Energy for a Slice of Life

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Cover: Everyone has a slice of the U.S. economic pie. Will the slices be as big in 20 years? Today's energy decisions are determining the size of the pie for a growing population.

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Energy Choice: The Major Issue

America's present energy position is perilous. We are vulnerable to foreign actions that affect the price and availability of oil, but we have been slow to take even those few actions of our own that could limit emergency situations. No national problem more urgently requires attention.

As though this were not enough of a challenge, we must also make choices and take actions during the next several years to establish the nation's long-term energy future. That future is not automatic. Energy solutions, particularly those requiring technology development and capital turnover, have very long lead times. It will take near-term decisions to meet long-term objectives. What are to be those objectives, and what decisions are needed?

In this *Journal*'s opening feature, Chauncey Starr argues that the nation is at a crossroads, that we must choose between accepting and accommodating to chronic energy scarcity—as we now seem to be doing—or creating conditions that will bring energy sufficiency. Which one of the two becomes the real future will be determined not by the unfolding of historical or resource trends beyond our control but instead by the policies we pursue, beginning now.

Energy abundance has characterized our history—until the 1970s an abundance based essentially on domestic fuel resources. Fundamental features of our economic, social, and technical landscape are rooted in this circumstance. Not the least among the salutary impacts have been energy-using technologies that have greatly multiplied the productive efficiency of industrial, agricultural, and household operations, totally transforming and greatly enriching the everyday lives of most of our people.

We do not inevitably face a future in which energy can no longer serve us as it has. To be sure, some of today's conventional resources look to be in increasingly short supply. But technologies are within reach for greatly expanding the availability of both mineral fuel and renewable energy supplies and for setting tolerable upper limits on their long-term real costs. Technologies also exist or can be developed for improving the efficiency of energy use (thus lowering demand growth below historical trends) and for reducing the deleterious environmental impacts of energy production and use.

The sheer number of these opportunities for expanding supply, moderating demand growth, and improving the environmental consequences of energy operations reasonably ensures that radical reductions in our energy circumstances can be avoided. The requirement is a firm policy choice and a steady policy course to capitalize on the nation's underlying energy potentials. Aggressive technological R&D on a wide front is an essential element in such an approach.

Sam H. Schurr

Sam H. Schurr
Deputy Director
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Authors and Articles


Starr

Urgency is flagged by labels in the jargon of energy R&D planning: *near term* for the next 5 years, *midterm* for 6–15 years, and *long term* for anything beyond 15 years. One is thereby easily led to speculate about energy alternatives for the year 2000 with still-academic interest.

Choosing Our Energy Future (page 6) shows how, in one important sense, 2000 might as well be tomorrow. Most of the people who will then be working and who will rely in some measure on energy for their pay are already born. Thus, concludes EPRI's Chauncey Starr, by creating the U.S. labor force of 20 years from now, we create the need to establish what can, may, or must be its energy environment. Even without per capita economic growth, energy needs will grow, and today's energy anxiety clearly reveals the role of our perceptions in the energy choices we make.

Since May 1978 Chauncey Starr has been vice chairman of EPRI and director of its Energy Study Center, where issues of technology are joined with those of national and international economic and social outcomes. Previously, he was president of EPRI from its inception in 1973. Starr was dean of the School of Engineering and Applied Science at the University of California at Los Angeles from 1967 to 1973, and he had earlier been with Rockwell International Corp. for 20 years (including 6 years as president of its Atomics International Division).


Landers


Searl

One hundred miles offshore, 2000 feet or more above a tumbled sea and a dozen hours before landfall, we know the maximum velocity of the winds in a hurricane. Ten miles inland, 80 feet up on a utility power transmission tower, when the hurricane is at hand, we don't. Our assumptions about that velocity govern the wind load forces used in design codes and equations for transmission structures.

Taking the Measure of a Hurricane (page 12) explores this gap in meteorological data, explains the phenomena that must be correlated, and describes a cooperative program of utility field measurements that will build the needed data base. The author, Phillip Landers, comes to his subject from a dozen years of first-hand experience, 10 of them with Florida Power & Light Co., where he was a transmission project engineer and principal R&D investigator in design criteria for extreme wind loads.

Since January 1978 Landers has been a project manager in the Overhead Lines Program of EPRI's Electrical Systems Division, coordinating industrywide research in the economic design of engineered structures.

Landers is a civil engineering graduate of the University of Miami, a member of the American Society of Civil Engineers, and chairman of the newly formed research committee in its Energy Division.

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Charting the stock market draws mixed opinions as a basis for investment strategy, but there's no denying that a proven predictive quality in some combination of historic data would be a boon. So the effort persists. A comparable search by energy analysts would yield predictions of energy demand from past trends and do much to help utilities plan for future generating capacity.

Electricity Growth: Part Trend, Part Cycle? (page 18) reviews energy and economic correlations that may prove useful. Jenny Hopkinson, *Journal* feature writer, is the author, reporting on research that goes behind trend data and suggests that some independent cyclical phenomena are also at work.

The research is led by Milton Searl, technical manager in EPRI's Energy Study Center since August 1979 and formerly Supply Program manager for the Institute's Energy Analysis and Environment Division. Before joining EPRI in December 1973, Searl was a senior research economist at Resources for the Future, Inc., and his career in energy economics also includes 3 years on the energy policy staff of the U.S. Office of Science and Technology, 9 years with the Atomic Energy Commission, and 11 years with Pan American Petroleum Corp.

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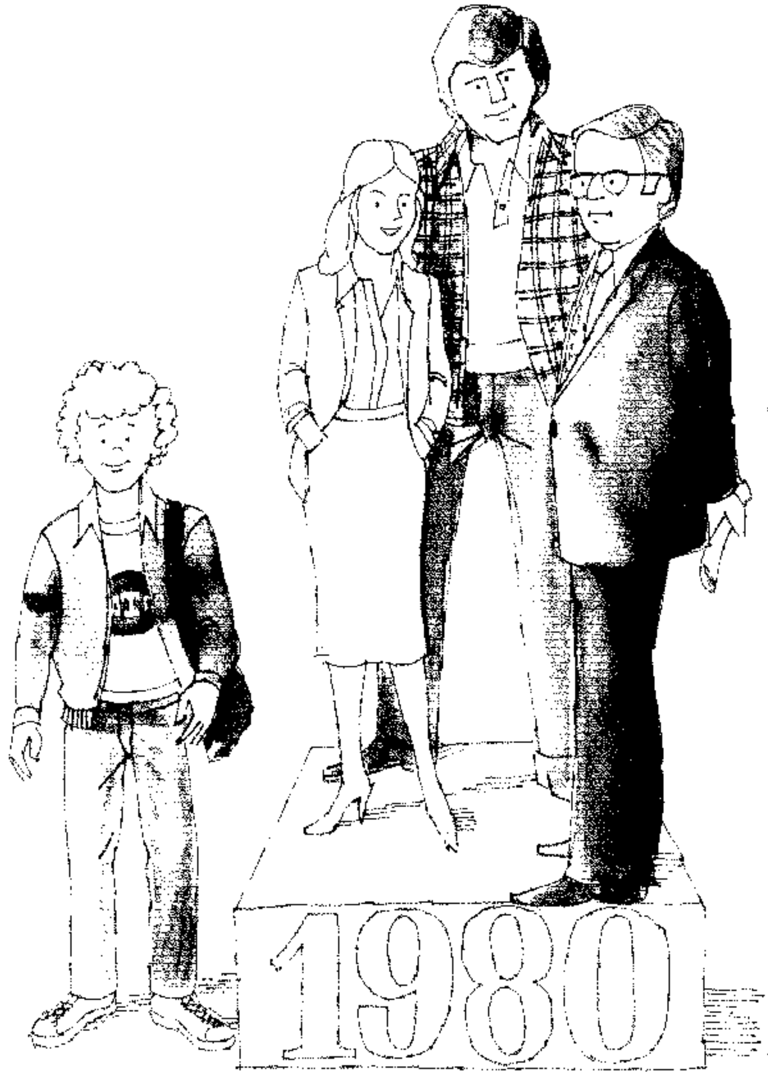
No matter how objective the matters of science, they are better understood when their spokesmen are clearly seen. The *Journal*'s intermittent articles on members of the EPRI Advisory Council thus seek to illuminate some of the larger problems that underlie the planning and conduct of energy R&D. Appointed by the Board of Directors for three-year terms, the 25 Council members contribute expertise and viewpoints gained from their careers outside the electric utility industry.

Gerald Tape: Fostering the Scientific Quest (page 23) merges the experience and insights of this year's Advisory Council chairman, who also is president of Associated Universities, Inc. Feature writer Jenny Hopkinson drew the information for her article from an interview with Tape last June.



Written 150 years ago, the words of historian Thomas Macaulay are an apt commentary on today's prevailing mood about energy: "We cannot absolutely prove that those are in error who tell us that we have reached a turning point, that we have seen our best days. But so said all who came before us, and with just as much apparent reason. . . . On what principle is it that when we see nothing but improvement behind us, we are expected to see nothing but deterioration before us?"

The attitude that sees "nothing but deterioration before us" is repeated endlessly in much that is now written about the outlook for energy in the United States and throughout the industrialized world. If this perception existed in isolation, it would not be a source of much concern; in that case, the future would take its own course and today's dire predictions would eventually be forgotten. The danger is that in large measure our energy future will be the result of the policies we pursue; and those policies, in turn, are products of the prevailing perception of what lies ahead.

Are we facing a fundamental structural change in the conditions of energy supply with which the world will be forced to live forevermore? I don't think so. I do not believe that the world is imminently running out of its fuel supplies, not even its supplies of mineral fuels. Nor do I think that we are approaching the pollution limits imposed by the carrying capacity of the natural environment.

We are, however, in a period of energy transition away from the transient bonanza provided by low-cost petroleum and natural gas. Because of worldwide inflation in basic energy costs during the past 10 years, industrial nations now face two alternatives: accommodate to perceived shortages and plan an energy-limited society or exploit new energy sources to ensure their availability, even though they may be more

Choosing Our Energy Future

by Chauncey Starr

For every three individuals in the U.S. labor force today, there will be four 20 years from now—better trained and more mature in their careers—calling for two-thirds more national income if each is to earn what we do today. ven that no-growth economy requires that we choose to have enough energy to fuel it.

Dr. Starr's article is adapted from his presentation to the Second Annual Conference on International Energy Issues at Cambridge, England, in June 1980.

costly than today's sources.

Conservation without shortage

The usual initial response to increased energy costs is to seek a reduction in demand. Conservation is an obvious mechanism, but its mode of implementation depends on whether we face a shortage or abundant supply at higher unit costs. Survival in an energy-deficient world generates pressures for political intervention, with energy price ceilings and mandatory limits on energy-intensive activities. Some are already being promulgated in the United States, such as requirements on automobile fuel performance, speed limits, room temperature limits, scheduled days for buying gasoline, and restrictions on home and building design. Rationing of fuel and leisure activities is on the horizon. These are the leading edge of a centrally planned lifestyle, the administratively controlled society so abhorred by those of a free spirit.

In contrast, if a successful effort is made to attain energy abundance, albeit at higher cost, conservation will follow naturally as a result of higher prices. Each user will adjust his consumption pattern to match his own resources and needs. He will select his own energy-efficient systems, but he will not face actual shortage. Abundance can result if we stimulate such technologies as shale oil recovery, coal conversion to liquid fuels and gases, nuclear power, and the numerous competitive low-temperature solar alternatives. These are on hand, and every analysis indicates a plentiful mix from them—certainly sufficient to guide our energy transition steps and to avoid serious limitations in the foreseeable future.

We are thus at a key crossroads on energy policy: we plan either to accommodate to enduring shortages or, alternatively, to vigorously promote the development of available energy sources. Higher-cost abundant energy will not have the same result as a truly constraining energy deficiency. Living with selectively affordable energy supplies is different from hand-to-mouth survival on short rations.

The issue goes to the root of our societal perception of the future. Either we foresee a future of shortages arising from limits to growth in a finite earth, or we foresee an expansionist future made possible by the "growth of limits" resulting from advancement of technology's frontiers. Historically, as Macaulay's words suggest, the world has always been faced with pending resource limitations, but technology has been able to expand those limits to meet society's needs. This faith in technologic progress is more than wishful dreaming; many of us see the energy paths that can lead us to such an outcome.

The United States provides a case study of these issues. It is, of course, the situation I know best. But there is more to it than that, because what happens here produces worldwide repercussions. Our precipitate movement away from essential energy self-sufficiency, mainly during the past 10 years, has been a major factor in producing today's worldwide fuel disorder; and our deliberate movement toward greater self-sufficiency in the future could profoundly encourage new stability in world energy markets.

Projecting U.S. energy needs

A key issue for decision makers is the anticipated growth in energy consumption for, say, the next 20 years. In the interconnected net of social expectations, economic growth, and energy demand, a minimal projection of social expectation is that each worker in the 1980–2000 labor force will look forward to the same lifetime pattern of real income for himself as he sees today for other workers of comparable age, skill, and education.

Empirical values for this concept of minimum expectations have been derived by EPRI. The forecast increase in the work force from 1980 to 2000 is about 32%, most of these workers already born. However, the average age of the work force in 2000 will be five years older, and the educational level will be higher: 30% college-educated (versus 16% now) and 60% high-school-educated (versus 50% now). These changes raise the average individual real income by about 25% and the aggregate personal income about 67%, meaning an average annual income growth rate of 2.5% for the intervening 20 years. If the ratio of personal income to gross national product (GNP) remains roughly constant, the U.S. economy must grow at about the same rate to meet this minimal social expectation.

It is doubtful whether the U.S. social fabric can survive with such low expectations of GNP growth in the coming decades. Income must be provided for a growing fraction of retired workers, and the lowest income sector of our working population is demanding a major improvement in its status; so our minimal social goal is likely to exceed this 2.5% annual rate of increase. How much, of course, is a political uncertainty, as is the maximum rate that we can pragmatically expect to achieve. Happily, GNP growth rates have always managed to provide for more than minimum expectations, except during the depression period of the early 1930s and the 1973 post-embargo recession. For reference, the 1950–1960 GNP growth rate was 3.2% annually; the 1962–1972 rate was 3.9%.

What does a GNP growth projection of even 2.5% tell us about total energy demand in the United States? EPRI's findings are not startling. Taking into account a 2.5–3.5% range of annual economic growth and an expectation of substantial conservation, the total annual energy demand in 2000 will be between about 103 and 138 $\times 10^{15}$ Btu, from a present base of about 80 $\times 10^{15}$ Btu, or roughly from 1.3 to 1.8 times what it is now.

Electricity growth projections are even more uncertain, because they involve the additional factor of interfuel substitutions between electricity and other energy forms. But electricity use has always grown faster than total energy use, and EPRI now foresees electricity use growing about twice as fast. For the year 2000, this means electricity generation at about 2 to 2.5 times today's level.

Three substitutes for oil

Where will the energy come from to meet these needs? Our national problem has usually been presented as one of oil availability, import price, and our resulting negative balance of trade. The understandable public interest in ensuring liquid fuel supplies for transportation has focused political attention and national planning predominantly on that sector. The litany of oil trade numbers and their financial and political implications are constantly reviewed (not to mention disputed), but it is important to recognize that technology can substantially alter the liquid fuel future.

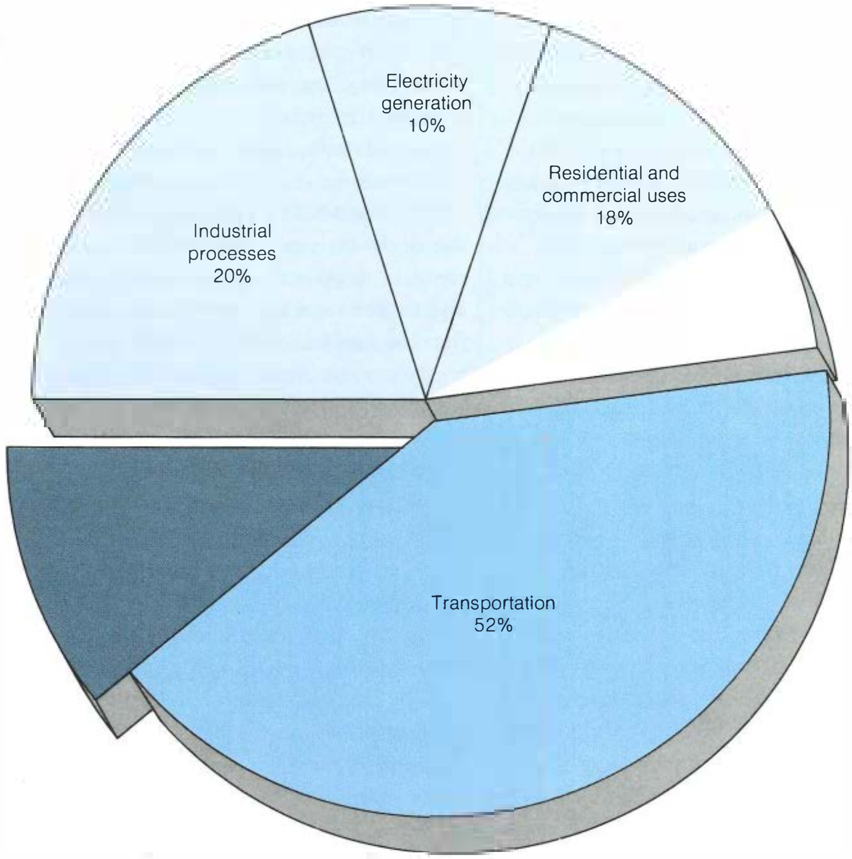
Accelerated near-term electricity production from solid fuels (coal and uranium) can eventually displace a portion of oil use in three areas: under power plant boilers (10% of total oil use), for space and water heating (12%), and in industry (20%). This 42% target is almost as large as all U.S. oil imports. Additionally, electricity can often substitute for gas, which in turn may substitute for oil as a feedstock for the petrochemical industry.

How many electric power plants would all this take? If heat pumps are used to efficiently convert electricity back to heat, each nominal 1000-MW power plant represents the use of about 30,000 bbl of oil per day. The United States now uses about 17.5 million bbl/d for all purposes, so 42% of that figure (7.35 million bbl/d) could, in principle, be displaced by 245 coal or nuclear plants. We now have the equivalent of about 580 such plants. An increase of less than half of our present capacity fulfills the need—assuming that complete and efficient substitution could actually occur.

How can the pattern of U.S. oil use be changed, and how soon? Coal and uranium can directly replace oil throughout electricity generation and process heat production and indirectly replace oil (by means of electric-powered heat pumps) in many residential and commercial applications. Early substitutions in these three sectors could total 42% of 1979 oil use (nearly as much as the 46% we now import).

By 2000, development of synthetic fuels from coal and shale could yield the equivalent of another 14% of today's use, probably most applicable in the transportation sector.

SUBSTITUTING FOR OIL



Beyond this displacement of natural crude oil alone, however, oil recovery from shale is potentially extremely large and could in time replace all our imported oil. The production process is inherently more expensive than from flowing wells, but the costs are within near-term commercial reach. What is needed now are large-scale demonstrations to settle all the technical uncertainties of environmental issues, equipment reliability, fuel-refining variables, and the like.

There is yet another source of liquid (and gaseous) fuel. The conversion of coal is a chemical engineering process that has been feasible on a small scale for some time but for which large-scale development remains to be accomplished. This might be done during the coming decade if proposed projects are started soon. Cost projections are promising but still uncertain because full-size engineering subsystems have not yet been demonstrated. The large U.S. coal resources make coal conversion a very attractive long-term objective for liquid fuel supply.

There is no question in my mind that technology is showing us a way to remove the oil squeeze, with room to spare. In industry, in buildings of all kinds, and among utilities, the displacement of oil by coal- and nuclear-powered electricity generation can be significant in the near term. Oil from shale and from coal conversion processes can do even more. We can therefore be optimistic about an eventual assured liquid fuel supply if we take the obvious steps.

But although substitutes for natural petroleum are obviously crucial to our total energy mix and are clearly seen to be technologically attainable, an adequate supply of electricity, in particular, is not thereby assured.

Fueling electricity growth

Almost one-third of our primary energy equivalent is used to generate electricity today, and by the year 2000 about one-half will be so used. Of this electricity, only a third is for residential use; two-thirds is for business (commercial and industrial) use. The implications of this deserve attention.

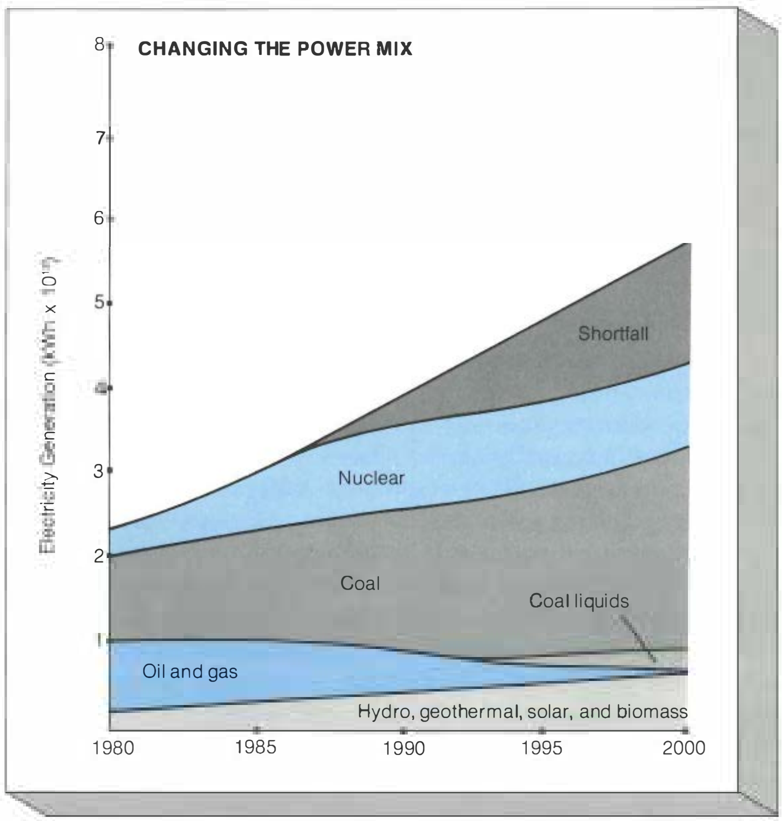
Electric utilities are generally in a good position to supply U.S. needs in the near term. Generating capacity undertaken during the economic growth period of the 1960s and early 1970s has been steadily coming on-line. With the reduced economic growth since 1973, this new capacity provides a reserve that can take care of the more slowly rising needs of the next few years, although probably with some regional shortfalls. But what about the long term? With as many as 12 years passing between decision and availability, deficiencies in electricity supply are not easily rectified.

How can a doubling of electricity output be realized by 2000? Obviously, the bulk must come from coal and uranium. Coal-fired plants now supply about 41% of our electricity needs, and they consume 480 million tons of coal annually in the process—two-thirds of our 720-million-ton total production. Considering all the constraints of environmental regulations on end use and the delays and institutional constraints on increasing coal supplies, coal-produced electricity may be limited to slightly more than double that of today—a 4.5% annual growth perhaps yielding a 45% share by the end of the century.

The increasing difficulty of building coal-fired plants is not generally understood. From time of decision to availability now takes 8 to 10 years, of which about half is used for the approval chain. To meet projected environmental standards, environmental controls cost about 60% of the total, and as a result a coal-fired plant now almost approaches a nuclear plant in capital cost. Its fuel costs, of course, are much higher.

Furthermore, the expansion of coal-fired generation may be more constrained if coal is extensively diverted to synthetic liquid fuel production.

As oil and gas are withdrawn from the electricity generation mix, increased use of other utility fuels and technologies may not be enough to meet U.S. requirements by the turn of the century. Nuclear power, in particular, could play a greater role if we reconsider what is wise and possible for that technology.



One ton of coal may yield three barrels of oil. Fully half (360 million tons) our present coal production would be needed to produce about 1 billion (10^9) barrels of oil per year—some 16% of our present use and about a third of our imports.

Hydroelectricity provides about 11% of our generation now, and it can possibly be increased during the next 20 years, but not to the extent of doubling; it may provide about 7% of the output in 2000. Geothermal energy supplies are about 0.2% now and may be about 2% in 2000.

Solar electricity is projected in the February 1979 report to the president, *Domestic Policy Review of Solar Energy.* That interagency forecast for the year 2000 presents estimates of solar-thermal, photovoltaic, and wind generation based on extremely optimistic (in some cases unrealistic) assumptions for technical development. Its projection for equivalent energy displacement by solar resources is 2–6% of the electricity demand projected by EPRI.

Completing the technology mix

The total electricity from all these generation sources is 56–60% of what is needed to meet EPRI's projection of requirements in 20 years. The remainder must come from uranium, coal-derived fuels, oil, and gas. Right now about a third of our electricity generation comes from oil and gas. Given our need for liquid fuels in transportation and strong federal policy to diminish their use in electricity generation, it is unlikely that synthetics and new oil and gas can be assumed to be available for electricity growth. Oil and gas will probably generate somewhat less electricity than today, perhaps 7% of the year 2000's requirements.

We are left with about a third of our needs unfilled, even assuming only minimal growth, and nuclear energy is the only source that can fill this gap. Recognizing that these forecasts already include more than a doubling of coal-fired generation, it becomes apparent why utilities see nuclear power not as a matter of preference but as a clear necessity.

The de facto moratorium on nuclear power is thus a prime threat to the secure supply of electricity in the future. Nuclear plants have represented about half of all planned capacity in the United States. Although nuclear power questions have generally been addressed to the utility industry alone, their implications are crucial to the nation's economic future. What is at issue is the future availability of sufficient electric energy to permit the production of industrial goods and services that match realistic projections of the growth of the national economy.

An energy shortfall might take the form of measurable physical shortage, or it might be partially absorbed by gradual adjustment of the economy to a chronic condition of scarce supply in the 1980s and 1990s. Because two-thirds of all electricity is ordinarily consumed by commercial and industrial establishments, the impact on our productive sectors would be large, even if shortages were evenly shared by all users. However, past experience indicates that shortages are likely to be allocated—less on voting consumers and more on business establishments. But no matter how shortages are managed, their impact on the economy is bound to be severe.

Moving past the crossroads

Like the attitudes cited by Macaulay, the prevailing energy outlook for the 1980s is indeed bleak. However, if we can rise to Macaulay's question squarely and objectively, we may be able to *use* the period of the 1980s to implement technical options that will ensure energy abundance in the long run.

The electricity consumption estimates introduced early in this discussion are based on social expectations of economic growth well below trends of the recent decades. In addition, those estimates assume a very high level of conservation in the years ahead, the result both of higher energy prices and of improved energy-use technologies.

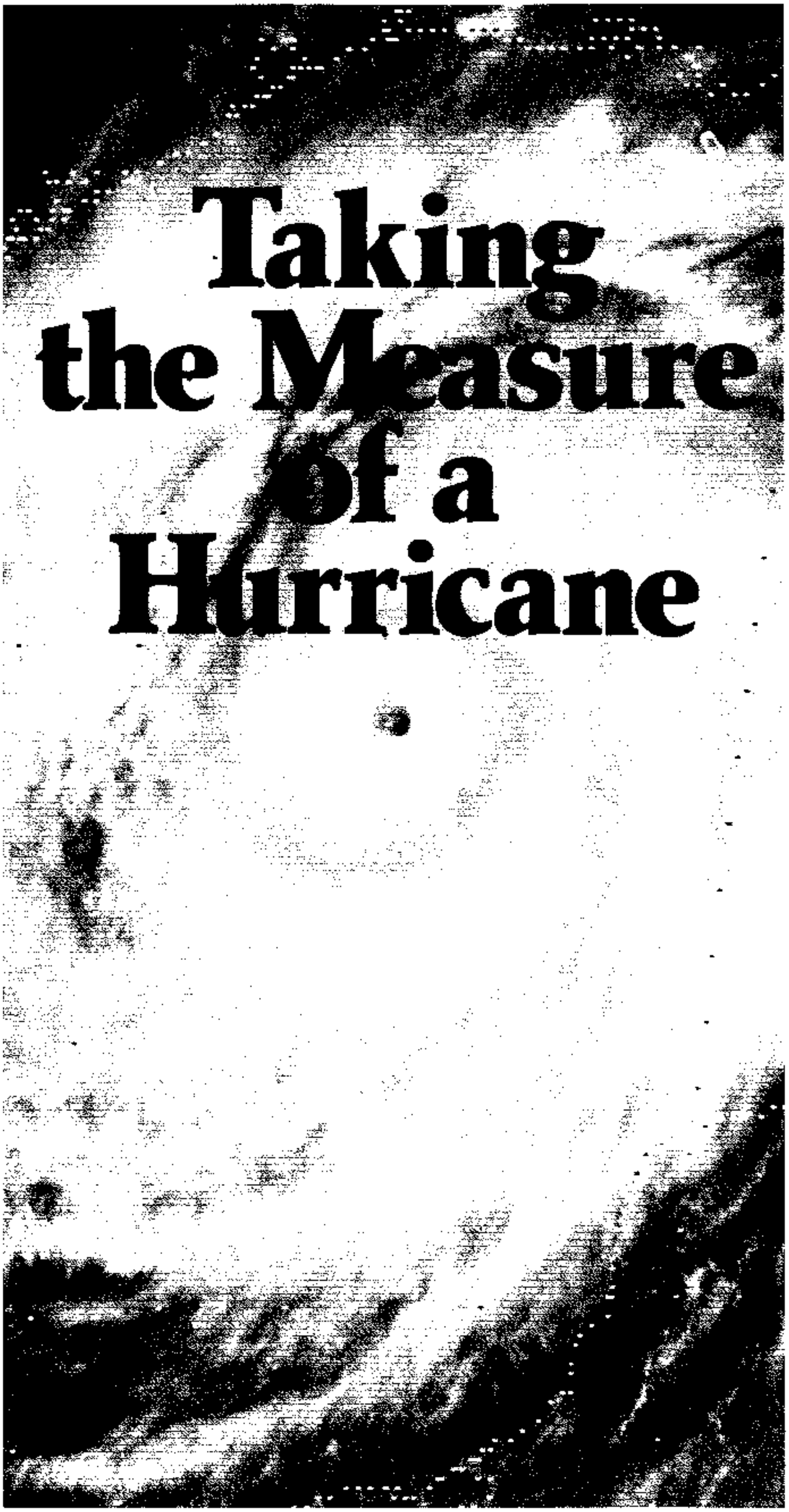
I believe that industrial nations must develop and expand those fuel and electricity sources that technology has brought within the range of economic feasibility. And, of course, they must explore new concepts to ensure energy for the distant future. Energy abundance is a foreseeable goal and at costs that should be acceptable to our economies.

