The Electric Smart House

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Cover: The Electric Smart House in Stone Mountain, Georgia, is a showcase for advances in integrated home automation.

The Intelligent Home: Enhancing the Value of Electricity

Ever since the first central electricity station supplied power to incandescent lamps in the late nineteenth century, electricity has been steadily improving our quality of life in the home. Over the years, the value of this tremendously versatile energy form has increased directly with advancements in technology. Color televisions, dishwashers, vacuum cleaners, and so many other appliances that have become common in the American household all found new applications for electricity—new ways to capture its potential. The homeowner has benefited through increased comfort and less time spent on menial tasks.

Today, thanks to the microprocessor chip, the electric utility is powering even more sophisticated technologies in the home—technologies as diverse and intelligent as personal computers and self-diagnosing heat pumps. But electricity's potential has not stopped there. Integrated home automation, a relatively new phenomenon, is taking it a giant leap further, establishing a communications network between advanced appliances and systems. The result: a safer, more comfortable and efficient home, perhaps more accurately called the intelligent home, which can help meet the needs of an increasingly complex society.

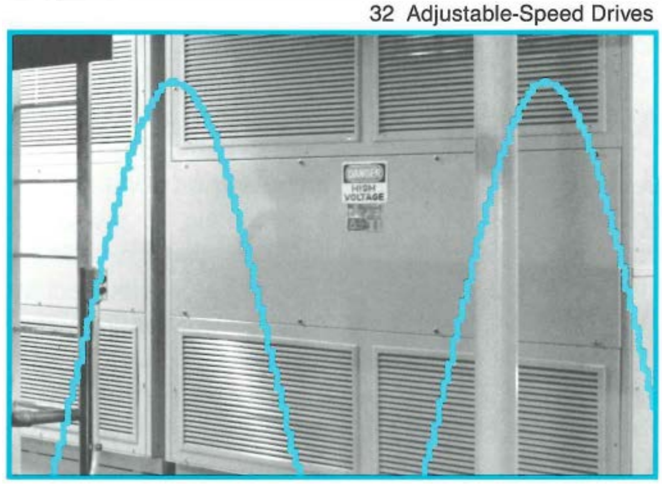
This is precisely what a consortium of electric utilities successfully demonstrated with the Electric Smart House Project. The home, which has been open to the public since early this year, represents but one approach to integrated home automation. Until it is occupied by its first owner in August, utilities are using it to show off the multitude of conveniences electricity can provide the homeowner today. These range from the practical, such as energy and security management, to the luxurious, such as control over "living moods."

The intrahome communications and control network is only one aspect of this approach to integrated home automation. The connections to the outside world—whether to the utility, police and fire departments, or business entities—are just as significant. And to the increasing number of people working from their homes today, these outside connections are critical. The intelligent home's network for internal and external communications will enable even more new technologies to be employed, leveraging the best attributes of electricity.

It's no wonder that 40 electric utilities from across the country joined forces to fund this project. The capabilities of home automation reflect well on our industry. The more our customers value our product, the more efficiently it will be used, the more satisfied the customers will be, and the brighter the electric industry's future becomes. The Electric Smart House Project established a firm utility link to home automation—a link that should remain solid. After all, tomorrow's electric utility will be far more than a generator and deliverer of electricity; it will be the customer's energy service provider.

Clark Gellings, Director
Customer Systems Division

RESEARCH UPDATE



DEPARTMENTS

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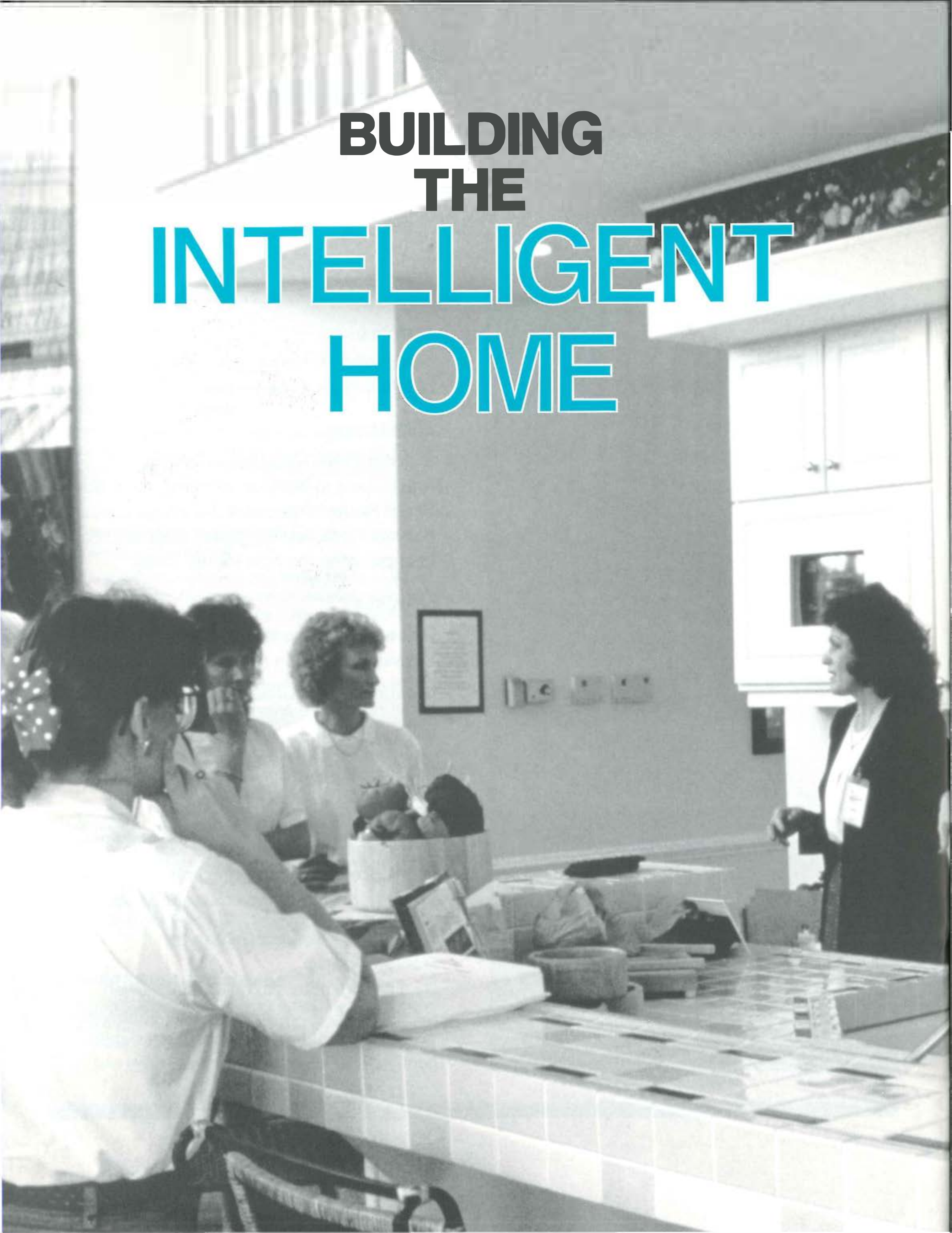
BUILDING THE INTELLIGENT HOME



From the exterior of the Georgian-style house in suburban Atlanta there are subtle hints of its differences, like the bluish-purple hue of the windows in front and the fist-sized propeller-like device out back. But to those who aren't aware that the house is far more intelligent than any of its neighbors in this placid subdivision, it could easily pass as any ordinary upscale single-family home.

This is the Electric Smart House, a 3000-square-foot, two-bedroom illustration of what whole-home automation can offer today. It combines electronic communications and intelligent control with the latest in energy-efficient end-use technology.

The Electric Smart House made its debut in January of this year, when it was toured by nearly 3000 builders attending the National Association of Home Builders (NAHB) annual convention. Since then, it's been leased by Georgia Power Company and Oglethorpe Power Corporation, who are showing it off to the public until the end of July. They've been averaging 900 visitors a week. In August the house will be occupied by its first owner, who will pay about $300,000.

"By joining forces with Oglethorpe on this project, we're showing the public that electricity is the energy of choice," says Joe Pruett, Georgia Power's manager for the Electric Smart House Project. "Only electricity can offer such a variety of sophisticated features. And they're easy to use."

A project of a consortium of electric utilities, the Greater Atlanta chapter of NAHB, and Smart House Limited Partnership (SHLP), the Electric Smart House is a milestone in home automation. It is a comprehensive demonstration of integrated home automation, incorporating a utility communications link. It also represents the first time the Smart House concept has been demonstrated in an actual home. The Smart House concept is the product of a for-profit venture initiated by SHLP. It includes a patented smart wiring system that enables whole-home communication between electrically powered devices.

About 40 electric utilities joined forces to fund the Electric Smart House. The Edison Electric Institute (EEI) managed the construction and public information aspects of the project. EPRI handled the technical aspects. Because of the long lead time required for the development of SHLP's special smart wiring, only a small amount of it was available for demonstration—enough for two rooms. However, EPRI integrated this wiring and other electrical components of the home to provide whole-house automation.

Visitors to the Electric Smart House may have to ask a few questions to find out that it's a low-emissivity metallic coating that gives the front windows their unusual tint. The double-paned, "low-e" windows keep heat out in the summer but let it pass through during the colder months. Though not part of the home's intelligence, they are one aspect of the energy-efficient building shell, contributing toward the house's potential for 50% savings on energy costs. The fist-sized propeller-like device is an anemometer, which measures wind speed. It can be programmed to trigger the retracting of the house's awnings when the wind gets strong enough to damage them.

Inside the house, its differences are slightly more apparent. On the wall immediately to the right of the front door is a brass plate covered with square white buttons bearing words like "ceiling fan," "floor lamp," and "volume up." This plate, which can be operated directly or through an infrared remote control, gives the homeowner access to the house's "smarts." There is one in almost every room. On a wall in the master bedroom there is another indication of the home's differences—a computer screen, framed like a painting. A similar screen is built into a cabinet area in the kitchen. These are touch-controlled screens—the user-friendly interface between the

THE STORY IN BRIEF

An average of 900 visitors a week have come to tour the Electric Smart House in Stone Mountain, Georgia, since it first opened in January. A milestone in home automation, this showcase residence demonstrates a multitude of efficiencies and conveniences that electricity can offer the homeowner today. The house's system integration, provided by EPRI, allows automated control of energy systems, security functions, audio/video options, and other innovations throughout the house. Integrated, whole-home automation, though a relatively new phenomenon, is gaining momentum worldwide in a variety of forms. While market challenges exist, both consumers and suppliers are optimistic about the widespread adoption of whole-home automation systems. Such systems hold clear advantages for utilities as well as homeowners: not only do they represent a potential growth market for electricity, but they also facilitate load management and enhance customer service.

homeowner and the house's electronic brains.

Touch one of these screens and a multicolored main menu will appear, offering a choice of control over features like energy management, security management, audio/video, and "living moods." With another touch of the screen, the home energy management system (HEMS) can show the homeowner, down to the penny, how much electricity the house or each major appliance has used over a given period of time. The security management system will display a floor plan that indicates the status (armed or disarmed) of the house's security zones. The audio/video system will allow a user to play a compact disc by touching a CD icon on the screen and dragging it into a room in the floor plan. The "living moods" application will adjust music, lighting, ceiling fan speed, and other elements to serve the mood selected; options include "romantic evening" and "normal day."

Consumers like it

These are just some of the myriad conveniences that integrated, whole-home automation can offer. Even the most skeptical visitors to the Electric Smart House are at least mildly amused. Most are impressed, to say the least. As one nine-year-old boy told his mother after a tour, "That was cool. I want to live in a house like that."

Frankly, consumers don't exactly need all of these amenities. But then again, they don't exactly need on-screen, remote control for their television sets, programmable microwave ovens, or videocassette recorders. Yet these and numerous other smart electronic gadgets today have become as common to the American home as the vacuum cleaner. This phenomenon is a reflection of a similar trend outside the American home. The personal computer revolution has brought silicon chips into offices, grocery stores, gas stations, and bank teller machines. As consumers become familiar with intelligent technology outside the home, they are increasingly interested in the conveniences this technology can provide inside the home.

To many consumers, the automation of menial household tasks means more time for leisure or more important activities. But practical needs are driving the home automation market too. Our country's population is aging, and the conveniences of whole-home automation offer older folks a number of benefits. For handicapped and special-needs people, home automation can simplify life. Even for people without special needs, there are many practical benefits. A security system tied to local police and fire departments can prevent disaster before it strikes. And the ability to link a smoke detector to the heating, ventilating, and air conditioning system and to lighting controls can, in the event of a fire, clear smoke and illuminate hallways to help occupants find their way out.

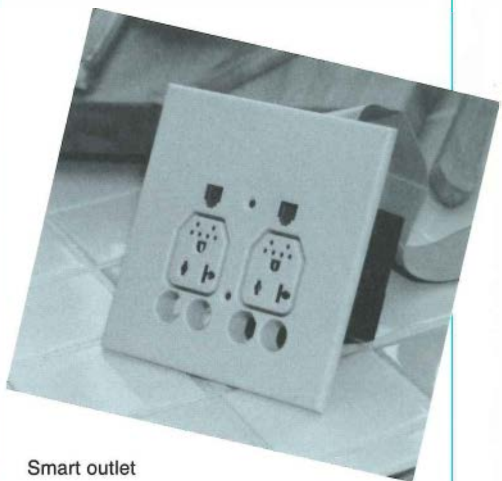
Observers feel that soon the benefit of energy savings also will become a practical driver of home automation. A number of utilities today offer innovative electricity rates, which typically are cheapest at times of lowest demand—during sleeping hours, for instance. Without home automation, residential customers cannot take full advantage of these rates. But a system like EPRI's HEMS allows customers to program high-energy-use appliances to run automatically when electricity rates are cheapest. Homeowners benefit from direct savings. (The sidebar offers more details on the HEMS and other EPRI developments in the Electric Smart House.)

SHLP's venture, initiated by NAHB in 1984 to draw more buyers into the new-home market, is one among many players in a growing, global home automation market that is still in its infancy. According to EGIS, Inc., an international high-tech research and consulting firm, the market for home automation networks and network management processors was about $50 million worldwide in 1988, equivalent to some 20,000 installed systems. EGIS forecasts this market will grow to $3 billion annually by 1998, equivalent to a cumulative 7 million to 10 million installed systems. These figures do not account for partial home automation systems, or subsystems. Subsystems provide a link between two or more products. For instance, an entertainment subsystem could offer control of a television, a VCR, a CD player, and a stereo through one hand-held device.

Subsystems increase the size of the home automation market considerably. A study released this spring by Parks Associates, a market research firm, reports the 1988 market for "high-end" controllers—which include automated whole-house systems and sophisticated subsystems that require installation—was $60 million in the United States alone. By 2000, this industry will exceed $2 billion, the study says. "Low-end" controllers, which can be purchased in retail stores and do not require dealer installation, further increase the size of the home automation market. This category includes products like programmable thermostats and remote controls that can operate more than one device. According to the Parks Associates study, this U.S. market alone was $606 million in 1988 and will reach $1.5 billion in 2000.

Among the countries most actively involved in home automation is Japan. In 1990, 88% of all Japan's new condominiums—the primary mode of housing in the country—were wired according to the nation's home automation standard, notes Karen White, CEO of EGIS. Home automation will also be a significant industry in France, market experts say. The country's national phone company, France Telecom, is expected to be among the biggest drivers. Telecom's Minitel terminals, which provide information, shopping, banking, and other services over the phone line, have been installed in 20% of the country's households. In the future, these terminals are expected to provide remote control of security and other home automation subsystems via the phone line. Since 12% of France's houses are second homes, a healthy demand for these services is anticipated.

In this country, the home automation market has fostered the establishment of groups like the Home Automation Association (HAA), formed in 1988. Market experts estimate there are between 5000 and 8000 whole-house, or integrated, systems installed in U.S. homes today, in addition to countless subsystems.



Smart outlet

According to White, 1500 to 2000 integrated, whole-house systems were installed in 1990, at an average cost of $20,000. Unity Systems, based in Redwood City, California, claimed the largest share of this market. Like the Electric Smart House, this company's product, Home Manager, uses a color touch screen as its standard user interface. White points out that the home automation market is difficult to gauge, because a number of existing home automation systems are not necessarily whole-home systems. In calculating its figures, EGIS considered that three or more subsystems linked together qualified as whole-home automation.

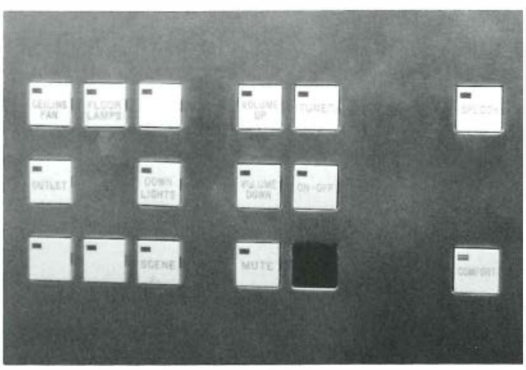
According to Nicholas A. Pyle, executive director of the HAA, a 300-member organization, there are about 25 companies in the United States that now manufacture and distribute home sys-

Wall-to-Wall Intelligence

A comprehensive demonstration of integrated home automation, the Electric Smart House offers centralized control over energy-using appliances and systems housewide. Users can access the house's electronic smarts either through wall plates available in almost every room or through the touch-controlled screens in the master bedroom and kitchen. The house employs the latest in energy-efficient end-use technology, such as the HydroTech heat pump and General Electric's induction cooktop.

Family room

Induction cooktop



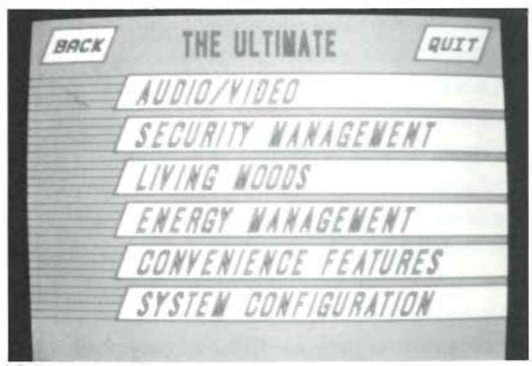
Wall plate

Entry hall

Living room

Home office

Kitchen



Touch screen's main menu

Touch screen
in master bedroom

tems that integrate at least three subsystems. X-10, Inc., based in Northvale, New Jersey, was one of the first to get such products on the market. As a result, the company's line of home control modules and controllers, which communicate by power line carrier, have set a de facto standard for power line communication in the home.

Communication is key

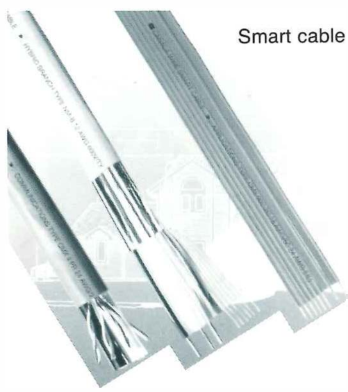
With so many different players in the markets for intelligent appliances and home automation systems, there has been a proliferation of gadgets that cannot communicate with one another. One simple example is that consumers typically need one remote control for their television set and another for their VCR. Getting a group of different appliances to work together is no simple task. Not only do they have to be intelligent, but they have to speak the same language. In technical terms, they must rely on the same communications protocol. Protocols offer a standard specification for passing messages between appliances.

One key element of the Smart House venture has been to establish protocols for communication through all kinds of media, such as infrared light waves, radio frequency, and coaxial (television) cable. Since Smart House is a for-profit venture, the protocols are proprietary. This means that a manufacturer who wants to participate must sign a research and licensing (R&L) agreement, committing to the development of particular technologies and the prepayment of royalties to SHLP. In exchange, the manufacturer gets access to the proprietary protocols, which will enable its appliances to communicate with appliances of other manufacturers via the patented smart wiring system. So far 23 manufacturers, including AT&T, Westinghouse, Pioneer Electronics, Carrier, and Lennox Industries, have signed R&L agreements.

Other home automation projects are also focusing on developing protocols for communication between appliances

Three Approaches to Integrated Intelligence

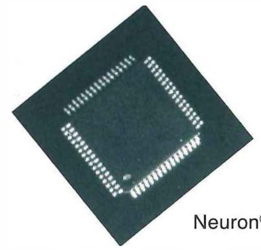
Smart House Limited Partnership (SHLP), the Consumer Electronics Bus (CEBus) Committee, and Echelon Corporation are taking different approaches to integrated home automation. With SHLP's approach, the brain power lies behind the walls. A patented three-cable wiring system delivers both power and control signals housewide; a system controller coordinates and distributes all communication signals that flow through the wiring system. Smart



Smart cable

outlets accommodate "dumb" appliances as well as intelligent appliances containing microprocessor chips. However, automated control of conventional appliances is limited to turning them on and off.

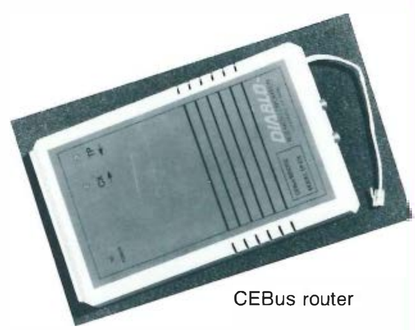
Both CEBus's and Echelon's approaches use existing conventional wiring in homes and build the brain power, including control and communication capabilities, into the products themselves. A homeowner can expand these capabilities gradually, as products are added one at a time. Neither approach requires a system controller. While the CEBus effort is



Neuron® chip

aimed at establishing standard protocols for communication, Echelon has actually developed a technology, called LonWorks,™ to allow products of different manufacturers to work together. Central to this technology is the Neuron® chip, which contains a communications protocol.

Manufacturers participating in the CEBus effort are expected to develop chips that provide similar controls. One prototype CEBus product, called a router, converts control messages from one type of medium to another. For example, an infrared signal from a



CEBus router

hand-held remote control unit could be converted to a power line signal to dim a light.

Among the more widely known is the Electronics Industry Association's effort to establish what it calls the Consumer Electronics Bus (CEBus) standard. Unlike the Smart House protocols, CEBus is an open standard, which means manufacturers can gain access to it free of charge. The protocols under development are based on the Open Systems Interconnection (OSI) model established for computer and telecommunications users. While CEBus provides protocols for communication, it does not design the technology required to run the protocols. That responsibility is left to manufacturers.

The CEBus effort, which is geared toward the existing-home market, began eight years ago as an attempt to reduce the number of remote controls required to run a household's entertainment devices. Today the project aims to incorporate all electric devices found in homes, from washing machines to security systems. The CEBus concept relies heavily on the existing power wiring in a home. To attain full capability of an automated system, coaxial cable for audio and video communications and twisted-pair wiring for telephone or data communications would have to be installed in rooms where those services are desired.

Like the Smart House venture, CEBus has the support of major manufacturers, including Zenith, RCA, Sony, and General Electric. Some, like AT&T, have a foot in both camps. Don Pezzolo, president of Diablo Research, a product development firm in Sunnyvale, California, involved in the CEBus effort, believes CEBus and Smart House may not necessarily be competitors. He expects that CEBus products will eventually be used in Smart Houses, once an electronic interpreter has been developed to enable the two systems to interact. The CEBus committee is still waiting for full approval on standards for all of its communications media. Two of them—radio frequency and coaxial cable—are still in the engineering phase of development. According to Pezzolo, the goal is to have all standards released by the end of the year. He predicts the first CEBus products will hit the market sometime in 1992.

Yet another major effort to establish protocols for communication is that of Echelon Corporation in Palo Alto, California. A three-year-old firm with about 100 employees, Echelon was founded specifically to develop a new technology that would allow electronic devices of various manufacturers to communicate and cooperate with one another. Last December, Echelon announced the availability of its LonWorks™ technology, which includes a chip containing a protocol, transceivers for communication, and tools to help manufacturers incorporate all of this technology into their products. Echelon's local operating network technology, called a LON, does not require a central controller, as does the Smart House system. Rather—as with the CEBus concept—control capabilities are distributed among products.

Echelon's effort reaches well beyond products for the home. Its chips are expected to turn up in offices, factories, and even automobiles. This vast market will drive costs down, says Keith Raffel, Echelon's director of customer support. Currently the chips can be purchased from Motorola and Toshiba for less than $10 each, in quantity. Manufacturers who want to incorporate LonWorks technology into their products must pay a licensing fee but no royalties. Already 16 companies, including AT&T Consumer Products, Lithonia Lighting, and Allen-Bradley, are working with the technology. In time, says Raffel, the home automation market will be substantial. But initially the biggest markets will be in the commercial and industrial sectors.

Utilities benefit too

Regardless of whether Smart House, CEBus, Echelon, or some other entity dominates the market for integrated home automation, electric utilities stand to benefit from any market growth. "Almost all utilities are watching the market very closely and looking at competing technologies," says William R. Coleman, managing director of marketing and customer services at American Electric Power Service Corporation. After all, he says, "Smart House is but one way of doing this."

What's in it for the electric utility? "Not only does whole-home automation enhance the value of electricity for utility customers. It also greatly facilitates electric load management and makes it customer-friendly," says Arvo Lannus, manager of the Residential Program in EPRI's Customer Systems Division. Frankly, integrated home automation allows electricity to flaunt its advantages. "From the electric utility point of view, home automation brings a natural advantage to electricity," says Lannus. "Electricity is a very flexible and sophisticated energy form. It can run your water heater and your computer. Electrons are electrons, and electric machinery like variable-speed motors with electronic controls is easy to integrate into local networks."

