Westinghouse ENGINEER

January 1966

Sunlight focused through a lens is used in this experimental technique to restore radiation-damaged solar cells to practically original power output. Semiconductor solar cells, commonly used to generate power for artificial earth satellites and interplanetary probes, are gradually damaged by radiation outside the screen of the earth's atmosphere. The radiation disrupts a cell's junction, but agitating the atoms with heat for a few minutes can restore the original junction configuration and with it the ability to produce power. This heating process must be performed in a vacuum, but that is no problem in space because the vacuum there is better than any created on earth. The thin light lens used in the experiments is proposed as a practical means of providing the required heat on board a space vehicle. (For more information, see page 30.)

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Electric Utility Report

Authors

Other Articles

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Cover Design: The first half of this issue is devoted to discussions of various aspects of design or application of equipment manufactured by Westinghouse for the electric utility industry. Artist Tom Ruddy used silhouettes of typical electric utility equipments for this month's cover design.

Equipment Developments Affect Utility Planning

The electric utility industry today is in the beginning stages of a technological change whose full impact has yet to be felt. In fact, the consequences of many technological changes have still not been fully evaluated—or in some cases even recognized. Nevertheless, it is already clear that the effect on both electric utilities and equipment manufacturers will be drastic, that the situation will require closer examination of each decision and even closer cooperation between utilities and manufacturers.

The rapid trend toward EHV is but one example of the increasing pace of technological change. One gauge of this trend is the kva capacity of power transformers in service at different voltages. The first commercial 345-kv line was put in operation in 1953, but even as late as 1964, only *four percent* of the total installed power-transformer capacity was rated at 345 kv. In 1965, three 500-kv transmission lines were put in service and Westinghouse engineers estimate that within the next ten years the installed transformer capacity at 345 kv and higher will increase to *30 percent* of the total.

However, EHV and its many ramifications for utility companies and manufacturers is but one aspect of the revolution. The rapid increase of interconnections and pooling, the coming of age of the nuclear power plant, the automation of plants and systems, the increase in underground distribution, and many other developments have occurred almost simultaneously. Most of these developments are interrelated. But, equally important, they have the effect of changing many of the customary "ground rules" on which technical and economic decisions are based. For example, in some areas where increased equipment efficiency has been a constant goal, overall economy may dictate a completely different goal in the future. Decision making is becoming more difficult and also more critical.

Since a substantial number of readers of the *Westinghouse ENGINEER* are directly connected with the electric utility industry, and most of the rest are directly affected by what goes on in that industry, we decided to present a manufacturer's view of some aspects of the technological changes and of how equipment may affect utility evolution. Thus, much of this issue is devoted to a special report to electric utilities.

The report begins with a look at some of the relationships of equipment and system costs to unit size. The attempt here is to show the heavy dependence of electric-utility planning on equipment characteristics, to examine the effects of new technology, and, in a few cases, to suggest what may now be fallacies in commonly applied criteria for selecting equipment. Five other articles follow, each highlighting a specific area of new technology or new approaches in equipment, and presented by the executive with direct responsibility for the equipment discussed.

These articles are *not* meant to be a comprehensive report on all equipment or all the problems facing the utility industry. Instead, they are meant to be thought-provoking—to encourage a closer examination of many aspects of utility equipment by focusing on a few. *The Editors*

Cost-Size Relationships of Utility Equipment

J. W. Simpson
Group Vice President
Electric Utility Group
Westinghouse Electric Corporation
Pittsburgh, Pennsylvania

One of the most important single contributors to the steadily decreasing cost of electricity during the past 15 years has been the increased use of higher-rated equipment, such as turbine generators of higher megawatt output, transformers of higher mva and voltage rating, switchgear of higher voltage and interrupting capacity, and similar equipment changes. In fact, we estimate that during this period the total cost to electric utilities of purchasing and operating equipment has gone down by 25 to 35 percent as a direct result of the manufacturers' ability to build, and the utilities' ability to use, larger sizes of equipment.

This past economic contribution of larger unit size is impressive. More important, however, are the major technology changes that will occur in the future in the electric utility industry; the industry today is conducting broad-scale studies of *future* patterns of industry evolution and growth. Of critical importance in these evaluations are the future economies that can be expected from larger unit size of electrical apparatus. This is a problem of two parts. One is the economics of the *use* of larger equipment, an assessment that utilities are in the best position to make. The second is the economics of *supplying* larger equipment, which is primarily the domain of the manufacturer.

Since the economic use of larger equipment depends heavily on the economics and technical feasibility of building larger equipment, I'd like to explore some of those factors, as viewed by the manufacturer, that will affect the economics and feasibility of larger equipment in the future.

This cost-size relationship deserves particularly careful study by the industry because it is not at all certain that the pattern of the last fifteen years will continue over the next decade and a half. Choices other than simply larger apparatus ratings may prove more economical in some areas, and particularly at any given point in time.

What Affects Cost-Size Relationship?

Functional operation of electrical apparatus is based on a relatively few theoretical electrodynamic or thermodynamic principles. However, in actual *product* design, size and weight are determined largely by the degree to which available materials vary from the desired "ideal" characteristics, that is the resistance in conductors, saturation and loss in magnetic steels, and space required for insulations. Further, these effects are *interrelated*: For example, more copper and iron may be required simply because insulation takes up space. Thus, the final design inevitably has more of every material than the designer would like.

However, as the design rating of a product is increased, the designer generally finds that he can use available materials more effectively, and the resulting physical size and weight do not increase as rapidly as the rating.

The relationship between increased rating and physical size differs for each product; however, as an example, in the case of a power transformer, as the physical dimensions are increased, weight of material rises as about the *third power* of the dimension increase. However, the electrical rating is a function of the product of the active cross sectional areas of copper and iron; therefore, electrical rating increases not as the cube, but as the *fourth power* of the dimension increase.

Thus, theoretically, transformer weight increases as the three-fourths power of electrical rating; hence, a 100 percent increase in rating would require only a 68 percent increase in weight. Theoretical weight per kva decreases along a negative ¼ power law curve.

While this "¾ power law" for transformers is theoretical, in practice it is reasonably typical of many types of electrical apparatus. The power exponent may be somewhat lower for certain types of circuit-interruption devices, and is generally slightly higher for heat-transfer apparatus where costs are more nearly related to surface area. The relationships are somewhat more complex for steam turbines where basic technical factors of volume flow, mass flow, and pressure containment are all involved. However, for purposes of this discussion we will consider this theoretical ¾ power law as typical of the broad family of electrical equipment.

Practical Considerations May Alter Future Relationships

While the theoretical relationship of the ¾ power law suggests a smooth variation in costs with increase in rating, in reality the variations are far from smooth. Four main practical considerations alter the situation:

1) Weight of materials is not a satisfactory index of overall cost. Maximum use of direct and indirect labor, and costs of design, development, and facilities may be much more important.

2) Because of the above, economies in repetitive design and manufacture, i.e., two smaller units instead of one large one,

offset some of the economies of larger size.

3) A given design approach is generally not useful over a wide range of ratings. The more normal condition is several different design approaches, each applicable to a block of ratings.

4) Manufacturers are set up to most efficiently design and produce a given range of products at a *given point in time*. Ratings outside this "present" range may require substantial additional investment in development or in facilities.

The effect of these practical considerations can best be illustrated by tracing them step by step on Fig. 2. Starting with the theoretical curve of weight per unit of rating, which should roughly match the cost per unit rating curve, let's examine the effects of these practical considerations. The black curve is the theoretical ¾ power curve. The curves in color represent the actual pattern of change of a typical product.

Effect of Design Changes—At some point in the life of a product, a major design change becomes necessary. This may come about because materials limitations are exceeded, because performance characteristics must be changed, or other technical or economic reasons.

For example, on small generators, conventional cooling methods are the most economic design approach. Thus, the solid color upper curve might represent the average cost-size relationship for generators of low rating. However, as ratings increase, the generator rotor diameter eventually becomes a limiting factor; an upper limit is reached in the ability of economically practical materials to withstand the centrifugal forces encountered. At this point, a more complex cooling system, such as inner cooling, may offer the only practical solution. With better cooling, the rotor diameter can be kept within reasonable limits for much larger sizes. However, because the cooling system is more complex, an upward step change in costs occurs, followed by a downward cost-size trend along a different curve.

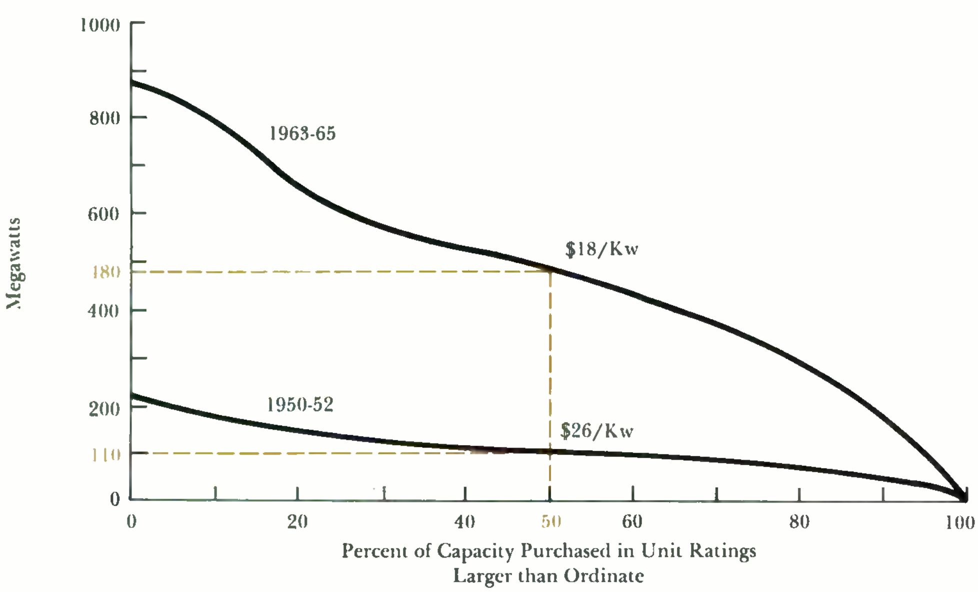
Similar step changes occur in almost all lines of electrical apparatus.

In their planning, individual utilities must watch these break points carefully. In studying future patterns of industry growth and evolution, they should explore the situation carefully to make sure that ratings beyond those presently available do not involve concealed breaks of this nature that might alter industry plans. Note, also, that each of these curves falls more steeply than the original theoretical curve, even though they start at a higher point. This is because within the framework of a *given* design approach, economics tend to improve more rapidly with increased rating. This is because the design approach, which was selected to cover a range of ratings, is more fully exploited at the higher ratings in the range where all the various technical parameters tend to be worked nearer their design capabilities.

Effect of "Integral Frame Sizes"— Engineering design, shop tooling, and inventory represent much more important cost factors to the manufacturer than they do to utilities. So to obtain the economic benefits of repetitive manufacture, while still offering a variety of product types and ratings, the manufacturer may use the same component part over a range of product ratings. For example, for rotating machinery, this may take the form of specific frame sizes, each of which may be used over a 10 to 20 percent range of ratings. The short dashed colored lines in Fig. 2 show this effect, each curve representing a particular "frame size." This situation occurs in most major electrical apparatus. For example, in circuit breakers, a standard mechanism may be used in several different breakers, another standard mechanism in the next higher rated units, and so on. Other examples are transformer tanks, relay mechanisms, disconnect switch operating mechanisms, or switchgear cubicles.

Actually, the effect of this "frame size" factor is similar to that of the effect of major design changes, except on a smaller scale.

Thus, the pattern of dashed segments roughly portray what the *actual* cost-size relationship looks like to a manufacturer at a given point in time; obviously there is a substantial difference between this pattern and the theoretical curve, a difference that must be considered and evaluated by utilities. Note also that this still represents the cost condition *at one point in time*; also, it represents only those costs associated with products that the manufacturer has *already* developed and is tooled up to manufacture.



1—Plots of the size distribution of all turbine-generators purchased during two time periods. The first period is from May 1, 1950 to April 30, 1952; the second period is from May 1, 1963 to April 30, 1965. In the early 50's, half of the total capacity was purchased in units of 110 mw or larger. By 1963-65, size had increased such that half the capacity was purchased in units of 480 mw or larger. In that time span, the effective average size approximately quadrupled with a similar increase in maximum unit size.

This calculation showed that at today's general cost and price levels, the mix of turbine-generator sizes and types of the early 1950's would run about $26 per kw; units actually purchased under this price list in the mid-1960's were only $18 per kw.

Effect of Ratings Beyond Those Commercially Available

Where the product rating lies beyond the bounds of those considered as generally "commercially available," a host of new factors enter the picture. Since here we are dealing with new ratings, a variety of patterns may emerge. Three are illustrated on Fig. 2.

In assessing costs for ratings beyond those commercially available, a common pattern might be *A*. For ratings moderately beyond those presently available, a step change in costs would result because of the investment required in research, design, development, prototype construction and testing, tooling, and facilities required to build just *one* unit at that rating. Further, the first units would probably have some excess design margin until field operating experience proved the design. If the step in ratings were larger, the temporary upward step in the curve might be larger, as indicated by curve *B*.

Assuming the above program was completed, costs might take several directions. First, the new ratings might fall neatly into line with the present pattern of costs—with no unexpected technology costs, no major change in design, and no unusual facility or processing requirements required. In such a case, the cost pattern might continue as shown in A'—and the "unexplored frontier" would merely have been pushed to the right. The cost pattern would fall into some range as shown by the shaded portion of the curve.

On the other hand, the outcome might be quite different. In pushing into a relatively unknown region of ratings, substantial new technology, new materials, or new processes might be required—not on a transitory basis but on a relatively permanent basis. Thus, the cost pattern might follow curve A'' with a relatively permanent upward break.

With this as a base, what kind of limitations might exist at a given point in time that would have to be overcome or allowed for in the move to larger units? Here are a few:

1) *Limitation of Existing Facilities.* The most obvious example might be that the proposed larger size apparatus is physically too large to be handled in present facilities. In the past eight years, Westinghouse has invested more than $65 million for facilities to produce the larger ratings utilities have needed.

2) *Shipping Limitations.* Railroad shipping limitations may set an absolute upper limit on the maximum dimensions and weight of individual units that can be shipped to locations where barge transportation is not available. This, in turn, would mean design for shipment of equipment in sections, with final assembly in the field. The implications here are many, but the end result would tend to raise costs above the theoretical curve.

3) *Possible Change in Design Concept.* Materials limitations or other factors may dictate the change to a basic new design concept.

4) *Possible Requirement for Higher Reliability with Larger Equipment.* Because of the larger concentration of power, the utility may require a higher degree of reliability and availability than was previously considered necessary. For certain products, increased design margins may be necessary to achieve the same degree of reliability if the new equipment has more components that are potentially subject to failure. If this requirement exists, it becomes a definite cost factor.

5) *Emergence of New Design Problems.* Some designs cannot be simply "scaled up." New design problems often occur in a move to a larger size, some of which may be evident in advance, some not.

6) *Other Costs Tied to Larger Units.* In addition to those mentioned, other costs may be involved, such as new manufacturing facilities and their associated start-up costs, shake-down costs of new equipment, new tooling or testing equipment, required prototypes, and others.

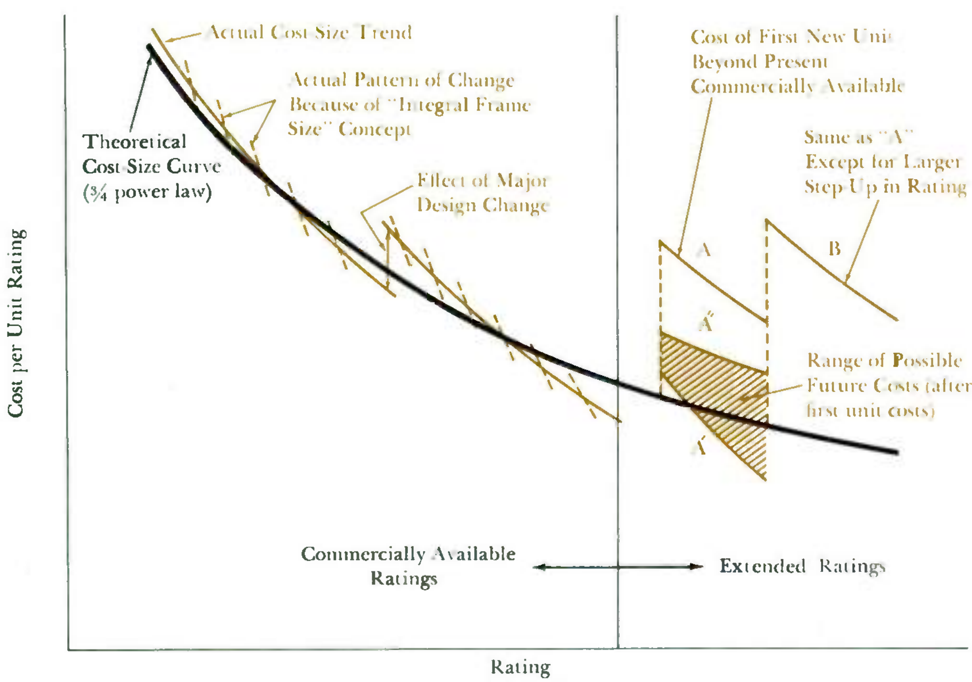
7) *Special Problems Where New Technology is Required.* Occasionally, an increase in rating may require a substantial change in technology; an extreme example would be the use of MHD to obtain increased rating. Here, the investment in facilities and development would climb enormously. Also, the risks include not only the hazard of poor service reliability, but also the risk of complete failure.

8) *Cost Penalty to Utilities of Owning Larger Equipment.* While this article is intended only to point out the economics of equipment from the manufacturer's standpoint, the economics of the *use* of larger equipment should at least be recognized.

The "value per unit rating" is not generally the same for various equipment ratings. There is usually a penalty associated with larger ratings. This is due to: (1) Higher reserve requirements to back up larger equipment; (2) excess investment until load growth permits loading up the larger facilities; and (3) some loss in system operating flexibility.

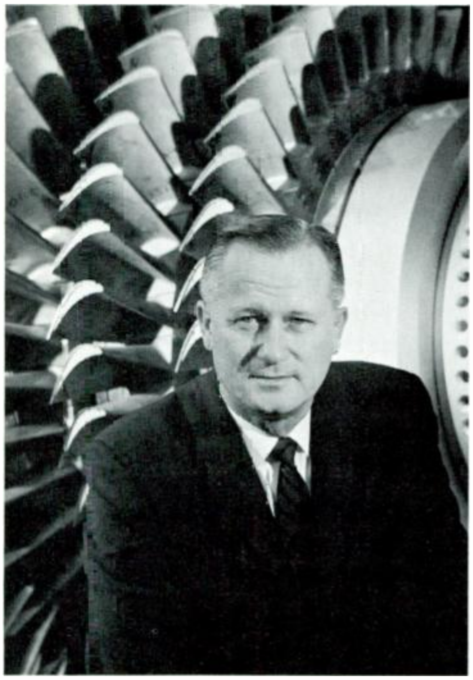
For generating units, the accelerated utility industry movement toward pooling has shifted these penalties significantly, so that they begin to become effective only at much higher equipment ratings than has historically been the case. The major shift will have occurred by 1970; additional shift in penalty toward larger sizes after 1970 will tend to be incremental.

