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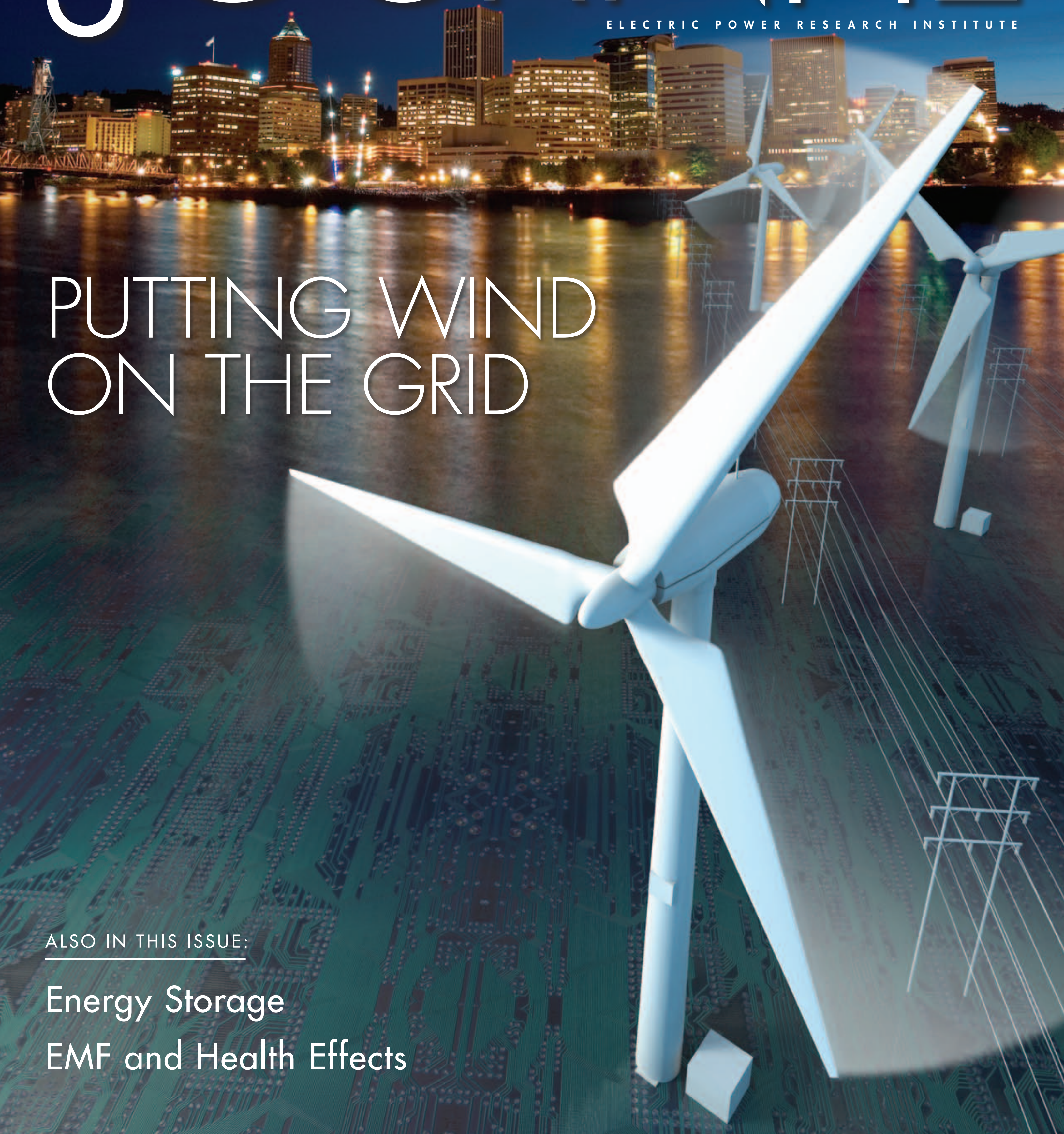

PUTTING WIND ON THE GRID

ALSO IN THIS ISSUE:

Energy Storage

EMF and Health Effects

ELECTRIC POWER
RESEARCH INSTITUTE

The Electric Power Research Institute (EPRI), with major locations in Palo Alto, California, and Charlotte, North Carolina, was established in 1973 as an independent, nonprofit center for public interest energy and environmental research. EPRI brings together members, participants, the Institute's scientists and engineers, and other leading experts to work collaboratively on solutions to the challenges of electric power. These solutions span nearly every area of electricity generation, delivery, and use, including health, safety, and environment. EPRI's members represent over 90% of the electricity generated in the United States. International participation represents nearly 15% of EPRI's total research, development, and demonstration program.

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EDITORIAL

COVER STORY

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Larger, more efficient wind turbines have spurred tremendous expansion of wind capacity worldwide. This success has brought two long-standing challenges to the fore: dealing more effectively with wind's intermittency and facilitating the integration of wind generation into electric power grids.

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New, smaller storage technologies are finding applications that add value across the entire electricity system, from power plants to customer premises.

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Wind Moves to the Mainstream

The emergence of wind as a mature electric power generation option is a great R&D story, not just because of its status as a clean, renewable technology but because after decades of innovative development, wind power is proving its technical and economic feasibility in the marketplace, becoming an integral part of energy portfolios worldwide.

Part of this progress has been the result of scientists and engineers resolutely applying the standard toolbox of evolutionary refinement techniques. Advanced materials and structural designs, for example, have made very large wind installations on tall towers economic; such efficient, multimegawatt machines are able to harvest much greater volumes of the more-energetic wind resources found hundreds of feet above the ground. Revolutionary improvements have also made their mark. The integration of power electronics into wind turbines—a state-of-the-art advance pioneered by EPRI—has added tremendous flexibility, allowing the turbines to operate efficiently at lower and varying wind speeds. Building on these and other improvements, wind has experienced tremendous growth worldwide, expanding from about 18,000 MW in 2000 to almost 60,000 MW at the end of 2005.

As impressive as this growth has been, wind power has inherent limitations that will continue to constrain its use. Land use concerns will make wind inappropriate for many sites. Wind resource limitations will exclude others. But such siting issues are concerns for most power generation technologies, from hydro to coal: it's only logical to build power plants where the fuel resource is greatest and most economically mined and delivered for use. In the case of wind, there are large, untapped high-energy resources in the United States—in the relatively unpopulated upper Midwest, Great Plains, and Southwest—and offshore installations being planned near the country's coastal population centers have huge potential. In fact, finding sites with the best wind regimes may not be as challenging as finding economical ways to transmit the electricity generated from remote locations to major load centers.

Resource intermittency is another limitation specific to wind and some other renewables; it is indeed difficult to find a place where the wind blows hard and steady 24 hours a day. So far, what nature has given us has been translated to an average capacity factor for wind generation in the United States of about 30%—a level low enough to pose problems for its effective, reliable integration with the rest of the power grid. As this issue's cover story delineates, innovations on the technical, regulatory, and business sides are beginning to deal effectively with integration concerns, clearing the way for wind to break out of its "special case" renewable status and operate more seamlessly as mainstream capacity.

It is impressive that, even with its inherent intermittency challenges, wind has been able to compete in U.S. energy markets, with an average cost in 2004 of 7.5¢/kWh, not counting tax incentives. Studies indicate that continued R&D will bring the cost down to 5.2¢/kWh at a 30% capacity factor by 2020; and in areas where the average capacity factor has the potential to be greater than 40%, the average cost will likely fall below 5¢/kWh in that time frame. This will make wind a very competitive component of the generation mix in many areas of the world by 2020, especially since fossil-based generation is likely by that time to face additional costs related to carbon constraints.

Still, wind's siting and resource limitations mean it will always be only a piece of the overall energy picture. Simply put, no technology is best for all locations and all situations. In light of our increasing need for clean, economic power, the energy future must be based on a robust portfolio of generation choices deployed according to the constraints and opportunities of appropriate technology. And in this context, wind is a model for the future of many advanced technologies that energy specialists and economists have rejected in the past as losing propositions. The lesson is, science and technology are strong forces for progress. Technical and economic barriers *will* yield to R&D if we have the commitment and patience to see the work through.

SR Specker

Steven Specker
President and Chief Executive Officer

Contributors

Putting Wind on the Grid

Putting Wind on the Grid (page 6) was written by science writer John Douglas with technical assistance from Tom Key and Chuck McGowin.

Tom Key, technical leader for renewable and distributed resources, started at EPRI-PEAC in 1989 and became part of EPRI in 2005 with the restructuring of the Institute's subsidiaries. Previously he worked at Sandia National Laboratory, specializing in the compatible interface of end-use equipment and distributed power systems. Key earned a BS in electrical engineering from the University of New Mexico and an MS in electrical power engineering and management from Rensselaer Polytechnic Institute.

Chuck McGowin is senior project manager in the Wind Power Program, focusing on wind turbine performance, system integration, and wind energy forecasting. Since joining EPRI in 1976, he has worked on engineering and economic evaluations of coal, environmental control, waste-to-energy, biomass, and photovoltaics technologies. McGowin holds BA and BS degrees in chemical engineering from Lehigh University and MSE and PhD degrees in the same field from the University of Pennsylvania.

Energy Storage: Big Opportunities on a Smaller Scale (page 16) was written by science writers Taylor Moore and John Douglas, with technical information from Steve Eckroad, Dan Rastler, and Robert Schainker.

Steve Eckroad is a senior technical manager in the Power Delivery and Markets Sector, specializing in energy storage and superconductivity. Before joining EPRI in 1992, he was the principal at EnerTech Energy Technology Consulting and was an R&D manager at Bechtel Group, Inc., from 1979 to 1990. Eckroad received a BA in physics from Antioch College and pursued postgraduate studies in electrical engineering at the University of Missouri.

Dan Rastler, technical leader and program manager for distributed resources, came to EPRI in 1991 to work on fuel cells and was an early developer of the distributed power grid concept. Previously he spent five years with General Electric's Nuclear Energy Division and four years in the U.S. Air Force. Rastler holds a BS degree in chemical engineering from the University of California at Davis and an MS in mechanical engineering from UC Berkeley.

Robert Schainker, an expert on grid infrastructure, is currently technical executive for strategic planning in EPRI's Office of Innovation. Before joining the Institute in 1978, he was with Systems Control, Inc., of Palo Alto for ten years, specializing in utility SCADA and energy management systems. Schainker has a BS in mechanical engineering, an MS in electrical engineering, and a PhD in applied mathematics, all from Washington University in St. Louis.

EMF and Childhood Leukemia (page 24) was written by science writer Robert Syfers with the close assistance of Rob Kavet of EPRI's Environment Sector.

Rob Kavet is manager of both the Occupational Health and Safety Program and the EMF Health Assessment and Radio-Frequency Safety Program. Kavet's first tenure at EPRI was from 1978 to 1984, after which he worked for two years at the Health Effects Institute. Following six years as a consultant on EMF health issues, he rejoined EPRI in 1992. Kavet received both a BS in electrical engineering and an MEE degree from Cornell University; he earned an MS in environmental health sciences and an ScD in respiratory physiology at the Harvard School of Public Health.

Innovation

Emerging technologies and cutting-edge engineering

Identifying Methylmercury Sources in Marine Fish

Strategic investments in cutting-edge scientific research are helping to quantify the relative roles of natural and man-made sources of mercury in the accumulation of this neurotoxin in marine fish species. If findings to date can be confirmed, they may potentially revolutionize the current science and policy paradigm, which assumes that previous and current anthropogenic emissions represent the primary source of mercury in the oceans and in marine fish.

Regulations focused on controlling mercury emissions from power plants and other sources are designed to reduce human exposure. The principal exposure route is through consumption of marine fish—such as tuna and swordfish—that contain high levels of methylmercury (MeHg) but that may live in areas remote from industrial sources. Though the bioaccumulation processes leading to high tissue concentrations in top-level predators are well understood, the principal source of the MeHg entering marine food chains in the open ocean is unknown. The extent to which emissions regulations reduce human exposure will depend on whether the predominant source is man-made or natural.

Since 2003, EPRI has been investigating MeHg production in the open oceans. In freshwater ecosystems, sulfate-reducing bacteria present in oxygen-free water and sediment layers are known to transform inorganic mercury into MeHg. In the open ocean, such anoxic regions are rare. It has been hypothesized that inorganic mercury deposited on the ocean surface might be transformed into MeHg by microorganisms found in the thermocline—a layer approximately 100–1000 meters below the surface, where the oxygen concentration is relatively low.

EPRI is examining this hypothesis, as well as an alternative one involving abiotic MeHg production from high-pressure reactions of methane with inorganic mercury entering the ocean. Potential sources of inorganic mercury include high-temperature jets in hydrothermal vents at the ridges between continental plates, and low-temperature, diffuse inputs along ridge flanks. If the first hypothesis proves correct, then some fraction of MeHg is of human origin via atmospheric transport and deposition and ocean mixing. If the second hypothesis proves correct, then the bulk of MeHg in the open ocean would be natural.

Laboratory and field experiments have found relatively high MeHg concentrations in hydrothermal fluid samples from the East Pacific Rise, and proof of concept has been established for abiotic MeHg formation via reaction of inorganic mercury with methane at high temperature and pressure. Additionally, MeHg-resistant genes have been detected in organisms living in hydrothermal vents, indicating that MeHg is naturally present in these habitats. To date, marine bacteria taken from oxygen-minimum zones of the ocean have proven incapable of transforming inorganic mercury into MeHg under naturally occurring conditions.

Continuing work is designed to firmly establish the source of MeHg in the oceans, to publish findings in high-profile peer-reviewed journals, and to inform the development of mercury control policies designed to reduce the risks posed by consumption of marine fish.

For more information, contact John Goodrich-Mahoney, jmahoney@epri.com.

Cross-Fertilization Expands Application of Decontamination Process

EPRI-developed decontamination options are the technologies of choice for treating components of operating nuclear reactors and decommissioned plants. The Low-Oxidation-State Metal-Ion (LOMI) process, for example, is widely used at operating boiling water reactors, while the Decontamination for Decommissioning (DFD) process has been successfully applied to components from boiling water reactors and pressurized water reactors that have been permanently shut down, as well as to end-of-life components from operating plants.

The DFD process was developed to remove the outer scale and a thin layer of the base metal from component surfaces in order to minimize radiation exposures during subsequent plant decommissioning activities. More recently, licensees of this EPRI technology have begun using it to treat ex-service components and systems at operating nuclear plants and at sites managed by the U.S. Department of Energy. Its extremely high

decontamination factors allow the refurbishment and reuse of components and the recycling of treated materials into new components. However, the DFD process generates a radioactive ion-exchange resin that must be managed as a secondary waste, introducing an economic penalty that constrains its application.

In 2001, an EPRI Innovator's Circle project was launched to demonstrate the feasibility of enhancing the DFD process by applying electrochemical ion-exchange technology originally developed for use with the LOMI process. This technology, when integrated with the DFD process, makes it possible to remove radioactive material from components and systems without contaminating the ion-exchange resin. The radioactive residue is collected in the form of metallic particles suitable for long-term, on-site storage as a low-level waste. No other wastes are generated, meaning that the overall waste volume is reduced by a factor of 10.

With promising results in the laboratory, design of a pilot-scale testing program for the new DFDX process was initiated in 2002 with funding from EPRI's Nuclear Sector, and a patent was awarded in 2003. Ultimately, interest from potential users led to the construction of a pilot plant suitable for demonstration under real-world conditions at the Studsvik facility in Sweden. The DFDX plant proved successful in decontaminating a variety of nuclear plant artifacts at the Studsvik facility, and the technology was commercialized in 2004 under license to U.S. and European vendors.

In recent developments, the DFDX process has been applied to a number of components at the UK Atomic Energy Authority's Dounreay facility. It has also been qualified for the in situ decontamination of buried pipes, which eliminates the need to remove underground piping from decommissioned facilities.

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Visualizing the Control Centers of the Future

Industry deregulation, market restructuring, and advanced information and communications technologies have changed the demands on grid control centers, exposing the weaknesses of their traditional architecture, which many have characterized as too centralized, independent, and inflexible. EPRI has pursued strategic research that examines how future control centers could avoid these weaknesses by exploiting trends in information and communications technologies.

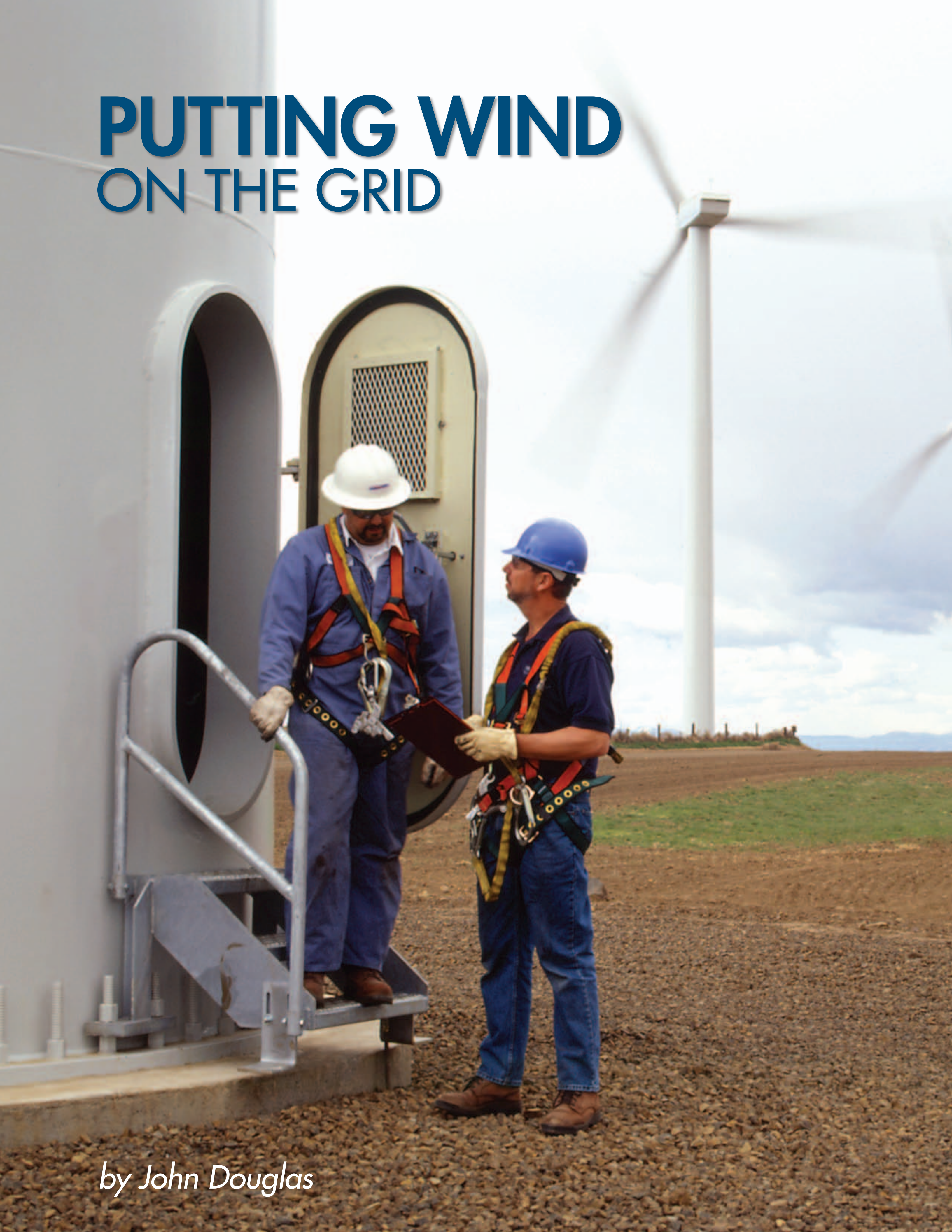
Both within and outside the electricity enterprise, the trend is toward decentralization of operational and business functions. Web services, which provide remote access to software applications through a programmable interface, are converging with grid computing, which involves the sharing of distributed processing, storage, and other hardware resources. The end result is known as grid services. The IntelliGrid^{SM} Architecture, being advanced by EPRI through a consortium of energy companies, independent system operators, equipment manufacturers, and government agencies, provides a technical framework for organizing the transition toward future control centers based on the grid services paradigm.

Future control centers are expected to evolve toward a grid services architecture that will offer greatly expanded supervisory control and data acquisition (SCADA), energy management system (EMS), and business management system (BMS) applications, as well as new services for electricity consumers. Under this model, the physical location of hardware, software, and data may, in fact, be of little concern; the control center will exist as a distinct entity only through the collective functionality of its applications.

Infrastructure will consist of large numbers of computers and intelligent, embedded processors scattered throughout the power system, with data shared through a flexible communications network that uses standard interfaces. With this web-enabled system, data acquisition, processing, and analysis will occur on a much wider, ultrafast scale, enabling just-in-time delivery of critical application services. The enterprise grids formed by different companies will be interconnected through nested intranet/Internet communications networks to create interregional partner grids that offer enhanced reliability, efficiency, and performance across broad geographic areas.