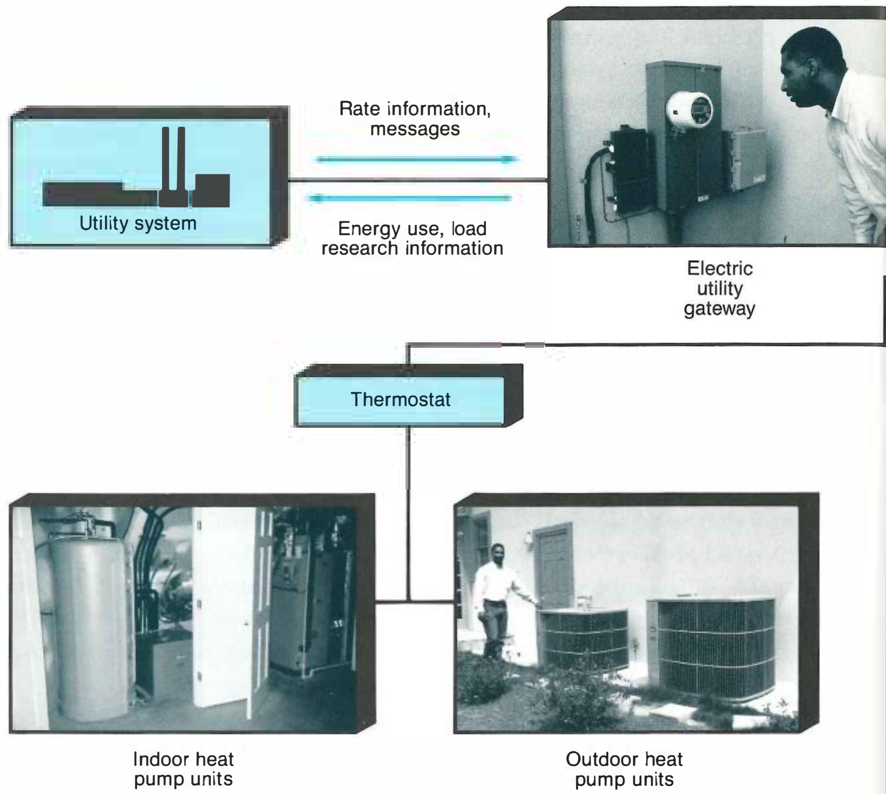
Industry experts say home automation offers a great opportunity for electricity to gain market share. As McGrath of EEI points out, electricity's share of the market for space heating in the residential sector has declined significantly since the early 1980s, while the gas industry's share has steadily increased. For new multifamily homes, electricity's share in 1990 was down to 53% from 70% in 1983. For new single-family homes, its share dropped to 33% from 49% in the same timeframe.

Home automation makes load control much more customer-friendly because the homeowner can choose when and where to control power. For the utility, it removes the financial burden of supplying special equipment, since all the necessary control capabilities are already in the customer's home. In the Electric

EPRI's Hand in the Electri

EPRI played a critical role in the Electric Smart House Project. The Institute provided the home automation system, which controls security, lighting, entertainment, and other subsystems. It also developed key technologies for the home, such as the energy management system and the electric utility gateway. In addition, EPRI was responsible for overall system integration in the house. This integration established and verified communications interfaces between various subsystems to ensure they would work together. Here are some highlights of EPRI's developments.

EPRI's Home Automation Concept



Home energy management system

The HEMS is a significant element of the whole-home automation system in the Electric Smart House. Developed by Custom Command under contract with EPRI, it is a software program that provides control and monitoring capabilities over major energy-using aspects of the house. Its touch screen interface offers a number of menus that allow the homeowner to program the temperature of the three zones in the house. With the help of EPRI's electric utility gateway, the HEMS can give the homeowner information on electricity rates and can even calculate the cost of energy used by the entire home or its individual appliances over a given period of time. By touching a box on the screen, the homeowner can program high-energy-use appliances like the clothes dryer to run when electricity is cheapest. Buttons next to certain appliances allow the homeowner to override the programmed settings. The HEMS is expected to be available on the market as home automation systems are more widely used.

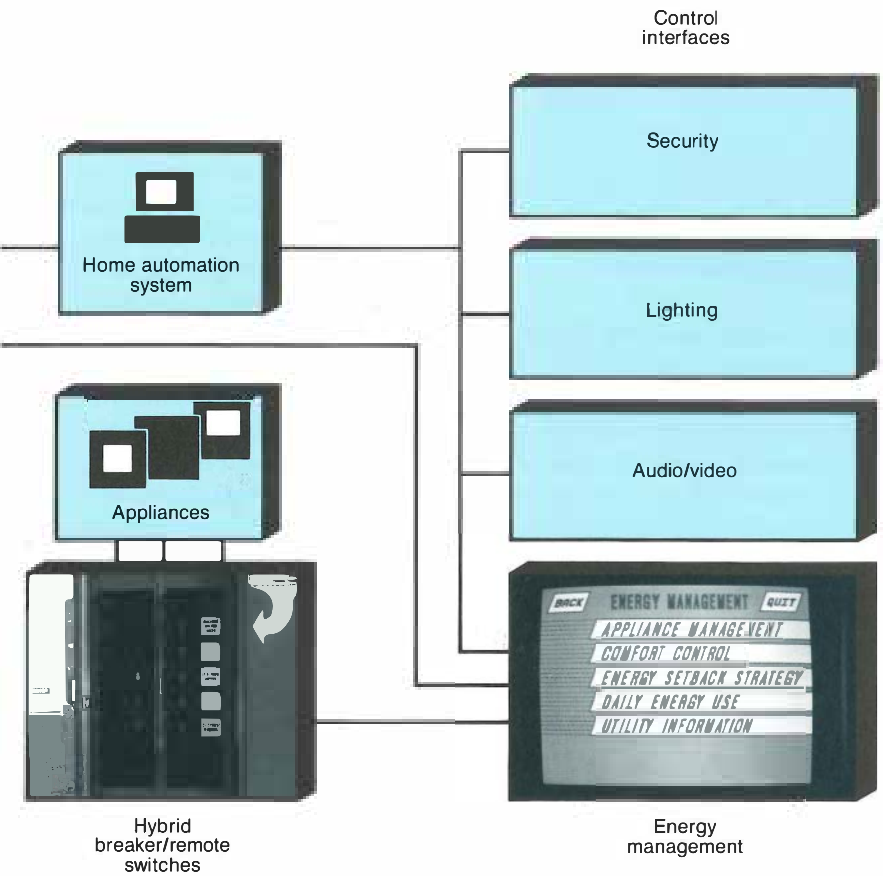
Electric utility gateway

Acting as an interpreter for both the meter and the utility, the gateway translates information it receives from appliances into information the meter and the utility can understand. The customer gets access to this information through the touch screen. The gateway provides remote meter reading capabilities. Every 15 minutes, a load profile is stored locally. This profile indicates how much energy is used by each of the Electric Smart House's six submetered loads: clothes washer, clothes dryer, dishwasher, backup water heater, and two heat pumps. The gateway's utility-customer link is also useful for other types of communication. For instance, a utility can pass on a message to the touch screen to inform the homeowner about tree trimming in the neighborhood. Currently in the prototype phase of development, the gateway is expected to be on the market within four years.

EPRI/Carrier HydroTech 2000

This integrated variable-speed heat pump, developed by EPRI and manufactured by Carrier Corporation, provides heating and cooling as well as hot water, year-round. Introduced to the market in 1989, it is 30% more efficient than conventional models. In fact, it is the most efficient space-conditioning and water-heating system available today, with the lowest operating costs. Its variable-speed

mart House Project



compressor and indoor fan motor allow the system to track indoor temperatures and respond appropriately, saving energy and providing greater comfort. The variable-speed features also allow for dehumidification and gradual startup. These control features eliminate the blast of cool air that results when conventional heat pumps start up on cold winter days. HydroTech 2000 provides the bulk of a home's hot water throughout the year. When the unit is in the cooling mode in the warmer months, it recovers waste heat rejected from the house and uses it to heat water. In the winter months, water is heated from the same warmth the HydroTech extracts from the outside air to heat the house. The unit provides multizone space conditioning through a motorized damper system. In addition, its self-monitoring and diagnostic capabilities can alert homeowners and service technicians to a problem and its cause. Microelectronic controls offer the possibility for utility load management. The HydroTech 2000 is the quietest heat pump on the market today. The outdoor unit generates about one-eighth the noise of a conventional unit. The indoor unit that contains the compressor is as quiet as a refrigerator.

In the Electric Smart House, the HydroTech works together with a second variable-speed heat pump, Carrier's Infinity 2000. The Infinity is a spin-off of HydroTech technology that does not include the water-heating feature. The two heat pumps are linked to the same communications bus, so they can provide the greatest level of comfort in the house's three zones.

Hybrid breaker/remote switch

The HBRS, developed by Matsushita Electric Works under contract with EPRI, is directly interchangeable with most conventional circuit breakers. In addition to the traditional protection offered by ordinary circuit breakers, these switches offer programmable, remote control of 220-volt appliances (e.g., dishwashers and clothes dryers) that run on dedicated circuits in a Smart House and at this time do not have the built-in capability of communicating directly with a home automation system.

In the Electric Smart House, a user can program the HEMS to send electronic signals to an HBRS, telling it to cut off power to a particular appliance when electricity rates are highest and to restore power when rates are cheapest. Other appliances in the home, such as its two heat pumps, are controlled directly through electronic signals sent by the HEMS.

Though not demonstrated in the Electric Smart House, another advantage of the HBRS is that it simplifies direct load control. Without an HBRS, an electrician must install a switch on the circuit supplying power to the appliance that is to be controlled by radio signals from a utility. With an HBRS, the circuit does not have to be broken, because the switch handles the control. Although a receiver is still necessary, it can be installed directly on the HBRS and does not involve rewiring. EPRI expects this advanced switch to be commercially available sometime this year. ■

Smart House, load management is offered through EPRI's home energy management system via the touch screen. Among other functions, the HEMS works with EPRI's electric utility gateway and hybrid breaker/remote switches (HBRSs) to allow the homeowner to program the operation of high-energy-use appliances. A quick glance at one screen can tell the homeowner precisely how much it will cost to run appliances like the dishwasher during the local utility's different rate periods. The customer can select a cheaper or more expensive option simply by touching the screen. The HEMS will store that response and, when the time comes, send an electronic signal to

the HBRS that controls the dishwasher. The HBRS will close a circuit, providing power to the dishwasher.

In the Electric Smart House, information on a four-tiered utility rate is communicated through EPRI's electric utility gateway. Acting as an interpreter for both the meter and the utility, the gateway translates information it receives from appliances into information the meter and the utility can understand. EPRI is working to make the gateway compatible with Utility Communications Architecture (UCA) specifications. Based on the OSI model, UCA-specified protocols developed by EPRI allow the exchange of information between all types of communications systems within a utility, as well as between utilities and external agencies, including customers.

The utility gateway on the Electric Smart House is a prototype. When completed, the gateway will be capable of translating messages from virtually any intelligent appliance in an automated home. It is expected to be available commercially in about four years, says Larry Carmichael, senior project manager in controls technology at EPRI. At the Electric Smart House, the gateway is located in a box beside the home's meter. Ultimately, says Carmichael, the device could be contained within the meter itself.

Utilities are looking forward to taking advantage of the gateway. Amy Houston, Oglethorpe Power's manager for the Electric Smart House Project, notes that two members of Oglethorpe (which is owned by 39 electric membership cooperatives in the state) have time-of-use rates in place. "They feel that the gateway offers a great enhancement over the load management available to our customers today," she says. "We're often in a situation where we're purchasing power, so load management is important to our system."

Pezzolo of Diablo Research is among those who believe that utilities' need for load management will significantly propel market growth. "We think the whole demand-side management equation will actually put a little more push into moving CEBus and other home automation products into the mainstream," he says. While utility involvement could certainly stimulate activity, it won't carry the market alone. Market growth will depend most heavily on the actions of consumers. Appliance manufacturers will also play a crucial role. Whether a significant number of them choose to develop new intelligent devices that can communicate and work together remains to be seen.

Like manufacturers and other players involved in this young, unpredictable market, utilities are cautious at this time. "Some are just waiting to see what happens before establishing programs and committing money to these developments," says Coleman. "Home automation is still an emerging technology."

Getting to market

Those involved in the Smart House venture are optimistic about the market. "This is the first really new thing in housing since air conditioning," says Bill Bryant, treasurer of Southland Development Corporation, which built the Electric Smart House. "I think this is going to be far-reaching." Bryant points out that 30 years ago builders never installed central air conditioning in new homes. "Today," he says, "you wouldn't build a house without it."

Bryant notes that the first homes with central air conditioning were those of upper-income families. At the time, it was viewed as futuristic and a luxury item for the rich. Today, however, central air conditioning has come down significantly in price and is regularly built into even the most affordable new homes on the market. Builders like Bryant forecast a similar transition for the Smart House concept—that the technology will start out in the more expensive homes but will ultimately be incorporated into virtually all new homes on the market. "In the future, 100% of new homes will be smart houses," Bryant predicts. In fact, that is the goal of the Smart House venture.

At this time, cost may be somewhat of a barrier to the market for just about any whole-home automation system. A core system alone typically costs at least $10,000. The core Smart House system, which includes the smart wiring and outlets and the system controller but not the touch screen, will add about $8600 to the cost of a 2500-square-foot home. This does not include the cost of intelligent appliances, which the homeowner can choose to add on.

SHLP plans to introduce Smart House systems in two phases over a 21-month period, to 150 metropolitan areas in the United States and Canada. According to Patti Montague, director of communications for SHLP, the first phase will get under way in August of this year, introducing SMART-REDI systems, which include the basic smart wiring and, for homes with gas appliances, flexible gas piping. The second phase is scheduled to begin in March 1992. At that time, SHLP expects to offer a complete operating system for the home, including the system controller and other electronic components required to enable whole-house automation. Builders will have the option of installing SMART-REDI systems, which can later be added to, or the complete, operative Smart House system.

"We're forecasting that by the end of 1992 there will be some 16,000 Smart Houses in the United States," says Montague. "Builders are very excited and are eagerly waiting for Smart House to come to market." But no matter how successful Smart House is, it is not likely to be the only driver of home automation. Its major potential market is about 1 million new homes a year. That compares with an existing-home market of about 100 million. This bigger market is being targeted by CEBus and Echelon, among other entities. In fact, SHLP is also developing a system for existing homes, according to Montague. While she could not offer details on this system, she said it would not involve rewiring behind walls but would include a raceway system that could be installed along baseboards. SHLP's target date to get this system on the market is 1994.

At this stage it's difficult to determine whether all players can be winners on the market. But many observers feel that open protocols do offer some advantages. McGrath of EEI draws an analogy to the personal computer market. Apple Computer, with its proprietary protocols, essentially created this market in the late 1970s. But it wasn't until IBM came out with its PC in 1981 that the market took off. The IBM PC is based on an open architecture that encourages cloning.

Today both IBM and Apple are successful leaders in the market, even

though they have been incompatible, McGrath points out. Similarly, he predicts, "I think it's highly likely that we're going to see significant market penetration by a number of home automation systems, which will probably be incompatible with one another."

While the many players involved in home automation may paint rosy forecasts of the market, success for Smart House and for whole-home automation in general is not going to come easily. There are a number of barriers to overcome. Aside from cost, there is a potential for consumer confusion about different, incompatible systems, and there's a need to inform the many groups involved in the housing market, including technicians who will be hired to service any equipment in need of repair. SHLP already has developed a training program for electricians who will be installing Smart House products. And the partnership is holding seminars to teach builders about the products. Plans also are under way to educate real estate agents, bank officers, salespeople, and others.

Another obstacle is that it simply takes time for new ideas to catch on. "It takes a while for people to get accustomed to something new and different," Pezzolo says. "Even the things that you're familiar with—VCRs, color televisions—if you look at their early few years of life, they didn't take off like a rocket. That's the way these markets go. You get the early adopters—people who always want to have something new and have money to spend, or who may be technically oriented and understand very early on how everything works together." Naturally, like central air conditioning, color televisions, PCs, and other products, whole-home automation systems will come down in price as market penetration increases.

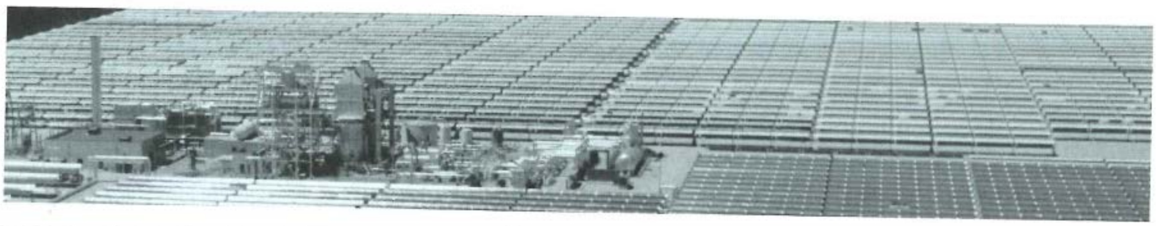
But is the image of widespread adoption of whole-home automation systems just a technological fantasy? McGrath is among those who think not. "I think this is really going to happen," he says. "I'm not terribly sure when, although I'd say we're probably 5 to 10 years from it really beginning to achieve market potential in any significant way. But home automation is definitely a comer."

This optimism reflects the feelings of both consumers and suppliers. But there are skeptics out there too. As one of them argued to McGrath, "I don't even know how to program my VCR. I really don't want to be held hostage by my house." Clearly this offers a challenge to the home automation industry. "These systems have got to be made friendly and easy to use," McGrath says. "For home automation to really take off, it's got to simplify our lives, not make them more complex."

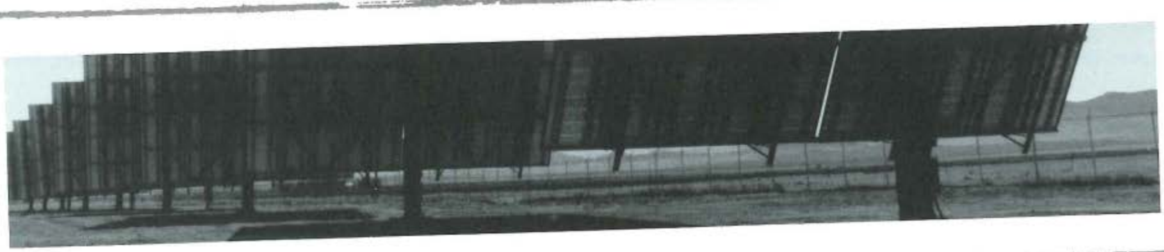
The way Lannus of EPRI views it, this is the utility industry's challenge as well. "Home automation can be the winning difference for electric utilities faced with increasing competition for residential space- and water-heating loads," he says. "And because it enables us to maximize the efficiency at which all systems in a house can be operated, it minimizes the impact of that energy use on the environment. Electric utilities clearly have a vital stake in the future of this technology." ■

This article was written by Leslie Lamarre. Background information was provided by Arvo Lannus and Larry Carmichael, Customer Systems Division.

RENEWABLES



ON THE RISE



Renewables are back on the nation's energy agenda. There are more bills in Congress promoting the use of renewable resources than ever before, and public interest is extremely high. While energy security, which provided the main push for renewables in the 1970s, is still an important concern, the interest in these technologies today is more sharply focused on their environmental advantages. Increased attention to the environmental impacts of fossil fuel use has, in effect, highlighted renewables' inherent "natural" appeal.

But even if the interest is clearly here, are we technologically equipped to put renewable energy to work on a commercial scale? Researchers and a growing contingent of private companies are saying yes. The decade of the eighties was one of significant progress in alternative energy R&D, and steady improvements in efficiency and costs have brought a number of renewable energy technologies to the threshold of commercial viability. A new generation of wind machines is producing bulk power reliably and competitively in favorable locations. Photovoltaic systems have become established as a cost-effective source of power in remote locations and will soon begin to compete for some grid-connected applications. Biomass energy has received a boost from the increasing disposal costs for municipal and wood wastes, which have stimulated the waste-to-energy business. Genetically improved strains of plants, innovatively harvested, will become a clean fuel for existing and new power plants. Meanwhile, the development of sophisticated power electronics and energy storage systems will facilitate the integration of intermittent or highly variable power sources into utility systems.

For many years, a key assumption about the commercialization of electric power technologies has been that the process is a linear one: research → development → pilot → demonstration → deployment. In the case of renewable energy,

THE STORY IN BRIEF

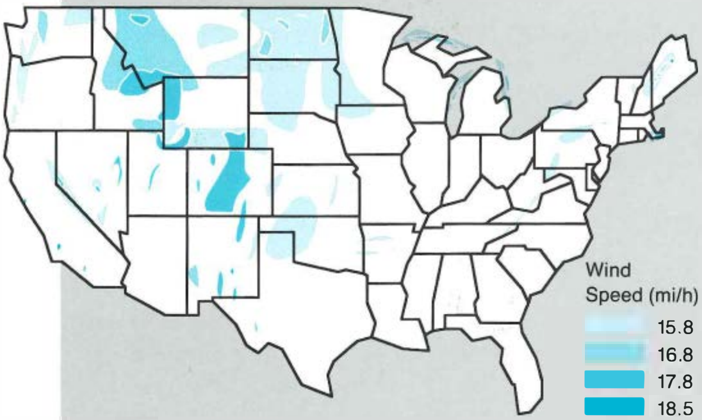
Increased attention to the environmental aspects of power generation has boosted interest in renewable energy options to its highest level since the energy crises of the 1970s. In the past, work centered almost entirely around a technological push, with development of ever-larger equipment to achieve economies of scale. Today, while technical advancement continues, the emphasis has shifted to the marketplace—getting the technology into the field and nurturing markets in locations where existing renewable technology can be economically competitive. Spurred by efficiency improvements of the past decade, several options have already been able to find such market niches—wind and solar technologies in particular. The evolution of these markets should broaden the scope for all renewable applications: government research indicates that renewables could be contributing between 28% and 40% of U.S. energy supply by the year 2030, with biomass by far the largest source.

Renewables for the Nation

The potential of renewable energy has often been seen as tightly restricted to the few sites that offer the very best resources. Today individual renewable options still tend to be regionally defined, but technology advances will expand practical applications into medium-grade resource areas—and to far more of the country than was thought possible a decade ago.

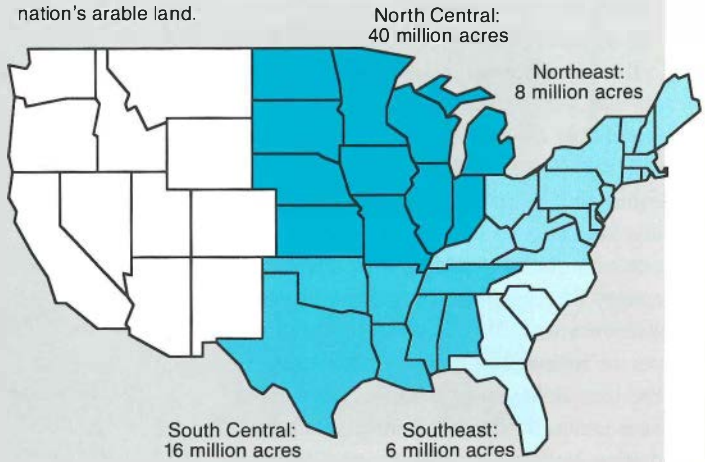
Wind

The midwestern states extending from North Dakota and Montana down to New Mexico have much greater wind generation potential than the few California sites developed to date. The ability to back up a good intermittent wind resource with plentiful hydro makes the Northwest look promising as well.



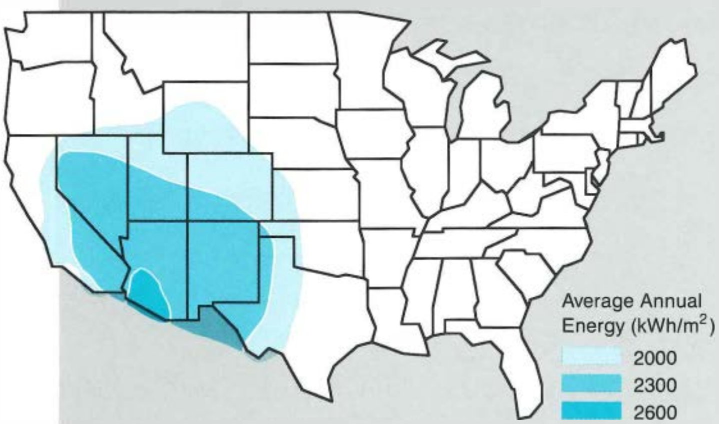
Biomass

The Midwest is ideal for growing short-rotation woody crops and other combustible vegetation, which could be planted on land that is idle or has only marginal value for growing food. The total U.S. energy crop potential is some 70 million acres—almost 18% of the nation's arable land.



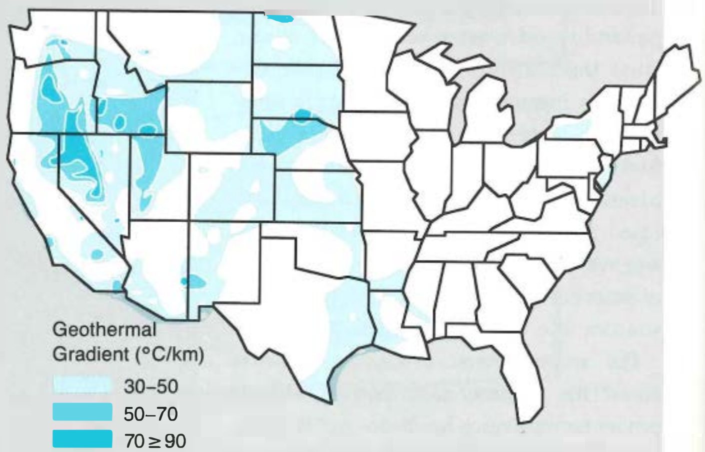
Solar

The desert regions of the United States hold the obvious first opportunities for significant penetration of solar technologies, although photovoltaics can be economic for remote low-power applications in virtually all parts of the country.



Geothermal

While most of the land west of the Missouri River is underlain by hydrothermal or hot dry rock resources, geothermal development for the foreseeable future will concentrate on pockets with thermal gradients of at least 70°C/km.



however, a very different pattern is emerging, which involves the evolution of markets as well as of technologies. Rather than engaging in a technology-driven effort to design and demonstrate ever-larger equipment to gain economies of scale, EPRI is working with utilities to emphasize the early application of technologies that can meet a variety of existing high-value needs, achieving "economies of scope." Underlying this market-driven approach to commercialization is the realization that experience with limited, near-term applications of renewables can stimulate technology development for a transition to long-term objectives.