These are our real alternatives: more nuclear power, still more imported oil for electricity production, or not enough electricity (even with extensive growth of coal-fired plants) to meet minimal social needs. If electricity is not provided, if industry must cut back energy use beyond cost-effective conservation, my concern is that a painful accommodation will be made at the expense of economic output and productive efficiency or by industries' moving to regions where electricity is available. Some industries already foresee regional electricity constraints. Their dilemma generally cannot be avoided by on-site power generation because that alternative either is very costly or requires fossil fuels, usually oil. Local resources, such as wood waste, are possible in only a few regions.

The basic issue remains our dedication to using all the resources of technology to build an energy abundance. The industrial world needs its technical resources for both efficient energy supply and efficient end-use devices. The scale of living in industrial nations does not have to decline. Higher-cost energy does not mean a depressed economy if we permit technology to compensate.

It is a dangerous platitude that we face a future of limited expectations because of energy shortages. Limited expectations lead to policies of retrenchment and cautiously riskless investment. These expectations become self-fulfilling—more important, they destroy the image of a better future that is so essential for motivating our social institutions. ■

Taking the Measure of a Hurricane



When Hurricane Allen came into the Gulf of Mexico early in August, it was considered the second most violent Atlantic hurricane on record, possibly exceeded only by one that hit the Florida Keys over 40 years ago. As it moved northwest between Cuba and the Yucatan peninsula of Mexico, radar and weather aircraft revealed an eye only 7 miles across, compared with the more usual 20 miles, a barometric pressure of less than 900 millibars, and winds of more than 230 mph at the eye wall. Only 8 hours before it was forecast to come ashore on the south Texas coast, Allen had 110-mph winds at a radius of 120 miles and had built seas 50 ft high. Its leading edge had already knocked down power distribution lines in Brownsville, Texas, at the Mexico border and had generated at least one tornado 70 miles to the north, halfway to Corpus Christi. Clearly, Allen was a 1-in-100-years hurricane.

However, the night of August 9 was uncommonly lucky. As the storm neared the Texas coast, it gradually became suffused with cooler air from the continental land mass. Its progress slowed, and its intensity eased. Allen's maximum wind velocity at landfall was about 100 mph, soon dropping to gale force levels in the 50–65-mph range. Even these, coupled with heavy rains and extraordinary tides, justified the evacuation that had been urged between Brownsville and Corpus Christi. But as Allen broke up, it was no longer a once-in-a-century storm. Analysis of the data and of damage left in its path will help researchers categorize it, but forecasters are left again with contradictory evidence of the predictability of hurricanes.

Questions about hurricane winds

Most important to Corpus Christi's Central Power and Light Co. and other utilities is that practically all their transmission towers and lines remained standing. (Central Power and Light lost about 160 structures, mostly single wooden poles along 69- and 138-kV lines dating from the late 1920s.) Such capricious storm behavior is of special interest to utility structural designers in the Gulf states and along the Atlantic coast as well, because their main design basis for transmission systems is the extreme winds of hurricanes. When a near-record storm does not destroy at least some of these structures, what does this say about the data base on hurricane velocities? At the very least, it suggests conservatism, resulting in uneconomic design. Realistically, occasional failures are the proof of design precision, particularly of background data fed into the design equations.

Hurricane Allen is recent—the first such storm of the 1980 season—and its numbers are dramatic. But it only emphasizes many unanswered questions that have been accruing for some time in the minds of meteorologists, utility structural engineers, and the committee responsible for the National Electric Safety Code, including its body of maximum-wind-velocity recommendations that carry over into many building codes.

What is the origin of hurricane wind records? What biases do they contain? What is the probability of a hurricane in a particular region? How and why does storm intensity change with travel across land rather than sea? How large a land area is likely to be affected? How does wind velocity vary with height above the ground? How much do the shape and size of a structure (especially a conductor) affect the stress induced in it by high winds? In sum, what is the source of the apparently conservative values of wind force used in transmission tower and line design?

Answers are important because the National Electric Safety Code is now being revised to incorporate more accurate wind load criteria. The first priority is to establish true values for extreme wind velocities. Regardless of corrections for turbulence, elevation, or the shape of an exposed structure, the force of wind loading is proportional to the square of wind velocity. A wind of 193 km/h (120 mph) produces a 44% greater force than a wind of 160 km/h (100 mph). The 20% difference in velocity alone is more than doubled in its design outcome.

Studies of historical hurricane data and of the methods used to correct and adapt figures for storm forecasting, as well as for transmission design, explain why those data are imprecise, but not by how much. Such analyses have shaped EPRI's determination of what measurements must be made to gain quantitative accuracy. They have led to the inauguration of an innovative hurricane measure-

FACTORS IN THE WIND LOAD EQUATION

Whether blowing against a conductor or against the steel lattice of a tower, wind is the major live load on a transmission line. It results in extra forces: tension along a conductor and at the suspension point of its insulator string, shear at a crossarm connection, tension and compression in opposite tower legs—even an overturning moment on the entire tower.

Air mass, density, and a gravitational constant are included in the calculation, but they all resolve as a minor constant in the equation that governs designs in U.S. coastal areas near sea level: force = $0.00256 V^2 A C_d$ where V = wind velocity, A = frontal area of a component, and C_d = a coefficient for the force-reducing effect of component shape.

Wind velocity means both its speed and its direction, and both must be recognized in design analysis. However, the numerical value denotes speed alone, and this is the criterion for designing structures to withstand the maximum wind intensity associated with a frequency of once in 50 years. Since this factor is squared in the equation, its accuracy is extremely important. For any wind speed higher or lower by a given percentage, the resultant force on the structure is higher or lower by approximately twice that percentage. This force markedly affects conductor and steel cross sections, material quantities, and their cost.

The frontal area of a transmission line component includes the width or height dimension that partly measures physical cross section and, thereby, material strength. That area depends on the wind load, but it also contributes to the wind load and therefore appears in the force equation.

The shape of the component is the final influence, introducing its own turbulence effects, which act as a drag on the wind speed and its force. Drag coefficients for various shapes have been experimentally determined by model studies in wind tunnels. However, the carefully contrived laminar air flow in a wind tunnel is not matched in hurricanes. First, these storms are turbulent within themselves, which reduces their effective wind speeds. Second, ground roughness also reduces wind speeds (and the resultant forces) below the values found at laminar-flow conditions.

A common rule of thumb in aerodynamic design is, The higher the turbulence, the less the drag. Thus, turbulence may reduce drag coefficients. In the absence of thorough data, a drag coefficient of 1.0 has often been assumed for round conductors. Some evidence supports a value as low as 0.6, which would markedly reduce the design force for any given maximum wind speed. Even a value of 0.7, according to preliminary utility studies, could have the ultimate effect of a 15% saving in overall transmission line cost.

In sum, wind force varies as the square of wind speed; it further increases in proportion to the frontal area of any component; and it decreases according to an imperfectly known correlation with the drag induced by structural shape. □

ment program in cooperation with 17 coastal utilities and Mexico's EPRI counterpart, the Instituto de Investigaciones Eléctricas (IIE).

Why the concentration on relatively infrequent hurricanes? After all, despite their spectacular character and potential for damage, they do not affect most of the states and their utility service areas. First, hurricanes are the most intense storms, and their wind velocities must govern coastal utility designs. Second, the relationships between a maximum wind and its resultant forces on towers and lines are applicable anywhere. To the extent that they are more complete as well as accurate, hurricane data are useful for inland utilities dealing with continental winds. Finally, the movement of individual hurricanes is sufficiently predictable to allow researchers to go out ahead of them and arrange for meteorologic measurements.

Even so, the best way to go about a measurement program is not clear-cut. Eight years ago, Japanese investigators, needing typhoon data, selected an island in the East China Sea that, according to all records, had a high probability of being hit by a storm again. They installed an elaborate network of anemometers and other sensors and waited for a storm, but since then no typhoon has hit Taramz Island.

Where to put instruments thus becomes a difficult choice. The evidence makes a strong case for portable instruments and mobile laboratory facilities that can take advantage of hurricanes wherever they may occur. Exactly what measurements have to be made and how can they be used to interpret and extend our present data? The answers devolve from how hurricane records are compiled and how winds are modified by the land and structures in their path.

Extreme-wind data from estimates

How realistic are the extreme-wind velocities that until now have been used in the National Electric Safety Code? The startling answer is that all the figures come from wind maps compiled with data from only 129 primary weather stations (generally at airports) across the entire continental United States. Some of these are several hundred miles apart, and some have as few as 10 years of data.

But of greatest concern is that this entire data base contains no actual measurements of maximum hurricane velocities, the true extremes they are intended to portray. Of necessity, these maxima have come from visual estimates (albeit by trained observers) or by after-the-fact correlations with storm damage. Both methods are inevitably inexact and have understandably led to conservatism, that is, high figures for wind velocity.

Two factors explain this deficiency. Until the last 20 or 30 years, the coastal regions in hurricane paths were relatively sparsely populated, precluding the need for weather stations there, much less for fully instrumented primary stations. Also, standard anemometers rarely survived hurricanes. After they blew away (or blew apart), it was up to the person who had been watching the dials to make a best guess of the maximum sustained wind velocity, as well as of the associated 2- or 3-second peak gust.

Earlier, of course, the Beaufort scale was the only estimating basis, heavily subjective because so totally dependent on the observer's experience: "Force 6: Strong breeze, 25–31 mph. Large branches in motion, whistling of telegraph wires. . . . Force 10: Whole gale, 55–63 mph. Trees uprooted, considerable damage. . . . Force 12: Hurricane, over 75 mph."

Only since 1957 have sophisticated Doppler radar and lidar been used as tools to measure hurricane winds. These velocity measurements are referenced to the ocean surface and corrected for the motion of the water under high wind stresses.

But what about measurements made by weather aircraft? Aren't these actual hurricane velocities carried into published figures for design wind speed? Not necessarily, and for an understandable reason: the primary concern of the National Weather Service is public protection, not structural design. Extrapolated judgments therefore go into forecasts and thus end up in the records.

In a study done for Florida Power & Light Co., the original measurements from 21 storms between 1957 and 1969 were analyzed and compared with the published maximum velocities for 41 locations during the lives of those storms. On average, the published figures exceeded the actual measurements by more than 20% (even though the measurements had been made at elevations between 460 m [1500 ft] and 6100 m [20,000 ft] above the ocean, free of the moderating effect of surface turbulence). Investigation of only 21 storms is insufficient basis for wholesale reduction of design wind speeds, but it substantiates the conservatism of today's practice and suggests that research can yield large savings in future designs.

Design factors from wind speed

Analytic models play a part in correcting ocean hurricane velocities for transmission designs progressively farther inland. One phenomenon common to most such models is reduced velocity, first noted at landfall and empirically found to continue with storm travel over land.

Two explanations for this are the so-called filling of the storm by its contact with cold air masses and the influence of ground roughness. Whatever the cause, transmission designers need quantitative verification of the modeled behavior: how much reduction or how far inland must a line be located to take advantage of a given decrease? So far there are very few, if any, field measurements that quantify this matter.

Particularly when modeled, these overland travel corrections are based on maximum offshore velocities (just before landfall), and other historical assumptions of the National Electric Safety Code come into play. They affect the frontal (coastal) areas presumed to be subject to an individual hurricane and the maximum velocity to be used in design.

One of these assumptions (now in

question as code revisions are planned) is that a maximum measured wind velocity applies throughout the 5° square of latitude and longitude in which the measurement was made. Depending on distance from the equator, 5° may represent 480 km (300 mi), thus an area of 230,400 sq km (90,000 sq mi). Stated another way, a wind velocity observed off Miami must be applied in designs for Jacksonville, 565 km (350 mi) away, even though Jacksonville has never experienced a major hurricane.

Transverse sectional flight measurements of hurricanes show that their maximum winds generally circulate close to the eye—that is, around a diameter of only about 32 km (20 mi), with a sharp drop-off beyond the eye walls. A detail in this connection is that the highest winds of all are characteristically in the right front quadrant of a hurricane. This results from its combined counterclockwise rotation and movement in from the sea. Yet the documented hurricane track is the path of its eye.

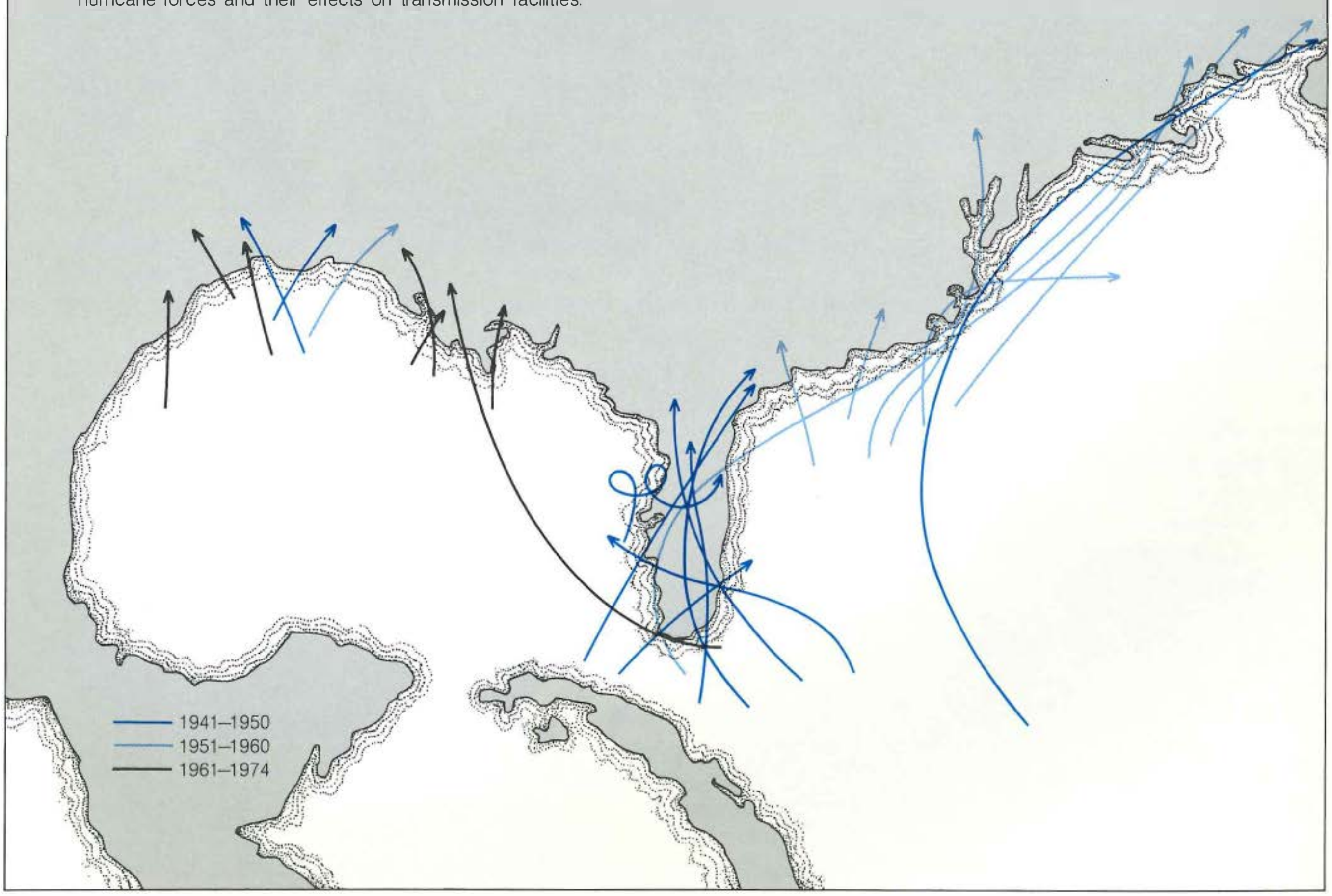
Considering the number of transmission lines now being designed and built at various distances from our coasts and considering that hurricane probabilities are quite different between points 645 km (400 mi) apart, it is important that these design assumptions be better documented.

Whether a design is for hurricanes or for extreme continental winds, the effect of ground roughness must also be taken into account. One such effect is the variation of wind velocity with height. As an air mass blows across the ground, roughness to some degree retards its speed near the surface. This in turn retards the

EPRI'S COSPONSORS IN HURRICANE MEASUREMENT

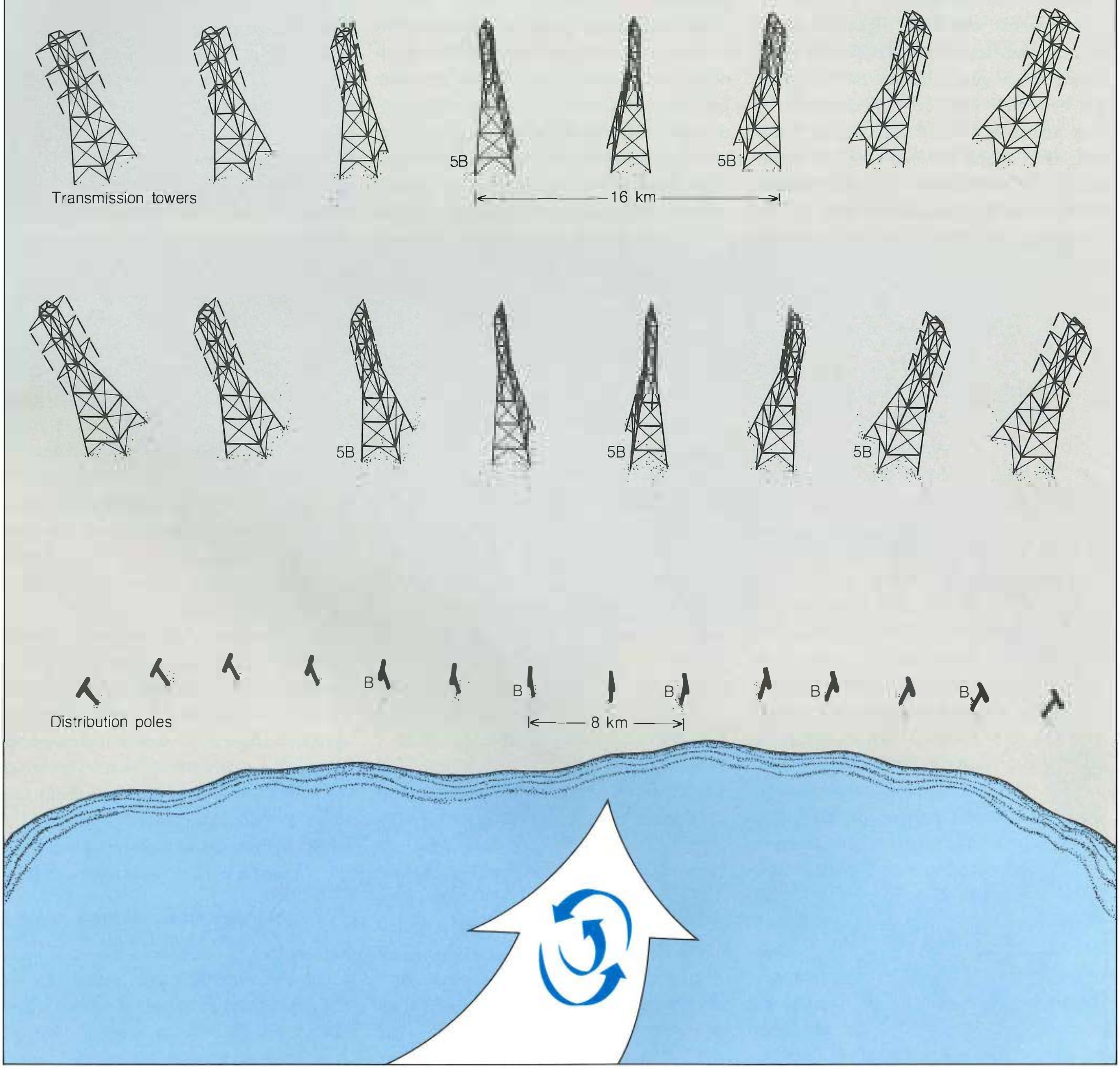
Alabama Power Co.
Carolina Power & Light Co.
Central Power and Light Co.
Florida Power Corp.
Florida Power & Light Co.
Georgia Power Co.
Gulf Power Co.
Gulf States Utilities Co.
Houston Lighting & Power Co.
Louisiana Power & Light Co.
Mississippi Power Co.
New Orleans Public Service Inc.
Savannah Electric and Power Co.
South Carolina Electric & Gas Co.
South Carolina Public Service Authority
Tampa Electric Co.
Virginia Electric and Power Co.

Groups of storm tracks show that most hurricanes in a given period hit the same coastal region. We don't know why, nor do we know where or when the pattern will shift. This phenomenon makes forecasting difficult, and it makes a strong case for EPRI's portable equipment to measure hurricane forces and their effects on transmission facilities.



Placement of portable data units is tentatively established along an 800-km (500-mi) front 72 hours before hurricane landfall. During the final 12-18 hours, as the storm approaches and its track is more precisely forecast, 30 BEASTIEs are installed at intervals on transmission towers (5B each) and distribution poles (1B each) to ensure storm interception. Ideally, there are three parallel lines of instruments: on the coast and 16 and 32 km (10 and 20 mi) inland to measure the falloff in storm intensity from overland travel.

A typical transmission tower installation of five BEASTIEs will measure and record horizontal and vertical wind velocity on two upper crossarms and at two other elevations, conductor swing angle on two crossarms, barometric pressure and temperature at two elevations, relative humidity at one elevation, and strain in at least two legs and/or diagonal members near the tower base.



incremental air mass immediately above (a little less), and so on. At some height the retarding forces diminish to zero, and the wind is said to move at gradient velocity. At this gradient height, wind speed is unaffected by ground roughness.

Recent measurements of Cyclone Trixie in Western Australia, however, give a new and startling indication of what the vertical profile of hurricane velocity may be. (Oceanic storms in the Southern Hemisphere rotate clockwise and are called cyclones.) The measurements were made on a 500-m (1640-ft) antenna tower at North West Cape, instrumented at five elevations.

The eye of the cyclone passed directly over the tower. As it approached, the velocities traced a conventional vertical profile. But as the eye wall passed, a totally different configuration emerged. Instead of increasing logarithmically with height, the velocity was nearly uniform up to about 30–40 m (100–130 ft) and again above about 80–100 m (260–325 ft). However, between 30 and 80 m (100–260 ft), the anemometers recorded a high-speed jet moving about 1.3–1.5 times as fast as the air above and below.

If such jets, well within the height range of transmission structures, are in fact typical in the velocity profiles of hurricanes, it becomes extremely critical that those profiles be quantified, using multiple instruments at each measurement site. (Aircraft measurements are made at much greater differences in altitude, necessarily separated in time, and all of them are above 460 m [1500 ft] as a matter of flight safety at sea. And no flight measurements are made in hurricanes over land, for the same reason.)

Hardware for hard data

One element threads throughout this investigation of hurricane data and design assumptions: there are not enough field data on either hurricane or continental winds. Research to quantify the basis for utility transmission designs therefore falls into two categories. One is clearly the critical assessment of historical data (on hurricanes in particular) to remove their biases and make possible their future use with more rational application criteria. This includes better definition of hurricane probabilities, that is, recurrence intervals.

The other category is that of field measurements of several kinds. These must take account of distance over land, height above ground, and surface roughness, and they must include stress measurements so that structural loads may be accurately correlated with wind velocities and forces. By contract with the Cooperative Institute of Mesoscale Meteorological Studies and with the cosponsorship of electric utilities, EPRI is undertaking this field measurement program in 1980. Every utility from the Virginia capes to the Mexico border—17 in all—is involved, plus Mexico's IIE.

The utilities are identifying candidate transmission lines in a 32-km (20-mi) coastal band, assisting in design of the hardware to attach instruments, and providing assistance in installation. IIE is working with EPRI and Mexico's national electric utility, Comisión Federal de Eléctricidad, to make measurements on both of Mexico's coasts.

Because of the Japanese experience eight years ago, quick-attachment portable instruments have been developed that can easily be placed on transmission towers during the last 12–18 hours before predicted landfall of a hurricane. Thirty duplicate instrumentation systems have been built for EPRI by the University of Oklahoma. Their name is bifunctional EPRI atmospheric and structural test instrumentation equipment (BEASTIE).

Each BEASTIE is a microprocessor-based system containing its own power supply and tape recorder. It can store 17 megabytes of formatted data from 6 analog input channels, operating for at least 48 hours. The sampling rate is software-selectable, through a range from 2 to 16 samples per second. Each BEASTIE is housed in a structural aluminum enclosure, sealed to prevent leakage of water into the system. Its dimensions are 203 × 457 × 711 mm (8 × 18 × 28 in), and it weighs only about 17 kg (38 lb).

Several kinds of meteorologic measurements will be made (wind speed and direction, barometric pressure, temperature, and humidity), some at more than one point on a tower and all with sensors designed to withstand full hurricane intensity.

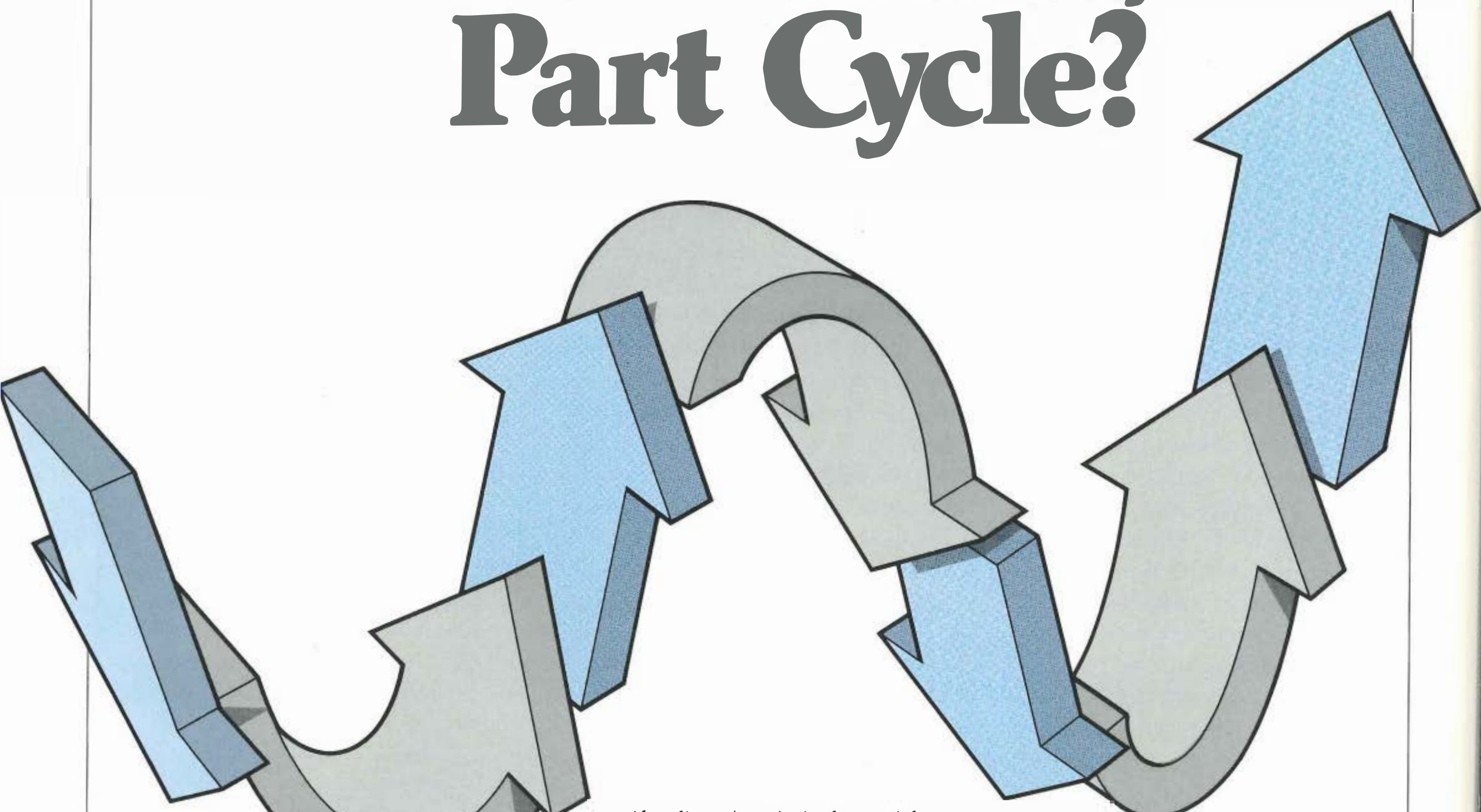
The structural response instrumentation will provide two measurements. One is the swing angle of the suspended insulator string from the vertical. The other is the strain in the tower legs (or at the pole base). Swing-angle measurements will come from a transducer attached to the top insulator of a string and hardwired to an adjacent BEASTIE on the crossarm. Strain measurements will use extensometers clamped to the tower or pole structure. When correlated with wind loads at conductor level, they will reveal the load components being carried through the structure to its foundation.

Correlation with continental winds

Hurricane Allen has passed, but other major oceanic storms are likely to follow it during 1980. The BEASTIEs will be ready. They will be placed in cooperation with the National Hurricane Center and the National Hurricane Experimental Meteorological Laboratory as part of their project known as Hurricane Strike—the system of aerial reconnaissance flights and meteorologic measurements in Atlantic storms. Hurricane movements tracked by the project will give EPRI and its cosponsoring utilities 72-hour warning of predicted landfalls.

