cooling capability."

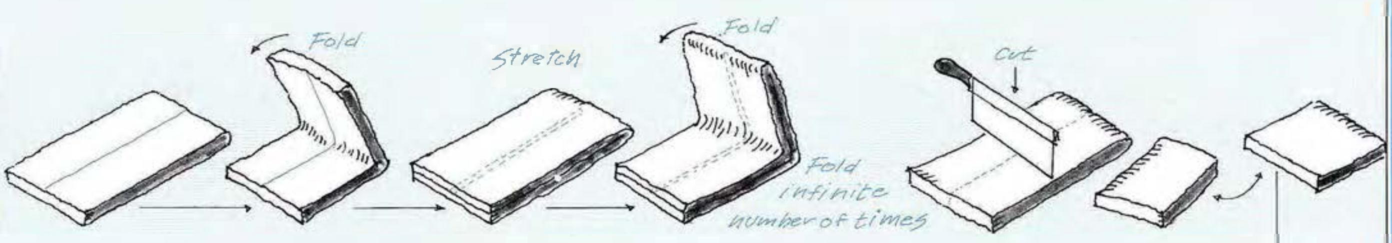
FBC: the search for strange attractors

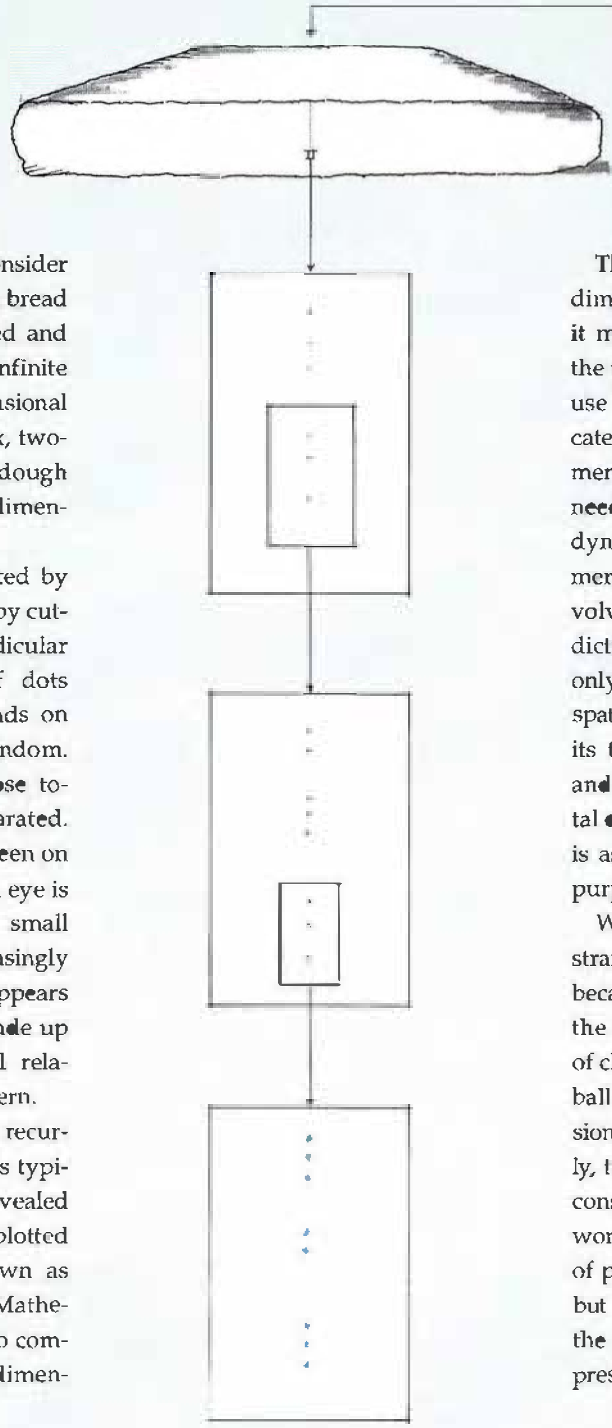
One of the times chaos is most desirable is during combustion, since turbulence causes fuel and oxygen to combine more efficiently than they would in a smooth flow of material. Predicting the behavior of these swirling gases has proved difficult, however, especially when questions of size are involved. A boiler configuration that works fine at laboratory scale may develop unexpected problems when constructed at a much larger size for commercial use. Changes in operating conditions may also bring unpleasant surprises. Unexplained instabilities, such as pressure surges, have occasionally been observed in conventional pulverized-coal units.

In order to better understand such phenomena, EPRI is sponsoring studies of chaos during fluidized-bed combustion (FBC). The results of this research are expected to be applicable for solving problems in a wide variety of combustion systems, including instabilities in low-NO_x burners and the formation of air pollutants at various stages in conventional boilers. An FBC unit makes an ideal model for studying chaos, since coal and limestone particles are lifted by upward-rushing gases to form a suspended bed of material that acts like a turbulent fluid.

At the heart of this research effort is a search for characteristic patterns, called strange attractors, that represent the signature of particular kinds of chaotic behavior. The Lorenz butterfly (some-

The Conundrum of Fractional Dimensionality





Part of the "strangeness" of strange attractors results from their being fractals—that is, having fractional extension into multiple dimensions. To understand this concept, consider a line drawn on the top of some bread dough. If the dough is stretched and folded again and again, an infinite number of times, the one-dimensional line seems to take on a complex, two-dimensional shape within the dough—that is, to have a fractional dimension between one and two.

The underlying pattern created by the line can be seen most easily by cutting through the dough perpendicular to the folds. The pattern of dots formed by the severed line ends on the transverse section is not random. In some areas the dots lie close together; in others they are separated. More surprisingly, the pattern seen on the cross section with the naked eye is similar to that revealed when small portions are examined at increasingly high magnification. What first appears to be a single dot is actually made up of several dots, whose spatial relationships repeat the larger pattern.

This same type of infinitely recurring pattern, or self-similarity, is typical of strange attractors, as revealed by cutting across all their lines plotted in state space (a process known as making a Poincaré section). Mathematical methods are available to compute the attractor's fractional dimensionality from these data, which can, in turn, provide information about how a dynamic system functions in a chaotic state.

The idea of multiple and fractional dimensionality is not as unfamiliar as it might at first seem. In addition to the three ordinary dimensions that we use to describe an object's size or locate its position in space, other dimensions, or parameters, may be needed to describe the behavior of a dynamic system. Consider the numerous independent variables involved in the flight of a baseball. Predicting the ball's behavior requires not only specifying its position by three spatial coordinates, but also knowing its three directions of linear velocity and three spin coordinates—for a total of nine dimensions, if each variable is assigned its own axis for graphing purposes.

When the ball seems to behave in a strange manner—the curve ball—it is because spin becomes important in the system dynamics. In the language of chaos, the nonlinear behavior of the ball is caused by its fractional extension into the spin dimension. Typically, then, the "dimensions" researchers consider in trying to explain real-world phenomena are not dimensions of physical length, width, and height, but rather the parameters that drive the dynamics of a system, such as pressure, velocity, or temperature. □

times called the Lorenz attractor) is just one member of this family of patterns, which are formed graphically by plotting changes in key variables of a system against each other. As the name implies, the behavior of a system settles into its particular pattern as though attracted by some strange influence that never lets exactly the same combination of variables occur twice. As long as a system starts out with conditions inside a certain range, called the basin of attraction, it will eventually operate in the characteristic way, although one cannot predict just which combination of variables will exist at any specific time because the pattern is infinitely complex and has fractional dimensions (see sidebar).

Once a strange attractor has been found, it may be possible to recognize its shape and perhaps identify the types of equations that generate its structure. Analytical methods are available, for example, for calculating the fractional dimensionality of an attractor. Furthermore, a powerful principle of chaos theory, known as the Takens embedding theorem, implies that—at least theoretically—the form of a strange attractor should be identifiable just by examining how *any* of the key variables evolves over time. This is particularly important for FBC, since the simultaneous measurement of multiple variables (for example, pressure and particle velocity) in some small region of interest is very difficult.

An additional problem, of course, is the presence of noise: How can you detect a recognizable chaotic pattern when it may be obscured by the random scribblings of stochastic events? When researchers at Argonne National Laboratory looked for strange attractors in pressure fluctuation data from a simulated FBC unit (using suspended sand, not burning particles of coal), they found nothing identifiable. On the other hand, as a result of similar experiments, researchers at Oak Ridge National Laboratory believe they have found a way to separate major dynamic effects from noise, producing a series of somewhat messy but still recognizable strange attractors. Equally important, these patterns are similar to those produced on a computer model of FBC behavior by Oak Ridge and Dutch scientists. EPRI has provided funds for the work at both Argonne and Oak Ridge.

"Chaos research may eventually provide a powerful tool for better understanding and controlling combustion," says project manager Jeff Stallings of the Environment Division. "Our first aim is to find a way of including chaotic behavior in our models of fluidized-bed combustion. Next we hope to use these models to improve our design capability, particularly in scaling up various kinds of major combustion devices. Finally, by learning how to recognize and control the chaotic patterns and key variables, we may be able to optimize combustion and heat transfer performance, prevent dangerous excursions of the operating variables, and minimize emissions."

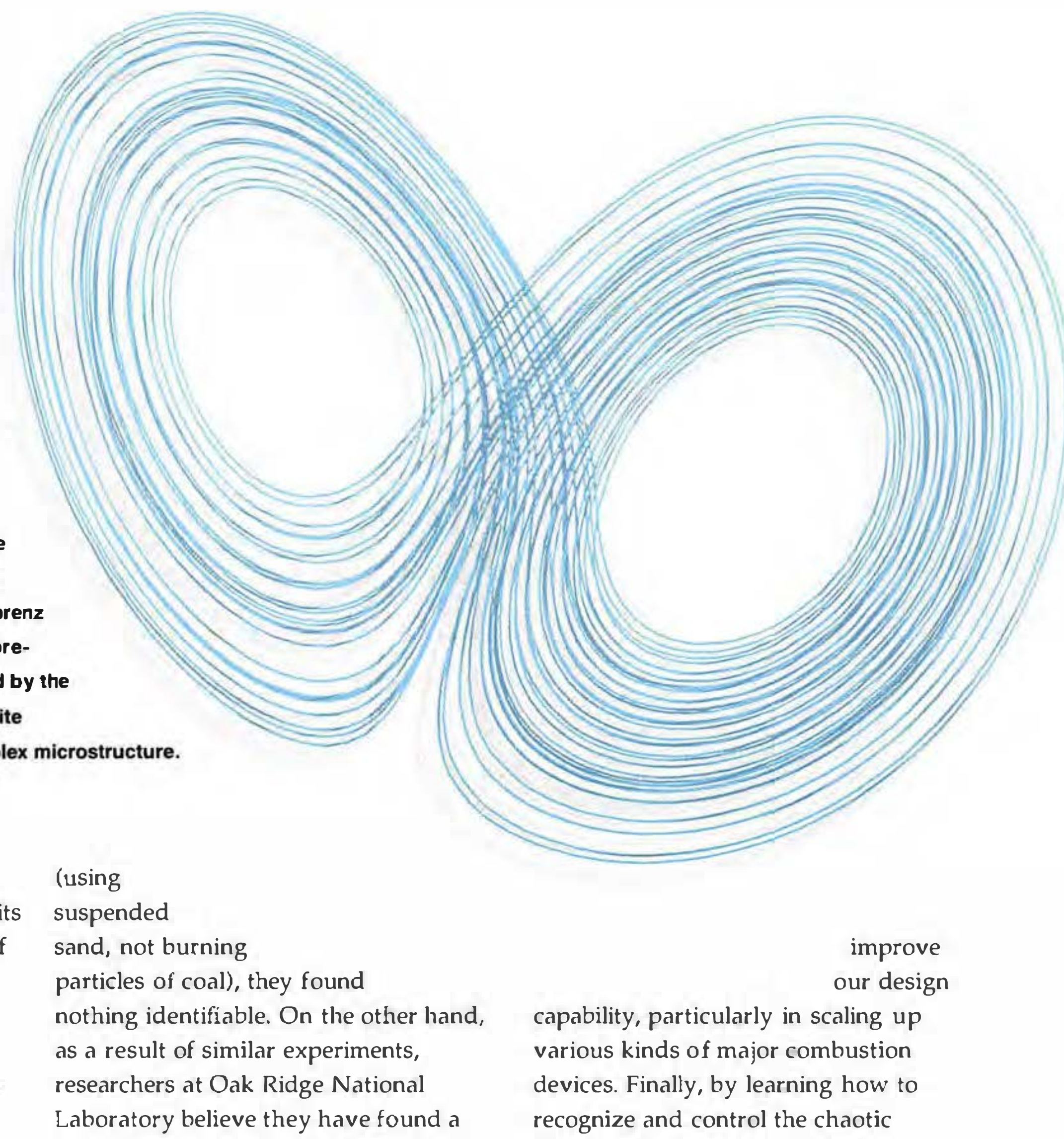


Diagram courtesy of James P. Crutchfield

AN ORDERLY DISORDER **The first strange attractor was discovered in 1961 by Edward Lorenz as he tried to develop a simple computer model of weather based on convection currents in the atmosphere. If the system were periodic, or deterministic, the "butterfly" shape would be cyclically traced by a single line in a closed loop; if it were stochastic, or completely random, there would be nothing more than a scribble. As a representation of deterministic chaos, the Lorenz attractor is globally organized but locally unpredictable: its underlying order is characterized by the overall butterfly shape, but its lines never quite touch each other, giving it an infinitely complex microstructure.**

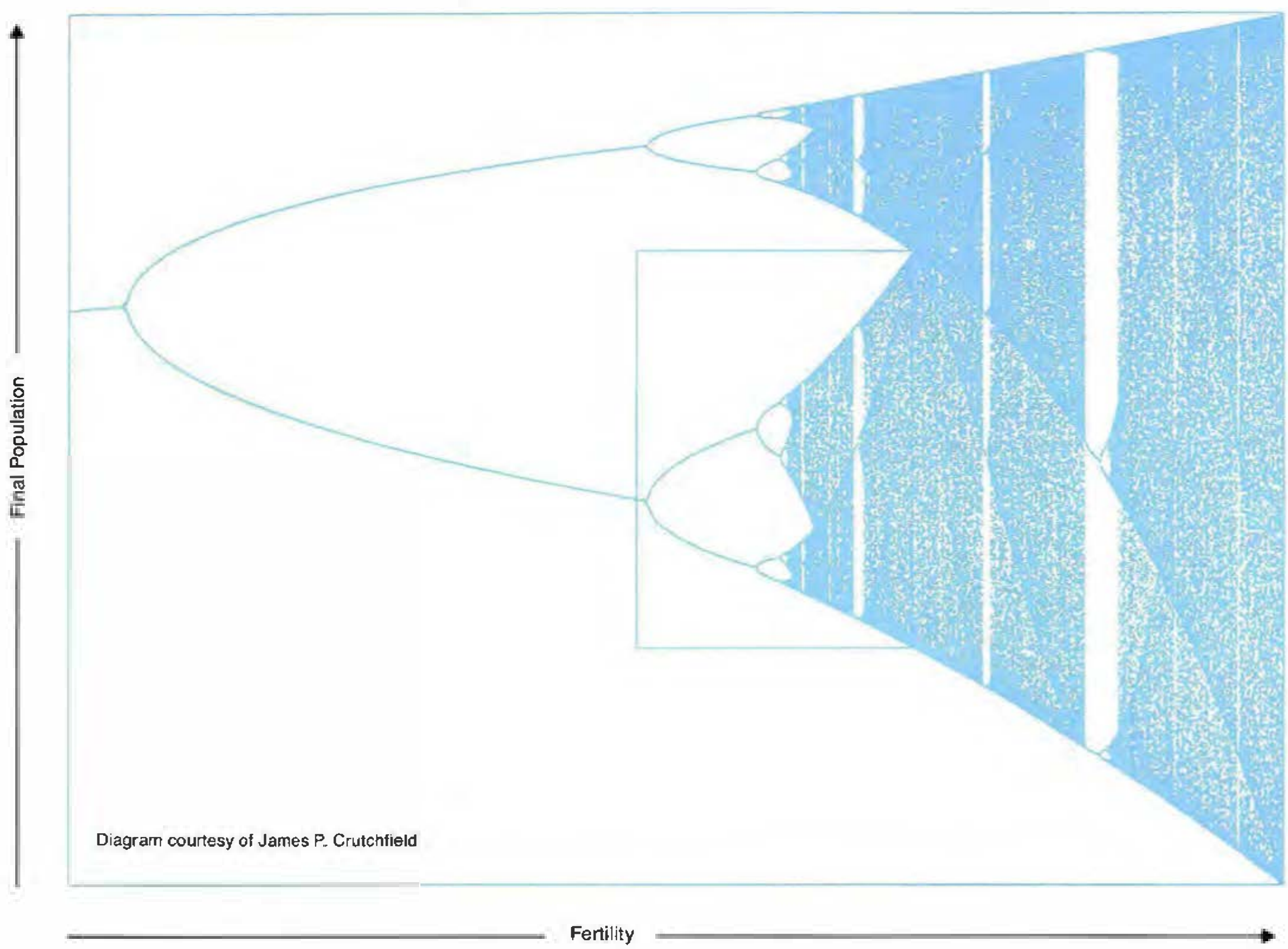
Power systems: blocking the path to chaos

The very idea that chaos may occur in electric power grids is about as welcome to utility planners as a heart flutter—and for many of the same reasons. If confirmed, it would at least prompt a fundamental rethinking of the analytical methods used to ensure network stability. At worst, it could mean that power systems harbor an unappreciated potential for voltage oscillations and collapse—the network equivalent of a heart attack.

EPRI research on this possibility has been under way since 1989 and focuses on the chain of events that might lead to fully chaotic behavior. Simple network models indicate that the onset of chaos is preceded by system bifurcations, in which operating characteristics can suddenly oscillate between two sets of conditions. Problems multiply if one or both of the new operating conditions lead to instability. Also, successive bifurcations can so disrupt a system that eventually the number of possible operating states becomes infinite; in other words, chaos ensues.

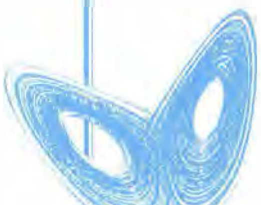
One common type of bifurcation that has been observed in utility power systems is period doubling, in which line frequency jumps between 60 Hz and 30 Hz. "It's like plucking the D string on a violin and watching the G string start to vibrate in response," says Mark Lauby, manager of power system engineering in the Electrical Systems

BIFURCATION BEFORE CONFUSION The onset of chaos is preceded by system bifurcations, in which operating characteristics can suddenly oscillate between two sets of conditions. In this diagram, which represents theoretical population cycles of fish in a pond as their fertility increases, a regular one-year cycle splits, oscillating between two different population values in alternating years. After the cycles split three more times in a stable fashion, the system turns chaotic and population cycles become impossible to predict. Similar patterns of bifurcation can signal the progression of power delivery systems from stable to unstable states during system disturbances.



ALICE IN STATE SPACE

(Being a primer of sorts on chaos, fractional dimensions, and the divergence of trajectories in strange attractors)



Having fallen to the bottom of the rabbit hole, Alice suddenly found herself caught in a violent whirlpool that tossed her up to the surface and then down into the depths, seemingly at random. When she was finally able to catch hold of an overhanging branch, she heard a soft, somewhat pedantic voice nearby.

"You realize, of course, that your movement isn't really random," said the White Rabbit. "If this were a purely stochastic process, you could wind up anywhere in the pond at any moment."

"Then just what would you call this?" Alice sputtered as she pulled herself toward land.

"Oh, this is a manifestation of chaos," the White Rabbit replied. "You're caught on a strange attractor in state space. Quite organized globally, but locally unpredictable. Very sensitive to initial conditions—you could jump into the whirlpool at *almost* the same place again and again, and each time you'd travel *nearly* the same trajectory for a while, but soon there'd be no telling where you might end up."

Alice finally made her way to safety and glared, dripping, at the White Rabbit, who clicked his stopwatch but made no move to help her. "I suppose you're going to tell me this is some kind of experiment," she said.

"Well, that's a matter of some controversy. You see, for years mathematicians wouldn't touch chaos theory because it had emerged from experiments on computers, and who ever heard of experimental mathematics? On the other hand, physicists dismissed it as an irrelevant curiosity."

"It must be physics," Alice declared. "You talk like my physics teacher. But what are those strange-looking mountains?"

"That's the range of fractals," the White Rabbit replied. "Watch what happens as we walk toward it."

As she approached the mountains, Alice noticed that they were just cut out of paper, with jagged peaks that looked ever more complex the closer she got to them. Then the White Rabbit handed her a magnifying glass, and she saw that even the smallest details reflected the same patterns as the largest peaks. "Curiouser and curiouser!" Alice exclaimed.

"Fractional dimensions," murmured the White Rabbit, retrieving his magnifying glass. "The outline of the mountains is infinitely long because it's infinitely detailed, yet it occupies a finite area. A fractional dimension tells how convoluted it is. The outline of this particular mountain range is known as a Koch curve and has a dimension of 1.2618, or thereabouts."

"But what does this have to do with chaos?" asked Alice.

"Why, fractional dimensions are the sine qua non of chaos," the White Rabbit snapped, a little petulantly. "If you draw a strange attractor in state space, it will have fractional dimensions. That's what keeps the trajectories from ever intersecting. The boundaries between basins of attraction are also fractal. Some are quite lovely, by the way—just look at our Mandelbrot sets over here in the garden."