Realizing this vision will present tremendous challenges. Strategic work has provided two recommendations for simplifying and accelerating the transition. First, web services, grid computing, and open standards should be embraced for adoption in control center and other power system functions that involve information and communications technologies. Second, the responsibilities of the electricity industry and its technology suppliers should be clearly distinguished: Energy companies need to become service integrators, focusing on the use of data and information services to perform specific functions without regard to physical location. Suppliers need to become service providers, focusing on the manufacturing, installation, maintenance, and upgrading of the needed software and information and communications infrastructure.

For more information, contact Peter Hirsch, phirsch@epri.com.



PUTTING WIND
ON THE GRID

by John Douglas

PHOTO COURTESY GE ENERGY

The Story in Brief

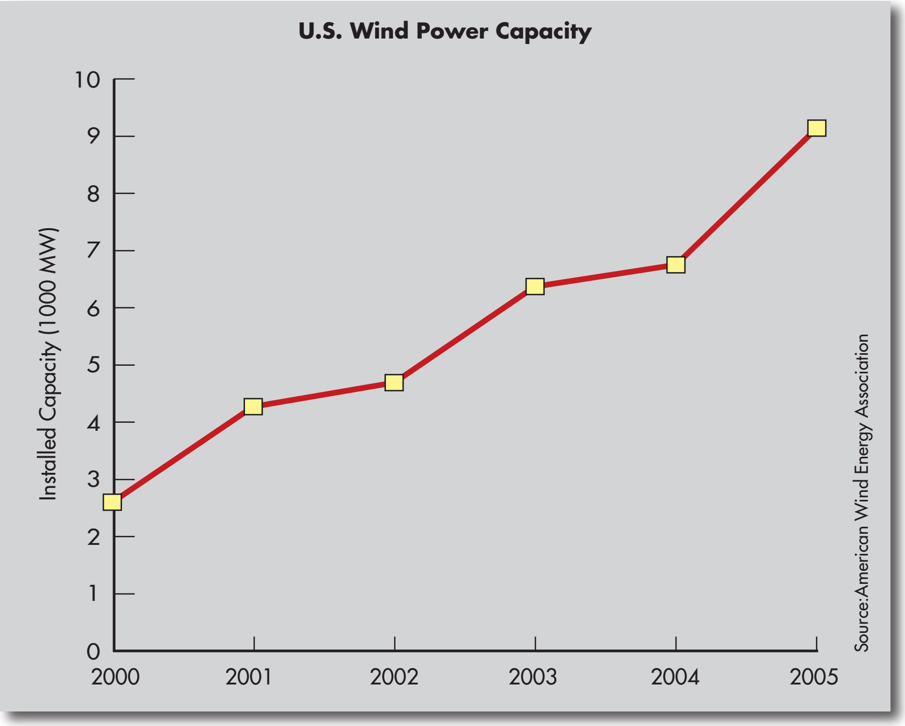
Over the last twenty years, technological advances and manufacturing experience have driven down the cost of electricity from wind by more than 80%—contributing to the 20–30% annual growth of wind capacity worldwide and making wind the fastest-growing large-scale power generation technology in the world. So far, most of the progress is the result of making wind turbine-generators larger, more efficient, and more reliable. Now, as the industry pursues development of even larger wind turbines for offshore applications and further improvements in cost and performance, it is also addressing a second technological thrust: to facilitate the integration of large concentrations of wind generation into electric power grids. If these efforts are successful, utility networks will be able to accept higher levels of wind-based generating capacity, potentially enabling wind power to increase its contribution to U.S. electricity from 0.4%, the figure for 2004, to as much as 5% by 2020.

Today's wind turbines literally tower over those of twenty years ago; they are taller than the Statue of Liberty and have rotor diameters equal to or exceeding the wingspan of a jumbo jet. Capacity ratings of individual turbines have grown even more spectacularly, from dozens of kilowatts in the early 1980s to multiple megawatts today. In addition to increased size, which allows turbines to access the stronger winds aloft and capture their energy more efficiently, today's generators have the ability to operate over a wider range of wind speeds, increasing annual energy output. The bottom line is that electricity from utility-scale wind conversion now costs about 7.5¢/kWh, not including tax credits.

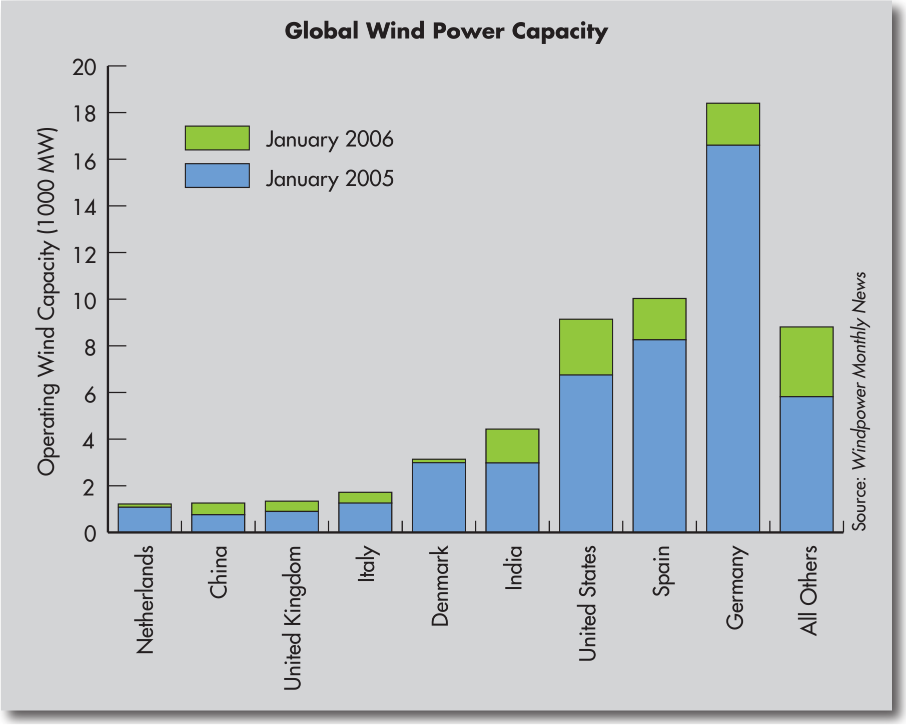
Although such costs make wind power roughly competitive with electricity generated from fossil fuels—particularly in a time of high oil and gas prices—other significant challenges need to be addressed before wind can provide for more than a small percentage of the nation's total electric energy. As installed wind capacity in a region grows and approaches more than about 10% of the system load, the intermittency of wind energy can become a significant issue. Even in areas with relatively favorable wind resources, the annual capacity factor of wind generators (the average actual output as a percentage of the rated output) is typically about 25–35%. This is because wind speed varies with the time of day and the month of the year; for much of the time, it is below the speed needed for a wind turbine to generate power at its rated capacity. In addition, the electrical characteristics of some wind generators affect grid operation and can make grid integration difficult. Fortunately, a number of new technologies and deployment strategies are making wind energy more grid friendly, promising continued growth in its share of total energy. These include improved wind energy forecasting, power electronics, and energy storage.

Better Forecasting Needed

Wind energy forecasting, which relies on numerical weather predictions, meso-scale



The increase in U.S. installed wind capacity has been impressive, with an average annual growth of more than 30% over the last five years. Extension of the production tax credit through the end of 2007 is expected to keep investment high.



Nine countries account for over 85% of the world's wind capacity. While Germany has been the world's largest market for nearly a decade, Spain, the United States, and India have had higher growth rates in recent years. Wind energy currently contributes more than 4% of Germany's electricity supply and nearly 20% of Denmark's.

Advanced designs and use of stronger, lighter-weight materials such as carbon fiber have made wind machines larger and more efficient than ever. Some turbines have blade diameters longer than a football field and sit atop towers as tall as 110 meters. At least one company is testing a 5-MW turbine, while others are working on design concepts in the 5–8-MW range.

wind-flow models, and advanced statistical methods, is already being used to support electricity system operations. Because wind speed and direction can vary over time periods that range from minutes to seasons, integrating electricity from turbines into a utility power system requires the system operator to compensate for these variations by using energy from other, conventional generators. The costs of providing such compensation can vary significantly, depending on the nature of the wind in a region, the characteristics of the control area into which the wind generation is integrated, and the rated wind capacity relative to other generation and system load levels.

One of the largest costs associated with wind operations results when day-ahead and same-day forecasts of hourly wind generation turn out to be inaccurate—that is, when the hourly wind generation is substantially higher or lower than the forecast. Typically, same-day forecasts are issued at least every hour, and next-day, 48-hour forecasts are issued twice daily. If next-day forecasts prove to be significantly off base, the grid operator must either arrange to supplement lower-than-expected wind energy output with other generation, or back off scheduled generation to allow higher-than-expected wind energy output. If same-day forecasts are in error, the operator must ramp other generating units—units usually held in reserve to provide load-following and regulation services—either up or down in response.

The impact of inaccurate forecasts depends on the wind penetration (the fraction of the system peak load supplied by wind), the ramp rate of wind generation (the hourly change in wind generation relative to the previous hour), and the makeup of the electricity system. In most cases, the cost of managing intermittency increases as wind penetration and ramp rates increase. A recent EPRI Technical Update shows that hourly-time-frame integration costs, such as forecast uncertainty and inter-hour load following, range from about 0.18¢/kWh for 3.5% wind penetration, incurred at Xcel Energy, to 0.55¢/kWh for 20% penetration, at PacifiCorp. Such extra unit-commitment costs could be reduced significantly if better wind forecasts were available.

EPRI has been monitoring and evaluating cutting-edge wind forecasting technologies since 1998 in collaboration with both the California Energy Commission and the U.S. Department of Energy. The forecasts are generated through a variety of techniques that include weather prediction, wind-flow modeling, evaluation of plant operating conditions, and statistical analysis. While better day-ahead forecasts will help system operators improve their generation-unit commitment planning, more-accurate hour-ahead forecasts will provide an opportunity for wind power producers to bid competitively into energy markets.

Developing better forecasts of up-and-down hourly ramp rates is becoming especially important for regions that have large blocks of wind generation. Such forecasts need to be received with sufficient lead time to allow system operators to anticipate the change and increase or decrease other generation to compensate. This capability will become even more important if wind development accelerates, as expected, in the United States and Europe in response to government mandates and other green-energy requirements. EPRI is continuing to work with utilities and regional system operators to develop, test, and implement forecast-technology improvements in collaboration with utilities and system developers. EPRI is also developing and testing a wind energy forecast workstation under an EPRI Technology Innovation grant.

The California Independent System Operator (CAISO) is currently offering a new time-averaging approach, the Participating Intermittent Resources Program (PIRP), to encourage wind power integration. Usually, generators of all types submit a schedule of hourly bids into the day-ahead or hour-ahead market, and penalties for deviation from this schedule are assessed every 10 minutes. The risk of deviation charges could be prohibitive for wind farm operators, who cannot control their power output. To provide a more attractive alternative, PIRP assesses charges on the basis of monthly net deviations—provided that the wind power bids are established using CAISO's own customized wind forecast service. The result has been a very low average monthly charge, and several major wind producers now participate in the rapidly expanding program.

Dealing With Short-Term Fluctuations

While improved forecasting can help with the dispatch problems that wind's intermittency introduces, shorter-term variations in the wind resource can cause other technical problems. Several of these concerns relate to matching the electrical characteristics of the wind turbine's power output to those of the local power network. For example, system energy balance can vary when wind gusts—lasting only minutes or seconds—cause the power output of the turbine to change rapidly. Voltage disturbances can also be a problem; voltage sags, which may result from a grid fault, can trip a group of wind turbines off-line unless the turbines are equipped with low-voltage ride-through capability.

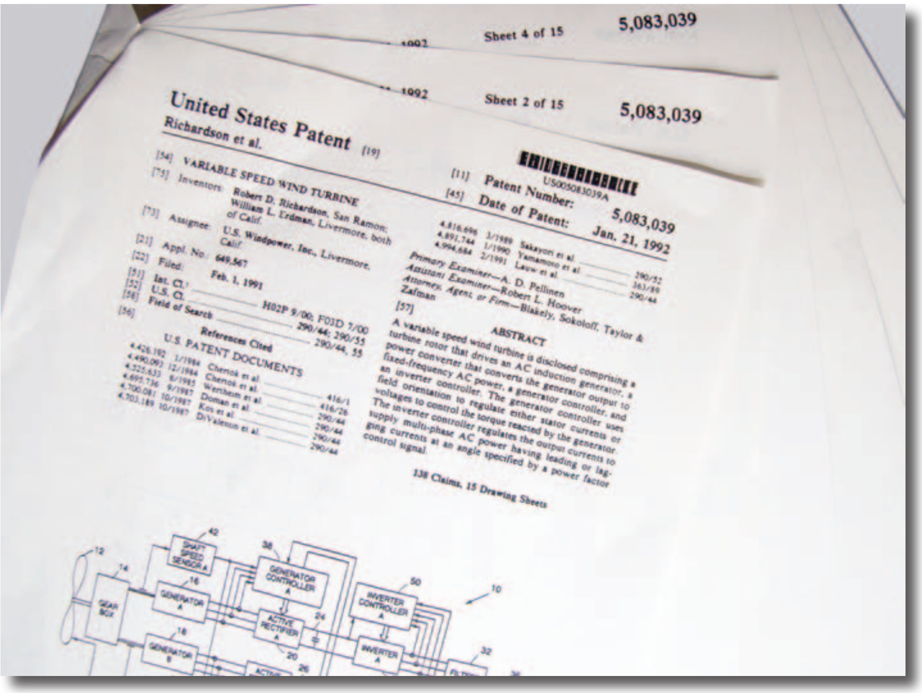
Another technical challenge to the widespread use of wind power is the fact that most wind turbines installed to date have only a limited ability to control reactive power. In addition to providing useful power, measured in watts, generators should also be able to create reactive power, measured in volt-amperes reactive (VARs), which is needed to support the constantly changing magnetic fields in ac circuits. While most conventional utility generators can control both real and reactive power, the induction generators used in most wind turbines absorb reactive power rather than control it, a problem exacerbated by variations in wind speed.

The use of power electronics with wind turbines can largely eliminate such problems, allowing efficient variable-speed operation, controlling reactive power, and providing better low-voltage ride-through capability when a grid disturbance occurs. Fortunately, the advent of larger turbines and massive wind farms is coinciding with the development of lower-cost power electronics technologies to make these solid-state solutions more economically attractive.

An important first step has been to establish a baseline for wind plant performance through high-resolution monitoring of wind intermittency, so that specific needs for power compensation can be better defined. Two recent studies, in particular, have provided important data on the

PHOTO COURTESY GE ENERGY

Capturing the kinetic energy of the wind is only the beginning of the challenge for wind farms. The intermittency of the wind resource can cause problems with unit scheduling and dispatch, load following, and contingency reserves, which can potentially add to the cost of operations. Another challenge is the fact that the wind generator's electrical output must match that of the grid that it's tied into, requiring control of reactive power and protection against voltage disturbances. These difficulties are being addressed successfully through improvements in wind forecasting, the use of power-electronic controllers, and additions of small amounts of energy storage.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United States Patent [19]
Richardson et al.

US005083039A

[11] Patent Number: 5,083,039
[45] Date of Patent: Jan. 21, 1992

[54] VARIABLE SPEED WIND TURBINE
[75] Inventors: Robert D. Richardson, San Ramon; William L. Erdman, Livermore, both of Calif.
[73] Assignee: U.S. Windpower, Inc., Livermore, Calif.
[21] Appl. No.: 649,567
[22] Filed: Feb. 1, 1991
[51] Int. Cl.5 .... H02P 9/00; F03D 7/00
[52] U.S. Cl. 290/44; 290/55
[58] Field of Search 290/44, 55

[56] References Cited
U.S. PATENT DOCUMENTS

4,426,192	1/1984	Chertok et al.	416/1
4,490,093	12/1984	Chertok et al.	416/26
4,525,633	6/1985	Wertheim et al.	290/44
4,695,736	9/1987	Doman et al.	290/44
4,700,081	10/1987	Kos et al.	290/44
4,703,189	10/1987	DiValentin et al.	290/44
4,816,696	3/1989	Sakayori et al.	290/52
4,891,744	1/1990	Yamamoto et al.	363/89
4,994,684	2/1991	Lauw et al.	290/44

Primary Examiner—A. D. Pellinen
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Attorney, Agent, or Firm—Blakely, Sokoloff, Taylor & Zafman

[57] ABSTRACT

A variable speed wind turbine is disclosed comprising a turbine rotor that drives an AC induction generator, a power converter that converts the generator output to fixed-frequency AC power, a generator controller, and an inverter controller. The generator controller uses field orientation to regulate either stator currents or voltages to control the torque reacted by the generator. The inverter controller regulates the output currents to supply multi-phase AC power having leading or lagging currents at an angle specified by a power factor control signal.

138 Claims, 15 Drawing Sheets

The first variable-speed wind turbine, commercialized in 1993 through a partnership of EPRI, U.S. Windpower, Niagara Mohawk, and Pacific Gas and Electric, revolutionized turbine design. Integrated power-electronic controls allowed the advanced turbine to generate 60-Hz ac power at varying rotor speeds. This innovation not only increased wind capture, reduced power output fluctuations, and prolonged the life of the turbine drivetrain, but also greatly expanded the regions where wind power can compete with other generation sources.

output power variability of large wind farms. The National Renewable Energy Laboratory (NREL) conducted the first monitoring project to collect data at very high resolution at large wind farms. Among other results, these data have provided a new understanding of how electrical disturbances on the grid can cause wind turbines to trip off-line and, conversely, how disturbances at the wind farm can affect the grid. This new information has allowed wind farm operators to design corrective measures and reduce forced outages of individual wind turbine rows, as well as of the entire wind farm.

Another high-resolution study, conducted by the New Energy and Industrial Technology Development Organization (NEDO) of Japan, determined some of the factors that affect power output diversity among individual turbines on a wind farm. For example, wake turbulence from upstream turbines was found to significantly affect downstream turbine output. The main question then was how much such diversity helped smooth out power fluctuations from individual turbines. NEDO researchers concluded that smoothing is significant over time periods of less than 10 minutes, because differences in fluctuations tended to cancel each other out. For periods of more than 100 minutes, however, there was more coherence among the outputs of various turbines and less smoothing, as more-persistent wind changes affected the wind farm as a whole. In both the short-term and long-term cases, there was more smoothing for multiple wind farms that had dozens of turbines dispersed over a wide geographic area.

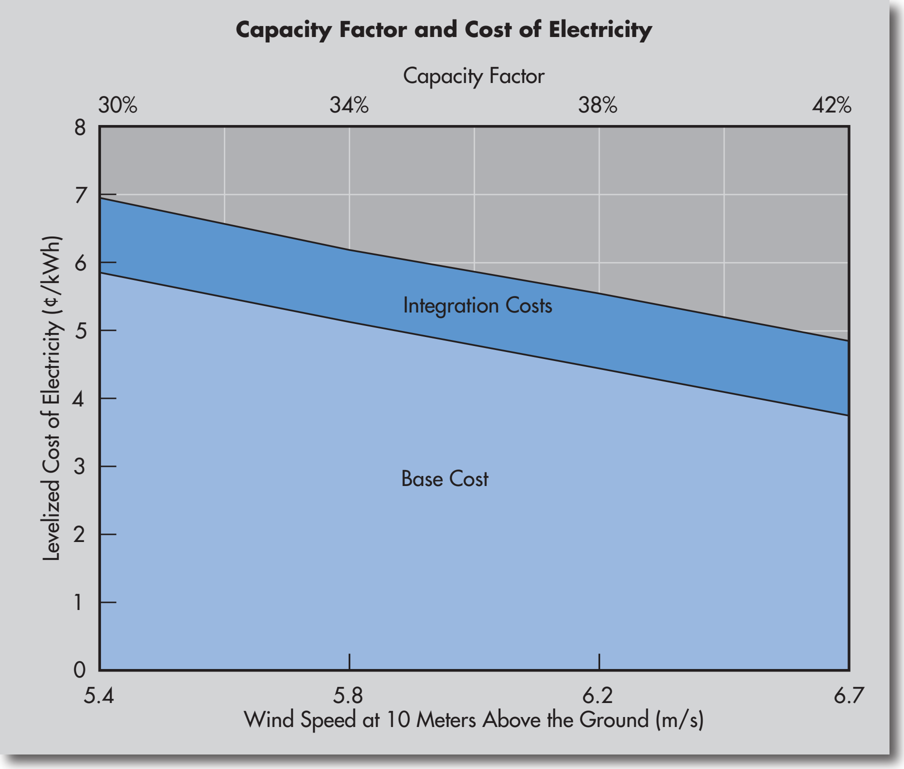
Power-Electronic Solutions

These monitoring data and new technological opportunities have led to considerable recent progress in smoothing short-term power fluctuations. Part of the problem stems from the relatively simple and inexpensive type of turbine generator that has dominated wind energy installations for many years. Now, as wind turbines grow larger and more powerful, they are becoming better able to support more-complex generator designs, including the addition of power-electronic controllers to provide power output smoothing. Although incorporating power electronics is still relatively expensive, the resulting support of variable-speed operation can lead to major savings elsewhere—for example, in lighter-weight mechanical components and lighter foundations for offshore applications.