The various influences on the cost-size relationship as viewed from a manufacturer's standpoint are especially important today, because of the recent rapid movement toward use of larger apparatus, and because utility systems of necessity must plan their systems far in advance. Thus, we believe it is important that the electric utilities carefully consider the factors suggested here, and in the following articles, which deal with more specific areas of utility equipment.



2—Theoretical curve of cost per unit rating (black) differs from actual conditions because of several practical considerations.

A New Peaking Plant to Reduce Capital Investment per Kilowatt



L. E. Hedrick
Vice President and General Manager
Steam Divisions
Westinghouse Electric Corporation
Lester, Pennsylvania

The desire of investor-owned utilities to lower capital investment and operating costs for power-generating facilities without impairing the quality of service has produced the two basic trends in new plant additions over the years: (1) more complex steam cycles, which include higher pressure and temperature, to improve plant efficiency; and (2) larger unit sizes to obtain the cost-size benefits (in $/kw) that result from the purchase and installation of larger equipment. The use of larger and more efficient base-load steam plants has been a key factor in lowering the cost of power generation.

For base-load generation, efficiency (or heat rate) is the most important single factor and consequently has received the primary consideration when new generating capacity was added. Thus, the addition of larger units with improved steam conditions and cycles has produced significant system heat-rate improvements over the years. But the improvement in heat rate has been getting smaller, particularly over the last 10 years. Because larger fractions of utility system energy requirements are now generated by modern plants, the spectacular heat-rate gains of the past are no longer possible. Thus, while future increases in plant size will continue to reduce the installation cost per kilowatt, the rate of improvement in heat rate will be much smaller.

If power production costs are to continue to drop, more attention must now be directed toward reducing investment per kilowatt. Recent studies have indicated that a logical place to look for reductions is in peak-load generation.

Newer and larger plants can generate large blocks of kilowatt hours at good efficiency but they are not economically suited to low-load operation. Therefore, more of the part-load operation has been necessarily placed on older units, which has resulted in rapidly relegating many machines of rather recent vintage to part-time or peaking operation. But these machines, many of them fairly recent reheat units, were also designed with the same base-load concept that is being applied to today's larger fossil fuel and nuclear plants. Such operation not only increases maintenance, but also makes poor use of capital by diverting good efficient plants to part-time operation. In general, the larger the units become, the more desirable it is to keep them at full rating while assigning the part-load duty to small plants. Thus, it is only logical to assume that a plant specifically designed for peaking type service could reduce the total cost of power generation and at the same time, improve system operating flexibility.

Peaking Plants

A conventional type steam plant could be designed for moderate steam conditions with a minimum of auxiliaries to reduce its costs and make it more suitable for frequent starts and stops. But this approach would still require a significant expense item in the heat rejection system—the condenser and its large circulating-water requirements.

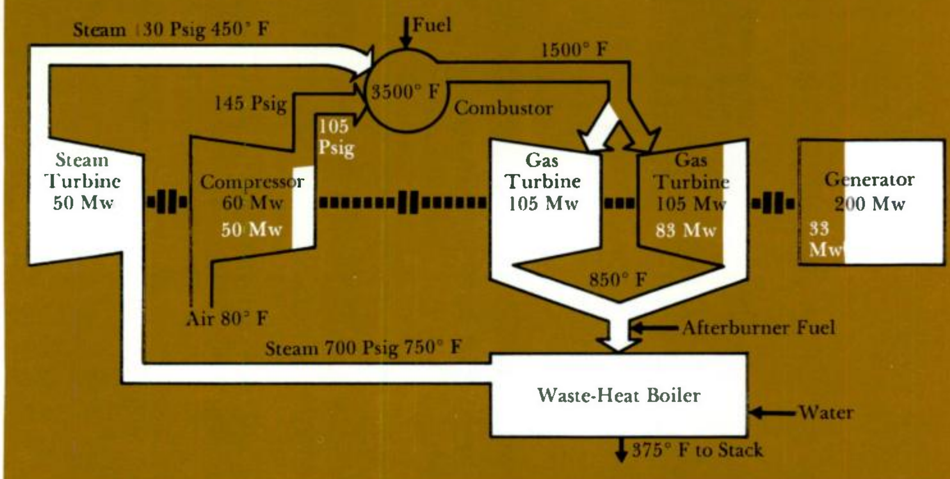
Another possible source of peaking power is the conventional dry gas turbine, which does not require a condenser and circulating water. But this alternative also has a major disadvantage from an economic standpoint: The simple-cycle gas turbine requires approximately 50 pounds of mass flow per hour to generate one kilowatt, as compared to a steam plant that needs approximately 9 pounds per hour. This high flow requirement effectively limits a gas turbine plant to relatively moderate unit sizes. Of course, gas turbines can be combined into multiples and arranged into a large plant, but in general, a more costly rotating machinery flow path will still be required.

Recognizing the need for a truly low-cost peaking plant, Westinghouse engineers set about to combine the desirable features of both the steam turbine and gas turbine cycles, and at the same time, minimize the effect of parameters that were significant contributors to high cost. The result is an arrangement comprising a steam injection gas turbine, a waste-heat-recovery boiler, and a steam turbine, combined to form a low-cost plant with a nameplate rating of 200 megawatts, a size that is suitable for peaking service on most systems today.

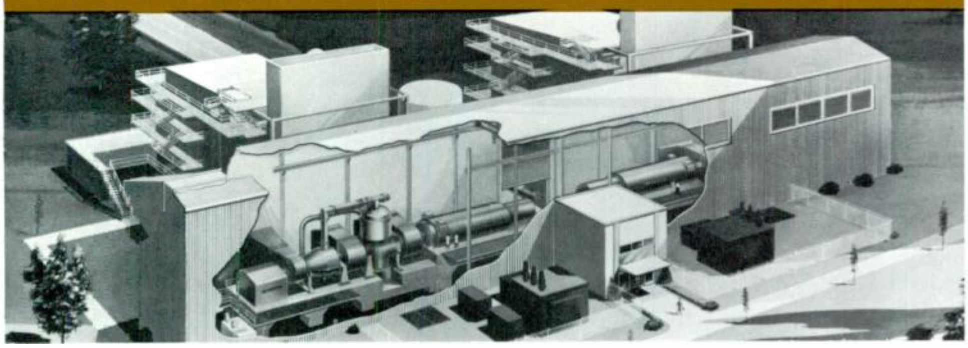
Steam Injection and Heat Recovery

A conventional dry gas turbine was the starting point for the new plant design. Normally 60 percent of the output of a gas turbine element is absorbed by the air compressor with only 40 percent of the turbine power available for useful work. Illustrated by the color portions of the diagram are the energy relationships which show that of the 83 mw generated in the turbine element, 50 mw are absorbed in the compressor for a net output of 33 mw. The large amount of power for the compressor is consumed in compressing air for combustion plus 300 percent to 400 percent excess air that is used to cool the combustion products to an acceptable 1500 to 1600 degrees F.

To reduce capital cost and improve



	Gas Turbine	Steam Turbine	Com-pressor	Generator
Combined Cycle:	105 + 105	+ 50	− 60	= 200 Mw Net
Original Gas Cycle:	83		− 50	= 33 Mw Net



New peaking plant combined cycle ***(top)*** has steam turbine, air compressor, and double-flow gas turbine connected on the same shaft driving a 3600-rpm generator directly without gearing. The color portion of the diagram illustrates the simple-cycle dry gas turbine from which the steam injection plant was developed. ***(Bottom)*** Artist's conception of a two-unit 400-mw plant. The entire plant can be built on a one-acre site.

plant efficiency, two basic modifications have been made to this cycle:

1) Steam is injected into the combustor to provide cooling so that a greater percentage of the air-compressor output can be used to burn fuel; the injection of steam provides additional mass flow for doing work.

2) A waste-heat boiler with afterburner is installed in the gas turbine exhaust to make steam for combustion cooling. With proper boiler outlet steam conditions, a pressure-reducing steam turbine installed between the boiler and combustor can supply all of the power requirements of the compressor. Thus, the total power output of the gas turbine is now available to produce power, and exhaust steam from the steam turbine provides the injection steam to the combustor at the desired pressure and temperature. The steam turbine exhaust, while cooling the combustor, is itself reheated to about 1500 degrees before expansion through the double-flow gas turbine.

With this new peaking-plant cycle, the combined flow of steam and air for the plant amounts to only 20 pounds per kilowatt so that the rotating-machinery flow path is moderate; the desirable features of steam reheat are obtained without the cost of a separate reheater; heat-transfer surface area has been minimized, and condenser and circulating water systems have been eliminated.

By using standard blade paths in the turbine and compressor, there are no major unknowns in the rotating machinery. To optimize cycle pressure, a few stages have been added to the compressor, which in turn increases the compressor work. Similarly a stage has been added to the turbine element, which increases its output to 105 mw, and allowing for the increased work of compression, the two turbine elements provide a 200-mw net plant output.

Conventional gas-turbine combustors have been tested through a wide range of fuel-to-air ratios with steam injection, and have performed well. In fact, more effective cooling was obtained from steam even though more fuel was burned. Tests indicated that combustion was complete with no evidence of smoke in the exhaust gases.

$60 per Kilowatt

With these modifications, the output per pound of air has increased by a factor of six while the increased cost due to addition of a waste-heat boiler, steam turbine, second gas turbine element, and combustion system for steam injection has increased by a factor of only 4¾. Thus, the $/kw ratio has been reduced by some 20 percent. The total installed cost of this new peaking plant is estimated to be $60 per kilowatt or less, which is lower than any other plant of comparable size.

The plant requires 2600 gallons of water per minute for continuous 200-mw output. A conventional steam plant requires the evaporation of one pound of water for each pound of steam that is condensed. When wet cooling towers are used for cooling condenser circulating water and blowdown is condensed, the water requirements for a 200-mw steam plant can be comparable to the steam injection plant, depending upon location.

Control of plant output is relatively simple and is effected by regulation of fuel input to the main combustor and supplementary burners. The plant design includes a complete complement of automatic control and instrumentation to permit remote plant loading if desired.

The plant design includes adequate silencing arrangements to keep noise level at the plant site comparable to that of a conventional steam plant.

Operating Flexibility

The new plant lends itself to several modes of use when standing by for scheduled peak-load operation or emergency service. Under normal hot standby operation, pilot lights will be maintained to carry full boiler pressure with the rotating parts on turning gear. From this condition, the plant can be brought to full load in approximately 15 minutes. For emergency service conditions, the plant can be connected to the system and operated with zero output; the plant can be raised to full output in less than one minute. From cold standby, the entire plant can be brought to full load in two hours.

The objective of the minimum plant cost per kilowatt has been achieved in the steam injection gas turbine plant. As utility systems continue to grow and base-load plant sizes increase, the need for more low-cost peaking plants will also increase. In our opinion, the steam injection plant best fills this need.

Pumped Storage—A New Opportunity for Hydro-Generators

J. M. Wallace
Vice President and General Manager
East Pittsburgh Divisions
Westinghouse Electric Corporation
East Pittsburgh, Pennsylvania

The National Power Survey of 1964 shows 41 million kw of hydroelectric generation installed in the United States. This includes 700,000 kw of pumped storage. Ultimate capacity according to this survey is 134 million kw of hydrogeneration plus 36 million kw of pumped storage. If this ultimate is reached, there will be almost as much pumped-storage generation then as the total hydrogeneration now installed.

The main reason for the growing interest in pumped-storage generation is obviously economic. The base-load steam units on today's large power systems should be operated continuously at full load. To do this, controllable sources of power, or load, are needed so that they can be varied over a wide range to level the peaks and valleys of the system load cycle. Pumped storage provides both variable power supply and variable load.

In its simplest form, a pumped-storage installation consists of a motor-pump unit that pumps water from a low reservoir to a high reservoir at convenient periods when excess power is available from the system; during peak-load periods, water returns to the lower reservoir through the same unit, which rotates in the opposite direction as a hydro-generator unit. Thus, a pumped-storage station absorbs energy at dump-power cost when system demands are low, and returns energy to the system during high-demand, high-cost periods. The overall efficiency of a pumped-storage station is usually between 65 and 75 percent, and at this level, system economy is improved.

Pumped-storage hydro also provides an ideal reserve to handle sudden outages of system generation, or unexpected load demands. These units can usually be started as generators from rest and be fully loaded within one to two minutes. Or, at a slightly higher operating cost, the units may be left on the line with the pump unwatered so that they can pick up load in about 10 seconds.

Inherent Limitations

While steam-turbine generators have been growing larger and larger over the past several years, growth has been slower in hydro-generators. There are some very good reasons for this. The principal one is that while the boiler and turbine designer can cooperate over a wide latitude of pressures and pounds of coal per hour, the hydro-station designer is limited by geographical considerations over which he has relatively little control. Given a certain stream flow and hydraulic head, most of the rest of the problems are circumscribed to a very real extent and many maximums (and minimums) are inherent.

Machine Considerations

In waterwheel applications, for a given hydraulic head machine, the speed must be decreased as the capacity is increased. This relationship can be expressed:

$$rpm \sim (1/kw)^{1/2}.$$

Thus, if the kilowatt capacity of a unit is doubled, rpm is reduced to approximately 71 percent. Considering the effect of speed reduction on other machine parameters, the cost per kilowatt of the waterwheel and generator does not change radically as a function of unit rating. The overall station cost varies as a function of the number of units, size of each foundation and penstock, facilities for erection, and other considerations. These have to be studied carefully to determine what other savings might exist.

Ratings of conventional hydroelectric-generator units have been governed by the practical limitations of waterwheel size. Waterwheels are limited by river flow, topography of the land (which determines the hydraulic head), and shipping dimensions. For example, the output for a 300-foot head for the largest one-piece water-turbine runner that can be shipped is approximately 150 mw. If the head is increased to 800 to 1000 feet, the output of the same runner could be increased to 500 or 600 mw. But because of the limited heads of suitable sites on large streams, most conventional hydro stations have units rated under 200 mva.

Pumped Storage Offers New Opportunities

Because pumped-storage installations are virtually independent of stream flow, requiring only the makeup water to take care of leakage and evaporation, geographical considerations are quite different from those of the conventional hydro-generation stations. In fact, the makeup water could be quite independent of the location of the storage reservoirs—piped in, that is.

A suitable site consists of an upper and lower reservoir at close proximity with an elevation difference greater than about 300 feet. Thus, a high-head site with either reservoir on a small stream is quite practical for large pumped-storage installations. With the development of high-speed pumps that act also as water turbines, units of 500 to 600 mw may be feasible with heads of 800 to 1000 feet. Unfortunately, there are not too many places where one can locate reservoirs in proximity and with 800- to 1000-foot height differences. Therefore, we must consider the economies of larger sizes on hydraulic heads that more nearly approximate the 200- to 400-foot range with which we are most familiar.

Changes Needed in Machine Design

To really produce maximum benefit to the industry, we must take another look at the design parameters normally used for hydro-generators.

Specifications for waterwheel generators in the United States have tended to grow progressively more restrictive, and they often limit manufacturers to practices that hamper construction in the size and type of unit best fitted for the application. For example, for units above about 120 mva, it is desirable for the generator designer to select machine voltage. Since there are a limited number of winding combinations available at many speeds, the designer should be permitted to choose the most economical voltage within a reasonable range to fit the final design. The larger the machine, the more necessary this option becomes.

Shafts above 50 inches in diameter are so heavy and large that it becomes economical to consider fabricated shafts of different proportions than have been typical for forgings. Fabricated shafts will not be absolutely round or centered except at the couplings. Machining of the shaft body in such a structure would be wasteful of the material and would serve no practical purpose. Any unbalance in such a shaft is meaningless since it would be such a small element in the entire rotor that it could be compensated easily with a small balance weight in the generator. In some cases, machine bearing arrangements must be altered because of the increased lateral stiffness of the large-diameter shaft.

In large machines of approximately 300 mva or greater, or where the rotor peripheral speed at overspeed would normally be above approximately 30,000 feet per minute, one of the advanced forms of cooling probably will become economical to reduce the physical size and peripheral speed. Advanced forms of cooling are many and will be utilized to varying degrees depending on the emphasis placed on machine efficiency and other factors. Most forms of advanced cooling when pushed to their limiting application will decrease machine efficiency at maximum load due to excessive I^2R losses. Consequently, the loss evaluation factors applied to a station will have considerable influence on the design of a large unit.

The machine flywheel effect is an important characteristic. The amount of WR^2, or inertia, is often specified at a value well above that inherent in the otherwise most economical machine design, simply to keep the maximum speed after full-load rejection below some arbitrary value. However, on today's large integrated systems with high-speed relaying and breakers, it is rare that a particular machine or station is required to operate in an isolated mode or to regulate system frequency by action of its own governors. With modern high-speed voltage regulators, the rate or magnitude of speed rise is not significant on load rejection from the electrical standpoint.

In the case where auxiliary motors are fed from the generator terminals, either the auxiliaries can be disconnected from the line above a set frequency of 125 to 130 percent of 60 cycles, or, if the auxiliaries are frequency sensitive, they can be supplied from a separate system to avoid the overspeed. Thus, the actual amount of generator WR^2 needed should be reexamined. Unnecessary WR^2 results in machines that are larger in diameter, heavier, more expensive, and generally slightly less efficient than those that otherwise would be designed. NEMA's published table of normal WR^2 for machines of many ratings was fairly representative at the time of compilation. However, with improvements in materials and design techniques, the values in these tables represent 5 to 25 percent higher values than are inherent in the most economical generator designs today.

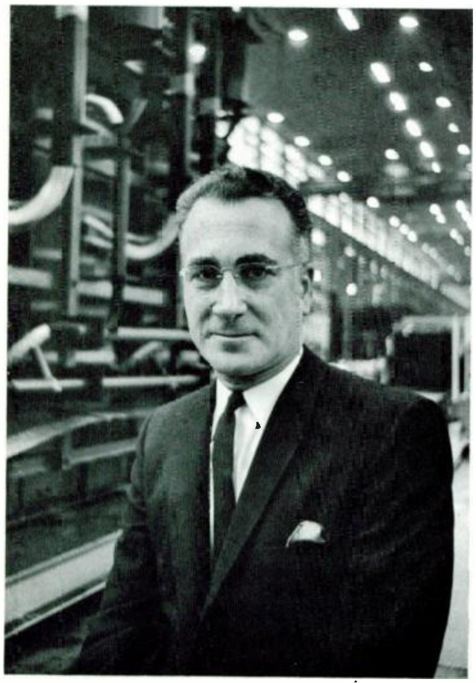
In the very large generator ratings, the use of more exotic forms of cooling can further reduce WR^2, possibly to half that of a conventionally cooled machine. This reduction is likely to bring the machine WR^2 below the actual hydraulic requirements. In the case of large pumped-storage units, the hydraulic requirements have often dictated high WR^2 to restrict the pressure rise in the penstock. Alternate means of restricting pressure rise, such as bypass relief valves, may become economical—particularly when the size of the generator reaches material or mechanical limits.

The 60,000 acre-foot capacity reservoir (background) of the Niagara Power Project permitted installation of an additional 240,000 kilowatts of capacity, bringing total project capacity to 2,190,000 kilowatts.

Conclusions

The actual installed capacity of pumped-storage units will, of course, be governed by economics. While larger machine size in itself should not be a goal, the economic benefits of larger ratings must be carefully investigated. The factors discussed here indicate some of the background for decisions that need to be made when large hydro-generators are used. In particular, they point to the fact that the historical bases for these decisions should be reevaluated to permit improved methods in machine design to benefit the industry.

