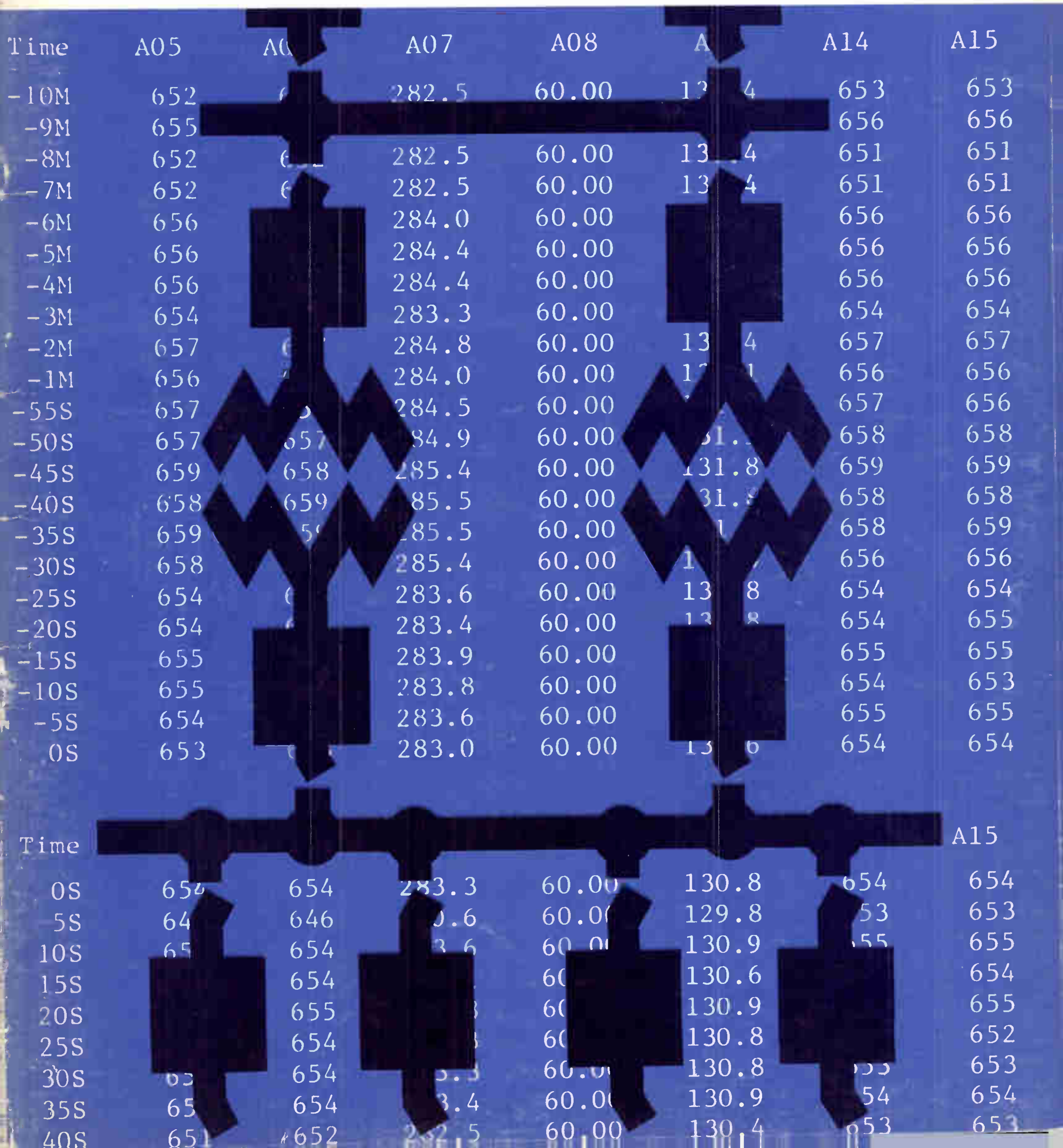
Westinghouse ENGINEER

May 1969



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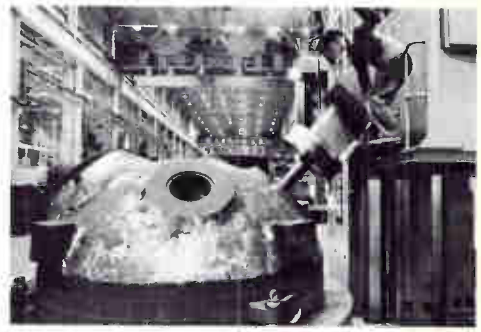

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Plant Capacity Increased for Steam Generators and Pressurizers

A new manufacturing facility has more than doubled Westinghouse Nuclear Energy Systems' plant capacity for production of the steam generators and pressurizers used in nuclear electric power plants. The increased capacity will help meet the electric utilities' needs both for more equipment and for larger sizes.

The plant is located at Tampa, Florida. It includes a factory building covering 236,000 square feet and a barge slip and dock area on Tampa Bay (*photos 1 and 2*). A typical steam generator made there is about 68 feet long by 14 feet in diameter, weighs about 330 tons, and has a capacity of more than 250,000 kW. *Photo 3* shows the massive outer shells being fabricated, and in *photo 4* a lower closure is being machined on a seven-axis tape-controlled boring and milling machine.

In the room at left in *photo 5*, shells are shot blasted to remove oxides and other foreign matter after stress relieving in the furnace at right. Welds are being X-rayed in *photo 6*. In *photo 7,* heat-exchange tubes are being welded to a tube sheet by an automatic tungsten inert-gas process. The crane in the final manufacturing aisle has an extension over the barge dock (*photo 8*) for loading finished equipment onto barges for delivery.