Present plans are for three years of measurements. If successful, the effort will establish an unprecedented body of correlated wind and structural response data along at least some portions of the hurricane-prone Atlantic and Gulf coasts. Applied also to the potentially vast volume of meteorologic data now being turned up at utility power plants in other regions, these correlations of extreme wind velocities and wind loads should yield new economies in transmission tower and line design throughout the United States. ■

Electricity Growth: Part Trend, Part Cycle?



If a firm basis is found for an enigmatic cycle in national electricity data, it may be the start of a more accurate method of forecasting the growth of power output.

Extending an analysis of the historical relationship between electricity output and gross national product (GNP), Milton Searl, technical manager in EPRI's Energy Study Center, observed a previously unrecognized cyclical pattern in the data. Although no cause has as yet been identified for the cycle that has been observed, utilities may benefit by recognizing the possibility of such a cycle in the output pattern of their own companies.

Searl and his colleagues are exploring the reasons for this electricity output cycle (EOC). Their search for theoretical foundations is still at the preliminary stage; the data pattern remains puzzling and provocative. Historically, the average annual growth rate of electricity output for 1947–1973 was 7.4%; for 1973–1979 the average annual growth dropped to 2.9%. Could this slowing in the growth rate be partly due to this previously unrecognized pattern?

In the normal course of forecasting national kilowatthour output, analysts account for the impact of two economic factors: the long-term trend in GNP and the business cycle. Searl found that in the last 60 years an EOC persists even after the effects of these economic factors have been taken into account. This indicates that the EOC itself is not explained by the usual national-level economic analysis.

In the data discussed below (Figure 1), two apparent 14-year EOCs can be discerned in the post–World War II period, plus a number of 7-year EOCs that date back to 1920.

Searl's analysis indicates that EOC was moving upward from 1967 through 1974 but turned down in 1975. This downward movement is now in its sixth year, with one more year to go if the 14-year EOC holds. Thereafter, 7 years of above-trend growth rates should follow. This does not imply a return to the historical 7% annual growth rate but, rather, to the long-term growth trend from which EOC is determined.

Some basic facts

Two types of trends are generally used by analysts who measure aggregate, or national, growth of output: one is the trend relative to time (e.g., 7% per year); the other, used here, is the trend relative to economic activity, such as GNP or some closely related variable.

Since WW II the long-term trend has been for increases or decreases of $1 in real GNP (GNP purchasing power) to be matched with a corresponding change in electricity output of 2.28 kWh.

In studying the long-term trend, Searl and his colleagues examined 58 years of electricity and GNP data from 1920 through 1977. It was this analysis that revealed an apparent EOC. (Data for 1978 and 1979 are shown in the figures, although they were not available when this analysis was first undertaken.)

In Figure 1, which shows the 1920–1979 EOC data in billions (10^9) of kilowatthours, the straight line represents the calculated trend of growth (output versus GNP). The deviations from this line represent the difference between the actual, observed output and the calculated trend. These deviations appear to be increasing over time, although when shown as a percentage of total output (Figure 2), the peaks and valleys of EOC are not really becoming more extreme.

The source of the data plotted in Figures 1 and 2 will be discussed more fully later. However, it is appropriate to note at

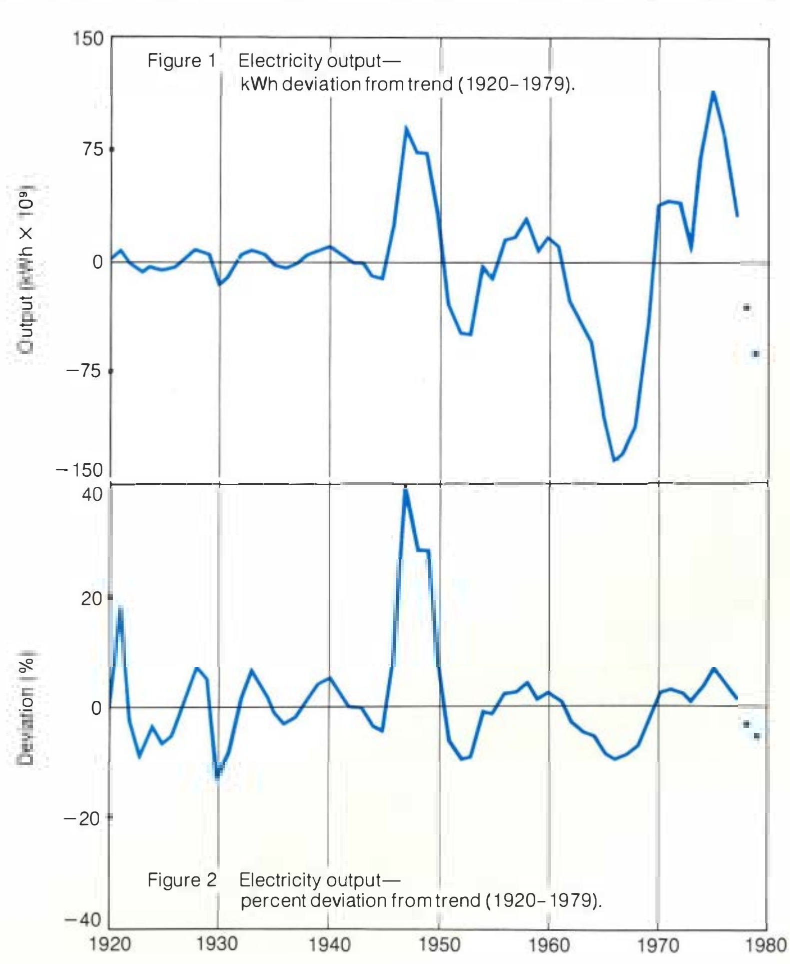


Figure 1 Electricity output—kWh deviation from trend (1920–1979).

Figure 2 Electricity output—percent deviation from trend (1920–1979).

this point that the data represent deviations from the trend and are a combination of the cyclical pattern and the random variations from that pattern. Fitting a smooth cyclical curve to the data separates the random variations from the cycle. Figure 3 shows the deviations and the fitted curve for the period 1947–1979. (A cyclical pattern can also be observed in the pre-1947 data shown in Figures 1 and 2, but it is not relevant to current analysis, except in reinforcing the EOC concept.)

As an example of the potential significance of EOC, Searl calculates that from 1958 through 1966 the actual observed growth rate was 2 percentage points per year below the long-term trend. In contrast, for the period 1966 through 1972, the actual observed growth rate was slightly more than 2 percentage points above the long-term trend.

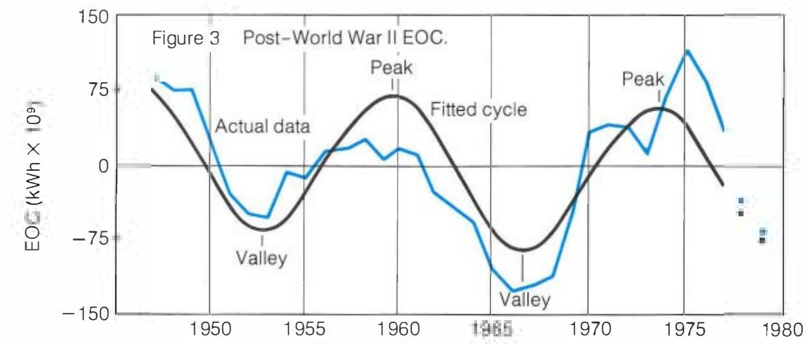


Figure 3 Post-World War II EOC.

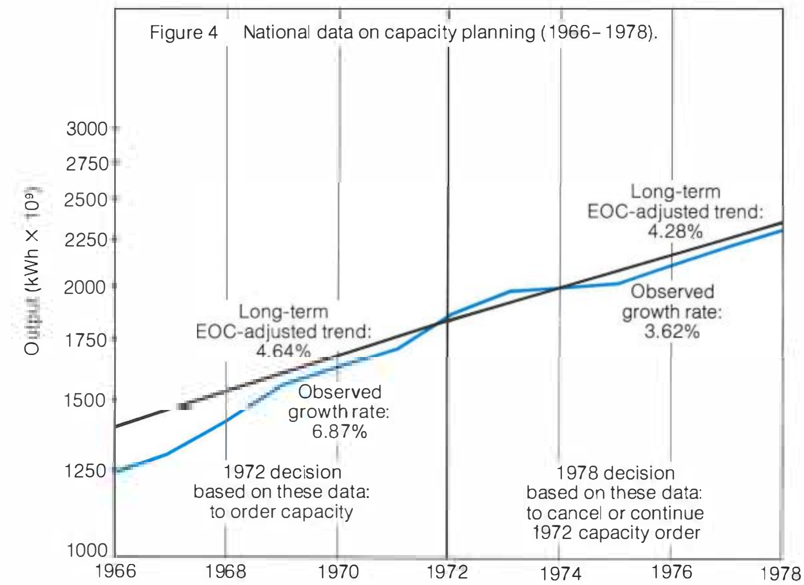


Figure 4 National data on capacity planning (1966–1978).

Possible upturn

The fitted curve shows the present EOC peaking in 1974, although the actual data, including the random variations, show the peak occurring in 1975 (Figure 3). While actual, observed electricity output grew at a low rate during 1974 and 1975, the fact that EOC was peaking tended to reduce the depressing effect of the recession on electricity output. During 1980 and 1981 the situation may reverse. The economy is again in a recession, but 1980 is also the sixth year of the downward movement in EOC, so the two effects may reinforce each other. In 1981 EOC could reach its lowest point. If the possible existence of an EOC is not taken into account, the low rate of increase or the slight decrease in output will probably be attributed entirely to the recession, prices, and conservation.

In the next year or two the economy may grow strongly, and EOC, too, should be on an upward swing. The combined effect could produce a number of years of strong growth, depending on the length and strength of the next business cycle. By 1988 or 1989 EOC should peak—there is not enough postwar history to foresee the exact length of the cycle. In fact, the EOC cycle could be gradually lengthening. (Each cycle was only 7 years between 1920 and 1946.)

Failure to recognize the possibility of an EOC may have contributed in the past to overestimates of growth, which, together with financial and regulatory problems, have led to subsequent widespread cancellation and deferral of new plant construction. Correspondingly, if the potential upturn in EOC is not now noted, utilities may find themselves with inadequate generating capacity even earlier than generally predicted by their analyses and that of the National Electric Reliability Council. Over a period of time, forecasting that accommodates an EOC may help mitigate financial and regulatory disharmony.

Figure 4 shows the hypothetical effect of a 14-year EOC in a utility's deliberations on plant construction and cancellation. Although the numbers are based on national data and do not refer to any specific utility, this example approximately parallels the reported experience of one major utility, which ordered new plants at the end of 1972 and canceled the order late in 1978.

The actual or observed growth rates referred to are the rates calculated on the basis of the amount of generation that actually occurred. If the period for which such a calculation is made spans more than a few years, this growth rate tends to be interpreted as part of the long-term trend. However, if the possibility of an EOC is accepted, the amount of generation in any year could be viewed as a combination of growth along a long-term trend and of shorter-term cyclical factors. To obtain a better estimate of the true long-term trend, it therefore would be necessary to adjust (add to or subtract from) the observed value by an amount equal to the cyclical component (Table 1).

Figure 4 shows that the actual growth rate observed by the hypothetical utility from 1966 to the end of 1972 was 6.87%. However, the long-term trend, or average growth rate (adjusted for EOC) was only 4.64%, or two-thirds of the observed growth rate. If the utility had been armed with this appreciation of the difference between observed and adjusted trend (and depending on the level of its reserve capacity and a host of other factors), it might have deferred its order, ordered less capacity, or ordered a different mix of capacity.

Table 1 Observed growth and EOC-adjusted growth.
(kWh x 10^9)

	1966	Annual Change (%)	1972	Annual Change (%)	1978
Reported generation	1250	6.87	1862	3.61	2304
Fitted trend	1387	4.65	1821	4.27	2340
Total:	−137		41		−36
Difference (EOC)	76		−38		50
Difference (random error)	61		− 3		−14
Total:	137		−41		36

However, let us assume that new

UNDERSTANDING THE METHODOLOGY

There is a high degree of correlation between real GNP in the United States and electricity output. Output (as used here) includes generation by electric utilities, generation by industrial and other nonutility sources, and net imports (imports less exports) of electricity. A close relationship between real GNP and output has been shown to exist for the last 60 years. Earlier annual data for electricity output are not available.

The same functional form serves well for the entire period. However, the parameters are different for the 1947–1977 period than for the 1920–1946 period. (Data for 1978 and 1979 are used as a check on the validity of the equation.)

Figure 5 shows the line of regression between output and real GNP. The line explains 98% of the variation in the electricity series. The equation is $E = 2.28\,(GNP) - 850$. The electricity output is equal to 2.28 times the real GNP (in 1972 $) minus an adjustment figure of 850.

The negative constant term is required to put output and GNP in the proper relationship in 1947, the first year of the relationship in this equation. GNP was growing long before electricity came into commercial use, so total electricity output and GNP are not directly proportional and their growth rates are not the same. However, changes in output and GNP are directly proportional (that is, 2.28 kWh per dollar of real GNP).

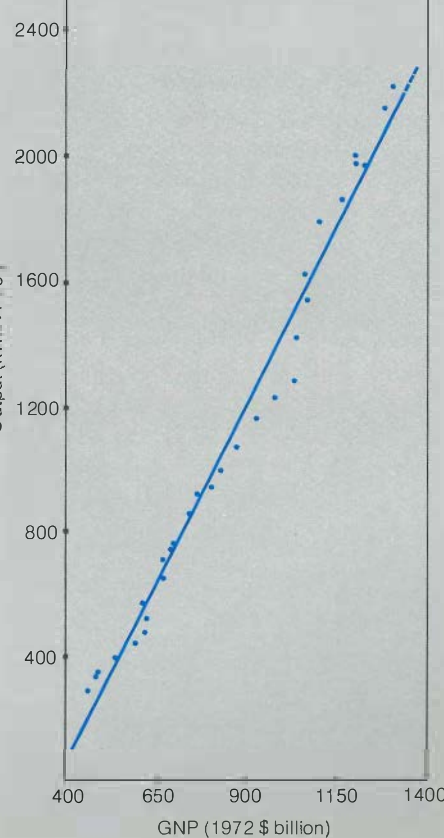


Figure 5 Electricity output versus GNP (1947–1979).

The rate at which output grows with respect to time is more rapid than that of GNP because of the negative constant term. The growth of output is basically exponential if the growth rate of real GNP is exponential. As GNP grows, electricity growth rates approach GNP growth rates. The basic trend is thus one of decreasing electricity growth rates through time.

Figure 5 shows how the data points tend to lie first on one side of the fitted line for a period of time and then on the other. It is in these deviations that the 14-year EOC is observed. The deviations themselves are shown in Figure 1. While the deviations appear small in Figure 5, because of the 14-year cycle the swing from peak to valley is about 140 × 10^9 kWh. □

plants had been ordered at the end of 1972 based on 6.87% annual growth, but licensing, site preparation, and related factors took several years, so full-scale construction had not started by the end of 1978. Actual observed growth from 1972 through 1978 was only 3.62%, or roughly half of the growth rate in the earlier period. On the basis of this information, cancellation of at least some of the plants would appear prudent. However, after adjusting for the position of EOC, the underlying trend growth rate during the period is stronger than the observed rate—4.28%—or only moderately less than the underlying trend in the 1966–1972 period, still suggesting the need for some cancellation or deferral if orders had been placed on the basis of 6.87% observed growth.

If, on the other hand, new plants had been ordered in 1972 on the basis of the 4.64% EOC-adjusted trend, that first decision would be reinforced by the 4.28% in the subsequent 1972–1978 period.

Figure 4 may well be analogous to the experience of Public Service Electric and Gas Co. of New Jersey. PSE&G ordered two floating (offshore) nuclear units in 1972 and subsequently ordered two more. In that year the company's annual peak demand was growing at 7.7%. Since the reactors ordered were baseload units, it is safe to assume baseload growth was also strong. PSE&G is known for its careful planning and sophisticated analysis, so the decision was doubtless a reasonable one in light of the information available in 1972. Yet in 1978 PSE&G canceled the four-reactor order, announcing that its peak load was growing only 2.8% a year.

It seems likely that the load growth data considered by the company were more like the observed data of Figure 4 than the hypothetical EOC-adjusted trend data. There is no guarantee, of course, that such adjusted data would or should have resulted in a different decision by PSE&G in 1972 or 1978. Power reserve levels and power pool responsibilities, as well as other factors, may have dominated growth factors in the analysis. Projected growth is only one of many considerations in expanding capacity.

Implications of an EOC for utilities

The implications of an unrecognized output cycle in national utility data are sufficiently serious that utilities may wish to analyze their own data for such cycles.

Although the possible existence of an EOC has been studied only in terms of national data, its hypothesized existence at the national level implies similar cycles in the output and sales of at least some utilities. In fact, because the process of aggregating individual utility figures to the national level must have some averaging effect on the combined data, it is likely that relatively more-extreme cycles exist for some individual utilities.

As long as potential EOCs are unrecognized by utility and other analysts, these cyclical movements will tend to be interpreted as part of the trend. With the long lead time needed for constructing new power plants, the effect of this lack of recognition is likely to be that utilities will either order construction or cancel or defer it on the basis of data that give unwarranted weight to short-term cyclical effects, thereby diluting the underlying movement of long-term trends.

If the EOC concept stands the test of further analysis, it will raise questions about the accuracy of recent estimates of price elasticity, that is, the way consumers react to electricity prices by conserving or by substituting other fuels for electricity.

It is, of course, premature to abandon present estimates of price elasticity and conservation on the basis of what is now known about the possible existence of an EOC. Indeed, causes (or at least a theoretical basis) for an EOC remain to be identified. Even so, utility analysts may wish to examine data for their own operations for evidence of the existence of such a cycle as an element that should be considered in deriving an appropriate measure of long-term trend. ■

Gerald Tape: Fostering the Scientific Quest

Believing in the validity of basic research in anticipation of future needs, Tape nevertheless considers it necessary that the electric utility industry follow a more pragmatic path in the present climate.

"A good research administrator cultivates scientists' own individual ideas and efforts. He is not so much one who directs; he is rather someone who understands the way in which scientists can be most productive and creates the appropriate environments."

Gerald Tape, president of Associated Universities, Inc. (AUI) and chairman of EPRI's Advisory Council, would add two qualities that befit an effective R&D administrator: flexibility and the confidence to encourage a researcher's independence of thought and pursuit.

No less important is the capability to stimulate the necessary financial support. All in all, an administrator should be "an effective interface between the producers and the sponsors—generally the customers—of research."

Early Work

Tape's own life work has been focused primarily on nuclear research, first in the laboratory, then in the executive office. "I made a decision in my midthirties that I was more cut out to work in the administration and management side of science than I was at the bench as a pure researcher." He felt comfortable with both the detail of administrative duties and the requirement for a broad comprehension of grass-roots research.

His four years' wartime experience at the Radiation Laboratory of the Massachusetts Institute of Technology, helping to develop and use microwave radar, grounded him well in how research and development in large enterprises could be made to move forward "with drive and inspiration."

At MIT he worked through three eras that formed part of his foundation of knowledge for the future role he would play as a research administrator at Brookhaven National Laboratory (BNL), AUI, and the Atomic Energy Commission (AEC).

The first was an experimental project in relaying radar information from aircraft to ships. The experiment proved successful in 1943, but to the disappointment of the developers, the naval commands saw little need for such capability at the time. However, one year later, when the Japanese began using their kamikaze aircraft, Allied fleet commanders suddenly were desperate for an airborne radar system with a relay link to the command ship. "The point is," says Tape, "one develops information and capabilities, but the actual need for them may only emerge later. One learns to be philosophical about research." In other words, although an immediate purpose for some research may not be apparent, its application may be indispensable in the future.

The second era at the Radiation Laboratory at MIT involved training equipment for radar operators in aircraft, ships, and ground stations. This equipment was the forerunner of today's instrument-panel simulators for aircraft flight crews and nuclear power plant operators.

During the third era, Tape spent eight months in the United Kingdom with the British branch of MIT's Radiation Laboratory, where he learned to work with the military at all levels on equipment development, operations, and defense strategy. Later he found it not uncomfortable to work on national security problems, having gained insight into the role of science in the military services.

Wider Research Fields

While he was at MIT, big laboratories proved to be particularly successful, and it seemed natural for him to go into the management of another centralized R&D operation. Following four years in the physics department of the University of Illinois as a teacher and researcher, he joined BNL at Upton, New York, as assistant to the director in 1950, rising to the post of deputy director a year later. BNL is a multidisciplinary laboratory oriented toward basic research—that is, the discovery of fundamental knowledge and the development of understanding in such areas as the chemical and physical forces of nature, the structure and behavior of materials, and the functioning of life processes. The laboratory also assists the government in attacking national problems that call for its special facilities and talents. Tape reiterated a statement recently made by the director of BNL: "From *Tradescantia* to transmission lines, from brain scans to studies of the New York bight, from solar neutrinos to solar homes, our wide-ranging research is fundamental, sound, useful, and fascinating." The work at BNL was originally focused on nuclear energy because BNL was operated for the AEC, but its program was expanded with the transition from AEC to ERDA, then to DOE, each agency having a successively broader charter. Other government agencies, such as the Nuclear Regulatory Commission and the National Institutes of Health, also support research at BNL.

The laboratory was created in 1946 by the founders of AUI to form a strong but democratic hub for the spreading spokes of exploratory research. This hub would be rich in resources, both cerebral and financial, from a number of universities and relevant government agencies. Not only could a more complex, more expensive facility be built according to this principle, but also the facility would be accessible to far more U.S. and foreign scientists than would smaller research operations on college campuses.

The nine universities sponsoring AUI—Columbia, Cornell, Harvard, Johns Hopkins, MIT, Pennsylvania, Princeton, Rochester, and Yale—recognized the advantages of a cooperative undertaking between the academic scientific community, represented by AUI, and the federal government.

After BNL was successfully launched with the support of the AEC, AUI undertook to establish, under National Science Foundation sponsorship, a second major scientific research facility according to the same principles that had nurtured the creation of BNL: the National Radio Astronomy Observatory (NRAO) at Green Bank, West Virginia. NRAO is now headquartered in Charlottesville, Virginia, and, in addition to Green Bank, has observing sites at Tucson, Arizona, and San Augustin, New Mexico.

In 1962, after 12 years as deputy director of BNL, Tape was asked to become vice president of AUI. Shortly after assuming that post, he took over as AUI's president. However, only six months later, President Kennedy appointed Tape as one of five commissioners of the AEC. Although responsible as a commissioner for all aspects of the program, Tape was most involved with those in national security and basic research. He served for six years until May 1969, when he resigned from the AEC to rejoin AUI, where he has continued at the helm.

Tape has assisted the government in a number of other ways. He served for four years (part-time) as U.S. representative to the International Atomic Energy Agency with the rank of ambassador, while still president of AUI. He has served on a number of government committees and panels, including the President's Science Advisory Committee, the Defense Science Board, and the ERDA General Advisory Committee. He continues to be a consultant to several government agencies. Recently, he was awarded the Henry DeWolf Smyth Nuclear Statesman Award by the Atomic Industrial Forum and the American Nuclear Society, for outstanding service in developing and guiding the uses of atomic energy in constructive channels.

Fission, Breeders, and Fusion

Tape's views on the destiny of nuclear fission reactors are indeed constructive. Calling attention to the major activities of the utility industry since the accident at the Three Mile Island nuclear plant, such as the creation of the Nuclear Safety Analysis Center and the Institute of Nuclear Power Operations, as well as follow-up by utility operators, Tape believes that credibility will be restored in these reactors as trustworthy power providers.

"There will be recognition," he says, "that nuclear energy costs, considering both capital and operating expenditure, are going to be as favorable, if not more so, than other alternatives. Furthermore, the public will become more aware of the environmental costs of the alternatives. I think confidence in nuclear will grow." In fact, Tape goes further and predicts that public acceptance of nuclear power is not far off and there will be increasing support for the position that coal and nuclear are both required as our only real electric utility options for the rest of this century. Indeed, he thinks the indispensability of nuclear power may become the prevalent public opinion.

"If we get into a situation," he continues, "where electric energy growth is necessary in order for the country to move forward, the one area in which we can probably expand the most rapidly is in nuclear power plants." He explains that even though new plant construction is dragging along because it is not needed at present in some areas, the capability of manufacture is available. Also, although the conservation ethic is important and is moderating the need for new plant construction, there will be a point at which most of the improvements in efficiency and conservation of electricity generation and use will have been made. "I think at that time nuclear will be a real competitor."

In a similar vein, he reckons some regions of the country could find themselves short of power in about 1985. Only then—that is, after a period of coasting—will people start to realize that implementation of long-term planning is essential; without it, the country will be in trouble. He maintains that utility management should not be pushed into a position in which they have to throw up their hands and say, "Sorry, we can't supply."

Tape concedes that the issue of radioactive waste from nuclear plants is a catch-22 situation; the public wants a demonstration that radwaste can be made safe indefinitely, but no local community or state government will agree to provide a site for the demonstration. The problem is political, not technical. In addition, it is impossible to demonstrate in a direct way over a short period the principle of safe storage lasting a hundred years or more. Tape hopes that the United States will be able to take advantage of the research, development, and demonstration that is going on in other countries, for instance, Canada, France, and Sweden.

In contrast to Tape's basic optimism with regard to U.S. fission reactors as relatively immediate and reliable sources of power, he sees other, less-developed concepts, such as the high-temperature gas reactor and the breeder reactor, as twenty-first-century candidates in the United States, although the breeder could be a nearer-term option abroad.

Queried on the proliferation aspects, he replies: "I think the United States is losing its leadership, and therefore control, because of its policies on reprocessing and breeder development and its unilateral actions affecting cooperation in fuel supply and technical assistance generally. I personally do not consider that the breeder of and by itself is a system that makes the proliferation problem any more difficult than it is anyway. Plutonium is being produced now in light water reactors, but it is not available for use. It's being stored in spent-fuel elements, and the thought is, 'We won't let it be separated; it'll just be stored.' Yet we preach the energy conservation ethic, which must include conservation of resources. The recovered uranium and plutonium represent energy resources that should be used. We should be paying attention to how we can best use them while minimizing the proliferation risks. It's going to take us so much time to achieve this goal that now is the time to start. I don't see our being ready in the year 2000 unless we're working actively on it today."

On the subject of fusion, Tape is not as positive. He accepts the fusion process as promising and has strongly supported the R&D program. But he disagrees with those who believe fusion is the answer to fission's problems of safety, waste management, and proliferation. Fusion has problems that must be solved, too. "We've got a long way to go before its marketplace position can be assured."

His views on solar are similar: "I think progress is being made in the solar field, and this is fine; but I don't agree with throwing an excess of money at new developments before they are technically right." In Tape's view, EPRI should have a hand in these R&D activities to be able to make utility inputs and be able to say to the utilities, "We'll keep abreast of it, but don't make a major commitment of funds right now."

R&D for the Electric Industry

This pragmatic philosophy—of concentrating on the solutions to present roadblocks while still seeking alternative solutions to long-term energy problems—forms the core of a report that Tape recently gave EPRI's Board of Directors. It was the result of a study requested by the board and carried out by the Advisory Council to determine an appropriate level of support for research and development by the electric industry. An answer was sought to the question, Is the level of R&D funding adequate to overcome the difficulties confronting the electric utilities and to provide opportunities for the near future?

Three main R&D challenges pinpointed by the council were to apply the results of research now under way, to emphasize near-term R&D that can increase productivity and thereby offset rising costs and satisfy environmental and safety concerns, and to expand testing and evaluation in order to bring promising developments to commercialization.

The council recommended that the electric utility industry continue to take an R&D leadership role. EPRI should also continue its dual role of providing a focus for industry R&D and for utility plant owners who experience common problems.

The council compared ratios of R&D spending to sales in U.S. industries and in foreign utilities. R&D support by the U.S. electric utility industry is about 0.65% of sales, about one-third the national average for U.S. manufacturing industries and less than that for the British and French nationalized electric utility companies. The council concluded that funding levels are best justified on the basis of specific R&D needs; however, the levels now supported by the electric utility industry should be raised, especially in light of the tasks confronting the industry.

The sum of all these obligations, reports the council, indicates that a minimum annual increase in R&D support of 10% is necessary, with an accompanying allowance for inflation.

An advantage of EPRI's focusing on near- and intermediate-term R&D is that there is a better delineation of the roles of industry and government. As Tape puts it, "In today's technology, some endeavors are so expensive and involve such high economic risks that many companies can't really afford to go it alone. So then one starts to look for the next step, that is, cooperation with organizations such as EPRI, other utilities, and manufacturers. The third step generally involves the government, although we recognize it's not always easy to have such cooperative projects. It's much like a partnership in which each partner wants to be in control. On the other hand, I think in due course, each will learn how better to work with the other."

Looking Forward

Tape's basic anticipation of successful outcomes must be at least part of the reason that he is sought after as a facilitator and manager of research.

His confidence in the people who do the research is obvious. "Through the years," he says, describing AUI, "we have been specialists, if you will, in the type of operation that is a kind of marriage between the government and the academic scientific community . . . in these specialized fields, we capitalize by bringing the best scientists together with the best equipment on a national basis. For example, at Brookhaven, there are very advanced accelerators for high-energy physics, and a new one is coming in to produce X radiation and ultraviolet radiation. It will be used by solid-state physicists, chemists, and biologists in the study of the structure of matter."

There is also much international interaction with such organizations as CERN, the 12-nation European center for nuclear research just outside Geneva. Tape points out: "These are types of cooperation that depend less on formal agreements and more on the interaction of the people and the ideas they generate."

A new research venture cultivated under AUI auspices is about to come to fruition: the very large array (VLA), a new radio astronomy facility on the plains of San Augustin in New Mexico. At a 7000-foot elevation in a wide, level valley stand 27 dish-type antennas in a Y-shaped array, electrically connected with one another. Each leg of the Y is a 13-mile-long rail track, and each has nine wheeled antennas distributed along its length. By computer processing, the radio signals received at any one time by each antenna from celestial bodies and interstellar gas clouds can be compared, contrasted, and synthesized so that the result simulates the total collection of signals as though it had been received by one giant antenna, or aperture. The facility is therefore called an aperture synthesis array.