EHV Transformers Lead to New Design Approaches



J. W. Stirling
Vice President and General Manager
Transformer Divisions
Westinghouse Electric Corporation
Sharon, Pennsylvania

Extra-high-voltage transmission is here.

The equipment that makes it necessary is here.

The techniques of system operation are here.

The recent and rapid transition to EHV is perhaps best demonstrated by the progress in system operating voltages:

230 kv in the early 1920's
287 kv in the mid 1930's
345 kv in the early 1950's
500 kv in the mid 1960's
700 kv in the mid or late 1960's

This did not just happen. Motivated by economics, it is the result of successful research, development, and experimentation—at a cost of millions of dollars—by both manufacturers and electric utility companies.

These jumps in voltage are not the result of mere extrapolation from one level to the next. Perhaps this is best illustrated by the fact that if the 230-kv transformer design of the 1920's were extrapolated to today's 500 or 700 kv, the transformer would be so large that no existing factory could build it, no railroad could ship it, and no one could afford it. However, better electrical steels, thermally stabilized insulating material, coordinated insulation systems, advanced cooling methods and more sophisticated testing techniques have led to transformers of the *same weight but with seven times the kva rating*. Today's transformer economics, as well as transportable size, still favor the high-voltage, high-kva, single-unit design.

Making specific predictions about the long-range future of transformer design is a risky—and somewhat pointless—exercise. However, at any given point in time, with the technical and economic knowledge available, the closer range future is easier to foresee.

We believe that 1000 kv is a distinct possibility, not limited by any known transformer technology. We believe that three-phase units of 500 mva at 2050-kv BIL, to 1000 mva at 450-kv BIL are within reach. Also, we believe that bank sizes—using three single-phase transformers—of 1200 mva at 2050-kv BIL or 1500 mva at 1800-kv BIL or lower are feasible.

These units are all within the capabilities of the Westinghouse Muncie plant, and can be shipped on Schnabel cars to many locations.

While these numbers, in themselves, are meaningful, of more importance are some of the factors that affect future designs, and some of the developments now going on.

What Affects Transformer Design?

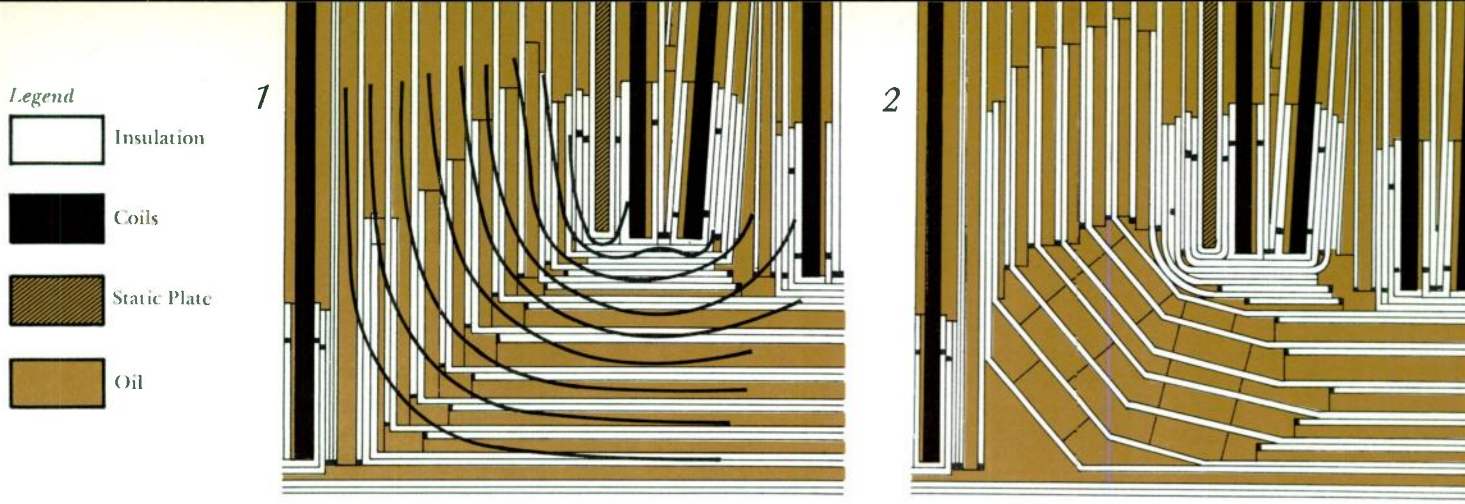
The cost of transformers, a major element in the cost of an EHV system, has been largely a function of the basic impulse insulation level (BIL). The lower the BIL, the less expensive the transformer, provided that the transformer can be adequately protected at these lower levels. Lightning arrester developments, improved system grounding methods, and more exacting system characteristic calculations have permitted the use of lower BIL's, frequently two levels below the "standard" level.

Transformer coil location and insulation configurations designed primarily to withstand impulse surge voltages resulted in clearances and insulation thicknesses that successfully withstood switching surges and steady-state operating voltages. However, the greatly reduced ratios of BIL to operating levels has shifted the emphasis of the design problem. The design criteria used in the past no longer remain valid, and a completely new look must now be taken at the basic relationships between the initial distribution of impulse voltage, the oscillations following the initial surge distribution, switching surge voltages, and 60-cycle or low-frequency voltage stresses. For example, arresters with improved characteristics may limit the magnitude of lightning surges and permit reductions in BIL, but the operating voltage will then stress insulation at a higher level per unit, which may become dominant in the design.

New Methods for Insulation Structures

In the past, insulation development was accomplished mainly by testing samples and models of electrode configurations, and incorporating this data into full-sized experimental models for further testing. Now, however, new techniques of investigating voltage stresses in shell-form transformer insulation, developed within the last year, allow more efficient insulation structures to be developed more quickly and inexpensively.

One tool is a new method by which an electrostatic field plot can be completed in a few hours; previous methods took from four to six weeks. In this method, basic carbon impregnated paper represents the dielectric constant of the oil, and the resistance of a conductive paint represents the dielectric constant of oil impregnated pressboard. Cross sections of copper conductors proportioned to the actual size of the coil conductors are positioned and connected exactly the



1, 2—Equipotential lines plotted on insulation design at left (1) led to improved design at right (2), which uses insulation more efficiently.

same as in a transformer. The static plate is mounted in the same relation to the coil as in the transformer, and ground planes are located around the field plot to represent the ground planes of the core and adjacent windings. The map on the field plotting paper thus is a direct analog of the capacitance circuit of the transformer, which determines the initial distribution of the impulse voltage. With direct current applied to the terminals, equipotential lines are plotted.

Following the initial surge distribution, voltage oscillations within the winding produce an entirely different pattern of voltage stress, and a plot of these is determined by a new and ingenious method. To determine the voltages at the different points in the winding, a ¼ scale model of the transformer is built. The inductances in the model are made exactly the same as in the transformer being investigated. External capacitances are connected into the circuit at different points in the winding to make the capacitance of the model exactly the same as the transformer. Other components used make the model an exact replica of the transformer.

Voltage of the proper wave shape is applied to the line end of the windings. Voltages are then measured at the different points under investigation. In a large complicated extra-high-voltage design, such as a model 700-kv transformer, as many as 500 points may be measured.

The voltage stress at any point is a function of the voltage at that point together with the voltages of the adjacent parts of the winding at any moment in time. Therefore, with voltages of the proper magnitude applied to the different points in the winding for the instant of time being investigated, equipotential lines can be plotted and the voltage stresses can be determined.

Sixty-cycle or low-frequency test stresses are also critical in EHV transformers. The voltage gradient at the crest of the 60-cycle wave is a function of the capacitance relationships of the insulation structure. The low-frequency field plot is rather simple because the voltages at different points in the winding are determined by the volts-per-turn relationships, and thus, the voltage at every point in the winding is known. The voltage gradients can be determined and plotted for both the 60-cycle condition and the conditions prevailing in the windings after the surge oscillations start.

A field plot on which the initial and final impulse and the low-frequency equipotential lines have been plotted shows that some areas have high stresses while other areas have low stresses. The ultimate insulation design is, of course, one in which the entire insulation structure would be uniformly stressed, and since insulation is much stronger when it is worked in puncture than in creep, if the insulation follows the equipotential lines, it is used most efficiently. Equipotential lines plotted on the insulation in Fig. 1 show the high creepage stresses that would normally exist at the inside edges of the line end of a winding. The same transformer redesigned, shown in Fig. 2, has contoured insulation items that more nearly follow the equipotential lines, thus considerably improving the structure's dielectric strength.

To demonstrate the correlation between field plots and actual test results, a full-sized experimental single-phase 825-kv BIL transformer was built, and an attempt was made to test it to destruction. Impulse tests, including front-of-wave, induced tests, switching surge tests, and corona tests were made corresponding to various BIL levels. Tests at several hundred kv above its BIL rating produced no difficulty. Tests could not be carried to destruction because at the higher voltages, the core saturated even at a frequency of 180 cycles.

A 500-kv experimental transformer is now being tested to verify the improvements in dielectric strength and reliability, plus other new ideas.

Intense development and testing programs of components to eliminate the effect of sheer physical size has resulted in new static plate designs, corona shielding of core edges, sectionalizing and multiple grounding of cores, and extension of the already proven condenser bushing. Importantly, the results are applicable to lower voltage units with promise of greater reliability and improved costs.

What the Future May Hold

The designs we believe feasible at this point in time have been mentioned earlier. However, the economic advantages of larger kva ratings and higher voltages suggest that every effort be made to achieve even higher levels.

One persistent problem, of course, is the shipability of large units. This is not a new problem; but through development, means have been found to circumvent it. As voltages increase, regardless of the kva rating, the problem becomes more severe, simply because of the insulation clearances required with higher BIL's. This means that extensive research and development will be required even to achieve the levels that we believe are entirely feasible technically.

For the longer range future, only time and the results of research on new approaches and new designs will tell the story. Many possibilities exist. Field assembly, cast solid insulations, superconductors, new magnetic materials, and other approaches still unrecognized may provide the answers. However, the pure economics of the situation indicate a continuing push toward higher voltages and higher kva ratings in power transformers.

Today's Power Systems Require Modern Relay Protection

A. J. Petzinger
General Manager
Measurements Divisions
Westinghouse Electric Corporation
Newark, New Jersey

As equipment sizes grow, the potential penalty to the utility system for inadequate protective relaying becomes more severe —both from an economic and an operational standpoint. Thus, relay protection for today's power systems must be engineered to provide more comprehensive coverage for more contingencies than previously could be justified.

Protective relays go hand in hand with circuit breakers. A protective relay without a circuit breaker to operate, or a breaker that is not controlled by a relay, serves little purpose above distribution voltage levels. The relay and the circuit breaker form a team and their application to the power system should be planned together.

The points of system disconnection or separation (by circuit breaker) generally establish the boundaries for the zones or areas of protection. If the number of breaker positions is limited to save cost, the protective relaying problems usually become more complex and difficult, and often involve protection compromises that require careful study and evaluation. The additional engineering required and the more complex relaying schemes needed are justified by the potential economic savings.

The multiterminal line provides a good example of the problems involved. Relay protection for two-terminal lines is fairly straightforward and standard. Trouble on these lines can be isolated from the rest of the system by opening a breaker at each end of the line; and as is frequently done on the highly interconnected system, instantaneous reclosing can be applied. But when taps are added without splitting the line into two-terminal sections, relay protection of the resulting multiterminal line becomes more complicated and requires more detailed information about the line and the associated system connections.

For example, current distribution must be determined at all terminals, both for normal operation and for various possible fault conditions. An analysis must be made to determine apparent impedances seen by distance relays. Weak sources and related problems that can affect protection must be determined. Where the tap or terminal is connected to a load that has little synchronous equipment to supply fault power, the terminal will often be difficult to relay, particularly at high speed. In this case, sequential tripping will be required and conventional instantaneous reclosing will not be applicable. Additional transfer-trip protective equipment and time-delay reclosure can be applied.

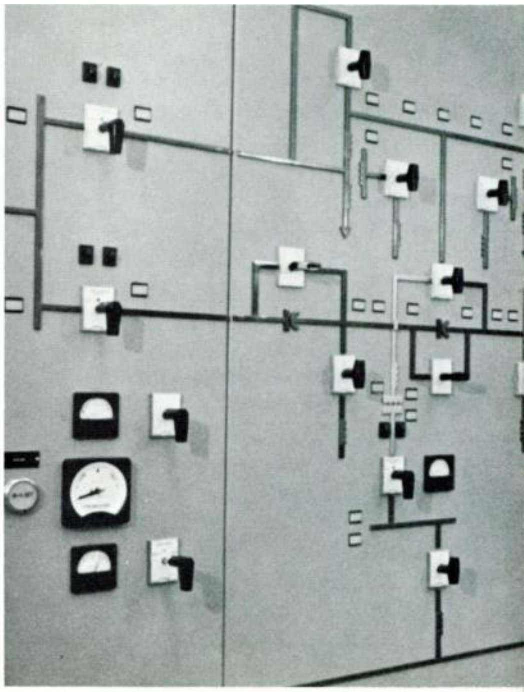
Dependability and Security

As power system interconnections grow more complex, the application of protective relays becomes more of an art than an exact science. Trouble requiring relay operation can occur in a variety of forms so that an exact prediction of what will actually happen on a given system becomes difficult if not impossible. And protection for every possible contingency becomes impractical, both from an economic and an operational standpoint.

Thus, a variety of protective systems has been developed for applying relays. The reasons for the variations involve many subtleties, but a fundamental consideration concerns the two basic but conflicting requirements of reliability—*dependability* and *security*. The question is whether it is more important to clear faults (dependability) or keep the system intact (security). Obviously, the primary objective is to provide both features, and both are provided by modern relaying systems. Therefore, the question often involves relatively small hills and valleys of possible contingencies—all on the same high plateau of protection reliability. But the question does account for much study and discussion among relay engineers. Each group of power system engineers will arrive at a particular protective system that best suits their needs, desires, and economics.

Although the protective relaying art is becoming more complex, continuous pro-

Power system laboratory represents EHV power system conditions presented to relays.



grams of research and development by relay manufacturers are producing relaying devices that require less adjustment and maintenance, yet provide increased application flexibility with far less system engineering effort.

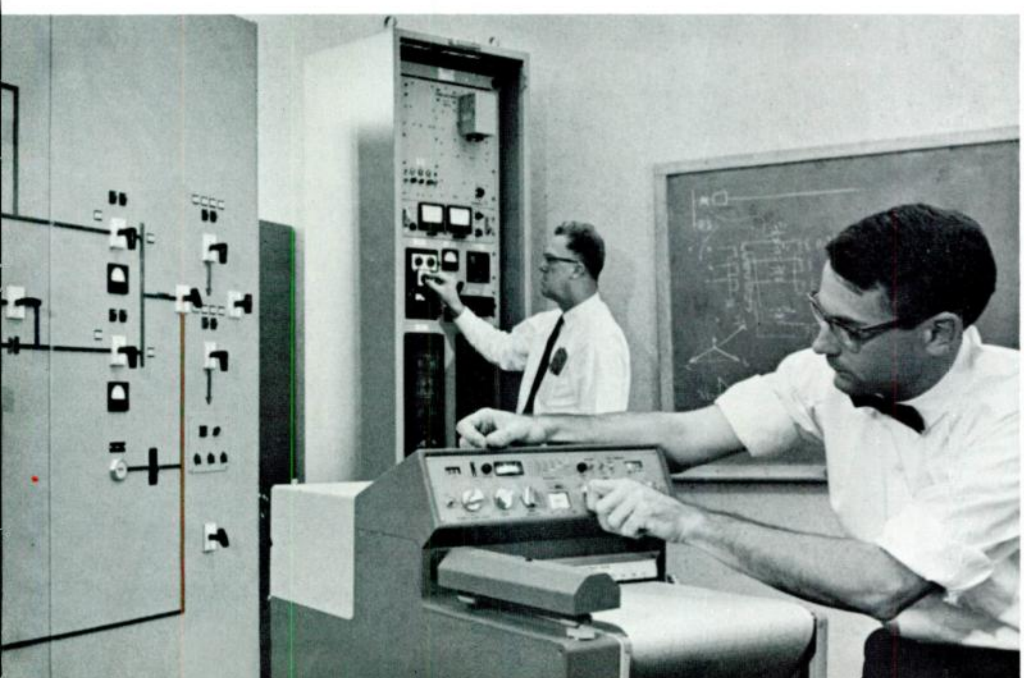
An example of this type of equipment development is the K-Dar family of distance relays, in which the decision-making logic is primarily provided by a static compensator. The compensator, which is essentially an air-gap transformer, determines the "reach" of the distance relay. By its very nature, this static device retains its high accuracy with practically no maintenance. Furthermore, with the compensator distance-measuring technique, relays are most logically packaged by zone rather than by phase. With this zone-packaging arrangement plus the wide range of distance adjustment available, many application combinations are possible with a minimum number of basic relays. K-Dar compensator relays are adaptable to straight distance-type protection, or in combinations for directional-comparison carrier, microwave, or pilot-wire systems.

Static Relays

Until recently, protective relays and protective relaying systems were primarily compact electromechanical analog networks, set to detect unwanted or intolerable conditions within an assigned area. As the relaying logic becomes more complex, the trend is toward the wider use of solid-state technology in protective relay design. With "and," "or," "not," and "flip-flop" logic circuitry, more complex combinations of logical decisions can be made simpler and faster with high reliability. These new techniques are applicable to trouble-sensing and detecting units as well as to interconnection logic. As a result, solid-state relays are available and in service protecting major transmission lines, subtransmission lines, distribution circuits, and generators. Similarly, solid-state relays are being used for such auxiliary functions as tripping, timing, and reclosing. All power-line-carrier and audio tone equipment now being manufactured for application on protective relaying channels is of the solid-state type.

The optimism about solid-state relays does not mean that Utopia is here, with all problems known and solved and all advantages realized. For example, these low-level devices must be secure and dependable in the high-power world of power stations, and added protection equipment and circuitry is necessary. Protection from multifrequency transients is built into the relay design with additional surge protection on the incoming circuits. Considerable knowledge of this protection has been developed and accumulated, both in the laboratory and in the field, with high assurance that most applications will not present problems.

The extreme reliability, long life, and proven performance of the electromechanical relays (many of which have been semistatic for some time) indicate that competition between the two will be keen. Consequently, in most areas both types are, and will be, available for many protection requirements. This will provide an excellent opportunity to compare and evaluate electromechanical and solid-state relays in similar installations. The comparison should be made on a present basis—a new static relay should be compared with an up-to-date semistatic or electromechanical relay—because as advances are made in static relay technology, significant improvements are being made in the semistatic and electromechanical types.



Power System Laboratory

In the development of new protective relaying systems and relays, the power system laboratory can be an invaluable tool in providing in a few hours the equivalent of many months of field testing and experience.

A new laboratory recently installed at the Relay-Instrument Division in Newark was designed to represent system quantities and conditions presented to relays by 500-kv transmission systems. This gives relay designers the opportunity to develop and thoroughly test relays and relaying systems under the extreme conditions and transients that can be encountered on EHV lines. Loads, charging current, power swings, and out-of-step conditions can be studied in the power system laboratory, including the effects of parallel line mutuals, taps, shunt reactors, and series capacitors in the transmission line. All combinations of both solid and arcing faults with tower footing resistance can be applied at the buses and at various points along the lines. Thus, the time required in the field for adjustment and calibration of relays can be minimized.