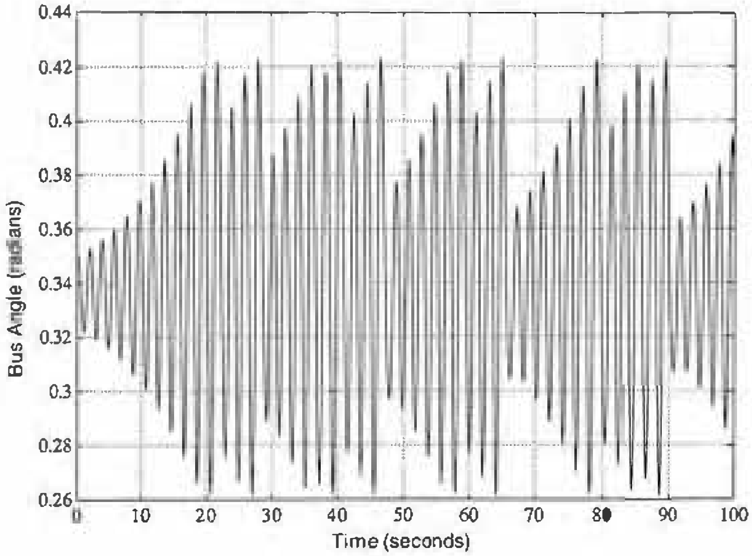
Alice was rapidly losing interest. "Does any of this have anything to do with the real world?" she asked.

"Oh yes," replied the White Rabbit. "Any nonlinear system has the potential to show chaotic behavior. Take fluidized-bed combustion, for example . . ."

But Alice found her head swimming in circles again and soon awoke under the tree where she had been sitting.

"You must have been dreaming," her mother remarked. "You were mumbling in the most chaotic manner."

"Oh yes," Alice replied, "I met a white rabbit, and he went totally nonlinear on me." □

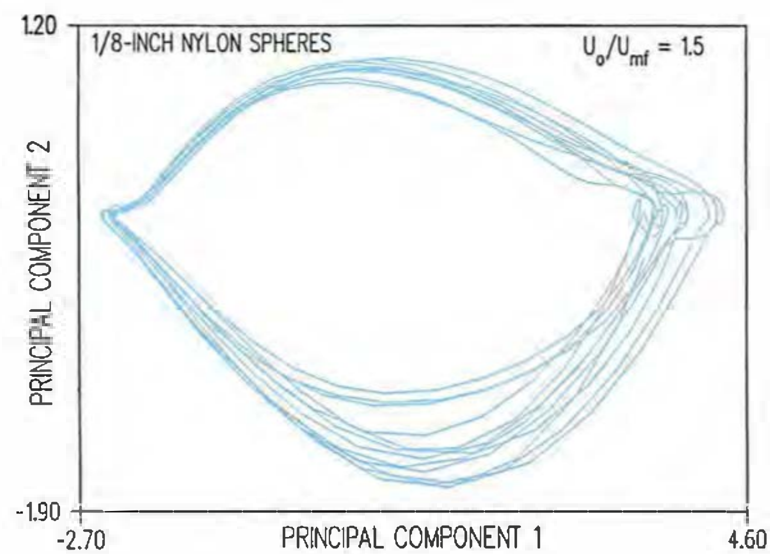


POWER SYSTEM STABILITY Researchers at the University of California at Berkeley are investigating the existence of chaotic behavior on power systems. The graph shows the relative generator bus angle on a simulated system, driven to an unstable, chaotic state by increasing the reactive power by only about 8%—quite a small change.

Division, who was a fiddler in his youth. "As long as the violin is constructed to withstand both kinds of vibration, there's no problem. But some power systems might be hypersensitive to the new frequency and collapse after a bifurcation—which would be like having the violin fall apart in your hands. With chaos there are an infinite number of possible frequencies, and the system could collapse from experiencing any of those outside its design limits. What we hope to do is learn how to eliminate conditions that could set up network bifurcations, and thus block the path to chaos."

EPRI-sponsored work in this area is being conducted at Cornell University and the University of California at Berkeley. Using highly simplified power system models, researchers have identified various kinds of bifurcations, as well as chaos, among the myriad operating conditions that affect the behavior of variables in the "state space" of the system. Although such observations must still be considered rather tentative—the problems observed could conceivably result from modeling inadequacies—they nevertheless raise an important warning flag. The researchers conclude: "These studies do establish the presumption that chaotic behavior will exist in most power system models. It is not clear, however, if chaos occurs for parameters in regions sufficiently near [ordinary] operating regimes to affect the stability region [of utility power systems] to a significant extent."

IN SEARCH OF A NEW ATTRACTOR EPRI research at Oak Ridge National Laboratory is zeroing in on strange attractors that describe the overall fluidized-bed combustion system. The inclusion of chaotic behavior in models of mixing and combustion is expected to help engineers optimize the design, scale-up, and control of future FBC units.



Observing the onset of chaos in a utility power system would require analyzing massive quantities of data that would not ordinarily be available, Lauby explains. Analysis of a 1987 voltage collapse on the Tokyo Electric Power Company system, for example, indicates that chaotic behavior may have led to its onset, but the case has not been proved. Current research is focusing on the use of larger models, in hopes of pinning down conditions that could lead to chaos on utility power systems and perhaps identifying the type of strange attractor involved.

"This work is laying the theoretical foundation for future developments," adds Neal Balu, manager of the Power System Planning & Operations Program. "We have always recognized that power systems have nonlinearities, but now that we have established the existence of chaos and bifurcations in these systems, we must develop accurate ways to reliably identify their presence. Then we must create remedial measures for controlling systems and steering them away from these conditions. Finally, analysis tools must be developed to enable us to design power systems that will not be threatened by this behavior."

Metal passivation: exploring microscopic chaos

Corrosion of metals exposed to reactive gases or liquids can be prevented by improving metal passivation—the reduction in chemical reactivity of a metallic surface as its electric potential increases. The rusting of buried iron pipes, for example, can be retarded by attaching the pipes to a power source that changes their electric potential relative to the ground. Similarly, the iron in submerged oil rigs is protected by attaching magnesium blocks that react chemically with seawater and create a potential difference like that in a battery. (The magnesium acts as a "sacrificial electrode"; that is, it is eaten away instead of the iron.) Being able to extend metal passivation to other structures could be enormously beneficial, since an estimated 4% of the gross national product is lost to corrosion.

The sets of equations used by various models to describe metal passivation are all nonlinear, so there is an inherent possibility of chaotic phenomena being involved. So far, however, no single model has been able to account for all the important aspects of passivation, and EPRI research is focusing on how chaos theory can be used to assess the adequacy of the various models.

"If a set of equations predicts that the world will end on Tuesday, and it doesn't, then you may suspect the equations are wrong," jokes project manager John Stringer. "In much the same way, we can use chaos to test different models' equations of metal passivation. Specifically, our contractors are looking for conditions under which the surface potential of metals becomes chaotic and are trying to understand what that means for corrosion. In addition, this kind of research may help us develop better methods of predicting catastrophic failure in metals, such as cracking. This work is exploratory in the best sense of the word—complicated, not well defined, but likely to produce a very fruitful outcome."

Already, work conducted under EPRI sponsorship at Battelle Memorial Institute and Ohio University has led to the development of a new model of metal passivation, which is based on elements of two previous models. The model indeed predicts that chaos will occur during the passivation process and identifies several different bifurcation routes to full chaotic behavior. The physical implications of the model remain unclear, however, because of the surprisingly complex way chaos appears and disappears again in response to even small changes in key parameters. Such results indicate that the analytical methods of chaotic dynamics must be employed in the study of even the simplest models of corrosion, and that experiments to interpret the results of models will require very precise control of electrochemical conditions at the metal surface.

A broadening of perspective

Perhaps as important as any of these immediate results is the growing impression among researchers in diverse fields that chaos theory opens new paths for understanding complex natural phenomena and offers new incentives for research that is cross-disciplinary on an unprecedented scale. The need for this broader perspective has been argued in particularly strong terms by John Dorning of the University of Virginia, who is conducting convection research under EPRI contract. "For decades," he writes, "engineers, scientists, and mathematicians alike, for the most part, when confronted with nonlinearity looked the other way, or looked and shrugged their shoulders, or worse yet, looked and saw nothing at all beyond that which their intellectual tunnel vision allowed."

The time when that kind of narrow focus was productive has now ended. "With chaos, we're on the brink of a new classical dynamics," declares Jong Kim, who then adds with a chuckle, "and people thought classical physics was dead." But John Stringer adds a note of caution: "It's called the curse of dimensionality—the amount of data you need to understand a system rises exponentially with the system's dimensionality, that is, the number of independent variables or degrees of freedom needed to describe it. Some of the projects involving what we thought would be simple questions have turned out to be very difficult. And, of course, there's the problem of noise. In many cases, it may be very hard to get data sets that are sufficiently tidy for understanding chaos. On the other hand, chaos theory can help us learn the limits of predictability for very complex systems, such as the weather, and may even give us new tools for controlling these systems." ■

Background information for this article was provided by John Stringer of the Office of Exploratory & Applied Research, Jong Kim of the Nuclear Power Division, Jeff Stallings of the Environment Division, and Mark Lauby of the Electrical Systems Division.

The Challenge of Global Sustainability

by Robert Fri

THE STORY IN BRIEF

A tremendous surge in world population growth—especially in the developing countries—will create unprecedented societal, economic, and environmental pressures in the coming decades, calling into question the likelihood of sustainable development for the world at large. Robert Fri, president of Resources for the Future and chairman of the Institute's Advisory Council, spoke on this issue at the Electricity Beyond 2000 forum, sponsored last October by EPRI and the International Electric Research Exchange. Fri points up the importance of technology and of investment by the industrialized world in resolving this dilemma, and he highlights why the electric utility industry should have particular interest in becoming part of the solution.

IT IS CLEAR THAT OVER THE NEXT SEVERAL DECADES the world will face a stark problem. During this time, world population will double to around 10 billion people or perhaps more. Most of this growth will take place in the developing world, where average per capita income is about one-tenth that of the industrialized nations. And so, in short, we face the prospect of a planet where 90% of the people are poor. Altering this prospect will be a formidable challenge. Just as an example, if the per capita income of the majority of the world's people were to rise to only one-third of that which the developed countries might enjoy a century from now, then the world economy would have to expand in real terms by 30-fold over the next 100 years. And although most of us—and surely the poor—would view this as a desirable result, such growth would place enormous demands on our stock of natural and environmental resources.

There is a new term in the debate which addresses this problem—the term *sustainable development*. The goal of sustainable development is to obtain that kind of rapid economic progress without exhausting the planet's resource endowment. The report of the World Commission on Environment and Development, usually called the Brundtland Report after its chair, rallied the nations of the world to this goal. The commission insisted that we attend to the economic needs of the world's people as well as the quality of our own environment, and in doing so the commission laid down its now famous definition of sustainable development: that we must meet the needs of the present without compromising the ability of future generations to meet their own needs.

The Brundtland Report takes on this challenge with a rare sense of hope. The message of the authors is "not a prediction of ever increasing environmental decay, poverty, and hardship in an ever more polluted world among ever decreasing resources. We see instead the possibility for a new era of economic growth, one that must be based on policies that sustain and expand the environmental resource space."

That sustainable development means economic development as well as environmental protection is often obscured in debates about global climate change and other environmental problems. But human well-being is central to the concept, and if meeting the obvious economic needs of the poor is not reason enough, the Brundtland Report stresses that the absence of development is itself a chief cause of environmental degradation. In other words, neither the rich nor the poor can have economic or environmental security without economic development.

For these reasons, it seems to me that the vision of the Brundtland Report is inescapably correct. But if we accept the need to enlarge per capita income for most people and the inevitability of significant population growth, then it follows that we must look to technology as the chief engine of sustainability. A central issue of sustainable development is whether technology—by which I mean both hardware and the knowledge to use it wisely—whether technology will allow us to manage our natural and environmental resources wisely. And on this issue there is a dispute. On one side stand those who believe that technology will continue to satisfy the wants of society without serious resource constraints. These optimists, who include both economists and technologists, believe in markets in which incipient scarcity triggers an increase in the price of the affected resource and, responding to this price signal, technology emerges that allows us to use that resource more efficiently.

History supports this view. Technology has been the reason that the industrialized world has been able to sustain unprecedented economic growth for nearly two centuries. New knowledge and innovative products and processes have enabled us to use our natural resources ever more efficiently to deliver food, fiber, energy, and the other services necessary for our economic well-being. According to the Brundtland Report, the global economy multiplied 50-fold in this century, and four-fifths of that growth came since 1945. And despite this enormous growth, the prices of many natural resources have not risen much in real terms for decades, suggesting that the process of market and technologies has in fact dealt with resource scarcity at acceptable cost. And it has done so, as I say, importantly because of technology.

Still, there is an alternative view that raises the possibility of ultimate limits. In this view, consumption of material goods cannot forever increase, and in any case, we should prefer quality over quantity of consumption. From thermodynamics comes the idea that it takes an ever-increasing amount of work to put nonrenewable resources back into usable shape. One cannot recycle the same beer can forever. So we are ultimately left, in this view, to rely on the sun's energy as our sole source of support, and when this daily ration of energy falls below that needed to overcome the dissipative use of nonrenewable resources, economic growth ceases. I suppose growth will end some day. But this fact is only a somewhat troubling curiosity if technology gives us ample time before the limits are reached.

But it is on just this point that the skeptics' argument is the most powerful. They simply insist that productivity of resource use cannot increase forever. And so, to make their case, the optimists—and I include myself among them—had better be prepared to show that there is real technology to support the assertion that resource limits can be overcome. And given the constraint of sustainability, it had better be the right kind of technology.

Against this background of a general notion of sustainable development and some of the problems the world is likely to face over the next century, it should be clear—at least in a general way—that the goal of sustainable development through technological change has significant implications for the electric power industry. More specifically, it seems to me that the industry is linked to sustainable development in three crucial ways.

First, sustainable development depends on electricity. The history of economic development is that the demand for electricity will outstrip the pace of economic growth, especially in rapidly developing countries. And the reason is perfectly clear: gathering fuel wood and running local waste digesters for fuel gas is not an attractive way to get energy for the economically well off. They would rather flip a switch, and of course it is well known that modern industry depends on electricity.

A few statistics will perhaps give some sense of the role that electricity plays in development. For instance, total per capita energy use in Western Europe is about 3 times what it is in China. However, Europe uses 10 times the amount of electricity, on a per capita basis, that China uses. South Korea is a country experiencing rapid economic development. Total energy use grew in South Korea between 1970 and 1990 by a factor of 4, but the use of electricity grew by a factor of 9 during this period. So the first link of sustainable development depends on electricity.

A second reason is, of course, that energy production has the potential for creating global and regional and transboundary environmental problems, and that it is also implicated in the climate change issue. Certainly the OECD countries are familiar with this link between energy and the environment. They struggle with particulate emissions and acid rain and other problems at some considerable expense to their electric power industries.

Neither the rich nor the poor can have economic or environmental security without economic development.

But even at an early stage of development, other countries have already encountered similar problems. For example, Seoul's average 1979–1984 sulfur dioxide concentration was the fourth highest among 54 world cities and substantially above the World Health Organization's guidelines for an acceptable level. Beijing's rank was ninth on that list, despite its low per capita use of energy. And these are not isolated examples that are unlikely to portend much for the future. Most developing countries have large reserves of fossil fuels on which to base the expansion of their electric power industry.

In consequence, a major influence on achieving the goal of sustainable development will lie in the way developing countries choose to meet their need for electricity. And these choices, of course, affect all of us. Again, just to give some statistics that suggest the importance of the developing countries in this process, carbon dioxide emissions in India, China, and the former Soviet Union grew at the annual rate of 6.4%, 6.0%, and 3.1%, respectively, between 1970 and 1988. Compare this with a growth in the United States of 0.6% over that period and a decline in France of 1.6% due to its nuclear energy program.

A major influence on achieving the goal of sustainable development will lie in the way developing countries choose to meet their need for electricity.

The final bond between sustainable development and the electric power industry is technology itself—the capacity for developing it possessed by the institutions that you in the audience represent. You have already demonstrated that technology can be the key to resolving conflicts between energy and the environment. But the demands for natural and environmental resources created by a more crowded and poor world will create the need for accelerated technological advances. The necessary technologies will use scarce fuels more efficiently to produce the economic goods and services that people desire, and they will produce fewer residuals left in the environment. And so if the essential challenge of sustainable growth is to develop such technologies, then it seems to me electric technologies must be in the vanguard of meeting that challenge. Now these tight bonds between the electric power industry and the goal of sustainability raise the important question of how, if at all, your industry should use its technology to serve the special needs of the developing world as well as the needs of industrialized nations. This question is especially relevant for research institutes gathered here, and trying to deal with that question will be the focus of the balance of my remarks.

To do so, it is useful to distinguish between two aspects of the issue: first, how the industry might use its technological capability to promote sustainable development, and second—but as important—why it should set out to do so. On the first point, it seems to me that the electric power industry is unusually well positioned to help developing countries put sustainable technology to work. To see why I reach that conclusion, let's consider what I regard to be the four prerequisites for successful technology cooperation, by which I mean the process of delivering technologies to people in the developing world who need it.

First of all, and most obviously, there must be the technology, and behind it the research and development programs necessary to bring that technology into being. Now there is no great mystery here for this industry and particularly for you. Considerable work has already been done to identify the research agenda for developing environmentally sound technology, and I'm sure that this conference will advance that agenda a long step forward. Moreover, your institutions represent a formidable capacity to carry out the necessary research for the world as a whole.

The second prerequisite to successful technology cooperation is almost equally obvious. It is that there must be an indigenous demand for environmentally sound technologies. It is a simple but very powerful idea. For if countries want to buy environmentally sound technologies as a matter of course, it seems to me we can be confident that the private sector will readily meet that demand. But it is also true that a demand for unsustainable technology will also be met. And since most electric technologies have a very long lifetime, it is critically important to create the right kind of demand and to do so promptly, especially in the developing world, which will be adding new capital stock in their electric power industry much more quickly than the OECD countries.

In the long run, the best way to create such a demand is through private markets in which prices reflect environmental costs as well as private costs. Creating such markets and the appropriate price signals is, of course, a very difficult task, although events in the Soviet Union, Eastern Europe, and elsewhere do provide some hope that markets will replace central planning as the dominant form of economic organization. Also, there are some signs of progress on how to incorporate social cost in the price system. In fact, a series of international studies now under way to calculate the social cost of energy production and use is an important example. But all of this will take time. So, in the nearer term, the mechanisms for creating a demand for technologies that serve both economic and environmental goals will fall short of that market ideal. More important, it is clear that whatever mechanism comes into being for expressing these demands, the electric power industry will do much of the demanding. Your industry has in its hands the ability to determine whether the right demands are created, and no industry is better equipped by experience to balance environmental and economic goals in the context of long-range investment planning.

The third prerequisite to successful

technology cooperation is that developing countries acquire the indigenous capacity to plan for, procure, and operate the technologies they need to solve their economic and environmental problems. There are a host of reasons behind this principle, but they boil down to essentially the fact that people want to do things for themselves. Of critical importance in this regard is that nations want to make their own informed economic-environmental trade-offs. And unless these trade-offs are made wisely at the national level, there is little hope for effective cooperation in international forums on issues like climate change.

But here again, the electric power industry can play a central role. Your industry, as I have noted earlier, will plan for, procure, and operate much of the technology needed for sustainable development. And because electric utilities tend to be large, stable, technically strong organizations, they are among the most attractive institutions in which to develop the indigenous capacities necessary to perform these functions.

Finally, global technology cooperation means sharing scarce resources. The developed and the developing world depend on one another, as I have said, both economically and environmentally. The developing world properly aspires to economic well-being and environmental sanity. But most of the needed financial and technological resources they must have exist in the industrialized nations. So, inevitably, we all must face the issue of transferring these resources from the wealthy to the poor—even at some expense to the former.

This outline of the conditions for successful technology cooperation demonstrates the central role of the electric power industry in achieving sustainable development. Utilities will create much of the demand for the right technologies, and the planning techniques for identifying this demand are understood by utilities, for they have already had to strike that economic and environmental balance. You have the capacity to develop the technologies thus demanded, and utilities are fertile ground for instilling the indigenous capacity to construct, to operate, and to maintain these technologies. So I submit that the central issue is not whether you can do the job but whether you want to, and, more specifically, whether you are prepared to undertake the transfer of resources from the developed to the developing world required to get the job done.

It is my own belief that helping developing countries use sustainable technologies to meet their need for electricity is in the self-interest of the utilities and governments of the industrialized world. One reason is avowedly commercial. If sustainable development succeeds—and I'm sure we all hope that it does—then the market for electrical equipment of all types will grow substantially. Nations that have developed such products and the means for transferring them to lesser-developed countries will have a major competitive advantage in future electricity markets. My second reason is equally self-serving. Global environmental problems require global solutions, and the most efficient solutions may be found anywhere in the world. Therefore, developed countries should be looking around the world and to the transfer of resources in tackling these problems.

Increased demands for natural and environmental resources will create the need for accelerated technological advances.