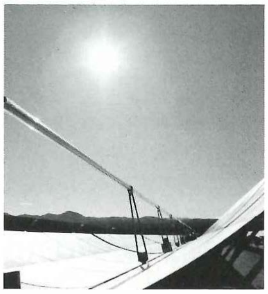
Finally, some utilities are beginning to question basic assumptions about their own business, in ways that could profoundly affect the acceptance of renewable resources by the electric power industry. Especially important is an evolving role for utilities as providers of a service—energy, generated and delivered in whatever form or manner is most cost-effective—rather than simply as operators of large central power stations and a wire-bound electrical delivery system.

Most renewable energy resources are in some sense diffuse. Because relatively large quantities of light, wind, or biomass must be collected to produce significant amounts of energy, these resources have often been used for low-power applications. In some cases the power source is installed on individual customer premises, as with remote photovoltaic applications. In other cases modest-sized generating facilities may be situated close to available resources—for example, placing wind turbines along a mountain pass or siting a biomass facility in an economically depressed area with marginal farmland. Renewable and storage systems can also be located strategically to lower transmission costs and losses or to enhance reliability.

"Utilities need to realize that many renewable energy technologies are already cost-effective for power generation in particular circumstances," says EPRI's James Birk, director for storage and renewables R&D. "The path to full commercial viability for these technologies lies in identifying and exploiting the early markets, then following through as they evolve toward bulk power applications. In addition to continuing technological development, EPRI's role in this area is to help utility members identify emerging opportunities and to catalyze markets through strategic alliances with both vendors and customers."

Renewables potential

Renewable resources now account for about 8% of the total U.S. energy supply. By far the largest components of today's renewable energy supply are hydropower and biomass. By 2030, however, this picture could change substantially. According to a recent government study, the portion of total energy represented by renewable resources will at least double by then, and it could increase more than fivefold under the right circumstances. The importance of solar, wind, and geothermal energy is also expected to increase substantially.



SOME 350 MW OF PARABOLIC TROUGHS HAVE NOW BEEN DEPLOYED, BUT CENTRAL-RECEIVER SYSTEMS MAY ULTIMATELY OFFER THE LOWEST COST FOR SOLAR-THERMAL POWER.

The study, conducted for the U.S. Department of Energy by five of its national laboratories, offers considerable insight into the factors that will affect the development of renewables over the next four decades. The results of the study, published as an Interlaboratory White Paper, *The Potential of Renewable Energy*, are based on three scenarios chosen to highlight the effects of key policy decisions.

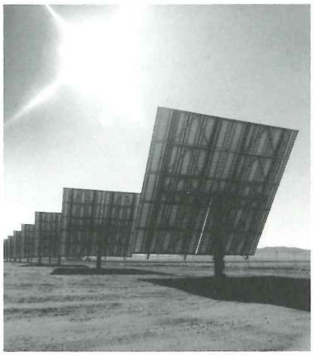
In the first scenario—business as usual—market penetration of renewable energy technologies is left to the forces of competition as they now stand, with research funding remaining at current levels. In the other two scenarios, the narrowing of the break-even cost differential between renewables and conventional generation is accelerated through R&D intensification or by a market-pull incentive. In the latter case, a price premium is placed on the use of clean energy—for example, a 2¢/kWh premium is assumed for generating electricity from clean renewables rather than from fuel combustion. Two cases are considered for each scenario: one in which the contribution of solar and wind energy is limited because of their intermittent nature, and one in which storage technologies help overcome this problem and thus facilitate market penetration.

The numerical results of these scenarios are controversial, but some implications are clear. Under the business-as-usual scenario, renewables are projected to account for 15% of total U.S. energy use in 2030, assuming that intermittent sources are constrained. If energy storage is available to help remove the constraints, the renewable energy contribution is projected to rise to 17%. With a modest increase in well-focused and well-managed RD&D, renewables could account for 28% of total energy with the constraints and could rise to 40% without constraints. The market-pull scenario produces estimates that lie between the other two sets.

One immediately apparent implication of these projections is that as the contribution of intermittent energy sources increases, storage becomes more important. Most of today's grid-connected solar and wind facilities provide power to very large California utilities that can easily absorb the energy from these relatively small, nondispatchable sources into their robust generation mix. In addition, the output of some of these facilities coincides with the seasonal and daily demand peaks of the utilities involved. When intermittent sources of power exceed about 10% of a utility's generating capacity, however, energy storage can prove critical in helping match supply and demand. By 2030, having adequate storage available could double the production of electricity from solar and wind resources. However, the study projects that between now and 2010, storage will not be a prerequisite to penetration by intermittent renewables.

A close examination of the individual resources covered by the Interlaboratory White Paper yields another important insight. Biomass is projected to become by far the largest source of renewable energy. Biomass—including both waste disposal and the use of crops raised for energy production purposes—could account for up to half of the total contribution of renewables by 2030. Whether burned directly to produce heat and electricity or used as raw material to produce premium liquid or gaseous fuels, biomass resources are expected to provide an increasingly attractive alternative to fossil fuels. They can be burned in a way that produces less pollution. Their availability is more secure. And the situations in which they have an economic advantage are expanding rapidly.

Overall, the Interlaboratory White Paper is considerably more optimistic about the future of renewable energy than studies by some other groups, including some within the Department of Energy itself. The recently announced National Energy Strategy (NES), for example, establishes as a working goal a level of development for renewables in 2030 that only comes up to the business-as-usual projections of the interlaboratory group. Like the White Paper, the NES foresees most renewable energy being derived from biomass, but many feel that the government's plan underestimates the overall importance of these options to the energy future. As George Preston, EPRI's vice president for generation and storage, points out, "The National Energy Strategy is almost silent on renewables—solar and wind get particularly short shrift. We may have made a lot of progress in advancing these technologies, but we still have a long way to go in getting decision makers in the utilities and the government to fully appreciate their potential."



UNTIL COSTS DECLINE SUFFICIENTLY FOR ECONOMIC CENTRAL-STATION SYSTEMS, PHOTOVOLTAICS WILL THRIVE IN NICHE MARKETS AND DISPERSED APPLICATIONS.

Without endorsing any particular set of energy projections, EPRI is committed to helping renewable resources fulfill their promising potential: "We need to get renewables beyond the curiosity stage so that they can become an important part of the global energy mix," says Kurt Yeager, senior vice president for technical operations. "That effort requires not only taking advantage of opportunities but also making a strong commitment to change. More cooperative programs are needed among the various agencies sponsoring development of renewable resources, and EPRI intends to be a leader in this effort. The framework for EPRI's leadership strategy and program plan is the enhancement of *both* the technological push and the market pull."

The Green Plan

In pursuit of such long-term goals, which potentially involve collaboration with numerous agencies outside the Institute, EPRI's Storage and Renewables Department is preparing what it calls its Green Plan. The plan will guide EPRI's strategic participation in the development and deployment of renewable energy systems. Its stated purpose is to "provide by 2000 a portfolio of technologies that will give most utilities commercial renewables/storage options that are cost-effective in their own right and are inherently environmentally and socially acceptable." And, over the longer term, the Green Plan seeks to ensure that renewables and storage systems become a major supply-side option for most electric utilities.

The Green Plan encompasses both technology development and market penetration. Primary emphasis is being placed on achieving immediate cost reductions in five areas: wind, biomass, solar thermal, photovoltaics (PV), and geothermal. Specifically, a cost target for favorable locations of about 4–5¢/kWh (constant, levelized 1991 dollars) by 2000 has been set for each of the technologies involved except PV, which is targeted to produce electricity for 6–8¢/kWh.

Achieving these goals by the turn of the century will require aggressive technological development in each area, as well as the nurturing of markets for renewable resources. Through alliances with other funding agencies, utilities, and equipment manufacturers, EPRI's role will be to stimulate a commercial infrastructure for renewable energy technologies and to build user confidence in deploying them. In particular, these alliances can help identify commercial opportunities, ensure the market compatibility of new technologies, and provide incentives for the development of suitable manufacturing processes.

Such a collaborative approach offers perhaps the best solution to the "chicken or egg" problem that has always afflicted the renewable energy market: the high prices of early technology stifle demand, but an investment in mass production to lower prices can't be justified without an ensured demand. Traditionally this problem has been addressed by building increasingly large pilot and demonstration plants. But for renewable energy conversion equipment in dispersed applications to compete with conventional power generation, it must be standardized, factory-assembled equipment that can be easily installed as prefabricated modules. Bringing about this degree of manufacturing efficiency requires closer coordination between groups of potential buyers and sellers than that needed for building large, one-of-a-kind power plants for conventional fuels.

Less certain is how the various parties interested in supporting renewables will be able to address the important institutional barriers that are also hampering their further development. Not all kilowatthours are created equal: some have hidden environmental costs; some depend on insecure fuel supplies; some bear a disproportionate regulatory burden. Renewables are generally attractive in each of these areas of concern, but such potential "external" costs have not yet been fully reflected in the price of electricity from various sources.

"In addition to developing technology and building markets, utilities have to find a way to explicitly take into account environmental and social values," says Brian Thomas, R&D administrator of Puget Sound Power & Light and chairman of EPRI's industry task force on storage and renewables. "During the planning stage of adding new capacity, the external costs associated with each type of generating system need to be considered. If we don't find a way to do this, the government will do it for us. If we can agree on how to account for environmental and social costs during planning, renewables penetration will be substantially accelerated."

THE NORTHWEST AND THE MIDWEST HAVE CONSIDERABLE POTENTIAL FOR GENERATING WIND POWER, EXPECTED TO EVENTUALLY BE THE LEAST EXPENSIVE OF THE RENEWABLE OPTIONS.

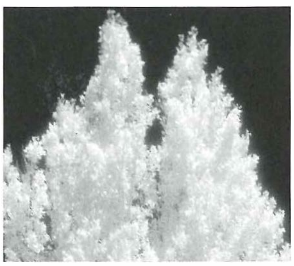
Wind—the first alliance

After a decade of rapid growth, "wind energy has come of age for bulk power generation," declares Ed DeMeo, program manager of EPRI's solar and wind research. "The tax credits that got things started have expired, and now hundreds of new wind turbines are being installed each year on their own economic merit. Our next big step is to broaden utility involvement in more parts of the country. A lot of folks just haven't taken wind seriously yet."

The total wind power generating capacity in the United States now exceeds 1600 MW, with most turbines located along a few mountain passes in California—the result of both favorable financial incentives and reliable wind conditions. Yet the band of midwestern states stretching from North Dakota and Montana to Texas and New Mexico has a far larger wind generation potential, although weather conditions are more extreme there than along the California coast. Throughout this band, wind resources are large enough to produce electricity far in excess of local demand, so these states could become major power exporters if economical transmission facilities become available. In addition, wind power is generally compatible with the type of agricultural activity predominant in the Great Plains, and payments to farmers could significantly increase their income.

In the best California locations, where winds are fairly predictable, it costs about 7–9¢/kWh to generate power from turbines that average about 100 kW in capacity. Prospects for expanding the wind power base to other geographic areas could be greatly enhanced if costs are further reduced and if the capability of turbines to handle severe winter weather and gusty wind conditions is improved. To achieve these goals, EPRI has taken the lead in the formation of a development and commercialization alliance with the major U.S. wind turbine manufacturer and interested utilities.

The specific objective of the Variable-Speed Wind Turbine (VSWT) Development Alliance is to develop a 300–400-kW turbine that can generate power at 5¢/kWh with good power quality (little frequency disturbance) at favorable locations. Key to this development is the marriage of existing state-of-the-art turbine technology with power electronics that can provide a steady source of ac current even as rotor speed changes with varying winds. Virtually all of today's turbines produce 60-Hz ac power by operating at constant speed. The extra torque caused by a gust of wind must be absorbed by the drivetrain, and the result is lower efficiency and considerable stress. Introducing a variable-speed turbine should increase energy capture and enhance drivetrain life, as well as lower costs and introduce new flexibility to siting.



BIOMASS—INCLUDING WOOD WASTE, MUNICIPAL GARBAGE, AND FUEL CROPS—WILL BECOME THE LARGEST SOURCE OF RENEWABLE ENERGY, SURPASSING HYDRO BY THE TURN OF THE CENTURY.

The power electronic converter that facilitates variable-speed operation essentially provides a dc link between the ac current being generated at varying frequencies by the turbine and the constant-frequency ac current of the utility grid. Such dc links are commonly used at a much larger scale to connect two power systems that may not be operating synchronously. The first prototype VSWT, built by U.S. Windpower, began field tests this spring, and commercial availability is expected in 1994.

In addition to EPRI and U.S. Windpower, the VSWT Development Alliance includes Pacific Gas and Electric Company and Niagara Mohawk Power Corporation. The U.S. Department of Energy is participating in a technical review of the project. Efforts are under way to extend the alliance by forming a utility advisory council, which will provide members with information about the progress of VSWT development, address integration issues, and enable members to become familiar with wind technology and local wind resources before committing a major investment. Beyond the current goals of the alliance, EPRI's Green Plan envisions further reducing the cost of wind power to about 3.5¢/kWh by 2005.

Biomass—urban waste and supertrees

Biomass energy is both familiar and exotic. Civilization probably started with gatherings around tribal campfires, but all biomass resources now account for less than 4% of U.S. primary energy demand. By far the largest use of energy from biomass occurs in the lumber, pulp, and paper industries, which burn wood and wood wastes for process heat and sometimes for cogeneration of electricity. Residential firewood ranks a distant second. And other forms of biomass fuels—solid wastes, methane from biological conversion, and ethanol from corn used as a gasoline additive—together produce only about one-tenth the energy derived from wood.

This picture is expected to change dramatically over the next several years: the overall contribution of biomass to total energy is projected to increase significantly, and electric power generation is expected to become the dominant use of biomass. From a utility perspective, promising opportunities to exploit biomass resources for generating electricity are currently arising in two very different areas—municipal solid waste, subsidized by "tipping fees" for disposal, and whole-tree burning, with costs reduced by improved harvesting techniques and faster-growing woody species.

More than 580,000 tons of municipal solid waste are produced in the United States every day. About 17% of this amount is burned for energy, generating some 2000 MW of electricity. Although utilities purchase approximately 90% of this power, most waste-to-energy (WTE) plants are independently owned. Only 20% of the revenue from the plants comes from power production; the rest comes from tipping fees, generally paid to the WTE plant owner by a municipality for reducing its requirements for disposing of garbage in landfills.

"WTE plants are more about waste disposal than electricity generation," says project manager Evan Hughes. "Many communities are looking to utilities to assist them with their growing waste problems. Frankly, many EPRI members are not sure they want to be in the business. Our job in this case is not so much technology development as providing assessment tools and expertise that can help utilities consider their options."

Toward this end, EPRI has produced a WTE screening guide and software that utilities can use to evaluate the economics and performance characteristics of various WTE technologies to see if they want to become operators. More than a dozen utilities are already using the guide. EPRI has also prepared a permitting sourcebook that provides information on the feasibility of getting a permit for a WTE plant under particular circumstances, together with directions on how to go about the process. The sourcebook also contains data that can be used to consider the environmental and health risks associated with operating a WTE plant, as well as information on waste disposal options.

Making wood cost-competitive as a utility boiler fuel—at 5¢/kWh—is the goal of an EPRI-sponsored project conducted in cooperation with Energy Performance Systems. The key to such cost reduction is to produce dedicated crops of fast-growing tree species and to harvest, transport, store, and eventually burn the wood as whole trees. Compared with cutting trees into sections and chips, this process provides fuel savings of 25% and greatly reduces the amount of hand labor. It also produces a smaller residue of small branches and leaves.

A self-propelled harvesting machine with a circular saw and manipulator arms in front cuts the trees and loads them onto a truck. The trees are then stacked in an air-supported, balloon-like structure with a rotating crane at its center. This structure is used to dry the trees for a month, reducing their moisture content from about 50% to 25%. The crane then loads the trees onto a conveyor system that injects them whole into a furnace. A first-in, first-out inventory system is maintained in the drying structure as the crane stacks and removes trees around a broken circle.

The trees themselves can be any of several fast-growing species, such as willow, poplar, or eucalyptus. Recent progress in genetic manipulation of such short-rotation woody crops, as they are usually called, has produced some varieties that can grow as much as 30 feet in three years. Such trees can be ready for harvest in six or seven years and can produce an average of 10–14 tons of wood per acre per year. At this rate, a 100-MW power plant could be perpetually fueled by a plantation of trees extending in a 6-mile radius around the plant. Most of the eastern two-thirds of the United States is suitable for growing short-rotation woody crops, which could be planted on land that has only marginal value for food crops or that has been idled by government programs to curtail oversupply. Ultimately, such resources could be used in an integrated "biomass refinery" that would coproduce electricity, fuels, and chemical feedstocks.

Project manager Jonne Berning reports that combustion tests using whole trees as fuel at a modified coal plant in Wisconsin have so far been successful. EPRI is also working with the Tennessee Valley Authority to evaluate stacking and drying procedures and to design a retrofit demonstration. "The use of short-rotation woody crops as fuel has several environmental advantages," Berning says. "Carbon dioxide is recycled. Marginal land is put to good use. And the three-stage combustion process has very low emissions."

Cost of Electricity in Favorable Locations (per kilowatthour)

Energy Source	Present (1991)	Intermediate (1995–2000)	Long Term (beyond 2000)
Photovoltaics	30–40¢	10–20¢	6¢
Wind	7–9¢	5¢	3.5¢
Biomass	5¢*	5¢	4¢
Solar thermal	10¢	8¢	6–8¢
Geothermal	5–7¢	5–7¢	≤6¢†

*Requires subsidy tipping fee.
†Hot dry rock will substantially expand the resource base.

Photovoltaics—utility applications now

A subtle semantic change is taking place among utility engineers when they discuss photovoltaics these days. Instead of saying that PV might be useful in "remote" applications, they are examining more opportunities that are simply "isolated from the grid." The significance of this change is that using photovoltaics has become more cost-effective than installing a transformer or stringing wire to low-power equipment such as sectionalizing switches, cathodic protection devices, nuclear warning sirens, and water pumps—even if power lines are relatively close by. Some of these applications benefit utilities themselves; others can be installed by utilities to meet customer needs at considerable cost savings to both parties. Power levels currently range from about 5 watts to tens of kilowatts.

"I can walk into any utility in the country and find application for photovoltaics *today*," declares project manager John Bigger. "So far we've identified 60 generic applications, which extend to all areas of utility operations, and more than 20 utilities have installed some of them. We're holding applications workshops, as well as helping set up users groups for particular applications and providing them with technical support. The first of these groups involves nine utilities that are installing PV-powered sectionalizing switches."

In addition, EPRI is developing assessment tools that can help utility managers choose between PV systems and conventional approaches. One analysis shows, for example, that a continuous 10-watt load is usually cheaper to power by using PV than by extending a distribution line more than 200 or 300 feet. Such comparisons have been of particular interest to rural electric cooperatives, many of which have had to run a power line several miles just to operate a single pump that supplies water for cattle. Photovoltaic modules now available could provide the same power at a fraction of the cost.

Such grid-isolated applications are already attractive with PV power at 25–30¢/kWh. Once the cost falls to 10–20¢/kWh, a variety of grid-connected applications in the range of tens to hundreds of kilowatts will also become cost-effective. Voltage support for distribution feeders, for example, has been evaluated, and at least a few utility installations are expected over the next five years.

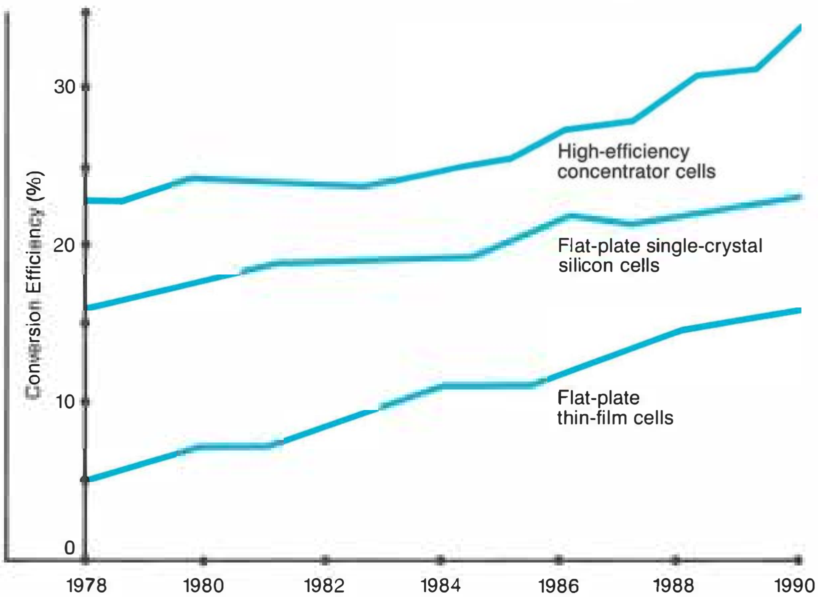
"We have already found 400 uses for PV, from gate openers to highway signs to substation applications," says Carl Weinberg, research director at Pacific Gas and Electric. "In all these cases, it is more cost-effective to use PV than to string wire."

To ensure that remote applications are not the only market for photovoltaics, R&D worldwide continues to drive down the cost by improving efficiency, streamlining production, and creatively engineering new system designs. Future success in improving efficiency will rely on multijunction cells that absorb a greater spectrum of light and on better materials composition and uniformity. EPRI's Green Plan aims at increasing the efficiency of commercial PV cells and modules by 50–100% over the next 15 years. Each incremental improvement in efficiency will lower the cost and expand the market for photovoltaics farther beyond the Sunbelt.

In addition, creative system engineering and simplified product design will lower the cost of PV systems. Engineering and design innovations, along with manufacturing development, will primarily result from an evolution of cost-effective applications that become increasingly significant in energy production. The Green Plan anticipates continued EPRI involvement in engineering and manufacturing development for concentrating-type PV systems, which are not competitive for the smaller, early market applications.

Photovoltaic Efficiencies Climbing

While photovoltaic conversion currently has the highest energy cost of the renewable technologies, steady gains in PV cell efficiencies over the past dozen years support projections of economic central-station PV generation for the early twenty-first century.



Source: U.S. DOE Photovoltaics Plan: 1991–1995 (draft). December 1990.

Solar thermal—improving efficiency

Generating electricity by using the thermal energy of sunlight means confronting the diffuse nature of this resource directly. Somehow the gentle warmth of a sunny day must be concentrated sufficiently to raise the temperature of a working fluid and drive a generator. The critical question is how to balance the need for higher temperatures and efficiencies against the cost of building heat collectors with large surface areas.

Current efforts center on three main types of light-concentrating collectors. Parabolic troughs use linear reflectors to focus sunlight onto tubes filled with a heat transfer fluid. As these troughs tilt to track the sun, the fluid is heated several hundred degrees and used to generate power, usually by raising steam for a turbine generator. Such trough systems, which can be manufactured and installed modularly, represent the most mature solar-thermal technology. Some 350 MW of generating capacity using parabolic troughs built by Luz International is currently operating on the Southern California Edison system. The latest addition to this capacity costs an estimated 8–10¢/kWh, and Luz expects to make further cost reductions of 30% over the next few years. Both the value and the cost of the system are improved by the use of supplemental gas firing, which provides 25% of the energy output.

A power tower type of solar-thermal system uses numerous flat mirrors to reflect sunlight onto a single receiver. Several mirrors are mounted onto individual heliostats, which tilt during the day to track the sun. Very high temperatures at the central receiver should make it possible to generate electricity from steam quite efficiently, but the cost of the heliostats remains relatively high. Solar One, a 10-MW pilot plant sponsored by DOE and Southern California Edison and based on this concept, operated in the Mojave Desert for six years in the mid-1980s.

Parabolic dish systems use individually mounted curved mirrors to focus sunlight onto a receiver attached to the mirror frame itself. In early versions, a working fluid was heated in the receiver and transported to a central power plant for use in generating electricity. More recently, small Stirling engines and generator modules have been mounted on the dishes. (A Stirling engine uses pistons that move in a sealed chamber, which is externally heated.) One such module has set a record of 29% overall system efficiency for converting sunlight into electricity.

Both the central receiver and dish systems offer lower cost than the parabolic trough. However, they also represent a greater challenge to develop and deploy. The market-driven trough technology has achieved its success by offering the lowest risk, not the lowest potential cost.

Geothermal—progress on hot dry rock

Geothermal energy currently provides 2800 MW of power in the United States, mostly in California. The largest portion of this energy is used in the form of dry steam, which represents only a small fraction of the total geothermal resource. A few hot water reservoirs are also being tapped, either by allowing the water to "flash" to steam, if it is hot enough, or by using a closed system with a hydrocarbon working fluid (a binary cycle), if the water temperature is lower.

The potential geothermal resource available for power generation would be much greater if heat could be recovered from areas of hot dry rock (HDR). In fact, a recent report from the Los Alamos National Laboratory suggests that there is "at least 500,000 quads of useful heat in HDR at accessible drilling depths beneath the United States." With HDR, water is injected through a deep well into previously fractured crystalline rock in hot regions of the earth's crust. Steam formed in the process can then be recovered from a second well and used for power generation. HDR geothermal will first be applied where the temperature gradient in the earth's crust is highest (greater than 70°C/km, compared with the average of 30°C/km). About 60,000 square miles of the western United States fulfills this criterion.

THE DEVELOPMENT OF TECHNOLOGY TO EXTRACT ENERGY FROM HOT DRY ROCK WILL ALLOW GEOTHERMAL TO BECOME THE PREDOMINANT RENEWABLE RESOURCE IN THE WESTERN HALF OF THE COUNTRY.

Significant progress has been made recently in the use of diamond drill bits for penetrating hot crystalline rock and in the development of high-temperature instrumentation and reservoir fracture diagnostic techniques. DOE is planning a long-term flow test to extract energy from HDR and evaluate the thermal and hydraulic characteristics of an HDR reservoir. The Green Plan anticipates EPRI participation in a program of test wells that would precede a full-scale commercial geothermal power plant.

Evolution of the renewables market

As prevailing assumptions about renewable energy, technology commercialization, and the nature of the utility business continue to change, the prospects for an environmentally attractive energy future brighten considerably. Much work remains to be done, however.