Advancing Technology

In recent years, the trend in protective relay design has been toward relays that can do their assigned job through more complex decisions, with better accuracy and higher speeds, rather than toward relays that can do a multiplicity of protection jobs. The latter approach would involve compromises that are not permissible on today's systems. And as the decisions to be made by the relay become more complex, there will be an increasing use of solid-state devices and techniques. Invention of better methods of protection will continue as the technology advances.

Already, one significant byproduct of solid-state technology is the acceptance of change in long-existing patterns. In some areas, solid-state relays will completely replace present electromechanical relays, while in others, the two will work together. The parameters to be optimized will always be dependability, security, simplicity, and economics.

Some Guides to Nuclear Power Planning

J. C. Rengel
General Manager
Atomic Power Division
Westinghouse Electric Corporation
Pittsburgh, Pennsylvania

The development and demonstration of nuclear power has been one of the major changes in the technological revolution taking place in the electrical industry. Today, nuclear power is no longer in the "feasibility stage"; it has proved itself to be a reliable and attractive electrical generating source.

This situation is no accident. It is due to the rapid but careful exploitation of a new concept in power sources. Moreover, the situation represents a unique instance of teamwork between a government agency—the Atomic Energy Commission—electric utility companies, and manufacturers. Had any one of these three groups failed to contribute, nuclear power would undoubtedly still be in its infancy. However, at this stage, certain trends are apparent. One is the gradual withdrawal of government support for *light* water reactors, the most advanced type now available. As this happens, the importance of utility participation in development increases. For example, industry must finance much of the technology for the recycling of plutonium in water reactors. Therefore, the burden of development is now falling largely on electric utilities and manufacturers.

The progress made in commercial atomic power in the last decade or so has not, of course, been without its false starts and mistakes, which naturally affect cost in one way or another. One of several examples is the Westinghouse Test Reactor, which eventually was shut down because of lack of business, and the investment written off. However, these were not complete losses; a great deal was learned from the aborted projects, much of which could be put to work on other development efforts.

In retrospect, one other fact is worth mentioning. Few projects have been dropped because of indications that the plants would not operate. In fact, there are hundreds of reactor concepts that could probably be made to work. Thus, not only is it essential that the most promising designs be developed to their fullest extent, but also it is critical that many concepts must be continually studied and evaluated to assess their potential.

From the very beginning, a major portion of the Westinghouse effort in nuclear power has been focused on the tremendous potential of the pressurized water reactor. The technical feasibility of this reactor concept was, of course, demonstrated beyond question in the Naval Reactors Program, but there was still the gap in knowledge, development, and proof that this could be an effective *commercial* reactor for electric utility use.

We recognized that the pressurized water reactor concept had economic promise, but only through a constant research and development program, plus the construction and operation of commercial plants, has the full potential and the tremendous flexibility of the concept become evident.

For example, a decade or so ago, seven and a half mills per kilowatthour was frequently cited as a reasonable target for nuclear power cost. Today, we are facing targets under four mills. The size potential of PWR plants was another area; at the time it appeared that reactor vessels were the limiting factor, with Shippingport and Yankee vessels as the largest possible. Today, we know that vessels can be built *twice as large in diameter* and *ten times as large in rating*, through a combination of vessel, core design, and control improvements.

The potential of the PWR is not fully realized. Throughout the 1970's, it will be a leading contender for lower electric power costs. Part of this is due to the flexibility of the design concept, which allows new developments to be incorporated in a plant easily and quickly. This is demonstrated by the costs for the Yankee plant, shown in Fig. 1, which are far below original predictions. In all probability, additional output could be obtained from the plant if the turbine-electric portion were not limited.

In 1959, we offered to build a 330-mwe net plant at an estimated capital cost to the utility of $237 per kilowatt. As a result, the San Onofre plant is being built and will go into operation this year at a presently estimated dollars per kilowatt figure of $203 including utility costs. The cost estimates were reasonably close, but the potential output of the plant was increased as the design progressed, because of new technical developments. A turbine of 450 mw has now been applied.

What of the Future?

For several years we have been capable of building a 1000-mw plant on a firm price, firm schedule, warranted basis. This indicates the trend in nuclear power, and the present ability to build units at least as large as utilities want today. Considerably larger pressurized water plants can be built without the necessity of radical design changes; only normal research and development will be necessary.

What about future costs? In 1959, we struggled to break the $200 per kilowatt barrier; today, with a 1000-mw plant, it appears entirely reasonable to expect that we will break the $100 per kw cost barrier.

A logical question is: Why concentrate largely on the PWR concept? There are several basic reasons: (1) It is highly competitive with any concept that can be made available to utilities prior to about 1975 or 1980. (2) A pressurized water reactor can be operated and maintained by a smaller crew than either a fossil-fired unit or most competing nuclear units, and the crew's skills need be commensurate only with those required in a fossil-fired unit. (3) The cost of maintenance and replacement components and supplies is significantly less than those for competing reactor concepts. (4) Another advantage is the ease of training, and of obtaining regulatory agency approval of designs, because of the unmatched background of experience, simplicity of operation, and absolute control over radioactive effluent at all times. (5) And a final major advantage of the pressurized water concept is the ability to modify individual fuel element and fuel assembly designs to take maximum advantage of fluctuations in fuel cost, such as possible future changes in the value of plutonium. These possibilities exist because of the simplicity of design of the reactor core, since the moderator is essentially single phase (no steam void), and the density change is relatively small across the reactor core.

A long-term advantage is the ability of a pressurized water reactor to follow load for peaking service. The technical feasibility of this type of operation again has a large background of experience.

Above plant sizes of 400 mwe, the pressurized water concept is already competitive with fossil fuel in the range of about 25 cents per million Btu. Within the next 15 years, it will be competitive with fossil-fuel costs of less than 20 cents. And should no new concept enter the picture, the pressurized water reactor could probably be developed to the point where its costs would be competitive with fossil-fuel costs of about 15 cents per million Btu. While this is an impressive potential, it also points to the need for continuing search for other reactor concepts for the longer range future.

The utility system of the future, say 1990–2000, will probably consist of a mix of units, depending upon their intended use in the power system. We estimate that the base load will be supplied by breeder reactors, probably liquid-metal cooled. We also believe that a large fraction of the load will be carried by water reactors, including some very advanced supercritical pressure units. The peaking portion of the demand curve will be supplied by older units, fossil units, pumped storage, gas turbines, etc.

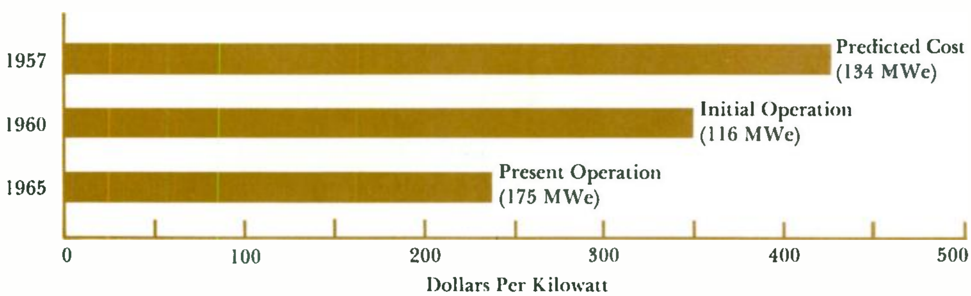
Obviously, the ideal nuclear power plant for electric utility service would be one that combined the features of low capital cost, low fuel costs, and high breeding ratio. We do not believe that this idealized nuclear power plant will ever be built, largely because no one concept has the potential to embody all three characteristics. The liquid-metal-cooled, ceramic-fueled, fast breeder reactors have potential *fuel costs* in the range of 5 to 8 cents per million Btu, and the ability to produce nearly 50 percent more fissionable material than they use. However, it appears that *capital costs* will remain significantly higher than those of pressurized water plants. Also, the characteristics of the liquid-metal-cooled fast reactor are such that load changes on the machine introduce temperature transients of several hundred degrees on components in the reactor system. It seems desirable to develop such a reactor for use at the time when plutonium is available in quantity, and against the time when uranium costs begin to rise. However, such reactors should operate as base load machines to justify the capital outlay and to take advantage of the extremely low fuel-cost potential. In the process, of course, the temperature transient duty is reduced if plants are not required to follow frequent load changes.

The lowest capital cost concept appears to be a very advanced water reactor, using supercritical fluid. Fuel costs would be intermediate, about 10 to 12 cents per million Btu. The specific design selected could be a breeder too, depending on the economic situation. Because of its low capital cost, this concept is well suited to load-follow duty, the middle portion of the utility demand curve.

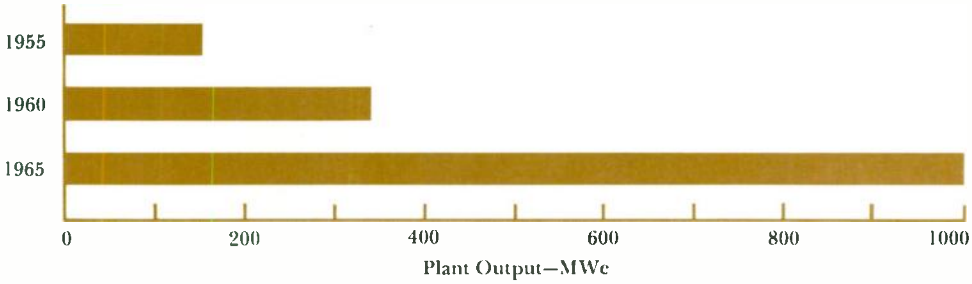
At this stage, nearly all of the Westinghouse profit in commercial atomic power is plowed back into development of improved PWR plants and the study and development of advanced systems. A limited amount of Atomic Energy Commission research and development assistance has been supplied on both breeding and supercritical pressure technology. To date, neither advanced system has received adequate utility support, either in the form of research and development financing or the construction of prototype and demonstration plants. This support is necessary if the best reactors are to be available when needed.

The stage is now set for rapid build-up of nuclear generating capacity. Nuclear power plants are ready to take their place in utility systems to produce the best mix of plants and fuels. Beyond any doubt, nuclear power can be an important factor in producing the lowest overall system power costs. For the long-range period, however, nuclear power must have the same continued cooperative effort that has brought the industry to its present state, or it will be a far less effective means of reducing utility power costs in the future.

1—Capital Costs of Yankee Plant



2—Increase in Capability to Design and Build PWR Plants



AC Motor Rerate—New Motors Are Both Smaller and Better

by R. F. Woll

Revised standards for integral-horsepower ac induction motors were discussed in the November 1965 issue of the Westinghouse ENGINEER. Opportunities for better value are inherent in the standards; the ways in which these opportunities are employed in the Westinghouse design approach are described here.

The new rerate industry standards issued by the National Electrical Manufacturers Association (NEMA) for integral-horsepower induction motors are based on recent technical advances in materials, design, and manufacturing. Consequently, as pointed out in the previous article, they carry much potential for better value in these standard motors so widely used in industry.

Each motor manufacturer has his own approach to the redesign of his line to embody the new standards. At Westinghouse, the approach has been to incorporate, to the fullest extent, all of the technical advances that made the new standards possible. The result is a superior line of standard motors, with Class-B insulation systems, known as Life-Line T motors.

General Construction

Life-Line T motors retain rugged cast-iron frames and end brackets for both dripproof and totally enclosed fan-cooled (TEFC) enclosures, frame sizes 182T through 445T. (See photograph.) The superiority of cast iron over aluminum and steel for corrosion resistance, strength, and dimensional stability has been amply proved through years of experience.

Bearings are double shielded and prepacked by the manufacturer with a highly stable oxidation-resistant grease, with provision for relubrication in service. The shields retain lubricant in the working parts of the bearing, protect against entrance of contaminants, and provide a metering action to minimize the hazard of overgreasing in service. In addition dripproof motors have either internal neoprene flingers or internal bearing caps at each end.

All insulation components are full Class B. They are largely made up of the new synthetics that combine mechanical strength, moisture resistance, and, in most components, thermal endurance equivalent to Class-F requirements.

Electromagnetic and thermal designs have been worked out through an advanced computer technology that goes far beyond simple calculation of performance. Computer calculation gave the designers the ability to optimize their designs through more effective utilization of active electromagnetic materials, thus assuring the highest levels of efficiency and power factor consistent with user requirements. External appearance was styled to complement the utilitarian aspects of the design.

R. F. Woll is a Fellow Design Engineer in Medium AC Motor Development, Motor and Gearing Division, Westinghouse Electric Corporation, Buffalo, New York.

Advanced Class-B Insulation System

Experience with the most advanced insulating components was drawn on in engineering the nonhygroscopic Class-B insulation system for the new Life-Line T motors. One of the most marked gains over previous insulation systems is in the wire enamel, where quality and uniformity of the enamel film have been vastly improved by special production control processes. The number of points of below-average dielectric strength—already low—has been reduced by a factor of 15. Moreover, the Class-F polyester enamel used is given mechanical protection by application of a tough "overcoat."

Special attention was given to the slot cell (or ground insulation) because, as is brought out in the *Locked-Time Capability* section of this article, relatively high winding temperature occurs if the motor is inadvertently stalled. Under such conditions, the wire might cut through to the lamination stack if the slot cell were solely of thermoplastic material. Consequently, a slot cell with glass-fiber reinforcement was selected. Besides providing a positive mechanical barrier against thermal cut-through, this Life-Line T slot cell is a positive moisture barrier and has high dielectric strength to assure long life in this vital area.

Phase insulation and wedge materials were selected to complete the nonhygroscopic insulation system with fully compatible components, including multiple dips of a Class-F thermosetting varnish.

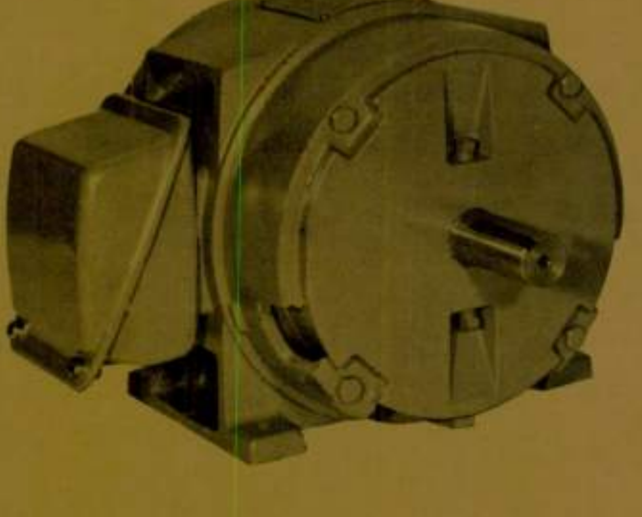
Qualification and verification testing of the insulation system included plug-reversing motor tests under accelerated conditions of heat aging, moisture, mechanical shock, transient voltage stress, and thermal shock. Dripproof motors were also tested outdoors at rated hot-spot temperature.

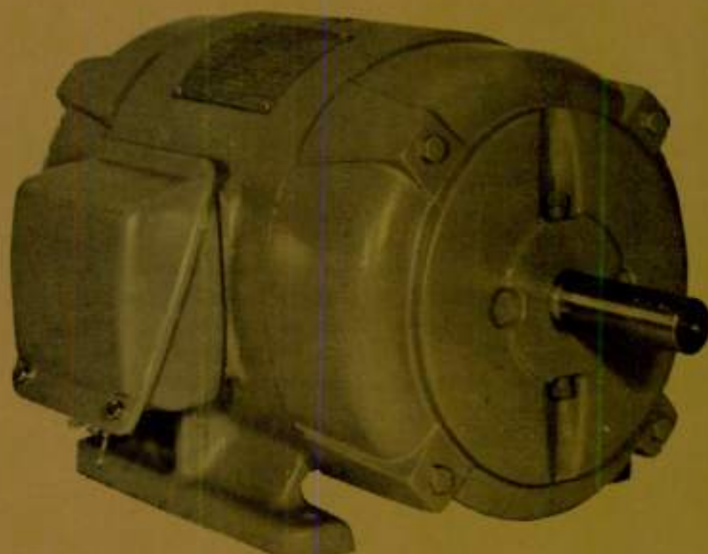
Improved Ventilation

A substantial increase in heat-dissipating capacity has been achieved by modifying the new Life-Line T dripproof motor ventilating-system design. The basic design is the familiar double-end ventilated type, with cooling air drawn in through each end bracket and expelled through outlets in the frame; however, careful attention to detail modifications in significant areas has afforded a marked gain in air movement and, consequently, the gain in dissipating capacity. These detail modifications are not normally found in motors of industrial size.

1—Substantial increase in air-flow section between frame and stator core of the new rerate Life-Line T motor over that of the present Life-Line A motor is provided by a small increase in frame shell diameter.

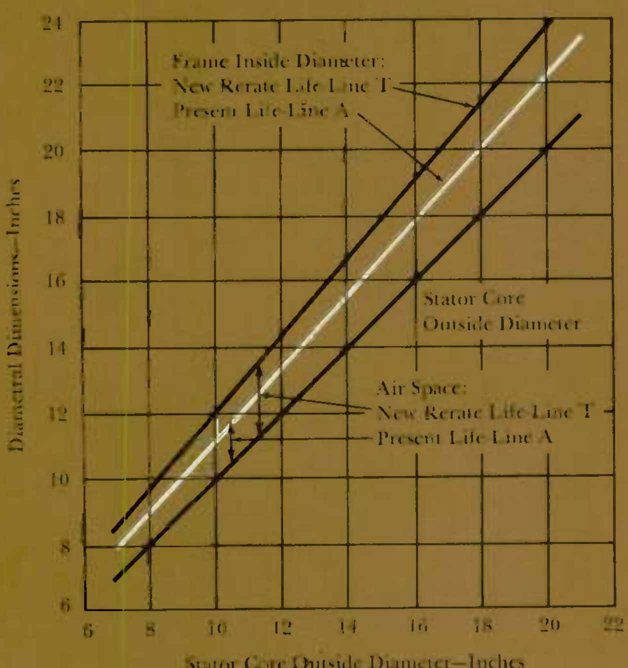
2—Improved heat-dissipating ability of the new rerate Life-Line T dripproof motors is illustrated by these approximate curves. The gain stems from the increase in air-flow section illustrated in Fig. 1 and improvements in the design of ventilation openings.





Size reduction of motors based on the revised NEMA standards is evident in this view of two five-horsepower 1800-rpm dripproof motors. On the left is the new Life-Line T motor in the 184T frame size; on the right, for comparison, is the present Life-Line A motor in 215 size. Use of Class-B insulation instead of Class-A is the major factor in the size reduction, which has been achieved without sacrifice of locked-time capability or other important service characteristics. Ventilation ports and frame shell have been redesigned to increase air flow and thereby increase heat-dissipating capacity. Shaft extension diameters remain the same.