Let me give you an illustration of what I mean. Suppose that the United States decided to invest heavily in the mitigation of carbon dioxide emissions; as you can see, this is hypothetical. If that happened, our electric utilities would incur substantial costs. Faced with this prospect, utility managements would try to minimize those costs by seeking the most efficient ways of reducing carbon dioxide emissions. And one of the best places for them to look would be in the developing countries, for it is almost certainly true that it would be cheaper to help a developing country reduce its carbon dioxide emissions than it would be to try to achieve the same result here at home. It is also likely to be easier, since these countries are likely to be building new power-generating facilities, while industrialized nations like the United States must contend with a slowly changing capital stock. In other words, efficient solutions to global problems are possible only if they are sought globally, and, therefore, individual developing countries ought to be motivated to find solutions on that basis, in their own self-interest.

To rely on these admittedly selfish reasons to motivate action toward sustainable development is not intended to devalue the persuasive ethical reasons for helping the world to develop in a sustainable way. Rather, it is only to suggest that electric research institutes of the industrialized world may find that the legitimate interests of their sponsors and their governments are well served by following this sustainable path. And if that is so, the goal of sustainable development should significantly shape the current and future research agenda of the institutions represented here, and I wish you every success on that voyage. ■

The electric power industry is unusually well positioned to help developing countries put sustainable technology to work.


X-Y-Z
O-P
G-H
E-F
Customer
Assistance
Center
Great Service

Introducing

by Leslie Lamarre

THE STORY IN BRIEF

EPRI's new Customer Assistance Center is designed to help member utilities take full advantage of the resources of the Customer Systems Division. Members can call the center's hotline with pressing questions and needs and get swift access to a variety of services, including workshops, customized consulting, and assistance in locating, selecting, and contracting with vendors. Utility representatives who have used these services report saving a significant amount of time and money and gaining valuable in-house expertise. Though the center was established by CSD, EPRI's other technical divisions are already getting involved.

LATE LAST DECEMBER, about the time most people were winding down for the holidays, an urgent call came into EPRI's Customer Assistance Center (CAC) hotline in Dallas. Entergy Corporation of Arkansas was on the line with a problem. The utility needed to find an experienced contractor—quickly—who could screen 100 potential demand-side management programs. In order for the utility to meet a regulatory deadline, the results had to be in hand within three weeks.

The problem was that finding the right contractor can be a lengthy process. Entergy would normally issue a request for proposals and, once contractors responded, would invite them in to make presentations. After selecting a vendor, Entergy then would initiate the process of putting together a contract that both sides could agree on. "We called CAC to see if they could help us speed up the process," says John Fritz, program support specialist at Entergy.

Larry Lewis, the manager of CAC, spoke with the utility over the phone on a Friday and arrived in Little Rock the following Monday to help Entergy plan its course of action. Two days later, a contractor arrived to handle the task. "In the course of a few days, we were able to accomplish what otherwise would have taken a couple of months," says Fritz.

Despite the holiday season, Entergy's vendor was able to meet the three-week deadline, turning in its results on January 8. "Without the Customer Assistance Center, we probably would have had to say 'We can't do it within that time frame,' " notes Fritz.

The help that CAC provided Entergy is just one example of the type of service the new center is offering EPRI members. Viewed by many as providing a critical link in the delivery of EPRI's expertise to its members, the Dallas-based center specializes in providing quick response to short-term questions and problems. It is designed to help EPRI members take full advantage of the resources of the Customer Systems Division (CSD), which works on issues ranging from demand-side management to power quality. In the words of Tom Sobey of Houston Lighting & Power, "CAC is helping us get the most bang for the buck out of our EPRI dollar."

The center offers training seminars and workshops tailored to members' needs, support for users of CSD software, and general consulting on products and services of the division, among other types of assistance. During its first year and a half of operation, CAC served more than 150 utilities across the country. Though the center was established as a CSD resource, other divisions are also getting involved. At least one of EPRI's five other technical divisions already offers some of the same services through CAC.

The birth of CAC

The idea for the Customer Assistance Center grew out of the results of a survey conducted early in 1990, in which EPRI asked its members to assess needs and concerns

SERVICES FOR MEMBERS

Designed to help member utilities take full advantage of the resources of EPRI's Customer Systems Division, the Customer Assistance Center links members with products and services that address their needs. By calling one central number, members can access the center's full array of services.

Hotline

An EPRI member can call the hotline (1-800-766-EPRI) with a pressing question and in most cases receive an answer within 24 hours.

Jump-starts

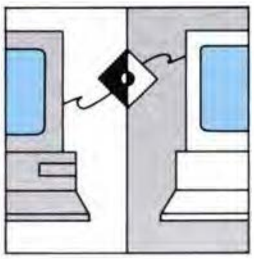
Jump-start consulting books members up with the tools they need to start their own studies or launch their own programs.

Workshops

CAC can organize workshops to be held at a member utility's location, tailored to the utility's needs.

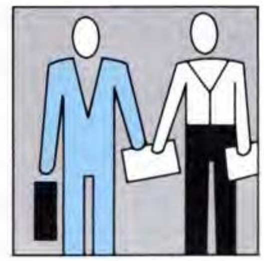
RemoteLink

With RemoteLink™ an instructor and a user can operate the same piece of software simultaneously at different locations. This allows for quick and effective software support.



Deposit Accounts

By setting up a deposit account with CAC, a member utility can speed up the contracting and payment processes. The center will pay the utility's consultants directly through this account, handling all the paperwork involved.



raised by increasing competition in the industry. The results showed that members placed a greater emphasis on the value of EPRI products and services and were counting on these resources to help them through trying times.

Investigating the matter further, Lewis determined that some valuable EPRI products and services were not always being fully exploited by members. Utilities needed access to a comprehensive source of expertise on a wide range of CSD products. Also, utilities said, once a particular product was in hand there was sometimes a need for additional user support.

The Customer Systems Division developed the concept for the center as a place that would provide services to help reduce the time required for members to take advantage of the division's resources. The division quickly gained support for the idea from utility representatives on related CSD advisory committees. Lewis began operating CAC on a pilot basis early last year from his office at EPRI's Palo Alto headquarters. For about eight months he experimented with different types of services, getting feedback from the member utilities involved. By late August the concept was much more refined, and Lewis was relocated to Dallas.

For three months Lewis operated the center out of temporary headquarters in Dallas. Then in January of this year the center opened its doors to the public at its present location, a business development park in Irving, just west of Dallas. Today, in addition to Lewis, the center's on-site staff includes two full-time employees. Office manager Sharon Ross oversees the day-to-day operations of CAC, while customer systems representative Diane Kendall answers calls that come in through the center's hotline and responds to members' inquiries. Providing a human link to the Customer Systems Division at EPRI is Paul Grimsrud, who serves as the CAC liaison. Grimsrud fields questions that come in from the center and helps handle utility requests that come in through the division in Palo Alto. He also fields CAC-related inquiries from the division's staff.

The center occupies the 15th floor of a 22-story building that demonstrates cool storage technology. The 7500-square-foot site also serves as a regional office for EPRI, housing representatives from the Membership, Environment, and Electrical Systems divisions and from the Technical Operations Group and the Delivery Systems Office. The center is just a 10-minute drive from the Dallas airport. In fact, Lewis can see the airport from his office window—which is a good thing, since he spends about 80% of his time on the road.

For many of the projects involving onsite work, Lewis tries to be the first one to arrive at the utility. On the basis of his assessment of the situation, the utility determines whether to handle the work inhouse or hire a contractor. The center will share the cost of assistance that simply involves the transfer of EPRI technology. Utilities are responsible for picking up the tab when projects involve gathering data, customizing software, or other types of additional work.

Even with the help of contractors, responding to an average of 200 calls to the hotline each month is enough to keep Lewis and his three staffers more than busy. "The real challenge is trying to sustain the utilities we're supporting while handling the increasing demand on our service," Lewis says. That demand is expected to increase steadily as more utilities learn about CAC. Lewis expects to hire a field representative soon, a change that will help ease his travel schedule. Still, he insists, "We're trying to stay lean and mean."

CAC services

The Entergy case is one example of what the CAC staff calls jump-start consulting. Through jump-start consulting, CAC hooks members up with the tools or consultants they need to start their own studies or launch their own programs. In 1991 CAC conducted 28 jump-starts. Some jump-starts, like Entergy's, are reactive, spurred by a utility that called the center's hotline with a problem. Others, called proactive, are initiated by the center. Unlike reactive jump-starts, which address a single utility problem, proactive jump-starts typically entail several EPRI products that address one or more problems.

In either case a representative from the center will visit the member utility to gather information, analyze issues, and identify resources that may help. As a result of this visit, the utility may decide that it can complete the project in-house. If consulting services are required, the center can make the arrangements.

In Entergy's experience, the need to screen 100 DSM programs was among the initial steps in the development of the utility's first least-cost plan. Entergy had experimented with conservation and load management programs in the 1970s, but the more sophisticated DSM programs that have emerged in the past decade were relatively new to the utility. "We needed a contractor to screen the programs but didn't really know where to find one and how to do it quickly," says Fritz. "But we knew that the Customer Assistance Center had experience with multiple vendors on a national basis and that they would know which ones would deliver a quality product."

CAC has more than 50 consultants nationwide under open purchase order, which means that the center can expect to direct them to a particular location on short notice. In Entergy's case, the CAC staff was able to get a contractor on-site within a couple of days. To further speed up the process, Entergy paid the consultant through a deposit account it set up with CAC.

CAC offers members the option of keeping money in a deposit account that the center can use to pay for the utility's consultant swiftly. The center also handles all the paperwork that accompanies each job, first issuing a statement of work and then invoicing the contractor. This saves the utility the time and effort that would be required to draw up small, separate contracts.

The jump-start approach to consulting helps minimize costs to the utility because the center's staff can resolve some issues and because the utility performs part of the work with its own staff. In addition, because the utility is actively involved, staff members are exposed to solutions and can apply their acquired knowledge to future problems. "The real benefit is that everybody wins," Lewis says. "EPRI gets its products used effectively, the utility gets its problem solved, and the contractors get additional work."

Another type of assistance comes in the form of seminars and workshops that are tailored to the needs of specific utilities. Houston Lighting & Power benefited from an on-site seminar on DSM. According to Tom Sobey, who manages HL&P's conservation and load management division, the utility wanted to take advantage of EPRI-sponsored DSM evaluation seminars in Denver and Chicago, but because of travel restrictions could send only one person. That one person would have to communicate what he or she learned to the rest of the utility's DSM staff.

Hotline

The Tennessee Valley Public Power Authority called the hotline asking for help with time-series forecasting. CAC recommended Forecast Master Plus, an EPRI-developed software program, and worked with TVPPA, a wholesale power company, to issue 165 copies of the code to its distribution customers. CAC also conducted four workshops at different locations to train users of the program.

Workshops

Houston Lighting & Power will save an estimated $500,000 over the next three years on the cost of evaluating demand-side management programs, thanks to an on-site workshop that CAC arranged. Some 50 HL&P staff members attended that workshop, acquiring the skills and knowledge to develop the plans without relying on outside contractors.

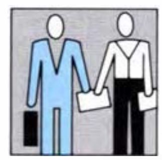
RemoteLink

Staff members at Northern States Power were using a piece of EPRI software when they ran into a problem in trying to read a data file. Through RemoteLink, a CAC contractor was able to examine the utility's situation from off-site and help the users resolve the problem within minutes.

In CAC's training room, an instructor teaches utility staff members how to use COMMEND, EPRI's software program for forecasting commercial end-use loads. The students are working on EPRI's new bundled workstations.

Deposit Accounts

Baltimore Gas & Electric was heavily involved in the development of demand-side management programs and knew it would need immediate access to a number of consultants throughout the process. The utility set up a deposit account with CAC and has used it to pay at least six consultants. This arrangement saved BG&E the time it would have spent identifying contractors, putting jobs out for bid, and paying the contractors.



Jump-starts

Salt River Project was interested in improving its demand-side management programs. CAC's experts came to the utility, assessed its needs, identified five DSM-related software codes, and trained staff members to use them. With this customized training, the utility now has the in-house capability to plan, implement, and evaluate DSM programs.

Sobey contacted CAC and asked if it would be possible to bring the seminar to Houston. "We were really gearing up for DSM at the time and getting more and more active," Sobey recalls. "We had reports that were due and evaluation plans that had to be written." CAC arranged for a DSM seminar on-site. Fifty staff members from HL&P attended the seminar, along with 20 from half a dozen other utilities.

According to Sobey, the HL&P staff members were able to use expertise acquired at that seminar in the preparation of a set of evaluation plans that the utility submitted to the Texas Public Utility Commission this year. Sobey estimates that HL&P will save $500,000 on the cost of evaluating DSM programs over the next three years. That figure is based on the average cost of $60,000 for an outside contractor to prepare a single evaluation plan.

Help from CAC doesn't always involve on-site visits. The center is equipped with videoconferencing technology, which can be used for meetings and training sessions. Also, utilities with staff interested in getting software support have the option of receiving such assistance over the telephone line, through a service called RemoteLink™. With RemoteLink, which involves an EPRI-modified commercial software product, an instructor and a user can operate a piece of software simultaneously at different locations. By telephone, the instructor explains how the software works as the user watches the demonstration on his or her own computer screen. The user can practice operating the program while the instructor observes and assists. CAC also uses RemoteLink for troubleshooting. For example, Northern States Power was running a piece of CSD software when it had a problem in trying to read a data file. With RemoteLink, a contractor was able to examine the utility's situation and advise the software users on how to resolve the problem so they could read the file.

The quality push

Regardless of what type of service utilities get from CAC, there is an infrastructure in place to ensure that members get a high-quality response. To start with, Lewis says, the center aims to provide, within 24 hours, an answer "we feel comfortable with" to any utility that calls the hotline with a problem. Also, staff members at the center keep an electronic log of every utility's interactions with the center, recording detailed accounts of the member's problems and the center's responses. Out in the field, CAC staff members can enter the system and record events that transpire during a visit to a utility.

Other types of monitoring and evaluation provide channels for valuable feedback. Starting in February of this year, for instance, CAC began the practice of calling member utilities that have ordered software codes from EPRI's Electric Power Software Center to find out whether users need help with the products. In addition, every month the center compiles an activity report that goes back to the Customer Systems Division in Palo Alto.

Every type of assistance the center provides is followed up with an evaluation. On-site responses are followed up with telephone interviews. Telephone assistance and workshops are followed up with evaluation forms. Utilities are asked about how the center and its contractors performed. Through these kinds of mechanisms, the Customer Systems Division receives feedback that can help improve future products. For example, one member utility suggested the development of a report that would indicate how various DSM products, such as end-use forecasting and planning models, could be used together. Such a report is now being produced.

"Through the Customer Assistance Center, we're getting almost instantaneous feedback on the operational performance and user-friendliness of EPRI's software products," says Bill Smith, manager of EPRI's Delivery Systems Office, which aims to enhance the delivery of the Institute's products to member utilities. "Offering CAC is probably one of the best things EPRI could be doing, because it means working with utility members to get them over the hurdles—technical or institutional—that prevent the technology from getting in the door and becoming used and useful."

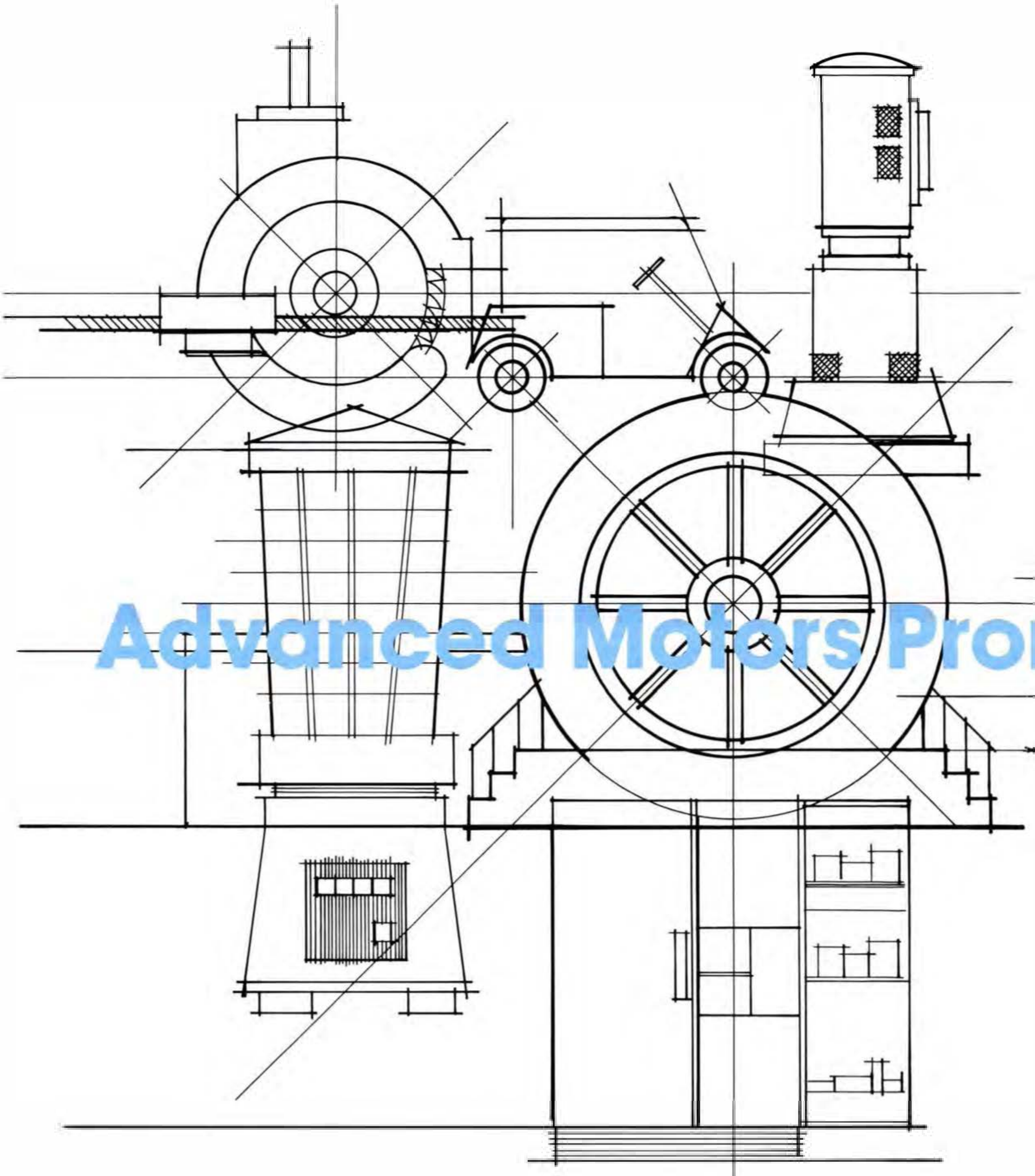
Smith's office, in conjunction with the Generation & Storage Division (G&S), wrote the specifications for the so-called bundled workstations used for training at CAC. The IBM-compatible workstations, which utility members may order through EPRI at a discount, are equipped with a 486 processor, a hard drive, a modem, and all the capabilities required to run any piece of EPRI software. G&S shares with CAC the funding of a full-time contractor at the center who supports training on the center's 15 workstations, setting up the machines and assisting the contractors conducting the training. (For more information on EPRI's bundled workstations, see *EPRI Journal*, April/May 1992, p. 26.)

Greg Lamb, manager of electronic technology transfer for G&S, says his division is becoming more involved in CAC. The contractor that G&S helps fund is handling RemoteLink calls related to G&S software products and will be using RemoteLink to support EPRI members running G&S software on their own bundled workstations. This person also trains some contractors to use RemoteLink. Lamb says his division is considering transferring its centralized software support from the G&S software hotline, based at the Electric Power Software Center, to CAC. Lamb believes that it's only a matter of time before other EPRI divisions start plugging into CAC. "People will catch on to this thing," says Lamb. "It makes sense for EPRI members to call one number in Dallas when they need help with an EPRI product—no matter which division it comes from."

Utility members who have used CAC agree. "EPRI does a lot of work in a lot of different areas," says Entergy's John Fritz. "It can be intimidating to approach that massive pile of information and expertise to find a solution to your problem. What the Customer Assistance Center does is provide immediate access to a whole world of knowledge with one contact." ■

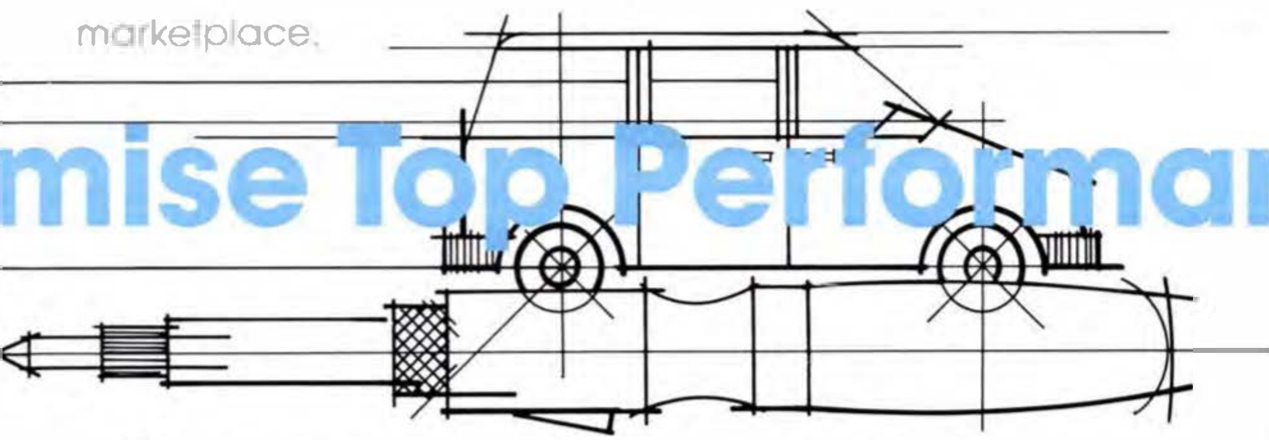
Background information for this article was provided by Larry Lewis, Customer Systems Division.