One popular way of using such controllers is to install a power-electronic converter that feeds the rotor winding of the generator, while the stator windings are still connected to the grid. This doubly fed induction generator not only enables variable-speed operation but also controls the exchange of both useful and reactive power with the grid. Such a design has the economic advantage of combining the low-cost induction generator with power electronics that need be rated at only about 30% of generator rating in order to control variations in output. One drawback of the doubly fed turbine, however, is that the power converters are relatively sensitive to grid disturbances. A low-cost way of keeping this turbine from tripping off-line is to add a set of resistors that the converter can use to divert power to the rotor winding and thus provide ride-through capability.

As the cost of power electronics continues to fall, more-versatile designs that process 100% of the wind power current—technology pioneered through EPRI funding—are becoming more affordable. These designs allow a wider range of variable-speed operation and provide cost savings by eliminating the wear-prone gearbox previously used in most turbines. Perhaps the most important advantage has been excellent low-voltage ride-through capability; as the penetration of wind power grows, the prospect of losing a large part of the generation to a grid disturbance is becoming increasingly unacceptable.

Further advantages can be realized by



Increasing the capacity factor (CF) of wind installations can significantly reduce their levelized cost of electricity. While efficiency gains and other technical improvements to the turbines can improve CF, the biggest increases will come from being able to tap into more-consistent wind regimes, such as those available at high elevations and offshore. A 42% CF could reduce the cost of wind generation to below 5¢/kWh, without tax credits.

physically splitting the rectifier and inverter stages of the power converter and connecting them with a high-voltage dc (HVDC) link. A short HVDC link between the stages of the electronic controls provides a convenient way to synchronize output power with the grid without concern about frequency shifts created by variable-speed operation. In addition, the HVDC link could potentially be extended to carry large amounts of power over long distances.

While individual turbines can be modified for output smoothing, a more adaptable (though more expensive) option is to control the interface between a wind farm and a grid by using power electronics in stand-alone auxiliary equipment. A number of custom power devices are being tried for such applications, particularly in situations where fast reactive power control is essential. The DSTATCOM, for example, is a device that uses power-electronic switches to insert an appropriate number of multistage power capacitors into the circuit so quickly it can help solve the problem of voltage flicker caused by certain types of large loads elsewhere on the system.

Energy Storage for Smoothing Output

Energy storage is an often-discussed option for dealing with wind's intermittency. (See the accompanying article "Energy Storage: Big Opportunities on a Smaller Scale" for more information on storage technologies and their application.) EPRI research indicates that although installing energy storage capacity at a wind farm is not essential, it practically eliminates wind integration issues and can add several value streams for overall grid operations. Unfortunately, the high cost of storage systems limits the situations in which they are useful. A preexisting energy storage facility, if available, can ease the solution of wind integration issues, but the business case for constructing high-capacity, long-duration energy storage solely to solve wind integration issues has been limited to very remote or island systems.

Nevertheless, for some applications, a relatively small amount of storage capability packaged for short-term and fast response can be quite beneficial. For example, adding storage to an electronically controlled interface between a wind farm and the grid can further enhance the dynamic response, providing reactive power for voltage control and real power for damping energy oscillations. More than a dozen large wind farms in North America currently use some form of static or dynamic reactive power compensation.

In applications where dynamics are more critical and where other compensation resources are limited, ultracapacitors and flywheels have also been considered. Hawaiian Electric Company, for example, recently patented and installed a prototype of its Electronic Shock Absorber (ESA) at a wind farm on the island of Hawaii. The installation is specifically designed to store energy during wind gusts and then return the energy to the grid during a lull or to compensate for sudden loss of one of the turbines. This function is most critical when other island generation is at a minimum, such as at night, when the wind power fluctuations could significantly affect the stability of the island's relatively small grid. The ESA can also add or absorb reactive power as needed to help compensate for voltage changes originating on the grid. Energy storage in the ESA is provided by ultracapacitors, which are compact enough to make the device potentially mountable on a truck trailer.

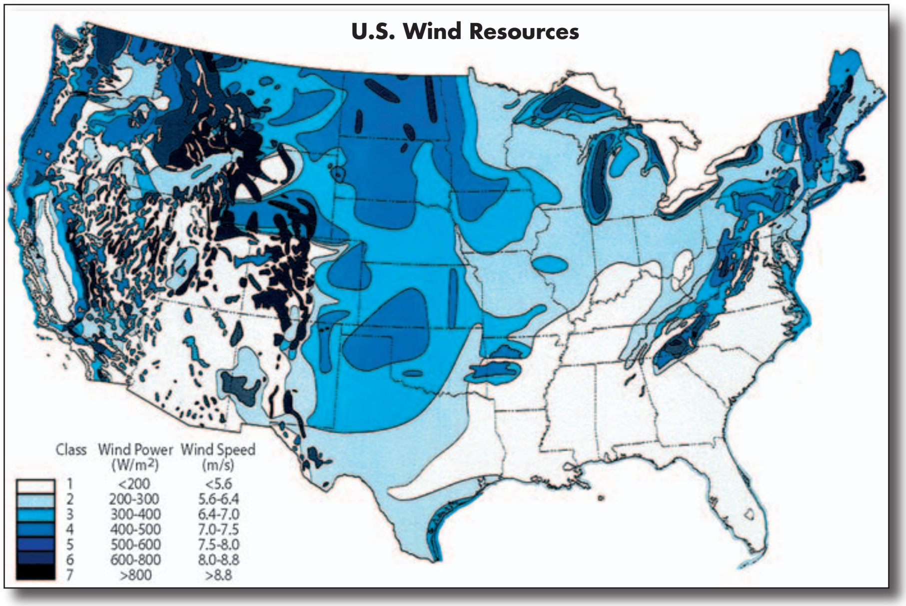
Other applications require adding enough storage to substantially shift the timing of wind farm output. Particularly during periods of minimum load, power output may exceed system requirements, resulting in curtailment of wind generation and lost revenues. A relatively large energy storage system could capture the extra energy produced at these times and deliver it later, when curtailment is not necessary. Similarly, output shifting could enable a wind farm operator to effectively arbitrage between times of peak generation and peak pricing. Even a few minutes' worth of storage capacity would enable a combined wind/storage facility to replace some conventional generation in performing ramping functions.

Bulk Storage Technologies

The most mature technology for handling bulk power over longer time periods is pumped-hydro storage, which uses electricity generated during off-peak hours to pump water from a reservoir at low elevation into a reservoir at a higher elevation. The energy is recovered when the water flows back to the lower reservoir through hydroelectric turbine generators. In principle, wind energy generated during off-peak hours can be stored in pumped-hydro facilities for regeneration at a later time. This approach has sometimes been optimistically called the "wind and water" scenario for expanding the use of wind energy.

The main obstacle to this scenario lies in the difficulty of siting new pumped-hydro storage facilities, which requires finding suitable terrain with sufficient water, purchasing the large amounts of land required, and obtaining the necessary environmental and building permits. In addition, since the remaining appropriate sites tend to be remote, construction costs would be high and new transmission lines would be required. As a result, the extensive construction of new pumped-hydro storage facilities for storage of wind energy is unlikely.

Existing hydroelectric facilities can be used as a sort of "virtual storage" to compensate for wind intermittency as needed, while allowing available wind energy to save water supply reserves for hydro generation. In one example, the Bonneville Power Administration (BPA) recently introduced its Network Wind Integration Service, charging wind farms a flat integration fee of 0.6¢/kWh to provide the necessary compensation for intermittency. In turn, the wind energy offers BPA a way to conserve its hydro resources, which tend to fluctuate seasonally and which provide more revenue if saved for use during peak hours.



The highest wind speeds in the country are typically found on mountain peaks and offshore, but good wind resources are available in large expanses of the Great Plains, the upper Midwest, and the Southwest. Unfortunately, many of the best of these sites lie far from population centers, requiring additional transmission capacity to get the power to where it is needed.

Besides pumped hydro, the only other mature commercial technology that can store and regenerate energy in bulk for utility-scale power generation is compressed-air energy storage (CAES). Air is stored at high pressure in underground salt caverns, mined hard rock, or the porous rock of a depleted gas field. The system is charged by an electrically driven compressor during off-peak hours; the compressed air is later fed into the combustion chamber of a gas turbine to generate on-peak power. This scheme reduces by 40% the amount of natural gas required to generate a megawatt of electricity, because gas turbines generally consume more than this amount just compressing air for use in combustion. Two CAES systems have recently been proposed for use with wind generation. One, with a generating capacity of 100–200 MW, is scheduled to begin operation in Iowa by 2009. The other, with a generating capacity of 270 MW, was evaluated for application to a wind farm in West Texas, but subsequent transmission line upgrades displaced part of the potential value of the storage facility.

Electrochemical storage batteries have often been proposed for storing energy from wind. Lead-acid batteries have been investigated for both stabilization and time shifting, but research to date indicates that such batteries would not be a cost-effective choice for deep-discharge applications. The limited storage capacity and short service life of lead-acid batteries make it difficult to make an economic case for them in wind support activities at present.

A relatively new battery technology that is already being installed to provide storage at the megawatt level for wind farm output stabilization and time shifting is the vanadium redox battery (VRB). The VRB is one of a class of devices known as flow batteries, in which the active materials are contained in two liquid electrolytes rather than in the solid electrodes. VRBs have already been installed for use with wind. On King Island, Australia, for example, a 200-kW unit provides stabilization and time-shifting services for a 2450-kW wind farm. A similar installation at a larger scale has been built in Japan at the Tomamae Wind Villa facility in Hokkaido. This VRB is sized to provide a 4-MW discharge for 1.5 hours or 6 MW for 20 minutes.

Another battery technology that has potential in wind applications is the sodium-sulfur battery, often known by its commercial name, NAS. The NAS technology is based on high-temperature electrochemical reactions between sodium and sulfur, mediated by a beta alumina ceramic electrolyte. In Japan, NAS technology has been used several times specifically for wind power stabilization and time shifting. In 2001, for example, a 400-kW NAS battery was used to provide stabilization as well as 7 hours of storage for time shifting for a small wind installation on the island of Hachijojima.

Prospects for the Future

Although most of the recent wind energy development has been focused on land-based installations, a recent EPRI report concludes that "the longer-term future appears to be offshore wind. . . . In fact, over the next five years, more than 2300 offshore wind turbines are predicted to be installed worldwide at a cost of $13 billion." Generally, the motivation for offshore development is access to higher wind speeds and, in some cases, fewer logistical obstacles. More than 600 MW of offshore wind capacity is currently operating in Europe, with major projects already commissioned off the coasts of Denmark and Ireland, another under construction off Scotland, and ambitious offshore programs being pursued elsewhere.

A major driver for offshore wind development in the United States is customer location: the best wind resources on the East and West Coasts are offshore, close to population centers; most land-based wind farms are situated in the middle of the country, far away from large populations. U.S. wind power developers have been hindered by local opposition to offshore installations and the lack of a clearly defined federal permitting process. NREL is focusing on a long-term solution of putting offshore wind turbines farther offshore—in deeper water and over the horizon—but this approach will require the development of affordable floating platforms similar to those used in the oil and gas industry.

In the United States, only two major commercial offshore wind projects have been proposed so far: the 130-turbine, 454-MW Cape Wind project off Cape Cod, Massachusetts, and the 40-turbine, 140-MW Long Island Wind Power Initiative off the coast of Long Island, New York. Although the Long Island project has generally enjoyed local public support and is expected to be operational in 2008, Cape Wind has become embroiled in bitter political battles at both state and federal levels. In addition to these commercial projects, Southern Company and Georgia Tech are evaluating the feasibility of a small-scale pilot project off the Georgia coast.

Further in the future, tying together wind farms on a regional basis would bring several advantages, including inherently

PHOTO COURTESY GE ENERGY

Ireland's Arklow Bank Wind Park exemplifies Europe's success in exploiting superior coastal and deep-water offshore wind environments. Two offshore projects are currently being pursued in the United States—a 130-turbine, 454-MW project near Cape Cod and a 40-turbine, 140-MW project off the coast of Long Island—and other offshore projects are being considered near Savannah, Georgia, and Galveston, Texas. However, the threat of local opposition and the lack of a clearly defined federal permitting process are tending to hinder offshore development in this country.

smoothing out intermittency problems by balancing strong winds in one area against lulls in another. It would also facilitate the delivery of power to load centers from abundant wind resources in remote areas, which might otherwise remain stranded. Bringing about such regional integration, however, will require changes in both transmission system planning and pricing. Today, few individual wind projects can afford to pay for transmission expansion on their own, and most transmission tariffs include penalties for differences between scheduled generation and actual production, which can significantly impact the cost of wind integration.

Several efforts are under way to overcome obstacles to bulk wind power integration on a regional basis. The Midwest ISO (MISO), for example, has considered the implications of introducing a 10% renewable energy objective throughout its region; this would require integrating about 19,000 MW of wind generation—a huge increase over the current 860 MW of network-connected wind capacity. As a guide to potential developers as they make their investment decisions, MISO recently conducted a study of the transmission expansion that would be needed for 10,000 MW of new wind generation. A companion study looked at the capital expenditures required to increase renewable energy penetration by the year 2020. The 10% renewable energy objective for Minnesota is modeled in these studies.

The Federal Energy Regulatory Commission is considering rule changes that would reduce transmission tariff penalties for intermittent generators. One proposed change would be to offer wind farms "flexible firm" transmission service when long-term firm service is unavailable. Under this proposal, wind facilities would be provided the equivalent of firm service most of the time, but not during hours of peak electricity demand or if the transmission system became unexpectedly constrained. Combined with other technological advances and deployment trends already under way, regulatory changes of this sort could help make wind energy a major contributor to America's electric power future.

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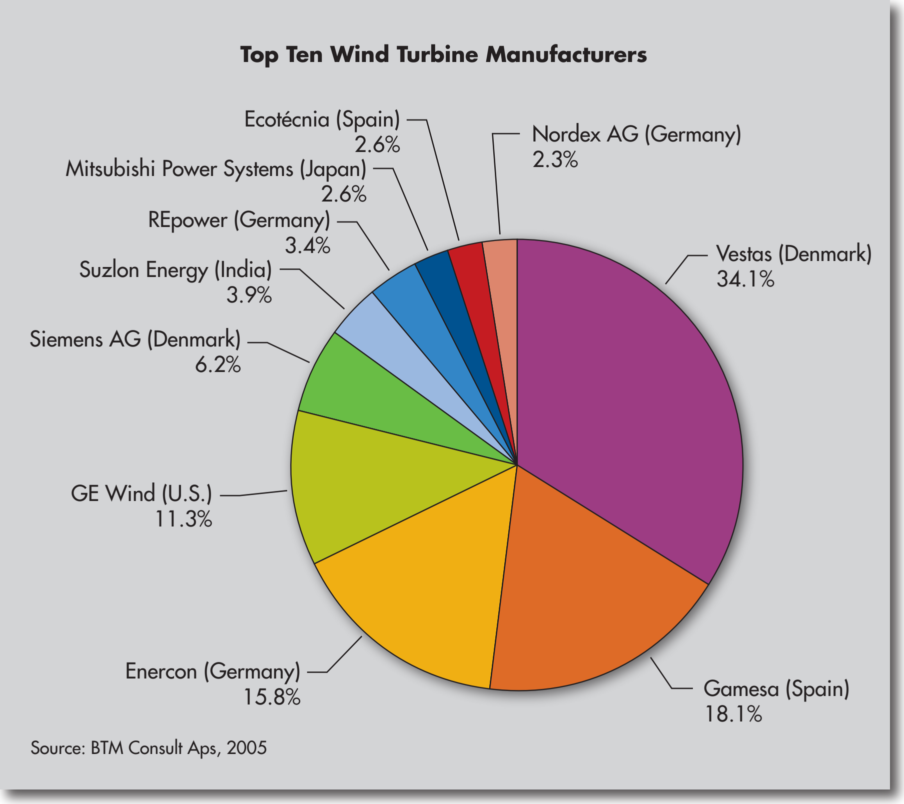


Vestas Wind Systems has dominated the world wind turbine market—accounting for roughly a third of the installed megawatts in 2004—but Gamesa, Enercon, GE Wind, and Siemens are all aggressively expanding production and closing in on the market leader. GE Wind is the leading supplier of turbines installed in the United States.

Further Reading

California Regional Wind Energy Forecasting System Development, Vol. 1: Executive Summary. EPRI and California Energy Commission. 2006. Report 1013262.

Survey of Wind Integration Study Results. EPRI Technical Update. March 2006. Report 1011883.

Wind Energy Forecasting Technology Update: 2004. EPRI. April 2005. Report 1008389.

Wind Power Integration: Smoothing Short-Term Power Fluctuations. EPRI. April 2005. Report 1008852.

Wind Power Integration: Energy Storage for Firming and Shaping. EPRI. March 2005. Report 1008388.

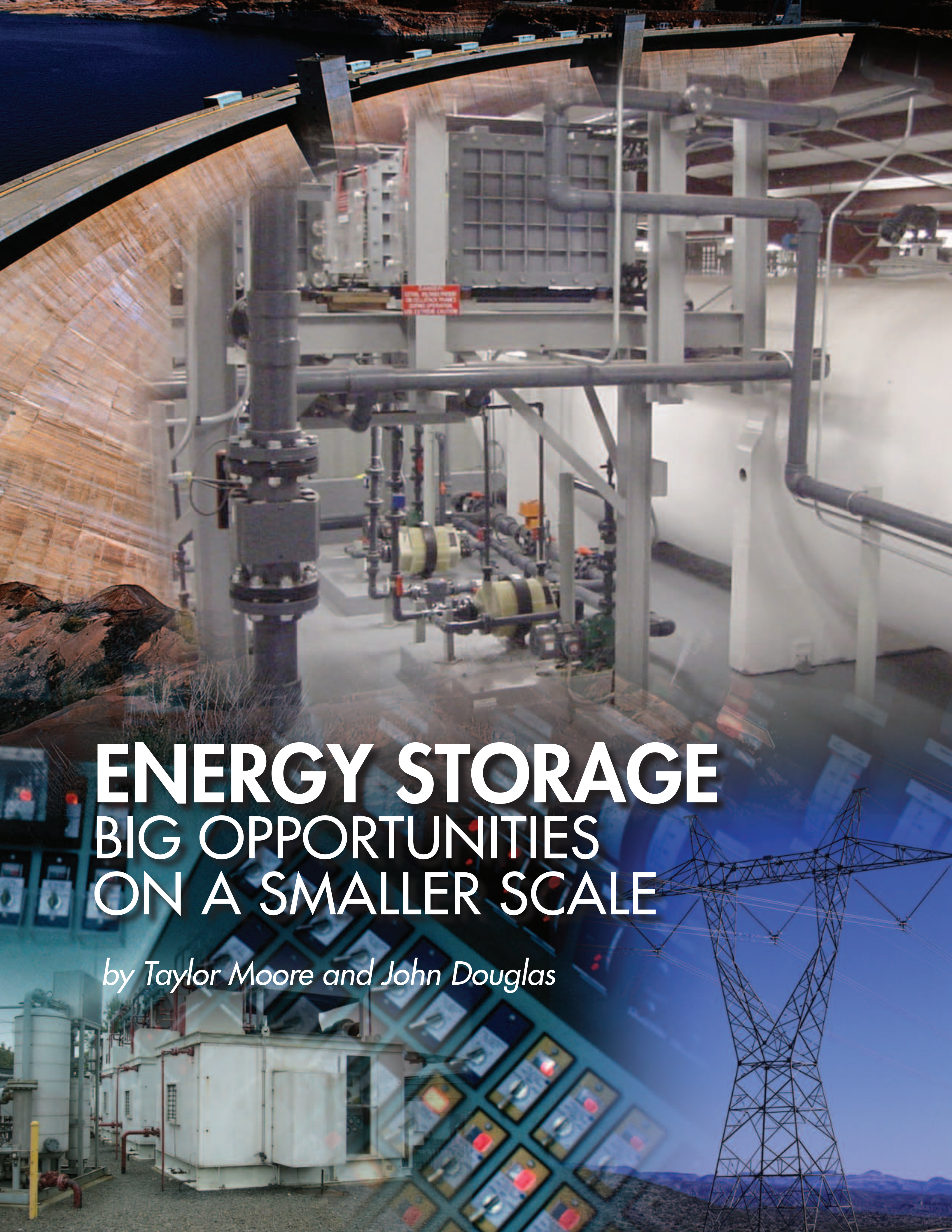
EPRI-DOE Handbook Supplement of Energy Storage for Grid-Connected Wind Generation Applications. EPRI. December 2004. Report 1008703.