"Early applications are a prerequisite for the commercial success of renewables and storage technologies," says James Birk. "Markets have to evolve. Installations of photovoltaics, wind, wood burning, and energy storage can all be justified in specific instances now on the basis of their own economic merit. What we're trying to do is broaden the scope of those applications so that these environmentally attractive technologies can play a larger role in the overall energy picture. Bulk power from PV, strategic use of storage, biomass refineries, broad national use of wind energy—they're all possible within a few years. But we have to be proactive in making it happen, both through technology development and by nurturing young markets." ■

Further reading

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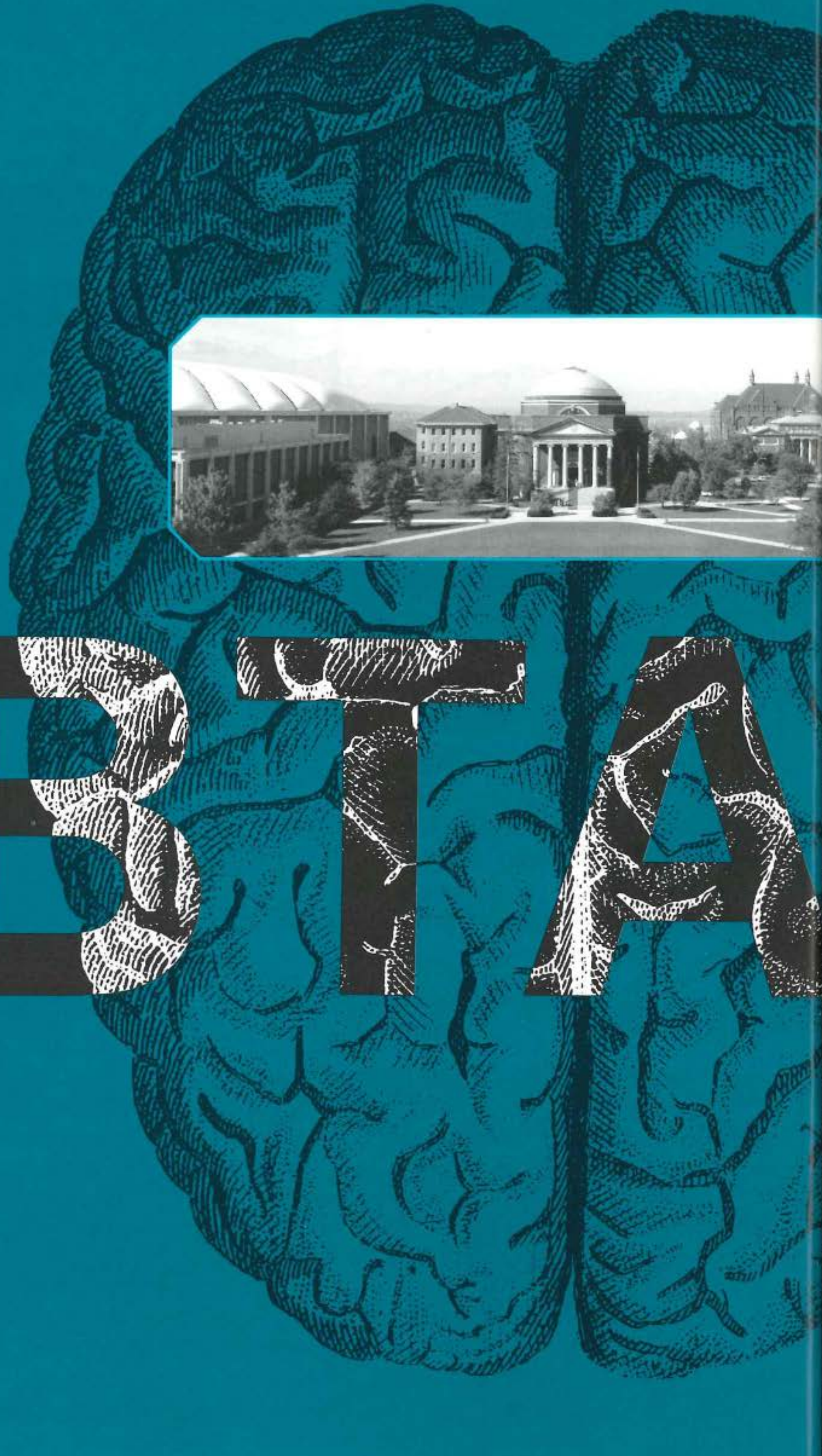
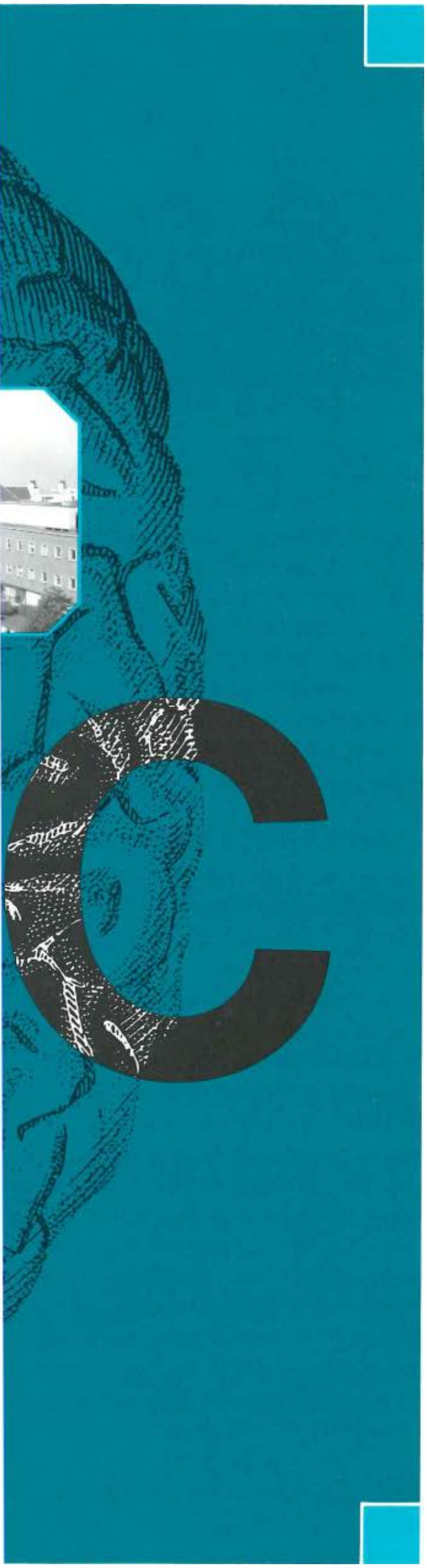
This article was written by John Douglas, science writer. Technical background information was provided by James Birk, Generation and Storage Division.

Knowledge-Based Technology Applications Center



KBTA

Helping Develop Expert Systems



THE STORY IN BRIEF

Expert systems are ideally suited to helping utilities with complex O&M decisions—especially those common to nuclear plants. But lacking experience with artificial intelligence, most utilities have relied on contractors to develop such systems, at high cost. The Knowledge-Based Technology Applications Center, established by EPRI, provides utilities with the know-how and resources to design, test, and implement expert systems tailored to their individual needs.

Electric utilities are among the early users of so-called knowledge-based, or expert, computer software systems. Such systems are particularly useful in helping utility personnel deal with complex operation and maintenance problems that do not lend themselves to the precise modeling techniques of conventional computer programs. EPRI has so far produced dozens of expert systems for utility use, addressing problems that range from dealing with an inefficient generator to assessing the level of emergency during an event at a nuclear power plant.

Adapting this powerful technology to specific utility situations, however, has not always gone smoothly, especially when expert systems have been developed with little direct involvement of a utility's technical staff. "In the early years of the technology, knowledge-based systems were sometimes misunderstood and oversold," says Karl Stahlkopf, director of the Safety and Reliability Department in EPRI's Nuclear Power Division. "Many applications have to be very plant-specific, so there's a need for utility staff to be able to tailor the knowledge-based system to the details of their plant configuration. Developing expert systems involves using the tools of artificial intelligence, which can be intimidating to engineers educated in conventional programming methods. We need to find ways to make these systems more accessible and to get more utility people directly involved in their development."

Responding to this need, EPRI has established the Knowledge-Based Technology Applications Center (KBTAC), where utility members can get help in scoping, developing, testing, and applying expert systems. The center, located on the Syracuse University campus, is a cooperative program of Kaman Sciences Corporation and the university. It draws on a wide range of expertise from Kaman staff and several university departments. KBTAC activities have initially focused on nuclear power; they are now being broadened to encompass several other areas of utility operations, including fossil fuel generation and transmission and distribution.

"Utilities are showing increasing interest in expert systems, but first they want to see some successes," declares Joseph Naser of the Nuclear Power Division, EPRI's project manager for KBTAC. "In the nuclear industry, particularly, there is concern over the reliability and licensing implications of untested new technologies. KBTAC can help utilities overcome these concerns about expert systems, while also providing a way for their people to become more directly involved in creating and adapting these systems for their own special needs."

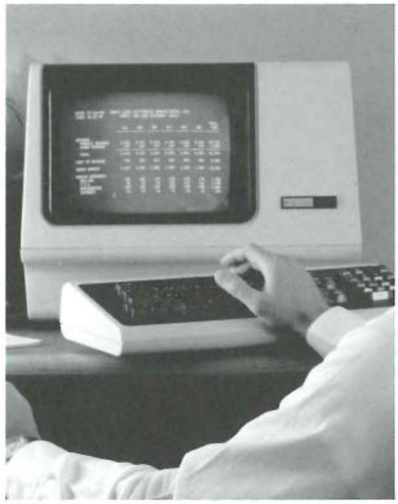
Expediting complex tasks

The motivation for utilities to increase the use of expert systems is clear. For some types of applications, expert systems can complete complex tasks much faster, more easily, and at substantially lower cost than conventional computer modeling systems can. In some cases, expert systems can solve problems that cannot be solved by conventional software. The expert systems development process itself involves capturing the otherwise perishable knowledge of top experts, who are then freed to concentrate on exceptional problems. Once deployed, expert systems tend to find new uses beyond their original task, such as training, expediting documentation, and promoting information exchange. Knowledge-based systems are also well suited for application in rapidly changing situations, since they can generally be updated without extensive reprogramming.

Expert systems are ideally suited to as-

Help From KBTAC

KBTAC provides a variety of services to help utilities develop expert systems to address important problems in operations, maintenance, and engineering.



Information clearinghouse
Through the EPRINET information network, utilities obtain access to a number of databases that allow them to learn about and evaluate expert systems alternatives before making a financial commitment. In addition to an electronic bulletin board, the service offers databases on commercially available tools and shells, EPRI prototype systems, current utility applications, and KBTAC staff expertise.

Technology transfer Tutorials, workshops, and training programs facilitate face-to-face information exchange on the evolving state of expert systems technology, tools, and applications. Both the Management Seminar and Seminar-on-a-Disk introduce KBTAC and its program to utility personnel. System development seminars teach engineers how to solve specific utility problems through the use of expert systems shells, while prototype development workshops stress cooperative work on concerns common to several utilities.

Technical support KBTAC offers direct assistance—in person or by telephone consultation—at crucial stages of a utility's expert system product development. Such help is particularly valuable for effective project scoping and for design of a product prototype. KBTAC also coordinates expert systems users groups and makes available data on commercial tools and on prototype systems developed by EPRI and other utilities.

> *People thought the KBTAC training course was fantastic. It gave them an opportunity to try out AI shells without having to invest a lot of money in them first.*
>
> Steve Trovato, Consolidated Edison

sisting workers faced with complex tasks, such as setting priorities during an emergency or figuring out which of many possible causes is actually responsible for an equipment failure. Assuming that a task is too complex to model precisely, the next best approach is to do what human experts do: fall back on a combination of rules, experience, and judgment—a knowledge base, in the language of artificial intelligence (AI)—processed through a series of computerized procedures known as an inference engine. Determining what knowledge and rules should go into an expert system usually requires input from human experts in the particular field.

Often, expert systems are designed to be highly interactive, with the computer guiding the user toward a solution by asking a series of questions. EPRI's LIFEX, for example, asks a nuclear engineer questions about structural materials and assesses the potential of plant component degradation from more than 20 mechanisms. An expert system may yield probabilistic, rather than exact, results. From LIFEX, for example, an engineer might learn of an 80% chance of pipe failure within three years due to stress corrosion cracking.

Creating expert systems that can tackle such difficult problems but that are easy to use can be a major challenge. Usually a knowledge engineer (the AI term for someone with expertise in structuring information for a software format) must work closely with a domain expert (someone with expertise in the relevant technical area). Although such pairings can prove productive, they have often led to mutual frustration. As a result, attempts are being made to provide domain experts with easy-to-use AI tools so that they can program knowledge-based computer software themselves.

"KBTAC can make artificial intelligence more accessible to utility engineers," says Al Sudduth, engineering consultant at Duke Power and chairman of the center's Utility Advisory Board. "Few of them now use expert systems as a standard tool. KBTAC can help internalize this tool by providing training and an environment where engineers can get the support they need."

Some utilities have already become involved in developing their own expert systems. Niagara Mohawk Power, for example, has been working with AI specialists at Syracuse University for several years and contributed funds to help start KBTAC there. Among other projects, Niagara Mohawk sponsored the development of ALFA, an expert system for forecasting short-term electricity demand, on the basis of weather pattern recognition from a huge, 10-year database of hourly observations of 12 weather variables. The utility also worked with the Syracuse team to develop ALEX, a system to analyze transmission status alarms, as many as 30,000 of which may occur in a single month. ALEX can determine in less than a second what transmission system events underlie these alarms.

Sidney Lipton, a senior research specialist at Niagara Mohawk, says his company's decision to invest in KBTAC was a good business decision: "Considering what consulting services for expert systems development cost these days, our investment will easily pay for itself. We've been pushing AI for years. This is a way to keep up with what's happening elsewhere in the industry. KBTAC is a good source of very advanced technology—easily transferable and very practical."

Support three ways

To help utilities become more familiar with knowledge-based technologies, KBTAC provides three kinds of support, which Bill Sun—the EPRI program manager who oversaw the center's creation—describes this way: "First, there's a clearinghouse function. This enables utilities to find out who's doing what and what tools are available. Second, there's a technology transfer program involving seminars and workshops, so engineers and managers can get some hands-on experience with expert systems. And, finally, KBTAC offers individual technical support to utilities, sort of a jump-start for devel-

> *Few utility engineers now use expert systems as a standard tool. KBTAC can help internalize this tool by providing training and an environment where engineers can get the support they need.*
>
> Al Sudduth, KBTAC Utility Advisory Board

oping their own prototypes. In each of these areas, the center's role is that of supporting utility technology champions —informing, encouraging, assisting."

Most clearinghouse services are available through electronically accessed databases. The Expert Systems Tool Database, for example, contains information on commercially available "shells"—easily adaptable programming frameworks that can be used to create an expert system tailored to individual needs. The Life Cycle/Project Database provides a vehicle for EPRI member utilities to share information about expert systems development and applications, thus reducing the likelihood of wasteful redundancy. An electronic bulletin board provides users with up-to-date information on planned events and topics of special interest. These and other clearinghouse services are available through EPRINET, the proprietary information network that serves EPRI members. KBTAC users now form one of the largest special-interest groups on EPRINET.

KBTAC's technology transfer program focuses on courses that vary widely in their intended audience and level of detail. Seminar-on-a-Disk is an interactive basic tutorial that runs on a personal computer. The Management Seminar is designed to introduce utility managers to KBTAC and show them how expert systems can improve productivity. Introductory and advanced expert systems development seminars train utility engineers in how to build and apply expert systems. A prototype development workshop facilitates a collective approach among a small group of utilities that want to develop a prototype expert system to address a common problem.

Technical support activities at KBTAC include project planning and scoping, feasibility assessment, tool selection, programming, and system verification. These activities are supported by the center's efforts to acquire and make available both commercial AI tools and prototype expert systems developed by utilities. The center also coordinates users groups and can provide individual support that ranges from telephone consultation to the opportunity for a utility staff member to spend some weeks in residence at KBTAC, working with center staff members.

"We're finding that the best way to educate people about expert systems is to get them started on their own projects," says Walter Meyer, technical director of KBTAC and a professor at Syracuse University. "As a result of our programs, we see more networking among utility people interested in expert systems. That way they can resolve a lot of problems very rapidly. They're also asking us for help on difficulties that come up with particular expert systems. In one case, for example, we were able to show some users how to modify a nuclear power–related expert system so that it could be updated more readily as regulations and technologies change. We're providing quick relief."

First-year report

KBTAC began operation in November 1989, and its first year of operation emphasized the establishment of an information clearinghouse and the presentation of seminars that enabled utility participants to become familiar with expert systems and the center's functions. Approximately 500 utility engineers, programmers, and general staff attended these seminars. Emphasis during the second year is being shifted toward direct technical support, and more than 30 support projects are currently being pursued.

As part of their initial outreach effort, KBTAC personnel conducted a training course at a technology fair held by Consolidated Edison for its own employees and visitors from other utilities. "People thought it was fantastic," recalls Steve Trovato, the senior mechanical engineer at Con Ed who arranged for the course. "It gave them an opportunity to try out AI shells without having to invest a lot of money in them first. The key to success, if you're planning to do something with AI, is finding help to get started."

Technical support continues to focus on specific projects related to nuclear

> *Considering what consulting services for expert systems development cost these days, our investment in KBTAC will easily pay for itself. KBTAC is a good source of very advanced technology—easily transferable and very practical.*
>
> Sidney Lipton, Niagara Mohawk

power, although it is being expanded to include other areas. Some current nuclear projects involve expert systems that support plant technical specifications, diagnose water chemistry conditions, forecast spare parts requirements, and help manage hazardous waste. Of particular note is KBTAC support for the Life Extension Committee of the Boiling Water Reactor Owners Group, which is developing an expert system to assist engineers in applying guidelines for screening nuclear plant systems and components for license extension.

KBTAC is also supporting the transfer of new EPRI-developed expert systems technology, such as the Safety Review Advisor (SARA), to EPRI member utilities. SARA aids utility personnel in performing safety reviews under 10CFR50.59, the federal regulation for design and procedure changes in a nuclear power plant. This project is being performed by Sargent & Lundy, under EPRI contract, and a prototype system is expected to be available for trial use by utilities this summer.

The KBTAC staff have also noted an apparent progression in the way utilities go about developing knowledge-based systems—increasingly internalizing the process. For some time, a small number of major development projects (such as nuclear life extension) involving multiutility task forces and contracts with software firms have been under way. Some utilities are now hiring applications specialists to increase their in-house use of expert systems. Reportedly the results have been mixed, however, since such specialists must often contend with organizational barriers that prevent them from working as closely as they might with potential clients within the utility. Finally, more individual utility domain experts are learning more about expert systems and are beginning to develop their own. Most of these involve relatively small applications, and many early ones have not reached operational implementation; yet such "homemade" expert systems can be expected to become more sophisticated as more utility engineers and programmers become comfortable with the programming tools used to develop them.

Prospects for the future

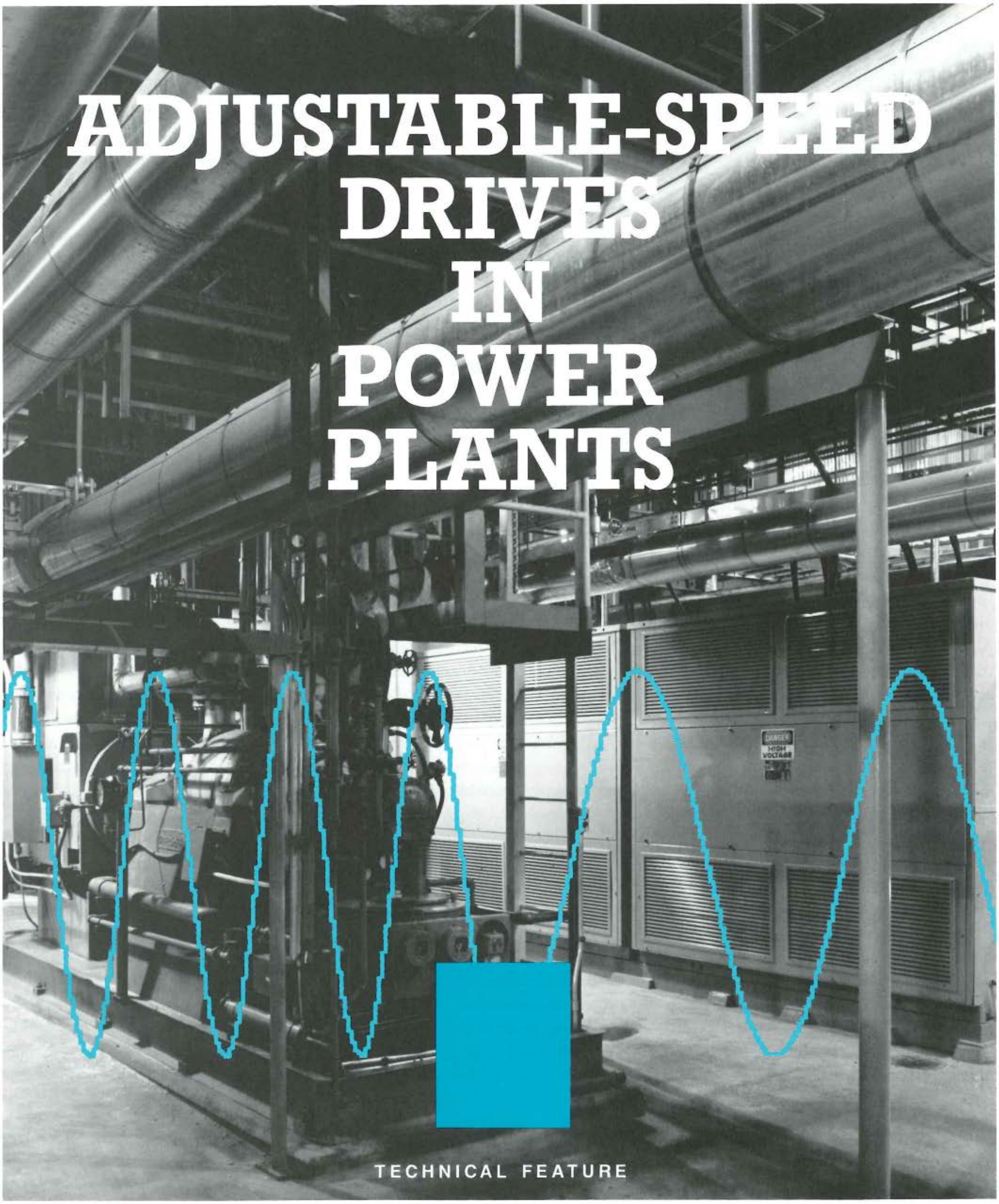
Given the level of commitment required, what are the prospects for utility applications of knowledge-based systems, and what difference is KBTAC likely to make?

EPRI's Joseph Naser offers the following observations: "Most programming work will continue to be done by outsiders for the foreseeable future, but even so, utilities can use KBTAC to give themselves more options. First, information from the center can help a utility determine whether an expert system is the right approach to a particular problem. If so, we can help them learn how to go about developing it themselves or how to write a comprehensive set of bid specifications for an outside contractor. In general, we're finding that the best results come when domain experts know enough about knowledge-based systems to do their own development work using off-the-shelf tools. That assumes, of course, that you're not trying to push the state of the art. We can also help utilities pool their development efforts by creating a users group, through KBTAC."

Walter Meyer of KBTAC adds, "In the past we've seen a lot of disappointed people. Implementing expert systems can be challenging. There has been no resource that engineers in the utility industry could turn to for help in solving problems with their expert systems. At KBTAC, we're providing that kind of help. As we have successes and the word gets out, people will come back to expert systems and not be stopped by small problems. Many complex problems can be approached efficiently only by using this powerful technology, and I expect that applications of knowledge-based systems in the utility industry will grow rapidly over the next several years."

This article was written by John Douglas, science writer. Technical background information was provided by Joseph Naser, Bill Sun, and Karl Stahlkopf, Nuclear Power Division.

ADJUSTABLE-SPEED DRIVES IN POWER PLANTS



The large electric motors that run the massive pumps and fans in power plants can consume as much as 3–4% of a plant's generating output. But new electronic controls for motors can cut their energy use 20–50%. They do it by synthesizing the voltage and frequency of power supplied to the motors so that they run only as fast as necessary to do the work required at a given moment. Because of the energy savings and precise process control they offer, these adjustable-speed drives (ASDs) are revolutionizing motor technology and applications. Motors of all sizes are candidates for ASD control, from those that run household heat pumps and individual room air conditioners all the way to the high-horsepower, multimegawatt induction motors used at utility power plants and industrial installations. EPRI has targeted ASDs as a major research priority since its founding and has played a key role in technology development and demonstration for utility applications.

THE STORY IN BRIEF

By allowing motors to run at slower speeds that match load requirements, electronic ASDs can significantly cut auxiliary power costs. EPRI has documented the energy savings and operating experience of ASDs retrofitted on motors at five power plants. The key technical and economic factors identified are helping other utilities get top value and performance from their ASD installations.

More than 200 large ASDs have been installed on squirrel-cage induction motors over the last decade, and many more are currently being retrofitted. As part of its broad-based R&D effort on ASDs, EPRI began a utility demonstration program in 1984 that grew to include five generating units. In this program, over a five-year period, three types of ASD were installed on power plant auxiliary motors, including units on five boiler feedwater pumps and two forced-draft fans. One site was the first full-scale ASD application made in connection with the conversion of a generating unit to sliding-pressure operation.

Working closely with the utilities and ASD vendors, the EPRI contractor gathered and analyzed extensive operating data at each of the installations with and without the ASDs in operation to establish actual energy savings. According to Marek Samotyj, a senior project manager in the Customer Systems Division, the results of EPRI's field demonstrations have documented the energy savings and improved plant performance possible with ASDs, indicating a range of potential economic benefits for the various applications.

More important for the utility industry at large, says Samotyj, EPRI's work provided the basis for developing a preferred configuration for a power-plant-specific ASD with optimal performance, reliability, and power quality. Spanning five years of ASD technology evolution, the demonstrations included one of the earliest drives for high-horsepower induction motors as well as installations incorporating more-recent design and electronics.

"Insights developed from the field tests led to ASD specifications that would probably never have occurred to a designer working on paper or a test board," says Samotyj. Utilities are already using the preferred configuration as well as purchase specification guidelines (contained in a recent EPRI report) in evaluating and meeting their own specific requirements for power plant ASDs.