Advanced Motors Pro



THE STORY IN BRIEF Drawing on recent advances in materials and electronic controls, a new generation of high-efficiency ac motors is on the threshold of commercial introduction. A number of innovative designs, all of which feature advanced power electronic converters, are being developed for applications that range from small hand tools to major home appliances to motor drives for large industrial processes. The new motors' capability for efficient variable-speed operation promises performance well beyond that of conventional ac units, especially when the power electronics and motors are optimized to the size and operational needs of the application. EPRI is pursuing such integration, working with researchers, motor manufacturers, and end-use equipment producers to simultaneously address electronic, mechanical, manufacturing, packaging, and cost concerns. The result is expected to be a variety of clearly superior motors that can compete successfully with conventional units in the marketplace.

mise Top Performance



by John Douglas

A NEW GENERATION OF ADVANCED MOTORS is rapidly approaching commercial introduction, offering significant advantages to electric utilities and their customers in all market sectors. Spawned by the development of improved solid-state power converters and novel magnetic materials, these motors are expected to achieve levels of performance and efficiency unattainable with today's conventional motors. At the same time, a growing demand for fundamental improvements in several kinds of end-use equipment is creating a favorable climate for introducing these motors immediately into important niche markets.

Motors are by far the dominant load on most utility systems—accounting for about 67% of total U.S. electric energy use. Consumption, however, is heavily skewed: out of the roughly one billion motors now operating in this country, only 2% are larger than 5 horsepower (hp), but this fraction accounts for more than 70% of the electric energy consumed by motors. A major question facing the designers of advanced motors, therefore, is where to focus development efforts in order to maximize the motors' inherent advantages.

EPRI is playing a key role in helping match the latest technological developments to the complex marketplace for motors. The advanced motors and drives initiative of the Customer Systems Division spans such diverse areas as technology development, market analysis, field demonstration, applications assessment, customer assistance—and even the writing of educational materials, because of the shrinking amount of time allotted to motor fundamentals in current electrical engineering courses.

"Our goal is to accelerate the commercialization of a wide variety of advanced motor technologies in all end-use sectors," says B. Ben Banerjee, manager for power conditioning and intelligent motion. "We're doing this by emphasizing their potential for improved operational flexibility, greater energy efficiency, reduced size and weight, and lower life-cycle cost."

Old ideas, new opportunities

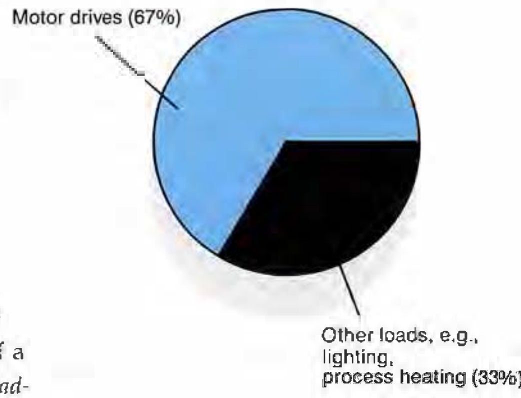
Most of the design concepts on which advanced motors are based have been around since the early days of electric machinery. Until recently, however, motor builders could not take full advantage of these ideas owing to a variety of problems—particularly the lack of affordable power electronic converters to vary the speed of ac motors and the need for permanent magnet materials strong enough for general use in multi-horsepower motors.

Over the past decade, considerable progress has been made in both these areas. Solid-state power converters, incorporating advanced high-voltage, high-current thyristors and transistors, have become available for controlling the speed and torque of a wide range of ac motors. (The term *adjustable-speed drive* is usually applied to such a power converter itself but sometimes refers to the combined converter-motor system.) At the same time, rare earth permanent magnet materials, such as samarium-cobalt and neodymium-iron-boron, now provide magnetic energy densities up to 10 times higher than those of conventional materials, thus allowing more-compact motor design. Although these exotic magnetic materials are expensive enough that they will be used primarily in large, high-performance motors, a group of new ceramic permanent magnets can provide moderate magnetic field strengths very inexpensively for small to intermediate-sized motors.

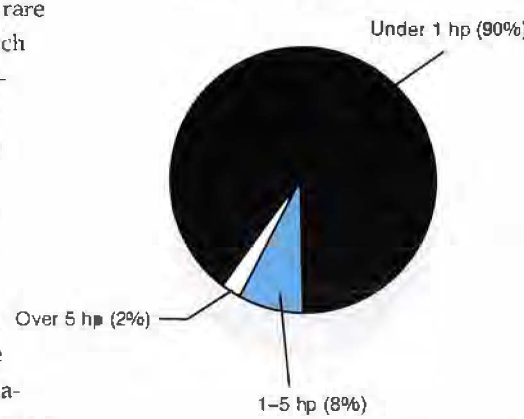
Such new capabilities have made possible several important design opportunities for advanced motors. Previous applications requiring large amounts of power and variable speed, for example—such as transportation and some industrial processes—often relied on dc motors, whose speed was easy to control. These motors are generally more expensive and less efficient than comparable ac motors and require more maintenance. Now that solid-state power supplies are available for varying the speed of ac motors, the trend away from dc motors is likely to accelerate. An ac power train for an electric vehicle, for example, could reduce weight and cost by 60%, compared with a dc system.

Adjustable-speed drives (ASDs) are already being used with conventional ac motors, but advanced motor designs will enable optimization of the motor–power supply combination. In particular, advanced motors will permit the use of simpler, less expensive ASDs while providing greater torque and cost-competitiveness in smaller units.

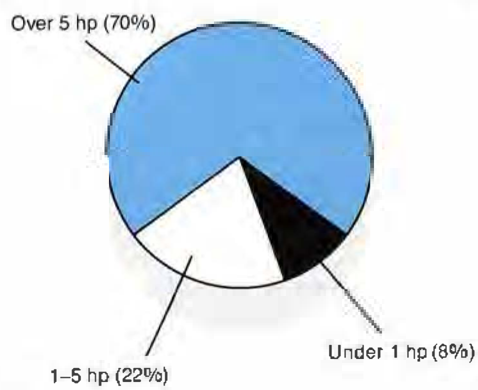
Electricity Use by Application



Number of Motors by Size



Electricity Use by Motor Size



MOTORS DOMINATE UTILITY LOADS Motors are the largest load on most utility systems, using more than two-thirds of the total electric energy consumed in this country. Although fractional-horsepower units represent 90% of the motor population, the 2% of motors that are larger than 5 hp account for more than 70% of the energy consumption.

Challenging the workhorse

The most significant impact of advanced motors will probably be their challenge to the workhorse of today's stable of machinery—the ac induction motor, which accounts for more than 95% of energy consumption by electric motors sized 1 hp or greater.

Induction motors are simple, robust, inexpensive, reliable, and easy to build. In its simplest, squirrel-cage form, an induction motor contains a rotor with straight aluminum or copper conductors that are arranged like the bars of a cylindrical cage. Currents are induced in these conductors by the constantly changing magnetic field produced by ac electricity in stator coils surrounding the rotor. The interaction of the two fields causes the rotor to turn. Squirrel-cage induction motors span power levels from 10 W to 10 MW. Some large induction motors have wire-wound magnetic coils on the rotor as well as on the stator, providing more-precise control for specific industrial applications.

From an economic standpoint, induction motors will be hard to beat for larger, constant-speed applications. For variable-speed operation, however, advanced motors can offer significant advantages in efficiency and performance. The main challenge will be to integrate the advanced motors, their

EPRI ADVANCED-MOTOR DEVELOPMENT

Motor Technology	R&D Organization	Applications	Estimated Commercialization
Converter-optimized, five-phase permanent magnet (PM) synchronous motor (both radial-gap and axial-gap designs)	McCleer Power Company, University of Tennessee at Knoxville	HVAC, compressors, fans, machine tools, off-road electric vehicles, washer-dryers	Starting in 1994 for some applications
High-speed fractional-horsepower PM motor	Proprietary commercial development by U.S. manufacturers	Electric hand tools, appliances, lawn mowers	Starting in 1995
Variable-reluctance motor (VRM) with auxiliary commutation winding	University of Wisconsin at Madison	Low-cost, low-horsepower consumer applications	Starting in 1995
Hybrid PM-VRM* (two designs: magnets in rotor, magnets in stator)	University of Wisconsin at Madison	Electric vehicles, high-speed machine tools, high-performance servodrives, pumps, fans, compressors	Starting in 1994 for some applications
Brushless, doubly fed motor*	Oregon State University	Low-cost adjustable-speed drives in small to large power ranges	Starting in 1995
High-temperature superconductor motor	Oak Ridge National Laboratory, University of Wisconsin at Madison, University of Tennessee at Knoxville, North Carolina State University	Many end-use applications anticipated	Still in exploratory stage

*For many applications, development will also include alternators.

power converters, and the mechanical loads being powered into cost-effective systems that can compete with more-conventional options for increasing efficiency.

So-called high-efficiency versions of most motors can be created simply by switching from aluminum to copper conducting elements, increasing the diameter of copper conductors, or changing the amount and kind of iron in the stator and the rotor. From a systems point of view, however, such changes may also have drawbacks. Higher starting currents, for example, may result in a need for time-delayed circuit breakers.

EPRI's work on advanced motors is focused on achieving higher efficiency through more-fundamental changes in design. Induction motors are basically designed for sine-wave, 60-Hz voltage. The output of power electronic converters, however, tends to have voltage profiles that are not sinusoidal; hence conditions under ASD operation are not optimal for induction motors, and their losses are high, even with proper design. Advanced motors can be optimized for operation with front-end power electronics to provide better overall system efficiency. They may also incorporate advanced "observer" circuits that can detect rotor position by electronically sampling power at the motor terminals, thus eliminating the need for mechanical sensors. Since all advanced motors inherently need power electronics to reshape the voltage and frequency, many applications that now use constant-speed drives may eventually be converted to ASD operation.

EPRI's advanced-motor development effort is being conducted in cooperation with motor manufacturers and the makers of equipment that will incorporate the motors. "Getting these companies involved early in the game increases the chances for success and also leverages our resources," says Banerjee. "One problem with motor development in the past has been the number of changes required at the prototype and production stages. We're trying to get more problems worked out at the initial design stage by applying a concurrent engineering approach that simultaneously considers electronic, mechanical, manufacturing, packaging, marketing, and cost issues. Manufacturing technology has also been improving, and EPRI is paying more attention to design for manufacturability."

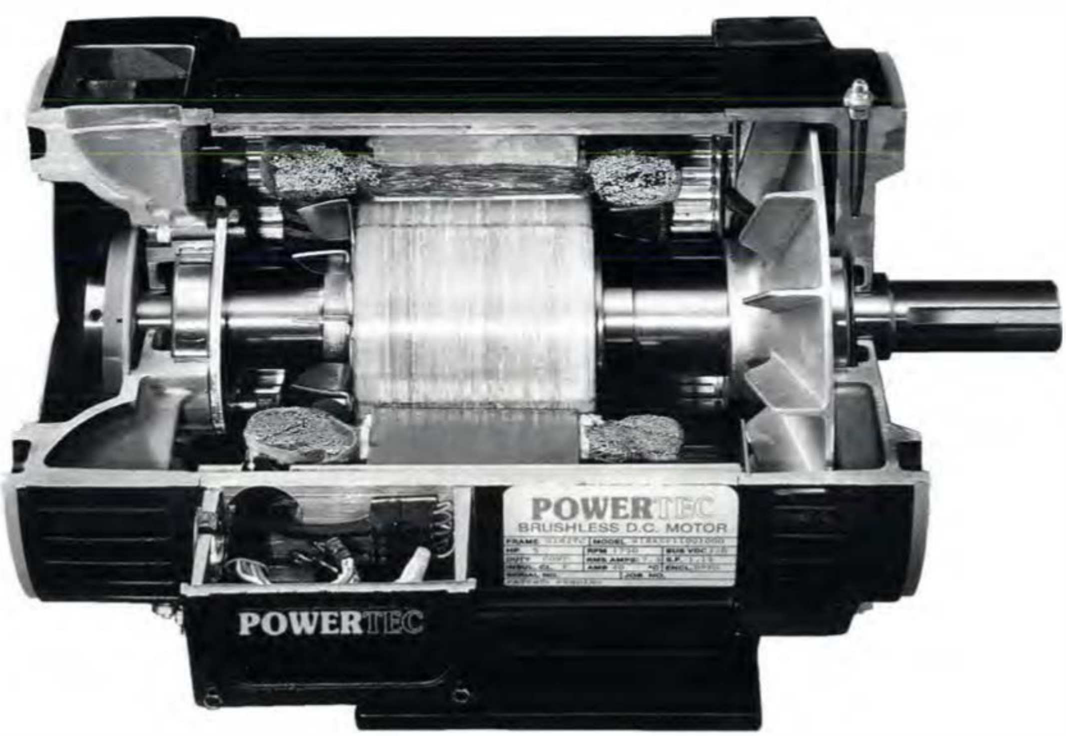
Permanent magnet synchronous motors

One of the most promising candidates for challenging the supremacy of induction motors, initially in the low horsepower range, is the converter-optimized permanent magnet ac synchronous (COPMACS) motor, developed by McCleer Power and the University of Tennessee. As the name implies, these motors are designed to run "in sync" with the frequency of the ac power applied. Permanent magnets mounted on the rotor are pulled along by a rotating magnetic field created by coils on the stator. Variable speed is achieved by changing the frequency and voltage in the stator coils with a five-phase electronic power converter.

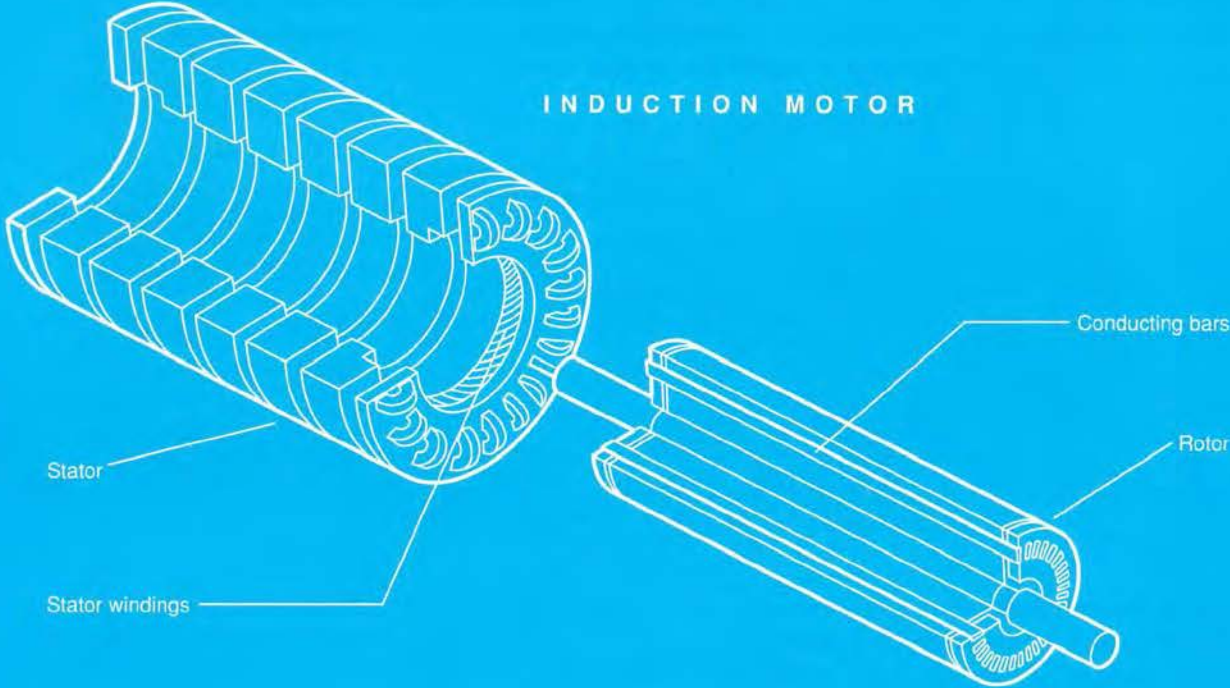
An important feature of the COPMACS motor is that its design has been optimized for use with a particular kind of power converter—rather than the other way around, which is more common. Specifically, most motors are designed to run on three-phase ac current because that is what's generally available from utility lines. By designing the new motor to run on five-phase current from a unique new type of ASD, the COPMACS developers have optimized its power delivery, compactness, strength, and efficiency.

The first advanced COPMACS motors, initially targeted for the low- to medium-horsepower range, are of axial-gap design—that is, the rotor and the stator are arranged in a pancake-like assembly rather than as concentric cylinders, as in most motors. This disk shape enables the COPMACS motor to fit compactly within such end-use equipment as textile ma-

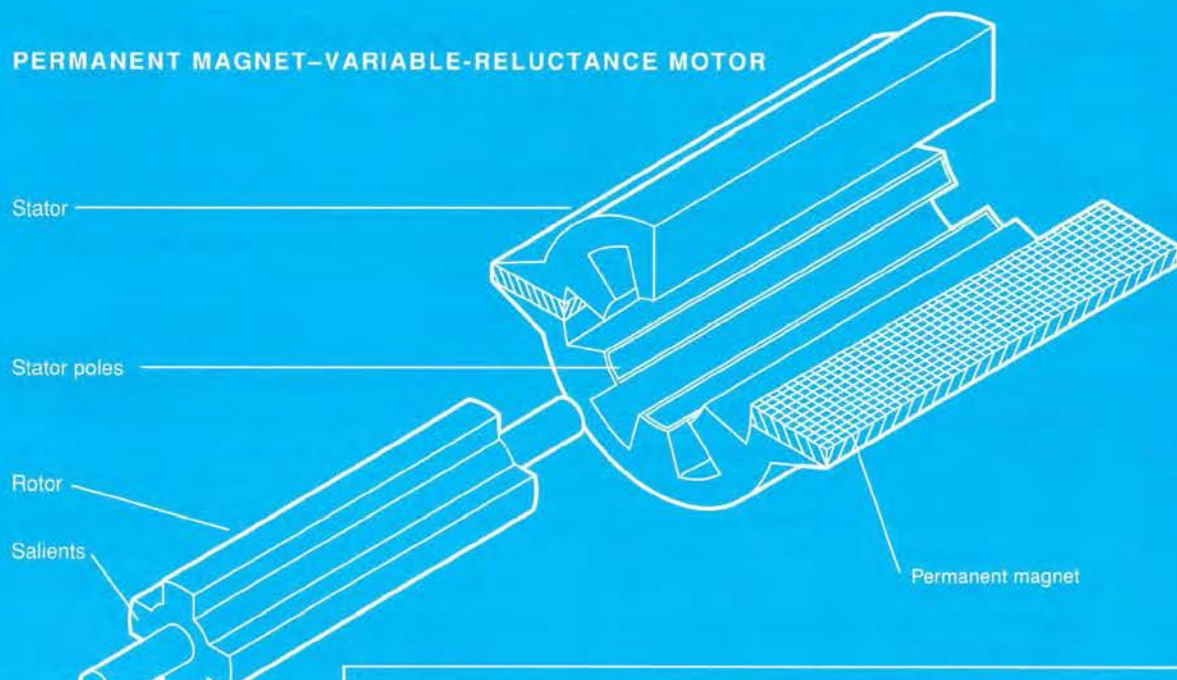
A PEEK INSIDE **One advanced motor, now commercially available from Powertec Industrial Corporation of Rock Hill, South Carolina, has ceramic permanent magnets bonded to the rotor shaft. The electronic power converter—a distinguishing feature of all advanced motors—is contained in the small box projecting from the motor casing.**



INDUCTION MOTOR

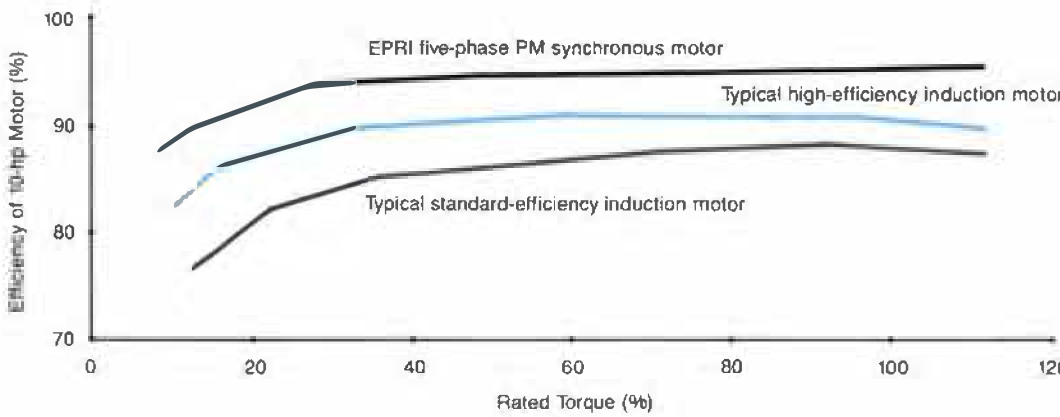


PERMANENT MAGNET–VARIABLE-RELUCTANCE MOTOR



CONVENTIONAL VERSUS ADVANCED DESIGNS The greatest challenge for advanced motors will be head-on competition with ac induction motors, which account for the largest proportion of electricity use. In a conventional, squirrel-cage induction motor (top), magnetic fields from stator windings induce currents in conducting bars embedded in the rotor. By contrast, the permanent magnet–variable-reluctance motor (bottom) features a solid steel rotor with salients that extend along its length. These salients are pulled around by fields from the stator poles, which are sequentially energized by a solid-state power converter. Permanent magnets on either side of the stator help provide control. The use of a solid rotor contributes to low cost, ruggedness, reliability, and ease of manufacturing.

