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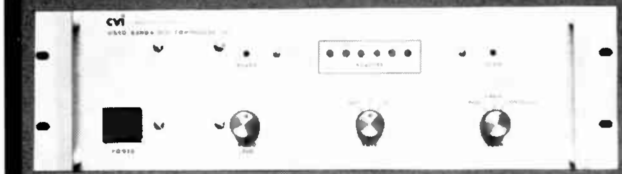

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Refueling one of Rochester Gas and Electric Corporation's nuclear fuel elements at its Ginna Station. Photo courtesy RG&E and the Edison Electric Institute.

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World Radio History

spectrum JUNE VOLUME 11 NUMBER 6

spectral lines

Our circles of concern

One's powers of observation need not be excessively keen to notice that each person and every institution tends to develop its own "circles of concern" regarding specific topics. Although such circles of concern are often geographic in nature, rarely are they literally circles. Sometime they are time-related, in which case they might better be likened to an antenna pattern, one lobe extending backward into history and the other forward into the future.

It is interesting to observe the extremes of circles of concern as they involve individuals. For example, an emotionally maladjusted person might draw the circle tightly about himself, whereas the "normal" person would include his immediate family, certain relatives, and, to some extent, his immediate community. At the other extreme, the exceptional person might concern himself with the "family of man." We observe the circumference of each person's circle through his behavior: the "constricted" individual dumps his refuse into his neighbor's yard; the expansive citizen's respect for the rights and property of others extends to public property as well.

By the same token, institutions exhibit circles of concern. Many companies, under the duress of economic pressures, abandon their social concerns at the company gate. It may be only when they become affluent, or are pressured (or embarrassed) by their competition, or are forced by means of legislation, that they extend their concerns, and, in effect, internalize some of the costs that were previously passed along to the public indiscriminately.

It is apparent that certain professions, by virtue of tradition and/or objectives, have larger circles of concern than others. It is interesting to conjecture about engineering in this respect. How does it compare to the other professions? How has the circle changed in recent years? Is it bigger? Is it better?

We do not mean to imply that bigger circles of concern are always better. Such is not the case. In fact, selecting a circle's boundaries is at once the most critical and the most difficult task. The process is somewhat akin to defining a systems problem, along with its related environment, boundary conditions, etc. Approaching the problem at a "micro" level might prove as ineffectual as approaching it at too "cosmic" a level.

Nevertheless, most of us probably draw our circles with a parsimonious hand rather than with largess. Inertia and conservatism seem always to be present. Furthermore, a natural human tendency is toward disinterest in a problem once it extends beyond the boundaries of comprehension (the scientist is an exception, although even he restricts his major efforts to his special area of interest). Thus, it is simply more immediately gratifying to do something about those things for which we can understand cause and effect than to experiment, sometimes dangerously, in the unknown. Then too, it often makes good sense to take action in regard to those things that seem most apt to pay off quickly.

Technologists, like all humans, tend to discount, with some reason, events that have occurred or may occur at a time or place that is remote. Contrariwise, an event that has just occurred or is highly likely to occur nearby, often assumes crisis dimensions, and, by definition, demands attention and action. (How the degree of discounting affects the size of our circles of concern—whether they occur in the space or time dimension—can perhaps be better understood through a reading of Harold Linstone's article, "Planning: toy or tool?" in the April issue of *Spectrum*.)

In spite of the foregoing factors, all of which tend to mitigate against our setting our concerns at a high enough (or broad enough) level, it appears that engineers are, individually and collectively, broadening their circles of concern. The extended charter of the IEEE is evidence in itself. Another indication is the increasing sensitivity of individual engineers to the social consequences of the application of technology. And one must cite the Institute's Committee for Social Implications of Technology, which is embarked upon projects in the areas of ethics, public communications, national security, and data banks.

Returning to the issue of bigger circles not necessarily being better circles, biting off more than one can chew can obviously lead to failure, frustration, and disillusionment. For example, attempting to develop a valid model of a system at too complex a level, and failing, could easily discourage or delay one from attempting a less ambitious, but usable, model of *part* of the same system. And, in regard to whether engineers are, or are not, as catholic in their interests as physicians or social scientists, that question may be of less importance than whether we are making real attempts to broaden our concerns. Equally important is that such broadening be knowledge-based as opposed to emotion-based (though the factors about which we are learning may well be emotional in nature!). Finally, it is important that our new, well-founded, and well-bounded concerns represent more than academic exercises, but rather, lead to action.

Donald Christiansen, Editor

Power special:

The Critical years

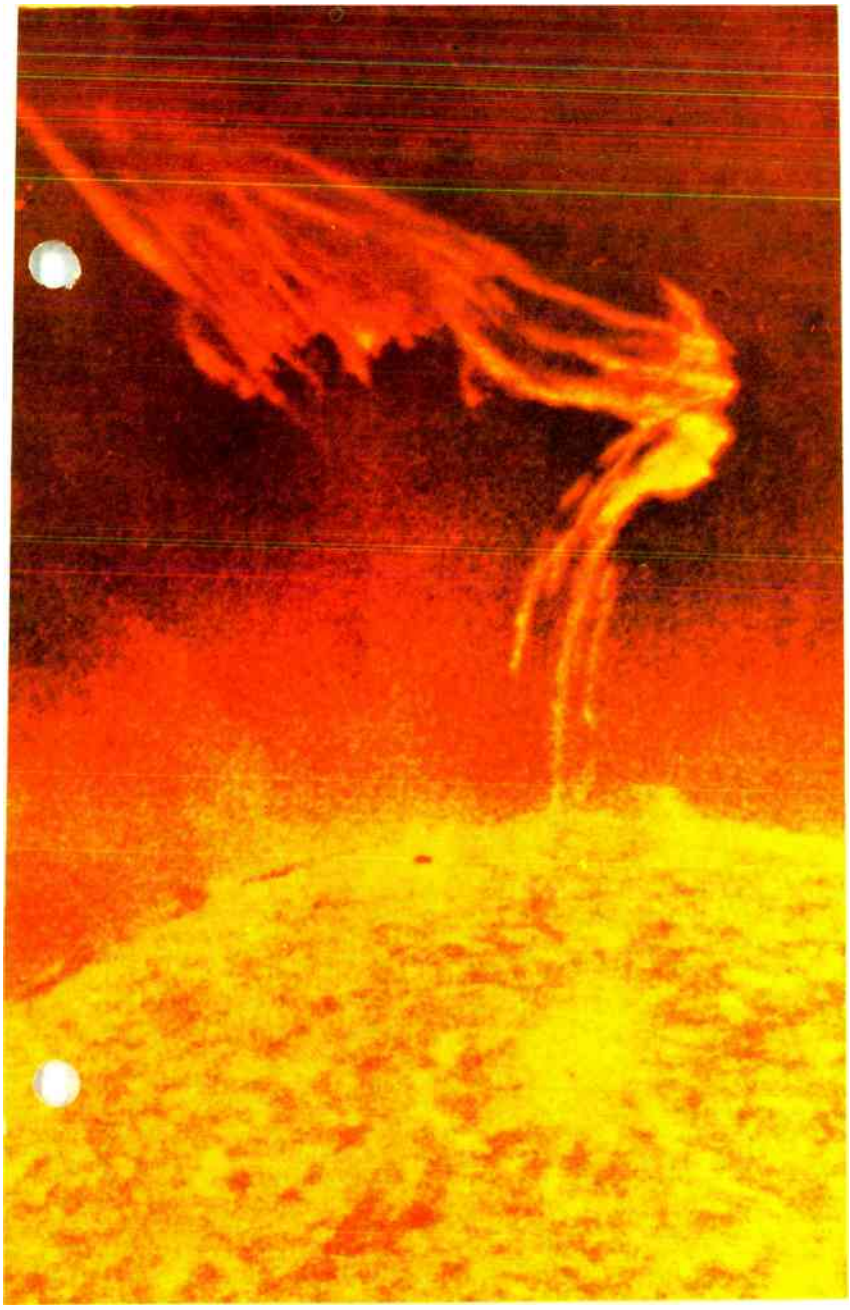
As this issue goes to press, Consolidated Edison, that much maligned electric utility serving New York City's demanding populace, faces bankruptcy unless the New York State legislature takes measures to provide state aid to the ailing power company. Part of its trouble stems from a rise in the utility's oil bill of $450 million, a figure Con Ed chairman Charles Luce notes is more than three times the company's 1973 dividend payments. Undoubtedly Con Ed's problems will be somehow solved. But, coming on the heels of a virtually nationwide shortage of gasoline at consumer pumps, the power company's problem seems just one more in an open-ended series of minicrises that together may characterize the next several years —not only in the U.S., but in advanced nations everywhere.

While *Spectrum* has tried valiantly to stay on top of the energy crisis on an issue-by-issue basis, beginning with "Energy: crisis and challenge" in the May 1973 issue, the task is a difficult one. Hence, this special issue of *Spectrum* is an attempt to both catch up and to summarize.

Three of the articles relate to immediate problems and consequently, in one way or another, to conservation and the efficient use of fuel and electricity. The title of one, "What to tell your neighbors," is written only partially with tongue in cheek, for about 37 percent of all energy consumed in the U.S. is used by the consumer in homes and autos. Not quite half of that goes for heating and air conditioning, and nearly as much is burned up in automobiles. So the check lists of energy saving techniques in this article should be of value not only to your neighbors but to you, yourself.

Among the measures taken to "save" power have been some that are open to question. In the article, "Exploding some myths," those "rules" relating to voltage reduction by power utilities, the switching off of lights by consumers, and the avoidance of heating by electricity are examined, critically, along with several other "mythconceptions" about energy (and cost) savings. The third article in this trio, "How manufacturers cope," is based upon *Spectrum*'s interviews with "energy czars" at several companies faced with the problems of energy conservation. Among the techniques you'll read about are the use of kiln radiation to heat a ceramic maker's plant, the installation of sun-reflecting films on the windows of IBM's San Jose plant, and Western Electric's use of air preheaters for its boilers. Also, this article suggests some ways that electrical/electronics technology can come to its own rescue in both optimizing power usage and in the replacement of energy gobbling devices.

To solve the energy crisis, most experts and enlightened observers agree on broad guidelines. For the short term, each nation does the best it can, relying on available fuels and conservation. For the longer term, most pin their hopes on nuclear energy, augmented by certain less universally applicable energy sources, such as geothermal. To summarize the options, and in particular to elaborate on the role of R&D, we



Power source: The photograph by NASA Skylab 3 astronauts reveals how helium erupting from the sun stays together to altitudes up to 500 000 miles.

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include the article by R. A. Huse of Public Service Electric and Gas (PSEG) entitled, "Breaking the crisis." Computers play a role worthy of separate consideration, and this is treated at length in the article, "Controlling and optimizing power systems," by William F. Tinney and Mark K. Enns, who are guest editors of the July 1974 *Proceedings of the IEEE*, a special issue on this same topic.

Many electric utilities are involved in evaluating the options discussed in the aforementioned two articles. *Spectrum* thought it appropriate to probe in greater depth how one of them is planning its future while at the same time living through its everyday operating problems. We selected American Power Co. for the "profile" story, "The 'other' power company."

Finally, *Spectrum* interviewed T. H. (Tom) Lee, the president of IEEE's Power Engineering Society. Mr. Lee's views concerning the energy crisis and the role of P.E.S. are presented on page 46.

In addition to the articles in this special issue the following energy-related articles previously published in *Spectrum* are commended to your attention: "Toward a national energy policy," June 1973; "Oil: the omnipotent energy source," July 1973; "Conservation: a positive position," August 1973; "Energy options for the United States," Sept. 1973; "Plumbing the ocean depths: a new source of power," Oct. 1973; "Energy conservation by design," Nov. 1973; "Power/Energy: problems and progress," Jan. 1974; "The fast-breeder reactor: when, where, why, and how?" Feb. 1974; "The energy outlook: ways to go," March 1974; and "A sunny outlook for solar power," April 1974.

Donald Christiansen Editor

Breaking the crisis

Options cover primary energy resource recovery, fuel conditioning, conversion, improved transmission, and storage

No industrialized nation can continue to ignore the serious depletion of fuel supplies that led to a near panic during the Arab oil embargo. Unless new options can be developed quickly, even the most stringent conservation measures will not prevent eventual "enervation." Recognizing this fact, the United States, and also its industrial competitors, has embarked on a major effort to discover and weigh all available near-term and long-term technological "solutions" to impending fuel shortages.

Spectrum has already discussed the domestic oil and gas resources of the United States,[1] which supply about three quarters of our present energy and are so limited that we have begun to heavily import these fuels. As the standard of living in other parts of the world improves, we will no longer be able to continue consuming one third of the world's energy as we do today. It is clear that coal will be available for some time to come, but its restricted use in recent years results from problems that remain to be resolved.

Two major strategies are available to reduce dependence on oil and natural gas; namely, fuel substitution and reduced consumption. At present, coal and nuclear fuels can substitute for oil in central station applications and coal can be liquefied or gasified. In the long term, however, nuclear energy may be used to produce hydrogen through thermochemical water splitting or electrolyzers. In turn, hydrogen can be used directly, converted to make electricity via fuel cells, or used in the production of other gaseous or liquid fuels by hydrogenation of coal.

Advances in energy conversion can result in improved efficiency as well as the use of previously uneconomic energy resources. In the meantime, the wise use of energy is important in providing the time necessary to identify long-term solutions.

Many technological options exist for primary energy resource recovery, fuel conditioning or processing, conversion, transmission, and storage. Some of these options are summarized in Table I, and many of the more likely possibilities will be reviewed in this article.

Nuclear energy—a near-term option

The most promising immediate relief from the dependence on fossil fuels has been from fission reactors. To fuel these reactors, however, requires a large increase in uranium mining and fuel processing, since the conventional light-water reactor (LWR) utilizes less than two percent of the energy derived from uranium ore. The breeder reactor is expected to increase this to nearly 75 percent and will also permit the use of thorium (Th), from which the fissile U233 can be bred.

The need for breeders is apparent after a brief look at the uranium supply picture. Annual uranium requirements (yellowcake) in 1990 are estimated to be about 100 000 tons. Total reserves (at $15/lb) are thought to be about 520 000 tons with an additional one million tons in "potential" resources; that is, uranium that may exist at $15/lb. Foreign resources, while somewhat larger than those in the U.S., are not considered available because of foreign demand.

These uranium requirements imply a tenfold increase in annual domestic uranium production over the next 20 years. In addition, to maintain the 1990 level of reserves plus "potential" resources recommended by the AEC, some four million additional tons will need to be found, although the discovery rate of about 5 lb/ft of drilling in the 1960s fell to 1.8 lb/ft in 1972. Even at double the 1972 rate, one billion feet of drilling will be required by 1990.

In the last decade of this century, when the breeder is expected to reduce growth in uranium ore requirements, a continuing annual demand of 100 000 to 150 000 tons is estimated. If the breeder is not commercially available by 1990, uranium demands will be even greater.

The liquid-metal fast breeder reactor (LMFBR) has been given high national priority and a demonstration plant is being built on the Tennessee Valley Authority (TVA) system through a joint Government–industry program in which Public Service Electric and Gas Company (PSE&G) is participating. Roughly $2.5 billion is expected to be spent between 1975 and 1979 for the development of the LMFBR. At present, there is concern regarding the predicted low breeding ratio of the demonstration plant (doubling time of 30 years or more). Development options for improvement are under study.

Another promising breeder concept that has not received the national priority of the LMFBR nor the intensive engineering development is the gas-cooled fast breeder reactor (GCFR), which is inherently capable of very high breeding ratios (doubling time of 10 years or less). High breeding ratios are possible because of the lower neutron absorption of the helium coolant. PSE&G and others are financially supporting development of this reactor at Gulf General Atomic. Further, the high breeding ratio offers the possibility of producing enough fuel for several conventional converter reactors, hence minimizing the number of breeders necessary.

The energy available from fission reactors with breeding is very large and is capable of meeting our

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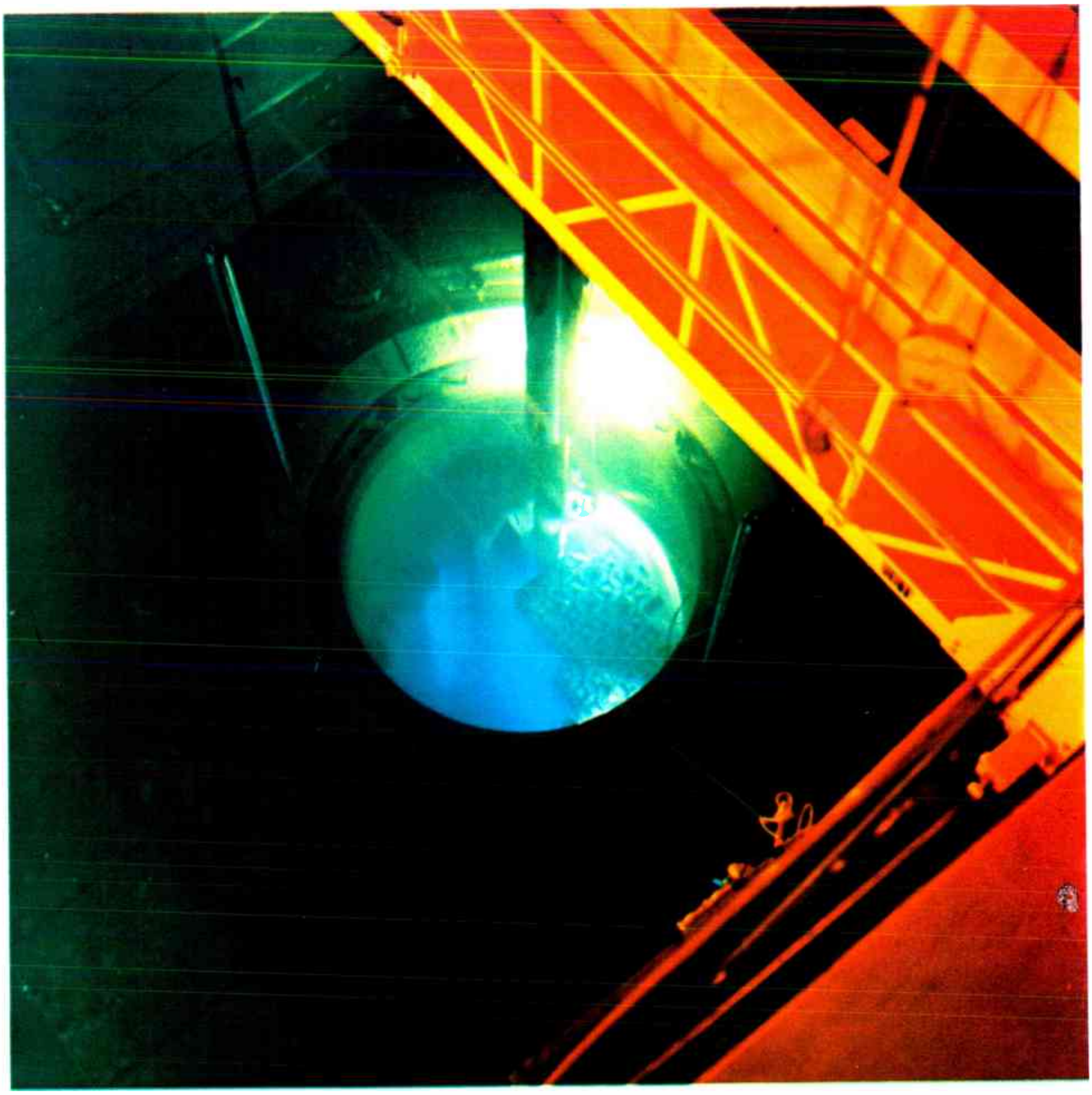
R. A. Huse
Public Service Electric and Gas Company



Fuel assemblies are being replaced in a reactor core cavity during refueling of Unit 1 of the Point Beach Nuclear Plant that is owned and operated by Wisconsin Electric Company. This generating station is situated north of Two Rivers, Wis. (Photo is reproduced through the courtesy of the Edison Electric Institute, New York, N.Y.)

future energy requirements for some time.[2] With \$15/lb uranium (including potential), approximately 100 × 10^{18} Btu is available or twice U.S. fossil reserves. If uranium available at \$100/lb is considered, the available energy is increased by a factor of about 17. The energy content of this ore, however, is very low (see Table II).

In addition to the approaches to breeders just described, there are also hybrid (fission/fusion) approaches. Such hybrids would incorporate a fusion reactor as a neutron source. Either a magnetic-confinement or an inertial-confinement (laser) fusion device could be used. Here the design would not be that of a power-producing plant, but would be a processing facility producing fuels for conventional reactors.

Coal: the most abundant fossil resource

Coal is the other large energy source that, with technological advances, could be used in the near future with greater environmental acceptability. Today it is burned in steam boilers and the combustion gases emerging from the stack are cleaned with electrostatic precipitators. Whether or not scrubbers to remove sulfur dioxide can be considered commercially available today is hotly debated; the other option, which has met strong environmental objection, is to disperse the effluent gas at high altitudes by means of tall stacks.