1



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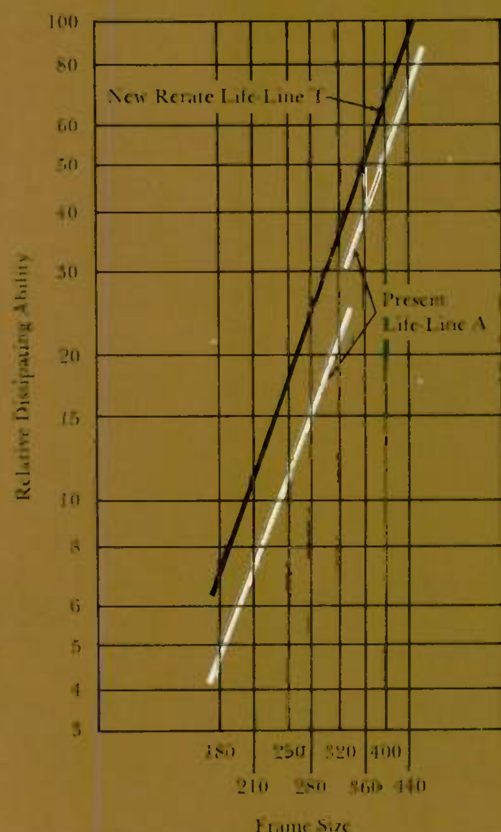

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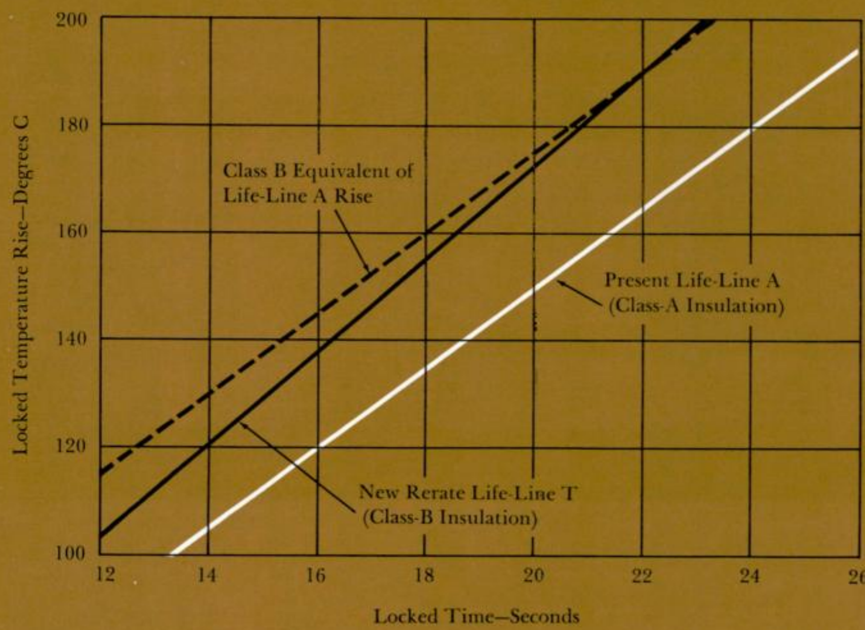


Availability Schedule of Rerate Life-Line T Motors

Size Frame	*1965*		*1966*				*1967*	
	Third Quarter	*Fourth Quarter*	*First Quarter*	*Second Quarter*	*Third Quarter*	*Fourth Quarter*	*First Quarter*	*Second Quarter*
140T*	A	B	C					
180T	A	B	C					
210T		A	B	C				
250T			A	B	C			
280T				A	B	C		
320T					A	B	C	
360T						A	B	C
400T					A	B	C	
440T		A	B	C				

Legend

A—Pilot period for first runs and stock buildup. Transition bases available.

B—Limited derivative period. Special voltage 100 to 600 volts; special shafts, screens, and sidewall mounting covers; and all insulations except Life-Guard available. No other modifications furnished.

C—Full-line period. Capability for all modifications.

Explosion-proof motors will follow the full-line schedule by three months.

*The 140T motors have a rolled steel frame and are single-end ventilated in dripproof construction. Development of explosion-proof motors is not planned for 140 diameter; 140 explosion-proof ratings will be provided in 180 frame.

3—Locked-rotor temperature rises for the new rerate Life-Line T and present Life-Line A motors are indicated by the two lower curves. The top curve shows the temperature rise that a motor with Class-B insulation could withstand locked and still be equivalent to a Class-A insulated motor. Since protective devices in a motor circuit would remove power before the Life-Line T temperature rise actually reached this level, the new motors conserve more insulation life than the present ones.

First, the frame shell is of slightly larger diameter than normal (flattened across the bottom for floor clearance), and this small increase in frame diameter provides a substantial increase in the section for air flow. In fact, about 6.5 percent increase in frame diameter results in approximately 55 percent increase in the air-flow section (Fig. 1).

Second, in addition to the conventional air outlets in the lower sides of the frame between the feet, a pair of well-protected outlet ports is provided in the upper half of the frame. They permit uniform air exhaust from all frame quadrants.

Finally, the circumferential span of the inlet openings in the end brackets was increased to feed air more uniformly into all frame quadrants.

The net effects of these detail improvements are high-volume air flow, which is relatively low in velocity and hence quiet, and the consequent gain in dissipating ability illustrated in Fig. 2. For the smaller machines, frames 180 through 320, the gain in dissipating capacity is about 60 percent; for larger frames, about 30 percent. This improved ventilation and the longer insulation life built into the revised NEMA standards add up to an insulation life expectancy for the new Life-Line T dripproof motor better than that of any present motor.

Similar improvements, though not to the same degree and not so obvious from the exterior appearance, will be provided in the new rerate Life-Line T TEFC motors. The gains here will come from reduced internal temperature gradients and increased finning of the frame surface.

The improved cooling of the Life-Line T dripproof and TEFC motors supports the observation in the previous article that rerate motors will have lower surface temperatures than older motors of the same insulation class. However, sufficient specific information is not presently available to make a quantitative estimate of the amount of the reduction.

Bearing Capacity

Shaft extension diameters of the new rerate motors will be the same as those of the present motors for a given horsepower, even though the new motors are in smaller frames. The Westinghouse rerate Life-Line T motors will generally have the same size bearings as the Life-Line A motor of the same rating. This fact would seem to imply that minimum bearing life will remain basically unchanged, but that is not the case. The bearing industry has been changing over to a new vacuum-degassed steel for making balls and raceways, and the new bearings will be used in all Westinghouse rerate motors. The new steel provides about a 40- to 45-percent increase in load capacity for a given bearing, which translates into triple the minimum bearing fatigue life at the same loading—another instance of improved value.

Locked-Time Capability

In case the load is jammed and a motor is stalled with full voltage across its terminals, it is vital that the motor have the capability to absorb the heavy power consumption without damage to itself for as long a time as it takes the control to sense the problem and remove power from the line. (Modern controllers have a reaction time under locked-rotor conditions of not more than 15 to 20 seconds.) When motors are to be built in smaller frame sizes, users naturally question whether the locked-time capability is being maintained.

The incremental locked temperature rise of an induction motor varies as the square of its locked current density. Life-Line A motors with Class-A insulation, which have been in production more than 10 years, have been designed to an upper range of locked current density that yields an incremental locked temperature rise of 7.5 degrees C per second. The new Life-Line T rerate motors with Class-B insulation are designed to just a slightly higher upper range of locked current density, one that will yield an incremental locked temperature rise of 8.6 degrees C per second.

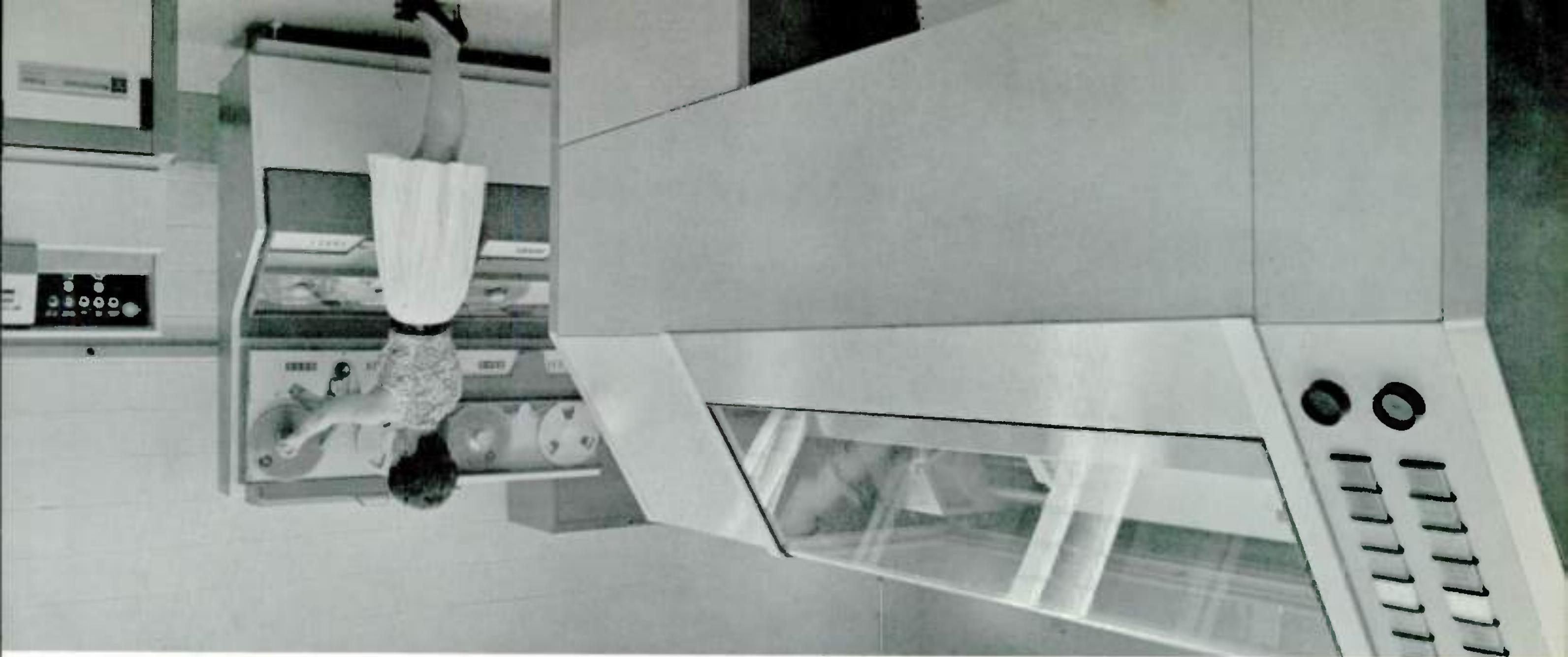
These incremental locked temperature rises are plotted as actual rises in Fig. 3. Since Class-B insulation has a hot-spot temperature of 130 degrees C for insulation life equivalent to that of Class-A insulation with 105-degree hot spot, a motor with Class-B insulation can stand a 25-degree higher temperature than a Class-A insulated motor for the same life. This 25-degree higher temperature capability is plotted in Fig. 3 to illustrate that, in the 15- to 20-second span of time that a motor is required to withstand locked conditions, the Life-Line T motor conserves more of its insulation life than the Life-Line A. Thus, the higher temperature characteristics of Class-B insulation have been used to effect a slight gain in locked-time capability, one more example of better value for the user.

Availability of Life-Line T

A condensed schedule of availability of the new motors is given in the accompanying chart. Each succeeding frame diameter is scheduled for introduction at about three-month intervals, a schedule that permits an orderly transition in the factory from manufacture of Life-Line A to Life-Line T motors and also gives users time to adjust to the new ratings.

Conclusion

The intent in this article and the preceding one has been to point out the potential for better value in the new NEMA standards and to report the approach taken by Westinghouse in designing to the new standards. The practical result of the new standards and the Westinghouse approach is progress and better value for all.



Digital Simulation for Testing Control Computer Programs

by R. Herbst
R. E. Hohmeyer

Acceptance of the computer as a controller in industrial processes has created a need for more effective techniques for testing programs. Simulation of the controlled process with another digital computer reduces system cost, shortens delivery time, and speeds start-up.

The total cost of a computer process control system is made up of hardware and programming costs. Since the programming cost is a significant part of the total, improved techniques that lower this cost significantly lower total system cost.

Moreover, delivery time for the computer system depends on programming as well as on manufacture of the hardware. While the hardware differs little among applications and so lends itself to assembly-line manufacturing techniques, the programming may differ considerably from one job to another. Standard programs are used as much as possible to eliminate reprogramming of common functions. But the functions that are unique to an application must be tailor made, and thus they have to be carefully tested and, if necessary, corrected. This "debugging" can have a significant effect on the speed of delivery of the computer system, and also on the amount of time required for installation.

A new technique for program debugging, developed by the Westinghouse Computer Systems Division, reduces cost and shortens delivery and installation time by employing another digital computer to simulate the process or system to be controlled. This *process-simulating computer* represents the process by simulating what the process is to the *control computer:* a variable, sometimes random, transmitter of input to the control computer and a receiver of output from the control computer. The process-simulating computer contains programs that accept input from the programmer, communicate with the control computer, and record events. The control computer contains the programs that will control the actual process—the programs that have to be checked to make sure that the control functions are properly stated and sequenced.

Process-control programs are developed and tested with this technique independently of the manufacture of the hardware. What used to be largely a serial effort—manufacture followed by programming—is now a parallel effort. The result is lower program testing costs and startup of thoroughly tested systems in shorter time.

R. Herbst is Manager, Simulation and Systems Programming, Computer Systems Division, Westinghouse Electric Corporation, Pittsburgh, Pennsylvania. R. E. Hohmeyer formerly was an engineer in Simulation and Systems Programming.

Process-simulating computer and control computer *(top)* are housed in cabinets in left background. The operator, seated at one of the consoles, makes a simulated process run by entering input information with the card reader at left center. Output data from the system is recorded by the high-speed line printer in foreground. Process-control programs are entered into the control computer on magnetic tape *(bottom)*. A reel of tape such as the one being loaded on the tape drive here may contain more than 100 complete programs.

Program Testing Techniques

The testing of a control computer program can be illustrated by comparison with that of a data-processing program—say a simple payroll program. Input data to a payroll program is on punched cards and consists mainly of the employes' badge numbers, hourly rates, and regular and overtime hours. The outputs from the program are earning statements and paychecks. The payroll program itself is a series of arithmetic and logical operations that transform the input data into the output. It is tested by running it with selected input data and checking the output against hand-calculated figures. If the results are not consistent, errors ("bugs") in the program are located and corrected, and the test is repeated. When the program successfully transforms input data to the desired output data for all test cases, it is considered debugged. The debugging procedure for a data-processing program, then, is simply a cyclic repetition of correlation of input to output, program modification, and program rerun.

Testing a control computer program is basically similar, but it is considerably more complex because the computer must correctly process a variety of inputs and outputs from and to many input-output devices. These devices can be classified in two groups. The first consists of devices that communicate with plant personnel: tape readers and punches, card readers and punches, and typewriters. The second consists of devices that communicate primarily with the process: analog inputs and outputs, digital inputs and outputs, and priority interrupts.

The analog input devices include, for example, pressure and temperature transducers. These transducers provide a voltage signal to an analog-to-digital converter, which in turn transforms the voltage to a digital quantity that can be entered into the computer. Several thousand analog inputs may be multiplexed into a single converter, and large systems may have several converters. Analog outputs are transmitted from the computer via digital-to-analog converters, which transform digital quantities to voltages that can be used by control devices for references or set points. For example, the reference voltage that controls the valve regulating flow of wood chips into a continuous pulp digester is a computer analog output.

Digital input devices consist of contacts, which are used singly to represent the on or off state of a switch or in groups for such devices as digital counters, shaft-position encoders, and decade switches. Digital outputs are used singly to actuate such electrical equipment as valve positioners and alarm annunciators, or they are used in groups to drive digital displays, provide set points for controllers, and drive low-speed document devices such as printers and paper-tape punches.

Priority interrupts are a special class of digital inputs brought into the computer to get its immediate attention. Examples are inputs from limit switches and operator controls, signals from asynchronous devices such as watt-hour meters, and completion signals from low-speed input and output devices such as typewriters and punches.

All the input and output devices may operate asynchronously and concurrently with many other operations in the system, and proper operation of some entails both timing and sequencing considerations. Unwanted interaction can occur between devices and must be eliminated.

Despite these system complexities, the debugging technique for a control computer program is basically the same as for a data-processing program. The programmer runs it with selected input conditions and observes the output. When correlation between all the inputs and outputs is correct, the program has been debugged.

However, the difficult problem with previously used techniques has been in setting up the inputs and observing the outputs. When industrial control computers were only data loggers, their programs usually could be debugged by simulating plant variables on an analog simulator (the analog-simulator method) or by checking them after they were installed and monitoring the process (the on-site method). The difficulty arose as the computer became less of a data tabulator and a more integral part of the control loop. The number and type of inputs increased so much that attempts to simulate them by analog techniques became increasingly difficult, and the on-site method had to be discarded because it invariably caused work stoppages or at least decreased production efficiency. Both methods lack the basic requirements that are essential for efficient process-control program debugging—control, flexibility, reliability, and documentation.

Control—The programmer must be able to vary each input over its permissible range, because only then can program debugging be comprehensive. While the analog-simulator method maintains control over the *range* of inputs, it provides only limited control over the *accuracy*. In the on-site method, inputs to the system are functions of plant conditions and, consequently, very little control is possible. For example, the operator of a chemical process would be reluctant to exceed the normal operating level of a tank to check the priority-interrupt signal from a limit switch in that tank.

Flexibility—The test procedure should be independent of system size and of the types of input and output devices. The on-site method is inflexible in the sense that system modification is nearly impossible; for example, it might be desirable to remove several inputs to isolate an error, but doing so after the system is installed may require major hardware changes. The analog-simulator method does permit system modification but generally requires that special equipment be designed to simulate some of the input and output devices adequately for a particular system.

Reliability—The programmer must be completely confident of the reliability of his test equipment. In both the analog-simulator method and the on-site method, the control programmer is working on equipment that is in some nonfinal state of manufacture or assembly and whose components may be subject to failure. Lack of confidence in a partially complete computing system may cause him to spend considerable time investigating apparent hardware malfunctions that are actually programming errors or investigating apparent programming errors that are actually hardware malfunctions.

Digital simulation facility *(right)* consists essentially of two digital computers. One acts as the process-control computer, "thinking" it is tied to an industrial process. The other simulates the behavior of the process and also monitors and reports the actions of the control computer. Punched cards and magnetic tape provide process and control input.

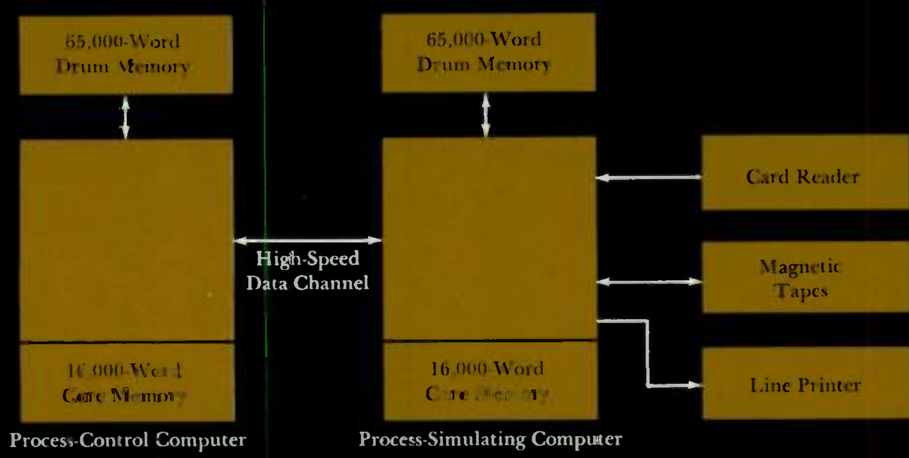
Documentation—Detailed records of inputs and outputs are required for diagnosing problems. However, the only printed documentation of plant variables in a control computer system are printed reports and alarms summarizing past plant operations; the computer input and output is in the form of voltages, contact closures, and interrupts, which are not documented by the computer system. Documenting large numbers of these types of inputs and outputs simultaneously in the on-site and analog-simulator methods would require extensive recording equipment such as strip charts.