Wind Power Integration Technology Assessment and Case Studies. EPRI. March 2004. Report 1004806.

Wind Energy Forecasting Applications in Texas and California: EPRI–California Energy Commission–U.S. Department of Energy Wind Energy Forecasting Program. EPRI. December 2003. Report 1004038.

Short-Term Wind Generation Forecasting Using Artificial Neural Networks. EPRI. October 2003. Report 1009219.

Power-Electronic, Variable-Speed Wind Turbine Development: 1988–1993. EPRI. November 1995. Report 104738.



ENERGY STORAGE

BIG OPPORTUNITIES ON A SMALLER SCALE

by Taylor Moore and John Douglas

The Story in Brief

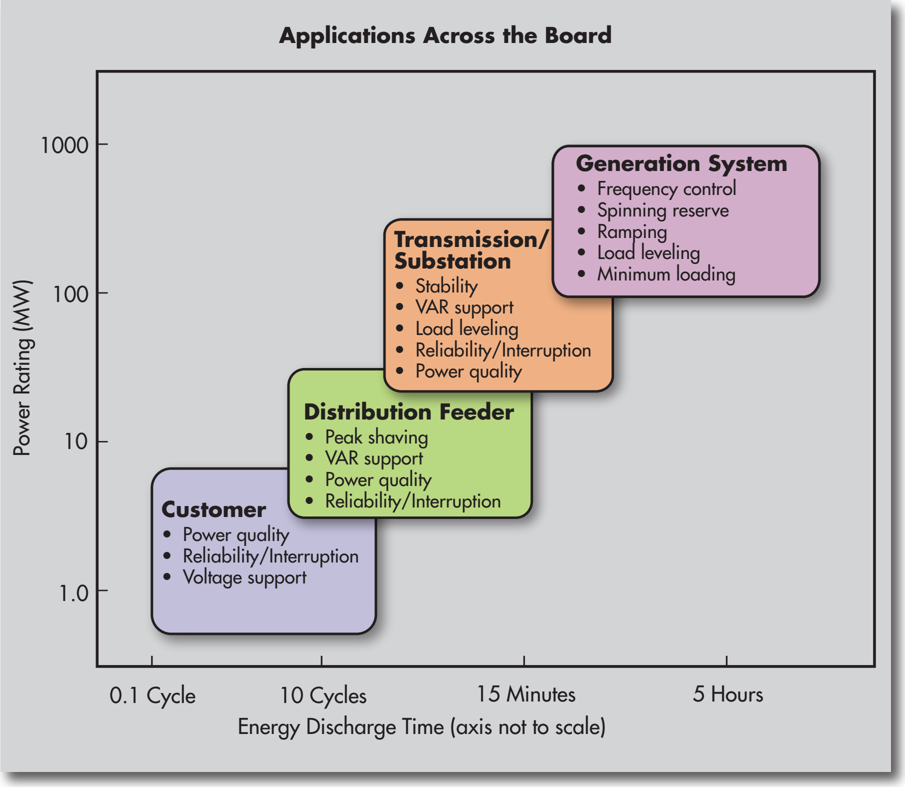
For decades, energy storage research was focused mainly on large-scale technologies for utility load leveling—storing cheaper, off-peak generation to serve customer load during hours of peak usage. While such installations can still make economic sense in favorable locations, a number of smaller storage devices that have been developed and demonstrated over the last ten years are substantially broadening storage applications for a wide variety of utility issues. Advanced batteries, ultracapacitors, high-efficiency flywheels, and superconducting magnetic storage have the capability to increase efficiency, reliability, power quality, and asset value across the entire electricity path, from power plants to customer premises.

Most visions of the electricity system of the future have included widespread, large-scale energy storage as a key component, and with good reason. Theoretically, the ability to store electric power in bulk could take care of some of the most difficult challenges in the electricity business, allowing the system to provide digital-quality power with rock-solid reliability using mostly baseload generation plants. These capabilities would result from overcoming the only major limitation on electricity's super-flexible form value: the need to use it the instant it is generated.

Yet despite these potential advantages, energy storage provides only about 2.5% of total electricity capacity in the United States, nearly all of it from pumped-hydro installations used for load shifting, frequency control, and spinning reserve. In sharp contrast, some 10% of all electricity produced in Europe is cycled through a storage facility of some kind, while Japan stores 15% of the total electricity it generates. These disparities reflect, in part, more-attractive sites for pumped hydro in both areas overseas and—particularly in Japan—higher electricity prices and a greater difference between peak and off-peak prices.

That's the problem: economics. Current bulk storage technologies involve physical scale and cost that have generally removed them from consideration in an industry whose commodity price has largely resisted inflation. In most cases where bulk energy storage would be useful in this country, it has simply been cheaper to build peaking combustion turbines to provide reserve generating capacity that can be dispatched when needed. Nevertheless, the prospects for storage on a smaller, less-capital-intensive scale—roughly tens of kilowatts to tens of megawatts—are bright indeed. A variety of new, intermediate-scale storage technologies are looking increasingly attractive for meeting a different set of utility needs, just as power industry restructuring is reshaping the economics of the services such devices would provide.

Many of the new potential applications are related to transmission and distribution system operations, and some technologies are also uniquely positioned for end-use applications as a demand-response tool. The Federal Energy Regulatory Commission (FERC) has defined a variety of what it calls ancillary services—services needed to support the delivery of power to customers while maintaining system reliability and for which the provider can seek compensation through restructured electricity markets. Energy storage is particularly well suited to provide at least two of these ancillary services: system regulation and spinning reserve. Regulation services involve supplying electric energy in real time to compensate for rapid changes in system load; spinning reserve restores the balance of supply and demand on a system after the sudden loss of a generator or power line or a sudden, unexpected increase in load. In



With the development of new intermediate- and small-scale technologies, energy storage can provide a broad range of benefits in applications that span the entire power continuum, from power plant to customer site. The choice of appropriate technology—advanced batteries, flywheels, ultracapacitors, or superconducting devices—depends primarily on the power capacity and discharge time required for the application.

addition to these power delivery benefits, energy storage may provide ancillary services that are not explicitly connected with current markets—for example, it may provide dynamic reactive energy (measured in volt-amperes reactive, or VARs) to the transmission system when needed.

To analyze the emerging business cases for using energy storage under various circumstances and to create a unique resource for comparing the specific technologies involved, EPRI and the U.S. Department of Energy have published the *EPRI-DOE Handbook of Energy Storage for Transmission and Distribution Applications.* A major conclusion of the research reported in this handbook is that, "while storage is not yet the universal solution for the ills of the electric delivery system, as more experience is gained and as technologies improve, storage may one day be ubiquitous in our power systems." A companion volume, the *EPRI-DOE Handbook Supplement of Energy Storage for Grid Connected Wind Generation Applications,* published a year later, has added coverage for wind energy applications.

An Expanding Role for Storage

By far the largest application of energy storage in today's electric power systems is the use of pumped-hydroelectric facilities to provide daily load shifting. The United States currently has 150 such facilities in 19 states, providing a total of 22 GW of generation capacity. Typically, these facilities consist of two reservoirs at significantly different elevations, connected by large penstocks and with a power-generating station between them. Electricity from a conventional power plant is used to pump water from the lower reservoir to the higher one during off-peak hours; gravity pulls the water back to the lower level through a hydroelectric turbine when additional energy is needed to help meet peak system loads. Such facilities range in size from hundreds of megawatts to over 2 GW and are capable of discharging at full power for 8–10 hours. Scarcity of suitable surface topography that is environmentally acceptable, however, is likely to inhibit further significant domestic development of utility pumped-hydro storage.

Another well-proved bulk storage technology for daily load shifting is compressed-air energy storage (CAES), which uses electrically driven compressors to charge an underground reservoir during off-peak hours. When needed, air is discharged from the reservoir into an expansion turbine connected to a generator. When electricity is used for the compression cycle, the fuel normally used by a simple-cycle combustion turbine plant is reduced substantially. One CAES plant, rated at 290 MW, has been operating in Germany since 1978 and is currently being used to provide spinning reserve and to store off-peak power from a nearby wind farm. Another facility, rated at 110 MW and having a maximum discharge period of up to 26 hours, was built and installed in 1991 by the Alabama Electric Cooperative with EPRI participation. More recently, several bulk storage CAES projects have been proposed to take advantage of salt caverns in Texas and an underground limestone mine in Ohio, but none of the plans for these plants have come to fruition yet. To advance the state of the art, EPRI is exploring the use of above-ground pipelines to store compressed air for CAES applications. Such pipes, similar in size and pressure to those used to transport natural gas, could be sited within an existing transmission right-of-way.

At a much smaller scale, lead-acid batteries have also been used for bulk storage. Indeed, one of the earliest uses of such batteries was to supplement the output of utility generation plants for meeting peak loads. As the size of utility grids grew, however, this application became less common because of the relatively high cost of the batteries. During the 1980s and '90s, a 17-MW battery facility in Berlin, West Germany, a 10-MW facility in Southern California, and a 20-MW plant in Puerto Rico were built to demonstrate the continued technical and economic feasibility of lead-acid batteries for load shifting and grid support. The Berlin project reached payback in approximately three years, operated for seven years, and was decommissioned only after reunification in Germany eliminated the need for the plant's frequency-regulation services. The facility in Puerto Rico provided similar services on the small island grid. According to Steve Eckroad, EPRI program manager for energy storage, "All three of these projects inspired a 27-MW battery facility with similar functionality in Fairbanks, Alaska, that uses a different battery technology—nickel-cadmium. The Fairbanks plant has operated successfully for over two years, providing spinning reserve and local voltage support, thus saving the local utility customers from numerous outages."

While new centralized bulk storage applications are constrained by economics and siting issues, smaller distributed energy storage (DES) options are expanding the role of energy storage into other areas of the electricity value chain, with T&D applications and end-user solutions appearing to be particularly promising. "The benefits of storage are greatest at the customer level, when you consider the value of the reliability that storage makes possible," says Dan Rastler, EPRI program manager for distributed resources. "The locational value of distributed storage could also benefit utilities in supporting the grid and helping to reduce grid congestion and other constraints." However, he adds, "Our research has shown that utilities would be much more able to monetize the value of distributed storage assets than a customer would."

The lack of suitable mechanisms for either utilities or customers to reap tangible monetary benefits from investments in storage remains one of the leading regulatory and economic issues impeding more-widespread deployment of energy storage. In some states, for example, electric utilities can no longer participate in the power supply business; they are allowed only to manage power delivery. But since a storage device is neither a generator nor a traditional part of the "wires" business, it remains unclear how a utility would be able to recoup the money spent installing one on its T&D system. And if a customer installs a storage device on his own property, the tariff treatment it would receive is also unclear. In one state, such a use of storage might be rewarded as a demand reduction effort by the customer. In another state, it might be considered an exiting strategy to avoid grid service and result in a standby charge to the customer.

"Industry restructuring is helping create a new demand for energy storage, particularly in T&D applications" says Eckroad. "New technologies will facilitate these applications, but significant regulatory questions need to be resolved before their true potential can be realized." Adds Rastler, "One area the EPRI program will be working on is to help inform all stakeholders in the policy debate of the value of electricity storage to electric utilities, to end-users, and to society. We will be working to shape a win-win-win strategy to enable the emerging energy storage technologies to contribute value to the electricity system."

Advanced Storage Plants

A variety of new storage technologies have recently been either commercialized or demonstrated at commercial scale. The priority applications for these technologies are concentrated largely on optimizing the existing T&D infrastructure or providing new ways to deliver premium-quality power to customers—or preferably, both. These devices will probably not be used for bulk storage and central-station load shifting any time soon. Rather, they offer a way to make T&D systems more reliable and responsive to customer needs by supplying ancillary services and enabling utilities to defer more capital-intensive infrastructure investments.

"The choice among candidate storage technologies comes down to a question of how much energy you need to store and how long you need to use it to supply power," says Robert Schainker, EPRI director for strategic planning. "Bulk storage

Pumped-hydro facilities such as TVA's 1.6-GW Raccoon Mountain plant represent the most mature option for large-scale utility applications like daily load shifting. There are currently 150 such U.S. facilities operating in 19 states; however, high construction costs and a scarcity of suitable surface topography are likely to severely limit further development of pumped-hydro storage in this country.

allows you to arbitrage large quantities of electric energy between different times and places. Distributed energy storage enables you to shore up your system by supplying smaller amounts of energy when and where it's critically needed."

One DES option—advanced batteries—builds on the industry's long familiarity with lead-acid batteries but improves on that technology's equally familiar shortcomings, such as limited deep-cycling lifetime and high maintenance requirements. In comparison with other advanced storage technologies, the great advantage of batteries is their inherently high energy density, which results from their use of chemical rather than physical processes to store energy.

A leading competitor for DES applications is the sodium-sulfur battery, which is offered commercially by NGK, Ltd., under the trade name NAS. This technology is based on a high-temperature reaction between sodium and sulfur, separated by a ceramic electrolyte—a configuration that has excellent stability, robust cycling, and minimal on-site maintenance requirements. As early as the 1980s, Tokyo Electric Power Company (TEPCO) had selected this type of battery as an alternative to growing reliance on central-station pumped-hydro storage. TEPCO has already installed several NAS units in the 1–6-MW range to provide load leveling and uninterruptible power at the substation level. The first NAS battery demonstration in the United States was hosted in 2002 by American Electric Power, with the cooperation of EPRI and other partners. AEP is now following up that demonstration with the installation of a 1.2-MW NAS battery at a substation where growing load will eventually require substation and/or feeder upgrades. The battery will defer those upgrades for a few years, after which the plan is to move the unit to another substation. Meanwhile, New York Power Authority (NYPA) plans to install a 1.2-MW, 6-hour NAS battery on Long Island to provide peak shaving for one of its mass transit customers. Although initial cost remains an issue, NAS manufacturing capacity is expanding and should lead to lower prices, making this technology increasingly attractive for T&D applications.

Large-scale battery storage was demonstrated in the mid-1980s at Southern California Edison's Chino facility, which offered 10 MW of power with a 4-hour discharge capability using lead-acid batteries. Such projects paved the way for more-advanced battery projects, including a recently built 27-MW, 15-minute-discharge nickel-cadmium installation in Fairbanks, Alaska.

Other advanced batteries now being developed for use in plug-in hybrid electric vehicles (PHEVs) may have the potential for stationary applications as well—either on the grid or at customer locations. Both nickel–metal hydride (NiMH) and lithium ion (Li-ion) batteries have demonstrated energy storage capacities much higher than those of conventional lead-acid batteries of equal weight and can live through 5–10 times as many deep-discharge cycles. If PHEVs are successfully demonstrated and become commercially popular, the costs of NiMH and Li-ion batteries could be reduced by as much as 80% over a relatively short time, making them more affordable for stationary uses. One particularly intriguing possibility is the use of a PHEV as a backup power unit in the home. The vehicle would normally be charged through a simple electrical hookup in the garage; designers say that the charging unit could be configured to automatically feed electricity from the vehicle batteries back into the house wiring to cover basic electricity needs during a local power outage. Recent EPRI research suggests that advanced Li-ion batteries could result in crossover DES applications.

For long-duration discharge applications, a more fundamental departure from traditional battery design is being considered—so-called flow batteries. Generically, these batteries utilize active materials contained in the fluid electrolyte rather than in solid electrodes. The advantage of this design is that the battery's energy rating depends on the volume of the electrolyte, while the power rating depends on the size of the reaction cell stacks. As a result, the cost of extending the discharge time of a flow-battery system depends only on the size of the tanks used to hold the electrolyte, which is low in comparison with the cost of changing the number of cells in traditional battery systems. Thus, flow-battery systems are especially attractive for applications that require energy delivery for several hours. The corresponding disadvantage is that flow batteries tend to be complex systems with pumps, plumbing, and other auxiliary components.

Sodium-sulfur batteries, offered commercially under the trade name NAS, have shown great promise for utility applications in the 1–6-MW range. Based on a high-temperature reaction between sodium and sulfur, the NAS battery features excellent stability, robust cycling, and minimal on-site maintenance. Shown is a 6-MW unit installed at a substation in Ohito, Japan.

Flow batteries of two types—the vanadium redox battery (VRB) and the zinc-bromine battery—are now available from developers as commercial prototypes. In the VRB, the positive electrolyte tank contains vanadium ions with a valance of +4, which lose an electron to the positive electrode during charge-up, shifting the valance to +5. The negative electrolyte tank contains vanadium ions with a valance of +3, which gain an electron during charge-up and go to +2. These reactions are reversed during discharge as the electrolytes circulate through opposite sides of a reaction cell, separated by an ion-exchange membrane. There have been several VRB demonstration projects at utility scale. In 2003, for instance, PacificCorp installed an 8-hour, 250-kW VRB facility on a distribution feeder in Moab, Utah, designed for peak shaving and voltage support to defer a feeder upgrade.

Superconducting Devices for Fast Discharge

The most advanced nonbattery energy storage system at the megawatt-capacity scale is superconducting magnetic energy storage (SMES). This technology directly exploits recent advances in superconducting materials and cost reductions in power electronics. Energy is stored in the magnetic fields produced by continuously circulating current in a dc superconducting coil. Because there are none of the thermodynamic losses inherent in the conversion of stored chemical energy (batteries) or mechanical energy (flywheels), SMES devices have very high efficiency—theoretically as high as 95% in large installations. Although extensive design and development programs have been conducted to design large-scale (10–100-MW) SMES units, substantial cost reductions will be necessary before bulk storage applications are economically feasible.

For fast discharge at high power levels, SMES is very attractive. There are several commercial "micro-SMES" applications at the 1–3-MW level, capable of discharging more than a kilowatthour of energy in a second or so. Micro-SMES units typically provide protection against voltage sags for sensitive industrial equipment. In addition, a commercial product—the D-SMES, from American Superconductor—is designed to provide reactive power for voltage support on distribution lines, with real power injection also available to help customers ride through system disturbances. SMES units could be scaled to much higher power levels to inject tens or hundreds of megawatts into transmission systems to provide dynamic stability.

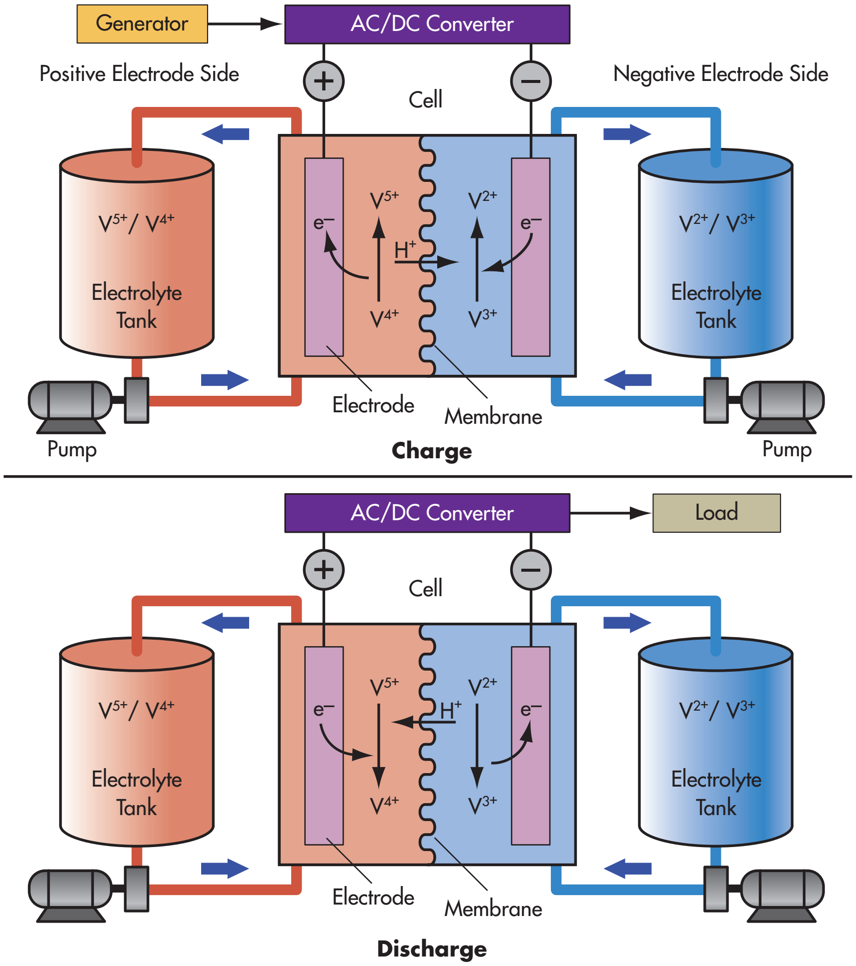
A new superconducting device to be deployed at the transmission system level is now being prepared for service at the Tennessee Valley Authority. Called the SuperVAR dynamic synchronous condenser and manufactured by American Superconductor, this device will increase grid reliability, help stabilize grid voltage, and help maximize transmission capacity. Like SMES, the SuperVAR is based on superconductors, but in a rotating machine configuration rather than a static coil. Dynamic synchronous condensers serve as "shock absorbers" for the grid by dynamically injecting or absorbing reactive power to minimize sudden and large voltage fluctuations. Two 12-MVAR condensers are scheduled for delivery to TVA in late 2006 and early 2007. This planned installation is following successful demonstration and accelerated-life testing of an advanced prototype SuperVAR unit at a steel mill connected to the TVA transmission grid, which helped smooth more than five million voltage sags and surges that accompanied 2300 steel mill melt cycles.