More advanced combustion processes are also under study. In fluidized bed combustion, the coal undergoes combustion in an air suspension. Heat-transfer surfaces in the bed permit improved heat removal and thus allow lower combustion temperatures with a consequently reduced production rate of nitrogen oxides; lime introduced into the bed removes sulfur. Binary cycles with liquid-metal "topping cycles" offer improved power-plant efficiencies (50 percent)

I. Power technology options

Resource

- Fission
  - U235, Th233, Pu239
- Fusion
  - D–D, D–T–Li
- Fossil fuels
  - Coal, oil, gas, oil shale, tar sand
- Hydropower
- Geothermal
  - Brine, hot rock, steam
- Solar
  - Terrestrial
  - Orbiting satellite
- Organic wastes
- Wood
- Tidal
- Wind
- Thermocline

Fuel Conditioning

- Enrichment and reprocessing
- Desulfurization
- Gasification
  - Low-Btu, high-Btu
- Solvent refining
- Hydrogen production

Conversion

- Nuclear reactors
  - LWR, HWR, HTGR
  - Nuclear–gas turbine
  - Breeder reactors
    - LMFBR, GCFR, MSR, hybrids
- Fusion
  - Magnetic confinement
  - Laser
- Steam turbine
- Hydraulic turbine
- Combustion turbine
- Diesel
- Combined cycle
  - Gas turbine–steam
  - Potassium–steam
  - Steam–ammonia
- Fuel cells
  - Acid, alkaline
  - Molten carbonate
- Magnetohydrodynamic
  - Open, closed, nuclear
- Feher
- Solar
  - Concentrators
  - Flat plate collectors
  - Photovoltaics
  - Photosynthesis
- Other
  - Aerogenerator
  - Thermionic
  - Thermoelectric

Transmission and Distribution

- Electric
  - Open wire
  - Conventional cable
  - Cryogenic cable
  - Superconducting cable
  - Microwave
  - Laser
- Fuel
  - Truck
  - Train
  - Barge
  - Tanker
  - Pipeline
  - Conveyor

Energy Storage

- Pumped hydro
  - Conventional
  - Underground
- Compressed air
- Batteries
  - Lead acid
  - Sodium/sulfur
  - Lithium/metal sulfide
  - Zinc/chlorine
- Hydrogen
  - Compressed gas
  - Liquid
  - Metal hydride
- Electromagnetic
- Thermal
- Flywheels

and could be used in conjunction with conventional boilers or fluidized bed combusters. General Electric Co. is now performing an economic analysis of liquid-metal topping cycles and a boiler tube bundle and combustor are being designed and operated at Oak Ridge National Laboratory.

Magnetohydrodynamics (MHD) is another combustion approach that has been emphasized, particularly as an improved method of coal combustion. Serious problems such as generator channel life, seed and NO_x removal, flow stability, and air preheating have prevented development, however. Although projected efficiencies are in the 50–60-percent range, other energy conversion devices, such as high-temperature gas turbines, are expected to have comparable performance with less extrapolation of technology.

Coal gasification

The other basic approach to the use of coal is gasification to produce either a high-Btu, pipeline quality gas (1000 Btu per cubic foot) or a low-Btu industrial gas (100 to 500 Btu per cubic foot). Sulfur is also removed during the process. The high-Btu gas is preferable if it is to be transmitted over appreciable distances for consumption; the low-Btu gas offers economic advantages if it can be used in nearby industrial processes or electric generation. The energy efficiency of advanced high-Btu processes is projected at about 65 percent and about 90 percent for low-Btu gas.

Three processes are commercially available today for the gasification of coal; namely, the Lurgi process, the Koppers–Totzek process, and the Davy Powergas Winkler process. Several Lurgi plants are now being built to improve system performance and increase the range of coals the process can accept. As the gasification stage produces a mixture of carbon monoxide and hydrogen, a final methanation step is required to produce high-Btu pipeline quality gas (methane). Methanation is not yet a commercial process but a pilot plant is now in operation.

A number of more advanced gasification processes are now being studied for high-Btu gas production. One common problem is the supply of heat for com-

II. Effective energy content of uranium ores[3]

U_3O_8 Ore Concentration, ppm	U_3O_8, cost/lb	Effective Ore Energy Content	
		Fast Breeder (75% Utilization), Btu/ton	LWR (1% Utilization), Btu/ton
Greater than			
1600	Up to $10	720×10^8	960×10^6
1000	Up to $15	450×10^8	600×10^6
200	Up to $30	90×10^8	120×10^6
60	Up to $50	27×10^8	36×10^6
25	Up to $100	11×10^8	15×10^6

Note. There are 60×10^{12} Btu/ton of U_3O_8, and 26×10^6 Btu/ton of coal.

plete gasification. This can be accomplished by combustion of the coal or by an external source. Gas-cooled nuclear reactors (HTGRs) are being studied as a possible external heat source as they are capable of producing sufficiently high outlet temperatures. An example of a well-advanced, large-scale coal gasification pilot plant is the HYGAS process operated by the Institute of Gas Technology located in the Chicago, Ill., area. This facility, now in partial operation, is capable of converting any type of coal into methane with minimal environmental pollution. The project is sponsored by the American Gas Association (AGA) in cooperation with the U.S. Department of Interior, Office of Coal Research. Research in this area is highly desirable and PSE&G is contributing to the project. It is expected that a number of the advanced processes for the production of high-Btu gas will also be adaptable to the production of low-Btu gas.

Shale oil has been identified as a large alternative source of oil, which could become competitive at a price of approximately $8/barrel. Projections for a shale oil industry have suggested that, by 1985, a production level of one million barrels per day could be achieved (present U.S. consumption is 17 million barrels/day), with a maximum rate of five million barrels/day, water availability being the limiting factor.

Transmission

A high-priority research objective is the improved utilization of scarce transmission rights-of-way to carry larger amounts of energy. Research work on ultra high voltage (UHV) funded by electric utilities is helping to provide a thorough understanding of the electrical characteristics of tower structure and conductor configuration requirements for transmission in the 1000–1500-kV ac range. Health, safety, and audible noise considerations may determine overall designs because of the electric field gradients involved. Moreover, dc transmission research is tackling problems in the areas of switching, circuit breakers, optimum control, and more compact, efficient, and inexpensive terminals.

In the field of underground transmission R&D, the Electric Power Research Institute (EPRI) has a comprehensive program initiated by the Electric Research Council in 1965 and now funded at nearly $20 million covering 29 separate projects. Briefly stated, the objectives are to increase voltages and power-handling capabilities of state-of-the-art systems and develop new systems that will meet the needs of the utilities at least through the year 2000. Ultimately, it is hoped that costs may be cut by as much as 50 percent but even this will be more expensive than overhead transmission.

An essential element in the acceptance of any new system is the demonstration of its ability to render dependable long-term service. To meet the need for a test facility that subjects cable systems to accelerated aging tests under field conditions, Westinghouse Electric Corp. has built the world's most advanced cable test facility at Waltz Mill near Pittsburgh, Pa. This prototype 1100-kV substation has 6 EHV test bays for testing 345–800-kV cables and 6 HV test bays for cables below 345 kV.

Several projects are also directed toward the paper- and oil-insulated pipe-type systems, forming the bulk of U.S. underground transmission. Cables suitable for 500 kV have successfully completed a scheduled two-year test. The results have been so encouraging that the same cables are now being tested for 800-kV operation. In addition, forced cooling will be installed to demonstrate the feasibility of using conventional ca-

Meeting peak loads—maximizing technology

To meet the intermediate and peaking loads of electric utilities, several types of systems are now being considered. In one way or another, they all rely on premium fuels; namely, oil, pipeline gas, or synthetic gas. This same function can be performed by energy storage, which permits the substitution of off-peak nuclear and coal energy for the use of premium-priced distillates and gas.

Of particular interest in energy storage is the projection that within ten years high-capacity batteries will be commercially available. Examples include sodium/sulfur, lithium/metal sulfide, and zinc/chlorine. Serious efforts are also under way to use hydrogen for storing enery. At our PSE&G Laboratory, we are now operating an electrolyzer during off-peak times to produce hydrogen, which is then stored in a metal hydride (iron–titanium) and subsequently converted to electricity with a fuel cell (12.5 kW).

Combined gas–turbine–steam cycles have been widely discussed as an efficient method for meeting intermediate loads and substantial R&D has been carried out on these systems by the turbine manufacturers. Such systems operating on pipeline gas or light oils are being installed by electric utilities today, but efficiencies are limited to about 40 percent by present turbine inlet temperatures (1800°F). Improvements in efficiency to 45–50 percent are possible with higher inlet temperatures; cooling the blades with a thin film of air or using ceramics to reduce deterioration is being studied. Since oil or gas is used for fuel, an important consideration is availability. Coupling these plants with a low-Btu gasification system is one promising option. A Lurgi gasifier will be installed on the Commonwealth Edison system in conjunction with EPRI for use with an existing boiler. The gasifier will be the equivalent of a 70-MWe (electrical megawatt) unit.

The fuel cell is another intermediate or peak load option that appears promising and PSE&G and other companies support it as part of a three-year, $42 million development program with Pratt & Whitney Aircraft. The goal of the program is to make 26 MWe units commercially available by the end of this decade. Unlike combustion devices, fuel cells generate power electrochemically and this leads to a number of advantages, which are:

- High thermal efficiency at rated or partial load
- Very low pollution levels
- Minimal noise
- Heat rejection to air
- Modular construction permitting a wide-capacity range using standard components
- Automatic operation
- Multiple units easily operated in parallel

bles in an 800-kV, 2000-MVA line. Additional projects to develop prefabricated splices and to improve the engineering of forced cooling of conventional cables are in progress.

Conventional paper-insulated cables when used at 500-kV and higher voltages are severely limited in capacity by charging current and heating from dielectric losses. Over the last 15 years there have been numerous attempts to develop economic EHV cables with new types of low-loss synthetic insulation. Two projects now nearing completion are the development of 500-kV and 750-kV samples for testing at Waltz Mill.

Cables insulated with compressed SF_6 gas are now being installed at 230 kV and 345 kV in applications where short, high-capacity links are required. These cables appear to be technically suitable for 500 kV and above. EPRI has several projects for further development—one at M.I.T. for basic insulation studies, another for the development of a system with three phases in a single pipe, and a third exploring design optimization.

In the more distant future when circuit capacities of 4000 to 10 000 MVA may be required, cryogenic and superconducting cables are promising candidates. Two cryogenic cable types are presently under development. Both cool their aluminum conductors to the temperature of liquid nitrogen, thereby reducing the conductor resistance and the consequent loss to 10 percent of a conventional cable. One of the cryogenic

Looking Ahead

Future energy needs, not just electric power needs, will flow largely from nuclear, coal, and—to a much lesser extent—solar and geothermal energy conversion. Nuclear fission, which is just now getting under way, may well be followed in the 1990s by nuclear fusion. This is not long on a utility time scale, as it now takes 12 years to complete a nuclear plant. Before fusion becomes available, however, we can expect breeding of fertile material to extend, to a significant degree, the fuel supply of fission reactors. In this, there are three major options: liquid-metal, gas-cooled, and possibly fusion breeder reactors.

As the U.S. becomes more dependent on nuclear reactors for its total energy requirements, we can expect this type of energy to be used to produce industrial fuels such as hydrogen and methane, as well as chemical feedstocks. This can broaden and diversify the base of utility operations.

In parallel with our nuclear effort, we must learn how to use coal more effectively, including its mining, processing, transport, and utilization. There is excellent work going on in coal refining, but much remains to be done.

Most of us in the utility field have looked a little askance at solar energy. Although there were good reasons for this initial reservation, rapidly increasing fuel costs and improvements in solar collectors and converters make for an entirely new ball game. While solar energy reaches us through unpredictable meteorologic conditions and as a diffuse source, it nevertheless is limitless and readily available for reasonable lengths of time. Certainly by the end of the decade, we will see solar energy used as a source for water heating, and space heating and cooling in some new homes, particularly in southern regions. In turn, this application will extend to commercial buildings, especially shopping centers, and some industrial centers. Utilities can expect to provide backup power when the stored solar energy is inadequate.

Finally, electric utilities should not overlook the fact that they are in the energy business and provide *only ten percent* of end-use energy needs. They should also be prepared to adapt operations to changing conditions, particularly as population densities increase. Electric generation, for instance, may find itself banned from large population areas, making long-distance importation of clean energy absolutely necessary. While this may be achieved by high-capacity underground cables, the possibility of gas or liquid sources of energy delivered by pipelines and tankers cannot be ruled out.—*R.A.H.*

The case for more R&D

Beginning perhaps ten years ago, serious concern developed in the U.S. over the public utilities' ability to assure the continuing availability of energy supplies. In the late sixties, it had become apparent that a greatly expanded national R&D effort was essential for the viability of the electric industry. It was also recognized that new and improved ways had to be found to meet energy needs and that this could only be accomplished through a well-conceived R&D program. In fact, the nation's survival literally depended on its ability to be in the forefront of energy R&D.

In recent months, consumers, not just in the U.S. but across the globe, have had brought home to them the potentially serious nature of long-term shortages of low-cost energy. In the U.S., both the Federal government and the electric utilities are engaging in concerted efforts to eliminate such future shortages as would result from insufficient R&D.

For its part, the electric utility industry has undertaken a coordinated R&D program that is national in scope. This program is documented in the R&D Goals Task Force report to the Electric Research Council submitted in June 1971. Entitled "Electric Utility Industry Research and Development Goals Through the Year 2000," this "Goals" report proposed the establishment of an Electric Power Research Institute (EPRI). This Institute is now located in Palo Alto, California, and is undertaking its responsibility to manage and coordinate an industry-wide research effort. As of the end of 1973, there were nearly 400 member organizations of EPRI, with the formula for member contributions being 0.5 percent of present yearly revenues, rising to 1 percent in several years. Over $60 million was pledged in 1973, and $96 million for 1974.

At the same time, the Federal government is embarking upon Project Independence. This program is aimed at insuring self-sufficiency in energy by 1980, and requires a commitment to a long-range R&D strategy with initial emphasis upon short- and intermediate-term results.

Of course, in the near term, only "off-the-shelf R&D" can have an impact—i.e., R&D already accomplished but not yet utilized. In the intermediate term, large-scale programs based upon well-advanced, existing R&D efforts coupled with present laboratory and pilot plant operations can lead to the rapid development of commercially available equipment. For the long term, the author believes that only a strong, well-balanced program can provide the necessary momentum to ensure success. In the Federal government, this may well require a cabinet-level energy agency.—*R.A.H.*

cables utilizes insulation of synthetic tapes while the other uses vacuum as the insulation. Such cables will probably have capacities in the 3000- to 5000-MVA range. Superconducting cables with the conductor cooled to the point of vanishing resistance by liquid helium have capacities up to 10 000 MVA. Such cables are under development but so much remains to be done that they may not be commercially developed until the 1990s.

Long-term energy options

Geothermal and solar conversion techniques provide two long-range, potentially large, energy sources, although both have the fundamental disadvantages of being diffuse (low energy density) and to some extent geographically constrained.

The heat of the earth—geothermal energy—is an energy resource that is coming of age today in the western part of the United States. Geothermal resources can be placed into four general categories: (1) dry steam, (2) wet steam, (3) hot water and brines, and (4) hot rocks. Of these, dry steam is considered the most desirable by the electric utilities for use in power generation.

Large-scale geothermal operating experience comes mainly from the 302-MW Geysers plant. Here, the geothermal wells operated by Union Oil Company supply dry steam to Pacific Gas & Electric Company. Steam from the wells is collected, filtered, and passed through turbines at approximately 100 psi and 350°F. The total potential at the Geysers is at least 1000 MW and may be substantially more.

Techniques to extract heat from hot dry rock at moderate depth are under investigation at the Los Alamos Scientific Laboratory. Hydraulic fracturing of the hot rock would permit the circulation of cool water down one well, and subsequent heating and returning through another well to a surface power station. The development of such an approach could lead to a wider use of geothermal energy.

At present, the U.S. geothermal potential is being carefully assessed. One recent estimate by the Department of the Interior's Panel on Geothermal Energy Resources indicated that at least 19 000 MW of generating capacity could be installed by 1985 using technology presently available or under development, and more than 75 000 MW by the year 2000. More optimistic estimates of the magnitude of the economic geothermal reserves exist and the ultimate geothermal potential warrants closer examination.

Despite the optimistic outlook for geothermal energy there are substantial technical problems remaining to be solved. In particular, most potential sources have environmental problems that include dissipation of unused heat, noise, air pollution (hydrogen sulfide and ammonia), land subsidence, brine disposal, and the inducement of earthquakes.

Solar energy research is currently being directed toward heating and cooling of buildings, supplying hot water, producing electricity, and developing clean fuels from organic materials through photosynthesis and plant growth. (See April *Spectrum*'s "Perspective" on solar energy.[4]) Of immediate concern to utilities are programs to develop solar climate-control systems that would use supplemental heat from a gas furnace, electric resistance heaters, or heat pumps.

Studies on conversion of solar energy to electricity will investigate thermal, photovoltaic, wind power, and ocean thermal applications. While each of these program areas will result in demonstration projects, the development schedule for wind power systems is worth noting. The current NSF program calls for the completion of system proof-of-concept experiments for a 5–10-MWe system by 1978.

The direct conversion of solar energy to electricity by solar cells is prohibitively expensive today for utility applications and would require excessive land areas. Technical breakthroughs, however, could occur. If, in 15 to 20 years, low-cost and efficient solar cells are developed, this could have a marked effect on the electric power industry.

In addition to the Federal research program, other efforts are under way and some have received considerable recent attention. For example, the Arthur D. Little Company is conducting a program in conjunction with a large number of companies to develop a solar climate control industry. If successful, this could lead to commercial ventures and the marketing of solar climate control equipment in the near future.

Solar water and space heating devices may be widely available and economically competitive for residential and commercial use within 5 to 10 years; solar air-conditioning systems may be available shortly thereafter. The prospects for central-station solar power are not as optimistic however, but significant breakthroughs could result in these systems also becoming economically viable.

Fusion

Nuclear fusion offers the possibility of meeting man's energy needs indefinitely with potentially little adverse effect on the environment. Among the principal advantages are:

1. An effectively infinite supply of fuel—deuterium—is available from the oceans at low cost. Lithium, to be used in first-generation reactors, is required to breed tritium (another fuel used), for which there is a large, but finite supply.
2. Inherent safety with no possibility of nuclear run-away.
3. No chemical combustion products.
4. Less radioactivity and attendent hazards than associated with fission reactors.
5. No emergency reactor core cooling problem.
6. No use of weapons-grade fissionable nuclear materials; no possibility of diversion for clandestine purposes with existing weapon technology.

Two basic approaches for the confinement of reacting fusion plasma are currently under investigation—namely, inertial and magnetic. Inertial confinement, used in conjunction with lasers, uses high-power, shaped light pulses to heat and compress a millimeter-size fuel pellet, initiating fusion and producing a net energy gain before it has a chance to fly apart. Several kilowatt hours of energy would typically be released per pulse so that, for a one-second repetition rate, thermal power levels of the order of 10 MW would be achieved. The concept of laser fusion is new and not as well developed as the magnetic confinement approach, but the FY 1974 Federal budget in this area was $44 million, largely for the efforts at the Livermore and Los Alamos Laboratories. For FY

1975, $66 million has been earmarked for laser fusion.

One of the magnetic confinement concepts that appears to offer the earliest chance of success is that of the torus. Results in the past few years in Russia, as well as at Princeton and Oak Ridge, have demonstrated favorable plasma behavior as the dimensions of the torus were increased. Princeton is now constructing the world's largest toroidal device (PLT-I), which may be characterized as a credibility experiment in that, if it demonstrates plasma behavior in accordance with present ideas of scaling with size, it will be reasonably certain that the plasma confinement problem has been solved. This device is scheduled for operation in mid-1975.

If the scientific feasibility of plasma confinement from a plasma physics standpoint is established by the end of this decade, possibly with one further device, an optimistic development program could have a fusion reactor commercially available by the end of this century. Such a reactor would be large, perhaps 2000 MWe, and would have an efficiency of about 40 percent using a DT (deuterium-tritium) reaction and a thermal cycle. The reactor development must solve a number of difficult problems[5] such as: lifetime of the first or inner reactor wall under intense neutron bombardment, fabrication of large high-field superconducting coils (16 meters in diameter), injection of fuel, and removal of reaction products.

Recently a new, two-component, toroidal reactor (TCT) concept has been given high priority and preliminary designs have been initiated. In this plan, a low-temperature plasma (tritium) would be confined at temperatures of several kiloelectron volts (a few tens of millions of degrees) and bombarded with an ion beam (deuterium) at perhaps 150 keV. Construction of a small test reactor could be initiated in the next several years. Significantly, this device, dubbed the "Wet Wood Burner," could have breeding capability.

PSE&G and a number of other utilities have strongly supported fusion and the Electric Power Research Institute now indicates it plans to spend several million dollars annually on fusion research.

Reducing waste: a move toward the future

To buy time for developing future energy options and avoiding needless waste of energy, much can and should be done in the area of energy conservation. Several factors, however, affect the rate at which conservation measures become effective. In the short term, the limiting factor is in developing a proper combination of incentives and regulations to reduce energy waste by consumers and to encourage invest-

Tom Lee speaks out

"There are no short-range shortcuts to plentiful energy supplies." So says Thomas H. Lee, newly inaugurated president of IEEE's Power Engineering Society. But the fact that Dr. Lee views the fuel/energy shortage as a problem likely to continue to plague us for a long time to come does not imply pessimism in his nature. Rather, he sees himself as a realist who believes that technological progress is achieved one step at a time, and that dramatic technological breakthroughs will offer no facile panaceas to the consequences of expanding populations and industrial economies.