The reason for building on high ground is to reduce the interference of water vapor above the earth's surface, thereby allowing the antennas to pick up shorter and shorter wavelength radiation. Thus a finer resolution, or distinction, can be made between signals that are clustered.

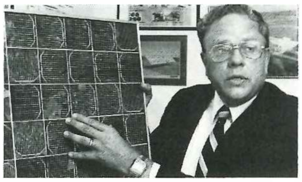
AUI, in addition to others, has also proposed to NASA the establishment of a space telescope science institute at Princeton, New Jersey. The telescope, to be launched late in 1983 or 1984, will be part of a space-based observatory with about five different optical instruments on board. It will be the first major equipment launched by NASA that will have a user facility, bringing in people from many universities with proposals to do experiments. Should AUI be chosen as the contractor, the institute would be an additional user-oriented research facility under its aegis.

The phenomena that the space telescope "sees" and the remote signals that the San Augustin antennas "hear" may well be written up in *Science News*, a short weekly magazine for general readers published by Science Service, Inc., of which Tape has been a director for a number of years. Science Service also runs two annual educational projects for students: the Westinghouse Science Talent Search and the International Science and Engineering Fair. Tape points out that one of AUI's objectives is education and training, as evidenced by the postdoctoral appointments of young people to use the facilities at BNL and the radio astronomy observatories.

Tape is certainly true to his belief in fostering the scientific quest, from the presidential to the high school level.

DOE Explores Solar Photovoltaics

DOE's R&D program for photovoltaics focuses on reducing costs of the solar cells. Early use by utilities will be to offset oil use in peaking plants, predicts DOE's photovoltaics director.



Maycock

As the Department of Energy's director of the Photovoltaic Energy System Division, Paul Maycock presides over the government's $157 million solar program, which aims at making electricity from the sun through solar cells attractive for utilities, industries, and residences. EPRI has an active and what Maycock terms complementary program to the federal effort. "We work very closely with EPRI," Maycock said.

The heart of the solar photovoltaic system is a cell consisting of two very thin layers of semiconductor material. One layer has negative electrical properties and the other, positive. Sunlight hitting the negative layer of the cell will knock electrons loose from some of the atoms in the layer. These free electrons create voltage in the cell that can force electric current through a circuit.

Research has been focused on efforts to reduce the cost of the solar cells. Costs, usually computed in terms of dollars per peak watt from a photovoltaic module, are dropping. The costs per peak watt (expressed as Wp) have dropped from $22/Wp in 1976 to as low as $7/Wp in 1979. DOE is trying to encourage the fledgling solar industry to reduce costs further. Goals are $2.80/Wp by 1982, 70¢/Wp by 1986, and 15¢/Wp to 50¢/Wp in the period 1990–2000. An intensive program of basic materials research underpins the effort to drive prices down.

If these cost goals are met, Maycock predicts, solar photovoltaics will be fully economic for all central station utilities in 1990, economic for municipal utilities in 1986, and possibly economic sooner for residential applications. In his view, the major factor is the cost of money. "All the economics of a new option is done essentially by comparing the marginal cost of coal, oil, and nuclear to the marginal cost of putting in photovoltaic, solar-thermal, and wind," he said. "Once that comparison is made in terms of capital costs, operating expenses, fuel and system characteristics," he said, "one of the key factors that determines the economic viability then is the cost of money."

Municipal utilities can issue bonds, and when the prime rate is 15, their rate may be only 9. "This difference," Maycock observed, "means that the municipals can raise more capital with the same debt service costs because the required capital return to the investors is lower." This argument underlies his opinion that the municipal utilities will find photovoltaics attractive sooner than the investor-owned utilities.

The precise role of photovoltaics in a utility grid is under investigation. Maycock said it is apparent that solar photovoltaics will be most attractive to summer peaking utilities. Until practical, cost-effective electricity storage systems are developed, photovoltaic applications are likely to be confined to replacing oil and inefficient coal-fired units used for peaking. "EPRI has spent about a million dollars with GE and others to address this, and DOE has also spent about a million dollars on this general issue. And it's very utility-specific. If a utility has oil peaking, then photovoltaics is best used as a peaking offset, and you need to design the system and to size it so that it affects the peak. However, you can design photovoltaics to have some baseload credit. Not very much, maybe as much as 10% of its power can be credited for baseload. Generally speaking, photovoltaics in its early adoption will be to offset the use of oil in peaking," he said.

The questions of integrating photovoltaic systems into a utility grid are being addressed in two major (200–300 kW) experiments, Maycock said. One is planned for a Phoenix site owned by the Arizona Public Service Co., and the other is with Dallas Power & Light at the Dallas airport. "The central utility person," he said, "would probably like to see about a megawatt's worth of photovoltaic peak capacity and would like to see that run for a year or so before he'd say, 'By golly, the equipment works.' At the moment we are not doing any 1-MW experiments, primarily because of budget limitations. However, it is very possible that we will be doing those sometime next year." The utilities operating these projects are telling DOE that "we are expecting to get the information we need, except we don't have information on high-voltage strings and we don't have power conditioning that really meets our size requirements," he said. (The power-conditioning equipment converts voltages received from the cells to either dc voltages appropriate for the transmission system or ac current.)

The modular aspect of photovoltaics may make it attractive to utilities, Maycock believes. As photovoltaics becomes economically attractive to utilities and a manufacturing base is strengthened and expanded, a utility could add about 1 MW of arrays a month. If the goal is to have 1 GW in 10 years, a utility could build up to that point and be generating electricity from the first month. Construction, he said, is relatively simple. "If I were committed to photovoltaics, I would first locate the area in which I were going to put the systems. And I would have a crew that each day leveled the ground, put the concrete lugs in the ground so that I could mount the hardware that came in on trucks. Constructing the array is just a simple process of bolting triangular pieces to the ground at 45° angles with the arrays on them. And so that's just a continuous construction process, almost like plowing earth; you can do so many acres a day. You get your shipping schedules, and in it comes. You bolt the arrays together. The wiring can be prefabricated and lugged together by an electrician. The power-conditioning system is modular, depending on whether you are doing 1 MW at a time or 2 MW at a time, or whatever. It's just a black box."

While much has been made of the land-use consequences of installing acres and acres of photovoltaic arrays, Maycock believes there is a practical way to overcome the land-use problem. Utilities, he points out, have tremendous amounts of land available underneath power transmission lines in dedicated rights-of-way. Many of these lines run through desert areas that are well suited to photovoltaics. Another suggestion would be to mount the arrays in the exclusion areas that surround nuclear power plants.

Manufacturing capability for photovoltaics is not large at present. However, that capability is growing quickly and could grow more quickly, he said. In 1979, the United States had the capability to produce about 10 MW of photovoltaic arrays, and, in 1980, about 30 MW of new capacity is being built. "They'll double capacity every year for several years," he said. "And so, I would estimate that in the 1988 time frame, there'll probably be on the order of 1 GW a year, or the equivalent of one nuclear reactor a year." And, he added, "If the market develops, there are no limits that we can find to going to a few hundred nuclear reactors' worth a year, which is the highest we ever dreamed of for nuclear. So I see no physical limits. Capital availability will have to be an issue, but that's always an issue when you're expanding capacity, whether it be nuclear or coal or photovoltaics. You've still got to have the plant capacity and the mining capacity to do this." If price, capital, and utility demand for photovoltaics optimally converge, Maycock believes the technology could be providing roughly 10^{15} Btu of U.S. energy by 2000. Residential and commercial use of photovoltaics tied to any large-scale development and mass production of electric automobiles could spur the fledgling industry further.

For the earth-bound systems that Maycock is exploring, the critical question is what to do when the sun goes down or when there is a cloudy day. Storage could be one answer. If Maycock had to pick a system or two today, he said he would favor improved lead-acid batteries and some of the new reduction-oxidation batteries as the prime candidates, although DOE is examining other options, such as flywheels. Beyond the terrestrial systems, DOE is also examining a stationary satellite photovoltaic system that would use microwaves to constantly beam solar electricity to the earth.

Utility industry and energy company attitudes toward solar photovoltaics appear to be changing. Major energy companies are making large investments in the field, Maycock noted, with large infusions of risk capital coming from several major oil companies. Utility attitudes appear to be more and more favorable. Utilities, Maycock said, went through a very skeptical phase at first, but that gave way to what he calls the engineering curiosity phase, in which a number of leading utilities began to assign engineering talent to explore the area. Utilities recognize that there are some institutional uncertainties associated with an electricity system that could be both distributed and intermittent, and those questions are being addressed. At this point, "There are about 20 major utilities that are thinking about or doing a little photovoltaic experimentation. Or they're coming to see the work we're doing and saying, 'You know, I kind of like that,'" Maycock concluded. ■

Regulators Briefed on EPRI

Exposure to the information resources of EPRI may assist state regulatory commissioners in understanding the costs, benefits, and timing of new technology.

A major step in explaining to state regulatory commissioners what EPRI is and does occurred July 28 when 50 commissioners and staff members representing 24 states attended a day-long conference at EPRI headquarters in Palo Alto. It was the first meeting of its kind, bringing together the largest contingent of state regulators outside their annual meetings, according to C. Burton Nelson, director of regulatory affairs for EPRI and conference coordinator.

Floyd Culler, president of EPRI, Richard Balzhiser, vice president, and Richard Rudman, director of EPRI's Policy Planning Division, gave an overview of the Institute's history, funding, organization, and goals. Directors and representatives from the six technical divisions then outlined the major projects now under way and answered questions from the regulators.


Studying an exhibit of EPRI research results at the recent regulators' meeting are (from left): James Plaskett, commissioner, Indiana Public Service Commission; Paul Rodgers, administrative director and general counsel, NARUC; Ralph Gelder, chairman, Maine Public Utility Commission; and Leigh Hammond, commissioner, North Carolina Utilities Commission.

Culler commented that after six years of research effort, EPRI is now "beginning to reap the benefits of a well-organized and well-conceived program. The next few years are going to provide us and the energy industry with the best data . . . to slow the inevitable increase in the cost of power."

René Malès, director of EPRI's Energy Analysis and Environment Division, told the group that much of EPRI's research "reduces uncertainty and allows for informed decision making" by regulators and the utility industry.

Nelson said that the conference was scheduled to coincide with various national regulatory committee meetings to ensure wide participation and was intended to give regulators the information they need to make policy decisions that take into account the various costs and benefits of new technology. Although some commissioners have served on the

Advisory Council and Rate Design Committee and others have taken a personal interest in EPRI's research, many are largely uninformed about EPRI. This, he hopes, will change as meetings of this kind continue in years to come. ■

Advances in Solar-Thermal Conversion

Efforts to demonstrate viable concepts for central collection of solar-thermal energy were advanced when EPRI's program entered a new phase on July 1.

Following the successful testing of a 1-MW (th) gas-cooled solar receiver at DOE's central receiver test facility near Albuquerque (*EPRI Journal*, June 1979, pp. 18–21), the full system experiment project is now under way. This new project will seek to demonstrate the technical feasibility of a complete solar-thermal central receiver concept.

In addition, the power generation system will also seek to demonstrate a solar-fossil hybrid arrangement using fossil fuels for dependable generating capacity whether the sun is shining or not.

The experiment will use the gas-cooled solar central receiver technology supported by EPRI and developed by Boeing Engineering & Construction beginning in late 1974. Boeing will serve as the prime contractor for the full system experiment.

Relative to other central receiver technologies under development, the gas-cooled technology is expected to offer operating efficiency, simplified design, more flexible siting, and less water use.

The experiment will provide an opportunity for direct utility operating experience with a complete solar electric generating system. A series of utility teams will be actively involved in all phases of the experiment. The teams will provide technical expertise and assistance to the contractor, operate the experiment during part of the solar test phase, and offer an independent assessment of the system.

Public Service Co. of New Mexico will act as the lead utility. Jack Groves, supervisor of resource analysis, will coordinate the activities of utility teams that will make up a users group for the experiment. Utility teams have not yet been selected. Utilities interested in participating in the experiment may contact EPRI Project Manager J. E. Bigger (415-855-2178) or J. Groves (505-848-2575). ■

FGD Reports Available

Three reports have been recently published by EPRI's Desulfurization Processes Program, according to Stuart Dalton, manager. Each report deals with aspects of flue gas desulfurization (FGD) economics.

Economic and Design Factors for FGD Technology (CS-1428) was prepared by Bechtel National, Inc., and compares published FGD cost data from 8 sources in 10 different studies. It also discusses reasons for differences between estimates and actual costs and presents a standard evaluation format by which 8 selected processes were estimated.

Comparison of the 8 FGD processes showed that the alkali-based, nonregenerable processes have the lowest capital and levelized revenue requirements. EPRI is using the economic and design premises developed in this study as a basis for future economic comparisons.

A more limited study by Stone & Webster Engineering Corp. and Milton R. Beychok is *Comparative Economics of Advanced Regenerable Flue Gas Desulfurization Processes* (CS-1381). This report compares four advanced commercial or semicommercial processes and was the basis for much of EPRI's R&D work in regenerable FGD technology.

Investigation of High SO_2 Removal Design and Economics (CS-1439) is a two-volume report on possible designs and costs for high SO_2 removal processes, including two-stage scrubbing and use of additives. The report illustrates the beneficial effect of magnesium and the detrimental effect of chloride on scrubber design and operation. ■

Probabilistic Risk Assessment

NSAC and Duke Power Co. are undertaking a probabilistic risk assessment (PRA) of one of the units at Duke's three-unit Oconee nuclear power station. The purposes of the study are to provide a model—in terms of scope, approach, and methodology—on which utilities can pattern future studies, and to offer utility personnel an opportunity to gain timely, direct experience with PRA techniques. An introductory workshop was held at Duke in July; about 50 utility representatives attended.

The Oconee study is expected to take one year. The project team will include several NSAC staff members, about 5 contractors specializing in risk assessment, and about 10 utility participants. Duke and NSAC have solicited utilities with nuclear plants to nominate one or more employees to join the project full time. Nominees should have several years of experience in nuclear power plant design, operation, or maintenance; experience with PRA methods, while desirable, is not required.

The project is planned as a mechanism by which utilities can develop their PRA capability in order to improve decision making and deal more effectively with regulatory requirements. ■

Swedish Ecologist at EPRI

Folke Andersson, project leader in the Department of Ecology and Environmental Research, Swedish University of Agricultural Sciences, spent nearly two weeks at EPRI this July gathering information on the effects of acid precipitation on forests and watersheds. At the invitation of Robert Goldstein, EPRI's manager for the atmospheric deposition subprogram, Andersson presented a lecture on the status of Sweden's Forest Research Program.

Improving Precipitator Performance

Tests are under way to demonstrate a possible solution to the problem of substandard precipitator performance at power plants that burn low-sulfur coal. Sponsored jointly by EPRI, EPA, and Southern Company Services, the test program applies to precipitators installed on the hot side (300°C) of air heaters at coal-fired power boilers.

The test involves adding sodium sulfate to the coal before burning. The sodium sulfate facilitates ash removal and allows the hot-side precipitator to perform more efficiently and with less downtime for maintenance. If the tests are successful, the use of sodium sulfate as a flue gas conditioning agent could enable some utilities to continue precipitator operation and still meet stringent emission control standards. Utilities will save money as they won't have to install new precipitators, retrofit existing ones, or pay noncompliance penalties.

Substandard precipitator performance problems first appeared when a number of electric utilities began burning low-sulfur coal to reduce sulfur emissions from stack gases. Fly ash from low-sulfur coals is difficult to collect at normal precipitator operating temperatures of 150°C. Therefore, the utilities installed electrostatic precipitators to collect ash particles at relatively high operating temperatures (300°C and above).

But as full-scale units were brought online, unexpected problems developed. In a typical case, the precipitator performs excellently for a few weeks after startup. Collection efficiency begins to decrease thereafter, however, reaching unacceptably low levels. The initial performance can be restored by washing the precipitator during a plant outage, but the degradation of performance with time begins again as operating time is accumulated.

The current test program, taking place at the Lansing Smith plant operated by Gulf Power Co. in Panama City, Florida, includes extensive performance evaluations of the precipitator immediately after washing, after the performance degradation has occurred, and after the coal supply has been treated with sodium sulfate. Southern Research Institute is serving as the test contractor.

Initial results show that the addition of sodium sulfate increased the useful power of the precipitator by a factor of four and reduced emissions by a factor of five. These improvements were achieved at a cost of about 20¢/t for the sodium sulfate. Although the initial results are very encouraging, long-term testing is required to determine if adding sodium sulfate to the coal causes any adverse effects in the boiler. The long-term effects of the conditioning agent on precipitator operation must also be evaluated and the applicability of the procedure for other ash chemistries examined. ■

CALENDAR

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

OCTOBER

6–7
Third NO_x Control Technology Seminar
Denver, Colorado
Contact: Edward Cichanowicz
(415) 855-2374

13–16
Coal Conversion Technology Conference
San Francisco, California
Contact: Seymour Alpert (415) 855-2512

22–23
Seminar: 1980 Progress in Nondestructive Evaluation
Palo Alto, California
Contact: Gary Dau (415) 855-2051

27–29
Coal and Ash Handling Systems Reliability Workshop
St. Louis, Missouri
Contact: I. Diaz-Tous (415) 855-2826

30–31
Turbine-Generator Nondestructive Evaluation Workshop
Washington, D.C.
Contact: Anthony Armor (415) 855-2961

DECEMBER

2–4
Utility Seminar on the Use of Coal in Oil Design Utility Boilers
Lake Buena Vista, Florida
Contact: Steven Drenker (415) 855-2823

JANUARY

21–22
Seminar on Prevention of Failures in Condensers
Palo Alto, California
Contact: Barry Syrett (415) 855-2956

R&D Status Report
ADVANCED POWER SYSTEMS DIVISION

Dwain Spencer, Director

SOLAR PHOTOVOLTAIC CONVERSION

Research on solar photovoltaic conversion has increased considerably in the past several years. DOE's 1980 budget for photovoltaics is approximately $140 million, and significant activity is under way in the private sector. The appeal of photovoltaic devices stems from the fact that they convert sunlight directly to electricity with very few moving parts. They have successfully provided electricity in spacecraft for over 20 years and are beginning to find ground-based remote power applications. But photovoltaic apparatus is currently too expensive to be considered for application on a wide scale; thus most R&D efforts are aimed at reducing costs while maintaining acceptable performance levels and apparatus lifetimes.

Photovoltaics research is a high-risk, high-payoff activity. Because of the wide range of materials, devices, and concepts under investigation, it seems fairly probable that major advances will occur. This notion has become sufficiently popular to ensure widespread media coverage, often with much fanfare, of developments in the field. Within this context EPRI's activities in photovoltaics are aimed at assessing, communicating, and advancing the status of the technology and clarifying the prospects for utility applications. These objectives are being pursued through hardware R&D projects and through assessments of potential utility applications and impacts.

EPRI's photovoltaic hardware research falls into two major areas: high-efficiency devices for use with high sunlight concentrations and thin-film devices with the potential for acceptable performance at low cost. The emphasis on these areas stems from a belief that ultimate success in photovoltaics will require a long-term commitment to basic research into new devices and concepts, as distinguished from the engineering development and manufacturing scale-up of devices available today (EPRI ER-589-SR). This development and scale-up is also important, however, and is the major thrust of the DOE photovoltaics program. Related work includes several novel approaches that may lead to significant advances.

TPV and other high-efficiency devices

A high-efficiency, high-concentration concept receiving major EPRI attention is thermophotovoltaic (TPV) conversion (*EPRI Journal,* April 1979, p. 19). In this approach, highly concentrated sunlight heats a high-temperature radiating body to incandescence. The resulting light spectrum, shifted toward longer wavelengths (which allows conversion at increased efficiencies), illuminates specially designed and fabricated silicon photovoltaic cells. Very long wavelength light that is not converted to electricity is reflected back to the radiator. The combination of spectral shifting and infrared light recycling theoretically promises high cell conversion efficiencies.

During 1978 a research team at Stanford University demonstrated cell conversion efficiencies of 26% (RP790) and defined a program for achieving higher efficiencies through improved electronic characteristics and reduced parasitic optical absorption. Key to this project was the design and installation of an ultraclean processing facility for TPV cell fabrication. This expanded research has been supported by EPRI over the past two years and is now beginning to yield results. Cell efficiencies have been raised to 28%, and important improvements in two major optical and electrical device parameters have been made. Each of these could correspond to an increase of several percentage points in cell efficiency. Current efforts are aimed at improving fabrication process control sufficiently so that all the recent advances can be incorporated into TPV cells (ER-1272) and at refining cell geometry to reduce parasitic absorption of light.

The prospects for TPV conversion hinge not only on cell performance but also on the performance of other key subsystems, such as the optical sunlight concentrators and the high-temperature radiator. In a recently completed feasibility assessment, Science Applications, Inc., and Itek Corp. addressed important subsystem issues in the context of complete TPV conversion systems (RP1415-1). This study identified no insurmountable technical or economic barriers to the TPV concept, but conclusive demonstration of feasibility will require detailed analysis and design efforts, as well as experimental verification of subsystem and system performance. The final report on this research is in preparation.

In a project recently initiated to study sunlight-concentrating optics, the University of Arizona and the Smithsonian Astrophysical Observatory are refurbishing a high-quality reflecting telescope, 10 m in diameter, to enable testing of solar receivers under conditions of very high sunlight concentration (RP1415-6). This work is an outgrowth of a study that assessed the suitability of the instrument, which is owned by the observatory, for solar testing (TPS79-751). The facility is expected to be useful not only for TPV component and subsystem testing but also for experiments with solar-thermal electric conversion involving high-temperature thermodynamic cycles.

Another new project is addressing the high-temperature radiator subsystem in detail. An acceptable radiator subsystem will require both a suitable refractory material and an operational approach and configuration compatible with requirements for the entire TPV system. In the first phase of this project, two contractors—Battelle, Columbus Laboratories and Atlantic Research Corp.—are conducting parallel, independent analytic investigations in these areas (RP1415-5, RP1415-4). Following this work, a second phase is planned for 1981 in which selected materials and approaches will be experimentally qualified and verified.

A recently completed study assessed the feasibility of TPV conversion from conventional heat sources, such as fossil-fired combustors (RP1348-3). Although this concept is intriguing, the contractor, Black & Veatch Consulting Engineers, concluded that it is less attractive than modern, high-efficiency combustion turbine combined-cycle power plants (ER-1262). Its disadvantages include limitations on the radiator temperature imposed by the combustion environment; reject heat temperatures too low for efficient bottoming; and a requirement for clean, expensive fuels.

In addition to TPV conversion, another promising approach for achieving high cell efficiencies with high concentration is under study with DOE and private industry support. This approach employs spectral decomposition of the sunlight. Two or more different photovoltaic cells are used, each tuned to the portion of the solar spectrum incident upon it. Several variations of this concept are currently receiving attention, and early results are encouraging. Systems based on these concepts may be able to operate with lower concentration levels than TPV systems; however, they may require a higher degree of solar flux uniformity. An improved understanding of both approaches is necessary as a basis for meaningful economic and performance comparisons.

Thin-film photovoltaic devices

Thin-film photovoltaic cells have several potential advantages over single-crystal silicon cells. These advantages include greatly enhanced optical absorption characteristics, which allow the thickness and photovoltaic material content of thin-film devices to be one-tenth or less of those required for crystalline silicon cells. Also, thin-film devices require continuity in material perfection over much smaller distances and thus have the potential for low-cost, high-speed production with forgiving processing techniques. However, a great deal more is known about single-crystal silicon than about thin-film materials because of silicon's commercial prominence in the electronics industry. Success with thin-film photovoltaic devices is therefore likely to require a commitment to fundamental research in thin-film properties and processing over the next decade or longer.

EPRI's activities in this area seek both to enhance understanding of the status and prospects of thin-film devices and to advance the state of the art. In one project, Poly Solar, Inc., has made an extensive experimental investigation of indium phosphide films for photovoltaic devices (RP1193-2). This material has performed well in single-crystal cells and is believed to be a promising candidate for thin-film cells. Poly Solar concluded that successful indium phosphide thin-film cells will require major advances (as yet unidentified) in film growth and/or processing techniques. The final report for this study is in preparation.

In another effort, Spire Corp. has carried out a preliminary investigation of a low-energy plasma deposition process for forming thin polycrystalline silicon films (RP1193-1). Although some progress was made, this work led to extremely complex problems in plasma diagnostics and control. Consequently, the project has been discontinued.

These activities, particularly the indium phosphide work, tend to corroborate a growing belief in the photovoltaics research community that major departures from today's film fabrication and processing approaches are necessary if photovoltaic thin films are to achieve array efficiency levels of 10–12%. (These levels will probably be required for economic large-scale applications because of significant area-related costs for array components other than the photovoltaic devices and for installation.) On the basis of this belief, the Poly Solar work has recently been extended to assess the feasibility of laser recrystallization of polycrystalline films as a means of improving film quality. This technique has been successfully developed for use in fabricating silicon semiconductor devices, but its applicability to polycrystalline films has not yet been investigated. Along with indium phosphide, gallium arsenide and cadmium telluride films will be studied.

Utility applications assessment

In addition to hardware research activities, EPRI efforts have been under way for several years to investigate the potential roles of photovoltaic generation in electric utility networks and the potential impact on utility operations. These analytic studies have developed value estimation and impact assessment methods that utilities can use for their own service territories, together with readily accessible system expansion planning tools.

One of these studies, performed by General Electric Co. and completed in 1978, estimated capacity and energy values for central station photovoltaic generation (ER-685). Another effort, currently nearing completion, has extended the impact assessment to transmission and distribution systems and has considered a range of generation aggregation and ownership—from residential, customer-owned installations to large, utility-owned central stations (RP1192). The contractor, JBF Scientific Corp., has concluded that the technical and economic impacts of dispersed generation on transmission and distribution systems will be small compared with its impacts on generation systems. This conclusion is in agreement with those of a companion assessment of distributed wind power systems (RP1271) and several other recent EPRI and DOE studies of distributed generation.

In the next two years DOE plans to install on utility networks several photovoltaic field test facilities, ranging in size from several kilowatts to several hundred. Beginning in 1981 EPRI will cooperate with DOE and the participating utilities in monitoring, evaluating, and reporting the operational experience of these facilities.

EPRI's future efforts in photovoltaics will continue to focus on utility integration assessment and selective device research. This plan stems from the belief that balanced attention to these areas will provide a firm basis for understanding, communicating, and advancing the status and prospects of this potentially attractive solar power technology. *Program Manager: Edgar A. DeMeo*

R&D Status Report
COAL COMBUSTION SYSTEMS DIVISION

Kurt Yeager, Director

PLANT AUXILIARIES RELIABILITY

Statistical data from the Edison Electric Institute (EEI) indicate that plant auxiliaries account for an availability loss in fossil-fueled power plants of approximately 8%, which represents a large portion of the 25.5% total plant equivalent availability loss. The goal of EPRI's plant auxiliaries performance and reliability subprogram is to develop technology options that will reduce outages caused by generic, industrywide problems involving the design, operation, and maintenance of condensers, feed pumps, fans, pulverizers, feedwater heaters, fuel- and ash-handling equipment, valves, and other auxiliaries. A continuing planning effort draws on EEI equipment data, utility industry equipment failure surveys, utility working groups, the EPRI advisory structure, and manufacturers to define an R&D program that is expected to produce significant short-term and mid-term utility benefits. This work focuses on three plant subsystems: water-steam, air-gas, and fuel-ash.

Water-steam subsystem

Condenser problems have been identified as the most common cause of auxiliary-related availability loss in large coal-fired plants (FP-422-SR), accounting for a loss of approximately 3.8%. Consequently, EPRI is sponsoring a group of projects to investigate condenser problems in fossil-fueled power plants and to develop technology for improving condenser reliability (RP1689).

One project is under way to identify and quantify generic problems with the condenser and its auxiliary systems, to evaluate the effectiveness of solutions already implemented, and to recommend further R&D efforts (RP1689-2). Another project is investigating (1) inlet-end erosion and corrosion of copper alloy condenser tubes as a result of water pollution, and (2) hydrogen embrittlement of titanium tubes in cathodically protected systems (RP1689-3). A third project, in cooperation with the EEI Prime Movers Steam and Gas Turbine Subcommittee, is developing condenser procurement and design guidelines (RP1689-5). A recently completed study investigated problems associated with the admission of high-energy fluids to steam surface condensers; it resulted in the development of design guidelines that will help mitigate condenser damage (RP1689-1). To develop analytic tools for condenser designers, future work will investigate the vibratory behavior of condenser tubes when high-velocity steam and moisture impinge on them.

Boiler feedwater pumps are responsible for an availability loss of approximately 1.7% in large coal-fired plants, the second-highest auxiliary-related loss. A survey of feed pump outages, which gathered data on the operating histories of more than 1200 large pumps, revealed generic weaknesses in design (RP641). A significant finding was that present feed pump designs frequently do not take advantage of advanced technological developments in such areas as hydraulics, rotor-bearing dynamics, and seals.

As a result of this survey, two parallel efforts to improve the state of the art in boiler feed pump design were initiated. The first involved pump rotor-bearing dynamics (RP1266-7). It focused on the improvement of currently available analytic tools to suit them for use in comprehensive analyses of the rotor dynamics of feed pumps and investigations of new bearing configurations for controlling pump vibration levels (FP-1274). In addition, an experimental rig to test advanced concepts and configurations was designed. A follow-on project to develop an advanced, highly damped rotor-bearing configuration for feed pump applications has begun (RP1884-4). This work will be aimed at developing and designing new support-bearing configurations that can be retrofitted into existing feed pump designs with minimal pump modification, and fluid annulus configurations that provide positive damping to assist the bearings in controlling pump vibration.

The second effort to improve the state of the art in boiler feed pump design addresses hydraulic instability. The initial project defined the causes of hydraulic instability in boiler feed pumps and related them to the geometries of a pump stage (RP1266-18). It also assessed the current theoretical and experimental knowledge on hydraulically induced forces and outlined a research program to improve pump hydraulic design. A follow-on effort (RP1884-5) will be initiated soon to implement the recommendations presented in the final report (CS-1445).