BEYOND THE STANDARD **Motor manufacturers have typically increased efficiencies by making incremental changes in standard designs—using larger conductors or better-quality iron, for example. Advanced motors, such as the five-phase permanent magnet synchronous motor, take a more revolutionary approach—and get a significant efficiency boost—by incorporating a front-end power converter to optimize motor operation.**



chines, high-speed machine tools, small household appliances, and transmissionless washers and dryers.

In a second COPMACS effort, 5-hp motors are being installed in variable-speed heat pumps. A significant redesign of space-conditioning equipment, including heat pumps, will be necessary during the next few years because of mandated efficiency standards and an accelerated phaseout of chlorofluorocarbons, or CFCs. An advanced variable-speed motor can further this redesign effort by facilitating the integration of a heat pump's electrical and mechanical systems. In particular, it will help eliminate the problem of "cold blow" during startup and provide better coordination between compressor speed and the operation of a backup resistance heater. EPRI is sponsoring the heat pump demonstration work in cooperation with the Tennessee Valley Authority and other utilities.

A third advanced COPMACS motor has 10 hp and is initially being demonstrated in golf carts. EPRI's plan is to use this application to set the stage for volume production of the motor, which could then become competitive for other electric transportation uses, including forklifts and other off-road vehicles. For golf carts, the new motor represents a "quantum leap improvement," according to Banerjee. It is lighter than conventional golf cart motors, requires fewer batteries for the same range, provides better speed control, and does not require a separate charger. (The power converter can simply be plugged in to serve double duty as a charger.)

Two versions of this 10-hp COPMACS motor will be delivered to a leading golf cart manufacturer later this year. One will have an axial-gap (pancake) design; the other, a radial-gap design, with concentric rotor and stator. The manufacturer will then determine whether one design offers any advantage over the other in golf carts. Since these carts generally travel a restricted range (because of the size of golf courses), the main attractions of the COPMACS motor will be to lower vehicle cost and improve vehicle performance. In other applications, however, the motor could be used to extend the range of vehicles without significantly increasing their cost or battery requirements.

Another advanced permanent magnet motor—a three-phase motor that is smaller than the COPMACS units—is being designed for compact, high-speed applications. The importance of very small (fractional-horsepower) motors is much greater than their combined energy consumption would indicate because of the vital tasks they perform. Thus these smaller advanced motors are likely to be valued for their productivity enhancements as well as for their higher energy efficiency. EPRI is working with a leading U.S. power tool manufacturer to develop a new line of electric power tools based on advanced, high-speed permanent magnet motors—tools that will have greater power and torque, higher efficiency and reliability, but smaller size, weight, and cost.

Variable-reluctance motors

Another type of advanced motor works on the principle of variable reluctance. The term *reluctance*, in this case, refers to the way magnetic lines of force naturally concentrate along rotor and stator poles. When a magnetic field is created by a wire coil around a stator pole, it attracts the nearest rotor pole. Energizing the stator poles in sequence causes the rotor to turn. A variable-reluctance motor (VRM) is being developed under EPRI sponsorship at the University of Wisconsin at Madison (UWM).

An advantage of the VRM configuration is that the rotor can simply be a shaped piece of iron, which contributes to low cost, ruggedness, reliability, and ease of manufacturing. Fault tolerance is inherent, since the motor will continue to run—although with reduced torque—if the coil of one stator pole is disabled. This technology will be used primarily in low-cost, low-power, adjustable-speed consumer applications.

EPRI is also sponsoring the development of a hybrid permanent magnet–variable-reluctance motor (PM-VRM) at UWM. This combination would produce a motor capable of starting and stopping very quickly—an ideal candidate for use in servomechanisms. Such devices (for example, robots and mail-sorting machines) use sensors to detect when an object has been moved a certain distance and then stop accordingly. Work on this application is being pursued with a leading U.S. manufacturer. The use of permanent magnets may also make the PM-VRM suitable for larger applications than previously possible for reluctance motors—including electric vehicles, where it would provide more-precise control. Although PM-VRM motors will initially be small, EPRI plans to develop a 70-hp version for electric vehicle use within three years, and the motors could eventually be scaled up as high as 3000 hp for other applications.

Other advanced designs

A variety of other designs for advanced motors have been demonstrated experimentally or are on the drawing board. One of the most promising is the brushless doubly fed motor (BDFM), which benefits from speed control by a power converter that has a much lower power rating than the overall motor system has. The trick is for the motor to get most of its power directly from stator windings connected to a three-phase power line. A separate set of stator windings controls the motor speed and receives power from a variable-voltage, variable-frequency converter. Additional advantages of this arrangement include fault tolerance—since the motor still runs at constant speed if the electronic power supply is disabled—and lower harmonic distortion sent back to utility lines by the relatively small electronic power supply.

A laboratory prototype BDFM was built in 1990, and field demonstration is expected in 1993. During this demonstration, researchers will be particularly interested in comparing BDFM performance with that of a comparable induction motor. EPRI is sponsoring this work at Oregon State University, with cofunding from Bonneville Power Administration, Chevron, Puget Sound Power & Light, and Southern California Edison.

Other research is focusing on how to build a better high-speed motor, usually defined as one with a shaft speed exceeding 3600 rpm. The main problem is maintaining the mechanical integrity of the rotor, which must be both simple and rugged. Current work is concentrating on making solid rotors in a single forging. Such rotors are being tested in motors with ratings of up to 10,000 hp at 10,000 rpm, with the rotor being held in place by a magnetic field rather than by conventional bearings. The main advantage of running motors at these speeds is that they can be linked directly to a load shaft without a complicated gear assembly.

Finally, the recent discovery of high-temperature superconductors (HTSCs) has renewed interest in superconducting motors. Using HTSCs, these motors could be cooled with relatively cheap liquid nitrogen instead of the very expensive liquid helium required by previous superconducting materials. Compared with ordinary motors, HTSC-based units might have as little as one-half the energy losses. A variety of designs are being considered, including an axial-gap motor in which a stator disk with superconducting magnets is sandwiched between rotor disks. Although HTSC motors have the potential for very high efficiency, performance, and power density, none is expected to be ready for commercialization for several years. EPRI's Office of Exploratory Research & Applied Research and Customer Systems Division are supporting work at Oak Ridge National Laboratory on variable-speed HTSC motors.

Remaining issues

Although much progress has been made in developing advanced motors that will challenge conventional units in a variety of niche applications, several issues still must be resolved before these devices have a major impact on the overall motor market. The present cost of ASDs, for example, is high enough to restrict their use primarily to motors of larger sizes. Novel motor and power converter designs are helping to loosen this restriction, but the cost of solid-state power converters remains a significant barrier. The cost of permanent magnet materials and of the associated motor manufacturing methods must also be lowered. Finally, if electric vehicles are to be built without the need for gear-shifting transmissions, the rated power and speeds of advanced motor alternatives must be improved. The PM-VRM, in particular, has advantages for scaling up for use in this application.

"Advanced motors already look promising for several specific applications, and market demand for higher performance is clearly evident in such areas as heat pumps, refrigeration, power tools, and transportation," concludes program manager Wade Malcolm. "EPRI is playing a lead role in eliminating the remaining barriers to the wider use of advanced motors. The best way we can do this is to work closely with the research laboratories where new motor concepts are being tried, the motor manufacturers, and the OEMs—original equipment manufacturers—where they will be applied. Such research investment has immediate benefits for the Institute—we have already filed about a dozen patent applications on advanced motor designs. But the ultimate winners will be utilities and their customers, as the new motors improve performance and efficiency in numerous applications." ■

Background information for this article was provided by B. Ben Banerjee and Wade Malcolm of the Customer Systems Division.

AT THE INSTITUTE

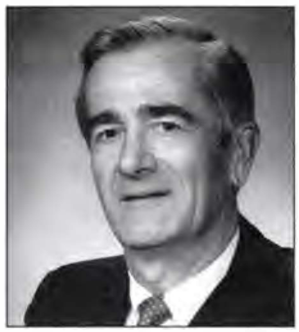
Ellis Elected Chairman of the Board

John W. Ellis, chairman of Puget Sound Power & Light Company in Bellevue, Washington, was elected to a one-year term as chairman of EPRI's Board of Directors at the Institute's annual meeting in April in Washington, D.C. Ellis, 63, who served as vice chairman of the 24-member EPRI Board during the past year, succeeds E. James Ferland, president and CEO of Public Service Electric & Gas Company, Newark, New Jersey. Succeeding Ellis as EPRI's vice chairman is Donald R. Norris, president and general manager of East Kentucky Power Cooperative, Winchester, Kentucky.

Ellis joined Puget Power in 1970 as a vice president after serving eight years as its chief counsel while an attorney with the firm of Perkins Coie in Seattle. He became president and CEO of the utility in 1976 and chairman in 1977. A graduate of the University of Washington Law School, he is a member of the Washington State and American bar associations.

Ellis has had a long-standing relationship with EPRI and was instrumental in its founding in the early 1970s. While working as an attorney, Ellis helped develop the concept of a privately funded research and development consortium, and at a 1972 Senate Commerce Committee hearing, he successfully argued that the private sector could best provide electricity R&D. He also served a previous term on the Institute's Board, from 1984 to 1989.

Ellis is a past chairman of the Edison Electric Institute, an association of investor-owned utilities. He served as the chairman of the Pacific Northwest Conference Committee in 1979, a director of the Association of Edison Illuminating Companies from 1988 to 1991, and the director of the National Energy Foundation from 1985 to 1987. Ellis also serves on the boards of directors of several other companies, as well as on the Governor's Council for Education Reform and Funding; he was recently named a regent of Washington State University.



A Seattle native, Ellis lives in Bellevue with his wife, Doris; they have four children. ■

Indian Delegation Visits the Institute

A delegation of high-level government officials from India visited EPRI recently to share concerns about electric power in their country and to learn about some of EPRI's research. The 16-member delegation included P. Chidambaram, minister of state for commerce; N. Ramji, a joint secretary for the Department of Power; and S. Dubey, the counsel general for the Indian consulate in San Francisco.

During the two-hour stay at EPRI's headquarters in Palo Alto, the Indian delegates heard presentations from EPRI's experts on a number of areas of interest to them. Narain Hingorani, vice president for electrical systems, spoke about flexible ac transmission systems; Ian Torrens, director of the Environmental Control Systems Department, spoke on clean coal technologies; Tony Armor, director of the Fossil Power Plants Department, talked about life optimization technologies and EPRI's state-of-the-art power plant; and Karl Stahlkopf, director of the Electrical Systems Division, gave a presentation on transmission and distribution efficiency. Other EPRI attendees included Kurt Yeager, senior vice president for technical operations, and Floyd Culler, president emeritus.

Ramji told his audience that India suffers an 18% shortage in power during peak demand periods. Among other concerns in the electric utility industry are coal with a high ash content, inefficient transmission and distribution systems, and the fact that a significant percentage of the population lives without electricity.

India is counting on foreign investment to help resolve some of these problems. The country is in the midst of a sweeping economic reform, initiated last year to transform the largely state-controlled economy into one operated on free-market principles. New economic policies that encourage foreign investment are an important part of this reform.

At this time India has an information exchange agreement in place with EPRI, but the delegates expressed an interest in extending this relationship to include collaboration on projects of mutual interest. While the delegates' visit did not result in an official agreement on a more extensive relationship in the future, EPRI representatives responded positively to the idea. Said Yeager, "We hope that this meeting will open many opportunities for EPRI and its members to engage in collaborative work with the power industry of India." ■

EPRI's Founder Honored

Energy experts from around the world gathered to celebrate the 80th birthday of Chauncey Starr, the founder and first president of EPRI, with a symposium on energy, risk, and the environment. About 220 people—from institutions as diverse and far-flung as Taiwan Power Company and Carnegie-Mellon University—attended the day-long event at Stanford University.

Sponsored by EPRI and Stanford, the symposium, held on March 27, recognized Starr's major contributions to energy production, risk assessment, and nuclear power. Wolf Häfele, director of Germany's nuclear research center in Dresden, delivered the keynote address. Among the other speakers were Robert White, president of the National Academy of Engineering; Jack Gibbons, director of the U.S. Office of Technology Assessment; and Lord Walter Marshall, president of the World Nuclear Power Operators.

Now a president emeritus of EPRI, Starr was at the University of California at Los Angeles serving as dean of the School of Engineering and Applied Science when he was selected to start the Institute nearly 20 years ago. In the position at UCLA, which he held from 1966 to 1972, Starr demonstrated his abilities as a pioneer, establishing a new environmental engineering department and the Institute of Medical Engineering. He also developed an analytical approach for quantifying societal risks that became the basis for today's risk management and risk communication sciences.

Starr has received numerous awards throughout his career. For his work in the peaceful uses of atomic power, he received the Atomic Energy Commission Award in 1974, the Walter H. Zinn Award in 1979, and the Henry D. Smyth Award in 1983. Among other honors, he received a Distinguished Contribution Award from the Society of Risk Analysis in 1984 and the National Medal of Technology in 1990. Just this year he was selected for the René Dubos Environmental Award for his outstanding career in industry and education and for his major contributions in nuclear power, risk assessment, and energy studies.

A videotape of the speeches given at Starr's symposium is available for $50 from EPRI's Janet Paler, (415) 855-2003. ■

Lighting Office Opens

In response to a growing number of lighting inquiries from member utilities, EPRI has established the Lighting Information Office. Open since February of this year, the office provides member utilities with quick responses to questions and easy access to information on lighting technologies, applications, and EPRI-developed tools available to resolve lighting problems.

Located in downtown Oakland, California, the office is operated by two employees of EPRI contractor Bevilacqua Knight, Inc. (BKI). Aside from answering questions from member utilities, the office staff produces fact sheets and other publications on lighting topics. Areas covered in the fact sheets produced so far include technologies for retrofit lighting projects, compact fluorescent lamps, advanced reflectors, and occupancy sensors.

"These publications are useful not only for utilities but for their customers too," says Larry Ayers, a BKI lighting consultant who runs the new office under the direction of EPRI's Karl Johnson, manager for commercial building systems. "Several utilities have requested hundreds of these publications to send to their customers."

The office's staff keeps abreast of activity taking place not only at EPRI but at member utilities, at outside research organizations, and in the lighting industry itself. In fact, the office is currently producing the first issue of what will be a quarterly newsletter covering lighting programs of EPRI, its member utilities, the U.S. government, and the lighting industry. This issue is expected to be released sometime this summer.

"I encourage EPRI members who have technical questions about lighting to give the new office a call," says Johnson. Adds Ayers, "I can't say we'll be able to solve all their problems, but if we can't, we'll help them find someone who can." Members with lighting questions can call the office's hotline, (800) 525-8555. ■

EPRINET Adds Customization Capability

The latest version of EPRINET™, Release 1.6, has been designed for easier use and provides new customization capability. Current users will automatically access the new release starting June 1, and manuals for the new version are being mailed to all users. New subscribers will begin EPRINET use with Release 1.6.

EPRINET is an information network and service for the electric utility industry that provides access to research around the world. The service includes electronic mail, news, bulletin boards, EPRI research databases, and interactive capabilities. Release 1.6 offers several improvements to the system, including new functions and screens that make bulletin boards easier to use.

In addition, a new Personal Profile service in EPRINET will enable users to customize the delivery of information to suit their needs. By indicating preferences, a user can control "BBS Waiting" and "News Waiting" messages, choose which menu to see first, add or delete services from the initial menu, and display or conceal certain commands.

To enroll as a new user, call the EPRINET Help Desk, (800) 964-8000. ■

Residential Program

Microwave Clothes Dryers

by John Kesselring, Customer Systems Division

ABSTRACT *Initial testing of an experimental microwave clothes dryer indicates that microwave dryers can dry normal loads faster and at cooler temperatures than conventional dryers and can also achieve a higher drying efficiency. After further laboratory testing of this unit, EPRI plans to develop and refine residential and commercial prototypes for field testing in 1993. The dryers, which might be commercially available in as little as three years, use a fundamentally different drying process than standard electric and gas dryers use and could help electric utilities increase their share of the energy market for clothes drying.*

EPRI has joined with leading companies in the appliance industry to launch a significant new venture into appliance R&D: development of a microwave clothes dryer. By applying microwave energy to clothes drying—energy that is generated in the same way as in microwave ovens—developers expect to be able to provide quicker, gentler drying and to lower drying temperature. As a result, woolens and delicate fabrics that would ordinarily have to be dry-cleaned could be washed and dried at home or in a coin-operated laundry.

At present, about 70% of all dryers in the United States are electric; some 3.5 million new electric dryers were installed in this country in 1991. Given the convenience that microwave dryers might afford by shortening drying time and enabling users to dry woolens and delicate fabrics, these new appliances could help electric utilities expand their share of the drying-energy market. In addition, much as microwave ovens spurred changes by the food-packaging industry to take advantage of the ovens' capabilities, the availability of microwave dryers could affect the clothing market in ways that increase the dryers' usefulness.

Microwave dryers and conventional dryers

Microwave dryers generate microwave energy by means of magnetron tubes like those in common microwave ovens. In magnetrons, steady electrostatic fields and steady magnetic flux densities are applied to moving electrons, accelerating them in a spiral path. The moving electrons resonate in tuned cavities to produce beams of microwaves at particular wavelengths. In microwave dryers, the beams of microwaves strike water molecules in wet clothing, causing them to quickly align and then reverse alignment—at rates as high as 2.5 billion times per second. This extremely rapid, repeated shifting produces heat, which evaporates the water.

The microwave energy gets right to the water, heating it while leaving fabrics largely unheated. Molecular structure is the key: it determines how rapidly microwave-induced molecular shifting takes place and consequently how rapidly different types of molecules are heated. The dielectric loss coefficient of a material provides a convenient measure of how readily the material is heated by microwaves. Water, which has a much higher loss coefficient than common fabric materials, seemingly attracts microwave energy and is readily heated by it, whereas fabrics remain relatively cool. The loss coefficient of water at 77°F is 12. In contrast, the coefficients of both cotton and polyester are extremely low (near zero), that of a typical wool fiber with 7% moisture is 0.29, and that of a commonly used nylon is 0.038.

The microwave drying process differs fundamentally from conventional drying. In standard dryers, air is heated as hot as 350°F and is blown into a drum. Clothes are tumbled in arcs in the drum so that heat can reach them, and heat is transferred from the air to the surface of the wet clothing, evaporating the water. This evaporation reduces the air temperature in the drum, but during drying that temperature typically climbs from 110°F to 160°F. Capillary action moves embedded water out to the fabric surfaces, and that water in turn evaporates. Eventually heat must be conducted into the fabrics so that water can be removed as steam. To shorten drying time, high fabric temperatures are needed. Conventional electric and gas dryers heat fabrics to about 160°F, but further heating the inlet air to speed drying decreases efficiency and weakens fabrics.

In a microwave dryer, by contrast, microwaves "target" the water molecules clinging to the clothes rather than the molecules constituting the fabrics. In experimental testing, dryer temperatures in the cool-drying mode generally have not exceeded 110°F, an excellent range for drying delicate fabrics. In addition, the air blown into the microwave dryer is not heated. When the shortest drying time is desired, the dryer can use heated air concurrently with microwaves.

Testing of experimental unit

Under RP3188-7, with guidance and support from members of an industrial advisory consortium, EPRI is conducting microwave dryer tests in three stages. Laboratory testing of an experimental unit began in mid-1991 and will continue through 1992. In this stage, researchers are evaluating dryer performance and studying hazards that might be associated with microwave clothes drying. Next, using data from the laboratory tests, EPRI will design and build prototype residential and commercial dryers for a second stage of testing. Following refinement of the prototypes, member utilities will participate in field trials of the units, completing the final stage of testing.

Two California companies—Thermo Energy Corporation of Palo Alto and JG Microwave of Twain Harte—developed the experimental unit for EPRI. The unit (Figure 1), which looks like a conventional dryer, is designed to provide test data for a wide range of drying conditions. Equipped with eight 0.85-kW magnetrons, the unit can supply 6.8 kW of microwave power and can dry a nominal 7-pound load in about half the time required by a conventional electric dryer. It includes a complete control panel, a 200-cfm variable-speed fan, and a variable-speed drum.

In addition to the 6.8 kW of microwave power, the unit can provide 5 kW of resistance heat. It operates in three modes. One uses both microwave and resistance heating to provide the quickest drying; another uses microwave heating and magnetron waste heat to provide the most efficient drying; and the third, least efficient mode uses microwave heating only, with no waste heat recovery, and permits drying at the lowest temperatures. In each mode researchers varied such factors as microwave power, electric field strength, air temperature to the drum, and load size, and then measured several key parameters, including drying time, humidity, and exit-air temperature. The tests have indicated that 3.5 kW of microwave power is sufficient for residential drying and that, compared with conventional electric dryers, the microwave unit can dry normal loads faster, at cooler temperatures, and with less tumbling.