These and other opinions were expressed by Dr. Lee during a March interview in his Philadelphia, Pa., office—an interview repeatedly interrupted by Power Engineering Society business via telephone. A medium-built, wiry man who exudes boundless energy (and what could be more appropriate for a president of the Power Engineering Society!), Lee is manager of the Group Technical Research operation of General Electric's Power Delivery Group. A Fellow of IEEE, his citation reads: "For contributions in the field of high-temperature arc plasma and in research and development of high-power circuit interrupters." But beyond just credentials, Dr. Lee's opinions warrant attention.

Ordering of energy priorities

In keeping with his basic philosophy, Lee believes that a logical evolutionary sequence should be followed in the development of new and practical energy sources; and, in this process, the cart cannot be put before the horse. Thus, fast-breeder reactors (FBRs) are the logical next step in nuclear power generation. He asserts that the power industry cannot bypass FBR development by pumping billions of dollars into a crash program that seeks a breakthrough into practical generation by nuclear fusion. Power by nuclear fusion processes is a long way off, and we should discard the notion that huge appropriations of money are a guarantee of "near-instant success" in any endeavor we decide to underwrite. No, Lee is convinced, dollars are not the answer; scientific and engineering talent is a higher priority need.

The utilities, consulting engineers, and the electrical suppliers will need more and better trained engineers to meet the challenging problems of today and tomorrow. Means and incentives must be found to reverse the current attrition in engineering enrollments at our universities and technical schools. And, because energy and power are basic to all industry, there must be a resurgence in the number of talented power engineers.

Tom Lee is basically conservative in his outlook and philosophy; but, his conservatism encompasses progress built upon a foundation of solid and proven accomplishment. Although he foresees an eventual important role for both nuclear fusion and solar power, he is amused and bemused by the strident clamor (principally by laymen, but also by some scientists who should know better) demanding both funding and pursuit to operational reality of these energy sources on, literally, an overnight basis.

Fuel and environment

In this important area, Lee foresees some necessary compromises in the public interest. For examment in more efficient plants and processes.

A second factor is the time and financial undertaking necessary to replace massive investments in existing less-efficient plants and equipment by both utilities and users. The rate at which existing structures, equipment, vehicles, and appliances can be retired and replaced sets the pace at which the benefits of conservation can grow. Good examples of equipment that can save energy are heat pumps and electric cars. The economic impacts of changes in energy-use patterns are complex and the added problems of early write-off for energy-efficient replacements can cause severe strain. Moreover, the energy investment in plant replacement must be weighed against operational savings of new processes.

Technology is a longer range pacing factor assuming greater importance as major system elements are retired and replaced with wholly new designs. Technology must be developed, therefore, to insure the efficient use of presently available energy sources and permit the use of other sources as they become available through R&D.

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Mr. Huse received the B.S. degree in electrical engineering from the University of New Hampshire and the M.S. in E.E. from Harvard. Starting as a cadet engineer with Public Service Electric and Gas Company of Newark, N.J., in 1939, he subsequently has held various positions and is presently Manager of R&D. During World War II, he served with the U.S. Navy.

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ple, the U.S. can ill afford to be the hostage of the oil-producing nations if they periodically decide to "shut off the valve" for political reasons. Therefore, it is in the self-interest of the United States to pursue the development of its own potential fuel resources with expedition coupled with necessary environmental safeguards that reflect reasonable attitudes. We know that our potential supplies of coal and shale oil are adequate to a time far into the future; however, some environmental sacrifices will have to be made to extract fuel from these sources. The Alaska pipeline, too, despite the controversial nature of the project, will have to be constructed to mitigate the impact of future oil shortages.

PES policy

In general, Dr. Lee emphasizes his personal dedication to a primary constitutional objective of the PES: "Easing the burdens of mankind by augmenting and amplifying, through the use of electric energy, the meager and insufficient energies available to him for his own capabilities." As a result, he believes in the expanded utilization of electric energy through assuring modern society a plentiful supply of this form of energy. Furthermore, he subscribes to a salient clause in the PES constitution that commits the professional discipline of power engineering to ensuring "the application of electric energy instantaneously at power levels suited to the need, whether it be the massive amounts required to turn the wheels of industry or to provide the essentials for a humane environment, or whether it be the minute amount required to pulse a heartbeat to sustain a life."

—*Gordon D. Friedlander*

Profile

The "other" electric company

American Electric Power is a study in contrasts—anachronistic, yet progressive, and a giant in spite of its relatively low profile

For engineers and nonengineer consumer alike, General Electric and Westinghouse Electric are household names. And as for utilities, most of us have heard of Public Service Electric and Gas, and Con Edison. But who, besides the power engineer, its customers, and its corporate stock-holders, knows American Electric Power? Yet the company today ranks as the largest investor-owned U.S. utility, with energy sales, during 1973, totaling nearly 75 billion kWh. Further, as the power engineer well knows, AEP is unique among the utilities in its reliance on coal, rather than oil, as its primary resource. Thus, the events of the last year—the Mideast petroleum embargo and the international energy crisis—have left AEP largely unscathed . . . and so too its 1.76 million customers, across seven midwest and midsouth states, who are currently paying fuel bills the bulk of us would envy. Through a combination of foresight and fortuitous circumstances, AEP, long regarded in power circles as a modern-day industrial anachronism, a dinosaur living off the remains of dinosaurs, has emerged as a glamor topic worthy of *IEEE Spectrum's* focus.

Thus, for example, AEP is at the forefront among power companies in transmissions systems. Its versatile 765- and 345-kV bulk transmission systems, including many interconnections, are models for the U.S., if not the world. Further, AEP has developed an unusual mix of fossil-fuel, run-of-the-river hydro and pumped-storage, and nuclear power generating facilities. And lastly, one of AEP's subsidiaries, American Electric Power Service Corp., which will be described in greater detail further on in this article, should be of interest not only to power engineers but to electronickers as well. Why? The service corporation, located in New York City, is deeply involved in planning, operations, management, and design for AEP as a whole and therefore can be considered the "brains" of the utility.

Founded in Philadelphia in 1906, as the American Gas & Electric Company (the name was changed in 1958), AEP is today a large holding company. Seven subsidiary power companies (see box, p. 51) serve the Midwest and Midsouth, but its corporate headquarters is located in New York. In addition, AEP operates captive coal mines in the East, and has contracts for the mining of coal in the western U.S. Why, with all this, is AEP so little known outside of power circles? Says Donald C. Cook, chairman and chief executive officer, "Perhaps we've been too busy to engage in PR." Whether or not this seems a satisfactory explanation, the fact is AEP has indeed been extremely busy.

Gordon D. Friedlander Senior Staff Writer

Back in 1967, AEP reaffirmed its commitment to coal as its primary fuel, despite the fact that coal was in disfavor and "nuclear" seemed to be "the way to go." So, AEP invested a quarter-billion dollars in developing its West Virginia and Ohio mines. This move was coupled with the lease or purchase of coal rights in Montana, Colorado, and Wyoming, plus the commitment—over the next two decades—to purchase no less than 118 million tonnes of deep-mined low-sulfur coal in Utah.

However, transporting coal over long distances to its Ohio River generating plants is another story: the acute shortage of railroad hopper cars and waterborne conveyance of this fossil fuel is a problem. AEP is solving this by contracting to have built 3200 rail cars, plus 280 barges and 16 river towboats.

AEP Chairman Cook has been subjected to much flak from environmentalists for going with coal—the Federal Environmental Protection Agency has rated AEP near the top of its list of polluters. Further, during the last several years, Cook and AEP have been similarly criticized, though from a different viewpoint, by other utilities, many of whom have been prevented by governmental regulation from utilizing coal. But AEP and its customers have clearly benefited by its reliance on coal, while other utilities were targeting the Mideast oil producers as the scapegoats for their woes. With abundant fuel reserves, AEP now estimates that it can meet the energy needs of its approximately two million customers until well into the next century. Furthermore Cook, despite the environmentalists, believes that domestic coal reserves could provide the *entire* energy demands of the U.S. for up to 500 years.

Nuclear futures

Yet, it would be unfair to say that AEP's management is wedded to King Coal for the duration; it has moved to explore alternative options for tomorrow—one of which is a joint venture with General Atomic Company toward a standardized design for a high-temperature gas-cooled reactor (HTGR), with a generating capacity of 1500 MW_e. Other forward-looking activities include collaboration with the Swedish electrical firm ASEA, Ohio Brass, and The Hydro-Electric Commission of Quebec in feasibility studies of UHV transmission lines at voltage levels above 765 kV. Now under construction, "stage 3" in this endeavor involves the installation of a 2300-kV test-line facility in Indiana, in which 6- to 24-bundle conductor configurations will be used to explore the upper limits of practical transmission and corona limitation. But these projects are part and parcel of an R&D effort that will not lead to commercial installations until, perhaps, the mid-1980s.

American Electric Power Service Corp.

A major subsidiary, American Electric Power Service Corporation is, as the name indicates, the arm of the AEP System that provides a multiplicity of engineering, environmental study, design, and management services to the parent company and to the operating companies. Within the service corporation, in New York City (and other locations) are 14 divisions and/or departments dealing with engineering, design, projects, fuel supply, system operating, environmental problems, computer applications, and so on. The Design Division, for example, is headed by Gerald Field. Its activities include the translation of engineering decisions into completed drawings for the design of the system's major generating stations, transmission lines, substations, etc.

The Design Division consists of engineers, designers, and draftsmen who specialize in the three principal engineering disciplines—electrical, mechanical, and structural—plus architecture. In the normal "throughput" process, engineering projects, and their design philosophy and criteria, are initiated and formulated by the various engineering divisions; then, the actual design development is handled by the design branch where the working plan and drawings are produced.

Mr. Field says, "We have from 400 to 600 engineers, designers, and draftsmen on our permanent and temporary staffs. If we are confronted by a work overload, then we 'farm out' the engineering design surplus to established firms of consulting engineers."

Of this large force of engineering personnel, Field estimates that about one half, or 50 percent, are graduate engineers; and, of the total, perhaps 10 percent hold advanced degrees (there are no Ph.D.s, however).

"The hot projects," says division leader Field, "are presently three coal-fired generating plants, Amos 3, and Gavin Stations 1 and 2, which will have 1300-MW turbogenerators—the largest such units built to date. We are also winding up the design phases on the Cook nuclear station, and our collaboration with General Atomics on the HTGR."

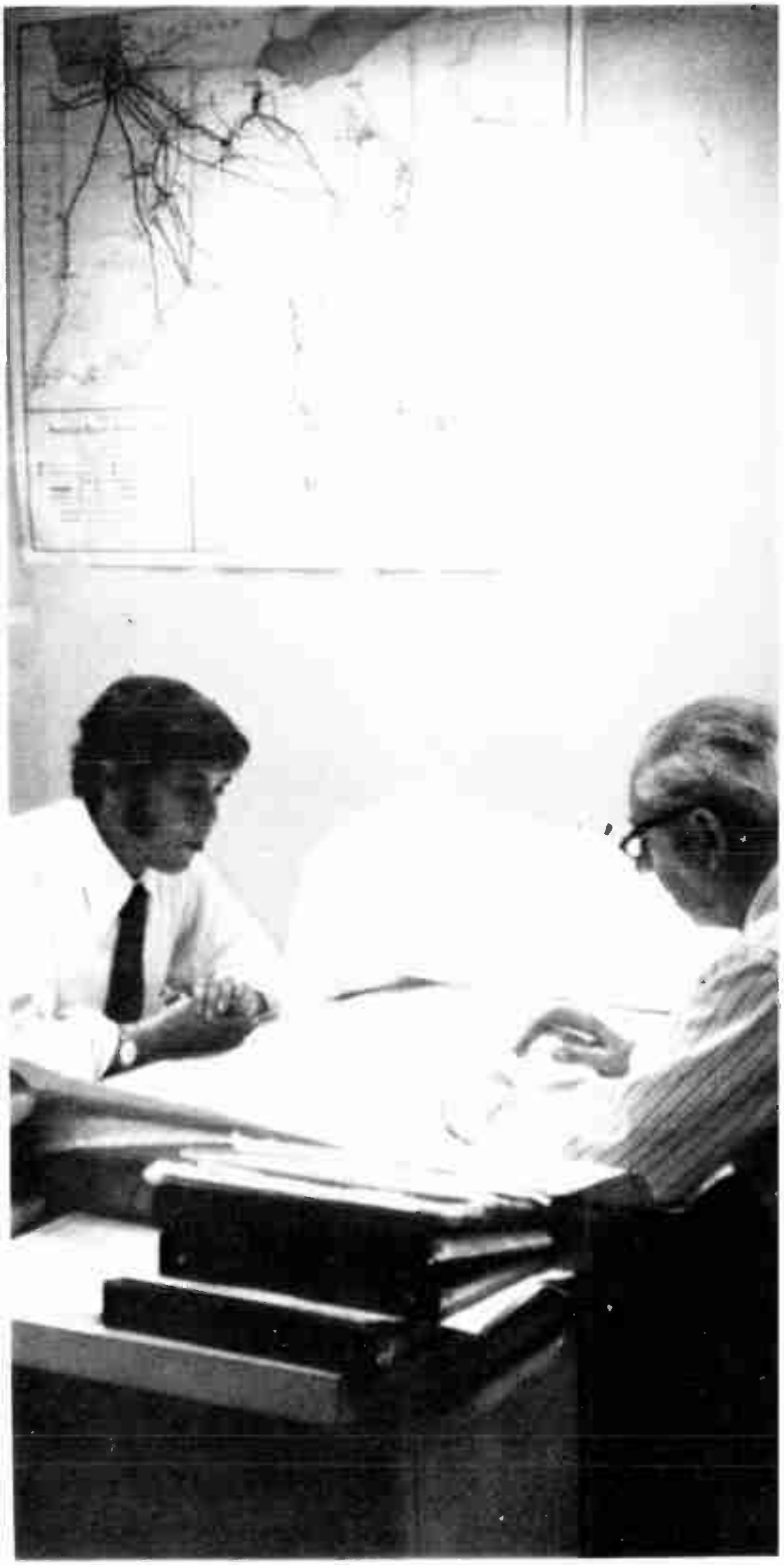
The engineering computer center, another part of the Service Corporation in New York, is headed by Assistant Vice President Anthony Gabrielle. It serves in solving advanced and complex engineering and design problems for the entire AEP System. It consists of about 100 technical personnel. As an example of one of its many functions, computer-controlled data plotters are used to generate both electrical circuit diagrams and structural/mechanical design drawings. One new application in the R&D stage, called "power plant graphics," will significantly improve productivity in design and drafting for major engineering projects.

The computer center also handles accounting and corporate finance matters.

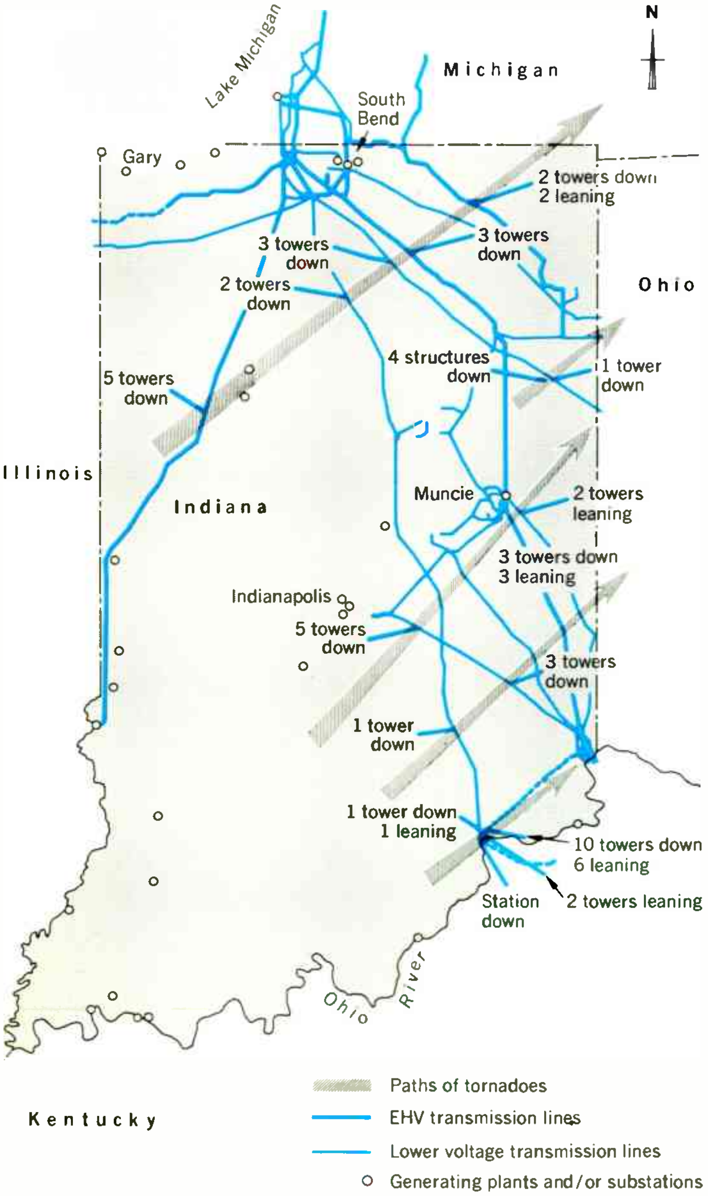
Power transmission

One of AEP's recent major operations was the construction of its 765-kV EHV transmission network (see map, p. 53) that already extends about 1800 km through portions of six states, from Michigan to Virginia. The construction began in 1967, and is still ongoing. AEP Service Corp. engineers designed the

The Design Division's five design sections are staffed by about 400 personnel, including civil, electrical, and mechanical engineers—plus architects, designers, draftsmen, and other supporting employees. Their utilization of the most modern techniques in the industry, and careful study of alternative practices have contributed to the production of efficient and economical designs of power plants (both nuclear and fossil fueled), and switchyards ranging from 4 to 765 kV. It is the responsibility of the Design Division to translate engineering decisions into completed drawings for the major generation, transmission, and other AEP System facilities. These objectives necessitate collaboration of all sections and the Engineering Divisions.



One of the major strengths and attributes of the AEP System is its solid reliability under extreme adversity. Practically all of the AEP System lies in a multistate area that is subject to major tornado damage—each and *every* year. The map below, which is primarily of the state of Indiana, shows the paths of five major tornadoes that ripped across the state on April 3–4 of this year. The havoc to the transmission lines (and sometimes generating stations and substations) may be seen in the callouts along the swaths of destruction that occurred over a two-day period this spring (the pattern of damage has been repeated, in a variation of geographic paths in this state since AEP first entered the service area—thus it is hardly a novel experience to the company). What is extraordinary, however, and attests to the basic integrity and reliability of the AEP network—not only in Indiana, but also in six other states that are served —is the fact that, despite all the damage to major transmission lines and other power facilities, there was *no* service interruption to *any* of its customers in Indiana or southern Michigan. This, in itself, bears witness that AEP has constructed a power grid and system of interconnections, with so many tie lines and alternative bypasses, that it can withstand the ultimate and most destructive "narrow-band" devastation devised by Nature—the unpredictable tornado; and, in this case the most unusual occurrence of five of these lethal phenomena striking almost simultaneously! This degree of service reliability is the result of years of careful planning and design on the part of the Service Corporation.



34- to 44-meter-high towers that carry the transmission lines in a vast interstate loop. "Bundle" conductors, consisting of four 3-cm-diameter cables arranged in a 46-cm^2 configuration, are employed on the lines. This design is a practical substitute for the much heavier single cable that would otherwise be required for equivalent performance. Three of these bundles comprise a single circuit.

Computerized power control

Another project that has occupied AEP during recent years involves economic dispatch, electronic monitoring, and improved communications. Back in 1964, AEP installed its integrated "nerve" center in Canton, Ohio. This installation originally consisted of a power-control focal point that automatically supervised the economic dispatching of more than 6000 MW of power (now appreciably more) from 15 major power plants, regulated power frequency, and controlled the power interchange with neighboring utilities. In addition, a data-processing center automated and centralized the billing functions for the system's then 1.5 million customers; and, it correlated its own accounting, financial, engineering, and management information.

In the original 1964 installation, the power control center combined an analog computer system and digital telemetering with a digital computer system. By the continuous monitoring of the demand for power, and the availability of the generating units to supply it, the installation attempted to meet the total electric power requirements of all AEP system customers —and the power commitments to other interconnected companies—in the most economical manner.

Data collected by instrumentation at hundreds of key locations on the AEP system were—and are—telemetered, via microwave, to the center. After computer evaluation, automatic instructions are routed back through the system by microwave to the appropriate generating units where power production is either increased or decreased automatically as required. The flow of data in this closed-loop system is accomplished in a few seconds' time and it requires no manual intervention.

One of the primary functions of the power-control center is to assist in maintaining constant load–frequency control at a steady 60 Hz. The digital computer is activated every three to five minutes for the economic dispatching calculation. A reliable analog computer accomplishes the continuous economic dispatching operation and load–frequency control. The automatic selection of power generating and dispatch alternatives takes into consideration:

- The relative incremental generating efficiency of each unit.
- The relative cost of fuel for each unit.
- The relative effect of incremental transmission system losses.

From these weighted factors, the computer accurately selects the units to load and how much to load them to produce the highest combination of generation–transmission efficiency and fuel economy for the entire system.

Scheduled transaction studies provide on-line calculations of various blocks of power—and their price —for sale to, or purchase from, interconnected utili-

Operating companies of the AEP system

Appalachian Power Company, Roanoke, Va.—serves almost 1700 communities and a population of about 2 million in a 50 000-km^2 area in western Virginia and southern and western West Virginia.

Indiana & Michigan Electric Company, Fort Wayne, Ind.—serves 233 communities and a population of more than 1.5 million in a 20 000-km^2 region of eastern and northern Indiana and southwestern Michigan.