Another effort stemming from the initial survey of pump operating experience was undertaken in conjunction with the EEI Prime Movers Steam and Gas Turbine Subcommittee (RP1266-18); its goal was to develop guidelines for the specification of large feed pumps. This work is now complete, and the guidelines have been accepted by the EEI Prime Movers Committee. In addition to the information gathered in the survey, the guidelines are based on the specifications of various architect-engineering firms and utility engineering departments. Their use should result in significant improvements in pump and unit availability throughout the industry (CS-1512).

Feedwater heaters are another part of the water-steam subsystem being investigated. They account for a plant availability loss estimated at 0.3%. With the cooperation of the EEI Prime Movers Committee, data were gathered on the operating histories of more than 900 heaters (RP1265-7). Analysis of this information revealed generic weaknesses in heater design and fabrication.

Air-gas subsystem

Fans are the component of the air-gas subsystem responsible for the largest plant availability loss (approximately 0.7%). Thus EPRI has initiated several research projects to investigate generic fan problems in the electric utility industry. Under RP1265-6 fan failures were surveyed to determine the major causes of outages and poor performance.

The vibratory behavior of rotating auxiliaries was examined under RP984, with emphasis on fans. This project has resulted in the development of a state-of-the-art computer program to aid designers in performing dynamic response analyses of a total vibratory system, including supporting soil, foundation, pedestals, oil films, fan wheel, and rotor (FP-864). The program's predictions were validated in seven field tests of power plant fan-foundation-soil systems. Two significant findings of a follow-on effort on fan-foundation system dynamics were that the stiffest rotor may not provide the best system dynamic response results and that a large foundation may be more sensitive and vibration-prone than a small one (CS-1440). The fan-foundation-soil design guidelines are currently being developed in connection with the design review and initial startup of several fan systems (RP1649-3); there are six utilities participating in this effort.

Another project has addressed the nature, severity, and cost of fan erosion (RP1649-4). It determined the tolerance of fans to various fly ash concentrations and size distributions, the erosivity of a large sample of fly ash, and the cost-effectiveness of developing field-replaceable armoring systems for airfoil-bladed centrifugal fans. It also outlined requirements for follow-on work to achieve optimal protection in power plant fans subjected to fly ash erosion.

Several other projects are under way in the RP1649 fan reliability series. One is attempting to validate a proposed ASME code for field-testing large power plant fans developed by the ASME PTC-11 Committee (RP1649-5). Although a final assessment cannot be made at this time, it appears that when the fan-specific energy test method and the effects of compressibility under the mass flow rate are taken into account, slightly higher fan efficiencies are obtained. Another project is seeking to identify the root causes of fan failures (RP1649-6). It will recommend short-term remedial actions and will define longer-term research activities to improve fan reliability. RP1649-7 is examining the problem of fannoise, particularly the tone of the blade-passing frequency. Its goal is to develop a simple structural modification (the application of an acoustic resonator to the cutoff point of the centrifugal fan casing) to control this tone without degrading overall fan efficiency.

Another significant cause of plant availability loss is the large-amplitude, low-frequency pressure pulsations that occur in the air-gas subsystem because of its aerodynamic characteristics. Severe or catastrophic damage to fossil-fueled power plant equipment (including failures of induced-draft and flue gas recirculation fans, boiler casing leaks, excessive fan vibration, and duct failures) has resulted from these uncontrolled pulsations.

In the first phase of RP1651, a mathematical, computer-based model for determining the response characteristics of power plant air-gas systems has been developed and field-tested (CS-1444). The model can be used to study global stability in systems with multiple fans in parallel or in series and to analyze the transmission of disturbances throughout the system. It is expected that its application to the design and operation of boiler air-gas systems will minimize pressure transients that can severely damage boilers, fans, and ducts and will thus significantly improve unit reliability and performance.

The objectives of current work in system dynamics are to define and evaluate solutions to problems in existing plants and to provide a basis for selecting system components during the design stage that will minimize problems in new plants. Additional efforts to be undertaken in 1981 will include a study of air-gas system implosions.

A survey of air preheater failures is under way to determine R&D objectives and priorities for this large auxiliary (RP1265-8). Air preheaters are estimated to account for a plant availability loss of 0.3%.

Fuel-ash subsystem

Coal pulverizers are responsible for an availability loss of approximately 0.9% in large coal-fired plants, the third-highest auxiliary-related loss. An EPRI reliability study gathered data on the operating histories of nearly 500 coal mills representing the major types currently in service (FP-1226); most had a coal capacity greater than 40 t/h. Five problem areas were identified and evaluated: grinding zones, with such equipment as rolls, rings, and balls; air systems, including primary fans and classifiers; mill fires and explosions; drive components, such as shafts, gears, and bearings; and boiler problems associated with poor pulverizer performance (e.g., furnace slagging and coal pipe plugging). The root causes of problems in these areas were determined and documented.

Follow-on work is under way to develop guidelines for the specification of coal pulverizers; this is a joint effort with the EEI Prime Movers Boiler Subcommittee. Plans for future pulverizer research include an investigation of coal dust fires and explosions, a study of the effects of coal characteristics on pulverizer performance, and development of grinding elements that have reduced wear rates. These projects are scheduled for 1982.

Another area of concern is the reliability and performance of coal- and ash-handling systems. The severe winters experienced recently in much of the country have created great problems in handling coal and moving it from mine to boiler. Under RP1265-9 these problems were studied, and the state-of-the-art techniques for handling frozen coal and mitigating the effects of freezing weather were evaluated. In addition, a workshop on coal freezing was held this past winter in Cincinnati, where the subject was discussed in detail by more than 170 participants (WS-80-110). Another conference and workshop is scheduled for October 27–29 in St. Louis to consider the reliability problems of coal- and ash-handling systems (WS-79-236).

Future research

In addition to the three major areas discussed, the plant auxiliaries subprogram includes research in the areas of monitoring and diagnostics, nondestructive examination, equipment performance, valve reliability, and auxiliaries redundancy.

The goal of this subprogram—improving performance and reliability of plant auxiliaries, especially for coal-fired baseload plants—is in keeping with the national goals of efficient energy use and reduced dependence on oil and gas. The R&D investment in this effort is relatively small and the possibilities of success are high, with potentially significant benefits for the electric utility industry. *Project Manager: Isidro A. Diaz-Tous*

RESOX SULFUR RECOVERY PROCESS

Resox is a unique sulfur recovery process that uses coal rather than natural gas to reduce the SO_2 in power plant stack gases to elemental sulfur. On the basis of an assessment of various technologies (RP784-1), EPRI identified Resox as a promising pro-

cess for use in regenerative flue gas desulfurization (FGD) systems and in 1977 began to participate in its development. (Resox is a trademark of Foster Wheeler Energy Corp., which holds the basic patents on the process.) EPRI's Resox program has included economic and technical evaluations by several architect-engineers (RP982-17, RP1180-3), 1-MW pilot plant testing (RP1257-1), and cosponsorship of prototype testing of a 42-MW Resox unit in Lünen, West Germany (RP784-2).

Table 1
RESOX TEST RESULTS FOR VARIOUS COALS AND FRONT-END PROCESSES

	H_2O/SO_2 Mol Ratio	SO_2 in Feed (mol%)	Inlet SO_2 Conversion (%)	Elemental Sulfur Yield (%)
Bergbau-Forschung process				
Sophia Jacoba coal	2.2	20.7	90.0	79.5
Black Mesa coal	2.2	12.0	92.1	85.2
Seneca coal	2.2	15.3	86.4	71.8
Wellman-Lord process				
Sophia Jacoba coal	2.5	24.4	91.3	80.0
Black Mesa coal	5.0	14.0	88.7	82.7
Seneca coal	6.0	11.8	84.5	75.0
Chemico-Basic process				
Sophia Jacoba coal	5.0	8.3	91.6	79.7
Black Mesa coal	5.0	8.3	88.3	69.4
Seneca coal	4.0	9.0	82.6	68.1

Prototype testing

Foster Wheeler originally developed the Resox process in conjunction with the activated-char adsorption FGD technology of Bergbau-Forschung GmbH. In this front-end desulfurization process, dilute (200–4000 ppm) SO_2 is absorbed from flue gas, and a concentrated stream composed primarily of SO_2, N_2, and water vapor is regenerated. The Resox process is employed to reduce the SO_2 in this stream. The stream is passed through a moving bed of hot (1300–1500°F; 700–820°C) crushed coal to yield gaseous elemental sulfur, which is then condensed to a high-purity liquid product.

A major part of EPRI's program has involved testing of the 42-MW prototype Resox facility at a utility plant in Lünen, West Germany. This work was cosponsored by Foster Wheeler, Bergbau-Forschung, Deutsche Babcock Ag, and Steag Ag; Umweltbundesamt, the environmental agency of West Germany, also participated. The Lünen site was chosen for the test program because Bergbau-Forschung's SO_2 removal system was developed there and was available to supply a concentrated SO_2 stream. Engineering studies for the facility began in May 1977 under RP784-2, and construction began the following December. The first sulfur was produced in July 1978, and testing was completed in June 1979.

The prototype Resox system was operated with a highly concentrated SO_2 stream for approximately 1000 hours—250 hours in combination with the Bergbau-Forschung system and 750 hours with synthesized gas from a model gas system. Much of the background information used to determine the operating conditions for the test program was developed at Foster Wheeler's 1-MW Resox pilot plant in Livingston, New Jersey, and potential process improvements identified in the Lünen program were tested there also.

Operation of the 42-MW facility showed that the Resox process is capable of using coal, rather than natural gas, as a reductant to yield a sulfur product with a purity of greater than 99%. Only about 70% of the incoming SO_2 was reduced to elemental sulfur, in contrast to the 80% that had been expected on the basis of the laboratory tests. Because the amount of data from these tests was very small, however, no significant conclusions can be drawn.

Testing different coals and SO_2 inlet gases

In the research efforts that led to the development of the Resox process, Foster Wheeler used anthracite coals as the reductant and an SO_2-rich gas that simulated the composition of the gas stream produced by the Bergbau-Forschung process. Anthracite coals were used because their physical and chemical properties allow for easier control of the reactor processes. To expand the applicability of the Resox process for utility use, EPRI also sponsored a series of tests at the 1-MW New Jersey pilot facility with different coals as the reductant and different SO_2-rich gases (RP1257-1, RP784-2).

Tested were three coals (Sophia Jacoba anthracite, Black Mesa bituminous, and Seneca subbituminous) and gases from three front-end FGD processes (the Bergbau-Forschung activated-char process, the Wellman-Lord sodium sulfite process, and the Chemico-Basic magnesia process). Table 1 presents results from the coal and gas combinations. These results were compared with those from a benchmark test that used anthracite coal and the simulated Bergbau-Forschung gas.

Care must be taken to maintain a proper balance between the reactivity of the coal and the SO_2 concentration in the inlet gas, or side reactions may occur that result in poor SO_2 conversion and/or low yields of elemental sulfur. Preliminary testing at the pilot facility indicates that a process modification will help maintain the proper reactivity balance. This development may improve the yields shown in Table 1 and will be used in follow-on work.

R&D plans

As a result of the work described above, several other equipment and process changes have been identified and will be tested at the 1-MW pilot facility in order to identify optimal operating conditions for U.S. coals. Work will concentrate on coals that may be used in a 100-MW demonstration to couple Resox with the Wellman-Lord front-end process. Discussions are under way to identify a host site for this demonstration. *Project Manager: Thomas Morasky*

R&D Status Report
ELECTRICAL SYSTEMS DIVISION

John J. Dougherty, Director

DISTRIBUTION

Converter harmonic and noise characteristics

Harmonics and electrical noise generated by ac/dc converters may interfere with the operation of electrical equipment on distribution systems. A variety of utility system components may be affected by such interference: high-power equipment (e.g., transformers, motors, capacitor banks, and circuit breakers) and low-power equipment (e.g., control and communications equipment). The high-frequency impulse noise that is always generated to some degree by power converters is a factor to consider in the performance of both voice and digital distribution communication systems. Electronic devices such as substation control and data acquisition (SCADA) systems, computers, relays, and meters may also be affected.

It is likely in the foreseeable future that energy storage devices and their associated ac/dc conversion equipment will be sited on utility distribution systems to augment central station power supplies. As a result, utilities are understandably concerned about the harmonics, noise, and current surges that may be generated by such devices. The objective of a project recently completed by McGraw-Edison Co. was to measure and analyze power harmonics and electrical noise generated by ac/dc converters on power distribution systems (RP1024). The research conducted in this project provides instrumentation and initial data to assist both utilities and manufacturers in evaluating the effects of converter noise and harmonics. This project's two major accomplishments centered on field measurement and system modeling.

Harmonics and noise were monitored and recorded at two distribution sites: at feeders connecting the Connecticut Light and Power Co. distribution system to the United Technologies Corp. plant in which converters were being manufactured and tested; and at feeders connecting a Potomac Electric Power converter substation to the Washington DC Metro Railroad system. The project's final report presents data showing a wide variety of noise and harmonics and describes two instrumentation systems.

A computer program was developed to model the distribution feeder and converter system so that the harmonic noise characteristics could be investigated. This model successfully simulated system resonance effects, harmonic amplitudes, and harmonic attenuation rates along the feeders; however, some observed characteristics could not be properly simulated, probably because the model parameters were not specified with sufficient detail and accuracy.

The research results suggest several important tasks in the areas of training, measurement, analysis, modeling, and planning that utilities should pursue if they intend to site power converters on their systems. First, utility personnel should be trained to understand the effects of harmonics generated by equipment on the distribution system. They should be able to identify critical locations on the system at which interference, such as harmonics, high-frequency noise, and surges, would be a problem.

In the area of measurement, utilities should develop guidelines and standards similar to those now used in Europe for measuring and limiting harmonics on power systems. It is in a utility's own best interest to assemble accurate instrumentation systems and develop expertise in measurement practice. The test methodology used for the RP1024 field tests can serve as a valuable initial guideline to utilities.

A digital computer program such as the one developed in this project for determining the frequency and amplitude of network resonances is useful for distribution network modeling. The program is a computational tool that requires engineering interpretation and even sensitivity analysis in certain situations; hence, appropriate engineering expertise would be required for each utility.

Utility engineers should become familiar with modeling techniques for utility systems in order to determine the characteristics of equipment that generates interference, such as electrical noise and harmonics. For example, techniques such as filtering are effective in reducing harmonics but have been shown to cause network resonance problems; hence utility engineers should also understand the limitations of many techniques for effective harmonic control and surge suppression.

Finally, system planning should be expanded to facilitate the integration of ac/dc power conditioners required by fuel cells, batteries, and solar energy devices. The planning process should also cover the impact of harmonics and noise on the system.

The research indicates that converter manufacturers should assume some responsibility for developing equipment that provides reasonable controls for system harmonic and electrical noise levels. It is important that manufacturers work to minimize the generation of harmonics and noise in designing new line-commutated and self-commutated converters. If the interference becomes a problem with existing converters, it will be necessary to provide filters or other equipment to control and minimize such interference. Manufacturers should work closely with utilities in planning and designing this equipment. *Project Manager: William E. Blair*

Thermal overload characteristics of solid-dielectric cables

The thermal limits of electrical conductors, especially in insulated underground cable, have a significant effect on system design cost. Cables must be capable of being operated at as high a temperature as is technically feasible without sacrificing reliability.

Present industry standards for solid-dielectric distribution cables specify normal operating temperatures for cross-linked polyethylene (XLPE) and ethylene-propylene rubber (EPR) cables to be 90°C, with 130°C as the emergency temperature limit. A project recently completed at the Institut de Recherche de l'Hydro-Québec on slab specimens of these insulating materials has quantified various physical, chemical, dielectric, and thermal property changes over a temperature range of 25°–170°C (RP933). These results show that changes at elevated temperatures, particularly physical property deterioration, are significant and that further investigation is required on full-size cables.

Cable Technology Laboratories, Inc. (assisted by the University of Connecticut and Triangle PWC, Inc.) has started a three-year project to investigate the thermal overload characteristics of full-size solid-dielectric-insulated cables (RP1516). The research goal is development of an accurate and reliable set of thermal overload conditions that installed cables can tolerate. A program for testing emergency thermal overload conditions and the criteria for determining the parameters of operability of cables will also be pursued. Various 15-kV and 35-kV cables will be subjected to field-simulated aging conditions, including cables with both aluminum and copper conductors and XLPE and EPR insulations. System voltages and temperatures of 125°–175°C will be applied to the test cables through a laboratory-controlled cycling sequence. Mechanical, dielectric, and chemical tests will be performed on the cables periodically to monitor the effects of the thermal aging. Identical test cables will be subjected to similar aging conditions and tests in conjunction with a field-representative duct bank system.

Following a comparison and correlation of all test results, it should be possible to establish what operating temperatures can be tolerated by extruded dielectric cables, as well as the criteria for determining such temperatures. *Project Manager: Robert J. Stanger*

OVERHEAD TRANSMISSION

Transmission line grounding

There are several comprehensive sources of information on substation grounding design—the *IEEE Guide for Safety in Substation Grounding* (IEEE 80) being the most widely used. However, no similar publication on transmission line grounding is available. Information on the design of grounds for overhead lines can be found only through a literature search, which can often be a tedious, time-consuming task for the transmission engineer.

To satisfy the need for a single source of up-to-date, comprehensive design information, EPRI is starting a two-year project with Safe Engineering Services Ltd. to produce a design manual for transmission line grounding (RP1494). The main goals of this project are to determine transmission line grounding requirements that will minimize failure caused by insulation backflashovers and to develop methods for determining currents and voltages present during line-to-ground faults. For complex grounding analysis, an easy-to-use-and-maintain computer program will be developed that will produce answers sufficiently accurate for design purposes.

The objective of this project is to develop suitable analytical methods for accurately predicting the influence of all significant performance factors that a transmission line is subject to during ground faults and to publish a design manual that will provide answers to grounding problems the transmission line engineer is likely to encounter. *Project Manager: John Dunlap*

UNDERGROUND TRANSMISSION

Magnetic refrigerator development

Force-cooled transmission lines, both conventional and cryogenic, are presently limited by the high costs and low efficiency of the present gas expansion-compression refrigerators. The low efficiency (10–30% of Carnot) of these refrigerators makes the operating costs prohibitively high for many applications of force-cooled oil or cryogenic transmission circuits.

Thus when the Los Alamos Scientific Laboratory proposed to develop a magnetic refrigerator with high efficiency at both low and high temperatures, the proposal was given high ratings by EPRI, ERDA (now DOE), and utilities. A research project was initiated to produce a prototype magnetic refrigerator with 1000 W of refrigeration from +20°C to −20°C, at 70% of Carnot efficiency (RP7867). In addition to the refrigerator's immediate value for use with conventional force-cooled lines, its successful development would have indicated that such a technique might be possible for the much lower temperatures needed for cryoresistive and superconducting cables.

As part of this 18-month project, two magnetic refrigerators, one rotational and the other reciprocating, were built and tested. Although it was quite an achievement to make such operational devices, the tests showed that the prototypes' power output and efficiency fell far short both of the design goals and of what would be needed for a practical refrigerator. Therefore EPRI has not funded further development in this area. *Project Manager: Mario Rabinowitz*

Fault location

Most of the underground transmission rated 69 kV and higher in this country is carried by high-pressure, oil-filled (HPOF) cables. Although these cables have established an enviable record of reliability, they are still subject to occasional failures. Delays in repairs of faulted transmission cables can impose severe economic penalties on utilities; hence rapid location of faults is of paramount importance. Since presently available techniques for fault location are frequently time-consuming, a project with Hughes Research Laboratories was instituted to develop a system for rapid, accurate, and unambiguous fault location (RP7874).

The equipment under development is particularly suited to locating high-resistance faults. In operation the faulted phase is connected to an unfaulted phase at the far end of the transmission system. At the near end, special high-voltage dividers are connected to each of the two phases. The divider connected to the faulted phase provides a start signal to a fast timer, and the divider on the unfaulted phase provides a stop signal. In addition, an adjustable spark gap is connected to the faulted phase.

In operation, the spark gap is adjusted to fire at a voltage level below the breakdown voltage of the high-resistance cable fault. The cable loop is then charged up to a high dc voltage, which is gradually raised until the spark gap fires. The start voltage divider immediately senses the collapse of the voltage and starts the timer. When the collapsing cable voltage wavefront traveling around the two-cable loop reaches the stop divider, the timer is stopped. The time interval thus measured is the time-equivalent of twice the system length. In the next step the spark gap is opened wide to prevent its firing, the cables are reenergized, and the dc voltage is raised until the high-resistance fault flashes over. The collapsing voltage at the fault generates two wavefronts, which travel to the start and stop dividers. The time interval thus measured is equivalent to twice the difference between the system length and the distance to the fault. From these two time measurements the distance to the fault relative to system length can be determined.

The most important feature of this scheme is that it makes use of only the forward-traveling wave. Because of this, the system is relatively immune to errors from reflections that occur at impedance changes or discontinuities at joints, terminals, and cable taps. Final laboratory tests on the first prototype unit are in progress, and the unit will shortly undergo field trials. *Project Manager: Felipe G. Garcia*

TRANSMISSION SUBSTATIONS

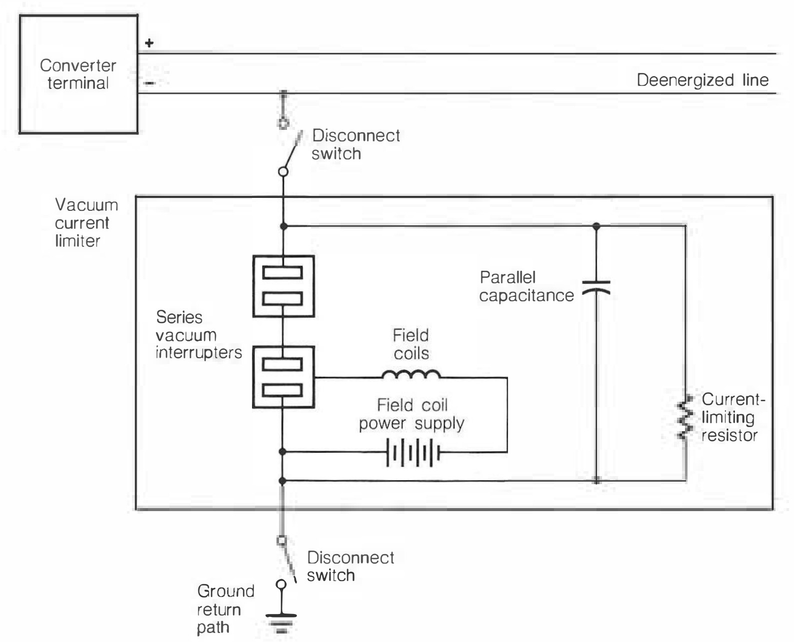
Vacuum fault current limiter

The main purpose of an ongoing project with Westinghouse (RP564) has been to develop a fault current limiter for use in ac transmission systems (*EPRI Journal,* November 1979, p. 56). In this concept a transverse oscillatory magnetic field is used to cause the arc in a vacuum device to become unstable. The high arc voltage that results from this instability then causes the fault current to be commutated into a capacitor connected in parallel and then into a parallel current-limiting resistor. A conventional vacuum interrupter is connected in series with the current-limiting device to aid in withstanding the resulting recovery voltage.

Although the Westinghouse research was going well, with experimental devices demonstrating the ability to limit fault currents on the order of 15 kA with recovery voltages that are representative of a 72-kV system, a good part of the work on the ac current limiter has been temporarily diverted in order to use this technology in an application for which there is a more pressing need: the development of a metallic-return transfer breaker (MRTB) for HVDC transmission systems.

When used as an MRTB, the function of the device will be to act as a dc circuit breaker. It will be used to transfer dc load currents flowing through the ground return path to the previously deenergized line during monopolar operation of the dc line (Figure 1). Since the deenergized line has a higher impedance than the ground return path, appreciable recovery voltages are imposed on the MRTB. In the specific application for which the MRTB is being developed, the switched currents will be up to 2.5 kA and the peak transient recovery voltage on the order of 70 kV. Laboratory tests have demonstrated that the system will work in this application with an appreciably smaller value of parallel capacitance than is required for the higher-current ac current limiter application.

Figure 1 Use of a vacuum arc current limiter as a metallic return transfer breaker on an HVDC transmission system. The current limiter transfers dc current from the ground return path to the previously deenergized (and lower-impedance) line, after which the disconnect switches are opened.



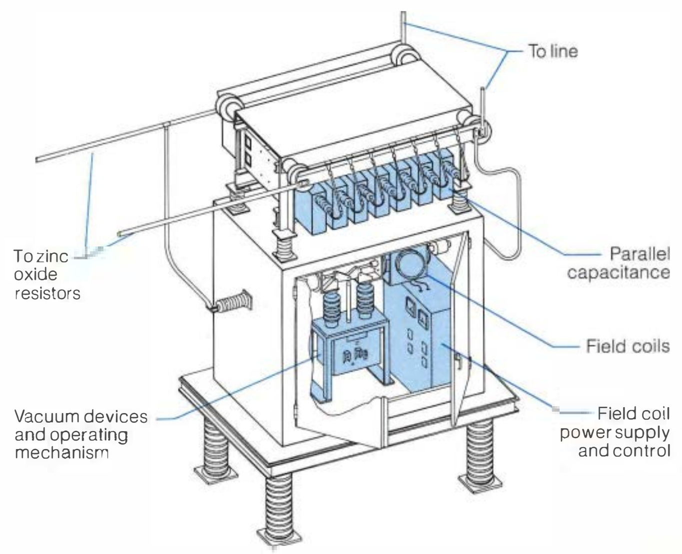


Figure 2 Conceptual layout of the major components of metallic return transfer breakers.

Work is in progress to supply an MRTB based on this principle for installation on the Pacific Intertie (Figure 2). It is expected that the device will be completed in the third quarter of 1980, with field trials at the Celilo terminal scheduled shortly thereafter.

While work on the MRTB has temporarily diverted much of the effort of the Westinghouse research team that developed this concept, development of the ac current limiter is continuing in two areas. The Westinghouse team is proceeding with the design of a limited number of ac current limiter prototypes, and a supporting research project at the State University of New York at Buffalo (RP993) is fully committed to research on this ac current limiter concept. The group at SUNYAB is working closely with the Westinghouse researchers in an experimental and analytical program to predict the performance of the vacuum current limiter and suggest areas of possible improvement.

When work on the MRTB is completed, full-scale work on the ac current limiter will be resumed by the Westinghouse research group. Promising new interrupter configurations, which are expected to bring further improvements in performance, will be evaluated in a study expected to be completed by the end of 1980. A conceptual design for a current limiter suitable for a 145-kV ac system will then be developed and will be tested to determine the application parameters and economic feasibility of this concept for use on utility systems. *Project Manager: Joseph Porter*

POWER SYSTEM PLANNING AND OPERATIONS

Advanced concept studies

In 1978 the Power System Planning and Operations Program solicited proposals from universities for innovative research topics. The intent of this research was to provide electric utilities with a mechanism for technology transfer from such disciplines as mathematical modeling, mathematical optimization, control systems, large-scale systems, and network theory. From the university responses, four studies were selected for funding under RP1355. These projects, described in an earlier issue of the *Journal* (May 1979, p. 55), will be completed in 1980.

During 1979 a second broad solicitation from the universities was made (RP1764). The three studies selected from this second set of responses are briefly described below. As with the 1978 projects, the funding for each of these studies will be less than $50,000.

One of the complicated and time-consuming calculations that has been added to some modern electric utility dispatch control centers is called state estimation. State estimation is a monitoring technique for interpreting readings from a power system to derive (estimate) either data that are not normally monitored or replacement data for malfunctioning measuring devices. State estimation can provide insight into which measuring devices are malfunctioning and which are beginning to provide inaccurate data.

In some cases it has not been possible to incorporate the state estimation calculation into the dispatch control center computer because of the extra computational resources it required. In a project scheduled to be completed in April 1981, Washington University will try to develop analytic techniques to break the state estimation calculation into smaller computation blocks (RP1764-1). These blocks can then be moved to other digital computer facilities. Candidate computers exist at power pool control centers, power company dispatch centers, and remote data-gathering terminal units having computation capability. These remote terminals, sometimes referred to as smart remotes, are becoming more numerous because the price of computing equipment has decreased so dramatically.

In the second study, at the University of Pittsburgh, researchers are investigating the effects of computer word length and floating-point representation on the power flow computation (RP1764-2). The results of this investigation, expected in March 1982, will be reported to the industry and will provide information and guidance for future EPRI computer-related projects.

In the third project, researchers at Carnegie-Mellon University are analyzing several power system planning programs to determine a set of small numerical algorithms that are common to several programs (RP1764-3). Once this set of algorithms has been identified, the contractor will investigate and report on procedures (performance models) for the evaluation of algorithm performance using a predefined computer architecture. One or more power system planning programs will be analyzed with the performance models. The objective of this project is to determine if an efficient, special-purpose computer architecture could be developed to perform several types of power system computations. If successful, it could be the first step toward implementing the program-on-a-chip concept. This project is scheduled for completion in June 1982. *Program Managers: Charles Frank and John Lamont*

CORRECTION

In the July/August *EPRI Journal* (p. 36), General Electric Co. was listed as a contractor for RP1497, a project that will investigate the feasibility of developing a remote-controlled device to perform overhead line maintenance work. The contract with General Electric has not yet been signed, although negotiations are continuing. Work on RP1497 is still expected to begin in 1981.

R&D Status Report
ENERGY ANALYSIS AND ENVIRONMENT DIVISION

René Malès. Director

UTILITY MODELING FORUM

EPRI serves as the synthesizer of frequently diverse utility interests in the formulation of R&D strategies. While it deals primarily with technological development leading to the commercialization of hardware, it is also concerned with the development of software, such as models that describe the utility industry's environment and advance the understanding of utility issues. Marked changes in the industry's environment have spurred various efforts to develop new, more sophisticated quantitative tools. One of the principal objectives of the Utility Modeling Forum (UMF), which is sponsored by EPRI under RP1303 (with Booz, Allen & Hamilton, Inc., as the contractor), is to help the industry refine and apply the analytic capability that has resulted from these efforts. The forum reflects EPRI's continuing interest in promoting a dynamic exchange of ideas with and among its members.