To be effective, then, the control programmer has to be placed in the same kind of environment as his data-processing counterpart: he has to be able to concentrate his efforts on the input and output relationships in his program. The digital simulation technique provides these necessities by permitting the programmer to simulate his input and output conditions easily. The facilities used meet the requirements of control, flexibility, reliability, and documentation.

Program Testing By Digital Simulation

In the digital simulation technique, the input-output equipment normally attached to the process-control computer is replaced by a digital process-simulating computer. (See diagram, top right.) Information usually obtained and sent through the input-output equipment now flows to and from the process-simulating computer. To accomplish this change, a short subroutine in the control computer reroutes information from the normal data channels to the high-speed data channel that links the two computers. This subroutine is the only programming difference between the final computer system and the simulated system. The application programs that will eventually control a process are not modified; they are exactly the same as they will be when controlling the process. Therefore, if the application programs run correctly in the simulated system, they will run correctly in the actual computer control system.

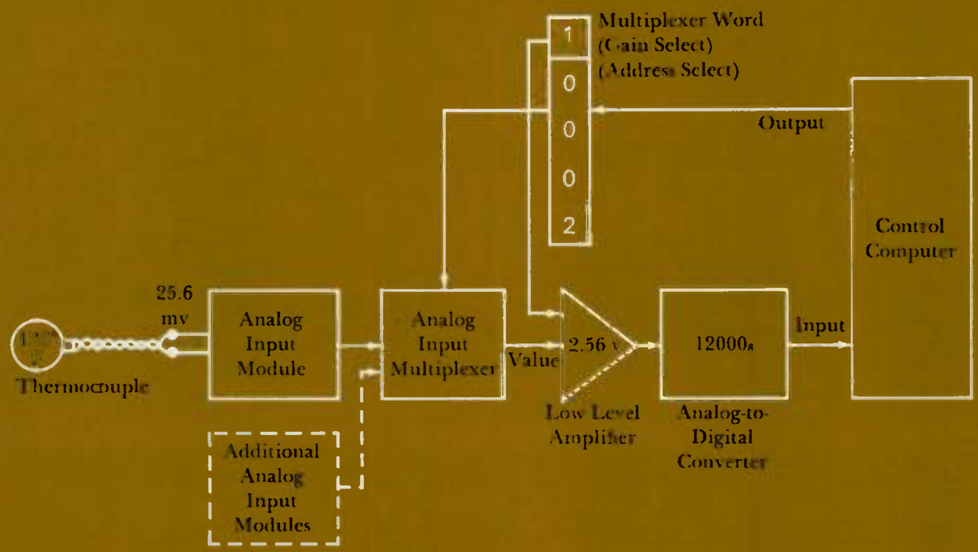
The process-simulating computer must simulate the operation of the normal input-output equipment attached to the control computer, it must simulate the behavior of the industrial process, and it must report all input and output events that occur in the simulated system. These three functions are implemented by three separate programs that time-share the computer at different priority levels.



Simulation of Input-Output Equipment

In an actual process, say a steam power plant, a multiplexer word is put out by the control computer when the computer wants to read the temperature (120 degrees F) of feedwater in a pipe. (See illustration.) The address portion of the word is used to select the transducer associated with the desired temperature sensor through a multiplexer, and the gain-selection part of the word selects one of several possible amplifier gains (100 in this example) to provide a signal in the range required by the analog-to-digital converter. Thus, the signal from the transducer (25.6 mv) is multiplied by 100 (2.56 volts), and that voltage is input to an analog-to-digital converter that changes it to a binary number—a form acceptable to the computer. (For convenience, the shorter octal form of this binary number—12000—is used in the illustration, as it is in written programs and in printouts.)

In simulation, an analog input system such as that just described is simulated by the program in the process-simulating computer. An analog address and gain word is output by the control computer exactly as it would be by the normal control system. The gain portion is used to select one of the gains from the memory of the process-simulating computer; similarly, the analog value stored in the memory of the process-simulating computer is selected by the address part of the word. The analog value is multiplied by the gain, converted to the form of the output of an analog-to-digital converter, and input to the control computer as a binary number. The control computer cannot distinguish between the real and the simulated input system. The programming for the simulated analog input system is illustrated in the figure.



Program for Digital Simulation of Analog Input

Procedure	*Data*
1. Get multiplexer word from control computer.	I 0002_8
2. Set I equal to most significant digit of multiplexer word.	I
3. Set J equal to least significant four digits of multiplexer word.	J
4. Set A equal to analog value (J) × gain (I) Converted value $= A \times C_1 + C_2$.	$2.56\ v = 25.6\ mv \times 100$ $12000_8 = 2.56 \times C_1 + C_2$
5. Send the converted value to the control computer as input.	12000_8

[Gain (I) is one of several gains on the amplifier, analog value (J) is one of the simulated analog values, and C_1 and C_2 are conversion constants of the analog-to-digital converter.]

Control computer reads a selected analog value in an actual process *(upper)* by putting out a multiplexer word that selects the proper transducer and the required gain. In digital simulation, the control computer does the same thing, but analog value and gain come out of the process-simulating computer's memory. The programming for this simulated input is illustrated *(lower)*.

The first program simulates the operation of the input-output equipment, which may consist of any combination of multiplexed analog units, process interrupt units, and contact closure units. This program maintains a value table in the core memory containing the value, state, or both of each component of the input-output system. It receives output from the control computer and stores the value in a significant form in the value table. It transmits input to the control computer when a simulated input unit changes state as requested by the programmer, or when a normal completion interrupt is required for the operation of a logging device. All communication within the simulator is handled by this program. For a simple illustration of the operation of this program, see *Simulation of Input-Output Equipment*, page 23.

The process-simulating computer's second program simulates the behavior of the process at the discretion of the programmer by accepting his card input and modifying the value table accordingly. Through it, the programmer enters changes of state of process interrupts, contact-closure inputs, and analog inputs into the value table. He may, for example, enter several different sets of inputs that operate the computer model of a steel-rolling process in several states other than the normal; this could include a test of all alarm or off-limit conditions by arbitrary setting of the inputs to simulate them.

The third program reports all input and output events initiated by the programmer and by the control computer. It prints the status of every simulated piece of equipment as it is changed and records the time.

Points and contacts can be referred to by their hardware addresses or by symbolic labels. Once the programmer defines symbolic labels, his input to the simulator and the printout from the simulator will be in terms of those symbols. This procedure saves large amounts of cross referencing from programming terms to hardware definitions and makes the card input and resultant printout more meaningful to the programmer.

Advantages of Digital Simulation

The digital simulation technique is far better than the previous methods of testing process-control programs because it has all of the basic requirements. The programmer has much more *control* over process conditions and over the sequence of events because he can vary the values of the inputs over their entire range, and in the order he desires, with simple card input. For *flexibility*, the programmer has access to all equipment in the system at all times; he can vary one input at a time without introducing any coupling or side effects that may change other inputs, and he can simulate normal and worst-case conditions at will. Digital simulation is *reliable* because it separates program testing from hardware testing. There is no doubt that only the program is at fault when a control program fails to operate as expected. Every event that takes place is automatically *documented* in one continuous printout report. Since all changes in inputs and outputs are recorded chronologically, correlation of input to output for verifying correct operation of the program is a simple task.

Another advantage is speed. Setting up the digital simulation of a system takes about a minute, since it consists only of loading the control computer with the control programs, which are stored on magnetic tape. No rewiring nor resetting of dials and switches is required. The simulation equipment is standard, no matter what control system is being simulated.

After the control programs have been loaded, a simulation run is accomplished by the reading of input cards provided by the programmer. The time between runs is short. Control program changes can also be entered by cards, followed by the input data for a run. Repeating runs with the same data while making corrections to the control programs is an efficient method of debugging; many detailed test cases can be run and duplicated in both the initial and final stages of debugging.

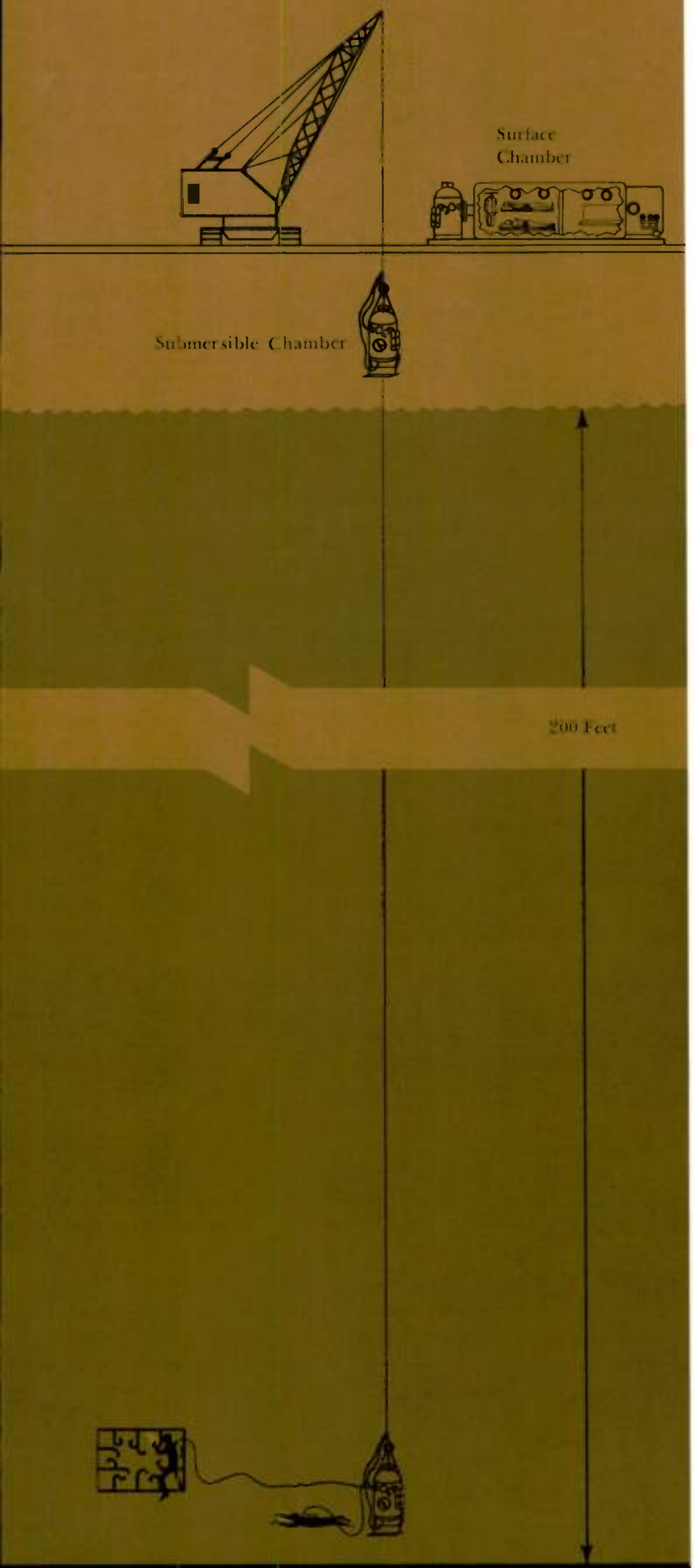
The control computer can be interrupted at any time by the process-simulating computer to permit a complete printout "snapshot" of the contents of memory in the control computer. Taking a snapshot of memory before and after a sequence of events is a most effective technique for diagnosing subtle problems in the control programs. Snapshots of the input-output equipment can be made at the same time, giving the complete state of the entire system at one instant of time.

Finally, the simulated events can be made to occur in exactly the same sequence and with the same timing in which they would happen in the actual process.

Conclusion

Digital simulation has reduced the problem of debugging process-control programs to nearly the same problem presented to the data-processing programmer. As in data-processing program debugging, the input to the process-control program is on punched cards and the output is from a high-speed printer. The only difference is that, in process-control debugging, a program in one computer first transforms the input data into simulated events in the process-control system. These simulated events are then presented to the control computer, the control computer responds to them by taking some action, and this action is immediately observed and logged by the process-simulating computer. The resulting printout is a simple cause-and-effect relationship of input to output data.

A process-control program can now be developed, debugged, and tested without any dependence on manufacture of the computer system hardware; what used to be largely a serial effort of manufacture followed by programming is now a parallel effort. Experience with systems debugged on the simulation facilities indicates that only a relatively short final testing on the actual process-control system is necessary. (This final testing makes sure that plant variables have been properly assigned to process inputs according to customer specifications.) Digital simulation has lowered system testing costs and enabled Westinghouse to provide thoroughly debugged control computer systems with shorter system delivery and installation times.



Divers live in the surface chamber at working-depth pressure while not working, and the submersible chamber transports them to and from the working depth.

Diving System Permits Longer, Deeper Dives

A new system of pressure chambers, controlled artificial atmosphere, and recirculation of the breathing mixture makes work at great depths safe and economically feasible.

Divers with conventional equipment, whether scuba or "hard-hat," have been unable to work long at any considerable depth before having to start slowly toward the surface to decompress. At 200 feet, for example, the time limit has been about 20 minutes. This severe limitation is the result of complex physiological effects of gases dissolved under pressure in the blood and tissues and of the cold below the surface. A new diving system, however, has enabled divers to work four hours a day easily at 200 feet, and experience gained with it indicates that divers probably could work eight hours a day at depths to 450 feet. The techniques used should ultimately permit divers to work at depths limited only by effects of pressure on the body. This is now considered to be more than 1000 feet and may be 1500 feet.

The diving system was developed by the Underseas Division of the Westinghouse Defense and Space Center. It was first used in the Smith Mountain Dam lake on the Roanoke River about 50 miles from Roanoke, Virginia, for repair work on the dam's outlet grates. (The repair work was done by a professional diving firm, Marine Contracting, Inc., as prime contractor on the project for the Appalachian Electric Power Company, which owns the dam and uses it for pumped storage for hydroelectric peaking service.) Successful use of the new system on this project has proved its feasibility for a wide range of applications, such as similar repair and inspection work on other deep-water dams, salvage and recovery in the ocean or in deep lakes, offshore oil production, ocean-floor mining, and deep-water research.

Called Cachalot (for the deep-diving sperm whale), the new diving system is the first commercial application of what had been an experimental technique—prolonged submergence using a mixture of gases for breathing. Divers live under working-depth pressure for a week at a time, continuously breathing the gas mixture required at that pressure. At the 200-foot working depth, this pressure is about 100 pounds per square inch, and the gas mixture consists of controlled amounts of helium, oxygen, and nitrogen. Most of the relatively expensive helium is reused.

System Operation

The Cachalot diving system consists of a submersible diving chamber, a surface chamber containing living quarters, and associated equipment necessary to support the operations. On the Smith Mountain Dam project, the surface chamber was located on top of the dam and the submersible chamber was lowered and raised to and from the working depth by a crane. (See sketch.) When brought to the surface, the submersible chamber is swung to its pad near the surface chamber. A hydraulic cylinder brings the chambers together, engaging their transfer locks, and the lock bolts are then put into place and tightened. The seal is airtight, so the divers can transfer to the surface chamber after the transfer lock is pressurized. Pressures in both the surface chamber and the submersible chamber are kept at the working-depth pressure at all times, except when divers are being decompressed.

Although the working depth on the Smith Mountain Dam project was 200 feet, the system is designed for depths up to 450 feet. For an extra margin of safety, the submersible chamber is built to withstand the pressure of more than 600 feet of water (over 300 pounds per square inch).

The surface chamber, including its transfer lock and access lock, is about 27 feet long and 7 feet in diameter. It has two inner chambers, each 10 feet long. This design is primarily a safety feature: pressure in the two inner chambers, the access lock, and the submersible chamber can be controlled independently, so any of several combinations of pressurization can be used if it should be necessary to decompress any of the divers while the others remain under pressure. The gas mixture and pressure inside the surface chamber are continuously monitored and controlled by a control unit developed by the life-support group of the Westinghouse division.

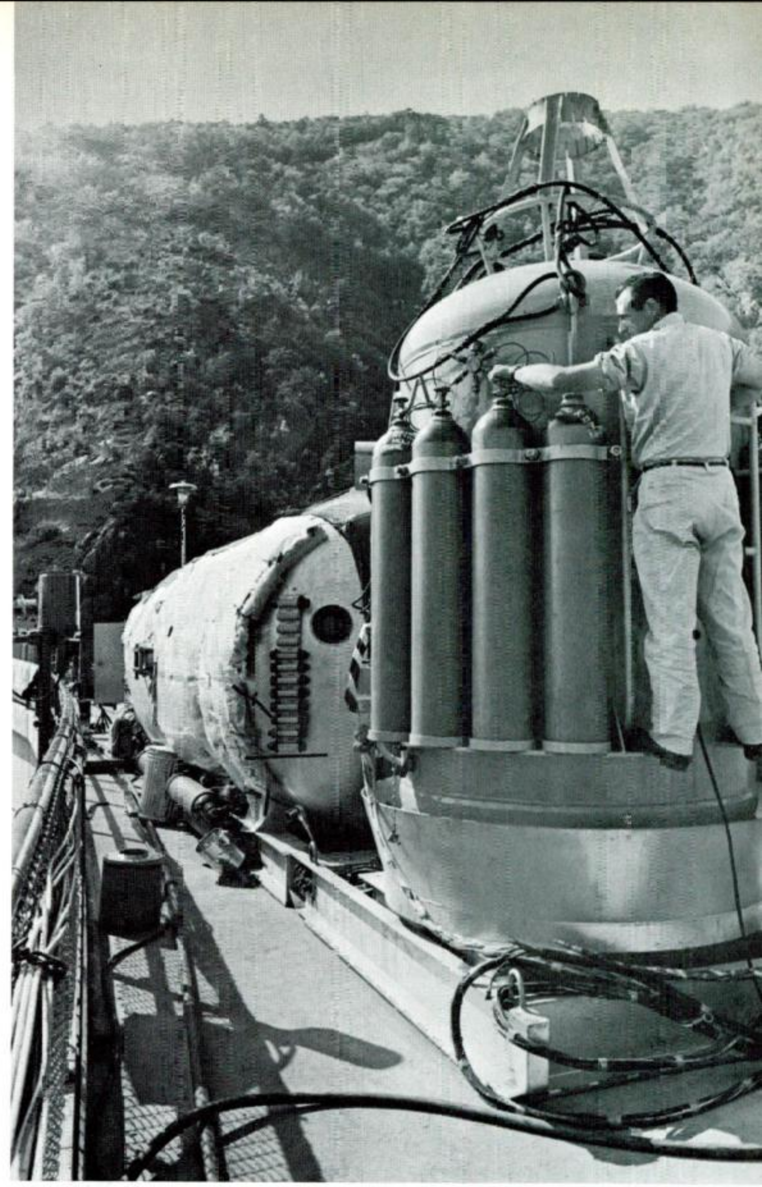
The submersible chamber is about nine feet in height and five feet in diameter. When the chamber reaches the working depth, pressure in it is adjusted to the point where it will keep water from entering. A hatch in the bottom is then opened, and the divers drop through the hatch into the water.