Kentucky Power Company, Ashland, Ky.—serves 336 communities and a population of 350 000 in a 14 750-km^2 area of eastern Kentucky.

Kingsport Power Company, Kingsport, Tenn.—serves six communities and a population of 86 000 in a 570-km^2 sector of northeastern Tennessee.

Michigan Power Company. Three Rivers, Mich.—serves electricity to 23 communities, with a population of about 70 000, in a 1350-km^2 area in southwestern Michigan.

Ohio Power Company, Canton, Ohio—serves 663 communities and a population of more than 1.6 million over a 19 000-km^2 section of eastern, central, southern, and northwestern Ohio.

Wheeling Electric Company, Wheeling, W.Va.—serves 45 communities (population of more than 100 000) in a 1160-km^2 area near Wheeling.

In addition, the AEP System includes the following other subsidiaries:

Beech Bottom Power Company (jointly owned with Allegheny Power System)
Cardinal Operating Company (jointly owned with Buckeye Power, Inc.)
Central Operating Company
Indiana & Michigan Power Company
Ohio Electric Company
West Virginia Power Company
Central Appalachian Coal Company
Central Coal Company
Central Ohio Coal Company
Southern Appalachian Coal Company
Southern Ohio Coal Company
Windsor Power House Coal Company
Twin Branch Railroad Company

An executive vice president of AEP heads up each of the *seven* operating companies.

ties. Off-line calculations help to evaluate the system's past and future operating performance.

The data-processing center, located one floor above the dispatch center, is the nucleus for the centralized processing of customer billing, general accounting, and management information for the entire network. The installation primarily consists of several large-capacity general-purpose computers that are served by an auxiliary data-processing system. Meter readings taken throughout AEP's division are converted into machine language and fed into satellite computers at Fort Wayne, Ind., and Roanoke, Va., for customers of five of the seven operating companies. The Canton center handles the accounts of the Ohio Power and Wheeling Electric customers directly. Information from the satellite computer centers enters the data-transmission units at Fort Wayne and Roanoke and is microwaved to Canton.

On receipt of the data, the master computer at Canton prepares customer bills. The system simultaneously records on tape the account status of each customer, plus information for the future processing of bills. As each billing calculation is performed, statistics are accumulated for rate and revenue analyses, marketing studies, and reports for Federal and state regulatory agencies.

Finally, tapes containing billing data are fed back through the microwave network to the satellite computers in Fort Wayne and Roanoke, where customers' bills and accounting reports are printed out.

Newly installed data-collection and -evaluation systems will continuously monitor and analyze the performance of AEP's largest generating units (up to 1300-MW capacity) and report potential problems. CRTs will visually display emergency conditions and requested data. If there is equipment failure, the system will reconstruct the exact operating conditions at the moment of failure for "postmortem" analysis.

All EHV substations on the AEP System are continuously monitored by electronic terminals. Circuit status and power flows on transmission lines are automatically reported to the Canton center, where they are shown continuously on a computer-controlled 7.3-meter-long dynamic-display board. Also, a more sophisticated system, which will permit on-line contingency analysis to warn of incipient problems, is under development.

In power distributions, the employment of solid-state automatic meter-reading is under investigation by AEP. Furthermore, recent advances in technology may permit the low-cost mass production of highly sophisticated electronic minicircuits to implement previously unattainable concepts. AEP's tests in 1972 confirmed the technical feasibility of using power-distribution circuitry, from the secondary wiring in the house, through the transformer, to the primary distribution circuit, as a communication path.

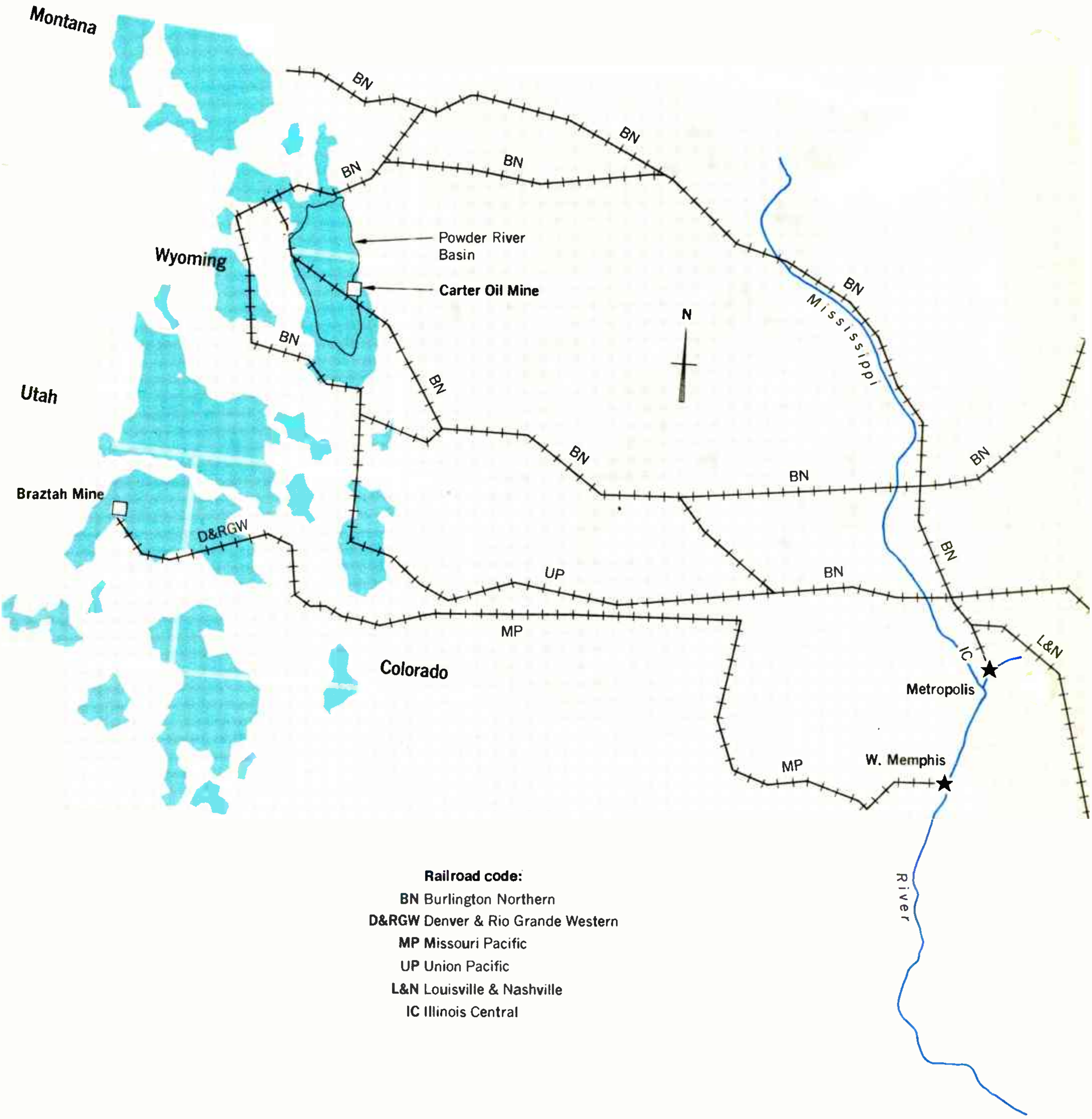
AEP's basic microwave installation consists of terminal and repeater stations. It operates in frequency bands up to 7000 MHz, and it can handle 300 voice channels for distances of more than 1600 km. A number of the repeater stations utilize the heterodyne principle, thus eliminating the necessity of demodulating the signal at each station. The data-transmission rate is as high as 30 000 characters per second on some links. The 3500-km network provides the communications link for the entire computer center operation at Canton.

The hub of the microwave network is a 120-meter-high tower, designed to resemble the Eiffel Tower, overtopped by a 3-meter-high antenna for the transmission and reception of signals between Canton and the power plants and satellite computers.

Progress in mining and other ventures

AEP's "Big Muskie" (no relation to the Senator!) dragline—the world's largest land-based machine—is being used in surface strip-mining and reclamation

Western coal mines and rail routes for transportation of fuel to AEP System

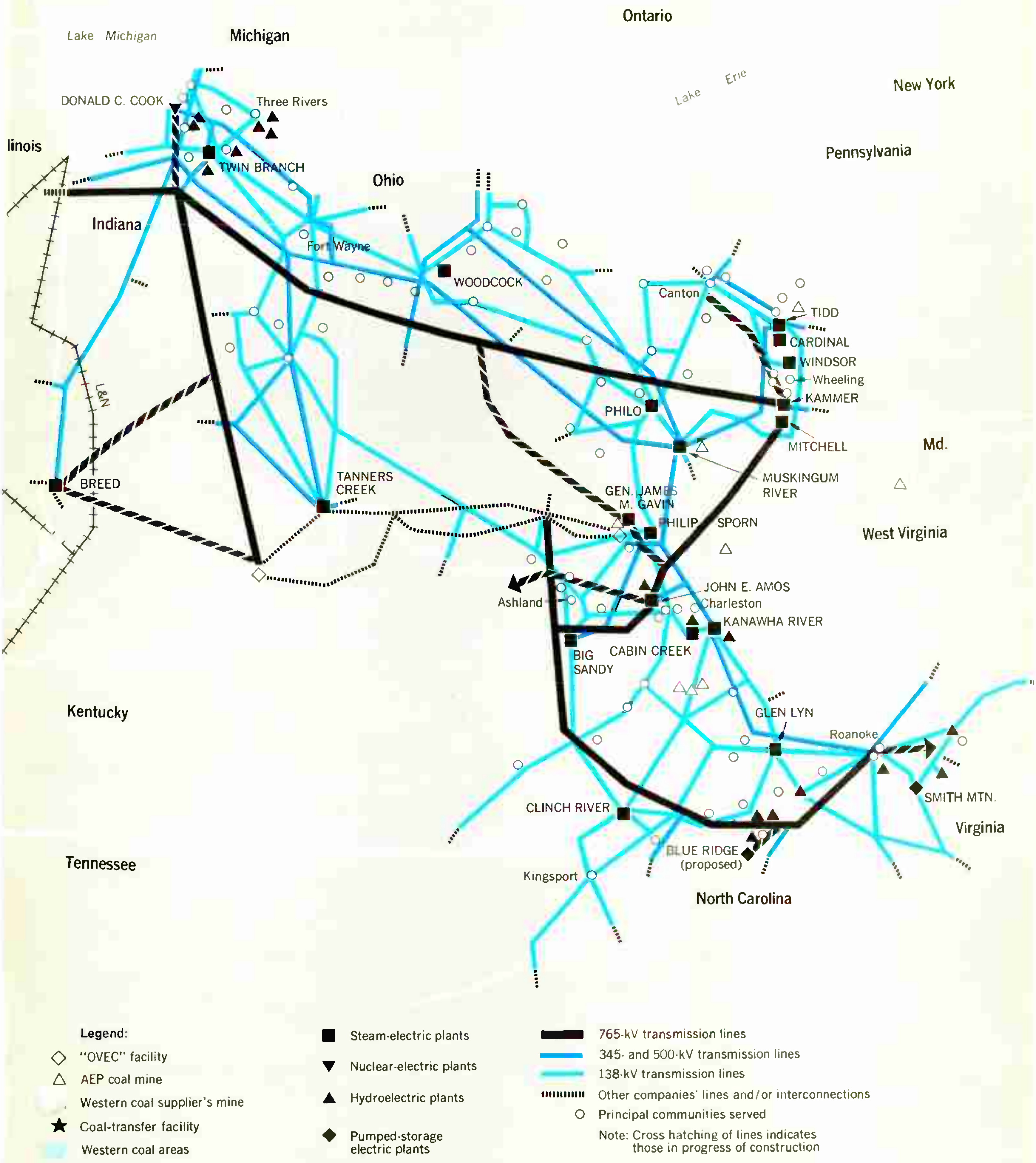


Railroad code:

BN Burlington Northern
D&RGW Denver & Rio Grande Western
MP Missouri Pacific
UP Union Pacific
L&N Louisville & Nashville
IC Illinois Central

The comprehensive extent of AEP's multistate generating, transmission, and mining operations—plus railroad lines for transportation of coal—may be seen in these maps. The bulk of its generating plants are steam-electric, with several run-of-the-river hydro stations, one pumped-storage facility (Smith Mountain)—and a proposed similar facility at Blue Ridge, Va.—and the Donald C. Cook Nuclear Plant now under construction on the shore of Lake Michigan. The Cook Plant, at Bridgman, Mich., is AEP's first nuclear power station; it will have a generating capacity of 2200 MW$_e$ and is expected to be in operation by next year.

The 7-state American Electric Power System



Power pioneering

When asked how he explained AEP's ability to withstand the sociotechnical stigma that accompanied the 1967 management decision to "go with coal"—a decision since proved correct, at least in the near term—AEP Chairman Donald Cook indicated that the one key might be the company's pioneering spirit. He attributed the credit for propagating this pioneering spirit to his predecessor, Philip Sporn, long a giant in the power industry; but, it should be noted that AEP boasts a long history of technological innovation.

For example, in 1916 AEP adopted 138 kV as its bulk transmission level. And, in that year, a 100-km-long double-circuit line at this voltage was run from the (then new) Windsor Plant on the Ohio River to the industrial load center at Canton, Ohio. It was a landmark event because, for the first time, electricity was generated on a large scale at a plant situated at its fuel supply (mine mouth) rather than at the load centers. This concept was—and is—a trademark of AEP's technological philosophy.

Following World War II, AEP deployed considerable R&D effort toward the realization of its first 345-kV transmission line in 1953 (the result of years of effort at its Tidd Test Project facility in Ohio). Then, after more years of research at the Apple Grove Project site in West Virginia, the previously-mentioned 765-kV transmission system was established.

Also in the realm of power transmission AEP—in 1926—pioneered research on the effects of lightning on high-voltage lines; ultrahighspeed reclosing of circuit breakers was adopted in 1935; guyed V-frame aluminum towers were first installed in 1961; and helicopters were first employed for transmission-line construction in 1962.

In the area of power generation—starting, logically, with the boilers—AEP introduced reheat steam in 1924, high-pressure steam in 1930, and double-reheat and supercritical pressures in 1957. In addition, AEP was the first utility company to employ the tall stack (1955) for minimizing the adverse affects of air pollution; and installed the first natural-draft cooling tower in the western hemisphere (1962), to protect water quality and to reduce the harmful effects of thermal pollution.

As far as turbogenerators are concerned, AEP began looking past the 450-MW nameplate capacity in the mid-1960s. Generators of 600- and 800-MW levels were next designed, built, and placed on the line. Now, higher plateaus of generating-unit size have been achieved—with 1100-MW nuclear units under construction, and the first of several 1300-MW fossil units already in service.*

* On October 22, 1973, the first of AEP's 1300-MW turbogenerators, supplied by the Swiss firm, Brown, Boveri Ltd., was put on the line at the John E. Amos Plant near Charleston, W.Va. This unit, together with two 800-MW units installed earlier, increased that plant's generating capacity to 2900 MW.

operations in southeastern Ohio. In addition, the company's Muskingum Electric Railroad, in that state, delivers the mine's production to a central preparation plant—all by automatic train control (ATC).

In another area, AEP's research into heat-pump development began back in 1934. Since that time, the company has tested electric space-heating equipment and has run computer analyses of the characteristics and economics of various central heating and cooling systems. They are continuing to encourage the use of heat pumps as a major energy saver in space conditioning.

Environmental concerns

A large portion of AEP's R&D activities is in the environmental area. For example, AEP Service Corporation's New York-based environmental engineering division, and its Environmental Laboratory in Huntington, W.Va., are heavily involved in these efforts—especially directed toward air- and water-quality assurance. Under pollution-control scrutiny are coal, fly ash, stack gases, fossil-fuel desulfurization, SO_2 emissions, thermal effects on waterways, etc. The present program of aquatic studies involves seven rivers: The Ohio, Muskingum, Wabash, Clinch, Kanawha, New, and Roanoke Rivers—plus Lake Michigan and Lake Erie.

Each of these research programs is being conducted in one of three ways by

- AEP itself.
- An independent engineering, academic, or R&D organization on a commissioned contractual basis.
- AEP in conjunction with an independent group.

A top-priority R&D effort is the intensive search for a method to control SO_2 emissions (either by removing sulfur from unburned coal, or from the stack after combustion). Among other efforts, the company is engaged in a proposed $10 million pilot project, over a two-year period, to convert coal to liquid form for the removal of sulfur. Collaborating in this effort are the U.S. Office of Coal Research and Allegheny Power System.

Installed and new generating capacity

At the end of 1973, the AEP System had a total generating capacity of 15 153 MW; this represented more than 2900 MW of reserve capacity—or about 19.3 percent—above consumer's peak demand. Either under construction or in the planning stages are 11 940 MW of additional generating capacity. By 1982, then, AEP's generation capability will be in the order of 26 000 MW. Of this total quantity, 66 percent (7800 MW) will be coal-fired stations, 18 percent (2200 MW) nuclear, and 16 percent (1940 MW) pumped-storage and run-of-the-river hydro.

But the salient strength—now and in the future—of the AEP System is the inherent strength and reliability of its highly integrated transmission systems. A major portion of the system is situated in states that are regularly subject to severe tornado damage. The map of the state of Indiana, on p. 50, dramatically illustrates the resilience and reliability of AEP's transmission, even under conditions of extreme adversity—such as *five* tornadoes carving a swath of destruction from west to east over a 24-hour period.

Controlling and optimizing power systems

Economic dispatch, stability, security, and reliable system operation are principal tasks for the computer

Computer-oriented power system control as the wave of the future is represented by new control centers equipped with multiprocessor real-time computers and high-speed data acquisition systems. In a given center, more than a hundred programs are likely to be on call to run in response to changing power system conditions or dispatchers' requests, performing a multitude of monitoring, logging, display, analyzing, and control functions. Only a few of these computer-oriented dispatch centers are presently in operation, but many more are in the construction or planning stage and the trend is industry-wide.

As yet, there is no general agreement on system philosophy, structure, hardware, software, displays, or communications for these computer-oriented installations. New concepts continue to emerge and many different ideas are being tried. Some of the functions being performed or planned for the new control centers are listed in Table I.

A clear trend is that established control functions, such as monitoring, supervisory control of substations, and automatic control of generation are still done in the new control centers, but in much improved form. Human dispatchers are still included in most of the control loops they formerly occupied, but their tasks are facilitated by more accurate, comprehensible, and complete information.

In addition to improving established functions, computer control of power systems is expected to enhance system security, and thus maintain reliable electric power service under all conditions. This is a main justification for installing the new centers. But it is difficult to measure and evaluate the extent to which computer control can improve security.

One approach that may help to clarify some of these problems is that of Tom DyLiacco of Cleveland Electric Illuminating Company, who points out that a power system may be considered to be operating in either a normal state, an emergency state, or a restorative state. In the normal state, all load demands are satisfied but the system may or may not be secure. The system is insecure if a single contingency such as a fault or the loss of a transmission line or generator would cause it to enter the emergency state. The system is in a steady-state emergency when it cannot serve all of the loads or when it can serve the loads but some equipment is being overstressed. The system is in a dynamic-stability emergency when synchronous operation is threatened or frequency is declining due to insufficient generation to match the load. The system is in the restorative state if, after the emergency has ended, control operations are required to bring it back to normal.

Under the normal operating state, the security control system should perform monitoring, analysis, and optimization. Security monitoring is the identification and display of the current operating conditions. Security analysis is the process of determining whether a probable contingency will cause the system to enter the emergency state; if the answer is *yes*, the system is considered to be insecure and some action should be taken to make it secure. Security-constrained optimization is the process of determining the *best* action to restore the system to the secure normal state. Actions that might be considered include starting up a new generating unit, curtailing loads, changing transformer taps, or switching capacitor banks.

Similar breakdowns into monitoring, analysis, and optimization could also be made for the emergency and restorative states, but at present most effort is concentrated on keeping the system in the normal state.