Organization of UMF

UMF brings together utility representatives from all levels of management to study current issues in a forum-type process. It seeks to encourage the use of and to improve existing utility models by (1) applying them to the analysis of a broad range of utility issues identified by the industry itself, (2) stimulating the transfer of modeling expertise across the industry and to EPRI, and (3) promoting effective interaction between model developers and users.

UMF was launched at a workshop held in February 1979. Over 80 utility industry managers and senior professionals from investor-owned, public, and rural systems attended, representing a wide variety of modeling areas and user interests. Round tables on peak load forecasting, energy forecasting, regional economics, corporate planning, fuel supply, rates, and model-user interfaces identified about 50 issues that the forum could address.

Working groups of 25–45 utility model developers and users chaired by senior utility personnel make up the core of UMF. Each working group is organized around a broad industry issue, to which it applies various utility models. The resulting analyses are used not only to develop insights into the topic, but also to compare the basic structures of the models. A panel of senior utility executives, including representatives of EPRI advisory groups, suggests topics for study and reviews the completed working group reports.

Working group on load forecasting

The first UMF working group, composed of 43 utility members under the chairmanship of James Cook of Consumers Power Co., addressed the issue of load forecasting. It held its first meeting in May 1979 and completed its final report the following December. The group broke into subgroups to examine four key issues related to the forecasting of electric load growth:

- Identification and quantification of the sources of uncertainty in energy and peak load projections, and comparison of the analytic methods used to measure uncertainty
- Analysis of key factors that influence load shape, with emphasis on the potential impact of time-of-day (TOD) rates
- Assessment of the impact of new end-use technologies—specifically, solar heating systems, more efficient air conditioners, and electric vehicles—on electricity consumption patterns
- Development of improved analytic methods through the integration of econometric and end-use forecasting models

Each subgroup prepared detailed study plans, performed analyses with the load-forecasting models currently being used by the members' utilities, and developed conclusions and recommendations after evaluating and comparing the results. In all, over 100 cases were run. The major conclusions from this work are discussed below.

Uncertainty Subgroup The quantification of uncertainty is an important part of the forecast description; it provides management with a means of identifying the magnitude and impact of the uncertainty with which it must cope. There is a sharp distinction between sensitivity analysis and uncertainty analysis. The former measures a model's response to change but, unlike the latter, does not provide a quantitative description of the likelihood of such change. Sensitivity analysis is, therefore, of less value to the decision maker.

The subgroup identified four sources of uncertainty, each with a potentially significant impact on forecasting results: unforeseen sociopolitical events, shifts in government and regulatory policy, projections of model variables, and model structure. It also examined various methods of dealing with uncertainty—scenarios, probability trees, and Monte Carlo techniques—and concluded that with proper treatment of the analytics, these methods will yield equivalent results. Three analytic considerations are critical to the development of an appropriate description of the impact of uncertainty: number of trials, interdependence of variables, and types of probability distributions.

A common technique used in constructing scenarios is to simply select the extreme lowest, extreme highest, and most likely values for all variables in the model. This procedure can result in an unrealistic description of the expected range of forecast results, overstating the measure of uncertainty by one to two standard deviations relative to the 10–90% confidence interval.

If little information is required about forecast uncertainty, a few scenarios will be sufficient. When a more precise definition of uncertainty is needed, the use of probability trees or Monte Carlo techniques is more appropriate. Criteria for selecting between these two methods are the number of variables to be examined and their interdependence. Monte Carlo techniques may offer particular advantages when many interdependent variables are involved. Software design and availability are equally likely to govern selection of an appropriate approach, however.

Load Shape Analysis Subgroup This subgroup identified two fundamental types of load shape models: top-down models, which use reference load shapes and adjust them for perturbations (e.g., the impact of TOD rates), and bottom-up models, which build load profiles directly from end-use consumption patterns. These types appear to offer equally satisfactory and consistent results.

The group noted that further development in load shape modeling is constrained by an inadequate data base. Load research programs under way throughout the industry are only beginning to produce results. There is a substantial opportunity for collaboration among utilities in the analysis of consumer behavior patterns, despite the fact that much of the information sought is region-specific.

An examination of TOD rates indicated that their effects are not always obvious. Even though the analyses performed were fairly limited in scope, they revealed that under certain circumstances higher (rather than lower) peak loads can result. The direction of total energy consumption can be similarly unpredictable, and small changes in rating periods and prices can produce significantly different results (i.e., revenues can become highly unstable).

The group noted that the imposition of TOD rate structures by regulatory commissions is likely to be based on a number of criteria (e.g., efficiency, equity, and conservation) but will not necessarily require, or result in, a constant level of total daily energy consumption. The treatment of total energy consumption is, therefore, critical to the analysis of revenue impacts from TOD rates. Algorithms that constrain total daily energy use at a fixed level and do not allow for price-induced changes in overall energy consumption cannot explicitly capture key effects of TOD rate structures on revenue stability and load shape.

Although there is a general expectation in the utility industry and elsewhere that TOD rates can work to the long-term benefit of utilities and their customers, analytic methods and supporting data bases are not yet sufficient for the establishment of definitive cost-benefit relationships. The group concluded that the optimization of efficiency, equity, conservation, revenue stability, public acceptance, and other relevant criteria requires an analytic capability—and an understanding of behavioral factors—well beyond the current industry and regulatory state of the art.

New Technologies Subgroup Models that assess the impact of a new technology on load forecasts must necessarily be end use–oriented. However, such models tend to have unique features that are unlikely to fit into the framework of most existing forecasting models. While it is possible to develop generic approaches for constructing new-technology forecasting models, detailed requirements will be influenced by the specific characteristics of each technology and by the technology's potential impact on energy use.

The characteristics of new technologies that must be examined in the modeling process fall into three major categories: technical, commercial (i.e., market penetration), and functional (i.e., utilization patterns). The subgroup found that the utility industry's modeling capability varies considerably among these key elements. Forecasting technical characteristics is a major problem that is typically left to experts, often those outside the utility industry. Studies of market penetration (i.e., internal saturation surveys) have received substantial attention, and a great deal of load research and model development activity is now being conducted in the industry. In contrast, modeling of the utilization of new technologies, in particular the interplay between technical and behavioral factors, is a largely untouched area.

Model Integration Subgroup Econometric models allow important economic and demographic factors to be incorporated relatively easily into the forecasting process. They are limited, however, in their ability to respond to structural changes that occur over time. End-use models are typically more elaborate and costly to develop and maintain, and are less capable of incorporating economic and demographic factors. However, their ability to explicitly analyze the effects of conservation and other changes in consumption patterns has led to their increasing use by the utility industry.

There have been limited attempts to integrate econometric and end-use methods to obtain working models that have the major benefits of each approach. Partial integration has been achieved by incorporating end-use methods (to varying degrees) into existing econometric models and vice versa. In comparing econometric and end-use models with integrated models, the subgroup noted that the former have fewer variables and are less complex in structure, while the latter can effectively address a broader range of questions. It concluded that more work is needed to determine the ultimate value of fully integrated models and the best way to develop them.

Implications for decision making and load-forecasting research

Although the four load-forecasting issues were addressed independently, the conclusions and recommendations of the subgroups contain common implications for utility decision makers. First, it is important that those who use load forecasts become familiar with the basic characteristics and limitations of the underlying analytics. They should understand the determinants of future load growth that are most significant in the model; the effects the model explicitly includes and those it does not; the new trends in energy consumption patterns incorporated into the model; and the degree of confidence that can be placed on the forecast results.

There are a number of reasons why senior utility executives should be aware of these factors. For example, in the development of financial plans for major capital programs, it is important to identify:

- The financial risk, which is largely dependent on the load forecast's quantification of uncertainty
- Events that could markedly change the financial climate for utilities, which may or may not be explicitly considered in the load forecast
- Potential sources of inconsistency, such as the revenue requirements of the capital program versus the cost of electricity used in the load forecast, or the anticipated costs of capital to the utility versus the inflation rate and other economic factors used to model consumer behavior

While it may be comforting to decision makers when a load forecast appears to be "right"—i.e., in agreement with their subjective judgments—the risks of not delving more deeply into the methods involved can be great. In most instances, it is only the senior executive who has the appropriate perspective from which to ask these probing questions.

In addition to developing an understanding of the basic features of the forecasting model, utility executives should be involved in decisions that affect the sophistication of the methodology. The working group's analyses suggest that substantial trade-offs are possible between the resources applied in model development (money, manpower, expertise, time) and the analytic capability achieved. It is important that these trade-offs be made by decision makers with full knowledge of the forecasting implications. For example, the working group found that various methods of analyzing uncertainty have been successfully developed and are generally available for application to load forecasting. Decisions to include a description of uncertainty in the forecast and to develop a corresponding analytic capability are decisions that should be made by the executive, not exclusively by the modelers.

The working group's findings in other areas likewise point to a need for informed executive involvement in matters of model sophistication. The group concluded that the ability to model the effects of new technologies and TOD rates is currently limited by lack of data. Decision makers must be aware of the time and money needed to develop an improved data base and, therefore, of the constraints on rapid advancement of the state of the art. The group also concluded that while the development of a forecasting model incorporating the best features of econometric and end-use models is a generally desirable goal, it is not necessarily optimal for all utilities. Thus senior executives must have a sufficient understanding of the capabilities and limitations of model types to make informed judgments about the need for model integration and the appropriate level of resources to be committed to it.

Regarding future load-forecasting research, the working group concluded that there is no ultimate forecasting method toward which to direct model development efforts. The emergence of new issues and complexities in the utility environment will require continual industry reappraisal of modeling capabilities, priorities, and directions. Four areas in which the working group identified a need for further research are the development of probability distributions for key input variables; development of techniques for integrating end-use and econometric forecasting models; assessment of the impact of peak/off-peak price differentials (and relative elasticities) on projections of load shape; and identification of behavioral influences on the use of new technologies.

The final report of the UMF working group on load forecasting, *Electric Load Forecasting: Challenge for the Eighties,* will be published by EPRI this fall.

Other UMF activities

To complement the analyses of the first UMF working group, a load-forecasting study focusing on the specific needs of rural electrical systems was initiated early in 1980. Three generation and transmission systems and five distribution systems participated. The study surveyed the systems' forecasting procedures and capabilities, determined their specific forecasting needs, compared these needs with existing procedures, and identified additional approaches and tools that would enhance the systems' forecasting capabilities.

A notebook of utility models of all kinds has been assembled to promote the exchange of modeling ideas and information. It lists many significant utility modeling achievements, providing a capsule sketch of methods, key features, and ongoing development activities. Also included with each model summary is the name of the utility manager from whom additional information can be obtained. The notebook is intended to serve as a reference document for the industry, and it will be updated on a continuing basis to include new models and major revisions of current models. The first edition of the notebook, which was compiled from a survey of EPRI members, was distributed in late 1979.

The second UMF working group, composed of about 25 utility members and chaired by H. Grady Baker, Jr., of Georgia Power Co., is focusing on corporate modeling. Its first meeting was held in April 1980, and its final report is expected in early 1981. *Project Manager: Dominic Geraghty*

ENVIRONMENTAL ASSESSMENT

The principal goal of EPRI's Environmental Assessment Department is to define the environmental impact of electricity generation and transmission. The department seeks to achieve this goal by assessing the contribution of utilities to pollutant distribution and by using that information, along with risk analysis techniques, to assess the effects on human health and aquatic and terrestrial ecosystems. This research provides much-needed data to EPRI and utility planners concerned with control technologies and allows them to make informed decisions about which pollutants might require controlling and to what degree. These data can also be used in making regulatory decisions. The Environmental Assessment Department comprises four programs: Physical Factors, Ecological Effects, Health Effects and Biomedical Studies, and Integrated Assessment.

Research focus

Coal burning is the department's major concern, accounting for well over 75% of its 1980 budget of $26 million. Over the next five years, research on the effects of coal conversion processes (liquefaction and especially gasification) is expected to increase, but the department will almost certainly continue to focus on the environmental effects of conventional coal use. Studies on nuclear power production and advanced technologies (solar and geothermal) will play only a minor role during that period.

This emphasis does not stem from a lack of appreciation or understanding of the environmental problems posed by noncoal technologies, but rather from a judgment about priorities and about how EPRI's resources might be used most effectively in the context of the total national research effort. The decision to devote little money to studying the environmental effects of nuclear energy, for example, was made for a number of reasons. First, the health effects of ionizing radiation are far better understood than those of coal burning. Second, the federal government has such extensive efforts under way in major nuclear areas that the department's contribution would be negligible in terms of an overall increase in knowledge. This is particularly true in the area of nuclear waste disposal. The Environmental Assessment Department believes it can best use its resources by addressing very specific problems about which little is known and on which little research is being done; thus its nuclear activities have been limited to the identification and study of such specific problems. For example, a project nearing completion has compared the amount of transuranics in the environment contributed by fallout with the amount contributed by nuclear power plant releases (RP1059).

The minor effort planned by the department over the next few years on the effects of such advanced technologies as solar and geothermal is based on a recognition of both the major federal effort in these areas and the more pressing need for information on the effects of fossil fuel use. Coal burning will almost certainly double over the next 15–20 years. Already, tens of millions of people are in an environment affected by coal burning. In contrast, probably no more than a few hundreds of thousands are affected by solar or geothermal use. Likewise, the land area currently affected by geothermal and solar technologies is minuscule compared with that exposed to coal combustion emissions. Thus, given its funding limitations, the department considers it more beneficial to focus on environmental questions related to coal use, especially in those areas of technology development being sponsored by EPRI. It attempts, of course, to maintain a dynamic program in which priorities can be readjusted as the need arises. And, at all times, it attempts to design projects that complement the research activities of others, especially federal and state government groups.

Physical factors

The Physical Factors Program, which now has the largest share of the department's budget, deals exclusively with problems of environmental physics and chemistry. Its principal objectives are to identify pollutants in the environment and to define the role of the utility industry in pollutant distribution. The program seeks to provide information on the characteristics of pollutants that the department's health and ecology groups can use in designing meaningful experiments to measure pollutant effects. Further, it coordinates its activities with the federal government to produce data useful for regulatory purposes.

Like the department as a whole, the Physical Factors Program focuses on coal burning, particularly on how it affects regional and local air quality. Regarding regional air quality, the program seeks to clarify the relationship between utility emissions and such phenomena as acid rain, visibility degradation, and the distribution of secondary pollutants (namely sulfates). Local air quality research deals mainly with the behavior of plumes. This work is concerned with identifying the specific chemical composition of particles in plumes and with devising methods for defining the utility contribution to a mix of ambient particles.

In addition, the Physical Factors Program supports a small but increasing effort on problems related to solid-waste disposal. One possible future task of this research is to model the subsurface transport of contaminants from disposal sites. Another of the program's concerns is the development of experimental techniques and instrumentation; it has, for example, made a significant commitment to the development of remote sensing devices, particularly laser instruments. Finally, the program is becoming more involved with the environmental aspects of coal conversion, especially source assessment.

Ecological effects

Several years ago, the Ecological Effects Program dealt mainly with aquatic systems—specifically, with thermal pollution and with impingement and entrainment. Now the program has broadened its scope to include problems involving both terrestrial and aquatic systems. By far, its greatest emphasis is on the ecological effects of atmospheric deposition, of which acid precipitation is one component. EPRI has supported acid rain research for over three years and currently has the largest and most comprehensive program in the United States. The Ecological Effects Program also has extensive research under way on gaseous pollutants, another factor in atmospheric deposition. The total atmospheric deposition research effort comprises studies of lake acidification, aquatic and terrestrial fauna, forests, grasslands, and commercial crops.

A developing area in the Ecological Effects Program involves toxic substances, especially pollutants that typically occur in the environment in trace or minor amounts. One important concern, for example, is the impact of toxic leachates from waste disposal sites; another is the impact of trace constituents in the atmosphere.

Finally, the Ecological Effects Program has an important role in terrestrial and aquatic resource management, including finding beneficial uses for the waste products and by-products of utility operations. Cooling ponds, for example, have a great deal of potential for recreational use, and rights-of-way need not serve only as sites for transmission lines.

Health effects and biomedical studies

The Health Effects and Biomedical Studies Program is concerned with the health of society as a whole and, increasingly, with the health of workers in the utility industry. Over the next few years, this program will command the largest single portion of the department's budget. Reflecting the national concern over health questions posed by increased coal use, the program is focusing on the effects of coal burning and air pollution. The effects of such pollutants as sulfur and nitrogen oxides on pulmonary function are an important topic of investigation, and the program has been instrumental in developing laboratory facilities for studying both acute and chronic effects. Another effort, in the initial stages, is examining health questions related to atmospheric trace metals and organics. Also, a comprehensive cancer research program is being developed to assess the risk both to the community and to utility personnel. Further areas of investigation may include birth defects and neurophysiological behavior.

Occupational health, on which EPRI has sponsored little work in the past, is now probably the most rapidly developing area of its overall health research effort. This work is concerned with assessing the effects on the utility worker of physical agents (e.g., noise), certain chemical agents (i.e., polychlorinated biphenyls and carcinogenic organics), and biological agents (e.g., amoebae and bacteria). In addition, EPRI is moving into the area of safety and health management, using the knowledge gained from assessment studies to devise management procedures to minimize any adverse effects of power plant operation on the worker.

The Health Effects and Biomedical Studies Program continues to support extensive research, much of it in cooperation with DOE, on the biological effects of electromagnetic fields. Past research has emphasized the effects of high-voltage ac transmission lines; these studies are some of the longest-running at EPRI. Now work is under way on dc effects—both field and air ion effects. The program's electromagnetic research has considered effects on small and large mammals, plants, insects, chick embryos, and humans, and has taken several methodological forms, including field, laboratory (chamber), and epidemiological studies.

Integrated assessment

It is almost impossible to subject a test system (whether plant or animal) to some experimental procedure without noting effects, particularly if high concentrations of pollutants are involved. The problem is to assess the significance of the effects or, put differently, to translate the effects into human risk (morbidity or mortality). Risk assessment is an important part of the work of the Integrated Assessment Program. This group takes information developed by other EPRI programs and uses it to evaluate the total environmental impact of utility activities in terms of cost (both environmental and monetary), benefit, and risk. Through its work in risk-cost-benefit analysis, the program also seeks to improve methods of risk assessment.

Another task of the program is technology assessment. This research compares the total impacts of different technologies, taking into account the full range of activities from obtaining raw materials to delivering electricity. The program also examines a wide variety of other environmental issues and evaluates their impact on society and on the utility industry. These issues include regulatory actions, public perceptions of environmental questions, siting decisions, and electricity shortfalls. In sum, whereas the department's other three programs provide data on specific environmental impacts, the Integrated Assessment Program attempts to create a comprehensive picture of the environmental effects of electricity generation and transmission. *Department Director: Ralph Perhac*

R&D Status Report
ENERGY MANAGEMENT AND UTILIZATION DIVISION

Fritz Kalhammer, Director

POWER CONDITIONING FOR DC ENERGY SOURCES

The application of new dc energy sources (such as battery energy storage systems and fuel cell generators) to electric utility systems will require suitable ac/dc conversion equipment for the interface between the device and the utility. Conversion technologies presently used in high-voltage direct-current (HVDC) systems and uninterruptible power supplies, while theoretically applicable to new dc sources, will have to be modified to satisfy utility performance and cost requirements. In particular, escalating fuel and capital costs are creating a strong incentive for energy system designers to strive for the highest possible efficiency and reliability in large-scale (MWh) battery and fuel cell systems. Meeting these goals—while keeping the costs of the ac/dc conversion equipment as low as possible—will require cooperation between utilities, converter designers, and producers of dc source systems. For their part, utilities must define and verify the characteristics a converter must have to ensure its compatibility and successful operation in a total energy delivery system. Ac/dc interface specifications, detailed converter configurations, and projected capital costs have been under investigation by EPRI since 1973. The specific objective of the ongoing power conditioning and control (PCC) system efforts under RP841 is to develop and verify advanced ac/dc converter designs appropriate for both battery energy storage systems and fuel cell generation systems.

Early PCC system studies

The need to define improved PCC systems capable of producing customer-usable ac power was identified in a fuel cell generator development program initiated in 1971 under the sponsorship of the Edison Electric Institute, 10 electric utilities, and United Technologies Corp. (UTC). Accordingly, one of the goals set for the fuel cell development effort under Electric Research Council project RP114 (which was transferred to EPRI in 1973) was to identify PCC systems technologies and designs suitable for utility applications.

Early studies of PCC concepts included evaluations of two basic types of inverter systems: line-commutated inverters (LCIs) and self-commutated inverters (SCIs), shown schematically in Figure 1. In LCIs the power required to turn off the silicon-controlled rectifier devices (thyristors) is supplied by the utility grid; in SCIs it is supplied by energy stored within the inverter itself. A number of system simulations and experimental studies showed that acceptable cost and efficiency figures could be achieved in a fuel cell power plant by using either kind of inverter. It was concluded, however, that the more flexible SCI system design was compatible with a wide range of dc bus conditions and offered the greatest potential for lowering system costs, improving full- and part-load efficiencies, and enhancing operating characteristics.

The main advantages of an SCI-based PCC system stem from the fact that it has the characteristics of a conventional generator; i.e., it features a controlled voltage behind a series reactance. Because of this, the SCI can generate a rapidly controllable ac voltage that is independent of utility line voltage. When connected to a line, the SCI-based PCC can be used to pass power in either direction by adjusting the relative phase angle between its voltage and the line voltage. No mechanical switching is required to reverse polarity for battery charging, as in the case of LCIs. Also, an SCI system can operate through most ac voltage disturbances, deliver unity power factor without switching the correction capacitors, and interface with a standard utility substation transformer. Since in most cases the

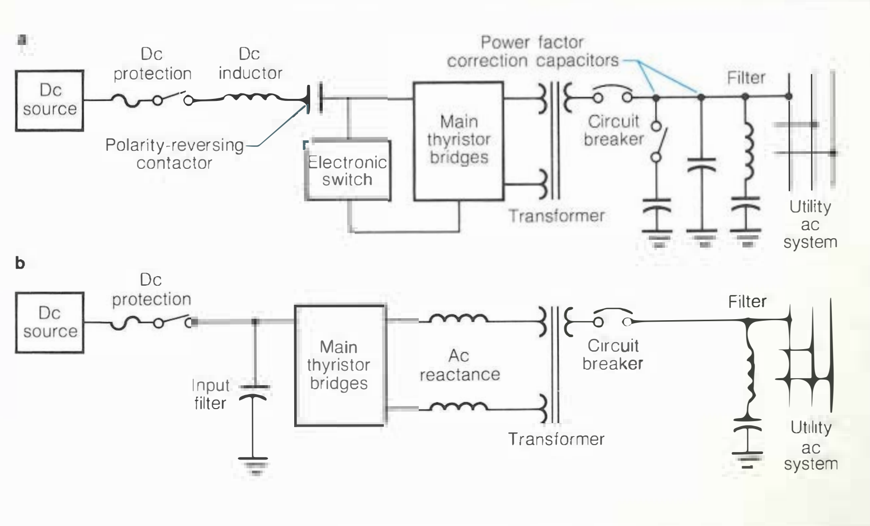


Figure 1 Schematic of **(a)** the line-commutated inverter and **(b)** the self-commutated inverter. Unlike the SCI, the LCI is dependent on power from the utility grid for operation. Note that the LCI requires a polarity-reversing contactor for use in battery applications.

SCI design cancels all significant voltage harmonics on the low-voltage side of the transformer, no tuned filters are needed to absorb harmonic currents on the high side. Further, as with a conventional rotating machine, it can provide leading or lagging VARs simply by increasing or decreasing the generated voltage.

Cursory comparisons between SCI and LCI systems (for similar applications) frequently favor the latter for reasons of efficiency and cost. But when an LCI system is modified so that some of its capabilities are comparable to the SCI's, the efficiency and cost differences become less significant. On balance, the SCI system is considered to be the more promising technology for future development.

As the EPRI R&D program was maturing, efforts to assess PCC systems for advanced generation and storage technologies were continued under a contract with Westinghouse Electric Corp. (RP390). The final report on this work (EM-271) was published in 1976. The project objective was to identify power conversion technologies applicable to and optimal for a number of advanced dc energy sources. Specific tasks were to review common conversion technologies, to investigate the use of a modular configuration to lower construction costs, to identify the research needed before practical application, and to develop a preliminary design based on the leading converter approach.

The contractor concluded that basically the same converter design could be used in battery and fuel cell applications. The current-fed LCI (a derivation of HVDC technology) was identified as the leading near-term candidate. It was also considered a leading candidate for the longer term, along with the voltage-fed, conduction-angle-controlled SCI. The contractor also concluded (1) that modularization would not yield cost benefits unless a complete departure from off-the-shelf packaging of converter components was developed, and (2) that some conversion equipment cost reductions could be expected as a result of semiconductor performance improvements.

Utility-tailored PCC systems for advanced batteries and fuel cells

On the basis of the results from these early projects, in 1976 EPRI initiated a comprehensive converter development project (RP841). The objective was to develop the preliminary design of an ac/dc power converter for use with both battery and fuel cell systems. This design was intended to become the basis for a hardware development program to achieve these technical, cost, and performance criteria:

- Suitable for siting in a wide range of locations and operating environments
- Easily maintained (modular approach), safe to operate, and low acoustic noise level
- Maximum total conversion equipment cost of $60/kW (1975 dollars)
- Compatible with a wide range of dc bus conditions
- Able to operate virtually undisturbed by ac voltage transients and utility grid imbalances
- Able to operate with a power factor near 1 most of the time
- High full-load and part-load efficiencies
- Low harmonic injection into utility ac network
- Low electromagnetic interference (EMI) and radio-frequency interference (RFI), so as not to affect the operation of local utility and consumer communications equipment
- Completely coordinated protection from dc source through ac system
- Highly reliable design
- Smallest "footprint" (on-site space requirement) possible

Under RP841, UTC was selected to identify an advanced PCC system approach based on commutation circuits and improved thyristors. The UTC work included a survey of semiconductor manufacturers in order to estimate the characteristics of thyristors that would be available in the 1980s for application in utility-tailored converters.

UTC's hardware work on PCC systems for utility application had begun in connection with fuel cell generator development efforts in 1972. First, UTC designed and built a 0.5-MW, two-bridge, three-phase inverter. Operation of this inverter on a local utility line effectively demonstrated the advantages of self-commutation and provided a base of experience for subsequent designs.

In 1976 UTC built a 1.2-MW inverter, which was used to deliver the output power of a fuel cell pilot plant into a local utility line. This inverter was subjected to numerous normal and abnormal line conditions during more than 2000 h of operation. The real-world conditions imposed included line faults, operation of various power factor correction capacitors, load switching, and substation tap changer operation. During the entire evaluation period, there was no problem with the inverter or its control and protection functions.

Finally, UTC designed and built an inverter for the 4.8-MW fuel cell demonstrator under construction in New York City. This unit is a factory-assembled PCC system, derated to 4.8 MW for use with the demonstrator (the converter is a full-sized module with a peak rating capability of 9.6 MW). The system has been installed, and startup testing is progressing on schedule. Results to date indicate that the system will meet all program goals. Fabrication of a second system with this configuration (ordered by Tokyo Electric Power Co. for a planned 4.5-MW fuel cell power plant) has begun.

Under DOE contract the SCI technology used in the 4.8-MW fuel cell demonstrator was evaluated for application in battery energy storage systems. It was concluded that the technology would meet DOE and EPRI goals for converter production cost ($60/kW in 1975 dollars) and efficiency (95% at full load and 90% at quarter load). The SCI characteristics appropriate to battery energy storage were demonstrated in a preliminary way by operating UTC's 0.5-MW converter system in both charge and discharge modes.

In 1979 UTC, C&D Batteries, Wolverine Electric Cooperative, Northern Michigan Electric Cooperative, and Daverman Associates submitted a proposal to DOE to design, build, and operate the Storage Battery Electric Energy Demonstration (SBEED) plant. The proposal was accepted and contract negotiations are under way. EPRI is participating in the program under RP1831. A 10-MW SCI based on the 4.8-MW fuel cell demonstrator inverter is being developed for the plant. Modified controls and 77-mm thyristors will be used to meet requirements for utility battery energy storage system operation.

Future research

Progress under RP841 has been extremely encouraging. Ac/dc interface specifications are being defined for batteries, fuel cells, and utility distribution systems. Thyristor characteristics have been identified that, in combination with commutation circuits, could be the basis for a still more advanced converter in the 1980s. These concepts are expected to reduce converter costs by approximately 25% (Figure 2). Also, with these concepts the rating of a three-bridge converter could be increased to 14 MW and that of a two-bridge unit to 10 MW. Cost and efficiency estimates for this technology ($50–$55/kW in 1977 dollars, efficiency better than 95% at full load and 92% at quarter load) are more favorable than previously projected goals. In other efforts under

Figure 2 Projected effects of technology advancement on the cost of self-commutated PCC systems. These figures assume a nominal converter rating of 10 MW, production of 150 units a year, a dc bus range of 2000–4000 Vdc, and compliance with all utility interface requirements. Point A marks the original converter production cost projection of $60/kW (1975 dollars); point B (1977 dollars) is based on EPRI projections of semiconductor improvements (RP841); and point C (1980 dollars) assumes the successful development of a high-frequency advanced converter bridge (RP1464).