"In today's digital economy, keeping voltage levels constant and stable is vital," said Terry Boston, TVA executive vice president of power system operations, in an American Superconductor news release. "That's what our customers expect, and we believe that's what this new product will help us deliver. We believe SuperVAR machines will help protect TVA's transmission system from voltage fluctuations and help ensure continued delivery of affordable, reliable power."

Other Emerging Technologies

At the submegawatt to megawatt level, two modern versions of technologies that have evolved substantially from nineteenth century origins are competing to provide voltage support and short-term ride-through capability. Flywheels have been present in power systems for more than a century, since the time when they were used to smooth the output of generators driven by steam-piston engines. Now low-speed versions with heavy steel wheels

The storage potential of flow batteries, such as the vanadium redox battery, resides in the fluid electrolyte rather than in expensive electrodes. Thus, the discharge time can be upgraded by simply using larger electrolyte tanks. When the battery is being charged, the V^{4+} *ions in the positive half-cell are converted to* V^{5+} *ions when electrons are taken up by the positive electrode, and electrons from the negative electrode convert the* V^{3+} *ions to* V^{2+} *in the negative half-cell. During discharge this process is reversed, resulting in a voltage to load.*



have penetrated power-conditioning markets, while lighter, high-speed versions with magnetic bearings are beginning to find commercial application. Similarly, double-layer electrochemical capacitors first found widespread application by supplying small amounts of backup power for computer memories and are now being scaled up for utility applications.

The major advantage of flywheels over batteries is that they are capable of several hundred thousand full charge-discharge cycles and thus have a much better cycle life. During charge-up, a flywheel is accelerated by an electric motor, which later acts as a generator during discharge. Low-speed flywheels are usually designed for high power output, while high-speed units can be designed to provide either high power or high energy storage. The most common power quality application is to provide ride-through of interruptions up to 15 seconds long or to bridge the shift from one power source to another. Flywheels have also been used for demand reduction and energy recovery in electrically powered mass transit systems. For example, NYPA recently tested a commercial-grade flywheel in a New York subway station for storing electricity from regenerative subway braking.

Multimegawatt flywheels have been installed by power-quality-sensitive customers such as communications facilities and computer server centers, and commercial systems can be used for reactive power support, spinning reserve, and voltage regulation as well. Beacon Power Corporation completed acceptance testing of a flywheel demonstration unit built under contract to the New York State Energy Research and Development Authority and DOE, and the system was installed and connected to the grid at a demonstration host site in Amsterdam, New York, in March. The unit was enhanced to also provide uninterruptible power to the site, as well as to provide reactive power to help stabilize voltage to electrical equipment. Another Beacon flywheel system is undergoing testing and evaluation in San Ramon, California, in a project for the California Energy Commission.

In addition to supporting flywheel system demonstrations in New York and California, Beacon reports continuing progress toward development of a next-generation 100-kW, 15-minute flywheel that will be the core of an integrated, full-power commercial electric storage system. A prototype is expected to be ready for testing in late 2006.

Electrochemical capacitors, also known as ultracapacitors, store energy by means of an electrolyte solution between two solid conductors, rather than by the more common arrangement of a solid dielectric between the electrodes. This arrangement gives the devices much greater capacitance and energy density than conventional capacitors and also enables them to be made very compact. Like flywheels, ultracapacitors have been used in power quality applications, such as ride-through and bridging, as well as for energy recovery in mass transit systems. EPRI is currently evaluating several new membranes and materials that, when configured as ultracapacitors, could potentially offer significant opportunities for energy storage.

National Benefits of Storage

With all the new technologies, products, and projects that are under way, it is not surprising that EPRI's energy storage program is sharing in the upsurge of activity and the early stages of industry investment in new applications for electricity storage. "Utilities are beginning to show a lot more interest in electricity storage to spawn a variety of technology solutions for distributed-resources deployment, renewables integration, and T&D management," says EPRI's Eckroad. "And we're seeing increased collaboration with DOE, as exemplified by the recent coproduction of the all-inclusive handbook on storage applications and benefits. Member funding for EPRI's program has risen by 150% from 2005 to 2006. The activity in the storage technology area in the last few years has been exciting."

Flywheel storage modules, such as this 100-kW, 15-minute unit from Beacon Power, can be ganged in parallel to provide storage on the multi-megawatt level. Beacon is demonstrating a flywheel storage system in Amsterdam, New York, to provide frequency regulation and reactive power.

In a project funded through the Technology Innovation (TI) program, EPRI is also working to accelerate cost and performance breakthroughs in integrated, customer-sited storage systems. Collaborating with Alliances for Discovery—a public interest, nonprofit organization specializing in collaborative innovation—and the Institute for Engineering and Management at Case Western Reserve University, EPRI will provide technical leadership toward the development of small-scale electric energy storage systems (auxiliary power units) that could be sited at residences, commercial establishments, and industrial facilities for a capital cost of less than $150/kWh. Though managed and funded separately, this TI work will be closely linked to R&D in EPRI's core energy storage programs.

The *EPRI-DOE Handbook of Energy Storage* provides some startling figures on the potential economic benefits of energy storage for the United States as a whole. The benefits of reducing financial losses from power quality problems, for example, could amount to nearly $23 billion over the next ten years, while the benefits of time-of-use energy cost management could exceed $32 billion.

"In the broadest sense, storage devices may be the most important element of power systems in the future," the handbook concludes. "Storage devices, if inexpensive enough and reasonably efficient, would be of highest value if placed at or near customers with variable loads. The second-best location is on utility feeders, followed by substations and the transmission system. If these devices are operated for the common good, the high-voltage wires could be nearly base-loaded and the reliability of the system as a whole would be much improved."

A major challenge in achieving these benefits, however, will be to ensure that storage technologies are smoothly integrated with existing power systems. "It is particularly important that we take all these technologies and hook them together in a way that optimizes their benefit to the system as a whole," says Steve Gehl, technical executive for EPRI's Energy Technology Assessment Center. "What we need to do is demonstrate the flexibility that storage provides to the power system, develop technologies that take advantage of that flexibility, and facilitate their integration."

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Further Reading

EPRI-DOE Handbook of Energy Storage for Transmission and Distribution Applications. EPRI. December 2003. Report 1001834.

EPRI-DOE Handbook Supplement of Energy Storage for Grid Connected Wind Generation Applications. EPRI. December 2004. Report 1008703.

EMF
AND CHILDHOOD LEUKEMIA

by Robert Syfers

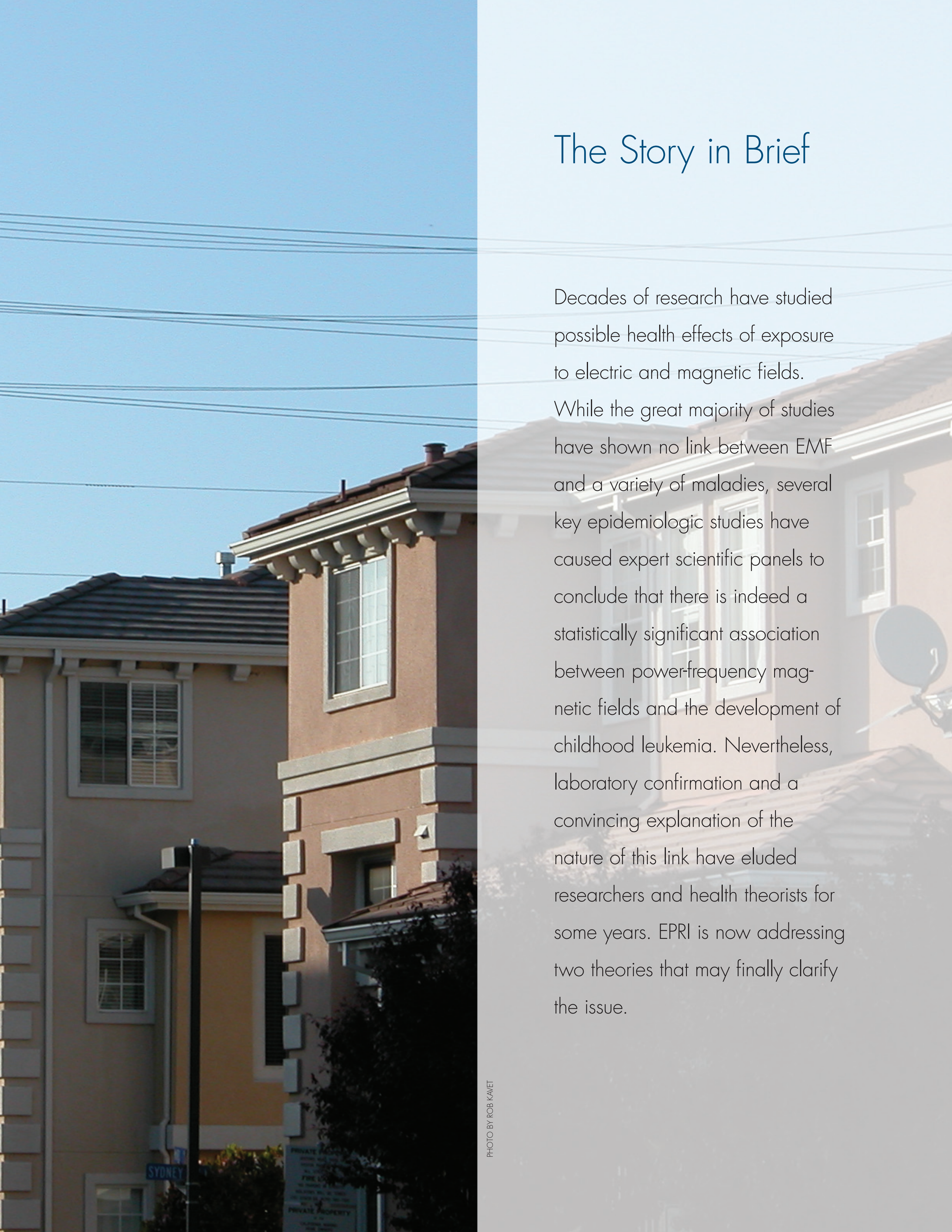


PHOTO BY ROB KAVET

The Story in Brief

Decades of research have studied possible health effects of exposure to electric and magnetic fields. While the great majority of studies have shown no link between EMF and a variety of maladies, several key epidemiologic studies have caused expert scientific panels to conclude that there is indeed a statistically significant association between power-frequency magnetic fields and the development of childhood leukemia. Nevertheless, laboratory confirmation and a convincing explanation of the nature of this link have eluded researchers and health theorists for some years. EPRI is now addressing two theories that may finally clarify the issue.

Researchers have been studying the possible health effects of exposure to electric and magnetic fields (EMF) since the late 1960s, and EPRI has been a significant part of this worldwide effort since the Institute was founded, in 1973. The early period of EMF study, which extended through the mid-1980s, focused primarily on electric fields, with little to no attention paid to cancer as a health outcome of potential concern. No scientific evidence emerged from that period that would link electric field exposure to adverse health effects in people.

About 20 years ago, the emphasis switched dramatically to the potential relationship between magnetic fields in homes and childhood cancers—particularly leukemia and brain cancer. Soon thereafter, researchers as well as state and federal agencies expanded this concern to cover occupational exposures and a far wider variety of health endpoints, including miscarriage, adult cancers of various types, cardiovascular diseases, and neurodegenerative illnesses such as Alzheimer's and amyotrophic lateral sclerosis (Lou Gehrig's disease). With its members' support, EPRI assumed a major role in this widening effort as well, addressing questions of potential health risk and developing measurement and software tools for researchers.

After a period of intense worldwide study through the 1990s, several national and international expert panels convened to evaluate the possible risks posed by EMF environments. Collectively, these deliberations narrowed concern from the broad array of health endpoints that had been studied to only one—childhood leukemia. When the results of many epidemiologic studies (studies that explore the patterns of disease and health in human populations) were evaluated and blended into a single analysis, a moderate association between magnetic fields above 3–4 milligauss (mG) and the occurrence of childhood leukemia—up to a doubling of risk—was evident. Because positive associations originated from studies of different designs from different countries, each with its own unique electrical transport system, random chance as a basis for this association was believed to be extremely unlikely.

From a scientific perspective, however, the presence of an epidemiologic association does not, by itself, constitute or substantiate a cause-and-effect relationship, which generally requires supporting results from the laboratory and a plausible mechanism of interaction. Indeed, laboratory studies using animals and cells have not supported a link between magnetic field exposures and childhood leukemia, and scientists have not identified a biophysical mechanism by which the low-level fields measured in homes could plausibly interact with biological tissue. Though random chance has been virtually ruled out, the possibility remains that the study results are somehow skewed or that another, unidentified exposure is involved. EPRI's EMF health assessment program is working to uncover a rational basis for the unexplained relationship between magnetic fields and childhood leukemia.

Over the past seven years, EPRI scientists have shifted the search into high gear, exploring two viable hypotheses, each of which may contribute to the ultimate explanation. One addresses the possibility, as suggested by many epidemiologists in the EMF community, that the link between magnetic fields and childhood leukemia is a product of artifact in study design—that in fact there is no causal basis at all; the prime suspect behind this possibility is a problem known as selection bias. The second hypothesis explores the possibility that an unrecognized exposure, contact current, is the active agent that has operated behind the scene, with magnetic fields at center stage.

Selection Bias

The term *bias* does not imply willful action by the investigator, but rather results from an undetected factor that insinuates itself into a study's execution and unintentionally skews the results. The selection bias hypothesis is based on the fact that the epidemiologic studies in question are virtually all of case-control design; for studies of rare diseases like leukemia, this design is the most practical option.

In a typical EMF case-control study, the distribution of magnetic field exposure across a group of children with leukemia is compared with the exposure distribution of children who are leukemia-free. The children with leukemia are referred to as cases, and those who are disease-free, as controls. The control group serves as a reference intended, in the ideal, to reflect the actual distribution of exposure through the greater population from which the cases originated. Thus if after carefully collecting and analyzing all of a study's data, an epidemiologist were to observe that exposure to an environmental influence was much more common in a set of cases than in a valid set of controls, that observation would suggest that the exposure under study represented a legitimate risk factor. However, the key word above is *valid,* for even if all else is done correctly and meticulously, if the controls are unrepresentative, the study results will be viewed in a dimmer light as possibly skewed by selection bias.

How could selection bias invalidate a result in concept? First, epidemiologists are generally able to identify all, or almost all, of the cases of the disease of interest within a study region—say, a metro area, a state, or a group of states. This is especially true of cancer cases, which are logged into registries that are available for public health surveillance, as well as for research purposes. The problem of selection bias usually concerns the selection and recruitment of controls—hence the expanded term *control selection bias.* If, because of selection pressures, the control group actually enrolled either under- or overrepresents the exposure of interest, then the study results will report risks that are artificially high or low, respectively.

As an example, consider the repeated observation that fewer people from lower socioeconomic groups participate in epidemiologic studies than people in higher socioeconomic strata. Further consider that people in lower strata tend to reside in less desirable neighborhoods—frequently near freeways and very possibly adjacent to transmission or distribution corridors, where magnetic field exposures would be relatively greater than in areas typical for other segments of the population. In the event that potential control subjects from these lower socioeconomic neighborhoods are underrepresented in a study of magnetic fields and childhood leukemia—because of refusal, unavailability, or simply indifference—then their relative absence will skew downward the exposure distribution of the control subjects that are enrolled. In other words, higher magnetic field exposures will falsely appear to be rarer in the background population than in the cases, leading to the suggestion that the magnetic field is a risk factor, when in fact the result is driven by control selection bias.

In 2001, the EMF health assessment program launched a full-scale foray into the question of control selection bias with a workshop in Canada, in which EPRI scientists gathered with an international group of eminent epidemiologists to brainstorm the best ideas to guide the program's research. Under the leadership of Gabor Mezei of the EPRI program, the research has been gathering full momentum, with several reports already published in the scientific literature and new studies coming on board. Many of these address the question of selection bias caused by differential participation across socioeconomic strata, as described above. The jury remains out with respect to the extent that control selection bias may have influenced earlier studies.

Contact Current

Contact current is current that flows within a person when two locations on that person's body are in contact with electrically conductive surfaces at different electrical potentials, or voltages. For example, if the thumb and forefinger are in contact with the top and bottom of an ordinary AA battery, a small current will flow in the loop created by the fingers and the battery. If the fingers are dry, the current will be relatively small, as dry skin has a high electrical resistance; with wet fingers, the moisture will breach the skin's insulation, lowering its resistance so that comparatively more current will flow. Likewise, contact current can travel through portions of the body from one hand to the other or to a foot, should those extremities be in contact with surfaces of different voltages.

The issue of contact current safety goes back to well before the EPRI program became involved with this exposure in terms of the EMF health issue. Underwriters Laboratories specifies limits for leakage currents from home appliances of 0.5–0.75 milliampere (mA), depending on the device; the National Electrical Safety Code limits exposure to 5 mA in the rights-of-way of high-voltage overhead transmission lines; and guideline-setting bodies, such as the International Commission on Non-Ionizing Radiation Protection and the Institute for Electrical and Electronic Engineers, recommend contact current limits of anywhere between 0.5 and 1.5 mA, depending on exposure circumstances. All of these limits are intended to reduce the chance of annoying or even hazardous startle or pain reactions to the exposure. EPRI's EMF research deals with lower exposure levels, which fall below the threshold of sensory perception.

Since 1999, Robert Kavet, program manager for EMF health assessment, has led EPRI's research on contact current as a factor that could explain the association of magnetic fields with childhood leukemia. Actually, the idea of a possible role for contact current in EMF health studies occurred to Kavet in the late 1990s, after the publication of several studies suggesting that one's occupation as a seamstress or tailor was a risk factor for neurodegenerative disease; the studies' authors attributed their results to magnetic field exposure from sewing machines. Kavet visualized the machine operators' manual contact with the machines through an entire workday, and with a quick back-of-the-envelope calculation, he realized that the dose of electricity in the body from contact current, particularly in the extremities, would dwarf the doses associated with magnetic fields from the machines. This line of research led to the development of a personal meter to measure occupational exposures to contact current; the meter was put to work in an EPRI study that reported that occupational exposures to contact current would be more likely to occur when equipment was poorly grounded. At about the time Kavet was considering occupational scenarios, thought was given also to the possibility of residential contact current exposures in children vis-à-vis the childhood leukemia connection with magnetic fields.