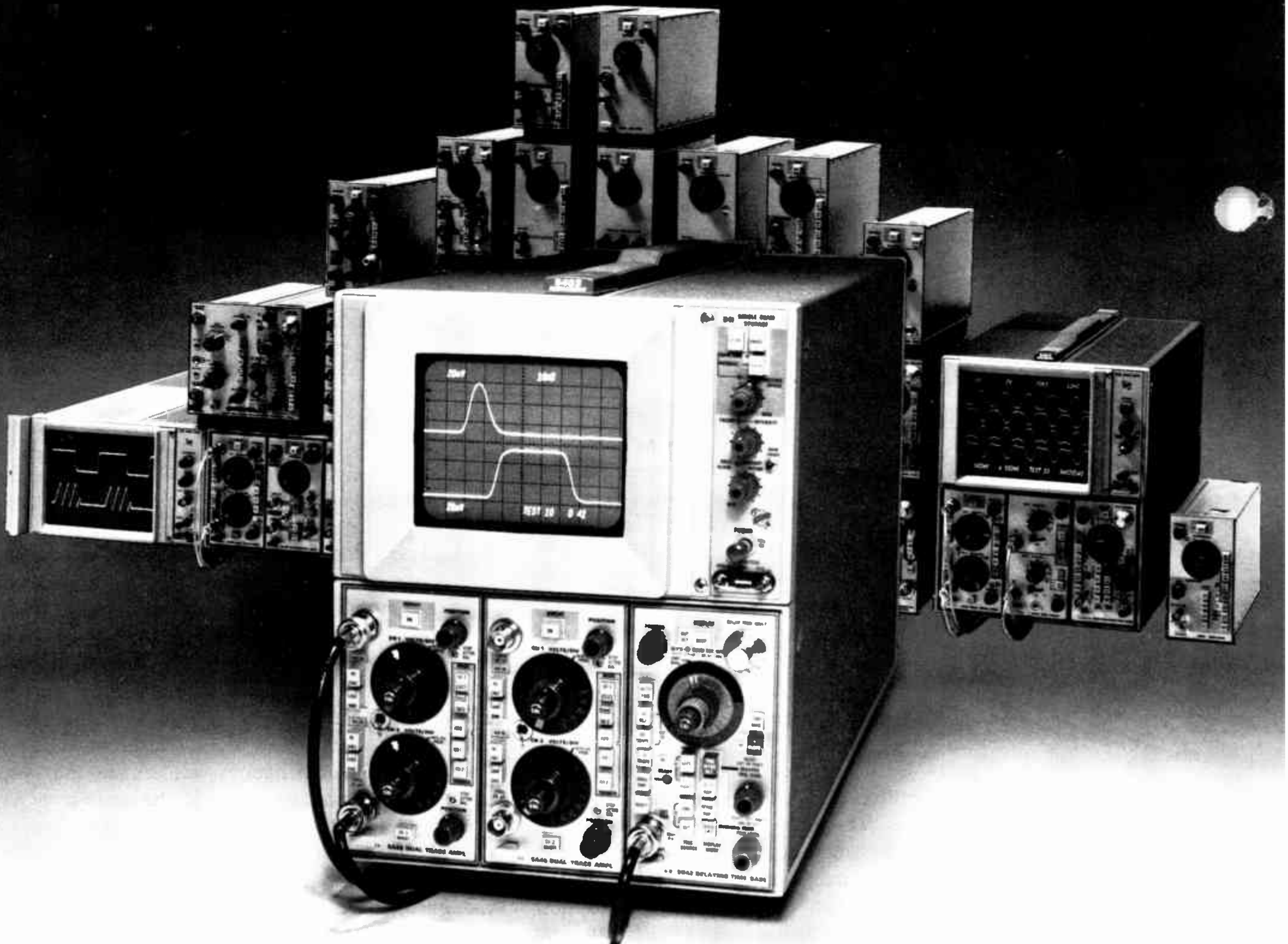
If power system control represents the future towards which computers are leading us, the present belongs to simulation programs.

Power system simulation

Today, the most important, often used, and time-consuming power engineering computer applications are those that simulate the operation of the power system. Digital computers have now replaced network

William F. Tinney
Bonneville Power Administration
Mark K. Enns
University of Michigan

I. Computer functions in power system control centers
Data acquisition and display
State estimation
Automatic voltage/VAR control
Security monitoring, analysis, and control
Dispatcher's on-line power flow
Load forecasting
Reservoir regulation
Pumped storage regulation
Unit commitment
Maintenance scheduling
Interchange analysis
Supervisory control



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The flexible 5000 Series is designed to handle your present measurements and is expanding to meet your future needs.

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One of the most basic types of simulations, power flow studies, provide descriptions of the balanced steady-state operation of an ac power system. Power flow data—sometimes called *load flow* data—produce essential information for system design and operation. These data help determine the ratings, locations and time schedules for system additions, help to evaluate the effects of outages, and aid engineers in finding ways to reduce losses and to answer a multitude of other questions that arise in planning and operating a power system.

Typical general-purpose power flow programs can handle systems of about 2000 buses but much larger programs have been written. The outputs of these programs normally provide computed magnitude and relative phase angle for every bus voltage in the system, real and reactive power flows and losses in every line and transformer, and reactive power for each generator. Many programs have provisions for printing the results on a specially prepared network diagram and some even automatically draw the diagram.

To reduce the number of cut-and-try cases needed to obtain acceptable results, power flow programs include features for adjusting generator voltages, changing transformer taps, and controlling reactive sources to regulate the overall system voltage, as well as adjusting generator power outputs to satisfy area power-interchange schedules. The more advanced programs provide "optimal" solutions in which all controllable parameters are adjusted to minimize a prescribed cost function.

Power systems are subject to unavoidable disturbances such as faults, and sudden load or generation losses. What operators and planners need to know is whether or not, following such disturbances, their systems can be restored to stable operation.

Transient stability simulation programs help to supply those answers. The most salient output of these programs is usually a set of curves covering such quantities as generator rotor angles, field voltages and currents, flux linkages, and angular velocities. Only a small fraction of the thousands of possible output data combinations are ever selected for any one simulation.

Unfortunately, present-day transient stability programs are slow, almost to the point of being impractical. To make matters worse, it is almost impossible to verify a transient stability simulation by comparing it to the response of an actual system. A staged test would jeopardize power service, and when a major disturbance *does* occur there are never enough recorded measurements to reconstruct the event accurately.

Currently, efforts are being made to extend simulation of dynamic response to cover the several minutes following a disturbance, because it is in this timespan that cascading events most likely to cause system breakups and regional blackouts will occur. For this longer simulation—still in an early stage of investigation—new models and simulation methods will be needed. The problem is a formidable one.

In addition to disturbances that cause system instability, transient electromagnetic overvoltages can be produced by switching operations, faults, lightning strikes, and similar events. Detailed knowledge of these transients is essential for determining proper insulation levels, for installing protective measures to limit the failures, for the investigation of interference in neighboring communication lines, for estimating the hazards of coupling effects to nearby people and objects, and for evaluating other power system transient problems.

Since the early 1930s, electromagnetic transients have been studied on network analyzers and these devices are still widely used today. Although the computer analysis approach is slower, it has the advantage of being able to model more complex systems and problems, particularly those involving the microsecond range, and it is accurate and flexible.

There are many obstacles to successful simulation of electromagnetic transients. Traveling waves on multiphase lines are mutually coupled, but for simulation purposes they must be transformed into uncoupled propagation modes, and the only transformations that fulfill the requirements are approximations. Fre-

Managing the growing flood of data

For power engineers who use computer programs, the most urgent need is for better technical data management. When the computer relieved them of computational drudgery, it burdened them with the equally distasteful task of data handling. Even for a simplified power flow problem the input data include: the real and reactive power at every load bus, the real power and bus voltage magnitude at every generator bus except one (the slack generator), the bus voltage magnitude at the slack generator, and the structure and constants for the transmission network including transformers, capacitors, and reactors.

For a single transient stability study, a hundred thousand items of data may be needed. Predisturbance steady-state conditions for a transient-stability study are obtained from a companion power flow program which transfers the input data and solution of the power flow problem to the transient-stability program. Then, the additional data needed for the stability study include constants for the generators, their exciters, governors, and prime movers, as well as constants for dynamic load models and a description of the disturbance and timing of subsequent switching events.

The various departments within a power company have overlapping and interacting needs for enormous quantities of rapidly changing technical data—much of it inputs and outputs of computer programs—all of which could be handled by a computerized data management system. A few attempts have been made to establish comprehensive technical data management systems in power companies, but they are not very highly developed and most companies have no system at all.

Data management is more than just an internal company problem. In making regional studies, power companies must exchange technical data describing their present and proposed future systems, and it may soon become necessary to make studies of systems that span whole continents. Effort is now under way to establish uniform standards for exchange of such data, but progress is slow because of the conflict with established company and regional standards.

quency dependence, especially of the earth return path, has an important influence on results, but it is difficult to determine and represent. Transient models for transformers, synchronous machines, arcs, and other elements of the problem are still not as realistic as they should be. The net result is that perfection in this type of simulation remains a remote goal.

Most users would be reasonably satisfied with their present simulation programs if they could get quick turnaround. But power system simulations have become unwieldy batch processing jobs with long turnaround times. Therefore, attention is now being given to the possibilities of interactive simulation programs in which the engineer controls the computer from a graphics CRT terminal. Because of their great size, power system simulation programs are not well-suited to time-sharing interactive schemes on present large computer systems. Some companies are now advocating dedicated minicomputers for this purpose. Although compromises in system size may be necessar because of the limited storage of minicomputers, it is claimed that their interactive capability more than offsets this deficiency.

Computer graphics also ties in with interactive computation. Power engineers and managers who review their work find that system diagrams are far more comprehensible than computer listings. More work is needed to improve the automatic generation

Computer techniques: developing but still problem-laden

To adapt the computer to power system problems, engineers and programmers are using a wide variety of computational methods, some of them borrowed from such other areas of electrical and electronics engineering, as control system analysis. For most of the problems in power systems, present computational methods are not entirely adequate, so improvement of these methods is a developing and growing activity.

Sparse matrix methods

The "curse of dimensionality" is a persistent obstacle to power system simulation. The systems being simulated are becoming increasingly large, because of the trend toward interconnection of previously isolated systems, and in many cases the interconnected systems must be simulated in their entirety. The solution of a large system of simultaneous network equations then becomes a large computational burden. Recently, sparse matrix methods have been used to help relieve that burden.

For example, the balanced three-phase transmission network is usually represented by its single-phase positive sequence components, thereby permitting a nodal formulation with one nonlinear complex network equation for each bus. The problem is nonlinear because power rather than voltage or current is specified at each bus. Although the resulting system of equations is large, it is extremely sparse, and all of the successful solution methods exploit this sparsity in some way.

Time-domain solutions

Time-domain simulation has proven to be the most successful digital approach for studying electromagnetic transients. The need to simulate nonlinear devices, such as lightning arresters, and problem-dependent switching events, such as opening a circuit-breaker at current zero, makes it difficult to use frequency-domain methods.

At present, the most widely used simulation schemes are based on the *method of characteristics* which avoids the solution of difficult partial differential wave equations by taking advantage of a constant linear relationship between voltage and current on a traveling wave. This formulation leads to a set of algebraic equations for conditions at transmission line terminals. These can be combined with algebraic difference equations representing the response of lumped circuit elements. At each time step of the simulation, a system of nodal network equations is integrated, using the implicit trapezoidal rule. This simulation program is comparable in function to the ECAP program, which is used for transients in electronic circuits. However, for power systems it is necessary to model distributed as well as lumped parameters.

Most of the practical programs for simulating transient stability, also use a time-domain approach. A set of nonlinear differential equations represents the generators, governers, exciters, and prime movers, while a set of nonlinear algebraic power flow equations represents the network and loads. At each time step (typically of 1 to 4 cycles) of the simulation, the two systems of equations are solved in some way such that their interface variables approximately or exactly match. There are several advantages in this two-part solution scheme, the most important being the elimination of the 60-Hz frequency from the simulation.

There is an urgent need for improvement in transient stability computation because the time-domain simulation is almost prohibitively slow. For a detailed study of a 2000 bus, 500 generator system, at least 30 minutes of computing time is required to simulate one second of real time using a CDC 6400 computer. Many of the models are imperfectly known, particularly the load models. There are drawbacks inherent in the simulation approach itself. Onl one condition, out of many that must be studied, is covered by each simulation. Generalized stability criteria, which can often be used to advantage on other stability problems, cannot be used for power system stability because the problem is too nonlinear. Attempts to apply the second method of Liapunov and other energy function methods have thus far been unsuccessful because of the magnitude and complexity of the problem. Approximations to make the problem more tractable tend to degrade accuracy and, therefore, can be used only for qualitative studies. A trend toward more detail in modeling further adds to the already excessive computing burden.

State estimation

State estimation is a procedure for converting telemetered transmission network measurements and switch positions into a reliable estimate of the current network structure and electrical state. It is accomplished by a group of interrelated computer programs at the control center. Under normal conditions there will be more than a sufficient number of measurements to define the system state completely. This redundancy makes it possible to compensate partially for inaccuracies in measurements and false circuit-breaker status information. At present, the estimate is "static" because it applies only to the quasisteady-state condition of the power system responding to normal load variations. The estimate, which is usually in the form of snapshots of intervals of several seconds to several minutes, provides a reliable data base for real-time functions in the control center, particularly security-related functions.

In conventional control centers, the dispatcher's knowledge of the network status and state is gathered from indicators that show actual telemetered switch positions, generator outputs, bus voltages, and certain line flows. Even when these quantities are accurate, they are insufficient to determine the complete system state and trained judgment of network diagrams and other graphical displays of computer results.

With improvements such as these, computer simulation of power system operation can be expected to become increasingly effective and widely applied.

Optimization brings new solutions

In the meantime, computers, together with modern optimization techniques, are offering new solutions to a number of power system planning and operation problems.

For example, generation planning efforts seek the lowest cost schedule of generating capacity additions that will satisfy projected load-demand within given constraints. The schedule of capacity additions includes the kind and size of generating units, their locations, and dates of availability. The planning effort must look twenty or more years into the future since work on a new generation plant must begin about ten years before its energization date. Constraints include reliability of service, limits on sizes and kinds of generation, environmental and political considerations, and availability of fuel resources. Some other factors affecting the problem are assumptions about expansion of neighboring systems, operating and marketing policies, maintenance practices, scheduled and forced outage rates, and the interface with transmission planning.

is needed to interpret them properly. With a state estimator, the dispatcher can request a display of the best estimate of any quantity of interest to him, even if it was not actually measured, was badly in error, or was lost in transmission.

Several schemes for power system state estimation are now known. Most estimators make a best fit in a least-squares sense of a redundant set of measurements to a mathematical model. The hardware cost of state estimation is high because of the need for redundant measurements, and the sophisticated software it requires adds a large burden to the computer complex. But the enhancement of system security, which state estimation is expected to make possible, is judged to be worth the cost and effort.

Optimization techniques

Because of the large size of many power system computational problems, formal optimization methods are used only to a limited extent in practical solutions. For example, the typical security analysis for the normal state of a power system is a series of fast, approximate power flow studies of the consequences of a list of contingencies. The data base for the analysis is provided by a state estimator program, and it includes a contingency list that is modified to reflect the current system state so that only those events that might cause trouble under the existing conditions are analyzed.

Security analysis by power flow simulation only identifies those next contingencies that would cause steady-state emergencies. In order to make a comparable analysis of the dynamic stability emergencies, it would be necessary to simulate the system dynamic response to the contingencies. With present digital computers, this problem is too large to handle. Fortunately, the steady-state contingency analysis provides some information that can be used to estimate the dynamic response.

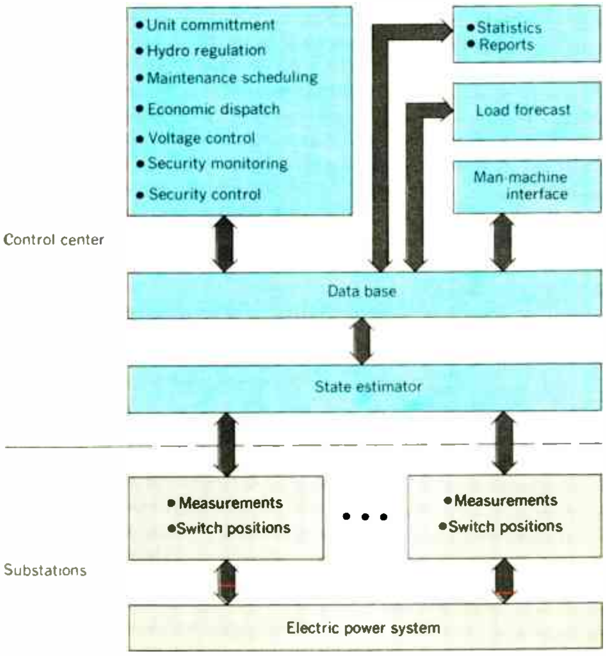
When the set of critical next-contingencies has been identified by the security analysis, the security-constrained optimization problem is defined. But its solution by formal optimization methods is quite difficult. Even without an automatic optimal strategy, however, the information provided by the security analysis should be a big help to the dispatchers, who will have at their disposal a power flow program with which to check the strategies they devise before applying them to the system.

The areas where formal optimization methods, such as linear, integer, and dynamic programming, *are* finding increasing use—albeit with drastically simplified system models—is in solving such problems as generation planning and unit commitment. These methods are yielding consistent solutions and they provide previously unavailable information on the sensitivity of policies and costs to system changes.

Hybrid computation

The extremely long running time needed for large power system dynamic simulations severely limits their usefulness and there is no hope of greatly improving this situation with conventional digital computers. The availability of very fast dynamic simulations could open up a whole new range of possibilities including centralized real-time control of power system stability. Because of these possibilities, research is being conducted on development of hybrid computers for simulation of power system dynamics. Speeds 100 times faster than real time have already been demonstrated on prototype systems. Hybrid computation could also be used for study of electromagnetic transients. However, more work is needed to establish the overall technical feasibility and costs of hybrid computation, and it is still too early to predict the outcome of these efforts.

Data flow in a typical power system. Control, simulation, and optimization programs within the control center produce various outputs, including switch position information to the substations. Measurements from the system are supplemented by computer state estimator data.



Transmission planning usually follows generation planning. It starts with the assumption that a schedule of generation additions and a load forecast by substation buses are known. The problem is then to find when, where, and what kind of transmission lines are to be built in order to provide reliable power service between the generators and the loads at lowest cost. For purposes of simplification, reliability is usually expressed in terms of outage contingencies which must not disrupt service. The nature and difficulty of the transmission planning optimization problem is much the same as that of generation planning. It is necessary to look ahead to determine how future requirements affect present decisions. Several approximate solutions have been used but none of these fulfill all of the requirements.

The earliest power system optimization problem was to minimize the cost of fuel at thermal plants by proper loading of the generators—in other words, the problem of economic dispatch. At first, the objective was simply to maintain equal incremental fuel costs at each plant. Later, an approximation for transmission losses as a function of generator loading was included. Most present day economic dispatch systems still adhere rather closely to the original methods, but this may soon change. In its ultimate development, the economic dispatch problem becomes the optimal power flow problem in which all dispatchable controls can be adjusted to achieve a complex weighted objective, while all relevant operating contraints are being observed. Such solutions are not yet feasible.

Economic operation of a power generation facility requires an optimal decision consisting of which generation units should be on line during given time periods and what their approximate power outputs should be. This is known as the problem of unit commitment. Its solution involves the fact that definite costs and time delays are associated with the startup, standby, and shutdown of thermal plants. Also, spinning reserve requirements for the system as a whole and for specified areas must be maintained. The number, size, and location of units also affect the decision. If the system contains both hydro and thermal generation, the problem is further complicated by the special performance characteristics and constraints of the hydro operation. Finally, scheduled outages and the probability of forced outages must be considered.

A number of other power system optimization problems have been tackled by computer techniques. These include: locating transmission towers along a right-of-way to minimize construction cost, scheduling seasonal drawdown and refill of hydro reservoirs to maximize power generation use, selecting size and location of shunt-capacitor voltage-regulation banks for lowest cost, minimizing pollution effects from thermal power plants, and scheduling maintenance to maximize reliability.

To dig deeper

This article is based on material that is to be published in the July, 1974, *Proceedings of the IEEE*, a special issue on computers in the power industry. The issue will include a dozen papers, each of which reviews the state-of-the-art on a particular power system computer topic.

The best English language sources for continuing coverage of power system computer applications are the *IEEE Transactions on Power Apparatus and System* and the *Proceedings of the Institution of Electrical Engineers* (IEE) in Great Britain.

In terms of meetings, an IEEE Power Industry Computer Applications Conference has been held every two years since 1959, and a Power Systems Computation Conference has been held in Europe every three years since 1963. Sessions on computer applications are scheduled at every Power Society meeting, and there have been many conferences and workshops on special power system computer topics. Proceedings of many of these meetings are available in libraries.

Most books on power engineering are concerned with engineering principles and give little, if any, attention to computer methods. Recently, however, several books have been published that emphasize the use of computers for power system problems. The following are the most well known:

Stagg, G. W., and El Abiad, A. H., *Computer Methods in Power System Analysis*. New York: McGraw-Hill, 1968.
Elgerd, O. I., *Energy Systems Theory*. New York: McGraw-Hill, 1971.
Anderson, P. M., *Analysis of Faulted Power Systems*. Ames, Iowa: Iowa State University Press, 1973.
Knight, U. G., *Power Systems Engineering and Mathematics*. Elmsford, N.Y.: Pergamon Press, 1972.
Billinton, R., *Power System Reliability Evaluation*. New York: Gordon & Breach, Science Publishers, Ltd., 1970.
Happ, H. H., *Diakoptics & Networks*. New York: Academic Press, 1971.

The best source of information on future needs in power system computer applications is a recent study commissioned by the National Science Foundation, RANN program, on *System Analysis Needs in Electric Power Systems*. Most of the topics discussed in the report of the study involve the use of computers. It was concluded that adequate techniques are probably already available for the solution of most of the problems that were identified, but much work remains to be done in applying them. It was also noted that the best methods and computer programs are not readily available to all of the industry.

William F. Tinney (SM), since 1950, has been employed by the Bonneville Power Administration, Portland, Oreg., where he is presently head of the Methods Analysis Group. He has been working on power system computer applications since 1955.

The author of more than thirty technical papers in his field, Mr. Tinney's early work on sparse matrix methods was a major influence in establishing this computational technique. He received the B.S. and M.S. degrees in electrical engineering from Stanford University in 1948 and 1949, and is a registered professional engineer in the State of Oregon.

Mark K. Enns (SM) is currently Harvey A. Wagner Professor of Power Systems Analysis and Director of the Power Systems Laboratory at the University of Michigan, where his principal research interests are in applications of computers to power system planning and operations. He received his Ph.D. in 1967 at the University of Pittsburgh after working at the Westinghouse Electric Utility Engineering Dept. on problems of power system analysis, and boiler-turbine-generator modeling and control.