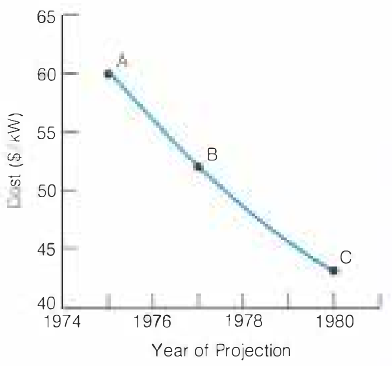
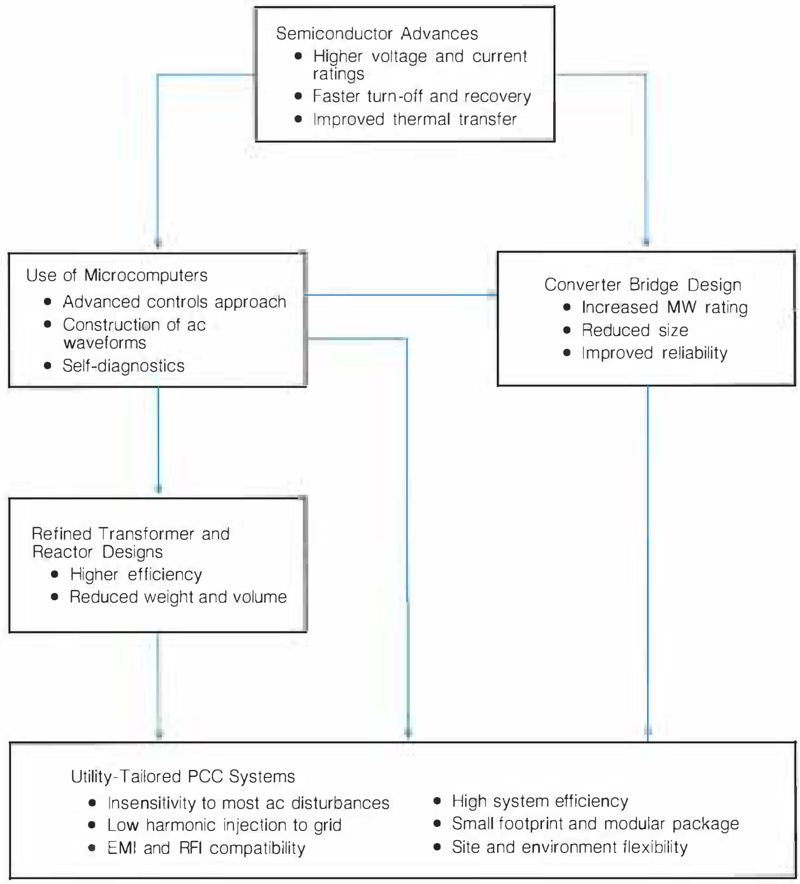


Figure 3 Development of improved total-system PCC designs is dependent on technical, cost, and performance criteria. Advances in semiconductor and microprocessor technologies are expected to facilitate improvement in many of these areas and to lead to lower costs and higher efficiencies for utility-tailored PCC systems in the 1980s.



RP841, a model of converter response to utility disturbances has been developed and further potential technological advances have been investigated.

The development of several concepts identified under RP841 is now proceeding under DOE contract, along with an effort to define and develop more effective interfaces between converters and batteries. EPRI is preparing a project plan (RP1464) that will include key subsystem design and development activities aimed at refining advanced converter concepts for utility applications. Design criteria evaluations, semiconductor and microcomputer advances, and mechanical design improvements are expected to result in major configuration improvements and thus still lower PCC system costs and higher efficiencies (Figure 3). Preliminary studies have already shown that higher-frequency converter bridge switching can reduce the need for magnetic components, increase rating flexibility, and improve reliability by permitting independent bridge operation and the use of redundant modules.

PCC systems clearly will be a key element in effectively integrating new dc source technologies into utility systems. Major advances have already been made in developing ac/dc inverters and converters that can meet stringent goals with respect to cost, efficiency, and reliability. Sweeping solid-state electrical and electronic technology advances through the 1980s promise significant opportunities for designing even more advanced PCC systems that can optimize the electrical match between advanced energy sources and the balance of the energy delivery system. *Project Manager: Ralph Ferraro*

ZINC CHLORIDE BATTERIES FOR UTILITY APPLICATIONS

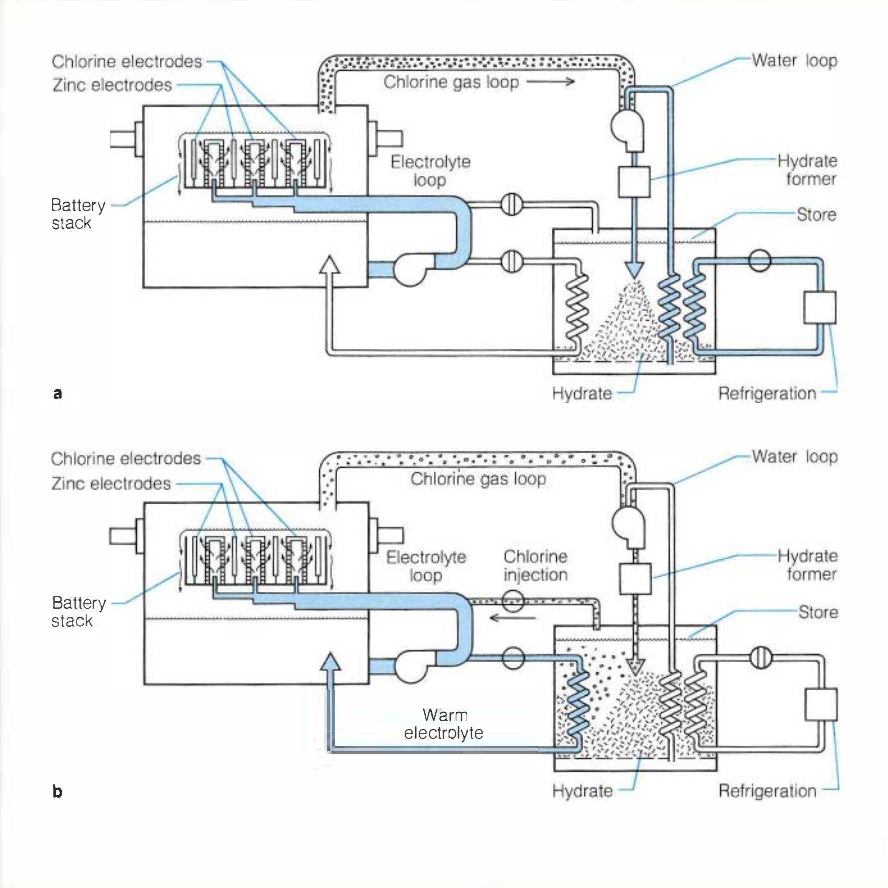
*Batteries offer several potential advantages over other technologies for storing electric energy (*EPRI Journal, *April 1980, p. 8). Present batteries are unsuited to this task, however. Thus EPRI has a substantial program under way to develop advanced batteries to meet the requirements of utility application (*EPRI Journal, *October 1976, p. 6). The zinc chloride battery is the farthest along the development path. Currently, 50-kWh battery modules are being operated under laboratory conditions, and a 5-MWh prototype being built by Energy Development Associates (EDA), a subsidiary of Gulf+Western Industries, Inc. (RP226), is scheduled to go on test at the Battery Energy Storage Test (BEST) Facility early in 1982 (RP255).*

Design

The zinc chloride battery uses an electrolyte of aqueous zinc chloride, which is circulated through the battery stack continuously during both charge and discharge. During charge, chlorine (which has a limited solubility at the battery operating pressure of about 0.5 atm) separates from the electrolyte as it is formed at the porous graphite electrodes; this chlorine is mixed with chilled water to form the clathrate chlorine hydrate, which is stored. Zinc is stored by electroplating the metal on dense graphite substrates. During discharge, the hydrate is melted to release chlorine gas, which is then mixed with the electrolyte and pumped with it to the stack for electrochemical reaction at the porous graphite electrodes. The electroplated zinc dissolves during discharge to complete the electrochemical reaction and return all active materials to solution as zinc chloride. This liquid state has no "memory" of the previous charged condition, which is a major reason for expecting a long cycle life from the zinc chloride battery. Figure 4 is a schematic representation of battery operation during charge and discharge.

Cell voltage is 2 V on discharge and about 10% higher on charge. Ten cell units, made up of interdigitated zinc substrates (dense graphite) and chlorine electrode structures (porous graphite plates held in polyvinyl chloride frames), constitute a submodule. The battery stack, or module, consists of six submodules, each with an output of 20 V and 83 A. A module storage capacity of approximately 50 kWh has been specified in the preliminary design of a 100-MWh utility load-leveling plant (RP226-3). Safety, manufacturing considerations, ease of maintenance, and reliability are among the factors dictating this size. Figure 5 is a schematic of the 50-kWh load-leveling module to be used in the 5-MWh prototype battery for the BEST Facility.

Figure 4 Schematic showing fluid flow and control of the zinc chloride battery. During charge **(a)**, chlorine released at the porous graphite electrodes is pumped into the hydrate former and mixed with chilled water. The resulting hydrate collects in the store. Electrolyte is circulated through the battery stack continuously. On discharge **(b)**, a portion of the electrolyte (warm) is directed through a loop that passes through the store and melts the hydrate to release chlorine gas. This gas is injected into the electrolyte loop and thus is available for reaction at the porous graphite chlorine electrodes. Zinc is electroplated during charge and dissolved during discharge. Electrical connections are not shown.



The corrosive nature of the module's wet chlorine environment is the most important factor in materials selection. For the electrode substrates, only graphite and ruthenized titanium are suitable. The porous graphite for the chlorine electrodes must be activated by anodization. The module's case is made of fiber-reinforced polyester and is protected by a polyvinyl chloride (PVC) liner. Much use is made of PVC in submodule and other internal parts as well. Where metal is required (e.g., electrical connectors, pump shafts, heat exchangers, and valve parts), titanium is the only selection. A considerable R&D effort has gone into designing the module's components and choosing materials for them. Two reports, EM-1051 and EM-1417, describe this work in detail.

Operation

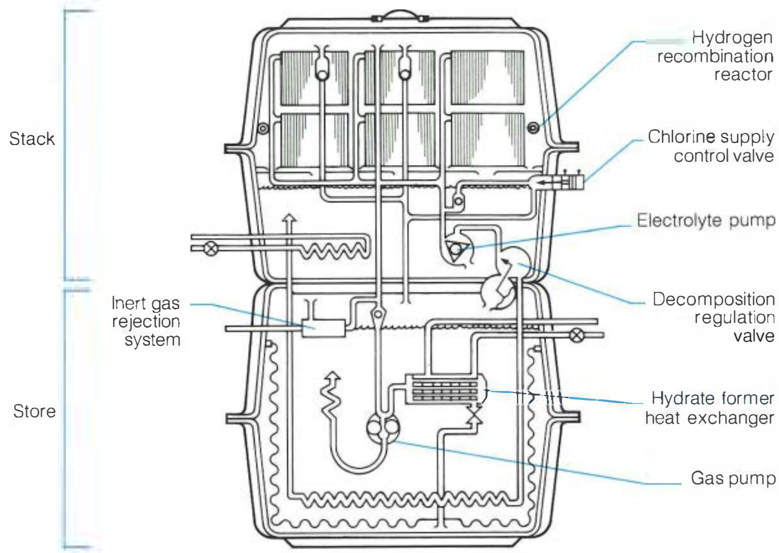
The objective of RP226 is to develop a battery module that will operate through many charge and discharge cycles without operator attendance and that will meet utility requirements in the areas of efficiency, cost, and reliability. To date, unattended operation of a sealed 50-kWh module has not been achieved. One serious problem is sporadic blocking of the hydrate former because of formation and adherence of ice (chlorine hydrate) on the pump and tubing surfaces toward the end of a charge cycle. The temperature and pressure ranges over which the system will operate for a full cycle (a 7-h charge followed by a 5-h discharge) without operator attendance have not yet been determined. The definition of a suitable control algorithm is a primary concern of development efforts funded by EPRI and EDA.

The crucial testing of prototypes for the BEST Facility battery (now scheduled to take place early in 1982) is predicated on battery modules capable of unattended operation. This, in turn, requires incorporation of a device that rejects inert gases from the interior gas space. The accumulation of inert gases results from (1) unavoidable air leakage into the stack compartment, which is operated at a pressure below atmospheric pressure, and (2) very slow oxidation of the graphite in the chlorine electrodes to form carbon dioxide. A clever design involving an electrowinning cell has been reduced to breadboard form for laboratory testing.

Efficiency

One of the most important criteria for the success of any energy storage system is the net plant efficiency, i.e., the ac energy output divided by the ac input. The efficiency achieved by pumped-hydro storage systems, 70–75% in most installations, is the current performance standard. The efficiency of a zinc chloride battery plant has

Figure 5 Operational schematic of the BEST Facility battery module, illustrating the components and subsystems required to allow continuous closed-system operation.



two major components: the efficiency of the module (electrochemical energy efficiency) and that of the auxiliaries, such as pumps, the refrigeration system, and the inverter. Figure 6 shows the energy flow for a 50-kWh module operating with an electrochemical energy efficiency of 75% and a net plant efficiency of 65%.

The highest electrochemical efficiency yet achieved in tests of zinc chloride modules is 60%. Coulombic losses resulting from the chemical reaction of dissolved chlorine with zinc represent the largest efficiency losses. Single cells incorporating present design dimensions for electrode area and interelectrode spacing have achieved coulombic efficiencies of 78%. The highest submodule coulombic efficiencies obtained are 74–76%; the additional loss in going to full modules is 1% or less. Voltaic efficiency (the ratio of operating voltage to charge voltage) presently averages 84–86% when the chlorine electrodes are properly activated. The product of the best coulombic and voltaic efficiencies that have been separately achieved in submodules is about 65%. However, the efficiency of modules prototypical of those for the BEST Facility has fallen short of this figure for several reasons, including deficiencies in both design and fabrication of the submodules and other components.

Recent work on coulombic losses under RP226-3 and RP226-5 entailed theoretical studies of the hydrodynamic factors controlling transport of dissolved chlorine from the cathode to the zinc anode. The studies concluded that present design is not optimal in several respects. The most important recommendation is that the interelectrode gap, now 2 mm, be increased to 3 mm for maximum coulombic efficiency. Empirical studies indicate that increasing the current density from 33 to 50 mA/cm² will also help reduce coulombic losses. The evidence suggests that a module incorporating these and other design improvements could achieve coulombic efficiencies in the range of 85%. Inconsistent activation of the graphite chlorine electrodes has been a contributor to voltaic efficiency losses. Correcting this should increase voltaic efficiency to 88%, which would yield the goal of an electrochemical energy efficiency of 75%. In an attempt to demonstrate this capability, an improved module is being designed, fabricated, and tested under RP226-5.

On the basis of present data, auxiliary components are estimated to be responsible for reducing battery plant efficiency by 20 points; the goal is to cut these losses to 10%. Potential improvements have been identified for the gas pump (hydrate former), the electrolyte pump, and the refrigeration system (EM-1417). The achievement of a net plant efficiency of 65% will, however, also require the reduction of inverter and rectifier losses to 4–5%; this is being pursued under RP841 and RP1464. Higher electrochemical efficiencies and, in turn, net plant efficiencies in the range of 75% will require new electrochemical design concepts. An objective of RP226 is to explore one or more candidate designs for higher efficiency.

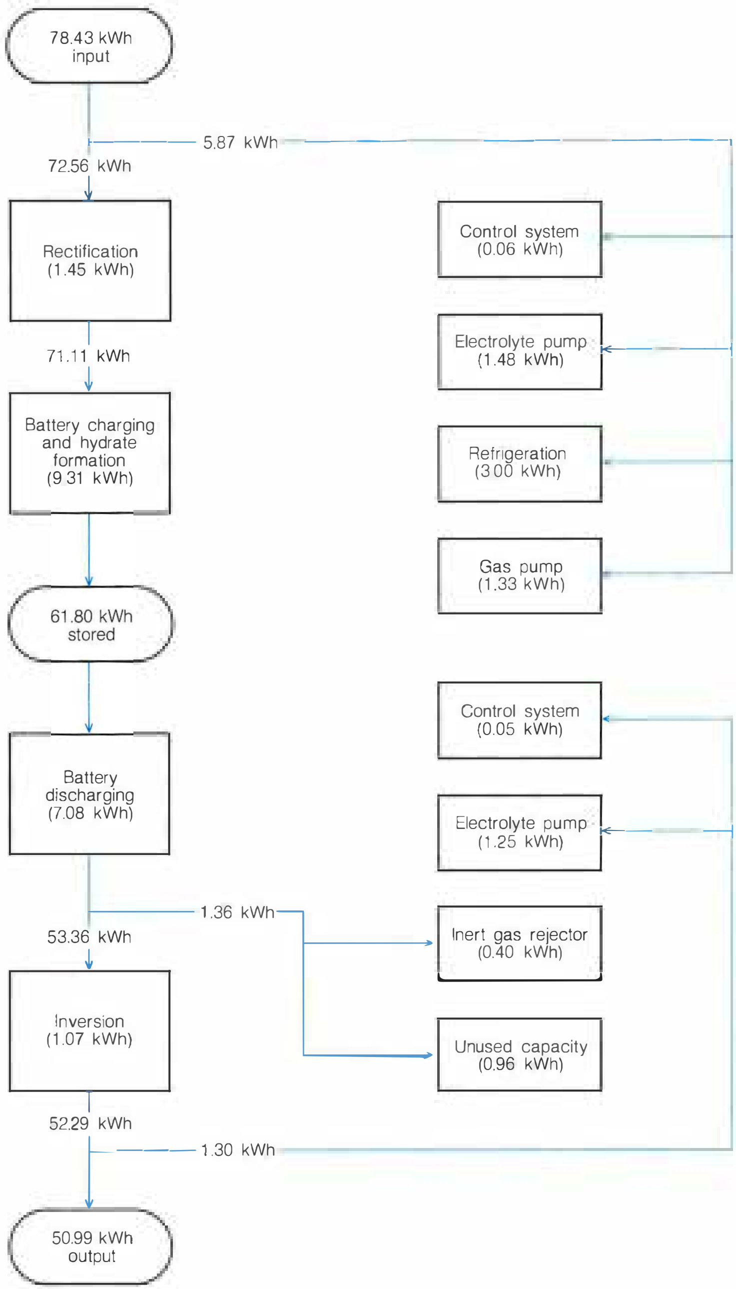
Cost

A thorough preliminary study of projected manufacturing costs for commercial units was conducted in 1977–1978 and reported in April 1979 (EM-1051). The estimated total cost was $37/kWh, which amounts to approximately $47/kWh in 1980 dollars. Break-even calculations comparing battery energy storage with combustion turbines suggest that in some locations $100/kWh will be competitive. Development goals are in the range of $60–$70/kWh (1980 dollars).

Two materials that drive up the cost are graphite and titanium, and it is clear that changes in their manufacture and use will be necessary if the cost goals are to be met. One estimate of graphite electrode costs, which is based on the present specific design and assumes a dedicated graphite manufacturing facility large enough to achieve all economies of scale, is approximately $20/kWh. The machining of parts is responsible for about two-thirds of this cost (RP1198-9). Further work will explore cost reductions that might result from producing graphite in larger billets, increasing the size of electrodes, and using one rather than two types of dense graphite. Additional cost reductions will require radical changes in the technology of graphite manufacture.

The only way to reduce the cost impact of titanium is to design it out of the system as much as possible. Assuming there are no improvements in the technology (e.g., the use of titanium cladding on a less expensive

Figure 6 Energy flow diagram for a zinc chloride battery plant, based on a nominal 50-kWh module. With an input of 78.43 kWh and an output of 50.99 kWh, the system would have a net efficiency of 65%.



base material) and no significant changes in module design, the titanium-related cost is estimated to be $20/kWh. The heat exchanger for chilling the water from the store before hydrate formation is one component in which the use of titanium cannot be avoided, but good design and heat-transfer-enhancing surface treatments offer hope for reducing the cost. Electrical busbar connections at the terminals of each submodule are required to carry currents on the order of 500 A. Metallic conductivity is essential for this function, and titanium is less than ideal. A design that permits the use of titanium-clad copper may be cost-effective.

Reliability

The operation of series and/or parallel arrays of batteries of any type imposes stringent reliability requirements on the elements of the system. This is a particularly important consideration with the relatively complex zinc chloride battery. Separate studies indicate that if failures are random, the mean lifetime of such an array of zinc chloride modules will be only a fraction of the mean lifetime of the modules themselves (RP307-17). For example, the lifetime of the current module being tested, which is made up of six submodules in parallel, will be one-sixth that of the individual submodules for random failure modes. Unfortunately, because there is as yet little or no operating experience with modules or components, it is difficult to assess the seriousness of the problem. The design philosophy being followed is to make key components, such as pumps and certain valves, as reliable as possible and, in addition, readily accessible. One positive test finding is that failed zinc chloride modules can be easily taken out of service by a simple mechanical shorting switch. Future work will emphasize reliability testing. *Project Manager: David L. Douglas*

R&D Status Report
NUCLEAR POWER DIVISION

Milton Levenson, Director

IN-PLANT HEAVY-SECTION RADIOGRAPHY

The examination of solid, opaque materials by radiography (i.e., by passing electromagnetic radiation through them) is a familiar technique, dental X rays being the most commonplace example. Virtually all major electric utility generation equipment suppliers have invested in industrial radiography equipment to ensure the quality of the heavy metal components (e.g., forgings, castings, and weldments) supplied to power plants. As in dental radiography, the aim of using this equipment is to detect an unseen flaw in what otherwise appears to be a healthy component without physically altering that component. Because many industrial components can be penetrated only by radiation substantially more energetic than conventional X rays, extremely large, heavy machines and massive concrete-shielded test cells have been required for their use. Under RP822, researchers from Schonberg Radiation Corp., Southwest Research Institute, and EG&G, Inc., are working with EPRI to reduce the size of high-energy radiographic equipment to permit routine inspections after components have been placed in service. The goal is construction of a portable, high-energy radiation source configured for the performance of in-service inspections inside nuclear plant containment vessels. The unit is presently undergoing final testing and will be used in inspections required by the ASME codes beginning in early 1981.

Design concept

X rays are high-energy electromagnetic waves produced by an electrical apparatus. Specifically, they can be generated by impinging a stream of electrons onto a metallic target; the higher the speed of the electrons, the greater will be the energy and penetrating power of the X rays produced. Industrial radiography has benefited from the development of techniques of accelerating electrons to higher and higher speeds and of adjusting the output to the requirements of high-quality image formation. The developmental sequence has included electrostatic accelerators, such as the Van de Graaff apparatus; the betatron, which uses a rotating magnetic field for acceleration; and, most recently, the linear accelerator, or linac, in which the electrons are carrried along by a continuous electromagnetic wave in a straight tube, either in a traveling-waveguide or a folded-waveguide configuration. The linac concept was selected for the EPRI program for two basic reasons: (1) its output beam characteristics are favorable for in-service inspections of thick metal sections, and (2) the availability of proven, reliable components (largely from military radar and communications applications) presents the opportunity for substantial equipment size reduction.

The physical size of a linac tends to be defined by the frequency of the carrier electromagnetic wave (the higher the frequency the smaller the size) and by the output energy level required. For example, the Stanford Linear Accelerator, about 2 miles long, generates energies measured in billions of electron volts for research into the nature of subatomic particles. Fortunately, the energies required for inspecting a 1-ft-thick steel section are on the order of only several million electron volts (MeV). Machines with such output are used for quality control in factories that manufacture plant components (Figure 1), but their size and weight have virtually precluded in-plant use. Application of modern microwave technology has led to substantial size reduction in EPRI's portable, high-energy linac, known as Minac (Figure 2).

Design criteria

The size and performance targets for Minac were derived from a detailed study (carried out as part of RP822) of the in-service inspection needs of nuclear units, with particular emphasis on both regulatory and plant operational requirements. Regulatory concerns tend to emphasize the need for detection of minute flaws at or near the threshold of radiographic detection. Operational aspects mandate a high-dosage output, assurance of accessibility to the exteriors and interiors of a wide variety of physical components (ranging from pipes to pump bodies and concrete walls), and compatibility with personnel protection requirements for normal radiographic operations and for those unique to nuclear plants. Although final testing remains to be accomplished, it appears that all targets have been met by Minac. The flexibility of the unit can be compared to that of a remotely operated camera system that uses interchangeable matched lenses and extension bellows to permit optimal photography for specific situations.

In baseline configuration, the measured output at 4 MeV exceeds 100 rads/min at a distance of 1 m, and the focal spot size is 2 mm. These values translate to a capability to acquire radiographs of a steel component 6 in thick in as little as 10 minutes. The resolution of the radiograph appears suffficient to permit detection of cracks smaller than 0.03 in.

The baseline configuration is a straight-ahead setup wherein the radiation beam is contained within a 20° cone angle. Changes in the beam are accomplished by the use of heavy-metal collimators, which can provide a full panoramic beam and various offset angles. Such beam variants facilitate access to various components of power plants. A panoramic beam permits good radiographic capability without the need for precision aiming of the unit. Thus, the radiation head can simply be hung inside a vessel by cables. In other circumstances, precision aiming via mechanical manipulators is required. Since all operations must be accomplished by remote control, the radiation head has

Figure 1 A representative high-energy (4-MeV) linear accelerator source used for industrial radiography in shop practice. The operator retires to a heavily shielded concrete cubicle when the unit is on.

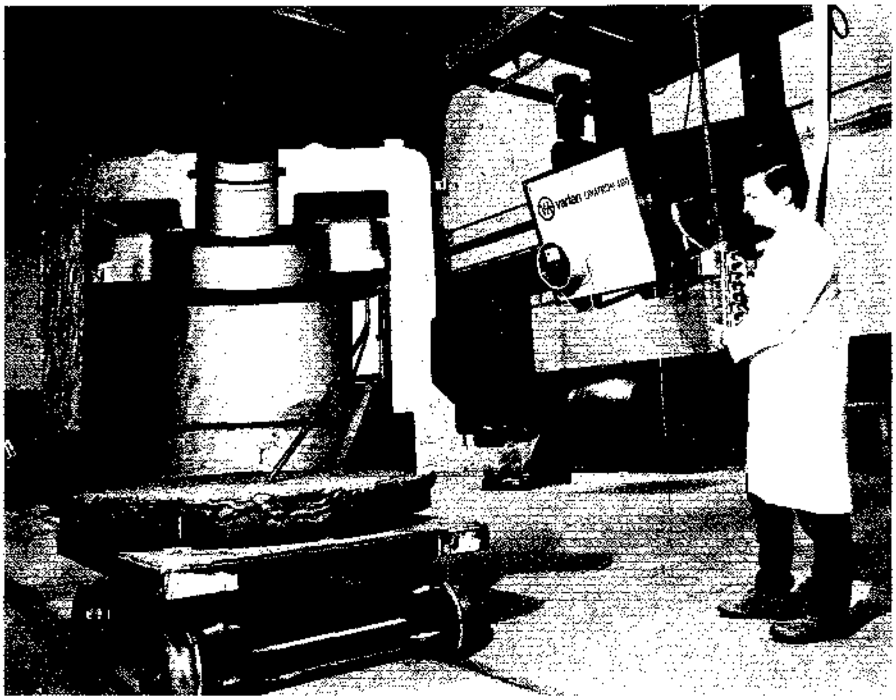


Figure 2 The EPRI Minac system being tested in near-final configuration. It includes a control console, a modulated power supply, and a radiation head, having a combined weight of less than 270 kg. This is about one-sixth the weight of the corresponding equipment the radiation head of which is shown in Figure 1. The weight and size reduction is derived from the use of components with higher microwave frequencies; Minac is believed to be the first X-band-frequency unit in practical use.

been designed for rugged use by technical personnel several hundred feet removed from the component being radiographed. This allows the built-in nuclear plant shielding to serve as the necessary personnel protection barriers.

Although Minac is based on well-proven components, its design incorporates substantial advances in integration technology, particularly in the area of control and frequency matching of internal components. Microsurgical techniques are required in fabricating and tuning the waveguide subsystems.

Minac offers utilities the capability to perform inspections not previously possible and to reduce the costs of many current operations. Field radiography of thick sections is presently performed by using sources such as cobalt-60. These radioisotopic sources produce a lower energy and less output than Minac, which limits their use, particularly in nuclear plants, where background radiation can fog the radiograph during long exposure times. Since radioisotopic sources can be neither switched off nor readily adjusted, long periods of time are required to remove and replace film packs when a series of radiographs must be taken. Minac, on the other hand, operates by a controllable electrical process. Its on-off capability is expected to markedly reduce the time required for a radiographic survey.