Workhorse motors get a face-lift

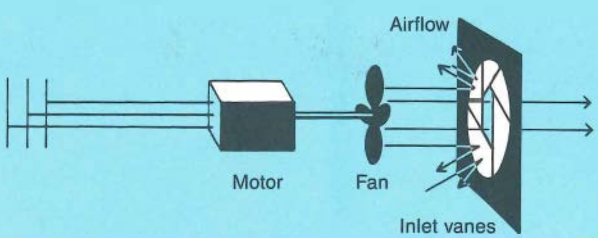
In a fossil-fuel-fired steam generating plant, the flow rates of boiler feedwater and combustion air are controlled by very large pumps and fans powered by motors that run at only one speed—full, in some instances as high as 3600 rpm. This may be fine when the generating unit is needed on the utility system at maximum output, but that is often not the case. When a plant's auxiliary motors are all running at full speed but the unit is generating at minimum load, its heat rate is at its highest (i.e., efficiency is at its lowest). A high heat rate means that more fuel must be burned to generate at a given power level, so emissions rates are typically proportionately higher than at full load. Air and feedwater flow can be throttled somewhat with control vanes and valves, but these do nothing to limit the power consumption of the motors, and they also add to plant maintenance costs.

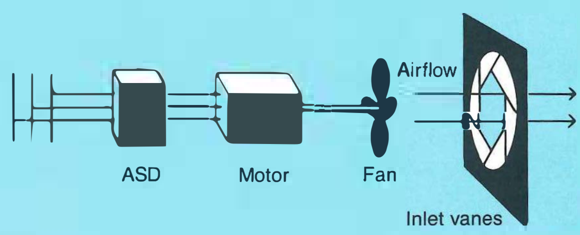
Equipping a plant auxiliary motor with electronic drive allows it to be operated over a wide speed range and thus permits unprecedented control over the flow of feedwater or air. Control vanes and valves and the power losses associated with them can be eliminated. When the unit is running at less than full load, its motors—and, in turn, its air and feedwater flow rates—can be slowed with ASDs, reducing heat rate and thereby raising efficiency and lowering the rate of emissions. ASDs also permit low-current ("soft") startup of motors and related systems, which reduces electrical, mechanical, and thermal stress and extends the life of major plant components.

Although an ASD (and its related auxiliary equipment) sized to control a high-horsepower induction motor can occupy considerable space on one or more floors inside a power plant, it is still compact enough to be retrofitted into confined areas. The equipment can also be conveniently located away from premium space near the motor. At its simplest, an ASD consists of a rectifier to convert 60-Hz ac power to dc power, a dc link to an inverter, the inverter itself (which converts dc into the full range of ac frequencies needed for motor speed control), and a solid-state, microelectronic control sys-

Reducing Auxiliary Loads With ASDs

Power plant fans and pumps propelled by ac motors operate at constant speed, so the flow of combustion air or boiler feedwater typically must be throttled mechanically by control vanes, dampers, or valves. This entails added maintenance costs and does nothing to limit the often substantial internal power requirement of the fan and pump motors. An electronic adjustable-speed drive, or ASD, controls the speed of a motor itself by synthesizing the voltage and frequency of the power supplied to it. Motor speed and, in turn, airflow or feedwater flow can thus be reduced to match the plant's operating demand, minimizing auxiliary loads.





Economic Summary of Utility ASD Retrofit Demonstrations

Utility	Power Plant	Retrofit Application	Annual Savings	Payback (years)
Sierra Pacific Power	Ft. Churchill	One 2000-hp boiler feedpump	$1,600,000	0.3
Gulf States Utilities	Willow Glen	One 2250-hp boiler feedpump	$130,000	2.5
Iowa Public Service	Neal	Two 7000-hp boiler feedpumps	$348,000	7.7
Oklahoma Gas and Electric	Seminole	Two 4000-hp forced-draft fans	$231,000	5.4
Sierra Pacific Power	Tracy	One 2000-hp boiler feedpump	$88,000	3.4

tem that continuously adjusts the inverter frequency and voltage to meet motor speed requirements. Both the rectifier and the inverter are built around high-power electronic switches called thyristors.

One evolution in ASD technology identified from the field demonstrations as a feature of the preferred utility configuration is the inclusion of an input transformer ahead of the rectifier to suppress harmonic distortion entering the ASD and to control line-to-ground voltage at the motor. This is now a standard feature of new installations.

Until Sierra Pacific Power installed an ASD on one of two boiler feedpump induction motors at its Ft. Churchill Unit 2 in 1984, the only ASD installations had been on more-recent-vintage synchronous motors, which are far less widely used by utilities and other industries. But within two years of the Ft. Churchill installation, induction motors had come to dominate the ASD retrofit market. In addition to Ft. Churchill, EPRI's utility field test program included ASDs on boiler feedwater pumps at Gulf States Utilities Company's Willow Glen Unit 1, Iowa Public Service's George Neal Unit 2 (two), and Sierra Pacific Power's Tracy Unit 3. Two ASDs installed on forced-draft fans at Oklahoma Gas and Electric's Seminole Unit 1 were also evaluated.

Besides analyzing energy savings at each of the utility installations, the researchers recorded power quality data on both the input and output sides of the ASDs to assess the electronic drives' impact on plant electrical control systems. ASDs can cause unwanted harmonic distortion on a plant's internal electrical systems that can lead to overheating and added wear on ASD-controlled motors.

EPRI's Samotyj remarks that the field demonstration program's fortunate timing helped refine the developing technology for large induction motor ASDs. The principal advances reflected in the systems examined involve different approaches to commutating the inverter and thus controlling harmonics entering the motor. Some of the earliest configurations featured a 12-pulse, modified load-commutated inverter. Later installations added input and output capacitor filters. The latest technology features 6-pulse current-source inverters based on asymmetric gate-turnoff thyristors. These are called GTO-PWM (gate-turnoff, pulse-width-modulated) inverters. The technology allows current wave shaping at all inverter outputs, giving the effect of a 12-pulse or 18-pulse inverter with a single 6-pulse bridge.

GTO-PWM inverters can be set to eliminate specific harmful output current harmonics that could adversely affect the motor. According to researchers, this resolves a reliability-related issue with ASDs: motor shaft torsional resonance at a harmonic frequency, potentially caused by the interaction of an ASD output capacitor filter and the motor winding. The phenomenon was not experienced in any of the non-GTO inverter installations that were part of the EPRI field demonstrations. The advanced inverters are also smaller and more compact than those based on earlier types of thyristor, requiring less plant space and cooling capacity. Enclosed in cabinets or prefabricated housings inside power plants, many ASDs are air-cooled, but the field demonstrations identified water-circulating systems as the preferred cooling approach.

Energy savings confirmed

Each of the utility motor ASD installations covered under the demonstration program was unique in specific aspects, and each yielded somewhat different operational and economic results. Collectively, however, they all confirmed positive energy savings from reduced auxiliary load requirements, acceptably low output harmonics, and good reliability after some initial startup problems were resolved.

The largest dollar savings were experienced at Sierra Pacific Power's Ft. Churchill Unit 2 in Nevada. Conversion of the 110-MW gas-fired unit—used mainly for spinning reserve—to sliding-throttle operation at low load with an ASD retrofit on one of two 2000-hp boiler feedpumps reduced the minimum load requirement by 4 MW, saving an estimated $1.6 million a year. That gave the installation a payback of 0.3 years.

After observing Sierra Pacific Power's ASD experience at Ft. Churchill, Gulf States Utilities decided to convert one of the two 2250-hp feedwater pumps at its Willow Glen Unit 1 to adjustable-speed operation, both to gain operating experience with large ASDs and, more specifically, to improve the 146-MW unit's heat rate by eliminating the need to use a feedwater control valve. The gas- or oil-fired unit was already operated in a sliding-throttle mode. GSU chose a transformerless, 6-pulse load-commutated inverter-type ASD.

In service since January 1986, the Willow Glen ASD has performed well despite some capacitor failures from overheating. The unit features an ungrounded inverter, which can result in common-mode voltage-to-ground at the motor, possibly leading to motor failure if not controlled. Although no such problems arose at Willow Glen, the ASD supplier installed a ground connection at the motor as well as input transformers (to absorb common-mode voltage), features that are now standard on all large ASDs of this type. Gulf States Utilities reports reliable operation of the boiler feedpump with ASD control and estimates annual savings of $130,000 from improved heat rate and reduced valve maintenance costs.

Largely on the basis of projected fuel cost savings from improved efficiency at part load, Oklahoma Gas and Electric installed a 5000-hp ASD on each of two 4000-hp forced-draft fans at Unit 1 of its Seminole plant. OG&E also hoped the ASDs would permit both improved fan performance and increased unit output at peak demand periods. The ASD components were installed outside the plant in a prefabricated, air-conditioned housing.

The ASD technology at Seminole is current-source-commutated, with a 12-pulse input rectifier and isolation transformer, a 6-pulse current-source asymmetric GTO-PWM inverter, and an output capacitor filter. The 12-pulse rectifiers give the units the potential for low input (voltage and current) harmonics, and the output capacitors reduce the harmonics that could cause motor heating. There is no resonance between the output filters and the motors, thanks to the ability of the GTO inverters to selectively remove harmonics.

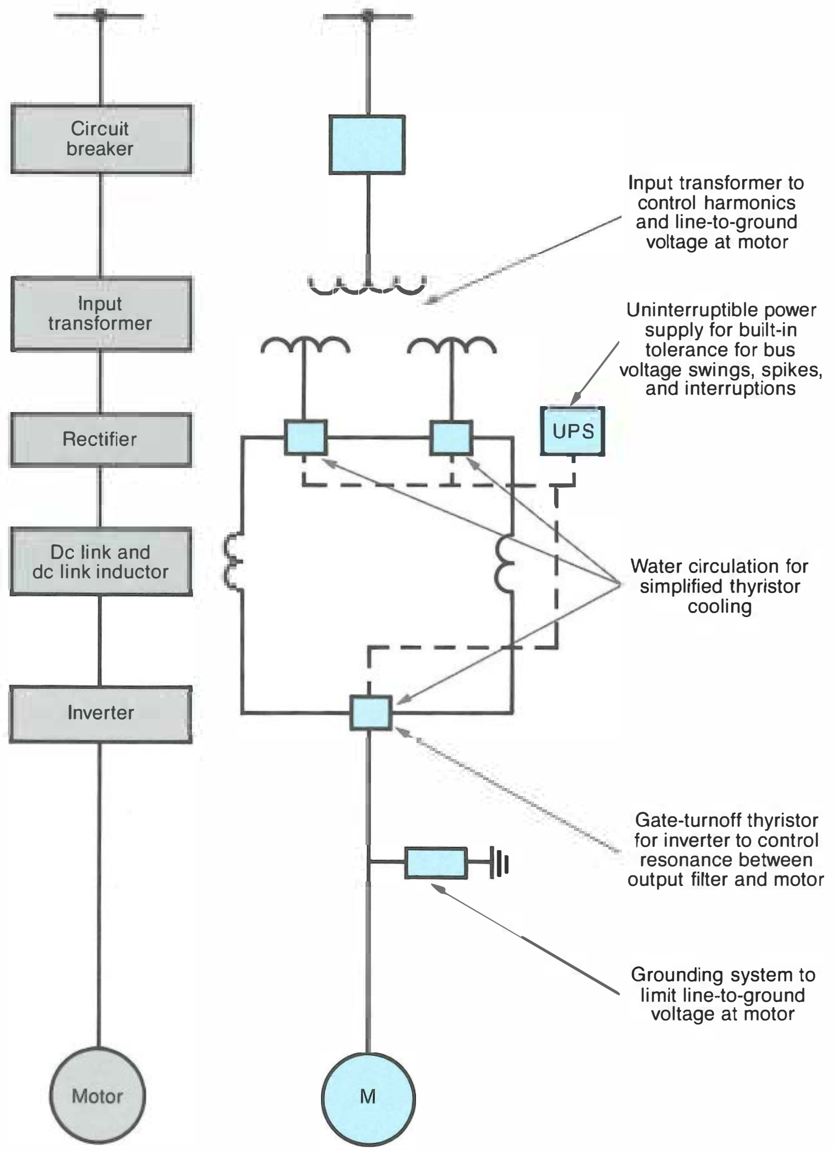
The power savings from ASD control on the Seminole unit's forced-draft fans were smaller than had been projected, and a study was made to determine why. It turned out that excess airflow and air preheater losses at low load had been understated in economic projections before the installation, thus overstating the anticipated benefits. The preheater's higher-than-expected air requirement at low load also limited fuel savings. Still, OG&E estimates that the ASDs save it $231,000 a year.

The harmonic distortion of voltage injected by the ASDs at the 4-kV service bus was somewhat higher than the 3.3% specified by OG&E until modifications reduced it to within acceptable levels. The asymmetric GTO-PWM inverters at Seminole experienced a number of failures during the first six months of operation, but problems with the power supply (for example, susceptibility to lightning-induced transients) were resolved with an improved grounding system at the input terminals and the inverters, and the ASDs have since performed reliably.

In the first full-scale application of ASDs in the main cycle of a plant using sliding-pressure operation, Iowa Public Service installed a 6300-hp ASD in 1988 on each of two boiler feedpumps at George Neal Unit 2. A member of the Mid-Continent Area Power Pool, IPS found that the pool was not making full use of the aging 290-MW coal-fired unit because of high operating costs; its two 7000-hp motor-

Preferred Configuration for Power Plant ASD

EPRI-sponsored evaluations of ASDs at five utility generating plants have led to the identification of a preferred ASD configuration for optimal performance, reliability, and power quality. Key features of the recommended design include water cooling of the thyristors in the rectifier and the inverter and the use of an uninterruptible power supply to protect the ASD control system against voltage irregularities.



driven pumps consumed a large amount of auxiliary power.

Significant energy savings from the ASD retrofit were reported at constant-throttle operation, and the savings were even greater when the unit was operated in sliding-pressure mode, which reduced pump speed at reduced unit load. This occurred because sliding-pressure operation reduces the feedwater flow requirements, resulting in a greater-than-normal pressure head at the control valve under part loading. Therefore, the ASDs could reduce the motor speed even further and yield increased energy savings for a given plant load. Sliding pressure improved the net heat rate and thereby reduced operating costs by some $560,000 a year. At full load, the ASDs reduced pump power requirements by 2 MW.

The final power plant ASD to be field-demonstrated under the EPRI program—in a sense completing a technology evaluation circle—was installed by Sierra Pacific Power in 1987 at its Tracy Unit 3, a duplicate of the 110-MW Ft. Churchill unit where an ASD had been operating since 1984. The ASD technologies varied, but on the basis of the Ft. Churchill results, the utility anticipated similar benefits from converting a boiler feedpump at Tracy Unit 3 to ASD—even though the unit was not equipped to operate with sliding pressure, as was the one at Ft. Churchill.

In contrast to the 12-pulse load-commutated inverter ASD installed at Ft. Churchill, Sierra Pacific Power selected for Tracy the latest technology available at the time: a 6-pulse input and output current-source GTO-PWM inverter with an input transformer and an output capacitor filter.

After a number of GTO failures due to severe lightning conditions, the Tracy boiler feedpump ASD has performed without major problems since late 1987. As at other installations in the test program, a bypass circuit around the ASD has proved valuable at Tracy in permitting unit operation without the ASD when there were problems or failures.

Because the Tracy unit uses a different turbine generator than the Ft. Churchill unit and has not been modified to achieve equally low minimum loads, the economic performance of ASD conversion was not comparable to that seen at Ft. Churchill. Without sliding-pressure operation and without the potential for a reduction in minimum load because of its more-recent plant design, the Tracy unit achieved less than half of Ft. Churchill's energy savings from reduced pumping requirements. Annual savings from ASD control at Tracy were pegged at $88,000. Still, the performance and reliability at both the Tracy and Ft. Churchill installations have been such that Sierra Pacific Power continues to install ASDs on other large power plant equipment.

Optimal power plant ASD now identified

Results from EPRI's field test program are bringing to the attention of member utilities the remarkable advances in power electronic control of large induction motors for power plant application. Various housings, cooling systems, rectifier arrangements, and inverter technologies have been analyzed, and preferred ASD configurations and application procedures have been identified.

Lessons learned from the field tests contributed directly to the development of a specification for a second-generation ASD specifically for power plant induction motors. Its features include an input transformer to control harmonics and, along with improved grounding, to limit line-to-ground voltage at the motor; a small uninterruptible power supply for greater tolerance of voltage irregularities; water cooling for simplified and effective cooling of the thyristors; and a GTO-based inverter to control harmonics to the motor and to eliminate shaft torsional resonance.

These features and other details of the lessons learned from the EPRI field tests have been incorporated in a set of guidelines utilities can use in specifying power plant ASDs for purchase. But even before the preferred ASD configuration and the specification guidelines were published, one utility built on the collective experience accumulated during the field tests in spelling out its requirements for what is one of the largest ASD installations of its kind.

Two 1970s-vintage forced-draft fans on Southern California Edison's 790-MW Ormond Beach Unit 2 used over 9 MW at full power output and more than 4 MW with unit load as low as 60 MW. Since installing ASDs on the fan motors in 1988, SCE estimates power savings of 3.9 MW over a wide load range. The installation incorporates all of the features of the EPRI preferred ASD configuration, as well as other features specified by the utility.

SCE estimates yearly savings of more than half a million dollars in fuel costs over the remaining 25-year life of the plant. The utility also figures it saves $250,000 a year by eliminating obsolete fan control vanes and their O&M cost. Moreover, it's anticipated that the unit's 17-year-old forced-draft fan motors will last longer, thanks to the soft-start feature of ASD control.

Utilities that want to begin to tap the benefits of power electronic ASD control for auxiliary plant motors can get the technical details of EPRI's field demonstration program, along with the preferred-configuration specifications and purchasing guidelines, from EPRI report CU-6914—*Retrofitting Utility Power Plant Motors for Adjustable Speed: Field Test Program.* The report is available from the Research Reports Center, (415) 965-4081.

Further reading

Power Quality Considerations for Adjustable-Speed Drives. EPRI brochure CU.3036.4.91.

Proceedings: Power Quality for End-Use Applications Conference—1990. Prepared by TEM Associates, Inc. January 1991. EPRI CU-7125.

Commercial and Industrial Applications of Adjustable-Speed Drives. Final report for RP1966-4 and RP2951-4, prepared by CRS Sirrine, Inc. July 1990. EPRI CU-6883.

This article was written by Taylor Moore. Technical information was provided by Marek Samotyj, Customer Systems Division.

TECH TRANSFER NEWS

Power Applications of Superconductivity

More than two dozen U.S. research organizations with interest in electric power applications of high-temperature superconductivity are proposing a largely government-funded, but industry-led, national program to accelerate the development of prototype components of a superconducting power system. In a white paper developed in response to a request from Dr. Robert White, undersecretary of commerce for technology, the ad hoc industry working group said that major advances in the current-carrying performance of bulk high-temperature superconductors last year, particularly in Japan, means that an aggressive, collaborative American effort to develop power applications should begin now. Otherwise, "the United States could find itself relying primarily on foreign manufacturers for efficient electrical equipment in the next century," the group says.

Citing a lack of coordination in industrial research and development in this country compared with Japan and Europe, as well as market forces and the present U.S. business environment, which discourages long-term, capital-intensive R&D, the industry group is calling for federal cofunding of a $250 million, five-year effort. The program would depend directly on support and resources from the departments of Commerce, Defense, and Energy, with additional support expected to come from the private sector.

The goals of the program would be to develop precommercial prototypes or test versions of motors, generators, transmission lines, transformers, and magnetic energy storage coils based on high-temperature superconducting wires and associated cooling systems, and to demonstrate their use as key elements of a superconducting power system. The widespread use of superconducting technology could significantly reduce the 7% loss typically attributed to the electrical resistance of copper wire in power generation and delivery equipment and could also reduce similar losses in end-use equipment. When cooled to very low temperatures, superconducting materials are able to conduct electricity with little or no loss of energy or power to resistance.

The industry working group noted that a program to develop wire and cable from the new materials for magnet and power applications was recommended by the National Commission on Superconductivity last year. But the present federal funding for high-temperature superconductivity—some $139 million this year—is focused either on basic science and technology or on defense-related applications in electronics, computers, and sensors.

An industry-government collaboration that targets superconducting power system components could preserve American prospects for leadership in a critical emerging technology that will strongly shape the forces of economic competition between the United States and its trading rivals in Japan and Europe in the next century, according to the industry working group. In addition to EPRI, the group's roster includes the major American electrical equipment manfacturers, national laboratories, and major corporate and university research centers active in high-temperature superconductivity for high-current applications.

The group noted that early this year Japan's Sumitomo Electric Industries built and operated a coil fabricated from a bismuth-based, ceramic high-temperature superconducting compound that has generated a powerful, 1-tesla (10,000-gauss) magnetic field—something that the U.S. commission only last year urged as the goal of a five-year program in this country. Although the coil was operated at a very low temperature (4.2 K/–459°F), which required liquid helium cooling, the industry group says that a coil generating 1 tesla in the much-higher temperature range of liquid nitrogen—the target for electric power applications—may well be demonstrated within the next year. ■ *EPRI Contact: Thomas Schneider, (415) 855-2402*

Magnetic Field Star 1000 Goes Commercial

A magnetic field survey instrument developed as part of EPRI research is now commercially available to utilities in a model small enough to be held in the hand. Under a recent agreement, the EPRI-developed Field Star™ 1000 is being marketed by Dexsil Corporation of Hamden, Connecticut. The company also markets EPRI's Clor-N-Oil™ kits for PCB detection.

The Field Star 1000 can be flexibly used as a survey instrument or as a data (time or distance) logger and can generate maps of magnetic flux density for areas inside buildings or outdoors—under a distribution line, for instance. It records the magnetic field components along three orthogonal axes within a range of 0.04–1000 milligauss. Dexsil offers the instrument and accompanying software for about $2400.

The instrument joins the EPRI-developed EMDEX personal magnetic field exposure recorder as commercially available tools utilities can use in responding to customer inquiries about magnetic fields and in determining field levels near utility facilities. The Field Star 1000 is a refinement of a research version of the instrument currently in use in a 1000-home nationwide EPRI survey of residential magnetic fields that is expected to be completed early next year. That version was also used in extensive studies of indoor magnetic fields at a special laboratory house at EPRI's High Voltage Transmission Research Center in Lenox, Massachusetts. The new model of the instrument is ideal for use by utility personnel in the periodic magnetic field measurement workshops held at the HVTRC. It incorporates many features requested by users of the research version, including a collapsible wheel for ease of transport.

EPRI and Dexsil will exhibit the Field Star 1000 at the IEEE Transmission and

Distribution Conference the week of September 22 in Dallas. For product information or ordering, contact Dexsil at (203) 288-3509. ■ *EPRI Contact: Greg Rauch, (415) 855-2298*

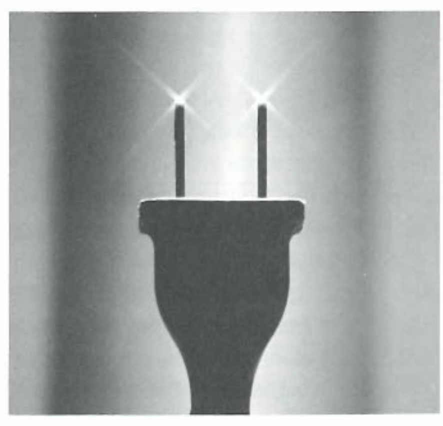
On-line DSM Information Service Launched

A new tool that gives EPRI members access to a variety of information and data on end-use technologies and demand-side management (DSM) issues has joined the on-line services available through EPRINET, the electronic communications network linking member utilities, EPRI research managers, contractors, and other research organizations. Utility staff can use the Demand-Side Information Service (DSIS) to get answers to many questions that often come from management, regulators, and customers about energy and end-use technologies.

The database management system that underlies DSIS runs as a Microsoft Windows application and can answer such questions as these: Who are the contacts at utilities that have high-efficiency commercial lighting programs? What penetration rates have utilities achieved with customer-side energy storage programs? How much has peak demand been reduced through direct load control programs for air conditioners? What is the average life of a heat pump? What battery technologies are being explored for use in electric vehicles?

Users can locate and retrieve both text and data from DSIS. With keywords commonly employed by utility marketing and DSM personnel, users can search the DSIS databases for summary and bibliographic information on EPRI and non-EPRI publications, as well as brief descriptions of end-use technologies and EPRI software products, methodologies, and research results. DSIS also contains easily retrieved numerical data on utility DSM programs and industrial energy use. The results of on-line searches can be downloaded for later review or use in other applications.

New information is incorporated into the databases on a continual basis. EPRI managers expect that additional databases will be added to DSIS, now available in a pilot release, as it evolves into a commercial-grade system. Current EPRINET users can get DSIS free during its pilot release. An improved version, expected in 1992, will carry a $300 license fee. EPRI's DSIS software requires an IBM 286/386 (or compatible) personal computer with 2 megabytes of RAM, a mouse, a modem, and Microsoft Windows 3.0.



Member utilities can obtain the EPRI software through the Electric Power Software Center, (214) 655-8883. ■ *EPRI Contact: Greg Lamb, (415) 855-2449*

Underground Transmission

Prospects for Superconducting Transmission Cable

by Ralph Samm, Electrical Systems Division

In response to dramatic recent developments in superconductivity, EPRI has organized a research project to evaluate the use of new superconducting materials in underground transmission cable applications. This project, known as the superconducting transmission initiative (STI), will draw on the results of both past and current R&D to develop practical transmission cable solutions utilizing superconductivity. The successful development of superconducting transmission cables is expected to result in a lower-cost option for underground transmission systems and will extend the single-circuit capacity now feasible with conventional tools.

Superconductivity developments

Discovered in 1911, superconductivity is the ability of certain materials, when cooled to extremely low temperatures, to conduct direct electric current with no resistance and no losses. For years the only known superconductors were metallic materials that had to be cooled to superlow temperatures—less than 23 K (–418°F)—by means of helium cooling systems, a process that is very complex and costly for practical electrical applications. Because such low temperatures are required, these materials are known as low-temperature superconductors (LTSCs).