What to tell your neighbors

The layman expects you to have the real facts. These tips may surprise him—and even you!

Of all the energy consumed in the U.S., 37 percent is used by private individuals for their homes and automobiles. Although the automobile accounts for about 15.5 percent of that total, and represents the single most energy-consuming product in our lives, the combination of space heating, water heating, and air conditioning consumes slightly more energy—17 percent. The remaining 4.5 percent covers all the rest—cooking, dishwashing, laundry, lighting, home entertainment products, beauty aids, etc. So, aside from using the family automobile, or automobiles, more sensibly, the next best way to save energy is by examining household uses of energy. Before putting the electric toothbrush in storage, it makes sense to assess all energy-consuming household devices. Then, a plan for attack can start with the high energy consumers and proceed down the list to the lower ones as time, energy, and the family budget permit.

Table I shows annual operating costs for typical home appliances and electrical devices. It is arranged by types of appliances—water heating, space heating/cooling, kitchen, etc.—and, in each category, the highest energy consumers are at the top of the list and the lowest at the bottom. Lighting is not included but is discussed in some detail later in this report. The list, as well as energy-saving techniques cited throughout this article, was compiled from several sources among which were the General Electric Company, Northeast Utilities, the Electric Energy Association, and Montgomery Ward. Although the kilowatthour rate used in computing the yearly cost for each appliance was 3c, the table can be converted easily to any other rate simply by multiplying the kWh figure shown in the energy consumption per year column by that rate.

Spend less for heating water

A water heater is one of the largest users of energy in the home and should be no larger than necessary to meet your family's needs. Oversizing wastes energy. A 40-gallon (152-liter) hot water tank is sufficient for the average family of four. And don't overheat water for your needs. A good hot-water temperature for a normal house with a dishwasher is 140°F (60°C); without a dishwasher, 110°F (43°C). For every 10 degrees the water temperature is raised above 140 degrees, hot water costs increase 3 percent.

To conserve hot water, take showers instead of baths unless you're a shower lingerer. An average shower takes 5 gallons (19 liters) of water; a bath averages 10 gallons. If you let the hot water run while shaving or rinsing dishes, you can waste from 10 to 30 gallons (38–114 liters) of hot water per day. Rinse the dishes under cold water and use cold and warm water cycles as often as possible for dishwashers and washing machines. Switching to cold cycles can lower gas or electricity costs by up to 4 percent.

Here are a number of additional ways to use less hot water:

- Run dishwashers and washing machines only when they are fully loaded. A half load uses just as much electricity and hot water.
- Turn the water heater off when you are away for extended periods of time.
- Replace worn washers on leaky faucets. One leaky faucet can waste up to 5000 gallons (19 000 liters) of water per year.
- Make sure your hot water heater is working efficiently.

Heat your house with less energy

No matter what type of heating system you have, the most effective way to decrease energy consumption is to increase the amount of insulation. Table II, for instance, shows the effect that increased amounts of insulation would have on a home heated by natural gas.[1] Table III shows the cost-effectiveness of increasing the insulation in that same home. Installing three inches of ceiling insulation is the most cost-effective, but provides the smallest incremental energy saving. Retrofitting wall insulation can save a significant amount of energy, as indicated in Table III, but it is not cost-effective.

If you are constructing a new home, or if your present heating system needs replacement, you might consider installation of a heat pump. Heat pumps work most efficiently in mild climates where they can supply twice as much heat output as the electrical energy needed to operate them. (They do not violate the laws of thermodynamics; the heat transferred and supplied to the home comes from the ambient air.) For example, a 5-tonne capacity heat pump operating with an outside temperature of 45°F (7°C) can deliver 60 000 Btu's (63.4 million joules) of heat for every 23 600 Btu's (24.9 million joules) of electricity used. In mild climates, heat pumps use about half as much energy as conventional electric heating, about 15 percent less than oil furnaces, and perhaps 5 percent less than gas furnaces. In colder climates the heat pump becomes considerably less efficient.

Solar heating for homes is just beginning to get increased attention because of its energy-saving possibilities. But even for new home construction, it is still a long way from being cost-effective. One company, Sunworks, Inc., Guilford, Conn., is in the process of building the first solar house in Connecticut. It has

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Ronald K. Jurgen Managing Editor

I. Annual operating costs for typical home appliances and electrical devices

Appliance	Frequency/Type of Use	Energy Consumption per year (kWh)	Yearly Cost*
Water heating			
Storage heater		5800	$174
Quick-recovery heater		4811	$144.33
Water pump		231	$ 6.93
Space heating/cooling			
15 000-Btu air conditioner	500 hours per year	1150	$ 34.50
Burner and pump†		810	$ 24.30
Burner and fan†		810	$ 24.30
Burner only†		410	$ 12.30
5000-Btu air conditioner	500 hours per year	410	$ 12.30
Dehumidifier		377	$ 11.31
Portable heater		176	$ 5.28
Attic window fan		170	$ 5.10
Humidifier		163	$ 4.89
Kitchen appliances			
14-foot^3 no-frost refrigerator-freezer		1548	$ 46.44
21-foot^3 manual defrost upright freezer		1392	$ 41.76
30-inch electric range, self-cleaning oven		1068	$ 32.04
Dishwasher	46 cycles per month	330	$ 9.90
Microwave oven		190	$ 5.70
Electric skillet	10 hours per month	182	$ 5.16
Coffeemaker	12 cups, 8 times per week, kept warm for one hour	92	$ 2.76
Toaster oven	Toast 4 slices of bread per day, bake 2 hours per week, top brown twice per week	92	$ 2.76
Hot plate		90	$ 2.70
Deep fryer		83	$ 2.49
Electric kettle	Boil one quart of water, 10 times per week	58	$ 1.74
Electric griddle	3 times per week, 17 minutes per use	56	$ 1.68
Two-slice toaster	8 slices of toast per day	40	$ 1.20
Food mixer/blender		15	45c
Food waste disposer	108 cycles per month	4.8	14.4c
Trash compactor	108 cycles per month	2.4	7.2c
Portable mixer	208 times per year, 3 minutes per use	1	3c
Electric carving knife	150 times per year, 3 minutes per use	0.7	2c
Can opener/ice crusher	Open 10 cans per week, crush 14 ice cubes twice per week	0.3	1c
Laundry appliances			
Electric clothes dryer (14-pound capacity)	7-pound load, 33 cycles per month	1212	$ 36.36
Self-cleaning steam/spray iron	2 hours per week on normal heat setting	88	$ 2.64
Automatic washer (14-pound capacity)	7-pound load, 33 cycles per month	76	$ 2.28
Entertainment products			
19-inch color television, hybrid chassis	5.7 hours per day	444	$ 13.32
25-inch color console, solid-state, instant color	6.6 hours per day	360	$ 10.80
(with instant color off)	6.6 hours per day	334	$ 10.02
19-inch color television, solid-state, instant color	5.7 hours per day	258	$ 7.74
12-inch monochrome television, hybrid chassis		187	$ 5.61
10-inch color television, hybrid chassis	3 hours per day	169	$ 5.07
19-inch monochrome television, solid-state	5.1 hours per day	129	$ 3.87
Automatic stereo phonograph	2 hours per day	68	$ 2.04
Stereo component system with FM/AM and FM stereo, tape player, four channel	3 hours per day	54	$ 1.62
FM/AM digital clock radio	24 hours per day for clock, 2 hours per day for radio	27	81c
AM clock radio	24 hours per day for clock, 2 hours per day for radio	18	54c
Bathroom appliances			
Salon-style hair dryer	2 times per week	44	$ 1.32
Hand hair dryer	4 times per week, 10 minutes per use	24	72c
Electric toothbrush (continuously charging)	2 times per day	12	36c

Appliance	Frequency/Type of Use	Energy Consumption per year (kWh)	Yearly Cost*
Lighted makeup mirror	10 times per week, 15 minutes per use	2.3	7c
Heated shaving-cream dispenser	1 time per day	0.3	1c
Miscellaneous electrical devices			
Swimming pool pump, 1 hp		2160	$ 64.80
½ hp		1080	$ 32.40
¼ hp		540	$ 16.20
Vacuum cleaner		46	$ 1.38
Electric clock		17	51c
Floor polisher		15	45c
Sewing machine		11	33c
Heating pad		10	30c

* Based on 3c per kilowatthour. Average rate for 1973, according to Edison Electric Institute was 2.3c per kilowatthour

† Electricity costs for operating oil and gas burners. Does not include cost of fossil fuels

three long slanted rows of glass-covered panels mounted on the roof. The panels contain blackened copper pipes carrying water for use in the home's space-heating and water-heating systems. The firm's owner estimates that the solar-energy system in the three-bedroom, $60 000 house will probably supply about half the heat, cutting annual fuel costs from about $600 to $300, based on present fuel costs. The solar heating system is adding about $3500 more to the cost of the home, compared to a conventional heating system. And a research team from Clark University, Holy Cross College, and Worcester Polytechnic has as its goal the building of a home self-sufficient in energy. The house would use methane gas produced in the home for cooking and heating, a windmill for minimum electrical needs, and solar panels for heating. In all but the coldest weather, the team feels that such a home could provide all of its own normal energy needs.

Other ways of making your home heating more efficient might include adding storm windows and doors if you do not already have them (see Table III for energy savings) and setting up a zoning system, if your house is large enough to warrant one, so that a separate thermostat can be used to control the temperature in each zone. Avoid constant readjustment of thermostats. Set them for the lowest comfortable setting during the day and lower the setting by 6 or 8 degrees at night. You can save up to 20 percent of your fuel bill by lowering the thermostat just 6 degrees. Thermostat settings in unused rooms should be lowered (or turn the heat off if separate thermostats are not used) and keep the doors to these rooms closed. If you are going to be away for a few days or longer, set thermostats for 50–55°F.

Some additional tips are:

- Close blinds and draperies at night to minimize drafts. Open them to the sun during the day.
- Clean or replace filters in forced-air systems regularly.
- Don't block radiators or air ducts.
- Close fireplace dampers when not in use so warm air can't escape up the chimney. If your fireplace doesn't have a damper, consider having one installed. Also, consider installation of a glass fireplace screen to minimize heat losses when the fireplace is in use as well as when it's not.
- Keep humidity at a proper level with humidifiers or with a water supply near the furnace vents. It takes more heat to make you comfortable if the air is too dry.
- Make certain your heating system gets regular maintenance to keep it working at top efficiency.

Cool your home more efficiently

Insulation makes just as good sense for air conditioning as it does for heating. So if you add insulation, or storm doors and windows, to keep heat in during the winter, you benefit doubly by making it easier to keep your house cool in the summer, with or without air conditioning. Since air conditioners can add appreciably to your energy costs, it pays to do everything possible to make their job easier. For example, if your home has an attic, it can get 40°F (4.4°C) or more hotter than the rest of the house in the summer. Attic louvers or other means of simple ventilation will help hold that temperature down. An attic fan will do the job even better and costs relatively little to operate.

If you are considering purchasing air conditioners, make certain that you get the right size for the job and, if you can afford it, buy the most efficient unit

II. Effect of insulation on heating requirements for a 1400-square-foot ranch house in a cold climate

Amount of Insulation	Annual Heat Required (1000 feet^3 Natural Gas)	Annual Savings (Percent of Max. Input)
None (typical pre-1940 construction)	270	
3 inches in attic plus storm windows and doors (typical 1950s)	180	33
Full (6 inches in attic and about 3 inches in walls, plus storm windows and doors)	122	55
Annual savings (maximum)	148	55

III. Cost-effectiveness of adding insulation and storm windows and doors

Amount of Insulation	Percent of Total Energy Savings	Retrofitting Insulation Cost*	Percent of Total Energy Saving/$ Cost
No insulation	0		
3 inches in attic	47	$105	0.45
6 inches in attic (addition of 3 inches)	7	$70†	0.10
Storm windows and doors	13–26	$250–$300	0.05–0.09
3 inches in walls	33–20	$720	0.05–0.03

*Installed by consumer on a do-it-yourself basis
†Based on average data.

available. Buying an oversized unit might sound like a good idea but it wastes energy because it cools a room so quickly that the compressor turns off too frequently, and the air conditioner can't dehumidify the room properly. Look for the energy efficiency ratio (EER) rating of the air conditioner. It is the ratio of the number of Btu's of cooling power of the unit to the number of watts it takes to run it. The higher the EER, the more efficient the unit, and the less it costs to run it. The additional purchase cost can be paid for in a short time by the savings on your electric bill.

Set your air conditioner at moderate settings—78 degrees F (25.5°C) is a comfortable indoor summer temperature for most people and shut it off late at night and start it early in the day before heat builds up inside the house. Be certain that all outside doors and windows are closed when air conditioners are on and seal all areas leading from air-conditioned spaces to the attic. Allow air to flow freely into and out of the air conditioner. Don't let indoor draperies or outdoor shrubbery get in the way. Use electric fans to circulate air even if you have air conditioning. By so doing, you can operate air conditioners at higher temperatures and still be comfortable.

Other ways to make cooling more efficient are:

- Use curtains, shades, and awnings to keep sunlight out of the house.
- When cooking, use covered pots and low settings when possible.
- Keep air filters clean.
- Turn lights off when not in use. They add heat.
- Use television sets, radios, and appliances wisely. They also generate heat.
- Confine use of ranges or dryers to morning or evening hours, if possible, when it's cooler.
- Plant trees to provide shade for the house.
- Use a bathroom exhaust fan or open the bathroom window, with the door closed, before bathing or showering to remove the heat and moisture so that the air conditioners will not have to use valuable energy to do the same job.

Saving energy in the kitchen

As can be seen from Table I, the largest energy-consuming device in the kitchen is the refrigerator-freezer. To use it wisely, defrost as soon as necessary to keep the internal cooling coils operating efficiently. Keep the external coils, fins, and motor free from dust and be certain that the door gaskets provide tight seals. When you are away for extended periods of time, turn the refrigerator dial two or three settings warmer.

If you're going to buy a new refrigerator, consider one with a power-saver switch that reduces the operating cost by letting you select an operating level that corresponds to the outside weather. If you're going to purchase a freezer, get a chest type (if you have the floor space for it) rather than an upright. A chest freezer loses less cold air when you open it than an upright.

When using the refrigerator, don't overfill it. Good air circulation is necessary for efficient operation. Don't block the air vents. Keep the freezer full, on the other hand, to prevent icing. Cool foods and food containers to room temperature before placing them in the refrigerator or freezer and cover all liquids stored in the refrigerator.

The next largest energy consumer in the kitchen is the range. There are many ways in which energy wastage can be cut down when cooking. For example:

- Thawing frozen foods before cooking requires less cooking time.
- Use covered pots and low settings whenever possible.
- Bake two cakes or pies at one time. Freeze one for future use.
- Plan oven meals around dishes requiring about the same temperatures.
- Use the right size pan for the cooking unit. Pans that are too small allow unused heat to escape into the room.
- Turn surface units down to desired temperature as soon as boiling starts.
- When using the self-cleaning feature on an oven, use it right after cooking while the oven is still hot.
- Have faulty elements or switches serviced as soon as possible for both safety reasons and to be sure your unit is operating at top efficiency.
- Make sure the pilot light on a gas range is adjusted properly.
- Put pots and pans on the range before the heat is turned on.
- When possible, use the oven instead of the surface units since less heat is lost in a confined area.
- Turn an electric range off just before cooking is completed. Residual heat will finish the job and keep food warm before serving.
- Use a microwave oven to reduce power consumption for cooking certain foods.
- Avoid preheating the oven if possible.
- Ceramic, glass, and stainless-steel dishes retain heat better than other materials. Lower the oven temperature by 25°F (14°C) if using them.
- Reduce oven peeking to a minimum. Everytime the

oven door is opened, the oven temperature drops 25 to 50°F (14°–28°C).

- When heating or boiling a large amount of water, start with hot tap water rather than cold.
- If you have a pressure cooker, use it whenever possible.
- Don't use any more water than necessary when cooking vegetables.
- Broiled meats cook faster than roasts.

Another kitchen appliance to use wisely is an electric dishwasher since it consumes both electric power and hot water. Some of the ways to conserve energy when using a dishwasher have already been discussed in the section on conserving hot water. Other energy-saving actions might include keeping the dishwasher drains and filters clear of debris; using partial load cycles, rinse-only cycles, mid-cycle turnoff, and other features whenever possible; skipping the drying cycle since dishes dry perfectly well at normal room temperatures; and, during the summer, using the dishwasher at night to avoid extra heat in the house during the day.

Wash and dry clothes for less money

It costs less money to wash clothes than to dry them, so, if possible, dry clothes outdoors rather than using an electric or gas dryer. Other ways of cutting down energy consumption when doing the laundry are:

- Wait until you have a full load before you run the washer.
- Sort laundry according to amount of soil, color, and type of material. Use the correct time and temperature for each particular load.
- To help remove heavy dirt, use presoak or prewash cycles.
- Use cold water and cold-water detergents when practical.
- Spin-dry wash before putting it in the dryer.
- Don't overload the washer or dryer. They'll have to work harder and longer and use more energy in the process. Also, overloading the dryer causes wrinkles that have to be ironed out later.
- Keep the lint filter on the dryer clean to permit air to move freely. Clean the filter after each use.

How to spend less for lighting

Although individual light bulbs or lamps use less energy than most small appliances, the total amount of lighting in a home can use a sizeable amount of the overall energy consumed. Here are some techniques for cutting down your lighting costs:

- Always turn lights off when not in use.
- Don't use larger bulbs than necessary.
- Switches for attic, cellar, and outdoor lights—as well as heating cables and outdoor pool pumps—should be equipped with indicating lights so that you know when they're on.
- Use three-way bulbs instead of regular bulbs in table lamps. Turn on high for reading; low for conversation.
- Use light-color paint or paper on walls to reflect more light and make it possible to use lower-wattage bulbs.
- Put fluorescent lighting in kitchen (or other) ceiling fixtures. A double 40-watt fixture will do the same lighting job more economically with less energy than one 150-watt incandescent, two 75-watt incandescent, or three 60-watt incandescent bulbs.
- Standard-life light bulbs conserve more energy than so-called long-life bulbs and give the most life for the lighting dollar. To produce the same amount of light as a standard 100-watt 750-hour bulb, a hypothetical 5000-hour long-life bulb would have to be rated at 130 watts. Over each long-life bulb's life span, it would consume an extra 150 kilowatthours, and, at the 3c per kilowatthour rate used in Table I, would add $4.50 to your light bill.
- One 100-watt bulb in a lamp gives more light and uses less electricity than two, 60-watt bulbs.
- Consider the new low-watt night lights to replace the regular 7-watt night lights.

Be entertained for less money

There are relatively few things you can do to conserve energy when using entertainment products, except the obvious. Don't entertain an empty room, don't have the television set and the radio on at the same time, etc. But when it comes time to replace an entertainment product, you can ensure future energy savings by, for example, buying an all solid-state television receiver rather than one using tubes or a combination of tubes and solid-state circuits. Table I shows, for instance, that it costs $13.32 per year to operate, 5.7 hours per day, a 19-inch color television receiver with a hybrid circuit, but only $7.74 per year for a 19-inch solid-state color set with an instant-on feature. And, more energy can be saved by turning off the instant on. For example, a 25-inch solid-state color console with instant-on, used 6.6 hours per day (see Table I), costs $10.80 per year to operate; without instant-on it costs $10.02.

Other ways to conserve energy

When using any of the many other electrical appliances not already discussed there are ways to save energy. Mostly, it's just common sense. For example, small appliances such as toasters, electric skillets, and popcorn poppers generally use less energy than a range or oven would for specialized jobs. And all appliances use less energy if they're maintained so that they operate at peak efficiency. A vacuum cleaner, for instance, will use more energy when operating with a nearly full bag of dirt than when the bag is empty.

One final rule of thumb is, in spite of what you might read or hear to the contrary, not be be penny-wise and pound foolish in trying to save energy. Don't give up your electric toothbrush, thereby saving 36c per year, but continue to waste hot water that may be costing you $10, $20, or more per year.

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How manufacturers cope

Component and equipment makers strive to keep production up while holding tempers and temperatures down

A new title is rapidly entering organization charts, that of the energy czar. In many companies, his sweeping powers have this winter affected even plush executive suites, sending chills up the spines of top brass and workers alike. In a similar vein, the approach of summer promises that even the most passive work tasks will be sweaty.

Adjusting thermostats and reducing lighting are the two most fruitful steps that electronic companies have undertaken to conserve energy. But there are many other methods as well. In addition to public spirited motives and the desire to reduce climbing power costs, many companies are making sincere attempts to reduce power usage as a means of self-preservation, to avoid the possibility of damaging blackouts or the exhaustion of allocated fuel supplies.

The energy crisis also has had far reaching effects on materials—not just in petroleum-derived products, but in shortages arising from lack of fuel to produce materials and delivery delays because of the recent gasoline shortage. As a result, substances that were formally considered as cheap waste, which companies paid to be carted away, are now being jealously hoarded and recycled.

Gerald Lapidus Associate Editor

Allocation proposals were an especially bitter pill to swallow for large segments of the electronics industry, due to the growth that has characterized its recent history. The result has been that 1972 base year allocations of fuel fall vastly short of needs. The spiraling growth that has affected semiconductor makers more than any other major industry area is the principal threat behind the gloomy headlines earlier this year predicting blackouts that could threaten the very survival of "silicon valley" (the electronicker's nickname describing the heavy concentration of semiconductor companies in the San Francisco Bay area).