How would a child be exposed to contact current in a residence? The most likely exposure, according to EPRI's research, results from grounding practices intended to provide electrical safety and fire protection. In the United States, the National Electrical Code has since 1918 required that a residence's electrical service be grounded to an available metal (electrically conductive) water pipe within the residence. As a result of this grounding connection, a small neutral-to-earth voltage—usually less than 1 volt—will appear on the water pipe, arising from household currents returning via the water pipe back to the substation or from induction on the neutral system from nearby sources of magnetic fields, such as overhead transmission lines or heavily loaded distribution primaries. This voltage will extend across all contiguous elements of the water system, including the metal water fixtures in a bathtub, sink, or shower. If the drainpipe sunk into the earth under a bathtub, sink, or shower is also made of metal, a bathing child touching the faucet or water stream will receive a contact current into the arm and through the body; in all but very extreme cases (for example, cases where there is a broken ground connection), these exposures are imperceptible, even to a small child. The current pathway includes the bone marrow (the site of leukemia development), with the highest dose

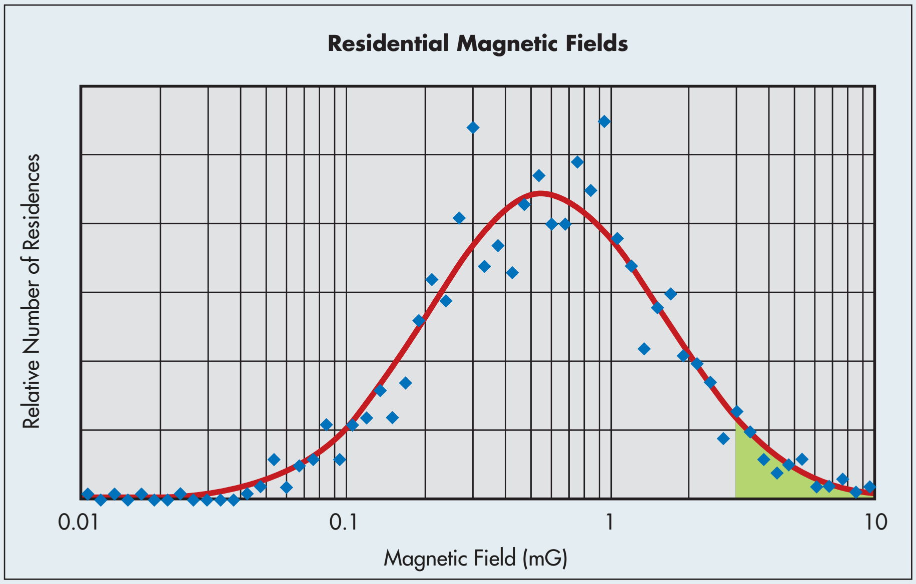
A Short History of EMF Research

by Rob Kavet

Questions about possible health effects from exposure to power-frequency electric and magnetic fields (EMF) in the United States first arose in the late 1960s and early 1970s, following the introduction of extra-high-voltage (765-kV) overhead transmission. The founding of EPRI in 1973 provided the U.S. electric power industry with an ideal organizational structure for investigating concerns about EMF health questions. For over a decade, EPRI's EMF research agenda, coordinated with a U.S. Department of Energy (DOE) EMF research program, focused mainly on electric fields.

Two noteworthy studies played a major role in redefining the EMF research agenda. The first study, published in 1979 by Wertheimer and Leeper, reported an association between residential proximity to heavily loaded distribution lines and childhood cancer mortality (including mortality from leukemia) in the Denver metropolitan region. In this study, exposure within a residence was assessed using so-called wire codes based on visual aspects of lines, such as line type (for example, one-, two-, and three-phase primaries and secondaries) and wire thickness (a crude index of line loading), and their distance from the residence. This scheme for exposure characterization became known as the Wertheimer-Leeper wire code. The authors' suggestion that magnetic fields could be responsible for the reported association could be neither substantiated nor refuted.

In 1988, a team headed by David Savitz published a second study. The Savitz study differed from the Wertheimer and Leeper study in its use of a more recent set of childhood cancers and a study design that included actual residential measurements of magnetic (and electric) fields as well as wire codes. Also, in accordance with accepted contemporary practice, the Savitz study analyzed cancer incidence (new diagnoses) rather than mortality statistics, which had been used in the earlier study. Once again, associations were seen between wire codes and childhood cancers. In addition, the study showed that homes with higher wire codes had higher measured magnetic fields, although, interestingly, the association with cancer reported for the measured fields was weaker than the association based on wire codes.



According to EPRI's 1000-Home Study, magnetic field strength in U.S. residences is distributed roughly according to a classic bell curve. About 5% of residences in the United States have an average magnetic field above 3 mG (green area).

Publication of the Savitz study marked a permanent change in the focus of EMF research. By this time, a large body of research supported by both DOE and EPRI had failed to uncover any acute hazard associated with electric field exposure. With the release of the Savitz results, attention shifted sharply to magnetic fields, and worldwide interest in potential health effects from EMF exposure grew virtually overnight. Magnetic fields were now regarded by the public as a ubiquitous, unexplored exposure that could potentially contribute to a variety of health risks and, moreover, could affect children. Health effects of concern included not only cancers of different types but also endpoints such as pregnancy outcomes and neurodegenerative diseases (e.g., Alzheimer's disease) related to both residential and occupational settings.

EPRI responded quickly to this turn of events, convening an advisory committee of scientific experts, expanding its technical staff, and launching a new research program. The new research included epidemiologic studies investigating leukemia in children and leukemia and brain cancer in a large cohort of 140,000 workers from five participating U.S. utility companies; laboratory studies of leukemia and other cancers in a variety of rodent bioassay models; and large residential and occupational magnetic field exposure assessment and engineering studies. One notable residential research effort was the 1000-Home Study, which provided insights into the sources and levels of residential magnetic fields that remain valid today. Not surprisingly, the major sources of residential magnetic fields were found to be outdoor distribution lines and residential grounding systems. Transmission lines were also a dominant source, but the fraction of homes affected was very small.

EPRI also initiated a field management program and developed instrumentation and software for characterizing electric and magnetic field environments. The EMDEX meter and its derivatives are now the standards for measuring residential and occupational magnetic fields, and EMF and TLWorkstation software have provided EPRI members with valuable tools for estimating both electric and magnetic fields in residential and occupational settings. Indeed, EPRI's efforts in measurement instrumentation were largely responsible for critical advances in exposure assessment and epidemiology.

To help transfer EMF measurement technology to EPRI's members, the program conducted the EMDEX Occupational Study and the EMDEX Residential Study from the late 1980s to the early 1990s. The studies benefited from extensive industry participation, with 55 companies involved in the occupational study and 39 in the residential study. The research provided insights into exposure levels in the power company workplace relative to exposures outside the workplace, and the range of exposure levels to be expected across the general population. The occupational survey indicated that power company workplace exposures exceeded those normally associated with environments outside the workplace.

At the federal level, Congress enacted the EMF Research and Public Information Dissemination (EMF-RAPID) Program in 1992, when it became clear that questions about EMF had attained a high profile in the scientific and public mainstream nationwide. The EMF-RAPID Program (supported in part by contributions from EPRI members) had three basic components: "1) a research program focusing on health effects research, 2) information compilation and public outreach, and 3) a health assessment for evaluation of any potential hazards arising from exposure to ELF-EMF [extremely low frequency EMF, which includes power-frequency fields]." The National Institute of Environmental Health Sciences (NIEHS) was charged with overseeing the health research and conducting a thorough EMF risk evaluation.

The 1999 NIEHS final report to Congress concluded that "the strongest evidence for health effects comes from associations observed in human populations with two forms of cancer: childhood leukemia and chronic lymphocytic leukemia in occupationally exposed adults." This conclusion was qualified with the following statement: "The lack of connection between the human data and the experimental data (animal and mechanistic) severely complicates the interpretation of these results."

Two years after submission of the NIEHS report, a panel of experts at the International Agency for Research on Cancer (IARC), a branch of the World Health Organization (WHO) and the world's foremost agency concerned with cancer risk assessment, conducted an evaluation of the scientific literature on EMF and, specifically, its potential link to cancers of all types. The panel's deliberations were strongly influenced by two analyses of the EMF–childhood leukemia literature that were published in 2000, one by a group of scientists in the United States and the other by a group of European scientists. Both groups arrived at the same fundamental conclusion: that childhood leukemia incidence was associated with average residential magnetic fields above 3–4 mG (0.3–0.4 μT), with an approximate doubling of risk above this range of exposure levels. According to EPRI's 1000-Home Study, about 5% of residences in the United States have an average magnetic field above 3 mG, and less than 3% are above 4 mG. The magnetic field from a heavily loaded transmission line will fall off to less than 3 mG about 500 feet from the line, with correspondingly lower exposures for a lighter electrical load.

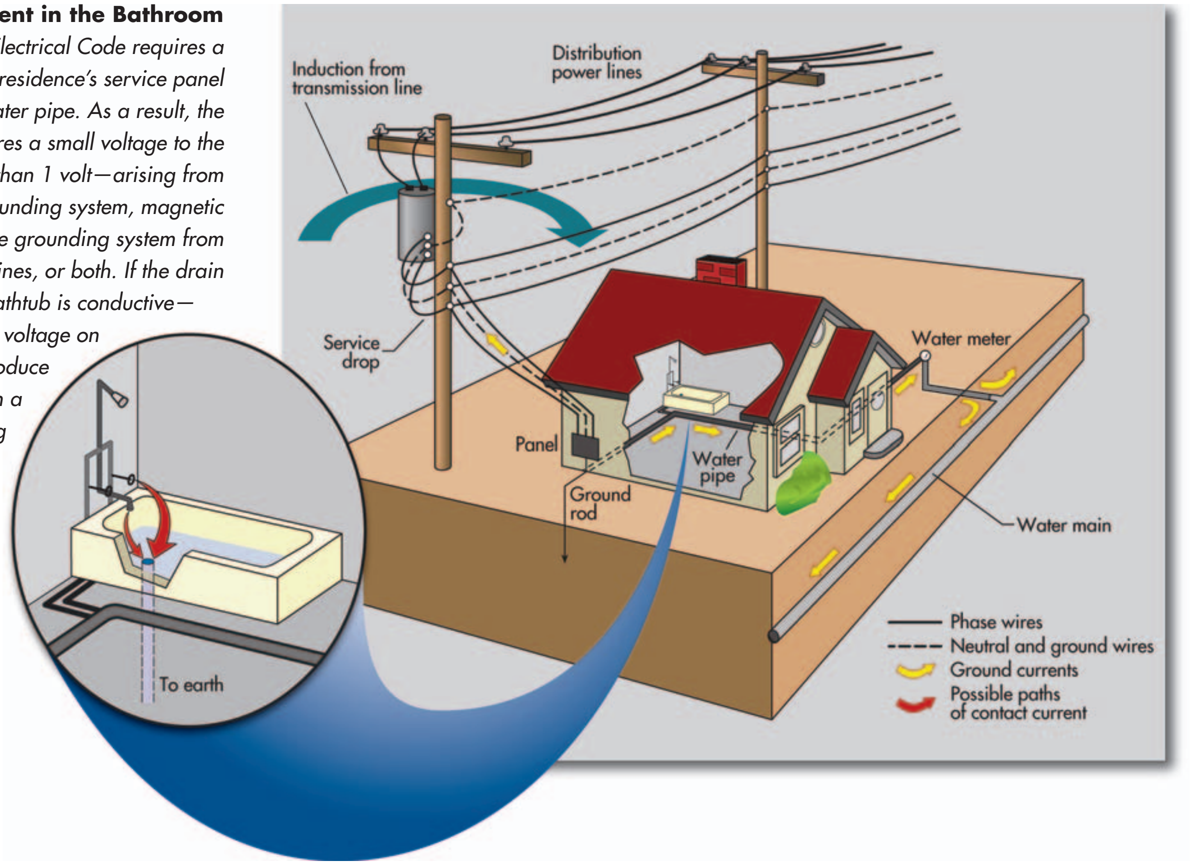
The IARC panel concluded that magnetic fields were a "possible" (IARC category 2B) human carcinogen, based on the "limited" evidence on childhood leukemia from epidemiologic studies and the lack of supporting evidence from cell and animal studies. The evidence concerning all other cancers was insufficient to form a basis for IARC's conclusion. To put this classification in perspective, coffee, pickled vegetables, chloroform, and welding fumes are among over 200 other exposures included in IARC's "possible" carcinogen category. IARC stated that the association between childhood leukemia and magnetic fields was not likely to be due to chance but conceded that epidemiologic artifacts could not be excluded. IARC also evaluated power-frequency electric fields, which by then were incorporated into several residential and occupational epidemiologic studies; electric fields were classified as a category 3 exposure (not classifiable as to carcinogenicity in humans), since the evidence was inadequate to assign even a "possibly hazardous" designation.

Other risk assessments have supported the IARC panel's conclusion. All the major assessments relied heavily on EPRI-sponsored research, and EPRI scientific staff were significantly involved in the panel deliberations held by both NIEHS and IARC. The presence of a credible industry-sponsored research program opened a seat at the table for EPRI. The next major development in EMF health assessment will be WHO's publication of its *EMF Environmental Health Criteria*, which will summarize and evaluate the relevant scientific literature and offer recommendations for further research. Scheduled for release in 2006, the report is likely to trigger a reassessment of research priorities, as well as further worldwide public interest in the EMF issue. Rob Kavet served as an observer to the final review of the report in October 2005, allowing EPRI to have a voice in the discussions and input to the final WHO report.

The credibility of EPRI's EMF health assessment work and the industry's commitment to research were highlighted in a September 2000 column in the *Wall Street Journal* by Marianne M. Jennings, a professor of legal and ethical studies. In contrasting other industries' approaches to well-publicized health and safety issues, she singled out the electric power industry's approach to EMF with praise, stating that "perhaps the best example of an industry willing to use the truth to set itself free was the electric utility sector. . . . EMF was managed with ethics and an attitude: If EMF is a problem, we manage it early and make it right. If it's a false alarm, we have the credibility and trust earned with voluntary action and disclosure at the moment of truth."

Contact Current in the Bathroom

The National Electrical Code requires a connection from a residence's service panel neutral to a nearby water pipe. As a result, the water pipe acquires a small voltage to the earth—usually less than 1 volt—arising from currents in the grounding system, magnetic field induction on the grounding system from nearby transmission lines, or both. If the drain in the residence's bathtub is conductive—made of metal—the voltage on the water pipe can produce a contact current when a person who is bathing touches the faucet or metal fixtures.



expected in the thinnest extremities, where the current densities must be the greatest —that is, in the lower arm and hand.

Evaluating Criteria for Plausibility

For contact current to be considered a viable candidate exposure that explained the epidemiology, investigators knew, three criteria would have to be satisfied prior to committing to further research: (1) a plausible dose to bone marrow, (2) a strong association of magnetic fields with the source of contact current, and (3) a child's frequent access to exposure. The failure to verify any one of the three would be a signal to stop this line of investigation.

Dose. If you discuss this issue with Kavet, he'll tell you that one of his heroes is a sixteenth-century scientist named Paracelsus, often referred to as the father of toxicology. Paracelsus put forward an idea that has become central to his field: Everything is poisonous in a high enough dose, and even strong poisons are harmless if the dose is low enough. In other words, "The dose makes the poison." Thus, to be a credible causal candidate, contact current would have to deliver a dose to tissue at levels that, according to biophysical principles, could plausibly elicit biological effects—a characteristic that residential magnetic fields did not provide.

Soon after the initial thoughts about contact current developed, the program teamed with Maria Stuchly and her research team at the University of Victoria to estimate the relationship of contact current exposure to electrical dose inside the body. Stuchly's research group already had extensive experience in using anatomically accurate computer models of the human body to estimate dose from exposure to EMF. The study, published in 2001, reported that small, imperceptible levels of contact current of the magnitude that could occur in the bathing scenario would produce doses in the arm's bone marrow that far exceeded (by factors of hundreds to thousands) the doses calculated from ambient magnetic fields; these were doses at levels that leaped over the hurdles that so challenged magnetic fields.

Association. Since the risk of childhood leukemia was observed to be greater in homes with fields above 3–4 mG, the higher values of voltage responsible for producing contact current—known as contact voltage—would necessarily need to coexist with these higher fields with a much greater probability than they would in homes with fields of lower values.

In 2001–2002, Kavet worked on the contact current idea with Enertech Consultants' Luciano Zaffanella, the architect of EPRI's well-known 1000-Home Study and the 1000-Person Study conducted for the U.S. Department of Energy as part of the federal RAPID program (see sidebar, page 28). Zaffanella developed a protocol for characterizing the sources of contact current exposure in the home, as well as for taking routine measurements of the magnetic field, and applied them in a small pilot study for EPRI in Pittsfield, Massachusetts. The protocol focused largely on home appliances but also included measurements in the bathroom at all possible sites that people might touch on a routine basis. As it turned out, Zaffanella measured a significant voltage between the bath fixtures and the drain in the first two homes he visited.

Kavet and Zaffanella discussed the results the day the measurements were taken, becoming excited over the possibility that this voltage could be the missing link in the relationship between magnetic fields and childhood leukemia. The idea made immediate sense to the researchers: a bathing scenario meant that an immersed child's hand would be at least damp, if not saturated with water, which would reduce the skin's electrical resistance to an insignificant value. The small pilot study of 36 homes also reported data that suggested a positive association between the residential magnetic field and the voltage from the residential water line to earth, the source voltage for contact current exposure in the bath. This study's success triggered a larger effort in the Denver area, site of the two most important early EMF studies. In a measurement study that included visits to 191 residences, Kavet and colleagues reported a positive association between the residential magnetic field and both the voltage from the water line to earth and the voltage that a child would experience in the bathtub.

Though the measurement programs produced valuable data, they could not by themselves show how the infrastructural characteristics of communities would contribute to a set of empirical observations. Zaffanella and his associate Jeff Daigle, working closely with Kavet, produced the Contact Voltage Modeler (CVM), a program that makes it possible to specify a neighborhood's features—its geography, electrical distribution system, and water system—and then to identify the factors influencing residential magnetic fields, the voltage from residential water lines to earth, and the interrelationship of the two. The results supported the hypothesis that if a broad variety of neighborhoods in an extended geographic region (like those in epidemiologic studies) were simulated, a strong relationship between the magnetic fields and the water-line-to-earth voltages would be observed.

Frequent Access. In addition to the induction of genetic or chromosomal anomalies that initiate carcinogenesis, the pathway to malignancy in most cases involves other influences and exposures that, though not genotoxic themselves, nudge the already-affected cells toward a malignant state. The past 60 years of cancer research has shown that exposures subsequent to the initiation stage need to occur on a relatively frequent or repeated basis to have noticeable effects. Thus any exposure being considered as responsible for associations with magnetic fields would also have to occur reasonably often.

Anecdotally, many parents may recall that their young children, while bathing, indulged in exploratory play with the water fixtures or the water stream. Working with researchers at the University of California at Berkeley, EPRI supported a survey of parents using interview and diary techniques to assess the extent to which children from younger than one year to five years old engage in behavior that would produce exposure. The results indicated that roughly 80% of the children studied indeed displayed evidence of such behavior, and that beyond the age of one (when their arm's reach lengthened), this behavior increased.

The Testing Phase

With the criteria of dose, association, and frequent access satisfied, EPRI's research into the contact current hypothesis has accelerated from the plausibility phase to hypothesis testing by means of a multidisciplinary strategy. In 2003, the program joined forces with the School of Public Health at UC Berkeley, which since 1995, under the leadership of Patricia Buffler, has been conducting the Northern California Childhood Leukemia Study, the most intensive U.S. investigation yet of the environmental, genetic, and biochemical risk factors for childhood leukemia. The merger is a true bonanza for the EPRI program, not only allowing research into contact currents and magnetic fields but offering the program a significant opportunity to expand its research into control selection bias as well.

In 2006, following a competitive bidding process, EPRI began research at UC San Francisco with Scott Kogan to develop a genetically engineered mouse that will model the pathological events that lead to leukemia in children; ultimately this model will be put to the test with contact current exposures. Finally, the program is adapting the CVM to characterize exposure scenarios in countries where influential EMF studies have been reported, including both Sweden and the United Kingdom. The results of these efforts will emerge within the next five years and, when factored in with other research developments around the world, will determine future directions for the program.

A critical component of the EPRI program today, as for the past 18 years, is the advice and counsel of an independent advisory group of eminent scientists. The Scientific Advisory Committee meets on an annual basis to thoroughly review the program and offer recommendations. The committee remains informed of significant developments year-round and maintains an active relationship with the members of the program's Area Council. Working together with all of its advisors, EPRI's EMF health assessment program is committed to unraveling the critical uncertainties to ensure that electric and magnetic field environments are compatible with public health and safety.

Background information for this article was provided by Rob Kavet (rkavet@epri.com).

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Efficient Power Supplies Could Save 1% of U.S. Electricity Use

The power supplies that convert normal ac power into the low-voltage dc power used by electronic devices consume at least 2% of all U.S. electricity production. New research conducted by EPRI Solutions and Ecos Consulting indicates that wider use of more-efficient power supplies could cut total consumption by half, saving consumers nearly $3 billion per year and reducing annual U.S. carbon emissions by 24 million tons.

External power supplies—sometimes called wall warts because of their obtrusive appearance when plugged into a wall socket—provide power mainly to small, portable devices, such as cordless phones and video games, and generally have efficiencies in the range of 30–40%. More than 1 billion of these external units are estimated to be in use in the United States, most of which continue to consume a few watts of power even when no load is connected. Improved designs could increase efficiency to 80% or more and reduce no-load consumption to about a tenth of current levels.

Larger electronic appliances, such as personal computers and televisions, generally have internal power supplies with efficiencies in the range of 65–70% when the appliance is in active use. About 1.5 billion internal units are now in use in the United States. Considerable progress has already been made through the federal Energy Star program to reduce power consumption by mandating a Sleep or Standby mode for small office equipment. As a result, most of the remaining energy savings need to come from improvements in the operational mode, which can be achieved with new power supply designs capable of efficiencies of 90% or more.