A dramatic breakthrough occurred in 1986 when researchers discovered a new class of ceramic materials that become superconducting at significantly higher temperatures. These new materials are called high-temperature superconductors (HTSCs). Since then, other ceramic materials have been discovered that have a critical temperature—the point below which a substance loses essentially all resistance to the flow of electricity—of 125 K (–234°F). Because of the higher temperatures, HTSCs can use cooling systems based on liquid nitrogen, which is relatively inexpensive and easy to handle, in place of the more costly and complex helium cooling systems.

While the discovery of HTSCs has enabled researchers to apply superconductivity principles to the development of underground transmission cables, high critical temperature is not the only requirement that must be met. Superconducting materials in transmission cables must also have high critical current density and high critical magnetic field. Further, they must have suitable mechanical properties; today's ceramic HTSCs are brittle and hence unacceptable for cable applications that require flexible conductors. Also, superconducting power cable applications must be in the voltage and power ranges commonly used by utilities—138 kV or higher and 500–1000 MVA or higher. Equally important, ac losses must be very low, or economic cable applications cannot be developed.

LTSC research

Since the early 1970s, numerous studies have been performed on LTSC transmission line scenarios for both ac and dc systems. These studies confirmed analytical data indicating that superconducting cable systems can be designed to transmit electricity more efficiently—however, only at much higher power levels (3–5 GVA)—than conventional high-pressure, fluid-filled (HPFF) pipe-type underground transmission lines. It was found that a three-phase ac superconducting cable circuit could carry about five times more power than a conventional cable at the same voltage.

The longest and most extensive study was undertaken at Brookhaven National Laboratory (BNL) from 1971 to 1986. This study was based on the testing of a 115-meter single-phase LTSC ac transmission line rated at 138

ABSTRACT *Superconductivity represents an unprecedented technology that can revolutionize the electric utility industry. It offers the potential for devices that are more efficient, compact, economical, and reliable than their conventional counterparts. EPRI is initiating a research project to study the application of new superconducting materials in underground transmission cable systems. The development of practical superconducting transmission cables would yield significant economic and performance benefits on a broad scale.*

kV and 1000 MVA. An actual transmission line would consist of three superconducting cables assembled with standard cable-taping equipment and pulled into a cryogenic pipe (Figure 1, top). The helical nature of the design allowed for uniform longitudinal shrinkage between the dielectric and the metallic components. A major drawback was that the gaseous helium used in the LTSC insulation system is a poor dielectric.

The BNL testing was a significant engineering development that demonstrated the construction and operation of an LTSC ac transmission line. The study showed that such a system must pay a high price for the losses occurring in the conductors and the dielectric and for the heat in-leak through the cryogenic pipe. To extract 1 watt of cable loss and heat in-leak from the transmission line requires about 200 watts of power at the refrigeration system. This inefficiency negates the "loss-free" benefit of the superconductor and results in a limited number of scenarios where LTSC systems could compete with conventional alternatives.

HTSC advantages

While the BNL study showed that LTSCs are not practical for many of today's transmission applications, the outlook improves appreciably when HTSCs are considered. The shift to higher temperatures significantly affects many aspects of a superconducting cable system, most notably the refrigeration system and its energy consumption. HTSC cable systems operating in the 65–80 K range require only 7–10 watts of power to extract 1 watt of cable loss and heat in-leak. This significant reduction of energy consumption has two major impacts on the potential of HTSC cable systems.

First, because of their much lower cooling costs, HTSC systems could become economically competitive over a broader range of applications. In modern HPFF cable systems installed for bulk power transfer of 500–1000 MVA, the capitalized cost of energy over the life of the system can be as much as 50–60% of the total system cost. If the HTSC alternative can halve the energy consumption, it can tolerate material and installation costs much higher than those of conventional pipe-type cable systems. Moreover, if ac losses are demonstrated to be low in the new HTSC materials, energy costs could be reduced to one-third or one-fourth those of present-day systems.

The second major impact of reduced energy consumption is that higher losses can be tolerated, which gives the cable designer greater flexibility in design options. Compared with LTSC cable, HTSC cable (Figure 1, bottom) has some subtle differences that can lower cost. The dielectric can be liquid-nitrogen-impregnated polymer laminate—similar to that developed for BNL—or even paper-polypropylene-paper (PPP) laminate, each of which can be applied with existing commercial equipment. The conductor configuration can be simplified to minimize the component and fabrication expense, depending on the type of HTSC material. Finally, it may be possible to eliminate the superconducting outer shield, further reducing the cost. The trade-off to be considered would be the increase in losses, which still must be determined.

Table 1 compares LTSC and HTSC cable

Figure 1 LTSC cable and HTSC cable for a typical 138-kV, 1000-MVA ac transmission system. The LTSC design, based on that used in the Brookhaven National Laboratory study, requires an expensive and complex helium cooling system that consumes large amounts of power. The HTSC design uses an inexpensive nitrogen cooling system that requires only small amounts of power.

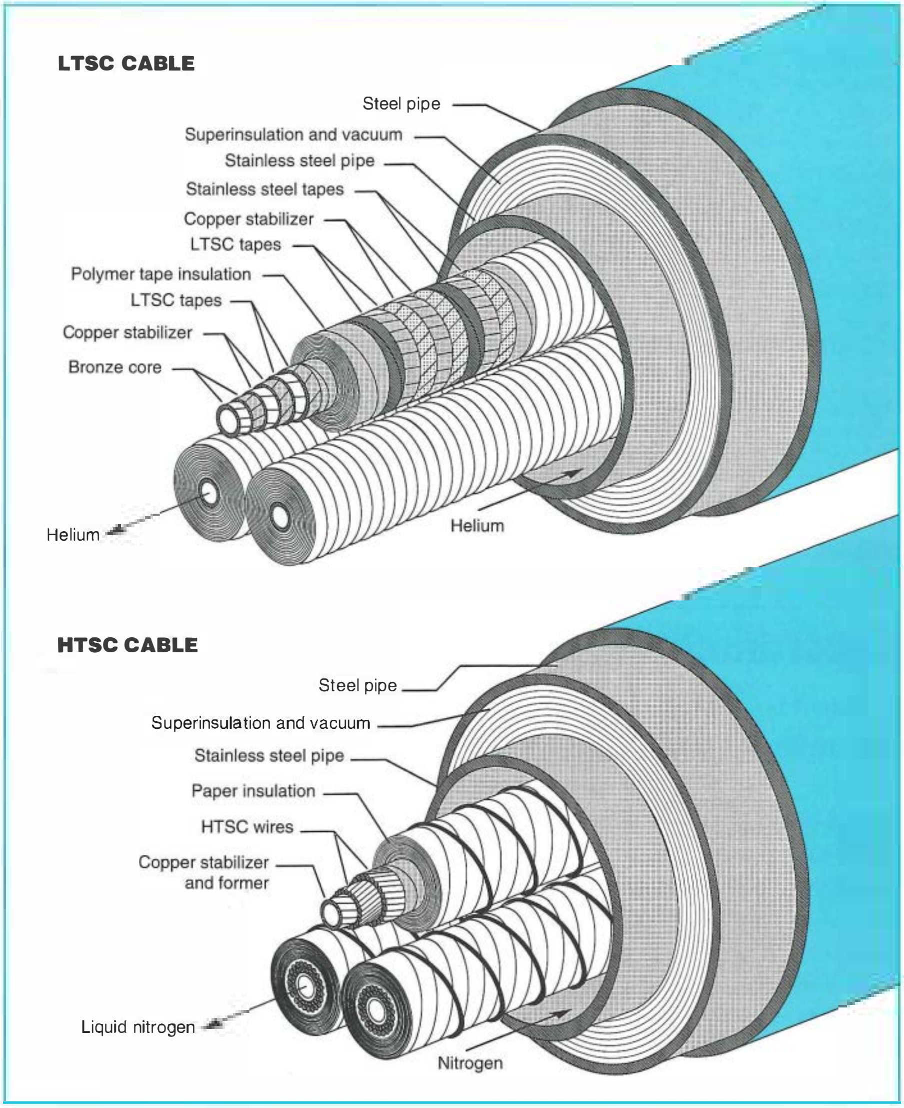


Table 1
KEY PARAMETERS OF LTSC AND HTSC CABLE SYSTEMS

	LTSC	HTSC
Conductor loss (W/m)	0.2	0.2 (assumed)
Dielectric material	Polymer tapes	PPP or paper tapes
Dielectric loss (W/m)	> 0.1	0.2–1.0
Enclosure		
Outer diam (cm)	30	30
Inner diam (cm)	15	15
Heat in-leak (W/m)	0.5	0.4
Total line loss (W/m)	0.8	0.8–1.6
System power consumption (kW/km)	160	6.4–16

Note These designs are for a typical 138-kV 1000-MVA ac transmission system

systems for a typical 138-kV, 1000-MVA ac system. Note the large reduction of power consumption with the HTSC cable.

STI objectives

The STI program seeks to combine the results of past LTSC studies with the results of current HTSC research and development to design viable HTSC cable systems. A major part of this program involves combining the principles of cable technology with those of cryogenics.

An effort is under way to develop a working HTSC dc prototype. While most utility applications require alternating current, a direct-current prototype will be easier to develop and test. Researchers then hope to apply the dc test data to the development of a more practical ac prototype.

Before a practical cable system can be designed, however, more research is needed. One important requirement is the development of an HTSC that has good mechanical properties as well as high critical current density and high critical magnetic field. Also, the ac losses of superconductors must be determined. Manufacturing techniques must be developed to make HTSC cables cost-competitive. And many other technical issues, such as operating temperature, insulation, refrigeration spacing, and contingency requirements, must be resolved.

Although a great many challenges remain, much progress is being made toward the goal of HTSC transmission cables as a commercial reality. Researchers estimate that superconducting transmission cables have a good chance of being used in utility systems early in the twenty-first century

Environment and Energy Management

Opportunities in Water and Sewage Treatment

by Myron Jones, Customer Systems Division

Municipal water and sewage treatment (MWST) facilities offer significant opportunities for demand-side management (DSM) and the application of electrotechnologies. Such facilities typically account for 25% or more of a municipal energy budget. Though nationwide data are limited, electricity consumption at MWST facilities may be as high as 8% of total U.S. electricity use. Many MWST plants were built before the energy price escalations of the 1970s and thus are excellent candidates for improvements in efficiency and load management. Further, the 1986 Amendments to the Safe Drinking Water Act will require additional treatment and new facilities, substantially raising the cost of operating water treatment systems and providing additional incentives for introducing new technologies.

In response to this challenge, EPRI is inviting member utilities and their MWST customers to join a collaborative project to evaluate and demonstrate DSM options and electrotechnology applications in MWST operations. Participants will receive reports, help conduct projects, support demonstrations, and attend workshops to review projects. DSM audits will be conducted at sites selected by participants. Also, on the basis of proposals received, utilities will be chosen to host electrotechnology demonstrations.

Facility characteristics

Virtually all electric utilities have MWST facilities in their service areas; more than 60,000 municipal water supply plants and 15,000 wastewater treatment plants are now operating in the United States. In both types of facilities, most of the electric energy goes to power motors that drive compressors and pumps. Electricity typically accounts for 25–30% of the annual operating costs of MWST plants.

Because energy costs had little influence on the design of many existing plants, considerable potential exists to retrofit more-sophisticated technologies to increase energy efficiency. At the same time, the expansion of facilities to meet rising demand and fulfill new regulatory requirements will accelerate the introduction of new treatment processes that are highly energy-intensive.

Specifically, many drinking water systems will have to satisfy new microbial standards, filtration requirements, and monitoring rules while providing enhanced disinfection, reducing by-products, and controlling corrosion. Sewage plants face toxicity reduction requirements as well as new limitations on sludge disposal. Meeting these needs in the most cost-effective, energy-efficient manner will require close cooperation between operators of water treatment facilities and electric utilities.

DSM options

Some older MWST plants can save 20–30% in electricity use by introducing more-efficient motors and drives and computerized process controls. The city of Columbia, Tennessee, for example, recently installed a 600-hp electronic adjustable-speed drive on two aeration blowers at a sewage treatment plant, which reduced power consumption by over 20%. And Detroit has completed a design study of computerized control of water distribution pumping facilities, which may save the city more than $1 million a year. The capital cost of such retrofit options is generally relatively low.

Operators of new facilities can consider more-ambitious DSM options. When Seattle expanded its Renton wastewater treatment plant, for example, it introduced electric heat pumps to recover thermal energy from the plant's effluent. This recovered energy is then used in the sludge digester system and in the facility's heating, ventilating, and air conditioning system. The thermal recovery system also provides energy for booster heat pumps that supply high-temperature applications. In the future, effluent thermal energy may also be used for district heating. Puget Sound Power & Light contributed to the cost of installing the heat recovery system.

Another DSM option is to use sludge digester gas to fuel an electrical cogeneration system. Such a system might generate electric power for sale to a local utility during peak demand periods, while also providing thermal energy for internal plant operations.

The EPRI project will undertake a generic study of the technical and economic feasibility of several DSM options for MWST facilities. These options include off-peak operation, energy control systems, adjustable-speed drives, and high-efficiency motors. The project will also explore other applications of heat pumps.

ABSTRACT *EPRI is launching a collaborative project to evaluate and demonstrate demand-side management options and electrotechnology applications in municipal water and sewage treatment (MWST). Most MWST facilities were built before energy efficiency became an important design consideration. Such facilities are major users of electric power, nationally consuming at least 100 billion kWh a year, and offer significant opportunities for load shaping and energy efficiency. The EPRI project, being developed in collaboration with the American Water Works Association Research Foundation and the Water Pollution Control Federation Research Foundation, will investigate the potential savings of such demand-side options as energy control systems and adjustable-speed drives. It will also sponsor development/demonstration of advanced electrotechnologies, including ozone disinfection and electroacoustic sludge dewatering.*

Electrotechnology applications

Recognizing the growing challenges of waste and water management, EPRI conducted a study some years ago to identify electrotechnologies that might prove useful in MWST facilities. The results were published in a 1987 EPRI report (EM-5418). Some of the applications and technologies identified in the study—as well as some newly available technologies—are candidates for demonstration in the collaborative MWST project. In particular, the project will investigate ozone disinfection, sludge dewatering, and electron beam sterilization.

Ozone (O_3) is a powerful oxidant that is often used in conjunction with ultraviolet light to treat drinking water, disinfect wastewater, and control odor. It is also used for treating cooling water and destroying volatile organic compounds. Ozonation is already a standard treatment for drinking water in Europe and is beginning to gain acceptance in the United States as a substitute for chlorination. It offers improved water quality, reduces toxic chlorination by-products, and enhances safety by reducing the need to store large volumes of liquid chlorine in urban areas.

Ozone is an unstable gas that must be produced at its point of use by passing air or oxygen through a discharge gap between high-voltage electrodes, a process that converts O_2 to O_3. This process is fairly energy-intensive, requiring 16–24 kWh of electric power per kilogram of ozone. However, because ozone is the strongest disinfectant and oxidizing agent used for water treatment, only short contact times and small dosages are necessary: 2–3 mg of ozone per liter of water. Ozone disinfection of drinking water for a city of 500,000 could use more than 10,000 kWh per day. Wastewater disinfection could add another 10,000 kWh per day.

The MWST project will evaluate both existing and potential ozone applications and will examine the possibility of using off-peak electric power to produce ozone. Demonstrations will include disinfection of drinking water and wastewater, and seminars on the results will include visits to the demonstration plant sites.

The second electrotechnology application to be investigated is sludge dewatering and disposal—one of the most costly and difficult problems facing municipal treatment plant managers. Many current sludge disposal options are being foreclosed. Ocean dumping is being banned outright; landfill disposal is costly and increasingly problematic because of restrictions on toxic materials and groundwater contamination; and while incineration is likely to increase, it requires supplementary fuel and produces an ash that may be hazardous. Improvements in sludge dewatering—typical moisture content is now some 75%—could simplify disposal considerably.

One of the more promising new technologies for this purpose is electroacoustic dewatering (EAD), which uses an electric field and ultrasonic sound to reduce the moisture content of sludge. Pilot plant testing of EAD has demonstrated a doubling of sludge solids content, which could reduce transport and landfill costs by as much as 50% or allow incineration without supplemental fuel.

A typical EAD device includes a positively charged roller (anode) and a multilayered belt, which passes over the roller and which has sludge squeezed between its layers. The outermost layer is a porous, negatively charged belt (cathode), through which droplets of water are pressed while negatively charged solid particles move toward the inner anode. Ultrasonic sound waves from a surrounding transducer assembly help separate the solid particles from the liquid.

Sludges that have previously been treated with ordinary belt presses or centrifuges enter the EAD press with a dry solids content of 10–23% and leave with a dry solids content of 28–40%. This process has lower energy requirements than other dewatering systems. It may provide a critical link in sludge disposal, given that incineration usually requires a sludge with at least 28% dry solids and that land application may require 35% dry solids.

Some researchers are studying the possibility of emulsifying a sludge-oil mixture for cofiring in utility boilers. In addition, Texaco is considering conversion of the Cool Water gasification–combined-cycle power plant in southern California to burn a mixture of coal and sewage sludge. Various techniques for drying and mixing the sludge are being evaluated.

Other advanced dewatering technologies include microwave processing of sewage sludge, which has been patented in Europe, and freeze dewatering, which has been demonstrated at small scale. In addition, electric arc furnace vitrification of sludge incinerator ash has potential for reducing ash volume and rendering the material nonhazardous.

The MWST project will evaluate several sludge-dewatering options and will conduct a demonstration of the EAD process. Plans also call for testing of incinerator ash vitrification.

The third main electrotechnology option to be investigated—electron beam, or e-beam, treatment—bombards a thin stream of water with high-speed electrons to kill microorganisms and destroy many toxic organic contaminants. Electron beams have been in commercial use for many years to disinfect medical supplies and to preserve food. Now experiments are under way to test the feasibility of this technology for treating both potable water and sewage. The EPRI project will evaluate the technology's commercial potential.

A collaborative approach

The MWST project is being proposed for funding through EPRI's recently announced "tailored collaboration" approach, whereby member utilities can augment their dues with research funds for specific projects; the Institute provides matching funds for these projects.

The participation of the Water Pollution Control Federation Research Foundation and the American Water Works Association Research Foundation, which represent water and wastewater treatment facilities nationwide, will benefit the project significantly—sharpening the research focus, accelerating technology transfer, and enhancing project resources. The U.S. Department of Energy is considering cofunding the EAD sludge-dewatering demonstration.

Exploratory Research

Amorphous Silicon Thin-Film Photovoltaics

by Terry Peterson, Generation and Storage Division

Thin films of amorphous silicon (a-Si) and a-Si alloys used in multijunction solar cells have very good prospects for meeting EPRI's cost and performance targets for flat-plate bulk power applications—about $70 per square meter of module at a sunlight-to-electricity conversion efficiency of 15%.

Multijunction cells, which consist of different thin-film layers tailored to absorb specific light wavelengths, can convert more of the sunlight spectrum to electricity than cells constructed of only one type of material. Triple-tandem multijunction cells containing layers of blue-light-absorbing amorphous silicon–carbon alloy (a-Si,C), green-light-absorbing a-Si, and red-light-absorbing amorphous silicon–germanium alloy (a-Si,Ge) are very likely to meet EPRI cost and performance targets if two major stumbling blocks can be overcome.

First, a better understanding of the fundamental properties of a-Si thin films, and how these properties depend on growth conditions, is needed. A particularly important challenge in this area is to overcome the light-induced degradation of a-Si, known as the Staebler-Wronski effect (SWE). Second, a better understanding of how amorphous thin-film devices work is necessary in order to optimize cell designs. To date, these problems have resulted in an empirical design approach that

ABSTRACT *Modules of solar cells using thin films of amorphous materials have the potential to be cost-effective providers of bulk power. To realize this goal, cell developers need a better understanding of amorphous thin-film growth and of cell operation and design. Exploratory research in these areas is making significant progress. Together with other, more-applied research, it could lead to the development, later this decade, of thin-film solar cells that meet cost and performance targets for utility applications.*

has forestalled improvements.

EPRI is focusing on these issues through its amorphous thin-film photovoltaics research program, which began in 1983. The program involves an extensive team: research contractors at five universities, an industrial advisory committee, and EPRI staff. The Solar Power Program of the Generation and Storage Division has primary responsibility for this work; the Office of Exploratory and Applied Research supports the division's efforts by funding some key projects that have broader and longer-range implications.

The research goals are to make high-quality thin-film alloys, optimize thin-film growth, design optimized thin-film devices, and mitigate light-induced instability in thin films. Because each of these tasks requires an improved understanding of amorphous thin-film physics and chemistry, the seven ongoing projects at the five universities are closely coordinated.

Five of the projects are sponsored by the Generation and Storage Division. At Princeton University, researchers have made the first low-bandgap (1.2 eV) a-Si,Ge thin films suitable for use in solar cells (RP2824-2, RP3063-1). Future work will involve constructing and testing cells made of this material. Researchers at Stanford University are using thermodynamic modeling to study the SWE (RP1193-11). To test their theoretical model, they are investigating the roles of temperature, light intensity, light-soaking time, and other variables. A different approach is being taken at Iowa State University, where researchers are using computer-generated atomic models of amorphous materials to investigate SWE mechanisms (RP3070-1). They have found that hydrogen, which is present in all high-quality a-Si materials, can increase or decrease the materials' stability, depending on its concentration and bonding configuration.

The growth mechanisms and properties of a-Si thin films are being investigated at the University of Illinois (RP2824-1). This project's goal is to develop methods for depositing improved thin-film materials at high film growth rates. At Pennsylvania State University, researchers are measuring the physical parameters of a-Si thin films and are also studying a-Si,C alloys (RP1193-14).

Complementing these more-applied projects are studies at Penn State (RP8001-3) and the University of Illinois (RP8001-7) funded by EPRI's exploratory research group. This report highlights milestones recently achieved in these two projects.

Blueprints for high efficiency

The Penn State researchers have developed one- and two-dimensional versions of a computer model capable of predicting how an a-Si thin film with specific characteristics will perform in a solar cell. Known as AMPS (analysis of microelectronic and photonic structures), the model will enable researchers to assess cell performance without having to create the cell. Previous cell models relied on numerous assumptions known to be generally valid for crystalline Si. AMPS has shown that some of these assumptions are often invalid for a-Si and that, as a result, earlier model predictions about the performance of a-Si solar cells are inaccurate.

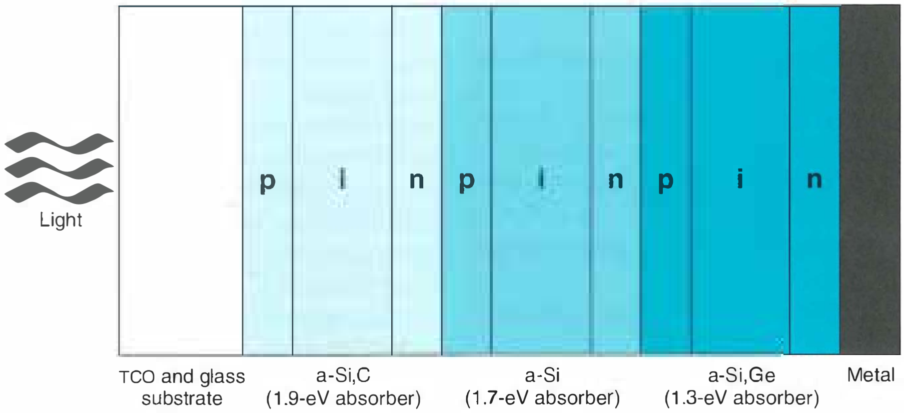
AMPS incorporates information about the fundamental physical properties responsible for the electrical behavior of a-Si thin films in photovoltaic devices. For example, it represents device contacts and layer interfaces in terms of electron-state densities and electron-hole recombination rates rather than by using arbitrary boundary conditions, such as a fixed quasi-Fermi level. This allows much greater insight into the key factors that affect device performance than is possible with more phenomenologically based models.

The Penn State researchers are using a-Si thin-film parameter measurements from the other EPRI projects to fine-tune AMPS. Materials parameters derived from various experiments are input into the model, and predicted film behavior is compared with actual results.

The most important contribution of AMPS to date has been to improve understanding of several common materials characterization experiments. For example, the model has provided new insights on the Kelvin-probe experiments used to map the internal electric fields in growing films. AMPS simulations have underscored the importance of properly accounting for the sample temperature when interpreting experiment results.

More significant, the model has shown that the surface-photovoltage (SPV) measurement (used to determine the average distance that electrons and holes diffuse between photoexcitation and their decay to equilibrium) does not generally work with a-Si materials. The SPV measurement requires that the semiconductor's internal electric fields be negligible in the diffusion region. Although this is often the case for crystalline Si, AMPS simulations have

Figure 1 Stylized cross-sectional view of the high-performance triple-tandem a-Si thin-film cell. Each of the three component cells has a p-i-n configuration (that is, three layers of doped and undoped material), and each absorbs a different portion of the solar spectrum. The three cells are connected in optical and electrical series between the front (transparent conducting oxide, or TCO) and rear (metal) current-collecting contacts.



revealed that it is almost never true in a-Si.

A new technique—the steady-state photograting method—has replaced the SPV technique for carrier diffusion measurements; but because it too relies on crystalline Si assumptions, it must be validated. The Penn State researchers will soon apply their two-dimensional version of AMPS to this problem. Although it is not usually necessary to simulate thin-film solar cells in three dimensions, a three-dimensional version of AMPS would be a valuable tool for developing more-complex devices, for example, field-effect transistors, metal oxide semiconductor–controlled thyristors, and polycrystalline-Si power devices. EPRI's exploratory research group is currently considering the option of developing a three-dimensional AMPS.

As AMPS matures, it is assuming a central role in EPRI's thin-film solar cell program. AMPS simulations of the triple-tandem multijunction cell (Figure 1) are identifying areas where a greater understanding of materials properties is needed and where efforts to produce films with specific properties would be particularly worthwhile. However, because researchers do not have exact values—or, in some cases, even appropriate ranges—for various key parameters, AMPS cannot yet produce precise performance predictions for the complete tandem cell. AMPS developers and a-Si materials researchers are cooperating closely to fill in the blanks and improve the model's precision.