Sweaters and squinting

For most electronic companies, the biggest savings have resulted from lowering thermostats this past winter and reducing lighting. These measures alone have produced savings of electricity and heating fuel running typically 10 to 15 percent, with many companies

surveyed by *Spectrum* showing gains of 25 percent or more.

At Western Electric, thermostats in offices and plants were turned down to 68°F (20°C) during working hours and reduced to 55°F (14°C) at other times during the heating season. Heat was entirely cut off or else maintained at a minimum of 40°F (4.4°C) in seldom-used facilities such as store rooms, and garages were kept at 50°F (10°C) or less. Preliminary plans for this summer call for cooling offices to no lower than 78°F (26°C) during working hours and 80°F (27°C) at other times.

The results of these and other measures show substantial economies. For example, Western Electric's Dallas plant forecasts an overall energy reduction of 25.1 percent, which is equivalent to 299 000 gallons (1.13 million liters) of no. 2 heating oil. The Oklahoma City Works expects to turn in a saving of 11.1 percent, which translates to 529 000 gallons (2 million liters), and the Kansas City Works will reduce energy use by 14.3 percent, equivalent to 1.17 million gallons (4.34 million liters).

A number of measures have been taken by companies to increase *efficiency* of heating and air conditioning systems. At IBM's General Products division in San Jose, Calif., plastic sheets having a silver film have been installed on some windows to reflect the sun, while still permitting light to pass. In the Information Records Division plant in Greencastle, Ind., it was mandated that venetian blinds be set to 45 degree angles in summer and set wide open in winter. At RCA, the roofs of some plants are being painted with reflective materials to repel heat. At a number of plants surveyed, heat from machinery and ovens is being piped to cooler areas in winter and timers have been installed to lights, air conditioning, and heating systems.

Plessey Frenchtown, a ceramics maker in Frenchtown, N.J., saved fuel this winter simply by cutting out heating altogether. Instead it relies on heat radiated off by its tunnel kilns, which operate at or above 2800°F (1810°K). This energy was both used to heat the surrounding air and distributed around the plant. The reason for this drastic course of action was that propane had been used for space heating and operating the kilns. Since the company was allocated propane equal to 90 percent of its average consumption in October, 1972, and its 1974 production requirements were still larger, it opted to cut heating in favor of maintaining production.

Burndy Corp. of Norwalk, Conn., achieved a 35-percent reduction in heating by carefully taking stock of its heating plant, in addition to simply reducing temperatures. The electrical equipment manufacturing company added insulation, repaired leaks in steam lines, and increased the return flow.

Producing in the dark. At the height of the coal shortage in England, many firms applied their fuel oil allocations to run auxiliary generators that were used to supply electricity so that plants could remain open longer than the specified three-day work week. To stretch this valuable resource, bulbs were strung just above work stations and some, as in this case, were powered from 24-volt aircraft generators.

Expansion offers a unique opportunity to take energy saving measures. Interdata's new building in Oceanport, N.J., is built with hollow outer walls filled with insulation. The lighting system is designed so that 13.5-square-meter areas can be separately controlled. A heat-pump system recirculates heat produced by the lights. For the heat pump, plenums were installed above the lighting fixtures to collect the heated air, which is then piped into the conventional heating system.

Another measure taken was to locate heat-producing activities in areas where there are no drop ceilings. The manufacturing and system test departments share such an area in the new building, so that the heat given off by these operations will help heat this large, open space and conversely, the lack of confinement of heat will reduce the cooling load in summer.

Some companies have even made substantial capital investments to conserve heating fuel. Western Electric's Electronic Research Center installed air preheaters on its two 17 billion-joule boilers and regulated the exhaust and intake air for its circulating air system. The estimated fuel saving of this system is about 10 percent.

Raytheon's hard look at all aspects of energy consumption yielded an extensive list of ways in which power can be saved (see the box on pp. 68–69), resulting in a 30-percent reduction in fuel oil usage and a 20-percent drop in electricity. Among the measures taken were the installation of recovery units on exhaust ventilators to remove heat from exhaust air and the recovery of heat from process cooling systems. Also, small air compressors have been added to control heating valves when tools and machines that use large amounts of compressed air are not in use.

One of Raytheon's major efforts has been a program to optimize the efficiency of boilers and associated heating equipment. An expert in boiler design and heating, who had been working on the development of a new heat-transfer module, was transferred to the corporate staff to administer a boiler-efficiency program. The major elements of the program were to conduct seminars for plant engineers and to check out heating equipment in the company's plants. The experience of the boiler design expert was that, with simple adjustments, a boiler's efficiency could be improved by as much as 10 percent. Among these adjustments are optimizing combustion air settings, cleaning heating surfaces, properly allocating boiler loads, and improving draft performance.

A key to determining whether the air–fuel mixture is correct is measurement of the carbon dioxide present in the stack gases. For an older burner, carbon dioxide readings of 10.5 percent are typical, with 50 percent excess air. If the stack gas composition is not monitored frequently, a change in the mixture could go unnoticed. Should the carbon dioxide content drop to 8 percent, for example, a fuel loss of 6 percent would occur. In a modern boiler, 12.5 percent carbon dioxide is typical, with 25 percent excess air. Although the leverage for improvement and fuel saving is not as great with such a boiler, if poorly adjusted, it could be allowed to operate at only 10.5 percent carbon dioxide and in so doing use 2.5 percent excess fuel.

Typically, home oil burners are cleaned only once a year, but Raytheon has stepped up the frequency of cleaning its burners, internal tubes, and other surfaces where soot could accumulate and reduce the heat transfer process. The burner tips that atomize the oil are cleaned every few days.

With more frequent cleaning and changing of burner elements, Raytheon's Spencer Laboratory in Burlington, Mass. has pushed the combustion efficiency of its boiler to 90.75 percent, well above the 75- to 82-percent efficiency generally reported for boilers of this type.

Probably the most universal energy-saving measure has been the reduction of lighting, both interior and exterior. Many companies with brilliantly lit signs may find, to their distress, that they no longer aid their public images.

Cutting energy in the plant

Heating and air conditioning

- Turn down heat during day to 65°–68°F (18°–20°C).
- Turn down heat at night and on weekends to 60°F (15.5°C) or less.
- Turn down heat in unused areas to 50°F (10°C).
- Use minimum heat in warehouses and storage areas.
- Turn on heat later than usual each day.
- Lower cafeteria temperature immediately after lunch.
- Reduce temperature in highly ventilated areas.
- Ensure that all outside doors are self-closing.
- Segregate special operations that require more heating or cooling than surrounding areas.
- Keep doors closed to unheated or uncooled areas such as corridors.
- Keep heaters clear of obstructions.
- Seal thermostats to prevent individual adjustments by unauthorized personnel or else install key-operated thermostats.
- Install clock thermostats or timers to control heating cycle.
- Use humidifiers to improve employee comfort at lower temperatures.
- Change three-pipe systems into two-pipe systems—either heating or cooling—never both.
- Redesign heating system for better control and more efficiency.
- Shut off chillers during winter months.
- Discontinue use of some building entrances.
- Close loading dock doors when not in use.
- Use dock curtains when unloading trucks.
- Use air curtains at doors that must remain open.
- Pull drapes at sundown to cut heat loss.
- Make maximum use of sunlight for heating and lighting.
- Rearrange office furniture so that desks are close to heating systems and/or natural sunlight.
- Inspect and repair insulation, weather stripping, and caulking.
- Install additional insulation especially on ceilings.
- Investigate more or better pipe and duct insulation in unheated areas.
- Cover windows with plastic sheets or film.
- Install storm windows.
- Cover all or a portion of windows with insulating material and/or wall panels.
- Install insulating glass in windows.
- Consider infrared or other spot heaters in small work areas where general heating can be reduced.
- Partition or temporarily close off underutilized floor space.
- Clean heating and cooling heat-exchanger coils and fans on a regular basis.
- Replace inefficient boilers with more efficient units.
- Use small automatic steam generators at remote locations requiring steam.
- Clean boilers frequently.
- Adjust burners regularly for maximum efficiency.
- Use boiler additives for maximum efficiency.
- Preheat combustion air with flue gas.
- Check steam traps, lines, regulators, and valves regularly for leakage.
- Reduce makeup air during day.
- Eliminate all makeup air at night.
- Seal ventilation controls to prevent unauthorized adjustments.
- Turn on ventilation later than usual each day.
- Cycle ventilation equipment during day.
- Use heat recovery units on exhausts.
- Rearrange furniture in drafty areas.
- Install baffles to eliminate drafts.
- Clean or replace air filters on a regular basis.
- Eliminate any unused roof openings and abandoned stacks.
- Supply colder makeup air to laboratory hoods.
- Close some laboratory hoods and consolidate user operations.
- Cool buildings with roof water sprays.

Lighting

- Turn off lights when not in use.
- Use timers to control lighting cycle.
- Put "lights out" stickers on room light switches.
- Mark panels and switches so guards can monitor lighting.
- Turn off parking lot lights after last shift.
- Restrict parking to specific lots so lights can be kept off in unused lots.
- Install photoswitches on lights that remain on at night.
- Put timed shut-off switches on lights in transformer rooms and similar closed-off areas.
- Turn off all electrical signs.
- Deenergize some light fixtures.
- Remove some light bulbs (and ballast where neces-

In many plants, lamps have been removed to assure that they will not be turned on. IBM's System Products Division Laboratory in Endicott, N.Y., has even gone as far as rewiring fixtures, holding four fluorescent lamps, to power only two lamps. Most companies queried by *Spectrum* say they have reduced office lighting by as much as 25 percent and corridor lighting by 50 percent. A number of firms also have installed many additional light switches to control lighting over smaller areas so that lights can be shut off in unoccupied spaces.

Another widely used practice has been the installation of timers to assure that lights are shut off after working hours. Cleaning schedules also have been changed so that they coincide as much as possible with normal working hours. However, one attempt to save

sary).

- Remove diffusers from lights.
- Replace incandescent fixtures with fluorescent ones.
- Replace incandescent bulbs with self-ballasting mercury or sodium bulbs.
- Clean light fixtures on regular basis.
- Reduce lighting in material storage areas except where required for production and security needs.
- Reduce lighting in all corridors.
- Provide improved localized lighting but reduce overall lighting.
- Turn off overhead lamps and substitute bench lamps, where appropriate.
- Remove desk lamps where overhead lamps are used.
- Rearrange office furniture so that desks and chairs are close to natural sunlight.
- Reverse trend toward uniform lighting which tends to make industrial buildings overlighted.

Process-related measures

- Turn off process exhausts when not in use.
- Schedule work so process exhausts are used less.
- Improve efficiency of exhaust systems by redesigning hoods.
- Substitute less toxic chemicals that require less ventilation.
- Cut down on process use of hot water (rinses, etc.).
- Check hot water systems for leaking valves and faucets.
- Use plastic spheres on hot liquids in open top tanks.
- Determine efficient "hold" temperatures on process tanks during overnight and weekend periods.
- Reduce temperature of processing fluids.
- Shut down gas burners in process equipment if not in use instead of idling them.
- Eliminate heat treating department if it is a marginal operation and subcontract work to a commercial heat treatment shop.
- Survey air tools and spray equipment, and upgrade them to reduce usage of compressed air.
- Eliminate compressed air leaks.
- Use ultrasonic leak detector to locate steam and/or compressed air leaks.
- Eliminate compressed air use for cooling product or personnel or for agitating liquids.
- Turn off machinery, test equipment, and ovens when not in use.
- Reschedule work to require minimum usage of electrical equipment (test equipment, motors, fans, etc.).
- Unplug all small electrical tools such as soldering irons when not in use.
- Replace oversized motors with ones of proper size.
- Use submetering to monitor power usage within certain areas of the plant.
- Deenergize excess transformer capacity whenever practical.
- Provide proper maintenance and lubrication of motor-driven equipment for the most efficient operation.
- Use alternative processing methods that require less energy, (e.g., powder coating versus solvent based).

Transportation

- Post signs on company vehicles for 50 miles per hour maximum speed.
- Encourage car-pool use by awarding preferential parking spaces.
- Use computer capability to assist employees to form car-pools.
- Arrange for bus service for employees.
- Run shuttle service between adjacent facilities or outlying buildings.

Other methods

- Improve power factor with capacitors.
- Improve power factor by proper equipment selection.
- Check power factor capacitors for blown fuses.
- Employ automatic control of electrical demands to level the load.
- Convert to high voltage to supply equipment that runs most efficiently at high voltage.
- Eliminate unnecessary power devices such as automatic doors, dryers in washrooms, and electric water coolers.
- Limit use of elevators.
- Prohibit individual space heaters unless specifically authorized.
- Turn off electric typewriters when not in use.
- Eliminate weekend overtime.
- Limit overtime to specific nights.
- Reschedule janitorial services for regular hours.
- Appoint "energy monitors" in all plant areas.
- Train security guards and night watchmen to recognize and report wasteful energy usage.
- Issue violation tickets for wasteful energy practices.
- Give proper weight to energy consumption requirements in make-or-buy studies.

electricity, that of reducing parking lot lighting, has met with mixed reactions. The problem is plant security and personal safety.

Pulling the plug on silicon valley

The Arab oil embargo, as it turned out, may have threatened the very survival of semiconductor companies in California; and, with continuing electric power shortages, this possibility still exists to some extent. The heart of the problem is that high temperature diffusion and growing furnaces used in processing semiconductor materials are electrically operated, and reductions or total cutoff of power would not only stop production but would cause substantial damage to the expensive furnaces. Other types of electronic manufacturing would also be greatly affected, but generally to a lesser extent.

Several mandatory curtailment plans have been under study by the California Public Utilities Commission. At the time of this writing, no decision has been made on which plan to follow, or whether any mandatory cutback will be necessary in the near future. Possible means of cutbacks include: reductions in usage to 10 percent below the 1972 or 1973 levels of power consumption, or else the imposition of rolling blackouts, in which entire areas would be without electricity for several hours at a time.

The potential effects of these curtailment plans on all types of electronics manufacturing were studied by the Western Electronic Manufacturers Association (WEMA) in a survey of its 575 California member firms. The study showed that cutbacks to 10 percent below 1972 energy consumption could result in layoffs of 12.4 percent of present employment. Projecting on the basis of the more than 500 000 employees of high-technology companies in the state, this could result in a reduction of an estimated 62 000 jobs.

The impact would be reduced considerably if 1973 were used as the base period, in which case employment would be cut by 4.5 percent, or by 22 500 jobs among all California WEMA companies. The difference between 1972 and 1973 relates to the heavy growth experienced by many of these companies.

Comments from participants show that any means of cutback would be disastrous for rapidly growing companies needing more, not less, power in 1974, and for manufacturers engaged in continuous processes or test procedures requiring a steady stream of electricity. While many high-technology manufacturers cannot live with mandatory controls, however, the majority are already reducing electrical consumption on a voluntary basis and say they can achieve further voluntary cuts averaging about 15 percent.

The possibility of rolling blackouts (programmed load shedding) could be devastating. The extent of devastation would depend upon how much advance notice is given. The 155 companies responding said, if no advance notice were given, each blackout would cost them between $2.8 and $3.5 million in equipment damage and an estimated $26.5 million of lost work in process. With at least three hours of advance notice, these losses would be reduced to $1.5 million in equipment damage and $21.8 million of work in process per occurrence. Many of the firms, however, indicated that with at least 24 hours advance notice of blackouts, these losses could be reduced still further—possibly even eliminated.

Northern California firms evidently would be harder hit than those in Southern California. The 79 companies in Norther California who responded said they would have to lay off 14.4 percent of their work force if 1972 were used as a base period, or 5.1 percent using the 1973 base. By comparison, 76 companies in Southern California said the 1972 base period would result in layoffs of 9.8 percent and the 1973 base period would necessitate layoffs of 3.7 percent.

Based on the estimated 175 000 employees of WEMA's members in Northern California, this would mean layoffs of 25 200 or 8925 using the 1972 and 1973 base periods, respectively. In Southern California WEMA member companies employ an estimated 345 000 people. Using the 1972 and 1973 base periods, this would mean layoffs of 33 810 or 12 765, respectively.

Robert Lorenzini, president of Siltec Corp., a Menlo Park, Calif., manufacturer of silicon crystals, noted, in testimony last December before the California Public Utilities Commission, that many companies doubled in size in 1973 and that the 10-percent cuts would be disastrous.

In the case of his company, production would have to be cut by 70 percent and this would have a "domino effect" on the companies that are supplied with the company's products. He recommended that if curtailment becomes necessary, the plan should make provision for rapidly growing companies that would be especially hard hit.

Another indirect effect of the oil embargo has been slumping automotive sales. And with the increasing use of electronics in the automobile, the drop in this market has affected many electronics jobs. Part of the job loss is due to reduced sales of big cars and the rest is the result of temporary layoff because of plant changeovers to small cars.

During the heart of the crisis, the General Motors Delco division had laid off 930 employees indefinitely and an additional 2000 temporarily. almost all were production workers making car radios, seat belt interlocks, and heating and air conditioning controls. At about the same time, Motorola had laid off about 100 workers from its Automotive Products Division. The reason Motorola had been less hard hit than Delco is that it supplies auto manufacturers more heavily involved with small cars such as Chrysler, American Motors, and Volkswagen in North America. The employment situation in the automotive industry has been easing, since the lifting of the oil embargo, but electronics suppliers are reducing their 1974 preembargo sales estimates, as consumers continue to hold back.

Getting enough to feed the machines

Materials, the lifeblood of any manufacturing process, are continuing to cause headaches. And not just petroleum derived products, but a wide assortment of other sorts of products, are in short supply. The shortages result chiefly from high demand (not a consequence of the energy situation), difficulties in processing due to the fuel shortage, and problems earlier this year and due to the fuel shortage in obtaining deliveries. An idea of what's in the greatest demand can be gleaned from the list, appearing in the box on this page, of the shortages expected at Western Electric for the rest of the year.

Companies have coped with these problems in three ways:

- Stretching-out and multiple usage of materials that previously were quickly discarded.
- Substitution of more readily available materials.
- The firming up of vendor commitments far in advance of need.

At IBM, these three approaches were put into action as early as the fall of 1972, when the possibility of an oil shortage became evident. This early action is credited by company officials in minimizing the effects of the energy crisis on the company, thus far. Soon after the problem was recognized, the corporate purchasing department asked all IBM locations to survey their existing fuel storage capacity and supplier contracts. Most, it turned out, had been maintaining a 30-day supply of fuel oil through the years. The rest were asked to bring their storage capability up to the 30-day level. This included some locations that found their "30-day supply" really was less than 30 days, due to factors such as accumulation of sludge in the bottom of storage tanks.

When the energy crisis began to affect the supply of basic petroleum feedstocks from which chemicals and plastics are manufactured, the company lined up worldwide sources of supply for some 56 chemicals and many other materials identified as critically short. Special steels from Germany were bought for shipment to Lexington, Ky. Australian plastics found themselves en route to Raleigh, N.C., and American steel went to Argentina.

IBM also studied the processes that require hard-to-get chemicals and plastics and they came up with some interesting conservation measures. For instance, keyboard buttons are being recycled because the styrene plastic from which they are made is extremely hard to obtain. Explains J. B. Long, procurement distribution manager in Raleigh: "The first step was when someone in Kingston [N.Y.] suggested we salvage the keys off some old terminals. We pull them off, have them ground up, and the result is a heck of a lot of new keys—all dark grey. But it will free the new plastic stock for keys in other colors." Mr. Long anticipates that reuse of the plastic buttons will grow as the supply of new styrene dwindles.

In the company's Endicott, N.Y., plant, R. J. Winters, heading a special task force for chemical conservation, has come up with extensive savings in chemicals used to manufacture printed circuit boards.

"We use hydrochloric acid to clean copper for circuit boards. We also use it to clean piping and machinery. The first thing we found was that use of the hydrochloric acid would be extended from two weeks to four weeks without losing efficiency. Then, instead of disposing of it, we hold it in tanks until we need it to clean the pipes and equipment—something we used to do with fresh acid." The net saving is some 50 gallons (189 liters) of acid a day.

Another major requirement is for solvents such as methylethyl ketone. Here, when time-in-use is stretched out, the results aren't quite up to those obtained with fresh solvent—but still are satisfactory.

And the East Fishkill plant learned that isopropyl alcohol, which once was so cheap that it was disposed of after a single use, could be reused in the Lexington, Ky., plant for a completely different industrial process.

Commodity shortages also have led to a housekeeping problem of sorts. Some IBM locations have been forced temporarily to store 55-gallon (208-liter) drums and bags of chemicals in parking lots. The drums and bags contain materials that used to be delivered in bulk quantities, such as tank-car lots. Now, the company sometimes has to make do with smaller shipments, which come in drums. Or else, for some materials, the products are purchased from overseas suppliers, who send them packaged only in drums rather than in tank cars.

Western Electric is a major U.S. user of polyvinyl chloride (PVC), a petroleum-derived plastic. An employee's suggestion prompted the company to recycle the PVC material from discarded switchboard cable. The program is expected to conserve three million pounds (1.35 million kilograms) a year. Bell Labs and Western Electric are now developing a pilot plant to reclaim waste PVC and produce material of sufficient quality to permit its reuse in cables and piping.

Other plastics being recycled include ABS (acrylonitrile butadine styrene), used in the manufacture of telephone shells, and polyethylene, used in exchange cable.

Electronics to the rescue

Electronic technology does have the means of solving some of its own energy problems, both in terms of tighter control over power usage and substituting solid-state circuits for vacuum tubes and other devices (see pp. 61–65, this issue).