The ongoing research program to improve power supply efficiency is sponsored by the California Energy Commission (CEC) through its Public Interest Energy Research (PIER) program. Specific goals include developing standardized test procedures to measure the energy efficiency of power supplies, collecting efficiency test data on current products, using this information to estimate total energy consumption, and working with manufacturers to improve the efficiency of power supply designs.

Some key results from the California program have already been applied. Specifically, efficiency specification levels proposed by the research team for single-voltage external power supplies have been adopted by the CEC and are scheduled to take effect in July 2006. The same levels were subsequently adopted by the Energy Star program and have been proposed for adoption as mandatory standards in other states. In addition, California's electric utilities are funding a program called 80 Plus to promote the marketing of power supplies with efficiencies of 80% or higher.

Using the test procedure developed earlier in the project, some 800 power supply samples have now been tested in the United States, China, and Australia, revealing an exceptionally wide range of efficiencies. For example, external power supplies with less than 20 watts output had efficiencies that ranged from 20% to 80%. Improving the efficiency of such units will not only save energy but also make the next generation of wall warts much smaller and less obtrusive.

These test results and additional research insights have been incorporated into *Improving AC-DC Power Supplies for Improved Energy Efficiency: A Technical Primer,* published by the CEC and designed to serve manufacturers as a design guide for future units. Intel has already adopted the standardized test procedure and has set aggressive efficiency targets for power supply efficiencies across a range of load conditions—a step that is expected to pave the way for future computer efficiency labeling.

Future work in this project will involve determining the grid impacts of widespread market penetration of highly efficient power supplies, evaluating secondary power supplies (such as voltage regulator modules in computers), and investigating the efficiency of display technologies. The power quality characteristics of various electronic loads may also be examined; for example, field measurements may determine the magnitude of energy losses in office buildings associated with low power factors and high harmonic distortion in power supplies.

For more information, contact Arshad Mansoor, amansoor@epri.com.

Cause of Puzzling Transformer Failures Identified

Over the past few years, a number of failures have hit large power transformers and shunt reactors in countries around the world. Such failures, which arise with no apparent cause and typically without warning, are occurring at an increasing rate. The transformers that have failed have not only been very expensive but have also performed critical functions; generator stepup units, for example, connect power plants to transmission systems, and their failure can result in heavy revenue loss for a plant. EPRI Solutions experts have now conclusively identified the underlying cause of some of these problems and are working with utilities and manufacturers to prevent their recurrence.

As they investigated the puzzling failures, which sometimes affected even relatively new transformers, the experts confirmed that an old nemesis had returned: corrosive sulfur contamination of the insulating oil and other materials. Such contamination not only corrodes the surface of copper conductors but—much more important—reduces the dielectric strength of the paper insulation around them. As a result, breakdown can occur through the solid paper insulation disks, causing the transformer to fail.

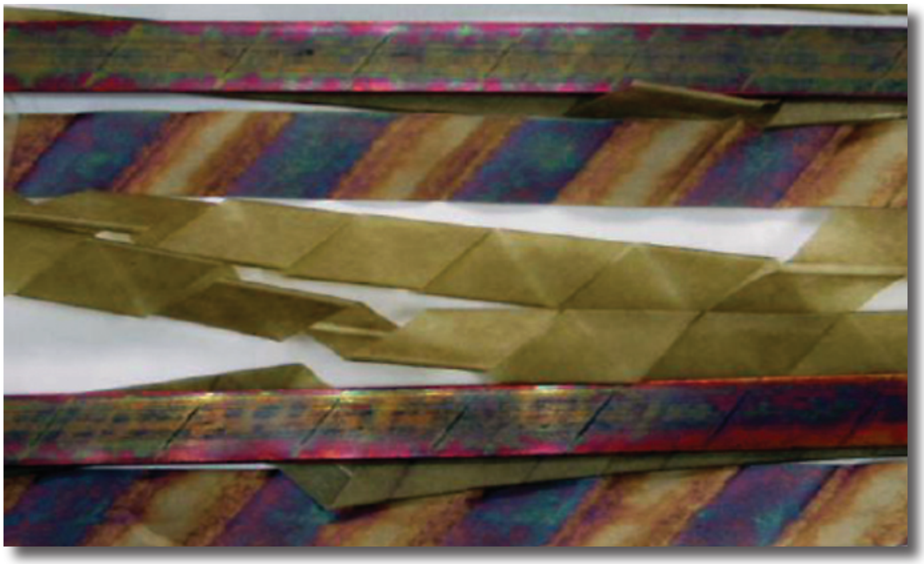
The potential for such problems has been recognized for decades, but the presence of corrosive sulfur in transformer oil was thought to have been virtually eliminated by improved industry standards and detection methods. Now it appears that some relatively benign sulfur compounds, present even in some oils that meet current industry specifications, can be converted into corrosive sulfur over time as a result of elevated temperatures.

In order to conduct a comprehensive investigation of this growing industry problem, EPRI Solutions is supporting a major new collaborative R&D project through EPRI, while continuing to work directly with utility clients to mitigate the impacts of corrosive sulfur. Specifically, EPRI Solutions has developed a number of new tests that can help identify the transformers and reactors that are most likely to fail from contamination with corrosive sulfur. In addition, hundreds of tests on paper insulation have been conducted to clarify the insulation degradation phenomenon.

Meanwhile, EPRI's collaborative project will evaluate these and other new testing methods, while also developing novel ways to predict the onset of damage. The project will look at reasons for the reemergence of the problem and investigate how damage may relate to different types of oil and various refining and treatment processes. Means to halt the process of corrosive sulfur contamination, such as the use of passivators and innovative filtration methods, will also be explored. Testing is planned to determine the effectiveness of such approaches.

Ultimately, the close cooperation between EPRI and EPRI Solutions is expected to produce new insights into the problem of sulfur corrosion and lead to development of better prevention and mitigation strategies. A web-accessible database will be established to help individual utility clients and project participants track the condition of their own transformers and to aid them in the procurement of future equipment.

For more information, contact Nick Abi-Samra, nabisamra@eprisolutions.com.



Copper sulfide deposits on insulating paper from a failed transformer.

Technical Reports & Software

For more information, contact the EPRI Customer Assistance Center at 800.313.3774 (askepri@epri.com). Visit EPRI's web site to download PDF versions of technical reports (www.epri.com).

Environment

Fate and Effects of Selenium in Lentic and Lotic Systems
1005315 (Technical Report)
Program: Mercury, Metals, and Organics in Aquatic Environments
EPRI Project Manager: Richard Carlton

RF Estimator, EPRI Radio Frequency Exposure Estimator, Version 1.05
1005420 (Software)
Program: EMF Health Assessment and RF Safety
EPRI Project Manager: Robert Kavet

Enhancement of Watershed Analysis Risk Management Framework (WARMF) for Mercury Watershed Management and Total Maximum Daily Loads (TMDLs)
1005471 (Technical Report)
Program: Watershed Management and Water Resource Sustainability
EPRI Project Manager: Robert Goldstein

Air-Cooled Condenser Design, Specification, and Operation Guidelines
1007688 (Technical Report)
Program: Integrated Facilities Water Management
EPRI Project Manager: Charles McGowin

Parameter Development for Equivalent Adult and Production Foregone Models
1008832 (Technical Report)
Program: Section 316(a) and 316(b) Fish Protection Issues
EPRI Project Manager: Douglas Dixon

Effects of Ammonia on Trace Element Leaching From Coal Fly Ash
1010063 (Technical Report)
Program: Groundwater Protection and Coal Combustion Products Management
EPRI Project Manager: Kenneth Ladwig

Groundwater Monitoring Guidance for the Industry Action Plan on Coal Combustion Product Management
1010064 (Technical Report)
Program: Groundwater Protection and Coal Combustion Products Management
EPRI Project Manager: Kenneth Ladwig

Identifying Alternative Fish Protection Technologies for Detailed Evaluation
1010111 (Technical Report)
Program: Section 316(a) and 316(b) Fish Protection Issues
EPRI Project Manager: Douglas Dixon

Framework to Evaluate Water Demands and Availability for Electrical Power Production Within Watersheds Across the United States: Development and Applications
1010116 (Technical Report)
Program: Watershed Management and Water Resource Sustainability
EPRI Project Manager: Robert Goldstein

Guidelines for Integrated Management of Multiple Constituents in Ash Ponds—Volume 1
1010123 (Technical Report)
Program: Integrated Facilities Water Management
EPRI Project Manager: Richard Carlton

Electric Transmission Right-of-Way Invasive Non-Native Woody Plant Species Control
1010127 (Technical Report)
Program: Rights-of-Way Environmental Issues in Siting, Development, and Management
EPRI Project Manager: John Goodrich-Mahoney

Aerial Patrol Rights-of-Way for Integrated Vegetation Management
1010129 (Technical Report)
Program: Rights-of-Way Environmental Issues in Siting, Development, and Management
EPRI Project Manager: John Goodrich-Mahoney

Compendium of Animal-Caused Outage Prevention Devices
1010131 (Technical Report)
Program: Rights-of-Way Environmental Issues in Siting, Development, and Management
EPRI Project Manager: Richard Carlton

Manufactured Gas Plant (MGP) Air Monitoring Survey Report
1010141 (Technical Report)
Program: MGP Site Management
EPRI Project Manager: James Lingle

Mercury Reactions in Power Plant Plumes: Pleasant Prairie Experiment and Compliance Scenario Assessment
1010142 (Technical Report)
Program: Air Toxics Health and Risk Assessment
EPRI Project Manager: Leonard Levin

Longer-Term Mercury Emission Characterization of Power Plants With Selective Catalytic Reduction and Flue Gas Desulfurization Systems
1010154 (Technical Report)
Program: Plant Multimedia Toxics Characterization (PISCES); Integrated Environmental Controls
EPRI Project Manager: Paul Chu

Occupational Health and Safety Annual Report 2005
1010164 (Technical Report)
Program: Occupational Health and Safety
EPRI Project Manager: Janice Yager

Program on Technology Innovation: Managing the Risks of Climate Policies
1010173 (Technical Report)
Program: Greenhouse Gas Reduction Options; Technology Innovation
EPRI Project Manager: Thomas Wilson

Evaluation of Mercury Speciation in a Power Plant Plume
1011113 (Technical Report)
Program: Air Toxics Health and Risk Assessment
EPRI Project Manager: Leonard Levin

Childhood Leukemia
1011716 (Technical Report)
Program: EMF Health Assessment and RF Safety
EPRI Project Manager: Gabor Mezei

Characterizing Contact Current and Nuisance Shocks in the Workplace
1011718 (Technical Report)
Program: EMF Health Assessment and RF Safety
EPRI Project Manager: Robert Kavet

Electric and Magnetic Fields (EMF) Workstation 2005 Program
1011720 (Software)
Program: EMF Health Assessment and RF Safety
EPRI Project Manager: Brian Cramer

Overview of Wireless Facilities for the Electric Power Industry
1011722 (Technical Report)
Program: EMF Health Assessment and RF Safety
EPRI Project Manager: Robert Kavet

Evaluation of an Angled Louver Facility for Guiding Sturgeon to a Downstream Bypass
1011786 (Technical Report)
Program: Hydropower Environmental Issues
EPRI Project Manager: Douglas Dixon

Valuing Regional Haze Changes: The Sensitivity of Contingent Valuation Results to Questionnaire Format
1011852 (Technical Report)
Program: Assessment Tools for Ozone, Particulate Matter, and Haze
EPRI Project Manager: Naresh Kumar

Potential Health Effects of Crystalline Silica Exposures From Coal Fly Ash: A Literature Review
1012821 (Technical Report)
Program: Occupational Health and Safety
EPRI Project Manager: Janice Yager

Test Performance for Assessment of Neurodevelopment in Children
1012822 (Technical Report)
Program: Air Toxics Health and Risk Assessment
EPRI Project Manager: Janice Yager

Prenatal Methylmercury Exposure and Developmental Effects
1012824 (Technical Report)
Program: Air Toxics Health and Risk Assessment
EPRI Project Manager: Janice Yager

Ergonomic Interventions for Fossil-Fueled Electric Power Plants
1012957 (Technical Report)
Program: Occupational Health and Safety
EPRI Project Manager: Janice Yager

Ergonomic Design for Fossil-Fueled Electric Power Plants
1012958 (Technical Report)
Program: Occupational Health and Safety
EPRI Project Manager: Janice Yager

Mitigation of SCR-Ammonia Related Aqueous Effects in a Fly Ash Pond
1013035 (Technical Report)
Program: Mercury, Metals, and Organics in Aquatic Environments; Integrated Facilities Water Management
EPRI Project Manager: John Goodrich-Mahoney

Program on Technology Innovation: Electric Technology in a Carbon-Constrained World
1013041 (Technical Report)
Program: Greenhouse Gas Reduction Options; Technology Innovation
EPRI Project Manager: Thomas Wilson

EPRI-GTC Overhead Electric Transmission Line Siting Methodology
1013080 (Technical Report)
Program: Rights-of-Way Environmental Issues in Siting, Development, and Management
EPRI Project Manager: John Goodrich-Mahoney

GHG-RISK 1.0—Greenhouse Gas Risk Assessment Prototype Spreadsheet Model, Version 1.0
1013094 (Software)
Program: Greenhouse Gas Reduction Options
EPRI Project Manager: Adam Diamant

SCICHEM, Version 1.602 on CD-ROM
1013197 (Software)
Program: Assessment Tools for Ozone, Particulate Matter, and Haze
EPRI Project Manager: Naresh Kumar

Generation

Plant Status Management Guideline
1008257 (Technical Report)
Program: Operations Management and Technology
EPRI Project Manager: Wayne Crawford

Condensate Polishing Guidelines for Fossil Plants
1010181 (Technical Report)
Program: Boiler and Turbine Steam and Cycle Chemistry
EPRI Project Manager: Barry Dooley

Simulated Boiler Corrosion Studies Using Electrochemical Techniques
1010187 (Technical Report)
Program: Boiler and Turbine Steam and Cycle Chemistry
EPRI Project Manager: Barry Dooley

Guidelines for Reducing the Time and Cost of Turbine-Generator Maintenance Overhauls and Inspections—2005
1010190 (Technical Report)
Program: Steam Turbines, Generators, and Balance-of-Plant
EPRI Project Manager: Stephen Hesler

Turbine-Generator Auxiliary Systems
1010191 (Technical Report)
Program: Steam Turbines, Generators, and Balance-of-Plant
EPRI Project Manager: Stephen Hesler

Replacement Interstage Seals for Steam Turbines
1010214 (Technical Report)
Program: Steam Turbines, Generators, and Balance-of-Plant
EPRI Project Manager: Stephen Hesler

Advanced Control Demonstration on a Combined-Cycle Plant
1010261 (Technical Report)
Program: I&C and Automation for Improved Plant Operations
EPRI Project Manager: Ramesh Shankar

Fleetwide Monitoring for Equipment Condition Assessment
1010266 (Technical Report)
Program: I&C and Automation for Improved Plant Operations
EPRI Project Manager: Aaron Hussey

Status of Mercury Control Technologies: Activated Carbon Injection and Boiler Chemical Additives
1010349 (Technical Report)
Program: Integrated Environmental Controls
EPRI Project Manager: Ramsay Chang

Advanced Electrostatic Precipitator (ESP) Power Supplies Update
1010361 (Technical Report)
Program: Particulate and Opacity Control
EPRI Project Manager: Ralph Altman

CTCC O&M Cost Analyzer 5.0—Combustion Turbine/Combined-Cycle Operations and Maintenance Cost Analyzer, Version 5.0
1010404 (Software)
Program: Combustion Turbine (CT) and Combined-Cycle (CC) O&M
EPRI Project Manager: Dale Grace

Renewable Energy Technical Assessment Guide (TAG-RE) Electronic Media
1010405 (Software)
Program: Renewable Energy Technology and Strategy
EPRI Project Manager: Charles McGowin

Solar Photovoltaic Technology Update—2005
1010412 (Technical Report)
Program: Renewable Energy Technology and Strategy
EPRI Project Manager: Alejandro Jimenez

Condition Monitoring of Wind Turbines
1010419 (Technical Report)
Program: Operations Management and Technology
EPRI Project Manager: Charles McGowin

Cycle Chemistry Guidelines for Shutdown, Layup, and Startup of Combined-Cycle Units With Heat Recovery Steam Generators
1010437 (Technical Report)
Program: Heat Recovery Steam Generator (HRSG) Dependability
EPRI Project Manager: Barry Dooley

Cycle Chemistry Guidelines for Combined-Cycle/Heat Recovery Steam Generators (HRSGs)
1010438 (Technical Report)
Program: Heat Recovery Steam Generator (HRSG) Dependability
EPRI Project Manager: Barry Dooley

CC ChemExpert, Version 1.0
1010439 (Software)
Program: Heat Recovery Steam Generator (HRSG) Dependability
EPRI Project Manager: Barry Dooley

Pulverizer Maintenance Guide
1010443 (Technical Report)
Program: Fossil Maintenance Applications Center (FMAC)
EPRI Project Manager: Alan Grunsky

Demonstration of Wear and Tear Sensors for Measurement of Damage
1010462 (Technical Report)
Program: I&C and Automation for Improved Plant Operations
EPRI Project Manager: Aaron Hussey

Feasibility of Renewable Energy From Poultry Litter in the TVA Region
1010486 (Technical Report)
Program: Renewable Energy Technology and Strategy
EPRI Project Manager: David O'Connor

TULIP 2.0—Tube Life Probability, Version 2.0
1010621 (Software)
Program: Boiler Life and Availability Improvement Program
EPRI Project Manager: Richard Tilley

Best Practices Guidebook for Integration of Distributed Energy Resources Into Utility System Planning
1011250 (Technical Report)
Program: Distributed Energy Resources
EPRI Project Manager: William Steeley

Ash Handling System Maintenance Guide
1011684 (Technical Report)
Program: Fossil Maintenance Applications Center (FMAC)
EPRI Project Manager: Alan Grunsky

2005 Workshop on Selective Catalytic Reduction
1011796 (Technical Report)
Program: Postcombustion NO_x Control
EPRI Project Manager: David Broske

Severe Duty Valve Maintenance Guide
1011828 (Technical Report)
Program: Fossil Maintenance Applications Center (FMAC)
EPRI Project Manager: Leonard Loflin

Metallurgical Guidebook for Fossil Power Plant Boilers
1011912 (Technical Report)
Program: Fossil Materials and Repair
EPRI Project Manager: David Gandy

Flue Gas Desulfurization Systems
1011913 (Technical Report)
Program: Fossil Materials and Repair
EPRI Project Manager: David Gandy

Field Evaluation of Fumigation Bi-Fuel Systems Installed on Diesel Engine-Generators
1012429 (Technical Report)
Program: Distributed Energy Resources
EPRI Project Manager: David Thimsen

Evaluation of Plug Power Gensys 5C Fuel Cell System in Mesa, AZ: Final Report
1012836 (Technical Report)
Program: Distributed Energy Resources
EPRI Project Manager: David Thimsen

Petcoke and Low-Rank Coal/Lignite Supply Outlook for IGCC Evaluations
1013038 (Technical Report)
Program: CoalFleet for Tomorrow
EPRI Project Manager: John Parkes

Coal Fleet Integrated-Gasification–Combined-Cycle (IGCC Permitting) Guidelines
1013046 (Technical Report)
Program: CoalFleet for Tomorrow
EPRI Project Manager: John Parkes

CatReact (Catalyst Reaction), Version 1.1
1013047 (Software)
Program: Postcombustion NO_x Control
EPRI Project Manager: David Broske

West Oahu Solar-Powered LED Lighting System
1013115 (Technical Report)
Program: Renewable Energy Technology and Strategy
EPRI Project Manager: Alejandro Jimenez

Technical Assessment Guide (TAG)—Central Stations and Wind Energy
1013215 (Technical Report)
Program: Technology-Based Business Planning Information and Services (TAG)
EPRI Project Manager: Gopalachary Ramachandran

Nuclear

Materials Reliability Program: Alloy 82/182 Pipe Butt Weld Safety Assessment for U.S. PWR Plant Designs (MRP-113)
1009549 (Technical Report)
Program: Nuclear Power
EPRI Project Manager: Christine King

Procedure for Rewinding AC Random-Wound Stators for Environmentally Qualified Motors: Continuous Duty Applications
1009747 (Technical Report)
Program: Nuclear Power
EPRI Project Manager: Neil Wilmshurst

CIR II Program: Crack Growth Testing of Fast Reactor Irradiated Type 304L Stainless Steel in BWR Environments
1009893 (Technical Report)
Program: Nuclear Power
EPRI Project Manager: Rajeshwar Pathania

Nuclear Maintenance Applications Center: Main Steam Isolation Valve Maintenance Guide—Update to NP-7211
1010012 (Technical Report)
Program: Nuclear Power
EPRI Project Manager: Leonard Loflin

Plant Support Engineering: Life Cycle Management Planning Sourcebook—Medium-Voltage Switchgear
1010031 (Technical Report)
Program: Nuclear Power
EPRI Project Manager: Gary Toman