Initial application

Present plans call for a field-qualified Minac unit to be used for inspecting the welds of main recirculation pumps at the Ginna nuclear unit, operated by Rochester Gas and Electric Corp. (RGE). To facilitate the inspection, RGE undertook construction in 1979 of a remote, TV-monitored manipulator system for the radiation head, a control console, and a full-scale fiberglass mock-up of the pump itself. This equipment will be used with Minac in late 1980 for orientation and procedural development work at the Ginna plant. The weld inspection itself will be performed in 1981 during a planned refueling outage. Commitment of this research program to inspection during a scheduled refueling outage (wherein delays can easily become very expensive) has increased the emphasis on planning, performance verification, and reliability testing. It is expected that the EPRI–RGE system will subsequently be used by many utilities with similar inspection requirements. *Project Manager: Melvin Lapides*

New Contracts

Number	Title	Duration	Funding ($000)	Contractor/ EPRI Project Manager
RP459-2	Testing of Filtration Equipment for Coal Liquids	5 months	10.0	Johns-Manville Sales Corp. *H. Gilman*
RP742-2	Induced AC Potential on Pipelines	2 years	260.9	Science Applications, Inc. *J. Dunlap*
RP832-4	Coal to Methanol via Texaco Gasification and ICI Methanol Synthesis	8 months	86.0	Fluor Engineers and Constructors, Inc. *N. Herskovits*
RP976-4	Installation of Improved Removal Treatment Capability in the PDQ-7	1 year	10.2	G.R.P. Consulting, Inc. *W. Eich*
RP1079-3	Heavy-Fuel-Fired Gas Turbine Emissions Testing	3 months	87.4	KVB, Inc. *H. Schreiber*
RP1096-3	Longitudinal Loading Tests on a Transmission Line	14 months	29.0	University of Wisconsin at Madison *P. Landers*
RP1129-8	Particulate Emission and Operating Characterization of a Fabric Filter Pilot Plant	5 months	223.0	Southern Research Institute *R. Carr*
RP1153-3	Integrated Regional Electric Power Planning and R&D Analysis	6 months	80.1	Southwest Energy Associates *H. Chao*
RP1179-10	Dynamic Test Plan for 20-MW (e) Atmospheric Fluidized-Bed Combustion Pilot Plant	3 months	28.5	Jaycor *W. Howe*
RP1201-12	Impact of Advanced Power Semiconductor Systems on Industry and Utilities	7 months	49.9	SRI International *J. Brushwood*
RP1233-5	NUCRAC-Benchmark Comparison	10 months	23.9	Science Applications, Inc. *I. Wall*
RP1250-3	Corrosion-Product (Crud) Buildup on LWR Fuel Rods	7 months	52.2	The S. M. Stoller Corp. *H. Ocken*
RP1316-5	Air Pollution and Human Health	1 year	107.7	Department of Energy *R. Wyzga*
RP1319-6	Putnam Combined-Cycle Plant Reliability Analysis	4 months	47.5	ARINC Research Corp. *J. Weiss*
RP1325-5	Cyclic Crack Growth in Reactor Pressure Vessel Steels	9 months	65.7	Fracture Control Corp. *R. Jones*
RP1330-5	Radwaste Evaporator Pretreatment by Ultrafiltration	11 months	91.0	NWT Corp. *M. Naughton*
RP1348-6	Electric Utility Wind Power Market Survey	1 month	16.1	JBF Scientific Corp. *E. DeMeo*
RP1395-7	Defect Characterization in Eddy-Current Testing	14 months	37.8	Washington State University *J. Quinn*
RP1415-5	Thermophotovoltaic Conversion: Radiator Development Program	7 months	58.2	Battelle, Columbus Laboratories *J. Bigger*
RP1484-4	Support for Over/Under Capacity Model Assessment	7 months	11.2	Decision Focus, Inc. *R. Richels*
RP1521-1	Solar Central Receiver Cavity Insulation Evaluation	1 year	100.0	Boeing Engineering & Construction *J. Bigger*
RP1523-1	Evaluation of Electric Vehicle Battery Chargers and Subsystem Technologies Related to Utility Grid Interactions	10 months	150.0	Purdue Research Foundation *R. Ferraro*
RP1548-2	Fission Behavior in LWR Systems Following Abnormal Occurrences	31 months	199.5	Babcock & Wilcox Co. *H. Till*
RP1579-5	Nuclear Waste Disposal: Risk Comparison and Criteria Development for Mill Tailings and Low-Level Waste	5 months	48.3	Rogers & Associates Engineering Corp. *R. Williams*
RP1645-3	Pressurized Fluidized-Bed Combustion Cycle Assessment and Demonstration Plant Specification	13 months	493.9	Brown Boveri Turbomachinery *W. Slaughter*
RP1658-2	Assessment of Solid- and Liquid-Waste Management for Coal Conversion Plants	8 months	69.2	Olympic Associates Co. *W. Reveal*
RP1677-2	Site-Specific Regulatory Requirements for Dispersed Fuel Cells	3 months	34.1	Gilbert/Commonwealth Companies *E. Gillis*
RP1691-1	Evaluation of Shale Oil as a Utility Gas Turbine Fuel	10 months	20.0	Long Island Lighting Co. *H. Schreiber*
RP1722-2	Moisture Separator—Reheater Instability Study	6 months	42.7	Westinghouse Electric Corp. *T. Libs*
RP1764-3	Dedicated High-Performance Computer Architectures for Power System Problems	2 years	50.0	Carnegie-Mellon University *J. Lamont*
RP1769-1	Radio-Frequency Interference From HVDC Converter Stations	28 months	434.2	International Engineering Co., Inc. *W. Blair*
RP1770-1	Mitigation of Geomagnetically Induced Currents and DC Stray Currents	18 months	275.3	Minnesota Power & Light Co. *J. Porter*
RP1772-1	Comparative Risk Analysis of Selected Electric Energy Systems	14 months	247.9	Arthur D. Little, Inc. *P. Ricci*
RP1776-1	Measurement of Emissions From Stacks of Coal-Fired Power Plants	6 months	99.9	Southern Research Institute *J. Guertin*

New Technical Reports

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

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ADVANCED POWER SYSTEMS

Coal Gasification–Combined-Cycle System Analysis

AP-1390 Final Report (RP986-2); $7.25

Thermal efficiencies of coal gasification–combined-cycle systems using commercially available United Technologies Corp. FT-4 combustion turbines and near-commercial Texaco oxygen-blown gasifiers were determined, and the effects of changes in configuration and design parameters on system performance were studied. Comparisons were made between air- and oxygen-blown gasifiers and between the Texaco entrained gasifier and the British Gas Corp. slagging fixed-bed gasifier. The feasibility of using a medium-Btu coal gas combustor with an FT-4 engine was also studied. The contractor is United Technologies Corp. *EPRI Project Manager: B. M. Louks*

Gasification–Combined-Cycle Plant Configuration Studies

AP-1393 Final Report (RP986-6); $6.50

The impact of plant configuration and operating parameters on the performance of a coal gasification–combined-cycle system was studied, using the commercially available Westinghouse combustion turbine and an oxygen-blown Texaco gasifier. Plant configurations were varied to determine attainable thermal efficiencies; results indicate that efficiencies as high as 38.5% are possible. The contractor is Westinghouse Electric Corp. *EPRI Project Manager: B. M. Louks*

Economic Screening Evaluation of Upgrading SRC to Low-Sulfur Solid Boiler Fuels

AP-1399 Supplementary Report (RP361-2); $3.50

The costs of upgrading solvent-refined coal (SRC) to low-sulfur solid boiler fuel were estimated for a 20,000-bbl/d facility (an ebullated-bed hydrotreater with a wastewater treater and a sulfur plant). Both utility and equity methods of financing were used. The contractor is Mobil Research and Development Corp. *EPRI Project Manager: W. C. Rovesti*

Feasibility Study of Wood-Residue-Fired Cogeneration at Heppner, Oregon

AP-1403 Final Report (TPS79-736-2); $12.00

The feasibility of constructing a wood-residue-fired steam and electric power cogeneration facility near Heppner, Oregon, was explored. Wood residue availability and costs were investigated. Three plants were considered (6, 12, and 24 MW), each supplying 45,000 lb/h of extraction steam to a lumber mill. Capital, operating, and busbar power costs were estimated, and the feasibility of marketing power at these busbar costs was determined. The contractor is Schuchart & Associates, Inc. *EPRI Project Manager: B. M. Louks*

Texaco-Based Gasification–Combined-Cycle System Performance Studies

AP-1429 Final Report (RP986-3); $6.50

The performance of integrated and stand-alone coal gasification–combined-cycle systems using oxygen-blown and air-blown Texaco gasifiers and commercially available combustion turbines was evaluated. Plants were sized to process 10,000 t/d of Illinois No. 6 coal. The effects of major design and component operating variables (e.g., turbine firing temperature, steam cycle conditions, slurry concentration, fuel temperature, system pressure, gas resaturation) on the plants' thermal efficiency are examined in detail. The contractor is General Electric Co. *EPRI Project Manager: M. J. Gluckman*

COAL COMBUSTION SYSTEMS

Coal Mine Disposal of Flue Gas Cleaning Wastes

CS-1376 Final Report (RP1260-14); $6.50

This report summarizes the state of the art of disposing of utility flue gas cleaning wastes (defined as fly ash and flue gas desulfurization wastes in active and abandoned coal mines). It presents six examples of full-scale mine disposal operations; discusses regulations promulgated under the Surface Mining Control and Reclamation Act of 1977 and their anticipated effects on mine disposal operations; and outlines areas for additional research. The contractor is Environmental Research & Technology, Inc. *EPRI Project Manager: R. Y. Komai*

Impact of Cleaned Coal on Power Plant Performance and Reliability

CS-1400 Final Report (RP1030-6); $4.50

This report analyzes the impacts on power plant costs of using cleaned coal instead of run-of-mine (ROM) coal. Several previous coal-cleaning studies are reviewed, including economic evaluations and studies of the effects of cleaning on coal properties. The results of a survey of utilities that have used both ROM and cleaned coal are presented. Because existing power plant experience was found to be limited, the development of a comprehensive data base and of a fuel-use model is recommended. The contractor is Stone & Webster Engineering Corp. *EPRI Project Manager: John Dimmer*

Preliminary Design and Assessment of Circulating-Bed Boilers

CS-1426 Final Report (RP1028-2); $8.25

Conceptual designs are described for both atmospheric-pressure and pressurized 600-MW (e) circulating-bed boilers. The boilers' expected performance is evaluated, and general economic conclusions are presented. The contractor is Pullman Kellogg, a division of Pullman Inc. *EPRI Project Manager: T. E. Lund*

Economic and Design Factors for Flue Gas Desulfurization Technology

CS-1428 Final Report (RP1180-9); $8.25

Published flue gas desulfurization (FGD) costs were reviewed, and several reasons for their variation were identified. A methodology was developed to improve the consistency of FGD cost estimates. Conceptual designs and cost estimates were developed for eight FGD processes for a 500-MW plant burning typical high- and low-sulfur coals. The sensitivity of the costs to changes in plant capacity factor, coal sulfur content, and utility and chemical costs was evaluated. The contractor is Bechtel National, Inc. *EPRI Project Manager: C. R. McGowin*

ELECTRICAL SYSTEMS

Research Into Load Forecasting and Distribution Planning

EL-1198 Final Report, Vol. 3 (RP570-1); $9.50

This volume describes the development of a unified distribution planning model that will facilitate the evaluation of alternative expansion strategies and the revision of distribution plans. Submodels for substation location, substation sizing, feeders, and load transfer are used to develop alternative system configurations; then another submodel is used to determine the optimal alternative over the planning period. The contractors are Westinghouse Electric Corp. and the Salt River Project. *EPRI Project Manager: W. E. Shula*

Long-Term, Mid-Term, and Short-Term Fuel Scheduling

EL-1319 Interim Report (RP1048-6); $5.75

This report describes the development of functional specifications for three computer programs for long-, mid-, and short-term fuel scheduling. A literature search and an industry survey were conducted to identify areas of key importance. Algorithmic approaches were defined for multimonth fuel planning, mid-term dispatch, and fuel-constrained economic dispatch. Fuel-scheduling requirements were identified, and a cost-benefit analysis of the developed programs was performed. The contractor is Boeing Computer Services, Inc. *EPRI Project Manager: C. J. Frank*

Light-Triggered Thyristors for Electric Power Systems: Phase 2

EL-1349 Interim Report (RP669-2); $8.25

Three light-fired thyristors suitable for one-to-one replacement of electrically triggered 2.6-kV high-voltage direct-current (HVDC) cells were constructed. This report summarizes the problems with devices developed in the first phase of the project and describes the development, testing, failure analysis, fabrication, and packaging of the new devices. Cost and efficiency comparisons are made between the light-fired thyristors and electrically triggered HVDC cells. The contractor is General Electric Co. *EPRI Project Manager: Gilbert Addis*

SF_6-Oil Dielectric for Power Transformers

EL-1358 Final Report (RP808-1); $5.25

The potential benefits of using sulfur hexafluoride (SF_6) or hexafluorethane (C_2F_6) in place of nitrogen as the insulating gas in oil-filled transformers were assessed. Screening, qualifying, and extended-life tests were conducted to determine the physical and chemical behavior and electrical insulating performance of SF_6-oil and C_2F_6-oil mixtures; the results were compared with the properties of the currently used nitrogen-oil mixture. The report includes a bibliography. The contractor is Westinghouse Electric Corp. *EPRI Project Manager: Bruce Bernstein*

Development of Power Poles From Fly Ash: Phase 2

EL-1384 Final Report (RP851-1); $6.50

This report describes the development of foamed-glass–fly ash composites and the manufacture of power poles from these materials in a pilot facility. It presents production costs and the results of tests on the poles. The objective was to produce full-size (40-ft) poles, but attempts to fire sections longer than 20 ft were unsuccessful. The contractor is ECP Inc. *EPRI Project Manager: R. S. Tackaberry*

Fault Data Acquisition System and Data Logger for HVDC Compact Terminals

EL-1395 Final Report (RP213-3); $7.25

A baseline fault data acquisition system for high-voltage substations was defined, and a demonstration system was developed and installed on a prototype high-voltage dc link in New York City. The system provides operational, sequence-of-event, and oscillographic fault data. It is also suitable for application at ac substations. The contractor is Boeing Engineering & Construction. *EPRI Project Manager: S. L. Nilsson*

Prototype Fault Current Limiter

EL-1396 Final Report (RP281-2, RP281-4); $5.25

This report describes the development of a switched-resistor fault current limiter for application at 69 kV, 2000 A, with an available fault current level of 6350 A rms. The device is based on a silver-sand fuse commutation concept. In full-power tests, a single-phase prototype repeatedly demonstrated successful first-loop peak limitation. Some components developed in this project—for example, an MgO-filled power resistor of megajoule capacity with fast cool-down characteristics, high-speed chemical bypass and fuse switches, and sensors that detect faults on the basis of di/dt—can also be applied to other kinds of fault current limiters under study. The contractor is Gould-Brown Boveri Inc. *EPRI Project Manager: V. H. Tahiliani*

ENERGY ANALYSIS AND ENVIRONMENT

Analytic Framework for Evaluating Energy and Capacity Shortages

EA-1215 Final Report, Vol. 2 (RP1104-1); $5.75

Methods for assessing the economic and social costs of energy and capacity shortages were developed and applied to two case studies: the 1976–1977 natural gas shortage and the 1978 electricity shortage in Key West, Florida. These case studies are described in detail in other reports (EA-1215, Vol. 1, and EA-1241). This volume summarizes the results and describes how the assessment methods were modified and improved as a result of the case studies. The contractor is Jack Faucett Associates, Inc. *EPRI Project Manager: A. N. Halter*

Revised Coal Resource Estimates: Four Case Studies

EA-1360 Final Report (RP804-2); $8.25

This report presents analyses undertaken to revise the coal resource estimates used in the coal and electric utilities model (CEUM), developed by ICF Incorporated. Coal fields in Illinois, Alaska, and Wyoming and lignite fields in Texas were studied. The shapes of the coal supply curves have been refined, with emphasis on nontonnage information (e.g., overburden ratios, seam thickness, and coal quality). The curves have also been extended to incorporate less desirable and/or less certain resources not included in the Bureau of Mines Demonstrated Reserve Base. The contractor is ICF Incorporated. *EPRI Project Manager: T. E. Browne*

Organic Material Emissions From Holding Ponds at Coal-Fired Power Generation Facilities

EA-1377 Final Report (TPS78-826); $4.50

A literature search was conducted to assess the known and potential organic emissions from coal-fired plant holding ponds. Because of a lack of data on emissions, this report is primarily concerned with known holding-pond influent streams. A theoretical 1000-MW power plant was used in making quantitative estimates of potential emission levels. A bibliography is included. The contractor is Systems, Science & Software. *EPRI Project Manager: P. W. Jones*

Methodology for Assessing Population- and Ecosystem-Level Effects Related to Intake of Cooling Waters

EA-1402 Final Report (RP876); Vol. 1, $14.25; Vol. 2, $11.25

Volume 1 is a handbook of methods for assessing power plant cooling-water intake effects at the population level. It discusses techniques for estimating population size and entrainment and impingement mortality, hvdrologically based models, the use of length data for assessment, the Leslie matrix model, population response analysis, stock-recruitment relationships, life-cycle models, and the LIFETAB code for computing population survival and reproductive characteristics. Volume 2 is a handbook of techniques for assessing cooling-water intake effects at the community level. Two general approaches—one involving stability, diversity, and niche theory and the other involving patterns in space and time—are reviewed in detail. Ecological simulation modeling and other approaches are also discussed. Several computer programs with sample outputs are presented, and guidance on experimental designs, choice of technique, application, and interpretation is offered. The contractor is Lawler, Matusky & Skelly Engineers. *EPRI Project Manager: J. Z. Reynolds*

Development and Evaluation of a Prototype Automated Telephotometer System

EA-1434 Final Report (RP862-14); $3.50

This report describes a compact, automated prototype telephotometer system for measuring visual range during daylight hours and gives the results of performance tests and calibrations. The system can also quantify other important measures of visibility, such as atmospheric discoloration of visual targets, target clarity, and scene texture. It uses a Reticon solid-state line scanner, a computer-controlled rotator, and microcomputers for data acquisition and analysis. The contractor is SRI International. *EPRI Project Manager: G. R. Hilst*

Workshop Proceedings: Noneconomic Factors in Energy Supply and Demand

WS-78-142 Workshop Proceedings; $3.50

The conclusions of a workshop on noneconomic factors in energy forecasting held in Airlie, Virginia, in June 1979 are presented. The participants selected significant noneconomic variables, evaluated different modeling approaches, and recommended future research directions. Summaries of the formal presentations are included. The contractor is Institute for the Future. *EPRI Project Managers: A. N. Halter and T. E. Browne*

NUCLEAR POWER

Evaluation of Near-Term BWR Piping Remedies

NP-1222 Final Report, Vol. 3 (RP701-4); $5.75

Statistical tests were conducted to evaluate four methods for improving the resistance of full-size welded type-304 stainless steel pipe to intergranular stress corrosion cracking: a solution heat treatment after butt welding, two methods involving the application of a corrosion-resistant cladding to the pipe's inside surface, and heat sink welding. The report presents the results of these tests, as well as ultrasonic examination results and failure analyses of failed remedies. The contractor is General Electric Co. *EPRI Project Manager: J. C. Danko*

Single-Nozzle Spray Distribution Analysis

NP-1344 Key Phase Report (RP1377-3); $5.75

This report describes a theoretical investigation of how steam condensation affects the trajectory of spray from a nozzle in an emergency core cooling system. Two mechanisms were investigated: the effect of the pressure gradient in steam on the trajectory of spray droplets, and the direction change of the continuous sheet of water at the nozzle exit as the result of a nearby pressure change. The contractor is Jaycor. *EPRI Project Manager: Mati Merilo*

Transient Modeling of Steam Generator Units in Nuclear Power Plants: Computer Code TRANSG-01

NP-1368 Final Report (RP684-1); $8.75

A one-dimensional computer code for detailed dynamic simulation of the thermal behavior of LWR steam generators during transients is presented. The report describes the code development effort and the basic model details, presents the results of several transient calculations, and summarizes the modest code verification undertaken so far. The models are based on a finite difference formulation and use an extended, implicit, continuous-fluid Eulerian solution method for both fluid compressibility and heating effects. Specific models for once-through and U-tube steam generators are presented. The contractor is University of Michigan. *EPRI Project Manager: S. P. Kalra*

On-Line Power Plant Alarm and Disturbance Analysis System

NP-1379 Final Report (RP891); $7.25

A minicomputer-based disturbance analysis system has been developed to assist operators in the on-line diagnosis and correction of plant disturbances. Models of two selected plant subsystems, the feedwater control system and the component cooling-water system, were developed as a data base for a demonstration system. In testing at a nuclear plant training simulator, the system proved to be technically satisfactory and to enhance the operators' ability to deal with simulated disturbances. The contractors are Combustion Engineering, Inc., and Systems Control, Inc. *EPRI Project Manager: A. B. Long*

Building Effects on Effluent Dispersion From Roof Vents at Nuclear Power Plants

NP-1380 Final Report (RP1073-1); $8.75

This report describes field tests conducted to determine the effect of nuclear power plant structures on the dispersion of effluent plumes. Zinc oxide smoke and sulfur hexafluoride gas were released from different heights on a plant structure and from ground level locations. The plumes were tracked and measured within a 1-km radius of the release point by gas tracer and lidar (light detection and ranging) techniques. Recommendations for improvements in dispersion modeling are included in the report. The contractor is SRI International. *EPRI Project Manager: Henry Till*

Deentrainment and Reentrainment of Droplets in Air-Water Mixture Flow Through a Rod Array and a Perforated Plate

NP-1383 Topical Report (RP443-2); $5.75

The discharge of two-phase flow from reflooded rod bundles into the upper plenum of a PWR might produce liquid phase separation. This report describes an experimental study of the deentrainment and reentrainment of water in air-water two-phase flow mixtures in geometries of vertical rod arrays and horizontal core plates. The results indicate that gas inertia is the main parameter of interest in separation and entrainment behavior. The contractor is Dartmouth College. *EPRI Project Manager: K. H. Sun*

Earthquake Ground Motion Simulation Study

NP-1387 Final Report (TPS79-734); $5.25

The feasibility of using ground motion created by underground nuclear weapons tests for earthquake simulation studies is considered. Ground motion observed in previous tests at the Nevada test site is evaluated in terms of its applicability to the simulation of soil-structure interaction effects; testing at the Pahute Mesa site is also discussed as a possible source of data. A proposed experimental program, with structural models located on both hard rock and alluvial soil, is described. The contractor is Civil Systems, Inc. *EPRI Project Manager: Conway Chan*

^{131}I Studies at TMI Unit 2

NP-1389 Final Report (RP274-06); $5.25

The behavior of ^{131}I released after the accident at the Three Mile Island nuclear plant was studied. Sources of iodine leakage were located and isolated. Efficiencies of the charcoal filters in the plant's ventilation system were monitored, and protection factors for the filtration canisters in face masks were determined. After the initial discharge, iodine release pathways were typical of those during normal operation. Resuspension from contaminated walls was a major source of iodine. The contractor is Science Applications, Inc. *EPRI Project Manager: Henry Till*

CALIPSOS Code Report

NP-1391 Interim Report (S129-1); Vol. 1, $8.25; Vol. 2, $18.00

CALIPSOS is a steady state, three-dimensional flow distribution code for modeling thermal-hydraulic conditions in recirculating steam generators. Volume 1 presents the basic features of the code—its assumptions, the equations solved, the finite difference grid, and highlights of the solution procedure. Volume 2 presents the thermal-hydraulic information contained in the CALIPSOS output for a hypothetical steam generator. The contractor is Combustion Engineering, Inc. *EPRI Project Managers: Gad Hetsroni and D. A. Steininger*

Thermal-Hydraulic Characteristics of a Combustion Engineering Series 67 Steam Generator

NP-1392 Interim Report (S129-1); Vol. 1, $5.75; Vol. 2, $9.50

CALIPSOS, a three-dimensional flow distribution code, was used to determine the steady-state thermal-hydraulic characteristics of a Combustion Engineering Series 67 steam generator at full, intermediate, and low power. Volume 1 describes the CALIPSOS model and presents selected graphic results. Complete numerical results are given in Volume 2, along with guidelines for interpreting this information. The contractor is Combustion Engineering, Inc. *EPRI Project Managers: Gad Hetsroni and D. A. Steininger*

Optical Scanner for Steam Generator Tube Inspection

NP-1397 Final Report (S103-1); $5.25

A prototype solid-state scanner for nondestructive inspection of the interior of steam generator tubes was developed and evaluated. A Reticon self-scanning photodiode array in a scanner head with integral optics and light source was used. The scanner can detect defects 0.2-mm wide and dents 0.1-mm deep, and signal amplitudes can be used to determine width and depth. The scanner's performance was compared with that of a conventional miniaturized vidicon television system. The contractor is Science Applications, Inc. *EPRI Project Manager: G. W. DeYoung*

Application of STEALTH–WHAMS to LOCA Hydroloads Calculations With Multidimensional Nonlinear Fluid-Structure Interaction: STEALTH-1D Single-Phase Fluid Studies

NP-1401 Final Report, Vol. 1 (RP1065); $5.75

The 1D STEALTH computer code was modified to create a code (1D STEALTH–HYDRO) that can simulate acoustic phenomena in piping and vessel networks. The improved code uses control volume models to simulate area changes, orifices, and tees in piping networks. The report describes the theory of these models and compares the results of the 1D STEALTH–HYDRO calculations with analytic results, results of WHAM calculations, and experimental data from a piping and vessel system subjected to rapid decompression. The contractors are Intermountain Technologies Inc. and Science Applications, Inc. *EPRI Project Manager: R. N. Oehlberg*

Rhodium In-Core Detector Sensitivity Depletion

NP-1405 Interim Report (RP1397-1); $3.50

The sensitivity depletion of two rhodium self-powered neutron detectors inside the core of the Oconee-2 PWR has been measured since July 1976. Depletion is determined as a function of electric charge expended (or released) by each detector over the exposure period. Results to date indicate that the depletion rate is linear with expended charge but about 8% smaller than the depletion rate in a pool-type test reactor. The contractor is Babcock & Wilcox Co. *EPRI Project Manager: H. G. Shugars*

Nondestructive Examination Acceptance Standards: Technical Basis and Development of ASME Boiler and Pressure Vessel Code, Section XI, Division 1

NP-1406-SR Special Report; $7.25

Section XI, Division 1, of the ASME Boiler and Pressure Vessel Code presents standards for evaluating flaws detected by nondestructive preservice and in-service inspections of certain nuclear power plant components. This report describes the rationale and technical bases of these standards, which determine a component's adequacy for continued service. It complements an earlier report on flaw evaluation procedures (NP-719-SR) and will serve as a reference document to facilitate future refinement and improvement of the standards. *EPRI Project Manager: J. R. Quinn*

Development of Ultrasonic Tomography for Residual Stress Mapping

NP-1407 Final Report (RP504-2); $4.50

The use of ultrasonic time-of-flight tomography to measure subsurface stress distributions in materials was studied, and a microprocessor-based ultrasonic tomographic instrument system was developed and tested. The report describes the system and its performance; it also discusses the acoustic-elastic effect, materials properties measurement, principles of tomographic reconstruction, and the reflected-beam tomography algorithm developed in the project. The contractor is Battelle, Pacific Northwest Laboratories. *EPRI Project Manager: J. R. Quinn*

Development of an Acoustic Emission Zone Monitor and Recorder for BWR Pipe-Cracking Detection

NP-1408 Final Report (RP505); $4.50

Three prototype field-usable instruments for detecting stress corrosion cracking by acoustic emission monitoring have been designed and built; they have demonstrated reliable operation in initial small-pipe testing. The instruments are based on a zone-isolation source-determination concept and incorporate digital memory chips for data recording. The contractor is Battelle, Pacific Northwest Laboratories. *EPRI Project Manager: J. R. Quinn*

Examination of Steam Generator Tube R45C52 From the Ginna Nuclear Power Plant

NP-1412 Final Report (RP1166-2); $5.25

A tube thought to have incipient inside diameter cracking was removed from a steam generator at the Ginna nuclear plant and examined at hot leg zones on the top of the tubesheet, at tube-support plate intersections, and at antivibration-bar contact points. The examination, which involved radiography, scanning electron microscopy, and energy-dispersive X-ray analyses, did not establish the presence of any process that would develop into tube leakage. However, a bulge in the tube, wall thinning, and a mottled or rippled appearance were noted; these were unexpected and remain unexplained. The contractor is Westinghouse Electric Corp. *EPRI Project Manager: J. A. Mundis*

Measurement of Residual Stresses in Type-304 Stainless Steel Piping Butt Weldments

NP-1413 Phase Report (RP449-1); $5.75

Residual stresses on weldments of 4-, 10-, and 26-in type-304 stainless steel piping were measured by strain gage and X-ray diffraction techniques. Stresses on both the inside surface and the through-wall thickness were measured. Weldments on autopsy pipes and mockups fabricated by following standard nuclear industry procedures were studied. The contractor is Argonne National Laboratory. *EPRI Project Manager: R. E. Smith*

Explosive Metalworking of Type-304 Austenitic Stainless Steel Pipes

NP-1414 Final Report (RP1071-1); $3.50

This report presents an assessment of the feasibility of using explosive metalworking to prevent intergranular stress corrosion cracking in weld-heat-affected zones of type-304 austenitic stainless steel piping. Both cladding techniques and straining techniques were explored. The advantages and limitations of these techniques are reported, along with test results and recommendations for future work. The contractor is Battelle, Columbus Laboratories. *EPRI Project Manager: R. E. Smith*

Numerical Methods for Thermally Expandable Two-Phase Flow: Computation Techniques for Steam Generator Modeling

NP-1416 Key Phase Report (RP963-1); $5.75

Equations and constitutive relations describing two-dimensional, thermally expandable, homogeneous two-phase flow are presented and discussed. Four numerical solution methods for these equations are reviewed. A fully and linearly implicit numerical method is developed that uses a dual-variable transformation technique to reduce the size of the matrix required for inversion at each time step. DUVAL, a computer code incorporating this method, is described briefly, and preliminary numerical results are given. The contractor is University of Pittsburgh. *EPRI Project Managers: P. G. Bailey and L. J. Agee*

Steam Generator Crevice Gap Measurement by Induced-Vibration Analysis

NP-1419 Final Report (S102-1); $3.50

The feasibility of determining the crevice gap between steam generator tubes and support plates by inducing and measuring tube vibratory motion was studied. Testing was performed on a single-tube, multiple-support laboratory rig capable of simulating a variety of field conditions. The vibration analysis techniques accurately measured gap clearances ranging from 1 to 30 mils. The contractor is Anco Engineers, Inc. *EPRI Project Manager: G. W. DeYoung*

Magnetic Flux Leakage for Measurement of Crevice Gap Clearance and Tube Support Plate Inspection

NP-1427 Final Report (S125-1); $4.50

Experimental studies undertaken in this project demonstrated that the variable-reluctance type of probe is sensitive to changes in crevice gap clearance, magnetite buildup, and support plate defects. A finite element model was developed that can be used to predict the probe's output signal. Design studies indicated two possible probe types: a single-Hall-plate, linear-scan (high-speed) probe and a multi-Hall-plate, rotating-scan (low-speed) probe. Experimental versions of both probe types were built and tested. The contractor is Colorado State University. *EPRI Project Manager: G. W. DeYoung*

Thermal-Hydraulic Analysis of Once-Through Steam Generators

NP-1431 Final Report (S131-1); $8.25

A developmental multidimensional code called THEDA was used to model local steady-state thermal-hydraulic conditions for the Babcock & Wilcox Co. once-through steam generator. Best estimates of these conditions are presented, and the sensitivity of the estimates to correlation uncertainties is discussed. The contractor is Babcock & Wilcox Co. *EPRI Project Manager: D. A. Steininger*

Workshop Proceedings: Basic Two-Phase Flow Modeling in Reactor Safety and Performance

WS-78-143 Workshop Proceedings; Vol. 1, $8.25; Vol. 2, $11.25

Multifluid modeling, constitutive relationships, condensation heat transfer, critical flow, advanced instrumentation, boiling heat transfer, and systems and components were covered in a workshop held in Tampa in early 1979. Volume 1 contains transcripts of the discussions, and Volume 2 contains most of the papers presented. The remaining papers were published in the *International Journal of Multiphase Flow*. *EPRI Project Managers: R. B. Duffey and Yoram Zvirin*

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