New windows on film growth

Over the past three years, Illinois researchers working on the other EPRI exploratory thin-film photovoltaics project have developed and proved feasible two new measurement techniques to identify and characterize bonding mechanisms between hydrogen (H) and Si atoms in growing a-Si films. The new techniques are called reflection-absorption infrared spectroscopy (RAIRS) and spectroscopic ellipsometry (SE).

This project was born of a paradox involving two methods currently used to grow a-Si thin films. The most commonly used method is plasma-enhanced chemical vapor deposition (PECVD), or glow-discharge deposition. Researchers working on the Generation and Storage Division project at Illinois have had success in making high-quality a-Si thin films with another method—reactive magnetron sputtering. Although PECVD chemistry and sputtering chemistry are believed to differ greatly, the resulting films (deposited under their respective optimal conditions) appear to have similar bulk properties. To explain this paradox, the Illinois researchers hypothesized that reactions between H and Si atoms in the subsurface layers (the region between the top atom layer and the next four or five layers) determine the bulk materials characteristics of a-Si films.

Ideally the Si atom forms four bonds, but it is structurally impossible for every Si atom in a growing amorphous film to align with four others. As a result, a-Si films contain some Si atoms that are bonded to only three others, leaving "dangling" bonds. H atoms saturate these dangling bonds, reducing the density of electron states in the energy gap between the conduction and valence bands from about 10^{20} to about 10^{15} per cubic centimeter. Without H, the high density of dangling bonds renders the material unsuitable for any electronic device.

Typically, a-Si films made by PECVD contain about 10% H, more than 10 times the amount needed to saturate the dangling bonds. Many now suspect that this excess H contributes to light-induced instability. To date, however, efforts focused on making high-quality a-Si films with less H have been unfruitful. This is one of the problems the Illinois researchers are attempting to resolve, using the new measurement techniques to improve their understanding of the role of H in a-Si film growth.

The RAIRS technique involves shining an infrared beam at a grazing angle onto a film as it is being deposited. The grazing incidence emphasizes the absorption characteristics of the region just below the surface of the film. As the beam's wavelength is altered, the changes in absorption characteristics are used to identify chemical species and their concentrations in the subsurface layers during film formation.

In the SE technique, a polarized, variable-wavelength infrared beam is trained onto the film. Changes in the polarization and intensity of the reflected beam provide a depth profile of the film's optical properties and, indirectly, of its structure and composition. The combination of RAIRS and SE gives new insight into the evolution of the physical, chemical, and electronic structure of a-Si thin films.

Looking ahead

The Penn State model will ultimately be used to determine the specific materials characteristics and configurations needed to optimize solar cell performance, and the growth mechanism experiments at Illinois will provide insights on how to set deposition conditions to produce films with these optimal characteristics. The goal of EPRI's amorphous thin-film photovoltaics research program is to transfer this knowledge to commercial thin-film photovoltaics manufacturers, enabling them to produce solar cells that meet the cost and performance requirements for electric utility industry applications. If research continues to progress as planned, this goal should be realized in the mid-1990s.

Utility Planning

Managing Reactor Vessel Embrittlement

by T. J. Griesbach, Nuclear Power Division

For utilities that operate nuclear power plants, the business forces continue to change. Conflicting regulatory pressures and a tougher competitive environment make nuclear plant management more difficult. In addition, the uncertainties associated with building and licensing new plant facilities make it attractive to renew the licensing of existing plants. Successfully dealing with these pressures requires close attention to decisions affecting plant operations and plant longevity through the development of a well-planned strategy. Because of rising operation and maintenance costs, it is important to weigh decisions in terms of the overall improvements in safety, availability, and efficiency. Strategic cost management has proved to be an effective approach for many utilities faced with decisions involving large capital expenditures.

Dealing with the issue of reactor pressure vessel embrittlement must be viewed as part of a nuclear plant maintenance program. The first objective of such a program is to ensure that the equipment maintains its basic reliability during operation. Because a failure of the reactor pressure vessel is unacceptable, safety margins defined by the ASME Boiler and Pressure Vessel Code and by the NRC must be strictly maintained. Once these safety margins are ensured, future decisions affecting the vessel can be viewed in terms of balancing overall costs and risks. As part of an embrittlement management program initiated in 1988 (RP2975), EPRI is developing tools to help utilities assess embrittlement-related concerns and make decisions consistent with the overall utility planning process.

ABSTRACT *Neutron embrittlement of reactor vessels is a concern for many utilities. To ensure vessel integrity, nuclear plant operators must keep embrittlement within acceptable limits. Corrective measures may be necessary to prevent embrittlement from exceeding those limits and perhaps forcing early plant retirement. A newly developed decision analysis code called VTESTER can help utilities identify and implement cost-effective, plant-specific strategies for managing embrittlement and ensuring safe operation. With VTESTER and other EPRI products, utilities can integrate reactor vessel decisions into the overall planning process. This approach can effectively extend the useful life of a vessel while minimizing operating costs.*

Embrittlement concerns

Exposure to neutron irradiation tends to reduce the toughness of reactor vessel steels. For the past 15 years, EPRI has sponsored research to investigate the mechanisms of neutron irradiation embrittlement in pressure vessel steels and to evaluate the effects on vessel integrity. The issue of embrittlement is most important for PWR vessels because of the relatively high levels of neutron fluence at the vessel wall. While the fluence levels are not as great in BWRs, embrittlement also affects these vessels. EPRI-sponsored research has been instrumental in the development of approaches that use material surveillance, testing, inspection, and analysis methods to protect vessels from any potential failure. These approaches rely on engineering fracture mechanics techniques that are now widely accepted by the ASME and regulatory bodies in establishing safe operating criteria for reactor vessels.

It is up to each utility to decide how best to meet the acceptance criteria established by the ASME Code and the NRC for safe vessel operation. The planning horizon must take into account the desired life of the vessel. Where-as other major components—even the large steam generators in PWRs—can be repaired or replaced, the reactor vessel would be difficult, if not impossible, to replace in most cases. Thus it may be the critical plant component, and decisions to ensure its safety and integrity must be integrated with maintenance decisions on other plant systems and components. Since reactor vessel embrittlement is an age-related degradation mechanism, the costs of ignoring or postponing vessel decisions may be high in comparison with the costs of implementing remedial measures. The timing of such decisions is therefore an important part of an effective strategy and must be factored into a cost control program.

The most important aspect of operating a reactor with an embrittled pressure vessel is preventing brittle fracture of the vessel. This safety issue is important during the unlikely occurrence of an event that results in cold safety injection water hitting the vessel wall—a phenomenon called pressurized thermal shock (PTS). In the early 1980s, many safety studies evaluated reactor vessel integrity during PTS events. These studies used both deterministic and probabilistic risk methods in establishing vessel embrittlement limits that would ensure safe plant operation. In 1985 the NRC issued a regulation based on these safety studies. Called the PTS Rule, it specifies criteria for the maximum permissible level of vessel embrittlement.

The index of embrittlement used in the PTS Rule is known as the nil-ductility reference temperature, or RT_{ndt}. This parameter is a convenient measure of irradiation damage, and it also serves as a correlate of the risk of vessel brittle fracture. The use of RT_{ndt} as the critical parameter makes it possible to predict future levels of embrittlement and thus to assess the vessel's remaining operating life within the prescribed safety limits.

Utility options

At all operating plants, neutron irradiation damage of reactor pressure vessels is carefully monitored, and future damage is predicted. Cumulative damage is strongly dependent on the composition of the vessel steel and the weld materials and on the extent of neutron exposure of the vessel wall. Mechanical testing is performed to determine the properties of the steel before it is exposed to irradiation. Then test coupons are placed in the vessel and are periodically removed and tested to measure changes in the material properties. The data from these tests are used to determine the vessel toughness—that is, its ability to resist fracture under severe loading conditions. The toughness of the vessel must be preserved by minimizing the irradiation damage resulting from plant operation. Ultimately, each plant owner must demonstrate compliance with the regulations governing the limits on embrittlement for all normal and abnormal conditions of the plant.

The most sensitive area of the reactor vessel wall is the beltline region (Figure 1), the portion of the vessel that is near the reactor core and that consequently receives the greatest amount of neutron irradiation. The welds in this region are usually considered to be the limiting materials; thus they must be accurately characterized and monitored for the effects of embrittlement. In addition to monitoring changes in the properties of the welds, it is important to be able to estimate the amount of future damage to the material by means of trend-curve prediction methods. The remaining vessel life can be determined by comparing the predicted levels of embrittlement (calculated as a function of years of plant operation) with the allowable limits.

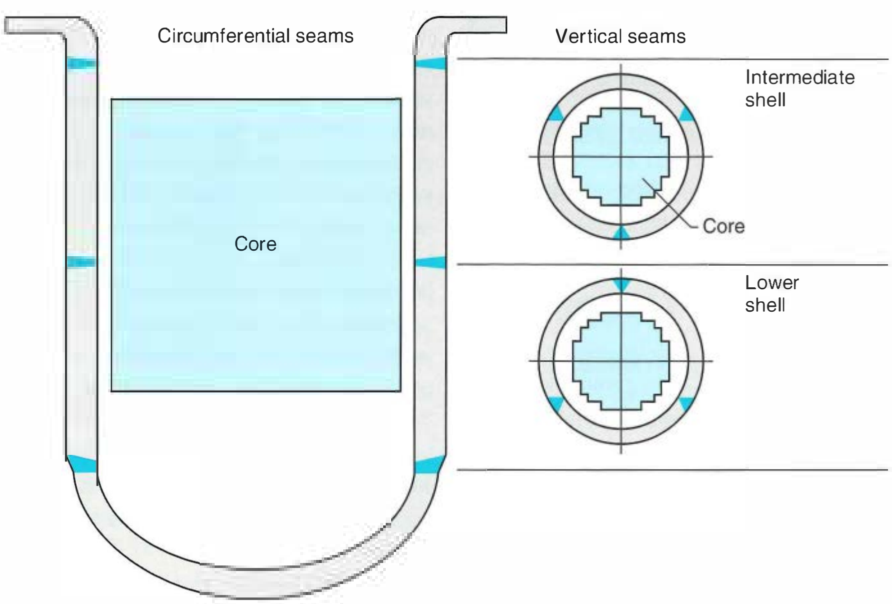
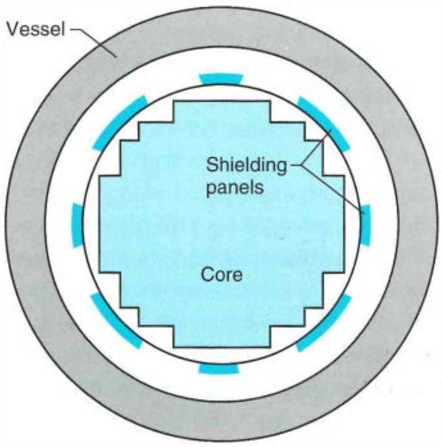


Figure 1 In the reactor vessel beltline region, where proximity to the core results in high levels of neutron irradiation, the weld materials at the circumferential and vertical seams are of particular importance to vessel integrity. The properties of these materials must be monitored closely for the effects of neutron embrittlement.

If the projections indicate that embrittlement limits will be exceeded and that the expected useful life of the vessel will be cut short, the utility must take some action to minimize the embrittling effects. Remedial measures include flux reduction at the vessel wall by fuel management, flux reduction by shielding, and vessel thermal annealing. These options vary in cost and effectiveness, depending on the particular plant. A plant-specific evaluation is needed to determine the best available option for reaching the desired vessel life.

The first option that may be considered for reducing flux at the vessel wall is to change the fuel-loading pattern. The more highly burned fuel is moved to the peripheral fuel assembly locations, thereby reducing neutron leakage from the core. Flux reductions on the order of 50% may be achievable with this strategy. Further reductions in flux at the vessel wall by fuel management may require that the outer fuel assemblies be modified to absorb more escaping neutrons. In most cases,

Figure 2 Shielding materials placed between the reactor core and the vessel wall can achieve major reductions in neutron flux, thereby minimizing embrittlement.



these severe changes to the fuel-loading pattern complicate the fuel management process and result in fuel-cycle cost penalties.

A second option for reducing flux at the vessel wall is to install a shielding material between the core and the wall. Effective shielding materials may either reflect or scatter the neutrons before they can cause damage to the vessel steel. Figure 2 shows an array of neutron-shielding panels that could be fixed to the internal core barrel structure. It is possible to achieve reductions in neutron flux of 50–75% by using this technique, although it may cost more than the fuel management option.

If flux reduction methods are not sufficient to minimize radiation damage, or if a further extension of vessel life is desired, a third option may be available: thermal annealing of the vessel material to restore the toughness properties. Annealing is done in place by heating the walls of the vessel to a temperature sufficient to remove some or all of the effects of neutron embrittlement. Although annealing has not been performed at any commercial plant in the United States, it has been successfully used in nine plants in the Soviet Union to restore vessel properties. Since the annealing approach requires significantly more development for application to U.S. plants, it may be the most expensive of the three options; however, its long-term benefits may justify the development costs.

Decision making

Choosing the best options for managing vessel embrittlement is a difficult decision for a utility, which must consider long-range objectives (e.g., plant license renewal) and short-term goals and constraints (e.g., plant reliability, plant availability, and utility revenue requirements). Each of the possible remedial actions presents some form of trade-off between a short-term cost and a longer-term benefit. This situation is further complicated by uncertainties in the overall planning process.

The technique known as decision analysis is appropriate for this situation. This approach can be used to evaluate and compare various decision strategies in order to determine the best method for improving plant safety (i.e., reducing risks) while minimizing maintenance costs. The reactor vessel decision process is complicated by the many interactions between various factors, including the timing of the possible remedial actions, their costs, their benefits in terms of extended vessel life, and the necessity of compliance with regulatory requirements. With decision analysis, uncertainties associated with the decision can be included in an explicit manner that allows a utility planner to choose an effective strategy with a high degree of confidence. Also, it is possible to address reactor vessel embrittlement in a manner consistent with planning for other revenue-intensive decisions when establishing a good maintenance program.

To assist utility planners and engineers with the reactor vessel decision process, EPRI has developed a software program called VTESTER. Developed jointly with Decision Focus and Westinghouse Electric, VTESTER uses a decision analysis approach for performing plant-specific cost-benefit analyses of decisions related to reactor vessel embrittlement. It operates on IBM-compatible personal computers and features the EPRIGEMS format for ease of use. With its built-in engineering and economic expertise and its sophisticated decision analysis techniques, VTESTER is a powerful tool; yet it operates in a simple, interactive manner.

Utility application

Under its embrittlement management program, EPRI is working with several utilities—including Commonwealth Edison, Pacific Gas and Electric, and Florida Power & Light—to identify options for minimizing the effects of vessel embrittlement in their plants. A prototype version of the VTESTER code has been applied to the planning process to help these

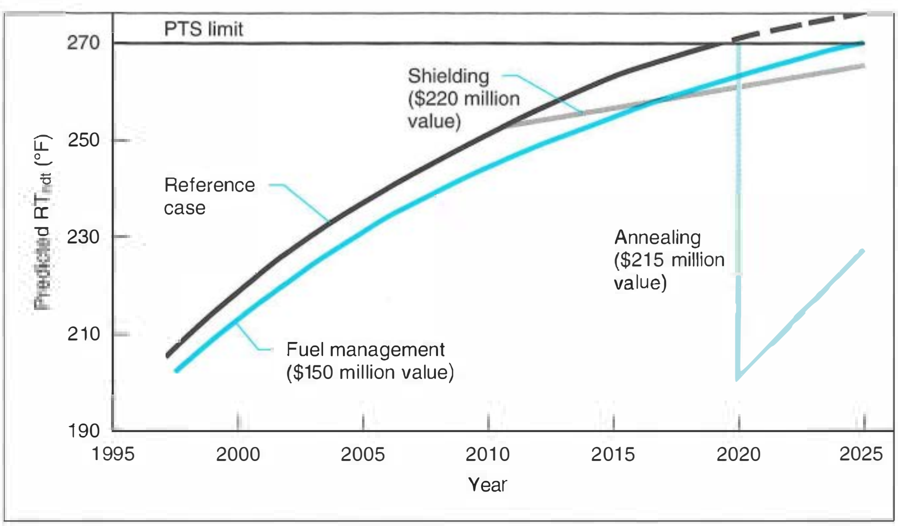


Figure 3 VTESTER was used in a utility case study to evaluate alternatives for controlling embrittlement. The goal was to keep the plant within the NRC's pressurized thermal shock (PTS) limit—as defined by nil-ductility reference temperature (RT_{ndt})—through the year 2025. The option of doing nothing (i.e., no change in strategy) was used as a reference case against which three remedial strategies were evaluated. The calculated net benefit (in 1991 dollars) to the utility of each remedial action is shown in parentheses.

utilities manage embrittlement issues; the results of these pilot studies clearly show the value of this approach.

For example, one planning study was performed to evaluate several alternatives for minimizing the effects of pressurized thermal shock on a vessel. The study's goal was to maintain the vessel within the NRC-defined PTS limit in the most efficient way through the year 2025. The options considered were doing nothing (i.e., no change in strategy), flux reduction by fuel management, flux reduction by shielding, and vessel thermal annealing.

The results of this study are presented in Figure 3, which shows the predicted reference temperature (RT_{ndt}) for each option as a function of years of operation. Taking no action appeared to be a costly option, since it would lead to premature retirement of the plant in the year 2019, when the PTS limit would be exceeded. The three remaining strategies were evaluated in terms of the net benefit to the utility— in present-value (1991) dollars—of staying below the limit. Each of the three was found to offer significant cost savings; shielding offered the greatest savings, $220 million in present-value terms.

This approach has proved to be effective for utility planning purposes: VTESTER can be used to determine an optimal vessel strategy consistent with other concerns for plant maintenance and aging management. The experience gained in the pilot studies is being incorporated into the VTESTER code, along with additional options for evaluating the full range of concerns associated with PWR vessel embrittlement. This soon-to-be-released product will be part of an embrittlement management handbook also being developed by EPRI under RP2975. With these tools utilities can identify effective aging management programs that include the goal of vessel life extension.

In summary, the VTESTER code brings together the necessary analytical techniques and expertise for performing value-based cost-benefit analyses as an integral part of overall system planning. The application of VTESTER will enable utility engineers and planners to ensure plant safety while minimizing the costs of the remedial measures necessary to address vessel embrittlement. This approach will give utilities a new basis for deciding how best to apply their resources for long-term vessel reliability

SO_2 Control

FGDPRISM Applications

by Robert Moser, Generation and Storage Division

The 1990 Clean Air Act Amendments call for substantial reductions in utility sulfur dioxide (SO_2) emissions in the next decade. One valuable tool for optimizing the design and operation of flue gas desulfurization (FGD) systems is process simulation modeling. Modeling FGD processes accurately is complex. Gaseous species are absorbed by, or desorbed from, the scrubbing liquor at varying rates, depending on mass transfer constants and chemical concentrations. Reaction products crystallize while reagent dissolves in both the absorber and the scrubber reaction tank. If chemical conditions are not carefully controlled, liquid-phase compounds precipitate in the absorber.

FGD system suppliers have used empirical models to design and predict the performance of new FGD systems. However, such models are valid only in situations comparable to those that yielded the original empirical data. Thus, to predict performance accurately for a wide variety of conditions, utilities need a simulation model based on chemical engineering principles rather than empirical data.

FGDPRISM (Flue Gas Desulfurization Process Integration and Simulation Model) is a process simulation model for wet limestone and magnesium-enhanced lime FGD systems. Available from the Electric Power Software Center as a production code since April 1991, FGDPRISM is a powerful tool for predicting a number of important FGD system performance indicators via personal computer simulations.

Not only can the model help engineers design and evaluate new FGD systems, but it is also useful for troubleshooting and for investigating process or equipment modifications to operating FGD systems. Through these functions alone, FGDPRISM could save EPRI member utilities millions of dollars in capital expenses in meeting Clean Air Act legislation for new FGD systems and millions of dollars annually in operating these systems. In addition, the model could play a role in several important EPRI SO_2 Control Program products in the next decade; for example, it could serve as the heart of an artificial intelligence control system for improving the reliability of FGD systems and reducing operating costs, and it could be incorporated into a computer based training system for FGD system operators.

About the model

Some 10 years ago, EPRI began developing FGDPRISM on a Univac 1100-series mainframe; today, development is proceeding on a network of Sun workstations. The model, which features the user-friendly EPRIGEMS interface, is designed to run under MS-DOS on IBM-compatible AT-class personal computers. It requires a hard disk drive; EGA graphics; an 80286, 80386, or 80486 processor and math coprocessor; 640 kilobytes of random-access memory; and 1.3 megabytes of hard disk stor age for data files and reports. Because complete system simulations require complex calculations and numerous iterations, speed is important. Therefore, though material balances and very simple system simulations can be run in a reasonable time on a 286-type machine, a 386- or 486-type machine is highly desirable.

FGDPRISM is based on fundamental chemical engineering principles. The model's unit operations modules use equilibrium, mass transfer, and thermodynamic utilities to simulate chemical processes. The unit operations are in sequence and "communicate" with each other through streams defined in the input file. A number of templates set specific sequences for unit operations and streams. These templates define configurations for performing the following: an overall system material balance; simulations of the reaction tank and of spray and/or tray absorbers; and complete system simulations for systems with spray and/or tray absorbers. FGDPRISM can simulate both wet limestone and magnesium-enhanced lime systems, and it can model operation with inhibited, natural, or forced oxidation.

EPRI developed the model in phases, continuously refining the key unit operations and physical chemical data. The first objective was to provide a valuable tool for researchers. The next step—equally, if not more, challenging—is to make the model useful to utility engineers and FGD system operators.

EPRI has been using FGDPRISM in research for three or four years, and in the past year it has become a truly effective research tool. It has been of value in planning and evaluating tests at EPRI's High-Sulfur Test Center (HSTC) and in conducting specific studies for member utilities under RP2248-1, which is investigating FGD chemical process problems. The model has performed well in evaluating the effects of chemical and/or physical changes on system performance. For example, it has accurately simulated how SO_2 removal efficiency is improved by the use of such additives as dibasic acid (DBA) and sodium formate, and how system performance is affected by changes in limestone source or makeup water. The model can also analyze physical changes quite well, such as the addition of a tray to improve mass transfer or the changing of spray nozzles or limestone grind.

ABSTRACT *Utilities have a powerful new tool for use in developing strategies to comply with the 1990 Clean Air Act Amendments: FGDPRISM, a process simulation model for wet limestone and magnesium-enhanced lime flue gas desulfurization systems. The program models FGD systems as a series of independent unit operations connected by process streams, and it uses equilibrium, mass transfer, and thermodynamic principles to simulate chemical reactions and predict performance. FGDPRISM allows utilities to investigate process or equipment modifications to existing FGD systems without performing extensive, time-consuming full-scale tests. The model is also useful for designing and evaluating new FGD systems. It was released as a production code in April 1991.*

FGDPRISM has limitations, however. It can model physical and chemical phenomena only to the extent that we understand them. Thus additional development work is necessary, particularly in the areas of oxidation rates, solids properties, additive consumption rates, and blinding effects on limestone dissolution.

FGDPRISM applications generally fall into three categories: research applications, applications involving operating FGD systems, and applications involving new FGD systems. Though most uses of the model to date have been in EPRI-related research projects, several member utilities used FGDPRISM during the recently completed prerelease test program.

EPRI research applications

The phased development of FGDPRISM allowed researchers to test the component modules as they became ready. This approach provided opportunities to use the modules for utility applications during the model's formative years. For example, EPRI used FGDPRISM in two very different applications for Houston Lighting & Power during this period. The first application investigated three sources of makeup water for HL&P's Parish station FGD system. The model predicted how each water source would affect FGD system chemistry and SO_2 removal efficiency. At that time the model was able to predict relative effects only, ranking the water sources in order of preference. Today, once the model is "calibrated" for the performance of a given plant, it can accurately predict differences in SO_2 removal as a function of the makeup water source.

The second application for HL&P involved its Limestone station FGD systems, which use the performance additive DBA. The utility expects to burn coal of considerably higher sulfur content at the station in future years, and EPRI used FGDPRISM to estimate the DBA concentrations that would be necessary to achieve the required SO_2 removal with this coal.

At EPRI's High-Sulfur Test Center, FGDPRISM is routinely used to establish test parameters and investigate test results for the 4-MWe pilot and 0.4-MWe minipilot wet scrubbers. Using the model for test screening can minimize the number of test runs made on the units. In the past few years, EPRI has used HSTC test results to validate FGDPRISM predictions. Confidence in the model has grown to the point that its predictions are now frequently used to check the data obtained in the test program. FGDPRISM simulations have also confirmed system chemistries under new configurations to determine whether operation is possible without incurring scaling in the units.

Another EPRI research application involved the Miami Fort pilot plant of Cincinnati Gas & Electric and Dravo Lime Company—a facility dedicated to investigating and improving the magnesium-enhanced lime FGD process. Data from the pilot plant, which is operated under the cosponsorship of the state of Ohio, were used to calibrate FGDPRISM for the magnesium-lime process. After calibration, researchers used the model to investigate the test results obtained for a high-velocity scrubbing test block.

EPRI has also used FGDPRISM in internal studies. For example, the Institute's FGD economic evaluations assume the firing of a standard coal and the removal of 90% SO_2. FGDPRISM simulations established the liquid-to-gas (L/G) ratios necessary to obtain this removal efficiency for open-spray towers for both forced-oxidation and inhibited-oxidation wet limestone scrubbers. Then a series of runs was performed to determine to what extent SO_2 removal could be increased by using additives (adipic acid, sodium formate, and magnesium-lime), by raising the pH, and by adding a tray to the tower. The model predicted that use of the organic acid additives would increase SO_2 removal efficiency to about 98% at additive concentrations as low as 400–600 ppm. The use of magnesium-lime as an additive would raise removal efficiency to about 96%; one perforated tray, to about 94%; and pH adjustments, to about 94%.

Not only were organic acids (adipic or formate) found to be the most effective way to increase SO_2 removal, but they also showed no deleterious effects on system operation. Magnesium-lime would be likely to reduce limestone utilization because the higher liquid-phase sulfite associated with its mechanism for improving removal efficiency causes poorer limestone dissolution. The use of a perforated tray would require a larger pressure drop through the tower. Raising the pH has implications for increasing scrubber scaling potential and is rather expensive. Though this study did not pursue the cost implications of these alternatives, researchers will use FGDPRISM in conjunction with the FGDCOST economics model in a future project to investigate ways to optimize FGD system design and flexibility.