Baseline Materials Data to Support Procedures for Rewinding Environmentally Qualified Motors
1010640 (Technical Report)
Program: Nuclear Power
EPRI Project Manager: Neil Wilmshurst

BWRVIP-151: BWR Vessel and Internals Project, Technical Basis for Revision to BWRVIP-97 Welding Guidelines
1011692 (Technical Report)
Program: Nuclear Power
EPRI Project Manager: Robert Carter

BWRVIP-152: BWR Vessel and Internals Project—NDE Development 2005
1011697 (Technical Report)
Program: Nuclear Power
EPRI Project Manager: Jeff Landrum

BWRVIP-153: BWR Vessel and Internals Project, Crack Growth in High Fluence BWR Materials—Progress Report for 2005
1011700 (Technical Report)
Program: Nuclear Power
EPRI Project Manager: Rajeshwar Pathania

BWRVIP-154: BWR Vessel and Internals Project, Fracture Toughness in High Fluence BWR Materials—Progress Report for 2005
1011701 (Technical Report)
Program: Nuclear Power
EPRI Project Manager: Anne Demme

BWRVIP-150: BWR Vessel and Internals Project, Report and NRC Correspondence, DVD, Version 12.2005
1011703 (Technical Report)
Program: Nuclear Power
EPRI Project Manager: Tom Mulford

Treatment of External Events in Configuration Risk Management: An Implementation Guide
1011762 (Technical Report)
Program: Nuclear Power
EPRI Project Manager: John Gaertner

Residual Chromium Effects on Flow-Accelerated Corrosion of Carbon Steel
1011837 (Technical Report)
Program: Nuclear Power
EPRI Project Manager: Albert Machiels

The Operational Risk Simulation Model (ORSIM)
1011911 (Technical Report)
Program: Nuclear Power
EPRI Project Manager: Martin Bridges

Use of MCC-Based Motor Torque Measurements for Periodic Verification of Motor-Operated Valves
1011919 (Tech Report Software)
Program: Nuclear Power
EPRI Project Manager: John Hosler

2005 EDF/EPRI Collaboration on Life Cycle Management and Nuclear Asset Management
1011925 (Technical Report)
Program: Nuclear Power
EPRI Project Manager: George Sliter

MAAP4 4.0.6: Modular Accident Analysis Program (MAAP4), Version 4.0.6
1012091 (Software)
Program: Nuclear Power
EPRI Project Manager: Frank Rahn

Alloy 600/182 Material Characterization Using Giant Magnetoresistive (GMR) Sensors
1012619 (Technical Report)
Program: Nuclear Power
EPRI Project Manager: Kenji Krzywosz

TFE v1.0, MRP-170: EPRI Thermal Fatigue Evaluation per MRP-146 on CD-ROM for Win 2000/XP
1012905 (Software)
Program: Nuclear Power
EPRI Project Manager: John Carey

Proactive Assessment of Organizational and Workplace Factors, Version 2.2
1012959 (Software)
Program: Nuclear Power
EPRI Project Manager: David Ziebell

Determining Piping Wear Caused by Flow-Accelerated Corrosion From Single-Outage Inspection Data
1013012 (Technical Report)
Program: Nuclear Power
EPRI Project Manager: Albert Machiels

An Evaluation of Flow-Accelerated Corrosion in the Bottom Head Drain Lines of Boiling Water Reactors
1013013 (Tech Report Software)
Program: Nuclear Power
EPRI Project Manager: Albert Machiels

Materials Reliability Program, Environmental Fatigue Testing of Type 304L Stainless Steel U-Bends in Simulated PWR Primary Water (MRP-188)
1013028 (Technical Report)
Program: Nuclear Power
EPRI Project Manager: John Carey

GOTHIC 7.2a—Generation of Thermal Hydraulic Information in Containments, Version 7.2a on CD-ROM for Win XP, NQA Product
1013072 (Software)
Program: Nuclear Power
EPRI Project Manager: Frank Rahn

GOTHIC 7.2a—Generation of Thermal Hydraulic Information in Containments, Version 7.2a (UNIX), NQA Product
1013073 (Tech Report Software)
Program: Nuclear Power
EPRI Project Manager: Frank Rahn

EQMS 3.0—Environmental Qualification Management System, Version 3.0
1013076 (Software)
Program: Nuclear Power
EPRI Project Manager: Christopher Abernathy

The Use of Proton Irradiation to Determine IASCC Mechanisms in Light Water Reactors
1013081 (Technical Report)
Program: Nuclear Power
EPRI Project Manager: Rajeshwar Pathania

Plant Support Engineering: Advanced Diagnostics and Life Estimation of Extruded Dielectric Cable
1013085 (Technical Report)
Program: Nuclear Power
EPRI Project Manager: Gary Toman

Graphite Decommissioning
1013091 (Tech Report Software)
Program: Nuclear Power
EPRI Project Manager: Christopher Wood

EPRI NDE Center Product Catalog: 2005 Update
1013101 (Technical Report)
Program: Nuclear Power
EPRI Project Manager: Greg Selby

Pipe Rupture Frequencies for Internal Flooding PRAs, Revision 1
1013141 (Technical Report)
Program: Nuclear Power
EPRI Project Manager: Frank Rahn

Proceedings: 2005 ASME/EPRI Radwaste Workshop
1013163 (Technical Report)
Program: Nuclear Power
EPRI Project Manager: Sean Bushart

Proceedings: 2005 EPRI International Low-Level Waste Conference and Exhibit
1013164 (Technical Report)
Program: Nuclear Power
EPRI Project Manager: Sean Bushart

Proceedings: 2005 Condensate Polishing Workshop
1013173 (Technical Report)
Program: Nuclear Power
EPRI Project Manager: Keith Fruzzetti

Power Delivery and Markets

Integration of COMTRADE Data Into a PQ Monitoring System Database
1010185 (Technical Report)
Program: Power Quality
EPRI Project Manager: Marek Samotyj

T&D System Design and Construction for Enhanced Reliability and Power Quality
1010192 (Technical Report)
Program: Power Quality
EPRI Project Manager: Marek Samotyj

Automated Algorithms to Identify Operations of Overcurrent Protective Devices: A Proof of Concept
1010196 (Technical Report)
Program: Power Quality
EPRI Project Manager: Marek Samotyj

Service Quality Index—Example Application
1010199 (Technical Report)
Program: Power Quality
EPRI Project Manager: Marek Samotyj

Steady-State Trend Data Analysis for Applications in Predictive Maintenance and Operations
1010200 (Technical Report)
Program: Power Quality
EPRI Project Manager: Marek Samotyj

Vibration 3.0—Overhead Line Vibration Analysis and Design Program, Version 3.0
1010219 (Software)
Program: Overhead Transmission
EPRI Project Manager: John Chan

OTLOT 1.0—Overhead Transmission Line Inspection Online Training, Version 1.0
1010220 (Software)
Program: Overhead Transmission
EPRI Project Manager: Andrew Phillips

230-kV Accelerated Aging Chamber
1010250 (Technical Report)
Program: Overhead Transmission
EPRI Project Manager: Andrew Phillips

Maintenance Best Practices for Switching Equipment and Transformers With Key Performance Indicators (KPIs) and Algorithms for "Living" Reliability-Centered Maintenance (RCM) and Performance-Based Maintenance (PBM)
1010555 (Technical Report)
Program: Substations
EPRI Project Manager: Bhavin Desai

The Direct and Indirect Costs of Regulatory Compliance
1010567 (Technical Report)
Program: Electric Transportation
EPRI Project Manager: Robert Graham

Overview of Methodologies for the Determination of Fuel-Cycle Emissions for Plug-In Hybrid Electric Vehicles
1010569 (Technical Report)
Program: Electric Transportation
EPRI Project Manager: Robert Graham

Seaport Land-Side Equipment Electrification Opportunities
1010577 (Technical Report)
Program: Electric Transportation
EPRI Project Manager: Robert Graham

Transformer Cooling Systems Improvements
1010585 (Technical Report)
Program: Substations
EPRI Project Manager: Raymond Lings

Application Guide for the Automation of Distribution Feeder Capacitors
1010655 (Technical Report)
Program: Distribution Systems
EPRI Project Manager: Ashok Sundaram

Delta Hedging Energy Portfolios: An Exploratory Study
1010686 (Technical Report)
Program: Value and Risk in Energy Markets
EPRI Project Manager: Art Altman

Probabilistic Load Flow, Version 3.0
1010696 (Software)
Program: Grid Operations and Planning
EPRI Project Manager: Pei Zhang

Guidelines for Power Delivery Asset Management
1010728 (Technical Report)
Program: Power Delivery Asset Management
EPRI Project Manager: Jeremy Bloom

P2: Project Prioritization System, Version 3.0
1010741 (Software)
Program: Power Delivery Asset Management
EPRI Project Manager: Jeremy Bloom

Energy Storage and Distributed Generation Technologies
1010746 (Technical Report)
Program: Energy Storage for DER, Renewable and T&D Applications
EPRI Project Manager: Robert Schainker

EPRI Transmission Line Grounding Guide Software (EGGS), Version 1.01
1011654 (Software)
Program: Overhead Transmission
EPRI Project Manager: Andrew Phillips

GPPTS, Guidelines for the Preparation of Power Transformer Specifications, Version 1.0
1011658 (Software)
Program: Substations
EPRI Project Manager: Ying Shen

Compliance Guidelines for Cyber Security Reliability Standards
1011750 (Technical Report)
Program: Energy Information Security
EPRI Project Manager: Thomas Kropp

Assessment of Wireless Technologies in Substation Functions
1011751 (Technical Report)
Program: Energy Information Security
EPRI Project Manager: Thomas Kropp

Technologies for Remote Monitoring of Substation Assets: Physical Security
1011752 (Technical Report)
Program: Energy Information Security
EPRI Project Manager: Thomas Kropp

HERBS 2.0: Hyperlinked EPRI Redbook (Transmission Line Reference Book—200 kV and Above, Red Book Applets) on CD-ROM for Win 2000/XP
1011973 (Software)
Program: Overhead Transmission
EPRI Project Manager: Raymond Lings

HERBS: Transmission Line Reference Book—200 kV and Above, Third Edition
1011974 (Technical Report)
Program: Overhead Transmission
EPRI Project Manager: Raymond Lings

IntelliGrid^{SM} Architecture Report: Volume 1—IntelliGrid User Guidelines and Recommendations
1012160 (Technical Report)
Program: IntelliGrid
EPRI Project Manager: Joseph Hughes

Linux PACE/OTS 3.6.26—Power Simulator With EPRI Operator Training Simulator, Version 3.6.26
1012878 (Software)
Program: Grid Operations and Planning
EPRI Project Manager: Peter Hirsch

Diesel Engine Idle Reduction in Class 8 Trucks Using On-Vehicle Equipment With Optional Shore Power
1012920 (Technical Report)
Program: Electric Transportation
EPRI Project Manager: Andra Rogers

Pilot Application of Enterprise Project Prioritization Process at Nebraska Public Power District (NPPD)
1012954 (Tech Report Software)
Program: Power Delivery Asset Management
EPRI Project Manager: Jeremy Bloom

EPM 5.0—EPRI Energy Portfolio Manager, Version 5.0
1012981 (Software)
Program: Value and Risk in Energy Markets
EPRI Project Manager: Art Altman

EPRI CIM Installer and Integration Project at LIPA
1012991 (Technical Report)
Program: Grid Operations and Planning
EPRI Project Manager: David Becker

XVisor 1.2 —XVisor Transformer Diagnostic Software, Version 1.2
1013056 (Software)
Program: Substations
EPRI Project Manager: Luke van der Zel

Program on Technology Innovation: Development of Acetylene Metal-Insulator-Semiconductor (MIS) Sensors for Use in Transformers
1013084 (Technical Report)
Program: Substations
EPRI Project Manager: Ying Shen

STLOAD 1.0, Substation Equipment Thermal Loading Program
1013103 (Software)
Program: System Approach to Increased Transmission Capacity
EPRI Project Manager: Rambabu Adapa

Study of Outage Request Switching and Clearance Forms
1013109 (Technical Report)
Program: Substations
EPRI Project Manager: George Gela

Harmonization of CIM With IEC Standards
1013110 (Tech Report Software)
Program: Grid Operations and Planning
EPRI Project Manager: David Becker

TOS 1.0—Transmission Outage Screening Using Network Flow Model, Version 1.0
1013203 (Software)
Program: Grid Operations and Planning
EPRI Project Manager: Peter Hirsch

EPRI Events

For further event listings, visit EPRI's web site (www.epri.com).

June

6–7
Work Planning Users Group
Charlotte, NC
Contact: Vicki Buchanan, 704.595.2158

7–8
Jodie Lane National Conference for Stray Voltage Detection, Mitigation, and Prevention
New York, NY
Contact: Robert Keefe, 650.855.1007

7–8
Preserving Equipment Qualification Training Course
Charlotte, NC
Contact: Beth McRimmon, 704.595.2036

8–9
EPRI Rod Control System Reliability Workshop
Williamsburg, VA
Contact: Linda Parrish, 704.595.2061

12–13
Distribution Advisory Council Meeting
Detroit, MI
Logistical and Registrar Contact: Joyce Jones, 413.499.5701

12–14
Transformer and Switchyard Users Group Meeting
Portland, OR
Contact: Linda Parrish, 704.595.2061

18
EPRI Bidirectional HVDC Thyristor Valve/Tripole Transmission Workshop
Montreal, Canada
Contact: Angelica Kamau, 650.855.7987

19
Electric Power Materials Committee Meeting
Ponte Vedra Beach, FL
Contact: Stacey Burnett, 704.595.2176

19–22
EPRI Fire Modeling Course 2006
San Luis Obispo, CA
Contact: Bijan Najafi, 650.855.2061

19–22
Repair and Replacement Applications Center Technical Program Meeting
Ponte Vedra Beach, FL
Contact: Stacey Burnett, 704.595.2176

19–23
The High-Voltage Transmission Line Design and Operation Seminar
Lenox, MA
Contact: EPRI Order Management, eprievents@epri.com

20
Fossil Repair Applications Center Members Meeting
Ponte Vedra Beach, FL
Contact: Stacey Burnett, 704.595.2176

20–21
BWRVIP Assessment Committee Meeting
Providence, RI
Contact: Bob Carter, 704.595.2019

20–21
EPRI Vertical Pump Workshop
Charlotte, NC
Contact: Linda Parrish, 704.595.2061

20–22
Eighth International Conference on Cycle Chemistry in Fossil and Combined-Cycle Plants
Alberta, Calgary, Canada
Contact: Tina Jackman or Carol Galle, 248.336.8611

21–22
BWRVIP Mitigation Committee Meeting
Providence, RI
Contact: Raj Pathania, 650.855.2998

21–23
Seventh International EPRI Conference: Welding and Repair Technology for Power Plants
Ponte Vedra Beach, FL
Contact: Stacey Burnett, 704.595.2176

22–23
Energy Information Security Advisory Council Meeting
Washington, D.C.
Logistical and Registrar Contact: Angelica Kamau, 650.855.7987

26–27
ASME/EPRI Radwaste Workshop
Albuquerque, NM
Contact: Linda Nelson, 518.374.8190

26–28
CHECWORKS User Group
Las Vegas, NV
Contact: Katy Ahrens, 415.455.9583

26–28
EPRI Plant Performance Enhancement Program (P2EP) Annual Coordinators Meeting
Orlando, FL
Contact: Beth McRimmon, 704.595.2036

26–28
Ninth EPRI Balance-of-Plant Heat Exchanger NDE Symposium
Big Sky, MT
Contact: Jill Lucas, 704.595.2074

26–28
PSE Electrical Aspects of Thermal Performance Engineering Pilot Training Course
Orlando, FL
Contact: Beth McRimmon, 704.595.2036

26–30
Materials Reliability in Nuclear Power Systems
Dedham, MA
Contact: http://web/mit.edu/canes/education/materialsreliability.html

27–29
BWRVIP IVVI Training Session
San Jose, CA
Contact: Greg Selby, 704.547.2095

27–29
EPRI International Low-Level Waste Conference and Exhibit
Albuquerque, NM
Contact: Linda Nelson, 518.374.8190

July

10–12
Fourteenth Annual NMAC Terry Turbines Users Group Meeting
Monterey, CA
Contact: Linda Parrish, 704.595.2061

10–12
IntelliGrid Steering Committee Advisory Meeting
Baden, Switzerland
Contact: Josephine Garcia, 650.855.8619

10–14
Predictive Maintenance Users Group Meeting and Vibration Technology Forum
Annapolis, MD
Contact: Linda Parrish, 704.595.2061

11–12
BWRVIP Inspection Focus Group Meeting
Tampa, FL
Contact: Brent Lancaster, 704.595.2017

11–12
Cable Aging Management Training Course
Charlotte, NC
Contact: Beth McRimmon, 704.595.2036

12–13
Hoisting, Rigging, Crane Users Group Meeting
St. Louis, MO
Contact: Linda Parrish, 704.595.2061

12–14
HVDC 2006 Congress—Meeting the Power Challenges of the Future Using HVDC Technology Solutions
University of KwaZulu-Natal, Natal, Westville, South Africa
Contact: HVDC2006@ukzn.ac.za

16–19
Substation Equipment Diagnostics Conference XIV
San Diego, CA
Contact: Paula Foster, 817.234.8221

17–19
Nuclear Utility Procurement (NUP) Training Course
Charlotte, NC
Contact: Beth McRimmon, 704.595.2036

18–20
Generator/Motor Rewind Seminar
Round Rock, TX
Contact: Jim Oliver, 951.735.5239

18–21
EPRI Infrared Thermography Utility Group (IRUG) Meeting
New Orleans, LA
Contact: Judy Brown, 704.595.2197

20–21
ASME Procurement Training Course
Charlotte, NC
Contact: Beth McRimmon, 704.595.2036

24–26
EPRI PQA 2006 and Advanced Distribution Automation Joint Conference and Exhibition
Atlanta, GA
Contact: Lisa Wolfenbarger, 865.218.8026

24–26
IERE 2006 North America Workshop
Charlotte, NC
Contact: Suzette Yu, 650.855.2798

24–26
PSE Service Water Piping Pilot Training Course
Annapolis, MD
Contact: Beth McRimmon, 704.595.2036

24–26
Twenty-Fifth EPRI Steam Generator NDE Workshop
Marco Island, FL
Contact: Brent Lancaster, 704.595.2017

24–27
NDE Performance Demonstration Workshop
Myrtle Beach, SC
Contact: Lynette Gulledge, 704.595.2194

24–28
EPRI Steam Turbine Generator Technology Transfer Workshop and TGUG Meeting
Charlotte, NC
Contact: Leah Graff, 704.595.2254

25–28
ABB Circuit Breaker Users Group Meeting
Nashville, TN
Contact: Linda Parrish, 704.595.2061

25–28
Fuel Reliability Program Working Group 3 and 4 Meeting
Freeport, ME
Contact: Evelyn Simons, 650.855.2728

26–27
Third Annual Operations Conference
Location to be determined
Contact: Thomas Nguyen, 704.595.2020

27–28
PSE SWAP Coordinators Annual Meeting
Annapolis, MD
Contact: Beth McRimmon, 704.595.2036

27–28
RI-ISI New Initiatives Workshop
Myrtle Beach, SC
Contact: Lynette Gulledge, 704.595.2194

31–August 2
EPRI Utilities Wireless and RFID Technology Conference 2006
Chicago, IL
Contact: Brent Lancaster, 407.595.2017

31–August 2
Identification and Detection of Aging Issues Training Course
Charlotte, NC
Contact: Beth McRimmon, 704.595.2036

August

1–3
Cooling Tower Technology Seminar and Conference
Des Moines, IA
Contact: Melissa Wade, 800.313.3774

1–3
Technical Advisory Group Meeting
Denver, CO
Contact: Ulla Gustafsson, 650.941.8552

8–10
Summer Pump Users Group Meeting
Chattanooga, TN
Contact: Linda Parrish, 704.547.6061

21–22
BOP Corrosion Advisory Council Meeting
Chicago, IL
Contact: Albert Machiels, 650.855.2054

21–22
Chemistry, LLW, and RM TAC Advisory Council Meeting
Chicago, IL
Contact: Tracy Wilson, 704.595.2043

21–22
EPRI's Increased Power Flow Conference and Call for Papers
Boston, MA
Contact: Melissa Wade, 704.595.2259

21–22
Instrumentation and Control Advisory Council Meeting
Chicago, IL
Contact: Tracy Wilson, 704.595.2043

21–23
EPRI Western Region R&D Collaborative
Palo Alto, CA
Contact: Melissa Wade, 800.313.3374

21–24
NMAC Large Electric Motor Users Group Meeting and Workshop
Denver, CO
Contact: Linda Parrish, 704.595.2061

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