Some items in short supply

Abrasives
Adhesives
Aluminum sheet and foil
Brass inserts, lead frames
Carbide tool inserts
Chemical compounds
Chemicals, oil, wax
Copper die castings and glass
Electrical components
Encapsulating materials
Ferrous metals
Hydrogen, oxygen, nitrogen
Laminations made by heat processing
Lubricants
Magnetic materials
Molding compounds
Neoprene
Nickel-zinc anodes
Paper products
Plastic-laminated sheets
Plastic-molded parts
Plasticizers/stabilizers
Printed wiring boards
Pulp exchange cable
Polyvinyl chloride
Rubber products
Silicon steel
Solder
Solvents
Tin
Tool steels

On the control side, the use of devices ranging in complexity from computers down to simple timers offers the possibility of more efficient use of electricity, heating fuel, and fuel for vehicles. One program that has been accelerated by the oil crisis is the use of computers to monitor and control building utilities.

The second IBM system/7 minicomputer off the production line went into service at the company's East Fishkill plant to explore techniques for energy control. Its mission is to monitor electrical and mechanical equipment in the central facilities building, as well as power distribution for the entire 207 000-square-meter plant site. It is estimated that the computer produces 10-percent savings in electrical costs and 6-percent savings in fuel oil costs. A later installation at IBM's 52-story office building in Chicago is producing 15-percent savings. This system turns off lights at night, controls dampers according to temperature and humidity, controls fans, regulates water temperatures, and adjusts peak power demand.

To understand how the system works, it helps to know how some power companies charge for their electricity. Although rates vary in different states, industrial and commercial users, generally, are charged for power on three major counts: total consumption, the highest peak of demand for power during a billing period (to compensate the power company for the additional resources required to provide such volume), and fluctuations in the cost of fuel.

The power company measures consumption from its power meters. Consumption is merely the total number of times the disk spins within a given billing period.

To assess demand, a power company uses a demand meter, to measure consumption of energy hit during 5-, 15-, or 30-minute intervals (the time varies with different utilities companies) during the billing period. The highest level of consumption during the time period establishes the demand rate for the month.

A customer who can keep his use of electricity from achieving high peaks can cut down on both consumption and demand.

By monitoring the consumption and demand rate, the computer can regulate energy usage. In this way, the user can, not only pinpoint the demand periods, but anticipate peaks and set a target he does not want to exceed. The computer regulates the controls on selective electrical equipment and cuts back on power when there is an indication the target may be exceeded in any demand period. Of course, consideration must be given to what can be cut back without danger or discomfort to building occupants.

One such system is in operation at Rich's department store in Atlanta, where the biggest energy absorber is the air-conditioning system. As a general rule, lights and air conditioning together account for about 80 percent of any commercial user's total energy consumption. The air-conditioning system contains 100 fans which deliver cool air throughout the store by

Computer control of furnaces in metals industries has led to substantial fuel savings, with National Rolling Mills of Malverne, Pa., reporting better than 90-percent efficiency in fuel utilization, compared to the U.S. average of 50–55-percent. Similarly, because the computer can smooth peak demands, the company anticipates savings of up to 40 percent in the cost of fuel.

blowing air across cold water heat exchangers. The computer shuts off the fans to conserve electricity—4 or 5 at a time—for 5–10-minute intervals. With this technique, the store found that it could vary the internal temperature by a degree or two with no noticeable effect. That action produced an added benefit. Shutting off the fans retarded heat transfer. Water entered the chillers several degrees cooler, and the chiller itself began to throttle back automatically. In fact, Rich's main store had considered the purchase of a fourth chiller, but it now gets along with two.

In another area, computers are at work in metals plants. Some of the most sophisticated applications provide a continuous report on a CRT display, telling the company load dispatcher

- How much power has been used in the current 30-minute period.
- How much is allowable in that period.
- In which mills the power is being used and at what rate.
- Whether, based on an up-to-the-second rate of consumption, the plant is likely to exceed its limits for energy use in that period.
- Which production facilities should be shut down temporarily to avoid exceeding the limit.
- Which of the company's own steam-powered electrical generators should be switched on, or stepped up, to take on some or all of the anticipated overload.

Japanese electronic firms feeling the pinch

The oil shortage and reductions in electric power have forced 30-percent cuts in materials supplied to electronic manufacturers in Japan. Prices of raw materials have increased generally by about 30 percent, with some rising as high as 100 percent. In shortest supply are polyester and polypropylene.

According to *Japan Electronic Industry*, supplies of copper-lined and phenolic-laminated circuit boards have dropped by 30 percent. As a result, there is a heavy demand for imported pc boards.

Silicon is also in short supply, due in part to an accident at Shin-etsu Chemical Co. The shortage is expected to persist for a long time, especially if power reductions continue. One estimate is that a 10-percent reduction in electric power will lead to a 20–30-percent drop in silicon production.

In the transformer industry, silicon steel boards are in short supply. The availability of polyurethane-coated wire is down by 50 percent, accompanied by price increases of 50 percent.

In resistors, there are shortages of caps and lead wires. And nonferrous metals such as copper, zinc, aluminum, and indium are also scarce.

In the meantime, the fuel shortage is leading to increasing use of telephones, with Nippon Telegraph and Telephone (NTT) mounting a campaign to increase telephone usage. This is a rather difficult task in Japan because face-to-face visits are traditional.

This trend is resulting in increased demands for telephone line data equipment such as facsimile systems, keyboard printers, and transmission equipment, as well as terminal pushbutton telephones and automatic telephone answering units. NTT also intends to promote facsimile services, which have an advantage over conventional voice communications in that they can transmit handwritten characters, such as Chinese ideograms—an important component of the Japanese language.

The dispatcher in such a plant used to work with a slide rule to try to come up with as many of these answers as possible in time to avoid overloads. But, often, the dispatcher would shut down part of the load before the situation looked too troublesome, with the result that production was lost along with the needed energy cutbacks.

Readings are taken by the computer at 5-minute intervals, beginning half-way through each hour, to trigger a number of automatic actions. For example, if a critical operation requires a high-heat furnace for the entire hour, other furnaces can be turned down for short periods. This kind of fine tuning was impossible previously, since it was almost impossible to calculate a precise balance between priority operations.

Computers are also being put to work in car-pool and dial-a-ride transit systems. Faced with the severe gasoline and the general energy shortages this past winter, Bell Laboratories initiated a computerized car-pooling program for its employees at five New Jersey locations.

With this system, each employee is supplied with a map of the surrounding residential area. The map is marked in a grid like an auto road map and has a coupon attached.

An employee who would like to enter a car pool fills out the coupon with his name, address, phone number, and his grid coordinates and sends it to a collecting point where the information is entered into a computer. The computer processes the names according to grid location and prints out names of people living within each grid area. The employee also can check another box on the coupon if he is interested in forming an employee-chartered bus service.

With regard to the application of solid-state technology to reducing power consumption, one program with easily measurable savings is an ongoing program of the Bell System in substituting transistor equivalents for vacuum tubes in its transmission equipment. When the replacement program is completed, there will be a savings of 250 million kWh per year—which is, indeed substantial! This amount of power can meet the needs of a community of 10 000 homes for three full years.

The Aluminum Company of America, a heavy user of electric power, recently converted the rectifiers on pot lines at several locations from mercury arc devices to silicon diodes. This resulted in annual savings of more than 60 million kWh.

Finally, there is the time-tested method of human exhortation. At RCA, deputy energy czars stalk the plant floors wielding large, luminescent tags that are inscribed *VIOLATOR*. Any machine in operation that should not be is tagged, and its operator faces the scorn of his fellow workers.

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Exploding some myths

When it comes to cutting energy expenditures, the seemingly obvious may prove fallacious under scrutiny

The road to energy conservation, we are told, is paved with simplistic "rules": cut voltage supplies by 5 percent, remove every other fluorescent lamp from fixtures, avoid electric space heating, etc., etc. Unfortunately, many of these suggestions are either completely or partially erroneous. And they can even be counterproductive, causing an increase in energy consumption. The misconceptions have arisen because energy conservation is not simplistic. It is fraught with complicating factors.

Myth no. 1: voltage reduction

In many parts of the U.S.—New York State, for example—electric power utilities have been ordered by state legislators, as an energy conservation move, to reduce voltages to customers by 5 percent. The theory is that, since electric power is proportional to the square of the voltage (assuming current and resistance remain constant), a 5-percent reduction in voltage will give a 10-percent reduction in power consumption. But, in truth, does this happen?

Gerald L. Wilson, director of M.I.T.'s Electric Power Systems Laboratory was one of the first to point out that such a move did very little to save energy. Professor Wilson and his colleagues at M.I.T. performed tests on a large electric power system in the eastern U.S. and found that heating and cooling systems, refrigerators, and any other appliances with induction motors (which means the majority of appliances), compensated for voltage reductions by running longer or drawing more current. With a heating system, for example, the thermostat would run the system for longer periods, if voltages were reduced, in order to maintain room temperature. The result was that both pumps and fan motors in the system would still use the same amount of energy. Similarly, refrigerator motors run longer to keep the temperature in the refrigerator down to the desired level, and the total amount of electricity used is the same, or higher, due to reduced efficiency. According to Professor Wilson, those electricity-consuming devices, such as incandescent lights, that do use less electricity when voltage is reduced, constitute only about 10 percent of the energy requirements of the average home.

Howard C. Barnes, assistant vice president, American Electric Power Service Corporation, at the IEEE Power Engineering Society's 1974 Winter Meeting, also noted the fallacy in the voltage-reduction technique. He said, "My own engineering training and experience leave me skeptical that this in the long term brings any savings of energy. Reducing the voltage doesn't change the number of Btu's it takes to boil water. It doesn't reduce heating demands. Only a lowered thermostat will do that. Some 45 percent of electric energy is used in industry for large motor loads. Motors become less efficient at lower voltages; they run slower and thereby lower productive output. In the overall, I question that voltage reductions are in the total public interest."

Charles Concordia, recently retired from General Electric and now a consultant in the power field, says that voltage reductions should be used to give reserve power for peaking purposes. Reductions do not conserve energy to any large degree, he emphasizes, and voltage reduction and energy conservation should not be thought of as synonymous.

Professor Wilson also questioned whether many power systems could effectively cut voltage at all. He said that most systems have transformers and automatically switched capacitors which compensate for reduced voltages. (Others have indicated, however, that these can be blocked and that peak loads have been reduced by voltage reduction.) And, even if this is not the case, many electric power systems do not have at their power substations the remote control that could reduce voltage. Instead, they must dispatch truck crews to throw the switches manually. In one system that he studied, 1200 such substations would be involved if such a step were contemplated. "I really wonder how much money and energy is being saved where power companies must manually reduce voltage in a system, consequently using gasoline and manpower to do so," he said.

Myth no. 1.5: lights out (a "half myth")

One of the seemingly most obvious ways to conserve energy is to switch off lights. A typical ad in a daily newspaper advises its readers to switch off a light to save oil—oil that must be used for boilers that produce steam for electric power generating turbines. It sounds logical and often is a legitimate energy-conservation technique. But if complicating factors enter the picture, there may not be any energy saved. Syska and Hennessy, Inc., consulting engineers, cite the case of an office building where half of the lighting fixtures were disconnected but there was no appreciable savings in electric power consumption. Investigation revealed that the air conditioning system had electric reheat coils in it which were switched on automatically by the room thermostat when the room temperature dropped because heat from the lighting fixtures was no longer available.

Certified Ballast Manufacturers Association, Cleveland, Ohio, has issued a warning bulletin about attempts to reduce consumption through the removal of fluorescent lamps from energized fixtures. The organization advises that, regardless of lamp type, all

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Ronald K. Jurgen Managing Editor

lamps connected to a given ballast should be removed to prevent possible adverse effects such as reduced ballast life or failure. Removing just one lamp from a two-lamp ballast can cause trouble. With the lamps removed, the ballast still consumes a small amount of power because it continues to draw magnetizing current. This situation can be eliminated only by disconnecting the ballast. For instant start, and other installations having circuit-interrupting lampholders, disconnection is automatic when a lamp is removed.

By removing a fluorescent lamp from a troffer, it has been noted elsewhere,[1] there is some savings in watts but line current increases. For example, a two-lamp, 20-watt ballast uses 6 watts even if lamps are removed. Similarly, an 800-mA or 1500-mA ballast draws almost as much current with lamps in or out. And an additional problem can develop: by removing fluorescent lamps, the ballast is overdriven, reducing ballast life and the life of the remaining lamps.

Myth no. 2: avoid electric heating

There is a widespread misconception that electric space heating, of necessity, is more energy consuming and, consequently, more expensive to the consumer than fossil-fuel heating. Electric heating may be more expensive than alternative means in some areas of the U.S., but in others it is a real bargain. For electric heating customers of power utilities such as Consolidated Edison of New York, electric heating has become a nightmare with newspaper accounts of monthly electric bills exceeding high monthly mortgage payments. But Con Ed is a utility with unique problems and exceedingly high rates and is hardly typical of all power utilities in the U.S.

American Electric Power Company, Inc., in its 1973 Annual Report, on the other hand, gives these statistics for the AEP system: average annual bill per residential customer with electric heating, $343.86; average annual bill per residential customer without electric heating, $151.53. Expressed another way, the average residential customer of the AEP system with electric heating paid a total of $192.33 to heat his home for all of 1973. That's not at all bad compared to some recent fuel oil prices for home heating. The AEP electric heating customers were charged an average 1.58 cents per kilowatthour compared to an average 1.98 cents per kilowatthour for all residential customers.

Another fallacy in the usual comparisons between gas- or oil-heated homes and electrically heated homes is that it is usually assumed, when making comparisons, that homes with fossil-fuel heating have maximum efficiency units (70-80 percent). But these efficiencies only apply to units in top condition when running at full load (efficiencies are usually about 50 percent), and neglect the fact that heat from a central heating unit must be transferred from the furnace either through attic pipes or under-floor ducts, both of which can be sources of great heat loss. Electric heating, on the other hand, with about a 35-percent efficiency of transfer of energy from fuel to electricity is physically located in the room to be heated (unless an electric furnace is being used). All of the heat produced is used for the purpose intended—to heat the room (assuming the walls and windows are properly insulated and electrically heated homes usually do have the proper amount of insulation). And, of course, electric heating usually gives the home owner a thermostat in each room so he can set varying temperatures throughout his home. This is an energy-conserving luxury that only the most expensive fossil-fuel heating systems provide.

Myth no. 2.5: pilots out (a "near myth")

One easy way to save energy, one hears, is for everyone to turn off the pilots on gas stoves. Once again, this sounds like logical reasoning and, in fact, it would save gas (about 1 percent of total gas consumption according to Con Ed for its system). But what else would this action do?

Turning off pilots is, aside from any other pros or cons, a dangerous energy conservation measure. Pilot lights are a safety feature as well as a convenience. The amount of gas saved is typically as little as two cubic feet (0.05 cubic meters) of gas per day for ranges made in the last 15 or 20 years that are equipped with fine, hollow hypodermic-type pilots. But even some of this relatively small amount of gas is not wasted. Heat from a pilot does make a house warmer and means that you require less heat from the home heating system. In the summer months this is a disadvantage, of course, but an American Gas Association study has shown that pilot light heat is beneficial about 72 percent of the time in New York State.

Miscellaneous "mythconceptions"

Here are some other possible misconceptions based on case histories of Syska and Hennessy experience:

- Setting room thermostats at 68°F (20°C) instead of 75°F (24°C) usually saves energy, but it can increase energy consumption under certain conditions. For example, building zones having high internal heat gains and solar loads will increase the demand on the air conditioning system to reduce room temperature to 68°F instead of 75°F.
- Switching off an office-building refrigeration unit working at about 15 percent load during the winter season to save energy was counterproductive. Refrigeration energy savings were exceeded by energy used for extra steam consumed for heating and humidification. The refrigeration unit supplied chilled water to a dual-duct air conditioning system. The chilled water load of 15 percent was imposed by the building interior. In the absence of chilled water, the air conditioning system automatically switched over to 100 percent outdoor air and 100 percent exhaust operation to cool the building interior. Heat was thrown away to the outdoors and additional steam was used to heat and humidify 100 percent of the outdoor air supply.
- Doubling the amount of insulation in a building generally saves energy but, in some cases, increasing the thickness of insulation could increase energy consumption. A single-story computer center, for example, may require cooling, even in winter, because of high internal heat loads. Additional installation would only aggravate the problem. Depending on the weather zone, reduction in glass could also increase energy consumption.

REFERENCE

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Inside IEEE

Cooperation is key to EUROCON success

A new partnership spelled a highly successful meeting for some 770 engineers from throughout the world who gathered in Amsterdam on April 22–26 to participate in EUROCON '74. This year's European Conference on Electrotechnics was the first to be sponsored jointly by IEEE and Region 8, in cooperation with the recently established Convention of National Societies of Electrical Engineers of Western Europe, representing 14 professional organizations.

A major contributor to EUROCON's success was the outstanding technical program organized under the direction of F. L. Stumpers of the Philips Research Laboratories in Eindhoven, which implemented the conference theme: "The Engineer in Society." As Prince Claus of the Netherlands pointed out in his opening remarks, "It is through technology that we are able to create new living conditions,"—a "highly political matter." Thus, it is the engineers and not the politicians "who are actually the pacemakers and inventors of politics." As such, they must recognize and assume the responsibility for the social results of their actions.

Prince Claus' sentiments were echoed by H. B. G. Casimir, president of the Royal Netherlands Academy of Arts and Sciences, who was the featured speaker at the opening session. In his discussion of "Technology for the Future," Prof. Casimir raised the question: How can technology remain advanced and advancing and yet reduce consumption of energy and materials, and respect, and even restore, the environment?

As a partial answer, he believes that electronics is a technology for the future. For instance, in just one important area—communications—the trend has been to smaller and smaller devices that consume less and less energy. Thus, Prof. Casimir sees no necessity, at least for the present, to limit the growth of electronics. However, he emphasized that all scientists and engineers have a moral responsibility for the end result of their labors—not only for a product itself, but for the use to which it will be put. In other words, we must reevaluate the role of "the engineer in society."

IEEE President John Guarrera also spoke briefly at the introductory ceremonies.

EUROCON's technical program featured 274 presentations from 21 different nations, including Indonesia, the United States, and South Africa. The program was divided into six main sections, all relevant to the place of the new engineer in the modern world: Controlling the Future; Instrumentation Electronics; Communication for the 1980s; The Computer in Society; Biomedical Engineering; and Education.

Of particular interest in the last section was an evening panel session that attempted to answer the question: Is our engineering education adequate for the future? Panel members included university professors, representatives from industry, and students from France, Indonesia, and Argentina.

EUROCON dignitaries gather for a moment of relaxation. Left to right: IEEE President John Guarrera; His Royal Highness, Prince Claus of the Netherlands; Carl A. Hagson, president of the Convention of National Societies of Electrical Engineers of Western Europe; and J. A. van den Broeke, chairman of the Steering Committee for EUROCON '74.

Candidates named for 1975 IEEE offices

The IEEE Board of Directors has announced the names of nominees for President, Vice President, and Regional and Divisional Directors for 1975, in accordance with the procedures cited by the IEEE Constitution.

The nominees for these offices are as follows:

President, 1975: Arthur P. Stern

Vice President, 1975: Joseph K. Dillard

Regional Delegates/Directors, 1975–1976:
- *2*—Howard B. Hamilton
  William W. Middleton
- *4*—Rolland B. Arndt
  Paul F. Carroll
- *6*—Carleton A. Bayless
- *8*—E. Folke Bolinder
  Giuseppe L. Francini
  F. Louis Stumpers

Divisional Delegates/Directors, 1975–1976:
- *II*—John E. Barkle, Jr.
  Joseph F. Keithley
- *IV*—Robert A. Rivers
  Joseph A. Suozzi
- *VI*—Charles W. Flint
  Robert W. House

Individual voting members of IEEE may propose by petition names to be added to the ballot for the aforementioned offices. Such a petition must be submitted in a letter to the Board of Directors, setting forth the office and the name of the proposed candidate, to be received at IEEE Headquarters no later than the Friday preceding August 1 (July 26). The petition must be signed by at least 2 percent of the total number of voting members eligible to vote for the office, as listed in the official IEEE membership records at the end of the previous year.

For the office of Regional Delegate/Director, the minimum number of signatures shall include at least 2 percent of the voting members in the Region, provided that a majority of the Sections in the Region shall each be represented on the petition by at least 2 percent of their voting members. For the office of Divisional Delegate/Director, the minimum number of signatures shall include at least 2 percent of the voting members of the Division.

On or before September 1, the Board of Directors shall submit to all members eligible to vote as of August 1 a ballot listing all nominees for the office named, to be voted on in accordance with the IEEE Bylaws.

Members and organizational units of IEEE are reminded that electioneering for IEEE office is not permitted. Members may announce their candidacy for office in a letter addressed to the editor of *IEEE Spectrum*. Candidates, whose names will be printed on the ballots in accordance with the IEEE Constitution and Bylaws, may make statements giving their programs and views on the issues facing IEEE, for publication in *Spectrum*, subject to the usual standards of accuracy, space limitations, and quality.

Arthur P. Stern

Arthur P. Stern (F) is vice president and general manager, Advanced Products Division, at The Magnavox Company, Torrance, Calif. He is presently IEEE Vice President for Regional Activities.

Mr. Stern was graduated from the Eid. Technische Hochschule in Zurich, Switzerland, in 1948, and received the M.S.E.E. degree from Syracuse University in 1955. After