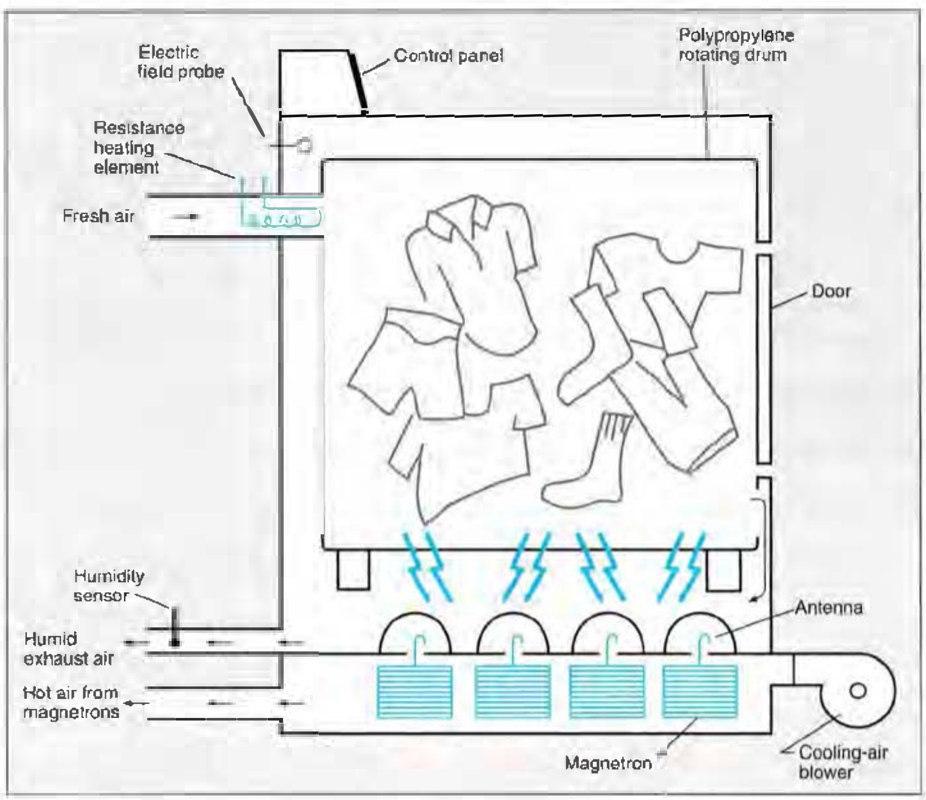


Figure 1 The experimental microwave dryer being tested by EPRI has the look and feel of a conventional dryer, but it is fully instrumented to provide data for use in designing residential and commercial prototypes.

Prototypes and field testing

The laboratory unit was designed to increase understanding of the microwave drying process, not to maximize energy efficiency, but EPRI plans to design and construct prototype residential and commercial dryers for fully efficient performance. Researchers believe that microwave dryers will eventually prove substantially more efficient than conventional dryers.

Plugs for dryers have to fit standard dryer receptacles, and the amount of power available at these outlets is one principal factor constraining the design of residential units. Commercial dryers can draw more power than residential dryers and could therefore use more magnetrons. With more magnetrons, commercial units could dry clothing more quickly and provide quicker payback on the relatively expensive magnetrons. For this reason, EPRI's prototype commercial dryers will contain more magnetrons and provide more microwave power than the residential prototypes.

In the process of qualifying prototypes for field demonstration, EPRI will initiate testing with Underwriters Laboratories. As in the case of microwave oven designs, the U.S. Public Health Service will have to approve the dryer designs. EPRI has twice briefed the Public Health Service Center for Devices and Radiological Health on project developments. Because dryers will be shielded like microwave ovens, EPRI anticipates no microwave emission problems.

Once the prototypes are qualified for use in field demonstrations, EPRI plans to manufacture six residential dryers and two commercial dryers. The research team will place the units with member utilities for field trials, will establish a data retrieval system, and will instrument the units for data gathering. EPRI plans to monitor and support the eight units for 12 months. Before the field trials, EPRI will conduct DOE efficiency tests on the prototypes and will assess the effects of microwave drying on fabrics by performing tests specified by the American Association of Textile Colorists and Chemists.

As testing proceeds and dryer designs are refined, development might well accelerate, leading to commercialization of dryers as early as 1994. Although the new dryers will probably cost more than conventional models because they will include microwave power supplies as well as standard dryer components, their energy savings, speed, and flexibility of use should more than make up for the initial cost premium.

Nondestructive Evaluation

Ultrasonic Testing: Computer Modeling Applications

by Michael J. Avioli, Jr., Nuclear Power Division

ABSTRACT *Under Appendix VIII of ASME Section XI, the qualifications of ultrasonic testing personnel who conduct in-service inspections at nuclear power plants must be established through performance demonstrations. To help utilities meet this requirement, EPRI is exploring the use of computer modeling in the design of qualification samples, the optimization of inspection procedures, and the extension of samples and procedures to a broader range of cases. Such modeling applications promise to improve inspection reliability and reduce the costs of qualification.*

The American Society of Mechanical Engineers (ASME) authors rules for the inspection of pressure boundary components such as power plant piping and reactor pressure vessels. These rules are reviewed by the Nuclear Regulatory Commission, and if they meet standards to ensure reliable inspections, they become part of the Code of Federal Regulations (CFR). Once ASME rules are entered into the CFR, U.S. nuclear utilities must follow them in inspecting their plants. The part of the ASME Boiler and Pressure Vessel Code that governs these inspections is Section XI, "Rules for Inservice Inspection of Nuclear Power Plant Components."

Code sections can be updated through appendixes. Appendix VII, "Qualification of Nondestructive Evaluation Personnel for Ultrasonic Examination," was added to Section XI in 1988; Appendix VIII, "Performance Demonstration for Ultrasonic Examination Systems," was added in 1989. Given the challenges of implementing Appendix VIII, EPRI is exploring the use of computer modeling to help utilities qualify their ultrasonic testing (UT) personnel.

Appendix VIII requirements

Appendix VIII requires that ultrasonic inspection personnel, using hardware and inspection procedures they have selected themselves, demonstrate their UT capabilities to a group of peers, which typically comprises regulators, utilities, and/or third parties. In such a demonstration, the candidates examine a collection of plant component mock-ups—called qualification samples—that replicate the components they are scheduled to inspect. UT personnel who satisfy the criteria of the performance demonstration receive qualification to perform similar inspections in a power plant.

The implementation of such performance demonstrations is fully the responsibility of U.S. nuclear utilities. In 1989 an ad hoc utility committee launched an effort called the Performance Demonstration Initiative (PDI) to address this issue. Almost all U.S. nuclear utilities are represented on the committee. Recognizing the high costs of replicating plant components and implanting defects, the growing shortage of inspectors, and the costs of conducting demonstrations, the PDI committee identified computer modeling as a key element in improving inspection reliability and reducing costs.

The committee defined these objectives for modeling:

- To extend the range of application of qualified procedures
- To minimize the number of necessary samples and demonstrations
- To optimize procedures

Under RP2687-11, EPRI is addressing some of the PDI objectives. The project aims to provide the most cost-effective and reliable inspections realizable under the requirements of Appendix VIII by applying modeling to three areas: the design of qualification samples, the evaluation of ultrasonic inspection procedures, and the extension of qualification samples to a broader range of application.

Modeling applications

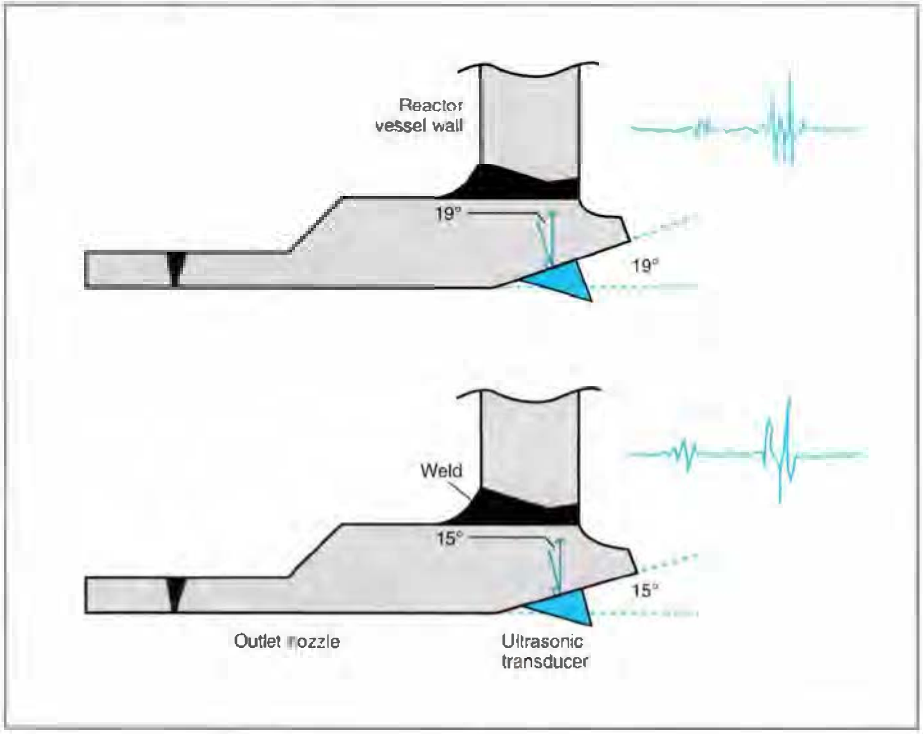
The design phase of qualification samples is critical. Because of cost considerations, a limited number of samples must be able to embody a broad range of the geometric and material characteristics of both BWR and PWR components. Modeling can provide guidelines for design by establishing ultrasonic inspection "equivalence" among groups of similar components (Figure 1). Using field data related to the geometric and material properties of plant components, a model can indicate which components will yield similar ultrasonic signals and can therefore be considered equivalent for UT purposes. After ultrasonic equivalence is established, qualification samples can be fabricated according to the equivalence model. For example, a set of "typical" nozzles that are equivalent to in-plant nozzles can be fabricated.

Qualification rules may also result from this approach. For instance, a rule might allow an inspection team to be qualified for any nozzle whose dimensions are within a specified range of those of the nozzle used by the team in the performance demonstration. Modeling can provide the technical basis for establishing such rules.

Computer modeling can also aid in the analysis and refinement of ultrasonic inspection procedures. Models can be used to determine the component coverage of procedures, as well as their sensitivity to defect type, size, and orientation at specific component locations. Performance demonstration candidates, knowing the limits of their inspection procedures, can modify the procedures, evaluate the new approach via modeling, and thereby increase the probability of satisfying performance demonstration criteria. By helping UT personnel optimize procedures, modeling can improve the overall reliability of in-service inspection.

The RAYTRACE beam-plotting model, developed by EPRI's Nondestructive Evaluation Center, is one example of a software tool that is useful for optimizing inspection procedures. With RAYTRACE, UT personnel can visualize how an ultrasonic beam will

Figure 1 Although these outlet nozzles are geometrically different, ultrasonic transducers can be modified so that the same area of each nozzle is examined. Here the beam entry angle is adjusted in order to inspect the narrow part of the weld. When similar signals result, the nozzles are considered equivalent for ultrasonic inspection purposes. Computer modeling can be used to demonstrate equivalence between components and to design qualification samples that can represent a group of similar components.



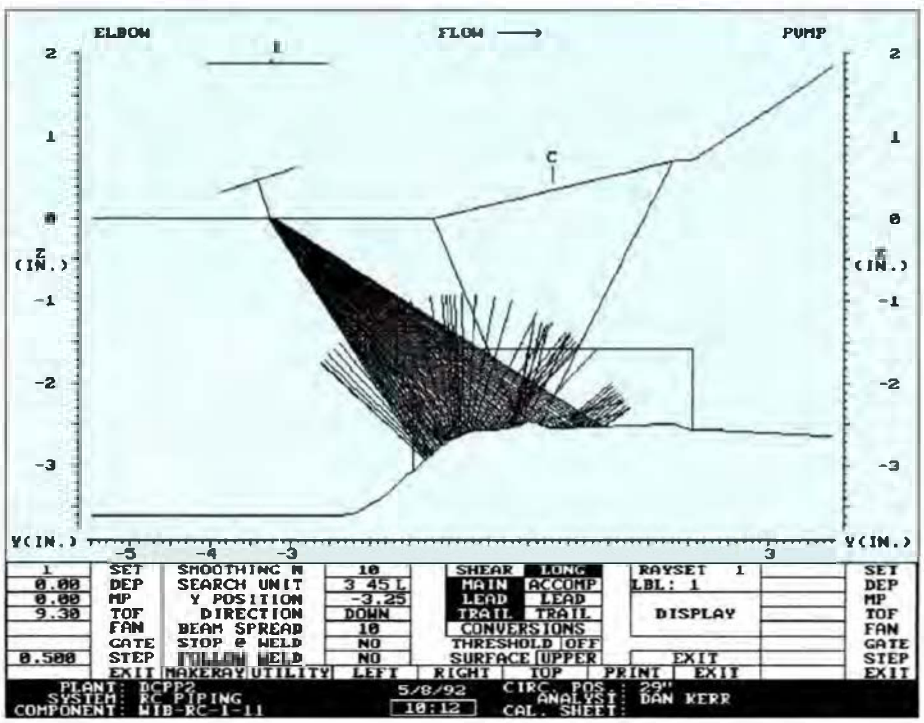


Figure 2 By quickly and accurately plotting the propagation of an ultrasonic beam through a component, EPRI's RAYTRACE software can help UT personnel optimize inspection procedures. For example, it can be used to determine transducer placement for adequate coverage of the area of interest—in this case, a piping elbow.

propagate through a given component during an inspection (Figure 2). A user can input a change in the position of the ultrasonic transducer or in the beam entry angle, and the RAYTRACE model will regenerate the beam path to show the coverage of the inspected area.

It would be highly advantageous to extend qualification possibilities beyond those cases represented by the available qualification sample inventory. Modeling can extend qualification to components not exactly represented by the samples. Modeling creates the opportunity for interpolation between qualification samples; that is, it may be possible to extend qualification to a component whose geometric and material properties are similar to, and fall between, those of two given samples. Extrapolation may also be possible, depending on the extent to which the models used have achieved credibility through extensive validation and verification. By extending the applicability of samples through interpolation and extrapolation, the need for qualification could be reduced, saving many utility and service vendor dollars.

Babcock Energy, Ltd., Scotland, is performing modeling work under RP2687-11. This work primarily involves the geometric modeling of nozzles by means of three-dimensional graphics and the modeling of ultrasonic beam propagation in nozzle interiors. The British utility Nuclear Electric has been subcontracted to model ultrasonic responses from reflectors arbitrarily located within the nozzle models.

The team of Babcock Energy and Nuclear Electric was successful in using modeling to establish the technical basis for the qualification of inspection methods related to the licensing of the Sizewell B reactor in the United Kingdom. The two contractors are taking a similar approach in the development of models for U.S. utilities.

Combustion Turbines and Combined Cycles

Tools for Gas Turbine Management and Maintenance

by Robert Frischmuth, Generation & Storage Division

For many electric utilities today, gas turbines represent only a fraction of overall capacity. Yet over the next 20 years, the installed base of gas turbine and combined-cycle units is projected to increase from about 60,000 MW to over 100,000 MW. There are a variety of reasons for this projected increase:

▫ Gas turbines can support a wide range of applications—from simple-cycle standby use for emergencies or peaking, to part-time combined cycling for system load and voltage management, to continuous operation.

▫ Compared with steam baseload units, gas turbines can be installed much faster and at significantly lower cost.

▫ The turbines are the most efficient option for burning environmentally "clean" natural gas. While natural gas has been expensive, it is now available in most areas for long-term contract supply at competitive prices.

▫ A growing confidence that coal gasification will be available as a commercial option within the next 10 years is offsetting the perceived risks in long-term natural gas availability.

▫ The modularity of gas turbines facilitates siting at existing facilities and easy installation of additional units as required.

▫ Design refinements are increasing the efficiency and reliability of gas turbines. For example, the new 150-MW advanced turbines deliver higher thermal-cycle efficiency—now more than 50% for combined-cycle units.

Resources for optimal performance

With the use of gas turbines on the rise, utilities are recognizing that proper management and maintenance practices can be a significant factor in unit reliability and cost-effectiveness. However, many owners simply have not been able to develop appropriate management and maintenance programs fast enough to keep up with the burgeoning technology. EPRI's Generation & Storage Division has developed a variety of resources to help owners gain a better understanding of their units, perform better preventive maintenance, more accurately analyze and specify materials, and more effectively negotiate vendor maintenance agreements.

These resources are yielding significant benefits for utilities, as the following sampling indicates:

▫ Reduction of unit overhaul costs by up to 25%, and of overhaul times by up to 50%, through the use of EPRI's Gas Turbine Overhaul Plan software and guidebook.

▫ Major reduction of the time required for analyzing failure-to-start incidents, and for performing other troubleshooting, through the use of the portable SA•VANT™ unit. SA•VANT's knowledge-based technology allows even a relatively inexperienced technician to quickly identify the causes of elusive problems.

▫ Isolation of the root causes of many generic problems—some potentially catastrophic. (Compressor blade walk is one example.) EPRI-developed procedures and tools can help correct maintenance shortcomings and eliminate the need for expensive (up to $1 million) component redesign or replacement.

▫ Quantification of the relationship between maintenance and reliability—a benefit of research by EPRI's Data Applications Center (DAC). In one case, DAC research supported a member utility's decision to purchase a new digital control system by showing that digital controls can reduce forced outage and scheduled outage factors by four and three percentage points, respectively, and improve starting reliability by five points.

EPRI's gas turbine maintenance and plant services subprogram develops products and services in the areas of outage management, training and expert systems, hot gas path maintenance, and technology transfer and communication. Examples in each of these areas are described below, and Table 1 summarizes the plant support resources currently available or under development.

ABSTRACT *With their modularity, ease of installation, low installed cost, and increasing efficiency and reliability, gas turbines are becoming a major source of new generating capacity for U.S. electric utilities. One of the challenges facing owners is that management and maintenance programs to optimize unit reliability and performance have not kept pace with rapid growth in the installed base. To extend and enhance utility maintenance capabilities, EPRI has developed a variety of resources, including products and services for unit efficiency analysis, outage management, troubleshooting, technician training, turbine blade refurbishment, and information exchange.*

Outage management

EPRI's gas turbine outage management services are aimed at helping utilities reduce downtime and costs, increase time between outages, and track machine condition.

Planned outages for gas turbine overhauls account for some 65% of equipment unavailability. Maintenance and overhaul tasks are performed by utility personnel and outside vendors working together—a situation not likely to change in the near future. However, utilities and vendors alike recognize that greater utility knowledge of maintenance requirements can result in better-matched expectations; more-effective communication, scheduling, and work planning; and lower costs during maintenance specification, procurement, and task performance.

To establish clearer expectations and a basis for better communication between vendors and utilities, EPRI has developed a work planning and control tool called GTOP (Gas Turbine Overhaul Plan). GTOP is being developed in vendor-specific versions. The first, released in 1990, covers General Electric MS7001 and Westinghouse 501 turbines.

To develop GTOP, EPRI contractors observed a number of unit overhauls and divided the associated work processes into some 2000 steps. For each step, they wrote a scope description to identify the necessary craft skills, tools, parts, and task durations. They then used a computer program to develop an optimized plan.

GTOP provides specific recommendations on planning, repair, and overhaul techniques for simple-cycle and combined-cycle combustion turbine plants. It includes task information sheets, critical path (PERT) diagrams, task crew resource requirements, and task durations. Available both as hard copy and on IBM PC–compatible software, GTOP data can also be imported into popular scheduling programs, such as Project2. Versions for GE's MS5001 and Asea Brown Boveri's 11N units are scheduled to be completed in 1992 and 1993, respectively.

Since the release of the first GE/Westinghouse GTOP in 1990, 69 utilities have requested it and 20 have used it for overhauls or major maintenance. The savings have been significant: up to 30% in manpower and 50% in time. Users are reporting overall cost reductions of 25%. Omaha Public Power District, for example, estimated savings of $225,000 in its first use of GTOP on one unit, and the utility plans to use GTOP for future overhauls.

Training and expert systems

A recent EPRI-sponsored seminar attended by gas turbine manufacturers and some 50 utility owners revealed a significant gap between utility training needs and the training services provided by manufacturers. To help close this gap, EPRI is developing a two-day training program called the Plant Improvement Course, which will focus on a strategic approach to improving operations and maintenance, including the principles of applying gas turbine operating data and information. The first session of the course, to be held later this year, will be for midlevel utility managers.

To provide further assistance with training and troubleshooting, EPRI is developing SA•VANT—a computer-based information system that both exerienced and novice technicians can use to troubleshoot operational problems.

The SA•VANT program will comprise four modules: the startup advisor will troubleshoot startup problems; the performance advisor will diagnose unit efficiency; the vibration balancing advisor will help balance the rotor; and the troubleshooting trainer will be an interactive, intelligent tutoring system with a graphic user interface. The first three modules are being tested by Jersey Central Power & Light (at its Sayreville plant), Carolina Power & Light (Darlington), Public Service Electric & Gas (Essex), Consolidated Edison (Ravenswood), Northeast Utilities (Cos Cob), and the Tennessee Valley Authority (Gallatin). The fourth module, which is under development, will be tested later this year.