The controlled gas mixture for breathing is supplied to each diver by a unit called the hookah lung. Cylinders of the mixture are attached to the submersible chamber, and the gas flows from them into a manifold system and a pressure-reducing regulator before passing through a hose to the diver. The diver wears a full face mask for protection and under it a smaller mask for breathing. About 10 percent of the exhaled gas is discharged into the water, and the rest passes through a canister on the diver's back that removes carbon dioxide. The divers wear high-intensity electric lights.

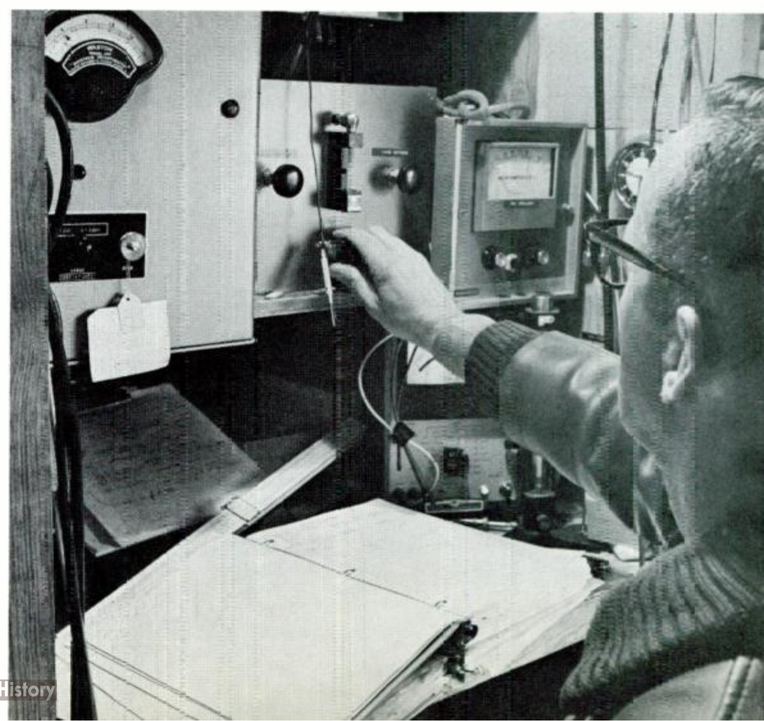
The special rubber diving suit used also was developed by the Division's life-support group. A hose from the submersible chamber circulates warm water through the suit, enabling the diver to work for hours in cold water.

Each diver is in telephone contact with the surface chamber and the support crew at all times, and his breathing-gas pressure and mixture are continuously monitored by an oxygen sensor in his diving suit. The unit warns surface support personnel if the amount of oxygen in the mixture varies beyond set limits, and the diver is then ordered back into the diving chamber.

The Cachalot diving system is one more step in the conquest of the earth's underwater regions. By extending the length of time divers can stay under water, and the depth to which they can go, it helps open vast new areas for work and exploration.



Submersible chamber is in foreground *(above)*, and surface chamber behind it. The breathing gas mixture is contained in the cylinders on the submersible chamber and is carried to the divers by lifelines. A control system *(below)* monitors and controls gas pressure and composition.



Advanced Control System for High-Speed Strip Mill

An on-line process-control computer system will control the largest and most modern continuous hot strip mill in the nation, a 13-stand line scheduled for operation in late 1967. The mill is being installed at the Middletown, Ohio, works of Armco Steel Corporation.

Steel strip will travel through the 13 stands at speeds ranging from 1700 to 4000 feet per minute. The mill will be capable of producing strip from slabs up to 33 feet long, 80 inches wide, 10 inches thick, and weighing 88,000 pounds. At the delivery end, strip thickness will range from 0.05 to 0.50 inch.

The Prodac 550 on-line computer control system will provide better product quality, higher production, better utilization of equipment and manpower, and lower operating costs than would otherwise be possible. Design and coordination of the project's control system and other electrical equipment is the responsibility of the Westinghouse Industrial Systems Division.

Laser Efficiency Increased

A recently developed technique has increased the efficiency of lasers made from neodymium glass by 50 percent and may eventually double present efficiencies. Such an increase in efficiency would raise the power in the brilliant coherent beam of light from a laser of given size and energy input by the same factor of two or more. The technique, called sensitization, depends on a change in the chemical composition of the laser glass.

The material composing a laser rod contains a small percentage of an impurity atom, and in glass lasers, the best impurity atom is the rare-earth element neodymium. Some of the neodymium ions are energized, or "pumped," to a higher energy state by the light from a flash tube. Then, a fraction of a second later, these ions return to their original condition of lower energy, and the pulse of excess energy they release is emitted from the end of the rod as a laser beam.

Sensitization is a method of getting more of the neodymium ions to absorb the available pumping energy. To do it, a second impurity ion is added to the glass; in the Westinghouse experiments, this added impurity is manganese. By themselves, the manganese ions will not "lase." Instead, they act as an energy transfer agent. They are pumped, by light from the flash tube that ordinarily is wasted, to higher energy along with the neodymium ions but, before the laser pulse occurs, they transfer their energy to additional neodymium ions. The result is a larger number of excited neodymium ions, which constitutes an increase in the efficiency of converting the pumping light into a useful laser beam.

The technique is so effective that laser output can be achieved from neodymium glass without directly pumping the neodymium ions at all. Instead, by pumping only the sensitizing manganese ions, the neodymium ions receive their total supply of energy secondhand through transfer from the manganese.

This selective pumping is done by using filters to select desired regions of the pumping light. Both the neodymium and the manganese ions can be pumped at the same time, or either one separately. The experimenters at the Westinghouse Research Laboratories found that pumping both ions at the same time gave a laser efficiency equal to the combined efficiencies obtained when each ion was pumped by itself. The amount of energy obtained through transfer from the manganese ions was roughly one-half that obtained by pumping the neodymium ions alone in conventional fashion.

Automation Comes to Workboats

Central engine-room control, developed for large ships, now has been applied to tugboats and towboats. The first automated tugboat went into service recently in New York harbor; its operators, Socony-Mobil Oil Company, expect its control equipment to pay for itself promptly in operational savings.

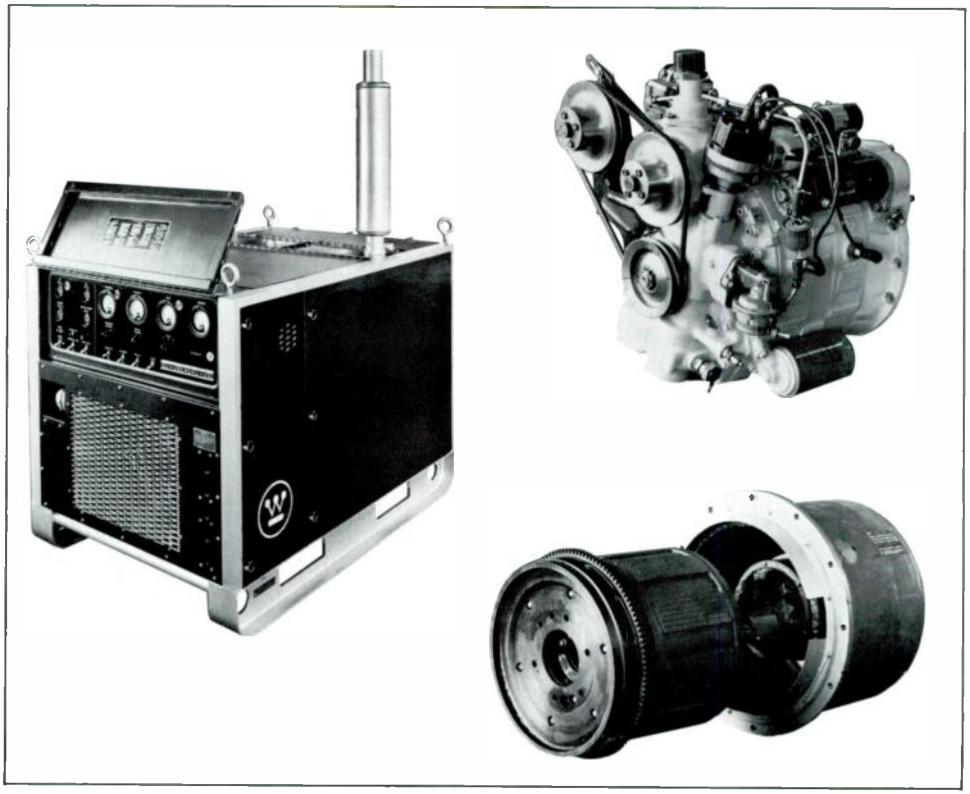
The main benefit in workboat automation is the efficiency gained from giving direct control of the engine room to the pilot house. Also important is the sensitivity of the controls and instrumentation, which improve reliability and safety because they can detect subtle trends that are beyond the "feel" of an operator and so might go unnoticed. Moreover, the system frees the workboat engineer from continuous duty in the engine room; an alarm sounds if the equipment being monitored requires the engineer's attention. The standardized controls and instruments applied also permit interchange of crews without loss in efficiency.

The workboat central engine-room control systems are designed and built by the Westinghouse Marine Division. Designs range from simple systems, consisting essentially of some engine-room indicators and electrical controls in the pilot house, to more comprehensive systems including a data logger to record performance for later analysis.

Portable Engine-Generator Set Based on New Type of Engine

The rotary combustion engine, a type of internal-combustion engine that has no pistons nor other reciprocating parts, has been put to practical use for the first time in this country in a portable engine-generator set. The set is a self-contained generating system built for fuel economy, maximum portability, superior electrical performance, high reliability, and ease of maintenance in military applications, and also for nonmilitary uses where a source of electric power is needed remote from power lines.

The rotary combustion engine, a descendent of the Wankel engine, was developed by Curtiss-Wright Corporation. It operates on the familiar Otto cycle like a four-stroke piston engine, but instead of pistons it has a triangular rotor that draws in a mixture of fuel and air, compresses the mixture between itself and the housing, transmits power to the shaft when the mixture is ignited, and sweeps out the combustion products. The engine was chosen because its characteristics are comparable, for this application, to the



Portable engine-generator set is smaller, lighter, and produces less vibration than a diesel-powered set of the same rating, and it consumes much less fuel than a comparable set powered by a gas turbine. It is powered by a rotary combustion engine and has an aircraft-type brushless generator.

best characteristics of conventional internal-combustion engines and gas turbines—the former's fuel efficiency and low cost, and the latter's small size, light weight, freedom from vibration, and durability in high-speed operation.

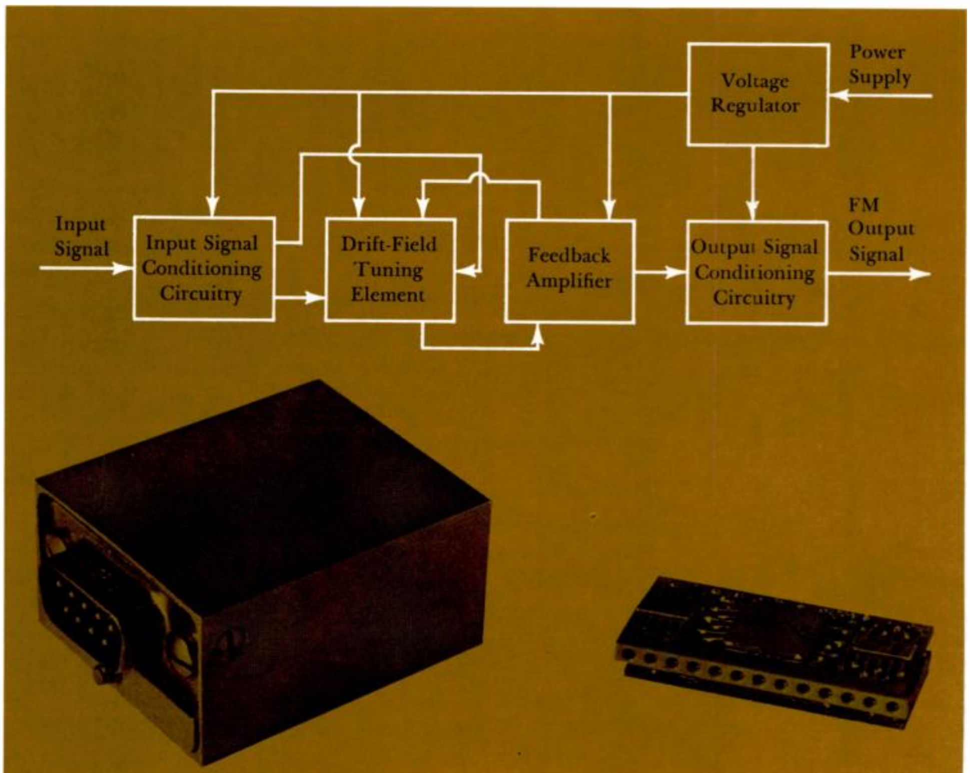
Approximate weight and fuel consumption of the rotary combustion engine-generator set, a diesel-generator set, and a gas-turbine-generator set of the same rating are compared in the following table:

Type of Unit	*Weight (lb)*	*Fuel Consumption (gal/hr)*
Rotary Combustion Engine	1080	9.5
Diesel Engine	4700	6.0
Gas Turbine	975	17.0

Future models of the rotary combustion engine-generator set are expected to weigh as much as 20 percent less.

The first unit produced by the Westinghouse Aerospace Electrical Division is a 60-kw 400-cycle set especially suited to applications in which close power and frequency tolerances are necessary. Its voltage rating can be changed in the field to supply either 120/208 volts or 240/416 volts. It is 34 inches wide, 37 inches high, and 49.5 inches long; its exhaust and muffler assembly folds down into the unit for transporting. The brushless generator and the power-conditioning circuits are derived directly from aircraft equipment that has proved itself in millions of hours of operation.

The new unit is the first in a family of engine-generator sets based on the rotary combustion engine; subsequent models are now being developed. The family is being designed to use common parts and assemblies as much as possible. In addition to easing maintenance, this feature will make possible the parallel operation of sets of the same frequency but different power and voltage ratings.



Maximum operating values for the set are: Voltage regulation, ±2 percent; voltage transients, ±15 percent (full load); voltage recovery time, 0.2 second; voltage modulation, ±0.25 percent; frequency regulation, ±0.25 percent; frequency transients, ±3 percent (full load); frequency recovery time, 1.0 second; frequency modulation, ±0.25 percent; 125-percent overload at 0.8 power factor, 5 minutes; 200-percent overload at 0.4 power factor, 5 seconds; short circuits, three per unit current for 5 seconds; sea-level temperature range, −65 degrees to +125 degrees F; maximum altitude and corresponding temperature, +95 degrees F at 10,000 feet.

Molecular-Electronic Telemetry Oscillators Developed

Telemetry oscillators that are more reliable, smaller, dissipate less power, and give better performance than others of their kind now in use have been developed and demonstrated. They were designed and built with integrated circuits primarily for use as frequency-modulated subcarrier oscillators for aerospace telemetry. They operate over the standard IRIG (Inter-Range Instrumentation Group) frequency bands and six additional high-frequency bands in the range of 95 kilocycles to 165 kilocycles.

In a frequency-modulation telemetry system, subcarrier oscillators convert analog signals from various sources to a corresponding frequency deviation. The outputs of several oscillators are then summed and applied to a transmitter for transmission. The oscillators built under this program were made possible through the development of a semiconductor drift-field delay element. This element, coupled with a feedback amplifier to form an oscillator, provides a linear relationship between the frequency of oscillation and the applied input voltage. The delay time, which sets the frequency, depends on the velocity of carriers injected into the semiconductor. The velocity is in turn directly related to the voltage applied across the drift-field element.

Each frequency-modulated subcarrier oscillator consists of a molecular drift-field tuning element and four universal linear molecular-electronic functional blocks. (See illustrations.) These four devices perform input signal conditioning, dc amplification, feedback ac amplification, output ac amplification, and voltage regulation.

The devices were fabricated by large-batch planar diffusion and passivation on silicon wafers. This uniform processing and the elimination of many wired interconnections both contribute to the high reliability of the oscillators.

The oscillators were built by the Aerospace Division of the Westinghouse Defense and Space Center under a contract from the Research and Technology Division of the U.S. Air Force Systems Command. The program was under the technical direction of the Communications Branch, Air Force Avionics Laboratory, Wright-Patterson Air Force Base.

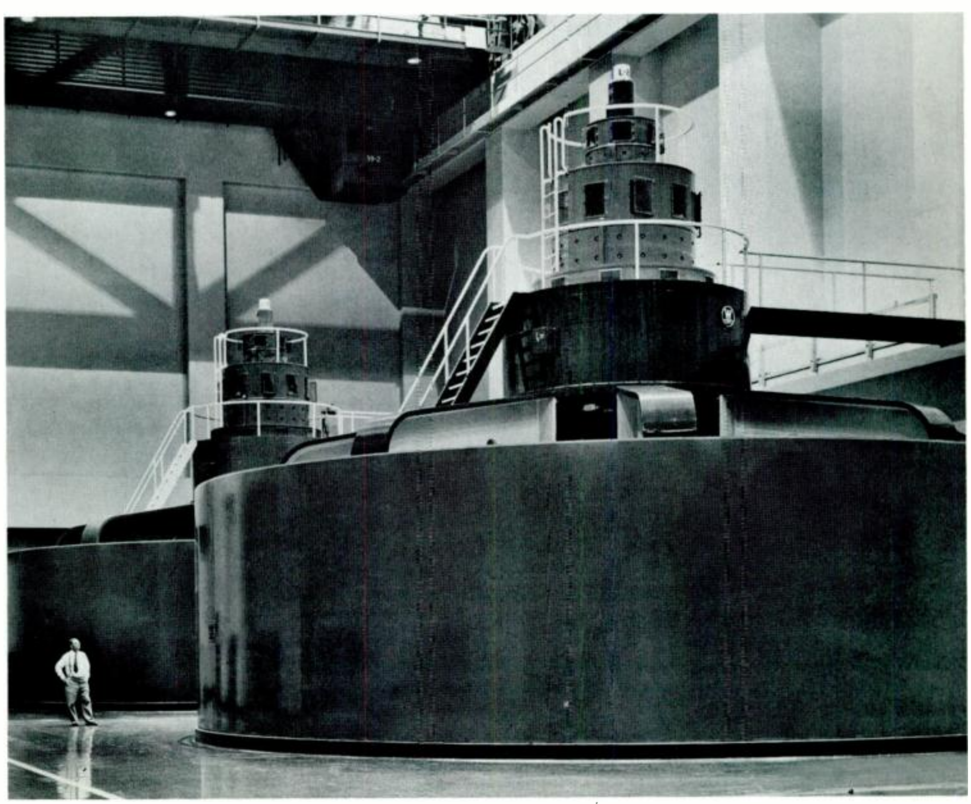
Molecular-electronic telemetry subcarrier oscillator is based on a drift-field tuning element and four other functional blocks. The oscillator, shown at right in the photograph in comparison with a conventional unit, is 0.19 cubic inch in volume, weighs 0.16 ounce, and dissipates 60 milliwatts or power—one-ninth the volume, one-fourteenth the weight, and one-third the power requirement of the conventional unit.

Rewinding Improves Grand Coulee Generator

The eighteen 108,000-kva waterwheel generators installed at Grand Coulee Dam between 1940 and 1951 constitute one of the largest hydro installations in the United States. These Westinghouse generators, in fact, provide much of the electrical energy for the northwestern part of the country.

Now the first of these generators has been rewound by Westinghouse for the U.S. Bureau of Reclamation. An im-

Generator at Grand Coulee Dam has been rewound with improved coils and Thermalastic insulation, increasing its rating from 108,000 to 125,000 kva.