Applications for existing FGD systems

FGDPRISM has been used for several utilities to investigate the possibilities of increasing the SO_2 removal efficiency of existing FGD systems—an application that is likely to become common, given the recent passage of Clean Air Act legislation. For example, the Tennessee Valley Authority (TVA) was interested in increasing the SO_2 removal efficiency of its Paradise station FGD system. Data from the plant were used to calibrate FGDPRISM for the mass transfer characteristics specific to the Paradise absorbers. Then simulations were run to predict efficiency increases from adding a perforated tray and/or using an organic acid. The model's predictions indicated that neither the use of organic acids alone nor the installation of a tray alone would increase the SO_2 removal efficiency enough to meet TVA's target. According to the simulations, both the tray and the organic acids would be necessary. This investigation has subsequently included testing at the HSTC. The testing validated the model's tray predictions, but it indicated that organic acids were able to achieve slightly higher SO_2 removal efficiencies than initially predicted by FGDPRISM. TVA is now considering the economics of pursuing these changes at full scale.

FGDPRISM is also useful in examining the effects of reagents on FGD system chemistry and performance. With limestones, both the chemical characteristics (primarily the amount of magnesium that becomes soluble at scrubber conditions) and the dissolution rate are important variables. The dissolution rate can be significant in establishing or limiting the pH at which a scrubber must operate in order to achieve acceptable limestone utilization. For new systems, this factor also helps determine how large the reaction tank must be. The amount of magnesium that becomes soluble in the FGD system affects SO_2 removal efficiency. Depending on the background level of magnesium in the absorber liquor, large increases in soluble magnesium could adversely affect limestone utilization because of sulfite blinding effects.

To adequately model the effects of different limestones in a particular FGD system, several steps must precede the actual modeling. The model must be calibrated for the specific FGD system, which requires using data from the plant at various operating conditions to "back out" mass transfer characteristics for the particular absorber tower. Also, the limestones must be investigated in the laboratory to determine dissolution rate (a model input), grinding characteristics, and the amount of magnesium that will become soluble in the FGD system. Looking at the chemical composition alone will not yield this information. EPRI has developed a laboratory procedure for investigating limestone dissolution at various background chemistries. This makes it possible to tailor an evaluation closely to a specific FGD system. EPRI has worked with Hoosier Energy and Tampa Electric to investigate the performance implications of changing limestone sources for their Merom and Big Bend stations, respectively.

Because the production code version of FGDPRISM has been available to the utility industry only since April 1991, its possible uses have not been fully realized. The following two examples emerged from the prerelease test program within the industry. The control of slurry density in a limestone FGD system has implications for limestone utilization, dissolved-solids levels, and solids precipitation kinetics. At PSI Energy's Gibson station, FGDPRISM simulations were performed to investigate what changes in limestone utilization could be realized by increasing the slurry density. The modeling results indicated that substantial improvements were possible without incurring any detrimental effects from increasing the slurry dissolved-solids levels. Station personnel successfully used these results to justify procurement of new density controls.

At New York State Electric & Gas Corporation's Somerset station, plant personnel used FGDPRISM to examine whether using water from the station's wastewater treatment plant as FGD system makeup would adversely affect FGD system chemistry. The model predicted that the wastewater could be used in the FGD system with no detrimental effects. Subsequently, the station has adopted this change in operating procedure and can frequently shut down its wastewater treatment plant because, under certain conditions, it no longer has to treat and discharge wastewater.

Uses for new FGD systems

To comply with the recent Clean Air Act legislation, Pennsylvania Electric is contemplating installing FGD at its Conemaugh station. In this connection, Radian Corporation—EPRI's primary FGD chemistry contractor and the FGDPRISM developer—has applied the model in a variety of ways that illustrate its usefulness in investigating new FGD system designs.

First, for the coal currently burned at Conemaugh, the analysts used FGDPRISM to prepare curves of SO_2 removal versus liquid-to-gas ratio for three types of wet limestone FGD systems (forced-oxidation, inhibited-oxidation, and DBA-enhanced forced-oxidation systems). A process type was then selected on the basis of economic comparisons, and FGDPRISM was used to develop design specifications.

Material balance calculations determined the impact of coal chloride content and liquid blowdown rates on circulating liquor chloride concentration for three inlet SO_2 levels. Two makeup water streams were used, one for mist eliminator washing and the other for the remainder of process water needs FGDPRISM was then used to determine the L/G ratio required for 95% SO_2 removal. Gypsum scaling potential was calculated for various streams in different parts of the system to determine whether scaling would be a problem. Complete flow diagrams and energy balances were prepared, showing waste production rates, makeup water rates, evaporation, the composition and flow rates of major internal streams, and limestone consumption rates.

FGDPRISM can also be applied to the evaluation of FGD system bids. PSI Energy has received proposals for retrofitting three FGD systems at its Gibson station. Because the utility was one of FGDPRISM's prerelease users, its personnel are familiar with the model and can use it unassisted. They intend to use FGDPRISM to evaluate the proposed designs for the Gibson station. L/G ratio, stream flows and composition, and gypsum scaling potential will be checked for each proposed system. Coal chloride content and makeup water composition will be among the input for these simulations.

Perhaps the most significant way in which FGDPRISM can contribute to better designs is for FGD system suppliers to use the model. In addition to simulating the chemical effects of such factors as liquid-phase alkalinity, limestone type, use of additives, and ultimate chloride concentration—effects specific to each application—the model can simulate such physical design parameters as nozzle type and location, header spacing, and use and location of additional mass transfer devices (e.g., trays and packing grids). Also, it can help suppliers evaluate and optimize designs in terms of their reliability and flexibility in achieving higher SO_2 removal. These qualities are significant in the case of no-spare or single-tower designs, the most economical way to design and operate FGD systems.

Model availability

EPRI member utilities can order FGDPRISM directly from the Electric Power Software Center. Because of the model's complexity, training will be offered—and in fact required—before delivery. Training workshops will be held quarterly in 1991 and semiannually thereafter Also, a users group has been established for support and technical information transfer It meets annually and publishes a quarterly newsletter. Group membership dues are used to fund contractor support for members.

To obtain technical details about the model or the FGDPRISM Users Group, contact the EPRI project manager, Rob Moser, (415) 855-2277. For licensing details, organizations not eligible for EPRI membership (e.g., FGD system suppliers, architect/engineering firms, government agencies, universities, and consulting firms) can contact Tom Guldman, EPRI licensing administrator (415) 855-2866. Nonmember utilities should contact Angus Laird of Member Services, (415) 855-2514, about model availability.

New Contracts

Customer Systems

Project	Funding/ Duration	Contractor/EPRI Project Manager
Hybrid Series Active/Parallel Passive Power Filters (RP2918-13)	$62,000 11 months	University of Wisconsin, Madison/*B. Banerjee*
Assessment of Industrial Demand-Side Management (RP3046-2)	$70,000 12 months	New York State Energy Research & Development Authority/*P. Meagher*
Customer Support Service Center Pilot (RP3085-3)	$99,300 2 months	Barakat & Chamberlin/ *L. Lewis*
Electric Smart House Home Automation and Project Support (RP3163-4)	$251,300 14 months	Plexus Research/ *L. Carmichael*
Commercial Heat Pump Water Heater Field Test (RP3169-2)	$103,000 15 months	Georgia Power Co./ *K. Johnson*
Compact Vacuum Insulation Fabrication Technology (RP3188-3)	$100,000 3 months	Solar Energy Research Institute/*P. Joyner*
Electric Vehicle Performance Testing (RP3271-1)	$76,600 2 months	Electrotek Concepts/ *G. Purcell*

Electrical Systems

Project	Funding/ Duration	Contractor/EPRI Project Manager
Self-teaching Neural Network for Voltage Control (RP2473-47)	$52,300 11 months	Louisiana State University/*D. Maratukulam*
Diagnostic Evaluation of Cable Insulation Aged Under Controlled Conditions (RP2713-10)	$59,900 11 months	University of Connecticut/ *B. Bernstein*
Advanced Expanding Monomers (RP2986-5)	$50,000 8 months	Baltimore Gas & Electric Co./*B. Bernstein*
Stability Workstation Service Center (RP3191-1)	$347,000 18 months	Ontario Hydro/*M. Lauby*
Power Transformer Tank Rupture: Risk Assessment and Mitigation (RP3212-1)	$866,000 24 months	Westinghouse Electric Corp./*S. Lindgren*
High-Temperature Superconducting Wires From Ductible Alloy Precursors (RP7911-21)	$50,000 12 months	University of California, San Diego/*D. Sharma*

Environment

Project	Funding/ Duration	Contractor/EPRI Project Manager
Biological Studies of Complex Mixtures Derived From Coal and Oil Gasification Processes (RP2963-4)	$861,800 35 months	University of Texas/ *L. Goldstein*
Acute Studies of Acid Aerosols in Children (RP3009-4)	$569,700 12 months	Harvard University/ *J. Yager*
Greenhouse Gas Risk Framework (RP3236-1)	$112,200 13 months	Applied Decision Analysis/*L. Levin*

Exploratory and Applied Research

Project	Funding/ Duration	Contractor/EPRI Project Manager
Theoretical Study of Quantitative Models for Uncertainty Management in Expert Systems (RP8010-14)	$93,600 15 months	Oak Ridge National Laboratory/*L. Valverde*
Response of Grasslands to Elevated CO_2 (RP8011-6)	$325,300 47 months	Commonwealth Scientific and Industrial Research Organization/*L. Pitelka*

Generation and Storage

Project	Funding/ Duration	Contractor/EPRI Project Manager
Instrumentation and Engineering Model to Predict Emissions From Residual Oil Combustion (RP2778-14)	$690,500 21 months	Electric Power Technologies/*W. Rovesti*
Acoustic Temperature and Flow Measurements (RP2818-8)	$50,000 13 months	Sierra Pacific Power Co./ *J. Tsou*
Amorphous Silicon Photovoltaics Research (RP2824-6)	$75,000 38 months	Iowa State University/ *T. Peterson*
Gas Turbine Overhaul Plan for General Electric Simple-Cycle Frame 5 (RP2831-2)	$97,700 8 months	Operational Services/ *R. Frischmuth*
Demonstration of Low-NO_x, Low-Particulate Combustion Controls (RP2869-12)	$76,800 17 months	Northeast Utilities/ *D. Eskinazi*
Advanced Tangentially Fired Combustion Techniques Demonstration (RP2916-13)	$1,000,000 39 months	Southern Company Services/*D. Eskinazi*
Hydrometeorological Study of Wisconsin and Michigan Drainage Basins (RP2917-29)	$181,500 14 months	North American Weather Consultants/*D. Morris*
Concurrent Front-End Controller for Fossil Fuel Power Plants (RP2922-4)	$396,300 16 months	Honeywell/*M. Divakaruni*
Commercialization of Gas Turbine Combustor Viewing System (RP2985-17)	$425,500 39 months	Conax Buffalo Corp./ *H. Schreiber*
Demonstration of DYNAMICS as a Unit Commitment Model (RP3116-2)	$149,100 9 months	Decision Focus/*B. Louks*
Demonstration of EPRI Fossil Fuel Plant Training Simulator Guidelines (RP3152-5)	$73,800 21 months	ABB Power Automation/ *M. Divakaruni*
Institutional Constraints to Use of Fly Ash in Construction (RP3176-4)	$100,000 12 months	GAI Consultants/ *D. Golden*
High-Volume Fly Ash Concrete Systems (RP3176-6)	$399,800 16 months	Matex Consultants/ *D. Golden*
Use of Fly Ash in Autoclaved Cellular Concrete (RP3176-8)	$150,000 9 months	North American Cellular Concrete Co./*D. Golden*

Nuclear Power

Project	Funding/ Duration	Contractor/EPRI Project Manager
Nuclear Power Plant Applications of Advanced Imaging Technologies (RP2705-14)	$103,100 9 months	Encore Technical Resources/*J. O'Brien*
Compaction Demonstration of Consolidation Scrap and End Fittings (RP2717-13)	$248,700 11 months	Northeast Utilities Service Co./*R. Lambert*
EPRI/CRIEPI Collaborative Studies in Inelastic Analysis and Testing (RP3030-10)	$154,000 6 months	Martin Marietta Energy Systems/*E. Rodwell*
Zebra Mussel Monitoring and Control Guide (RP3052-3)	$112,600 8 months	Stone & Webster Engineering Corp./ *N. Hirota*
Expert Systems Verification and Validation Methodology (RP3093-1)	$277,600 24 months	Science Applications International Corp./ *J. Naser*
Improvement of Maintenance Personnel Performance in Main Feedwater Pump Overhaul (RP3111-5)	$390,000 19 months	Anacapa Sciences/ *J. Yasutake*
CHECMATE/CHEXPERT Enhancements (RP3114-60)	$100,000 16 months	Altos Engineering Applications/*B. Chexal*
Analysis of Melt-Quenching Experiments (RP3130-3)	$65,300 14 months	University of Wisconsin, Madison/*M. Merilo*
B&W Owners Group: Internals Bolting Surveillance (RP3154-6)	$197,500 40 months	Babcock & Wilcox Co./ *L. Nelson*
Characterization of High-Strength Alloys (RP3154-7)	$66,600 12 months	Westinghouse Electric Corp./*L. Nelson*
Risk-Based Technical Specification (RP3184-1)	$214,200 13 months	Westinghouse Electric Corp./*J. Sursock*
Impact of Water Chemistry on BWR Fuel Cladding Corrosion (RP3247-1)	$1,228,200 40 months	Institutt for Energiteknikk/ *D. Cubicciotti*
Advanced LWR Phase 3: Westinghouse AP600 (RP3260-4)	$13,500,000 61 months	Westinghouse Electric Corp./*C. Welty*
Motor-Operated-Valve Test Program (RP3433-3)	$55,000 3 months	MPR Associates/*J. Hosler*

New Technical Reports

Requests for copies of reports should be directed to Research Reports Center, P.O. Box 50490, Palo Alto, California 94303; (415) 965-4081. There is no charge for reports requested by EPRI member utilities, U.S. universities, or government agencies. Reports will be provided to nonmember U.S. utilities only upon purchase of a license, the price for which will be equal to the price of EPRI membership. Others pay the listed price. Research Reports Center will send a catalog of EPRI reports on request. To order one-page summaries of reports, call the EPRI Hotline, (415) 855-2411.

CUSTOMER SYSTEMS

End-Use Technical Assessment Guide (End-Use TAG), Vol. 4: Fundamentals and Methods
CU-7222 Final Report (RP3084-5); $200
Contractor: Barakat & Chamberlin, Inc.
EPRI Project Manager: P. Hanser

Industrial Data Sources Handbook
CU-7246 Final Report (RP2885-2); $200
Contractors: Resource Dynamics Corp.; Battelle
EPRI Project Manager: P. Meagher

ELECTRICAL SYSTEMS

Cyclic Axial Loading of Drilled Shaft Foundations in Cohesive Soil for Transmission Line Structures
EL-7161 Final Report (RP1493-4); $200
Contractor: Cornell University
EPRI Project Manager: V. Longo

Distribution Workstation: Specifications, Vols. 1 and 2
EL-7249 Final Report (RP3079-1); $200 each volume
Contractor: Power Technologies, Inc.
EPRI Project Manager: H. Ng

ENVIRONMENT

Use of RAMAS to Estimate Ecological Risk: Two Fish Species Case Studies
EN-7176 Final Report (RP2553); $200
Contractor: Applied Biomathematics, Inc.
EPRI Project Manager: A. Silvers

Three-Dimensional Solute Plume Transport Through an Unsaturated Field Soil
EN-7283 Final Report (RP2485-6); $200
Contractor: University of California, Riverside
EPRI Project Manager: D. McIntosh

EXPLORATORY AND APPLIED RESEARCH

Proceedings: Electrochemical Synthesis Workshop
ER-7245 Proceedings; $200
EPRI Project Manager: R. Weaver

GENERATION AND STORAGE

Utility Stack Opacity Troubleshooting Guidelines
GS-7180 Final Report (RP2250-3); $400
Contractor: United Engineers and Constructors, Inc.
EPRI Project Manager: R. Rhudy

Sodium/Sulfur Battery Development—Commercialization Planning
GS-7184 Final Report (RP2123-4); $200
Contractor: Chloride Silent Power, Ltd.
EPRI Project Manager: R. Weaver

Proceedings: Fossil Steam Turbine Disc Cracking Workshop
GS-7250 Proceedings (RP2481); $1000
EPRI Project Managers: R. Viswanathan, T. McCloskey

INTEGRATED ENERGY SYSTEMS

A Comparison of Humid Air Turbine (HAT) Cycle and Combined-Cycle Power Plants
IE-7300 Final Report (RP2999-7); $200
Contractor: Fluor Daniel, Inc.
EPRI Project Manager: M. Gluckman

NUCLEAR POWER

Electropolishing Process Development for PWR Steam Generator Channel Heads
NP-6619 Final Report (RP2758-2, -3); $200
Contractors: Quadrex Corp.; Radiological and Chemical Technology Corp.
EPRI Project Manager: C Wood

Proceedings: 1989 Workshop on LWR Radiation Water Chemistry and Its Influence on In-Core Structural Materials
NP-7033 Proceedings; $5000
EPRI Project Manager: J. Nelson

PWR Passive Plant Heat Removal Assessment: Joint EPRI–CRIEPI Advanced LWR Studies
NP-7080-M Final Report (RP2660-51); $200
Contractor: MPR Associates, Inc.
EPRI Project Manager: J. Yedidia

BWR Passive Plant Heat Removal Assessment: Joint EPRI–CRIEPI Advanced LWR Studies
NP-7128-M Final Report (RP2660-50); $200
Contractor: S. Levy, Inc.
EPRI Project Manager: J. Yedidia

Destructive Examination of Steam Generator 11 Tubing at Calvert Cliffs Power Plant Unit 1
NP-7136-M Final Report (RPS407-9); $200
Contractor: Baltimore Gas & Electric Co.
EPRI Project Manager: P. Paine

Procedure for Evaluating Nuclear Power Plant Relay Seismic Functionality
NP-7148-M Final Report (RP2925-8); $200
Contractor: MPR Associates, Inc.
EPRI Project Manager: R. Kassawara

Measurement of In-Core and Recirculation System Response to Hydrogen Water Chemistry at Nine Mile Point 1
NP-7200-M Final Report (RP2680-5); $200
Contractor: General Electric Nuclear Energy
EPRI Project Manager: J. Nelson

Postmaintenance Testing: A Reference Guide
NP-7213 Final Report (RP2814-25); $8600
Contractor: BCP Technical Services, Inc.
EPRI Project Managers: M. Downs, B. Varma

Demonstration of Reliability-Centered Maintenance, Vols. 1–3
NP-7233 Final Report (RP2970); $160,000
Contractors: Rochester Gas & Electric Corp.; Southern California Edison Co.; Erin Engineering and Research, Inc.; Advanced Technology Engineering Systems, Inc.; NUS Corp.
EPRI Project Manager: G. Allen

In-Plant Electrochemical and Corrosion Studies of Service Water Systems
NP-7240 Final Report (RP2939-9); $200
Contractor: Structural Integrity Associates
EPRI Project Manager: D. Cubicciotti

Proceedings: 1990 EPRI Radwaste Workshop
NP-7257 Proceedings (RP2414-28); $200
Contractor: Ascent Services
EPRI Project Manager: C Hornibrook

Projected Waste Packages Resulting From Alternative Spent-Fuel Separation Processes
NP-7262 Final Report (RP3030); $200
EPRI Project Manager: E. Rodwell

The Cost of Processing Irradiated Fuel From Light Water Reactors: An Independent Assessment
NP-7264 Final Report (RP3030); $200
EPRI Project Manager: E. Rodwell

Feature-Based Imaging System: The Peach Bottom Field Trials
NP-7274 Final Report (RP1570-2, RP3232-1); $200
Contractor: J. A. Jones Applied Research Co.
EPRI Project Manager: S. Liu

Design Specification for the Core Management Program (COREMAP): Fuel Cycle Scoping and Preliminary Core Design Capability
NP-7279 Interim Report (RP2721-2); $200
Contractor: S. Levy, Inc.
EPRI Project Manager: R. Breen

CALENDAR

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

SEPTEMBER

10–12
Filtration of Particulates in LWR Systems
King of Prussia, Pennsylvania
Contact: Maureen Barbeau, (415) 855-2127

10–12
International Conference: Use of Coal Ash and Other Coal Combustion By-products
Shanghai, China
Contact: Dean Golden, (415) 855-2516

11–13
International Conference: Dam Fracture
Boulder, Colorado
Contact: Doug Morris, (415) 855-2924

17–18
Workshop: Superconducting Magnetic Energy Storage
Monterey, California
Contact: Robert Schainker, (415) 855-2549

18–20
Conference: Fossil Plant Construction
Washington, D.C.
Contact: Pam Turner, (415) 855-2010

19–20
Magnetic Field Measurement
Lenox, Massachusetts
Contact: Greg Rauch, (415) 855-2298

25
ETADS Users Group Meeting
Dallas, Texas
Contact: Paul Lyons, (817) 439-5900

OCTOBER

1–2
FGDPRISM Training Workshop
Austin, Texas
Contact: Rob Moser, (415) 855-2277

1–3
Air Toxics Workshop: Assessing and Managing Risks
Pittsburgh, Pennsylvania
Contact: Leonard Levin, (415) 855-7929

3–4
FGDPRISM Training Workshop
Austin, Texas
Contact: Rob Moser, (415) 855-2277

8–11
1991 PCB Seminar
Baltimore, Maryland
Contact: Maureen Barbeau, (415) 855-2127

15–18
Meeting Customer Needs With Heat Pumps
Dallas, Texas
Contact: Pam Turner, (415) 855-2010

15–18
EMF Science and Communication
San Jose, California
Contact: Robert Banks, (612) 623-4646

15–18
International Conference on Power Quality: End-Use Applications and Perspectives
Gif-sur Yrette, France
Contact: Marek Samotyj, (415) 855-2980

15–18
9th Particulate Control Symposium
Williamsburg, Virginia
Contact: Susan Bisetti, (415) 855-7919

16–18
Coal Gasification
San Francisco, California
Contact: Lori Adams, (415) 855-8763

16–18
Mutual Design: Transmission Lines and Railroads
Evanston, Illinois
Contact: Suzette Rius, (415) 855-2798

22–23
Zebra Mussels
Itasca (Chicago), Illinois
Contact: Barbara Evatt, (415) 855-2174

22–24
Power Quality Hands-on Training Course
Knoxville, Tennessee
Contact: Donna Eason, (615) 675-9505

23–25
8th Electric Utility Forecasting Symposium
Baltimore, Maryland
Contact: Phil Hummel, (415) 855-2855

29–November 2
Computer-Aided Control System Analysis
Birmingham, Alabama
Contact: Murthy Divakaruni, (415) 855-2409

NOVEMBER

4–6
International Conference: Managing Hazardous Air Pollutants
Washington, D.C.
Contact: Lori Adams, (415) 855-8763

5–7
Boiler Tube Failures in Fossil Plants
San Diego, California
Contact: Maureen Barbeau, (415) 855-2127

13–15
Power Quality Hands-on Training Course
Knoxville, Tennessee
Contact: Donna Eason, (615) 675-9505

19–20
NMAC Workshop: Circuit Breakers
East Dundee, Illinois
Contact: Jim Christie, (704) 547-6053

19–21
Rotating Machinery Balancing: ROBAL
Eddystone, Pennsylvania
Contact: Tom McCloskey, (415) 855-2655

DECEMBER

2–6
Fireside Performance of Coal-Fired Boilers (Short Course)
Charlotte, North Carolina
Contact: Bob Leyse, (415) 855-2995

3–4
NMAC Workshop: Circuit Breakers
Middletown, Connecticut
Contact: Jim Christie, (704) 547-6053

3–5
Strategic Cost and Quality Management
Orlando, Florida
Contact: Susan Bisetti, (415) 855-7919

3–6
Symposium: SO_2 Control
Washington, D.C.
Contact: Pam Turner, (415) 855-2010

4–6
NMAC Workshop: Solenoid-Operated Valves
Clearwater Beach, Florida
Contact: Vic Varma, (415) 855-2771

10–12
Power Quality Hands-on Training Course
Knoxville, Tennessee
Contact: Donna Eason, (615) 675-9505

11–13
Workshop: Generators and Motors
Scottsdale, Arizona
Contact: Lori Adams, (415) 855-8763

12–13
NMAC Workshop: Circuit Breakers
Charlotte, North Carolina
Contact: Jim Christie, (704) 547-6053

Authors and Articles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Sun


Stahlkopf


Samotyj

Building the Intelligent Home (page 4) was written by Leslie Lamarre, *Journal* feature writer, with assistance from two staff members in EPRI's Customer Systems Division.

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Renewables on the Rise (page 16) was written by John Douglas, science writer, with background information provided by **James Birk** of EPRI's Generation and Storage Division.

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KBTAC: Helping Develop Expert Systems (page 26) was written by John Douglas, science writer, with technical information provided by members of EPRI's Nuclear Power Division.

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Karl Stahlkopf is director of the Safety and Reliability Department. Earlier, from 1980 to 1989, he headed the Institute's Systems and Materials Department. He came to EPRI in 1973 after seven years in the Navy, where he specialized in nuclear propulsion. A University of Wisconsin graduate, Stahlkopf also holds MS and PhD degrees in nuclear engineering from the University of California at Berkeley. ■

Adjustable-Speed Drives in Power Plants (page 32) was written by Taylor Moore, *Journal* senior feature writer, with assistance from **Marek Samotyj,** a senior project manager for power electronics and controls in the Customer Systems Division.

Samotyj joined EPRI in 1985 after a year as a consultant to the Institute. Before that, he was a research assistant with the Energy Modeling Forum at Stanford University for three years. Still earlier, he held several consulting positions in Poland, including one with the Commission on National Economic Reform. Samotyj holds BS and MS degrees in electrical engineering from Silesian Polytechnic University and an MS in engineering-economic systems from Stanford University. ■

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