Table 1
GAS TURBINE MANAGEMENT AND MAINTENANCE RESOURCES

Service/Product	Description
Outage Management	
Gas Turbine Overhaul Plan (GTOP)	Outage planning database (available for GE MS7001 and Westinghouse 501 turbines; under development for GE MS5001 and Asea Brown Boveri 11N turbines)
Efficiency Maintenance Analysis Program	Thermal performance analysis program
Training and Expert Systems	
SAVANT	Expert system for troubleshooting operational problems
Plant Improvement Course	Two-day seminar on improving operations and maintenance
Compressor Blade Walk Inspection	Videotape and checklist (available mid-1992)
Hot Gas Path Maintenance	
REMLIFE	Computerized algorithm to estimate remaining life of first-stage blading
Advisor for Blade Coating (ABC)	Computerized selection of blade coatings
SPECS	Specifications for repair of nozzles and turbine blades
BLADE-CT	Finite-element analysis program to assess stress, heat transfer, and vibration of blading
Blade Life Assessment and Repair Guidebook	Manual of methods for determining condition of blading
Technology Transfer	
Combustion Turbine Center (Charlotte, North Carolina)	Technology transfer and advisory center; electronic bulletin board
Data Applications Center	Service that provides easy access to databases for customized reliability information
Inventory of Gas Turbines (INTURB)	Database of gas turbine engines, sites, and personnel
Standard Equipment Code	Standardized equipment breakdown for combustion turbine and combined-cycle plants

Hot gas path maintenance

Combustion turbine blades, which are fabricated from nickel-based superalloys, operate under severe mechanical loads in aggressive, high-temperature environments. Blades are subject to damage from creep (resulting from grain boundary cavity formation), foreign objects in the flow stream (especially if blades become embrittled), oxidation, and hot corrosion. Since blade replacement is expensive—and in many cases unnecessary—EPRI has developed a variety of tools to address these problems.

One such tool is the *Combustion Turbine Blade Life Assessment and Repair Guidebook* (EPRI report GS-6544). This guidebook provides a test methodology for determining the adequacy of impact toughness and rupture strength. Arizona Public Service Company used the test methodology on two units to demonstrate that undamaged second-row blades could be returned to service, saving about $590,000, and that lost creep rupture strength could be restored to first-stage blades, saving $850,000 over three years.

EPRI has also developed software and a guidebook (GS-7334-L) for specifying high-temperature coatings for combustion turbines. These tools help users specify appropriate protective blade coatings to minimize high-temperature oxidation and corrosion. One utility used the package to select a coating for replacement blades that it expects will double blade life and save $3.6 million over 20 years.

Technology transfer and communication

By sharing operations and maintenance information, turbine owners can eliminate unnecessary research and reduce maintenance costs. Accordingly, EPRI is making gas turbine knowledge available to the utility industry in a variety of ways. The Combustion Turbine Center in Charlotte, North Carolina, is an important part of this effort.

One goal in establishing the center was to provide an effective way to transfer maintenance technology to EPRI members. At this facility, utilities can learn about products and analytical techniques that can help them make more-cost-effective gas turbine maintenance decisions. They can also exchange information with other utilities through an electronic bulletin board.

The Data Applications Center, a service available through the Combustion Turbine Center, makes it easy to access a variety of databases to obtain customized reliability information related to specific gas turbine problems or projects. DAC personnel will search databases, interpret findings, and prepare a formal response to specific questions. The use of this service is free to EPRI members.

Also available through the Combustion Turbine Center (or as a stand-alone program) is EPRI's easy-to-use Inventory of Gas Turbines (INTURB). This database contains a wealth of information on some 2200 domestic units, including site names and locations, site personnel, engine makes and models, combined-cycle status, emissions controls, upgrade and modification histories, service factors, total fired hours, and total starts.

Bottom-line results

Over the past few years, utilities have reported many examples of substantial cost savings resulting from the use of EPRI's gas turbine products and services. Because of this bottom-line payoff, the Generation & Storage Division is increasing its efforts to develop new products and services that respond to owners' needs.

Planned or under development are an outage criteria database, sophisticated maintenance logging and recordkeeping systems, seminars on unit operations and maintenance improvement, an operating practices guide, training aids for blade inspection and refurbishment, technical specifications for nozzle and turbine blade repair, a sophisticated finite-element blade analysis program, standardized equipment codes for simple-cycle and combined-cycle units, and IBM PC-compatible software for maintenance accounting and reliability analysis.

For further information on the resources discussed in this article, contact Robert Frischmuth at (415) 855-2579. For information on the Combustion Turbine Center, contact David Dobbins at (704) 547-6161.

Power Plant Availability

ACOM: Availability Cost Optimization Methodology

by Jerome Weiss, Integrated Energy Systems Division

When utilities seek to improve the availability and thermal efficiency of generating units, they often must select from among several proposed changes. The need to take into account budget and personnel constraints and to evaluate the cost and performance interactions between proposed modifications can make this decision exceedingly difficult. If a large number of alternatives exist, the analysis is virtually impossible to perform manually.

Under RP2462-1, EPRI developed an availability optimization methodology to help utility management select, schedule, and implement unit improvement options that will provide the greatest return on investment within specified budget and other constraints. Now the methodology is available in a software package that capitalizes on the computational capability of the personal computer. The first large-scale application of this software—called ACOM (Availability Cost Optimization Methodology)—has demonstrated its usefulness as a utility planning and analysis tool.

ACOM was designed for situations in which utility personnel must evaluate many proposed changes to equipment and determine their impact on availability and heat rate. Candidates for the use of ACOM include availability improvement programs and routine equipment upgrade proposals. A typical situation might involve 50 proposed changes (or improvement projects) for one or more units, with associated costs, benefits, funding limits, schedule constraints, and performance requirements.

ABSTRACT *With EPRI's ACOM software, utilities can cost-effectively evaluate a large number of proposed options for improving the availability of power generating units and select the best candidates for implementation. The program determines the impact of each proposed change on unit availability and efficiency, considers funding and other resource constraints, and analyzes interactions between alternatives. Results include an optimal schedule for implementing the recommended changes. In a recent application, ACOM helped a member utility optimize a 10-year improvement plan for 12 fossil units, for an increase of $88 million in expected net benefits.*

The methodology

ACOM uses a three-stage process to evaluate single- or multiple-unit availability improvement programs for planning horizons as long as 10 years. The first stage involves a straightforward screening process to ensure that each change can be implemented within various schedule limitations, that each change has a positive expected effect on unit availability, and that the forecast benefits of a change exceed its implementation costs. This step uses EPRI's UNIRAM program to assess the effects of each proposed change on unit availability.

In the second stage, overall constraints, such as funding and available personnel resources, are introduced into the evaluation. Through a linear programming process, all the candidates remaining after step one are analyzed to determine a subset of proposed projects that represents an initial optimal solution within the specified constraints. This subset is the basis for the final evaluation in stage three.

In the third stage, a dynamic programming algorithm is used to determine the group of changes that will provide the greatest net benefit and to identify the optimal order of implementation. This final step analyzes the changes' interdependencies and interactions in reaching an optimal solution.

Applications

Initially, the availability optimization methodology was applied manually. The first application, to a sample set of proposed changes, led to the rejection of all the candidates—none passed the preliminary screening process. As a result, the participating utility decided to reevaluate each of the proposed projects.

The second application, for Potomac Electric Power Company (PEPCO), evaluated 41 proposed improvements to three units for implementation over a 10-year period. The results of the evaluation are presented in Table 1. In this case, the methodology and linear and dynamic programming algorithms were applied manually, and the UNIRAM software was used to perform each availability assessment in the process. This application demonstrated the potential value and applicability of the methodology. The extent and type of computations and the accompanying bookkeeping, however, made it clear that sophisticated computational assistance was required if the methodology was to be widely used. Especially in analyses of a somewhat larger number of project candidates and units, reliance on manual methods would require shortcuts and assumptions that could invalidate the conclusions. The insights gained in the PEPCO case led to the development of the ACOM software package.

Table 1
PEPCO APPLICATION

	Original Plan	Optimized Plan
Benefits (present worth)	$38,662,000	$33,019,000
Costs	$20,703,000	$14,613,000
Benefit/cost ratio	1.87	2.26
Net benefits	$17,959,000	$18,406,000
Avoided costs		$6,090,000

Note: For more details on the assumptions and calculations involved, see EPRI report GS-6266.

In the first large-scale application of ACOM, Centerior Energy used it to evaluate 182 proposed changes to 12 fossil units for implementation over 10 years. A comparison of the ACOM results with independent estimates developed previously by Centerior demonstrated the potential value of the methodology. The optimized plan produced by ACOM reduced the number of changes to be implemented to 124, for potential cost savings of $95 million and an increase of $88 million in the expected net benefits of the entire improvement program (Table 2).

Moreover, this case demonstrated the speed and ease of using the ACOM software to solve a large problem. A moderately fast personal computer was able to evaluate all the proposals and produce an optimal result in some 48 hours. Reaching a solution manually, if possible at all, would have required many analyst-years of effort.

Table 2
CENTERIOR ENERGY APPLICATION

	Original Plan	Optimized Plan
Number of proposed changes	182	124
Benefits	$532,000,000	$525,000,000
Costs	$281,000,000	$186,000,000
Benefit/cost ratio	1.89	2.82
Net benefits	$251,000,000	$339,000,00
Avoided costs		$95,000,000

Note: For more details on the assumptions and calculations involved, see the EPRI *Innovators* publication IN-100250.

ACOM benefits

The ACOM software package, which is now available for utility use, performs all three steps of the methodology by computer, selecting the optimal combination of availability or heat rate improvement projects from a large list of candidates. This selection takes into account resource constraints, schedules, and interactions between the candidates. Execution of the program, which can require literally millions of UNIRAM runs, produces a list of recommended changes, an optimal schedule and order of implementation, and the expected costs and benefits of implementing the recommendations. As shown in the Centerior application, ACOM can enable utilities to solve problems that previously would have been insoluble or would have required enormous expenditures of time and resources. Moreover, the program's ability to handle a large number of options eliminates the need for making simplifications and assumptions that could cast doubt on analysis results.

The ACOM software package runs on a stand-alone IBM-compatible microcomputer equipped with MS-DOS. ACOM is integrated so that a user can interactively prepare and modify all input data files via a series of menu screens, execute the program to obtain the solution, and prepare and format a series of output reports. A user's manual (TR-100225) provides guidance in program application. ACOM is available to EPRI members through the Electric Power Software Center, (214) 655-8883.

New Contracts

Customer Systems

Project	Funding/Duration	Contractor/EPRI Project Manager
End-Use Load Shape Modeling Study (RP2980-5)	$397,100 11 months	Quantum Consulting/*P. Meagher*
Thermal Energy Storage Using Perlite-Phase Change Material Composite (RP3164-2)	$86,100 7 months	Phase Change Technology/*A. Lannus*
Electrical Efficiency in Electric Arc Furnace Steelmaking (RP3243-5)	$60,800 16 months	Tekon Services/*P. McDonough*
Industrial Power Quality and Motor Drives (RP3245-3)	$365,000 18 months	University of New Orleans/*A. Amarnath*
Magnetic Field Transients Resulting From Thyristor-Controlled Loads (RP3254-2)	$58,600 11 months	Arizona State University/*M. Samotyj*
Supermarket Dehumidification Equipment Applications and Operating Strategies (RP3280-10)	$123,000 24 months	University of Colorado, Boulder/*M. Khattar*
Cool Air and Water Utilization (RP3280-16)	$112,200 16 months	Dorgan Associates/*R. Wendland*
Electric G-Van Development for Production: 1992 (RP3299-3)	$384,300 12 months	Conceptor Industries/*G. Purcell*
Integration and Demonstration of the Market Analysis Tools Commercial CLASSIFY-Plus and MarketTREK (RP3310-3)	$159,500 16 months	Research Triangle Institute/*T. Henneberger*
Integration and Demonstration of the Market Analysis Tools Commercial CLASSIFY-Plus and MarketTREK (RP3310-4)	$282,000 16 months	National Analysts/*T. Henneberger*

Electrical Systems

Project	Funding/Duration	Contractor/EPRI Project Manager
High-Phase-Order Demonstration (RP3210-1)	$720,300 51 months	Empire State Electric Energy Research Corp./*J. Porter*
Solar Magnetic Disturbances and Geomagnetically Induced Current Protective Relaying (RP3211-4)	$197,900 10 months	Electric Research & Management/*F. Phillips*
Measurement of Overvoltages on Underground Distribution (RP3326-1)	$116,000 4 months	Power Technologies/*V. Longo*
Metal Oxide Semiconductor–Gated Solar Cell Device (RP4000-33)	$73,500 5 months	Microelectronics Center of North Carolina/*H. Mehta*

Environment

Project	Funding/Duration	Contractor/EPRI Project Manager
Testing of Noncombustion Waste Options (RP3006-6)	$1,306,200 23 months	Radian Corp./*M. McLearn*
Climate Change Risk Assessment (RP3041-6)	$75,000 7 months	Resources for the Future/*L. Levin*
Decision Support for Air Toxics (RP3081-2)	$544,300 31 months	Decision Focus/*L. Levin*
Air Emissions Risk Assessment Methodology (RP3081-3)	$189,500 30 months	IWG Corp./*L. Levin*
SO_2 Advanced Retrofit Development (RP3227-1)	$394,800 9 months	Sargent & Lundy Engineers/*C. Dene*
Climate Model Sensitivity to Land Surface Interactions (RP3267-6)	$78,900 18 months	Macquarie Park Research/*C. Hakkarinen*
Climate Model Sensitivity to Atmospheric CO_2 (RP3267-7)	$235,100 24 months	Yale University/*C. Hakkarinen*

Exploratory & Applied Research

Project	Funding/Duration	Contractor/EPRI Project Manager
Intelligent Real-Time Condition Monitoring and Maintenance Management (RP8004-16)	$204,500 36 months	Stanford University/*J. Naser*
Detection of Hazardous Contaminants in Groundwater Using In Situ Fiber-Optic Probes (RP8004-18)	$74,900 36 months	University of Wyoming/*M. Elrashidi*
Demonstration of Scalable Parallel Processing for Complex Process Emulation (RP8004-19)	$175,500 15 months	Automation Technology/*S. Bhatt*
Transformation of Mineral Matter During Pulverized-Coal Combustion (RP8005-14)	$65,000 3 months	Massachusetts Institute of Technology/*A. Mehta*
Exploratory Studies of Deterministic Chaos in Fluidized-Bed Combustion (RP8006-25)	$89,000 16 months	Martin Marietta Energy Systems/*J. Stallings*
Evaluation of Unique Solar Energy Conversion Concept (RP8007-10)	$85,300 12 months	University of Lowell Research Foundation/*T. Peterson*

Generation & Storage

Project	Funding/Duration	Contractor/EPRI Project Manager
On-line Carbon-in-Ash Measurement (RP1893-17)	$55,000 15 months	GAI Consultants/*D. Broske*
Combustion Turbine Plant Reliability Guide (RP2989-6)	$194,100 12 months	Science Applications International Corp./*R. Frischmuth*
Midwest Ore Coal Desulfurization Technology Pilot Plant Design and Costing (RP3027-5)	$75,000 5 months	Mill Creek Co./*C. Kulik*
Gas Turbine Knowledge Base Planning, Conversion, and Evaluation (RP3031-13)	$194,800 12 months	Anderson Consulting Engineers/*G. Quentin*
Operability of Atmospheric Fluidized-Bed Combustion Boilers (RP3162-3)	$98,600 7 months	Combustion Systems/*T. Boyd*
Testing and Materials Support for High-Concentration-Photovoltaics Program (RP3256-1)	$73,200 7 months	Daedalus Associates/*F. Dostalek*
CAES Efficiency Improvement and NO_x Emission Reduction (RP3268-1)	$155,000 18 months	Energy Storage & Power Consultants/*R. Pollak*
CAES Concepts With Air Saturation and Other Configurations (RP3268-2)	$135,000 18 months	Energy Storage & Power Consultants/*R. Pollak*

Integrated Energy Systems

Project	Funding/Duration	Contractor/EPRI Project Manager
Potential Effects of Climate Change on Electric Utilities (RP3236-11)	$75,000 16 months	ICF Incorporated/*C. Clark*
Fuel Supply Business Strategies (RP3344-24)	$125,100 17 months	Applied Decision Analysis/*S. Chapel*

Nuclear Power

Project	Funding/Duration	Contractor/EPRI Project Manager
IPROM Phase 2 Development (RP3175-6)	$179,900 15 months	Decision Design/*S. Tagart*
Instrument Modeling and Survivability Database for Severe-Accident Condition (RP3183-1)	$75,300 7 months	Grove Engineering/*J. Chao*
Supporting Research for Advanced LWR Requirements Document and Small-Plant Conceptual Designs (RP3260-23)	$150,000 24 months	Massachusetts Institute of Technology/*C. Welty*
Determination of Temperature Limits for Dry Storage of Spent Nuclear Fuel (RP3290-3)	$110,000 7 months	Brookhaven National Laboratory/*R. Lambert*
Joining Technology for Borated Stainless Steels (RP3290-4)	$218,400 39 months	Engineering Resources/*R. Lambert*
Hydrogen Water Chemistry Verification (RPC101-23)	$85,000 12 months	Aptech Engineering Services/*L. Nelson*
Field Chemistry at Byron and Braidwood Nuclear Power Plants (RPS416-3)	$111,800 13 months	NWT Corp./*P. Millet*

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 and affiliates. Reports will be provided to nonmember U.S. utilities only upon purchase of a license, the price of which will be equal to the price of EPRI membership. Others pay the listed price or, in some cases (when noted), must enter into a licensing agreement.

CUSTOMER SYSTEMS

Regulating Vacuum Pump Speed With Feedback Control
TR-100173 Final Report (RP2782-4); $200
Contractors: Cornell University, National Food and Energy Council
EPRI Project Managers: A. Amarnath, O. Zimmerman

Solid-State Speed Controllers for Single-Phase Capacitor Motors
TR-100174 Final Report (RP2782-4); $200
Contractors: Kansas State University; National Food and Energy Council
EPRI Project Managers: A. Amarnath, O. Zimmerman

Performance of Microprocessor Controllers
TR-100175 Final Report (RP2782-4); $200
Contractors: University of Kentucky; National Food and Energy Council
EPRI Project Managers: A. Amarnath, O. Zimmerman

Delivering Customer Value: The Application of Quality Function Deployment to Demand-Side Management
TR-100239 Final Report (RP2671-8); $200
Contractor: Putnam, Hayes & Bartlett, Inc.
EPRI Project Managers: T. Henneberger, P. Hanser

Proceedings: Electricity Use and the Environment
TR-100254 Proceedings (RP1940-24); $200
Contractor: Decision Focus, Inc.
EPRI Project Manager: P. Hanser

1991 Survey of Commercial-Sector Demand-Side Management Programs
TR-100329 Final Report (RP2884-2); $200
Contractor: Plexus Research, Inc.
EPRI Project Manager: P. Meagher

Evolution of DSM: A Utility Segmentation Framework
TR-100344 Final Report (RP3084-11); $200
Contractor: Charles River Associates, Inc.
EPRI Project Manager: V. Rabl

Demand-Side Management Implementation Guidelines
TR-100349 Final Report (RP2548-1); $200
Contractor: XENERGY, Inc.
EPRI Project Manager: P. Meagher

ELECTRICAL SYSTEMS

Reliability-Based Foundation Design for Transmission Line Structures, Vol. 4: Transformation Models for In-Situ Tests
EL-5507 Final Report (RP1493-4); $200
Contractor: Cornell University
EPRI Project Manager: V. Longo

TLWorkstation™ Code, Version 2.0, Vol. 24: ETADS Example Problem Catalog
EL-6420 Computer Code Manual (RP2016-3); $200
Contractor: Sverdrup Technology, Inc.
EPRI Project Manager: P. Lyons

Characteristics of Lightning Surges on Distribution Lines: Second Phase
TR-100218 Final Report (RP2542-1); $200
Contractor: Power Technologies, Inc.
EPRI Project Manager: V. Longo

Experimental Investigation of the Uplift Behavior of Spread Foundations in Cohesionless Soil
TR-100220 Final Report (RP1493-4); $200
Contractor: Cornell University
EPRI Project Manager: V. Longo

Experimental Study of Undrained Lateral and Moment Behavior of Drilled Shafts During Static and Cyclic Loading
TR-100221 Final Report (RP1493-4); $200
Contractor: Cornell University
EPRI Project Manager: V. Longo

Experimental Study of Drained Lateral and Moment Behavior of Drilled Shafts During Static and Cyclic Loading
TR-100223 Final Report (RP1493-4); $200
Contractor: Cornell University
EPRI Project Manager: V. Longo

Development of Optimized DC Station Post Insulators
TR-100267 Final Report (RP2472-3); $200
Contractor: High-Voltage Transmission Research Center
EPRI Project Manager: J. Hall

Acoustic Intensity Measurement of Transformers
TR-100300 Final Report (RP2115-18); $200
Contractor: Westinghouse Electric Corp.
EPRI Project Manager: G. Addis