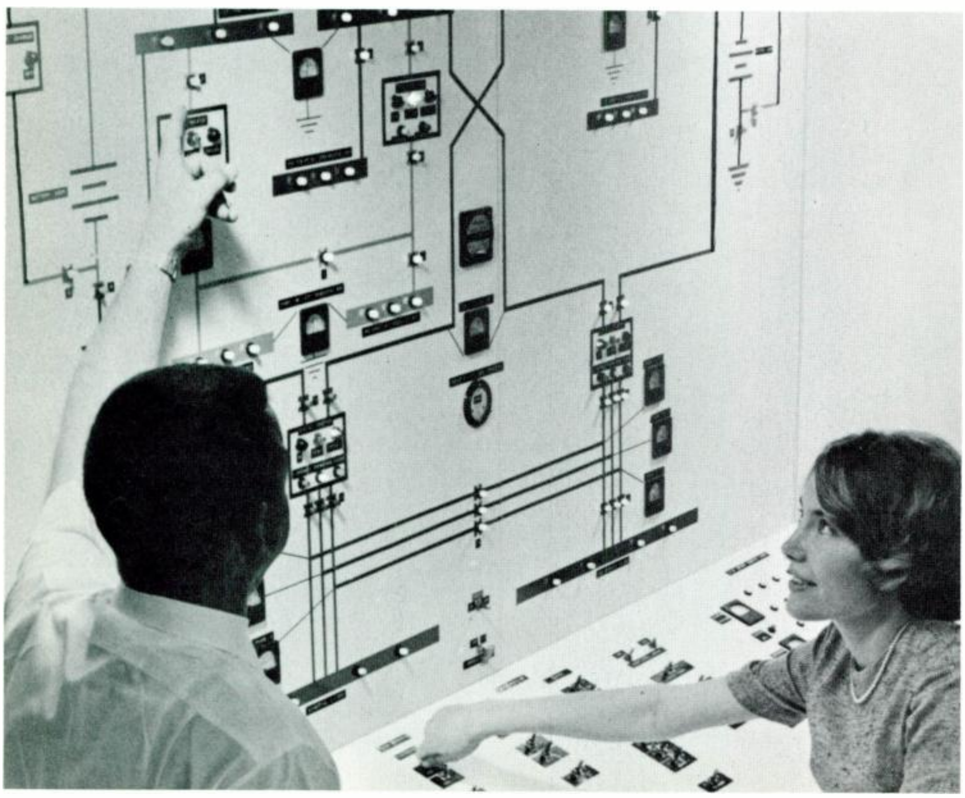


proved coil design and the new Thermalastic insulation were used, with consequent lower copper losses and improved insulation heat transfer. Rewinding increased the generator rating from 108,000 to 125,000 kva without any significant increase in operating temperature.

Simulator Helps in Design of Space Power Systems

Electric power-system components and design concepts for use in space vehicles are being tested in a simulator to assess their compatibility with each other and with the total system. The simulator enables engineers to test new design concepts with various types of inverters, regulators, and other space power system components of the present and future. It was developed and is used at the Westinghouse Aerospace Electrical Division.

Space electric power system simulator is used for compatibility testing of system design concepts and components.



Two adjustable power supplies provide dc inputs to simulate the electrical characteristics of such sources as solar cells and fuel cells. Outputs are regulated and unregulated 28-volt direct current and alternating current at 400 cycles (± 1 percent) and 115/200 volts (± 1 percent). The simulator displays the effects on the simulated system of the components being tested. It isolates abnormal conditions or bus faults automatically, and protection logic circuitry substitutes alternate components and paths. The complete condition of the system is continually displayed on the control console for analysis.

Heating System Proposed to Restore Radiation-Damaged Solar Cells

Space probes and artificial earth satellites (other than passive satellites) are useful only as long as they have electric power to communicate information. Their power usually is supplied by silicon solar cells, and, unfortunately, radiation damage to the cells limits their useful life. High-speed particles from solar flares, cosmic rays, and other sources can, within a few months, cause enough damage to cut power output almost in half.

However, radiation-damaged cells can be restored by heating them for a short time at a temperature of about 850 degrees F; the problem is how to perform this baking when the vehicle is in orbit or in deep space. Research workers at the Westinghouse Research Laboratories have proposed doing it with sunlight focused through a system of lenses. The lenses would scan the arrays of cells automatically on signal from earth, baking them just long enough and hot enough to repair the radiation damage.

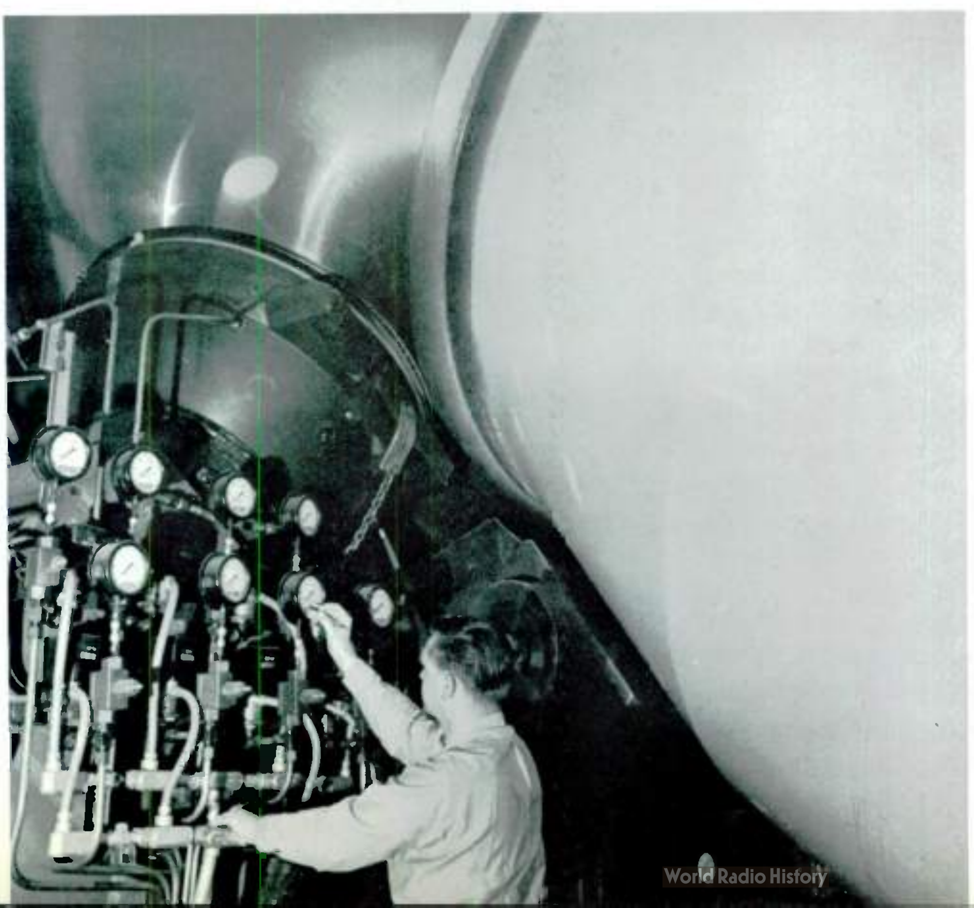
Experiments conducted with such a lens arrangement show that about two minutes of heating restores a damaged cell to almost 100 percent of its original output. Moreover, the heating cycle can be repeated several times. The experiments were made with a Fresnel lens, a type that can be made thinner and lighter than a conventional lens.

Huge Radio-Telescope Parts Float on Film of Oil

The large radio telescope recently completed at the National Radio Astronomy Observatory at Green Bank, West Virginia, is one of the most stable and precise in the world. It has to be, to meet its requirements of highly accurate determination of the positions of radio sources out in space and tracking of objects with great accuracy over long periods of time. A major factor in providing this accuracy and stability for the telescope's projected long service life is a 167-ton polished steel bearing.

The 2600 tons of steel and aluminum in the 140-foot dish and its supporting components are pivoted on this spherical bearing, which was machined and polished at the Westinghouse East Pittsburgh plant. A film of oil 0.005 inch thick sepa-

Large radio telescope (top) can be positioned with great precision because its moving parts "float" on a film of oil in a spherical bearing (bottom).



rates the bearing components to permit precise positioning of the dish without sticking.

The radio telescope is operated by Associated Universities, Inc., for the National Science Foundation. Engineering and design assistance in the construction project was by Stone and Webster Engineering Corporation, Boston, Massachusetts.

Products for Industry

Two larger-capacity dry-type distribution transformers, rated 250 kva (DS-3) and 750 kva (DT-3), 5000 volts and below, have been added to the Westinghouse line. Because dry-type transformers cannot explode nor release toxic gases, and because fire hazards are negligible, they are especially suited for hospitals, hotels, theaters, schools, factories, and other areas where large groups of people are present. Both units have Hipersil core construction for high efficiency and low sound levels. Terminals are at the bottom where cooling air is at ambient temperature, so oversize or high-temperature cables are not needed. Weather shields convert the units for outdoor service. *Westinghouse Distribution Transformer Division, Sharpsville Avenue, Sharon, Pennsylvania 16146.*

Super-Hi Output mercury-vapor lamp, designated the H33CD/79, provides 40 percent greater initial light output than standard clear mercury lamps and produces a cool blue-white light, without use of phosphor, that gives improved color rendition. It operates with present ballasts and fixtures. The new 400-watt lamp produces approximately 30,000 initial lumens, compared with 21,500 for earlier mercury lamps of the same wattage. *Westinghouse Lamp Division, MacArthur Avenue, Bloomfield, New Jersey 07003.*

Ultrasonic degreaser bombards parts with sound waves, knocking foreign particles off their surfaces. Contaminants are first washed away by a Freon emulsion in water, and the parts are then cold dried in a conventional Freon. Thus, particles that can be dissolved in a water solution (such as salts) and contaminants that must be dissolved by a solvent (such as shop oils) are removed in one cleaning unit instead of requiring two units as formerly. *Westinghouse Industrial Equipment Division, P.O. Box 416, Baltimore, Maryland 21203.*

Jet-pump motors (also suitable for centrifugal pumps and blowers) are available on 48 and 56 frame sizes, single-phase and polyphase (photo, top right). Ratings are 1/3 to 3 horsepower. Single-phase motors are for 115 or 115/230 volts, polyphase for 220/440 volts. Motors are of open-frame construction, but a totally enclosed front end bell protects starting mechanism from splashing water. *Westinghouse Small Motor Division, P.O. Box 566, Lima, Ohio 45801.*

Static dynamotor for dc to dc power conversion in trucks and other vehicles doubles a dc voltage input (center right). Standard model operates in the range of 3 to 14 volts (handles up to 15 volts input but limits the output to 28 volts). Units for other voltage ranges, either step-up or step-down, are available on special order. Warranty is 24 months or 24,000 miles. Typical application is converting the 12 volts of a standard truck tractor to a different voltage for electrical equipment in the trailer. The 28-volt 300-watt unit in its housing measures 5 by 5.3 by 5.8 inches and weighs less than five pounds. *Westinghouse Aerospace Electrical Division, Box 989, Lima, Ohio 45802.*

Small oil-filled potential equipment transformer provides either 120- or 240-volt output for operating automatic controls, oil switches, and switched capacitor banks (bottom right). The 84-pound unit can be used to supply low power continuously or high power for a short period. Intermittent thermal capacity is 5000 volt-amperes. A tapped secondary allows four styles of transformer to cover the full primary voltage range from 7200 volts to 16 kv for both secondary voltages. *Phoenix Repair Plant, Westinghouse Electric Corporation, 1825 East Jefferson Street, Phoenix, Arizona 85034.*

Services for Industry

Measuring a magnetic shield's attenuation ratio—the relationship between the field strengths on both sides of the shield—gives a direct measure of the shield's effectiveness and thereby aids in the design of shields for such applications as electronic tubes. This measurement is provided by the Westinghouse Materials Manufacturing Division, Blairsville, Pennsylvania 15717. The service enables designers to work to much closer tolerances than they otherwise could.

The testing equipment used has two Helmholtz coils four feet in diameter that generate a magnetic field of known magnitude about the shield; the field inside the magnetic shield is sensed by a pickup coil. Attenuation measurements are taken at various field strengths and with both ac and dc fields.

Chemical analysis of the gases present in a power transformer can often reveal whether or not an internal fault is present and, if so, what kind of fault it is. Such an analysis is offered as a service by the Westinghouse Power Transformer Division, Sharpsville Avenue, Sharon, Pennsylvania 16146.

Samples are taken from the gas spaces of transformers and, in addition, oil samples are taken. Gases dissolved in the oil are extracted and analyzed, a procedure that gives a full picture of gas generation in the transformer because it provides a secondary check on the gases and their possible source as well as a check on the oil condition.

New Literature

Solid-State Relaying for Transmission Lines (RPL 65-4) is a 31-page illustrated booklet describing blocking systems for pilot relaying, phase and ground distance line backup, and breaker protection. Two recent developments, the ground distance relay and the frequency-shift carrier set, are described fully. Copies available from *Westinghouse Relay-Instrument Division, Plane and Orange Streets, Newark, New Jersey 01701.*

About the Authors

Electric Utility Report Authors

About half of this issue is devoted to a special series of articles on electric utility subjects. The authors are executives of the Electric Utility Group; their experience is so extensive that it would be impossible to do full justice to their accomplishments on this page. Therefore, the following are simply thumbnail sketches of their backgrounds.

J. W. Simpson is Group Vice President of the Electric Utility Group and directs the engineering, manufacture, and marketing of basic electrical equipment for heavy industries. He is a graduate of the United States Naval Academy, and joined Westinghouse in 1937. Later, he earned an MSEE from the University of Pittsburgh in 1941.

The early part of his career, from 1938 to 1949, was spent in the Switchgear Division; during this period he was granted a two-year leave of absence to work at the Oak Ridge National Laboratory, from 1946 to 1948. In 1949, Simpson transferred to the Bettis Atomic Power Laboratory as assistant manager of engineering. He held successively more responsible positions at Bettis, was named Division Manager in 1955, and elected a Vice President in 1958. At the Bettis Laboratory, which is operated by Westinghouse for the Atomic Energy Commission, he was responsible for the development of nuclear reactors for naval propulsion and power generation.

From this assignment, he moved to Vice President and General Manager of the Atomic Power Divisions, which were involved in the development of commercial nuclear reactors as well as nuclear energy for space uses.

Simpson next became Vice President of Research and Engineering for the corporation, and in 1963 was appointed to his present position.

Lawrence E. Hedrick, Vice President and General Manager, Steam Divisions, joined the company's student training program in 1941 after attending Louisiana State University where he studied electrical engineering. After completing student training in Pittsburgh, he became a design engineer in the Atlanta manufacturing and repair plant. By 1951, Hedrick was manager of the Charlotte manufacturing and repair plant. He was appointed acting manager of the Hampton Micarta Division plant in 1954, and a year later was transferred to the Pacific Coast to become regional manager of the manufacturing and repair division.

Hedrick was appointed General Manager of the Sunnyvale Divisions in 1960 where he had major responsibility for the manufacture of the Polaris missile launching and handling equipment for the U.S. Navy.

In 1963, Hedrick was named General Manager of the Steam Divisions, and was elected a Vice President of the company that same year.

James M. Wallace, Vice President and General Manager, East Pittsburgh Divisions, joined Westinghouse in 1935 upon graduation from the University of Pittsburgh with a B.S. in Physics and Engineering. He spent 17 years in the East Pittsburgh Divisions, rising in 1950 to the position of department manager in the Switchgear Division.

In 1945, Wallace was named "the nation's outstanding young electrical engineer" by Eta Kappa Nu, honorary electrical engineering fraternity.

From 1952 to 1959, Wallace was manager of the company's Meter Division. He moved to Westinghouse headquarters in 1960 to become manager of the Manufacturing and Repair Division, and later was named General Manager of the Apparatus Service Divisions.

Wallace was appointed General Manager of the East Pittsburgh Divisions in 1963, and was elected Vice President in 1964.

John W. Stirling is Vice President and General Manager of the Transformer Divisions, and his responsibilities include both power and distribution transformers. Stirling is a graduate of the University of Pittsburgh, where he earned his BSEE in 1932. He joined Westinghouse on the graduate student course in 1933, and later was assigned to the Switchgear Division. After serving in various posts in both engineering and sales, he became manager of the Power Circuit Breaker Department in 1957. In 1961, he was made Deputy General Manager of the Electric Utility Group; in 1962 he assumed his present position, and was elected a Vice President shortly after.

A. J. Petzinger, General Manager of the Measurements Divisions, began his career in the measurements field as a design engineer, working primarily on watthour meters and demand meters.

He joined the company on the graduate student course in 1935 after graduation from Princeton University with BSE and EE degrees.

In 1952, Petzinger was made supervisory engineer of watthour meter design. From here, he rose rapidly through assignments of manager of the instrument engineering section in 1954, manager of the instrument department in 1955, manager of the Meter Division in 1959, to General Manager of the Measurements Divisions, his present position, in 1962.

Joseph C. Rengel, General Manager of the Atomic Power Division, has over eleven years experience in pressurized water reactor technology, dating back to 1954 at the Bettis Atomic Power Laboratory. In 1955, he became project manager for the PWR Project, where he directed for Westinghouse the design, development, and construction of the reactor portion of the Shippingport Station.

Rengel is a graduate of the U.S. Naval Academy (1937) and he joined Westinghouse the same year. He subsequently held positions in the Marine Department and in the Transportation Department, and in 1952 became assistant to the sales manager for the Defense Products Group.

After his assignments at the Bettis Laboratory, he moved to the Atomic Power Division in 1959, as project manager for the development of a large commercial nuclear power plant. In 1961 he was made manager of advanced development and planning, and in 1962 became Deputy General Manager of the Division. In 1964 he assumed his present position as General Manager.

Other Authors

Regis Herbst and **R. E. Hohmeyer** both have contributed to the development of a system for checking computer process-control programs with a digital computer, a system that they describe in this issue.

Herbst earned his BSEE at Carnegie Institute of Technology in 1957 and his MSEE the following year. He joined Westinghouse in 1958 as a systems analyst in the Advanced Systems Engineering and Analytical Department, where he worked on the solution of regulator and simulation problems with analog computers. He moved into the computer process-control area in 1959 and was responsible for the system programming and simulation for the Prodac IV application at the Sewaren generating plant of Public Service Electric and Gas Company, New Jersey. He joined the Computer Systems Division in 1962 and assumed his present position as manager, Simulation and Systems Programming, in 1963.

Hohmeyer graduated from the University of Michigan in 1961 with a BS in Science Engineering. He earned an MS in management sciences there in 1962 while working as a research assistant at the University of Michigan Research Institute. He joined the Westinghouse Computer Systems Division in 1962, where his major responsibilities were in the development of a time-and-space-sharing executive system for the Prodac 500 series computers and development of the digital simulation facility.

R. F. Woll is a Fellow Design Engineer in Medium AC Motor Development, Motor and Gearing Division, Buffalo. In this issue he completes his two-part description of the integral-horsepower ac motor rerate program; the first article appeared in the November 1965 issue.

Water Desalting: This working model of a flash evaporator demonstrates the principle of multistage flash evaporation in converting salt water to fresh water. For simplicity of construction and illustrative purposes, the three stages are made as separate units with a transparent condenser and flash compartment. The model operates on the same principles as the Westinghouse commercial desalting plants that supply fresh water to the Guantanamo naval base, Kuwait, and many industrial and electric-utility plants.