GENERATION & STORAGE

U.S. Bituminous Coal Test Program in the British Gas/Lurgi (BGL) Gasifier
GS-7091 Final Report (RP2525-1); $200
Contractor: British Gas plc
EPRI Project Manager: M. Epstein

Treatment and Testing of Wastewaters and Slags From the British Gas/Lurgi (BGL) Gasifier
GS-7092 Final Report (RP2525-1); $200
Contractors: British Gas plc; Lurgi GmbH
EPRI Project Manager: M. Epstein

Treatability Testing of British Gas/Lurgi (BGL) Coal Gasification Wastewater
GS-7108 Final Report (RP2526-1); $200
Contractors: CH2M Hill; Energy & Environmental Research Center
EPRI Project Manager: M. Epstein

Economic Evaluation of Flue Gas Desulfurization (FGD) Systems, Vol. 2
GS-7193-L Final Report (RP1610-6); license required
Contractor: United Engineers and Constructors, Inc.
EPRI Project Manager: P. Radcliffe

Motor and Generator Insulation Life Estimation, Vols. 1–3
TR-100185 Final Report (RP2577-1); Vols. 1 and 3, $1000 each volume; Vol. 2, license required
Contractor: Ontario Hydro Research Division
EPRI Project Managers: J. Stein, B. Bernstein

Dimethyl Ether Synthesis Process
TR-100246 Final Report (RP317-6); license required
Contractor: University of Akron
EPRI Project Manager: C. Kulik

Proceedings: 1990 Fossil Plant Cycling Conference
TR-100253 Proceedings; $200
EPRI Project Managers: D. O'Connor, J. Valverde

Calcium Injection Upstream of an Electrostatic Precipitator and a Fabric Filter for Simultaneous SO_2 and Particulate Removal: Pilot and Bench-Scale Results
TR-100260 Final Report (RP2784-1); $200
Contractor: Fossil Energy Research Corp.
EPRI Project Managers: B. O'Neil, R. Rhudy

Proceedings: 1990 Fuel Oil Utilization Workshop
TR-100309 Proceedings (RP2778-8); $200
Contractor: Carnot
EPRI Project Manager: W. Rovesti

Development of Fuel Oil Management System Software, Phase 1: Tank Management Module
TR-100311 Final Report (RP2947-2, -4); $750
Contractors: Carnot; Kennen Technology
EPRI Project Manager: W. Rovesti

Use of Coal Ash in Highway Pavements: Kansas Demonstration Project
TR-100328 Final Report (RP2422-15); $200
Contractor: Kansas Electric Utilities Research Program
EPRI Project Manager: D. Golden

Development Efforts on Silicon Solar Cells
TR-100403 Final Report (RP790-2); $200
Contractor: Stanford University
EPRI Project Manager: F. Goodman

INTEGRATED ENERGY SYSTEMS

Coal Transportation Risks for Fuel Switching Decisions, Vol. 2: Eastern Rail/ River Network
IE-7118 Final Report (RP3273-7); $200
Contractor: Fieldston Co., Inc.
EPRI Project Manager: J. Platt

Technical Assessment Guide (TAG™), Vol. 3: Fundamentals and Methods—Electricity Supply
TR-100281 Final Report (RP1678); $200
EPRI Project Manager: G. Ramachandran

NUCLEAR POWER

PWR Steam Generator Tube Repair Limits: Technical Support Document for Expansion Zone PWSCC in Roll Transitions (Revision 1)
NP-6864-L, Rev. 1, Final Report (RPS404-12, -15, -18, -19, -21, -24, -32, -37, -90, -92, -93); license required
EPRI Project Manager: L. Williams

Industry Approach to Seismic Severe Accident Policy Implementation
NP-7498 Final Report (RP2722-23); $200
Contractors: Jack R. Benjamin & Associates, Inc.; Yankee Atomic Electric Co.; Risk Engineering, Inc.; Pickard, Lowe and Garrick; MPR Associates, Inc.
EPRI Project Managers: R. Kassawara, C. Stepp

Full-System Decontamination of a BWR Using the LOMI Process
TR-100049, Tier 1, Final Report (RP2296-22); $200
TR-100049, Tier 2, Vols. 1–6, Final Report; $30,000 for set
Contractors: GE Nuclear Energy; Niagara Technical Consultants; PN Services, Inc.
EPRI Project Manager: C. Wood

Evaluation of Main Coolant Pump Shaft Cracking
TR-100154, Tier 1, Final Report (RP2455-24); $200
TR-100154, Tier 2, Final Report; license required
Contractor: Structural Integrity Associates, Inc.
EPRI Project Managers: T. Griesbach, J. Weiss

In-Pile Loop Studies of the Effect of PWR Coolant pH on Corrosion Product Radionuclide Deposition
TR-100156 Final Report (RP2295-4); $500
Contractor: MIT Nuclear Reactor Laboratory
EPRI Project Manager: C. Wood

Proceedings: Main Coolant Pump Workshop, 1991
TR-100299 Proceedings (RP3232-1); $200
Contractor: EPRI Nondestructive Evaluation Center
EPRI Project Manager: J. Weiss

Hydrogen Water Chemistry for BWRs: Materials Behavior
TR-100304 Final Report (RP1930-1); license required
Contractor: GE Nuclear Energy
EPRI Project Managers: J. Nelson, R. Jones

New Computer Software

The Electric Power Software Center (EPSC) provides a single distribution center for computer programs developed by EPRI. The programs are distributed under license to users. EPRI member utilities, in paying their membership fees, prepay all royalties. Nonmember organizations licensing EPRI computer programs are required to pay royalties. For more information about EPSC and licensing arrangements, EPRI member utilities should contact the Electric Power Software Center, Power Computing Co., 1930 Hi Line Drive, Dallas, Texas 75207; (214) 655-8883. Other organizations should contact EPRI's Manager of Licensing, P.O. Box 10412, Palo Alto, California 94303; (415) 855-2866.

CEM Database: Continuous-Emissions-Monitoring Utility and Vendor Databases
Version 1.0 (PC-DOS)
Developer: Engineering-Science, Inc.
EPRI Project Manager: Ruseli Binsol

COMTECH: Commercial Technologies Screening Model
Version 3.0 (PC-DOS)
Developer: Regional Economic Research
EPRI Project Manager: Karl Johnson

DSManager: Demand-Side Management Analysis Software
Version 1.5.5 (PC-DOS)
Developer: Electric Power Software
EPRI Project Manager: Phil Hanser

DSMLINK
Version 6.11 (PC-OS/2)
Developer: Stone & Webster Engineering Corp.
EPRI Project Manager: Rambabu Adapa

EGEAS: Electric Generation Expansion Analysis System
Version 6.12 (IBM-MVS; PC-OS/2)
Developer: Stone & Webster Engineering Corp.
EPRI Project Manager: Rambabu Adapa

ENVIRO: Corona Effects and Electric and Magnetic Field Profiles (TLWorkstation Module)
Version 1.13 (PC-DOS)
Developer: General Electric Co. (High-Voltage Transmission Research Center)
EPRI Project Manager: James Hall

ESCORE: EPRI Steady-State Core Evaluator Code
Version 1B (PC)
Developer: S. Levy, Inc.
EPRI Project Manager: Odelli Ozer

MOONS: Methods of Overlapping Networks Statistics
Version 1.0 (PC-DOS)
Developer: S. Levy, Inc.
EPRI Project Manager: G. S. Srikantiah

PLANETS: Plant Network Simulation Program
Version 1.0 (PC-DOS)
Developer: S. Levy, Inc.
EPRI Project Manager: G. S. Srikantiah

SGA-SGSYS: Substation Grounding Analysis (SGWorkstation Module)
Version 4.5 (PC-DOS)
Developer: Power Computing Co.
EPRI Project Manager: Giora Ben-Yaacov

SGA-SMECC: Substation Maximum Earth Current Computation (SGWorkstation Module)
Version 2.4 (PC-DOS)
Developer: Power Computing Co.
EPRI Project Manager: Giora Ben-Yaacov

SGA-SOMIP: Soil Measurement Interpretation Program (SGWorkstation Module)
Version 2.2 (PC-DOS)
Developer: Power Computing Co.
EPRI Project Manager: Giora Ben-Yaacov

SGWorkstation: System Grounding Workstation
Version 1.2 (PC-DOS)
Developer: Power Computing Co.
EPRI Project Manager: Giora Ben-Yaacov

SHORT/SHLDRTG: Transient Temperature of URD Cables
Version 1.0 (PC-DOS)
Developer: Power Computing Co.
EPRI Project Manager: Giora Ben-Yaacov

SSPS™: Site Screening and Priority-Setting System
Version 1.0 (PC-DOS)
Developer: Decision Focus, Inc.
EPRI Project Manager: Anthony Thrall

STARS: Statistical Transient Analysis by Response Surface
Version 1.0 (PC-DOS)
Developer: S. Levy, Inc.
EPRI Project Manager: G. S. Srikantiah

TOX-RISK: Toxicology Risk Assessment Program
Version 3.1 (PC-DOS)
Developer: Clement International
EPRI Project Manager: Abe Silvers

TRELSS: Transmission Reliability Evaluation for Large-Scale Systems
Version 1.0 (IBM-MVS; Prime-PRIMOS)
Developer: Southern Company Services, Inc.
EPRI Project Manager: Mark Lauby

UPSTUDY/TLOPGR: Upgrading Study/Transmission Line Optimization With Grounding
Version 1.1 (PC-DOS)
Developer: Power Technologies, Inc.
EPRI Project Manager: Richard Kennon

EPRI Events

JULY

6–9
International Conference on Electric Thermal Storage and Thermal Energy Storage
Minneapolis, Minnesota
Contact: Linda Nelson, (415) 855-2127

7–9
2d International Conference on Compressed-Air Energy Storage
San Francisco, California
Contact: Lori Adams, (415) 855-8763

7–9
Workshop on NO_x Controls for Utility Boilers
Boston, Massachusetts
Contact: Pam Turner, (415) 855-2010

14–15
Retaining Ring Life Assessment Computer Code
Palo Alto, California
Contact: Jan Stein, (415) 855-2390

19–22
EPRI-ASME Radwaste Workshop
Boulder, Colorado
Contact: Carol Hornibrook, (415) 855-2022

20–21
Demand-Side Management Training Workshop
Washington, D.C.
Contact: Matt Haakenstad, (612) 473-1303

20–22
COMTECH and COOLAID Training Workshop
Dallas, Texas
Contact: Karl Johnson, (415) 855-2183

21–23
Conference on the Management of Magnetic Fields in the Utility Workplace
Palo Alto, California
Contact: Gil Addis, (415) 855-2286

21–23
Predictive Maintenance Program: Development and Implementation
Eddystone, Pennsylvania
Contact: Mike Robinson, (215) 595-8876

23–24
Low-Level Waste Management Seminar
Boulder, Colorado
Contact: Carol Hornibrook, (415) 855-2022

23–24
Micro-AXCESS Training Workshop
Dallas, Texas
Contact: Karl Johnson, (415) 855-2183

28–29
FGDPRISM Training Workshop
Austin, Texas
Contact: Rob Moser, (415) 855-2277

AUGUST

3–6
Check Valve Applications, Maintenance, Monitoring, and Diagnostics
Eddystone, Pennsylvania
Contact: Joe Weiss, (415) 855-2751

5–6
Plant Monitoring Workstation Users Group Meeting
Denver, Colorado
Contact: Dominic Maratukulam, (415) 855-7974

6–7
Engineering Approaches to Residential and Commercial DSM Program Impact Estimation
Denver, Colorado
Contact: Jean Ciallella or Lorna Smith, (510) 987-8141

9–14
Wholesale Power Marketing Workshop
Chicago, Illinois
Contact: Scott Rost, (415) 855-1089

10–13
Computer-Assisted NDE and Plant Monitoring Workshop
Philadelphia, Pennsylvania
Contact: Mike Avioli, (415) 855-2527

11–13
4th Symposium on Valve Technology
Dallas, Texas
Contact: Jean Carpenter, (704) 547-6141

11–14
Transformer Performance, Monitoring, and Diagnostics
Eddystone, Pennsylvania
Contact: Stan Lindgren, (415) 855-2308

18–19
Effective Scram Reduction Techniques Related to Instrumentation and Control Activities
Eddystone, Pennsylvania
Contact: Richard Colsher, (215) 595-8870

25–26
Workshop on Optical Sensing in Utility Applications
Philadelphia, Pennsylvania
Contact: Linda Nelson, (415) 855-2127

25–27
3d International Conference on the Effects of Coal Quality on Power Plants
San Diego, California
Contact: Susan Bisetti, (415) 855-7919

31–September 3
Training Course on Determining Probable Maximum Precipitation
Denver, Colorado
Contact: Doug Morris, (415) 855-2924

SEPTEMBER

2–4
PEAC Training Course on Power Quality
Knoxville, Tennessee
Contact: Marek Samotyj, (415) 855-2980

3–4
13th Annual EPRI NDE Information Meeting
Seattle, Washington
Contact: Mike Avioli, (415) 855-2527

10–11
Electromagnetic Interference and Effects on Digital Computers
Baltimore, Maryland
Contact: Susan Bisetti, (415) 855-7919

13–16
International Conference on Avian Interactions With Utility Structures
Miami, Florida
Contact: John Huckabee, (415) 855-2589

15–16
Fluid Systems Testing and Analysis Forum
Boston, Massachusetts
Contact: Jong Kim, (415) 855-2671

15–17
Boiler Tube Failures: Correction, Prevention, and Control
Eddystone, Pennsylvania
Contact: John Niemkiewicz, (215) 595-8871

17–18
Training Workshop on the Measurement of Power System Magnetic Fields
Lenox, Massachusetts
Contact: Hazel Mazza, (413) 494-4356

21–23
5th Incipient Failure Detection Conference
Knoxville, Tennessee
Contact: Lori Adams, (415) 855-8763

23–25
Application of Fluidized-Bed Combustion Technology for Power Generation
Cambridge, Massachusetts
Contact: Linda Nelson, (415) 855-2127

28–30
Power Quality Conference: End-Use Applications and Perspectives
Atlanta, Georgia
Contact: Marek Samotyj, (415) 855-2980

29–30
Distributed Generation: Assessing High-Value Utility Applications
New Orleans, Louisiana
Contact: Dan Rastler, (415) 855-2521

29–October 2
Basic Vibration Testing and Analysis Course
Eddystone, Pennsylvania
Contact: Robert Frank, (215) 595-8872

OCTOBER

14–16
Feedwater Heater Technology Symposium
Birmingham, Alabama
Contact: Lori Adams, (415) 855-8763

19–23
Comprehensive DSM Program Evaluation Workshop
Palm Beach, Florida
Contact: Jean Ciallella or Lorna Smith, (510) 987-8141

21–23
Coal Gasification Power Plants
San Francisco, California
Contact: Linda Nelson, (415) 855-2127

21–23
Fuel Supply Seminar
Cambridge, Massachusetts
Contact: Susan Bisetti, (415) 855-7919

21–23
National Electric Vehicle Infrastructure Conference
San Francisco, California
Contact: Pam Turner, (415) 855-2010

27–28
Defining User Requirements for On-line Dynamic Security Assessment
San Francisco, California
Contact: Gerry Cauley, (415) 855-2832

29–30
FGDPRISM Training Workshop
Austin, Texas
Contact: Rob Moser, (415) 855-2277

29–30
System Voltage Stability/Security Analysis Seminar
San Francisco, California
Contact: Dominic Maratukulam, (415) 855-7974

NOVEMBER

4–6
Utility Strategic Asset Management Conference (call for papers)
Cambridge, Massachusetts
Contact: Lori Adams, (415) 855-8763

11–12
NSAC–Operational Reactor Safety Engineering and Review Group Workshop
New Orleans, Louisiana
Contact: Linda Nelson, (415) 855-2127

10–12
PEAC Training Course on Power Quality
Knoxville, Tennessee
Contact: Marek Samotyj, (415) 855-2980

17–19
AIRPOL '92 International Seminar: Solving Corrosion Problems in Air Pollution Control Equipment (call for papers)
Orlando, Florida
Contact: Paul Radcliffe, (415) 855-2720

17–19
Heat Rate Improvement Conference
Birmingham, Alabama
Contact: Pam Turner, (415) 855-2010

17–19
ROBAL Computer Code for Rotating Machinery Balancing
Eddystone, Pennsylvania
Contact: Tom McCloskey, (415) 855-2655

17–20
EPRI-EUMRC Market Research Symposium
Dallas, Texas
Contact: Susan Bisetti, (415) 855-7919

DECEMBER

2–4
Noncombustion Waste Seminar
Orlando, Florida
Contact: Susan Bisetti, (415) 855-7919

9–11
1992 Advanced Computer Technology Conference
Scottsdale, Arizona
Contact: Pam Turner, (415) 855-2010

FEBRUARY 1993

3–5
Coal-Handling Systems: State of the Future (call for papers)
Pensacola, Florida
Contact: Barbara Arnold, (412) 479-6012

17–19
Foodservice Symposium
New Orleans, Louisiana
Contact: Susan Bisetti, (415) 855-7919

MARCH

1–3
International Symposium on Improved Technology for Fossil Power Plants: New and Retrofit Applications (call for papers)
Washington, D.C.
Contact: Lori Adams, (415) 855-8763

Contributors


Stringer


Kim


Lauby


Stallings


Lewis


Malcolm


Banerjee


Fri

Seeking Order in Chaos (page 4) was written by science writer John Douglas with assistance from a number of experts from across the Institute.

John Stringer came to EPRI in 1977 and has served in several positions related to materials science. In 1991 he was appointed Director of Applied Research for the Office of Exploratory & Applied Research. Before joining EPRI, he headed the Department of Metallurgy and Materials Science at the University of Liverpool, England, where he had also taught from 1957 to 1963. From 1963 to 1966, he worked for Battelle Memorial Institute as a fellow in the Metal Science Group. Stringer holds three degrees from the University of Liverpool —a BS in engineering, a PhD in metallurgy, and a doctorate of engineering.

Jong Kim manages reliability and safety research in EPRI's Nuclear Safety Department and has also been involved with the Office of Exploratory & Applied Research as the technical leader for work in fluid mechanics and heat transfer. Before joining the Institute in 1980, he spent three years as a senior engineer with General Electric. Earlier he did research at Brookhaven National Laboratory and the Applied Research Laboratory at Pennsylvania State University. Kim received a BS in mechanical engineering from Seoul National University and MS degrees from the University of Missouri (mechanical engineering) and Stanford University (applied physics). He holds a PhD in mechanical engineering from the California Institute of Technology.

Mark Lauby recently became technology applications manager for the Electrical Systems Division, having served as a project manager in the Power System Planning & Operations Program since joining the Institute in 1987. Previously he spent eight years with the Mid-Continent Area Power Pool in Minneapolis. Lauby holds BS and MS degrees in electrical engineering from the University of Minnesota.

Jeff Stallings manages research on air quality and emissions control for EPRI's Environment Division and is also involved in exploratory work on fluidized-bed combustion. Before joining the Institute in 1988, he worked on FBC projects at Science Applications International Corporation and SRI International for three and six years, respectively. He was earlier employed by Energy Incorporated and the National Center for Resource Recovery. Stallings earned a BSE in chemical engineering from Princeton University, an MA in international studies from Johns Hopkins University, and an MBA in finance from the University of California at Berkeley. ■

The Challenge of Global Sustainability (page 14) was adapted from an address given by **Robert Fri** at the Electricity Beyond 2000 forum, held in October 1991 under the sponsorship of EPRI and the International Electric Research Exchange.

Since 1986, Fri has been president of Resources for the Future, a nonprofit research organization that conducts independent research and policy analysis on issues affecting natural resources and environmental quality. Previously he headed his own energy project development company and for a number of years was a principal of McKinsey and Company. Fri was deputy administrator at the Environmental Protection Agency from 1971 to 1973, and he held the same position at the Energy Research and Development Administration from 1975 to 1977. In these positions, he served for extended periods as acting head at both agencies. Currently chairman of EPRI's Advisory Council, Fri also serves on the President's Commission on Environmental Quality and the Secretary of Energy's Advisory Board. He holds a BS in physics from Rice University and also an MBA from the Harvard Business School. ■

Introducing the Customer Assistance Center (page 18) was written by Leslie Lamarre, *Journal* senior feature writer, with information from **Larry Lewis,** the center's manager.

Before taking on his position with the Customer Assistance Center, Lewis was the manager of the Customer Systems Division's Market Assessment Program. He came to the Institute in 1986 from Applied Management Sciences, where he was director of utility market planning. Before that, he was a manager of energy research at Battelle Memorial Institute. His earlier experience includes 14 years in rate and market research with Consumers Power Company. Lewis holds two degrees in economics—a BS from Indiana University and an MA from the University of Michigan. ■

Advanced Motors Promise Top Performance (page 24) was written by John Douglas, assisted by two members of EPRI's Customer Systems Division.

Wade Malcolm has been manager of the Power Electronics & Controls Program since July of last year. Earlier he was a project manager in the Distribution Program of the Electrical Systems Division, on loan from Philadelphia Electric Company. At that utility, 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.

B. Ben Banerjee, manager for power conditioning and intelligent motion, joined EPRI in 1985 as a senior project manager in the Industrial Program and moved to the Power Electronics & Controls Program in 1989. Before coming to the Institute, he was engineering manager for Square D Company. Banerjee holds a BS in electrical engineering from the University of Calcutta and an MS in the same field from the University of South Carolina. ■

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