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Cover design: A symbolic combination of the elements of an electric utility distribution substation and the printout of a computer monitoring system illustrates the marriage of substations with central and satellite computers discussed in the article beginning on the next page. The design is by artist Tom Ruddy.

Multicomputer Approach to Reliable Power System Operation

P. E. Couture
J. C. Russell

Power system security can be improved by computer coordination of generation, transmission, and distribution. The most practical way to apply such control appears to be by use of a central computer communicating with many satellite computers.

Digital computers have amply proved their efficiency in many areas of power system operation: engineering computers are used to plan system growth, for example, data processing computers handle billing and inventory accounting, and process control computers are used in dispatching (load frequency control, economic dispatch, and optimum unit scheduling). Now many utilities are considering another step—computer control and coordination of generation, transmission, and distribution as a means of improving system security.

Such a use of the digital computer requires first a basic decision on the approach to take. Most complex computer control systems to date have been installed in environments where input data are within reach of the computer through signal wiring, as in power generating plants, rolling mills, and chemical processes; the power-system computer, however, must reach many miles for its signals, yet maintain tight electrical continuity and interaction between variables. Two approaches are possible.

The first is to bring the power system to the dispatching computer by telemetry and supervisory equipment. That approach would be limited by the speed of the data-collection and computer system, both in the time required to bring the information to the central location and in the computer size necessary to solve the complex problems (which may involve thousands of data pieces).

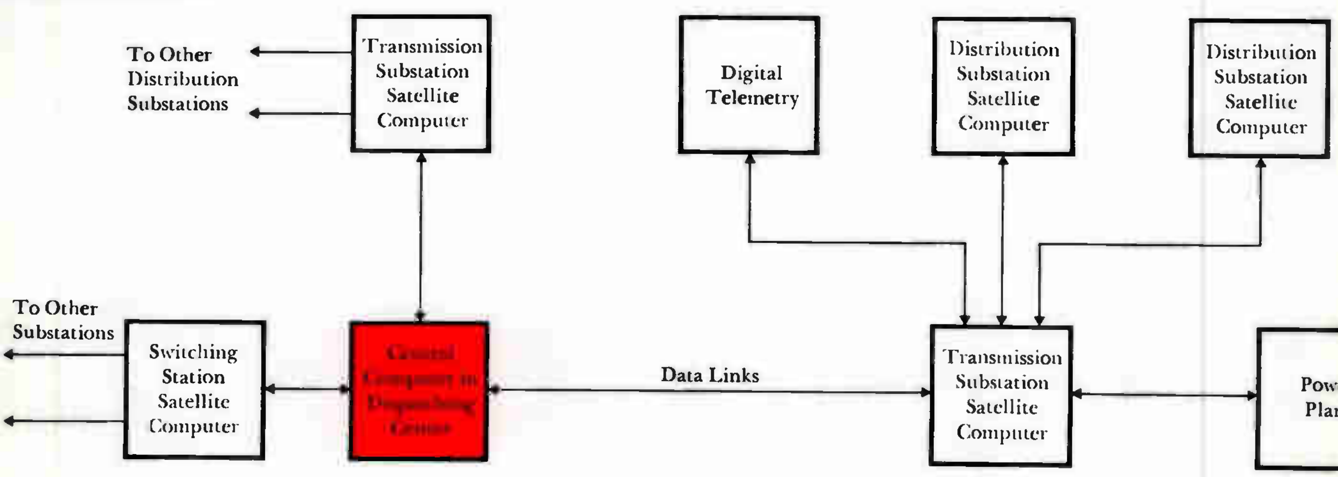
The second approach—the multicomputer approach—is to take the computer out to the power system by use of many smaller satellite computers (Fig. 1). Since power systems are rapidly increasing in both size and complexity, that approach seems the most practical and least costly way to achieve the necessary reliability. Computers are, by design, better adapted to mass production than wired logic systems, so their cost per function usually is lower. With smaller and smaller computers becoming available, they can economically take over many of the duties now performed by conventional equipment and, in addition, take on many more jobs. Their electrical and mechanical design are compatible with the limited space available in substation buildings. A further advantage of a multicomputer system is in its modular configuration: a utility can start with a modest size master computer and several satellites, then expand later into full system control.

First Installation

The first step toward multicomputer control of a power system has been taken by Pacific Gas & Electric Company, where eight Prodac 50 computers now monitor the operation of eight 500-kV substations (Fig. 2). Original justification of the PG&E system was the sequence-of-events recording it made possible. That is still its most important duty and receives the highest priority, although many other tasks have since been added, including data-logging, monitoring and alarming, kilowatthour computations, and post-disturbance review (Fig. 3).

The sequence-of-events program continually monitors approximately 200 contacts and notifies the substation operator of any change in their status. A computer printout records the exact time of any change and states whether it is an alarm or a return to normal operation. Every event is timed to the cycle in which

P. E. Couture and J. C. Russell are application engineers at Hagan/Computer Systems Division, Westinghouse Electric Corporation, Pittsburgh, Pennsylvania.



1—Multicomputer approach to electric power system operation decentralizes the control system by use of many satellite computers reporting to, and receiving instructions from, a central computer. Since the satellite computers collect and reduce data at the source, communications between the computers can be brief and fast for real-time operation. Such a control system can be readily expanded.

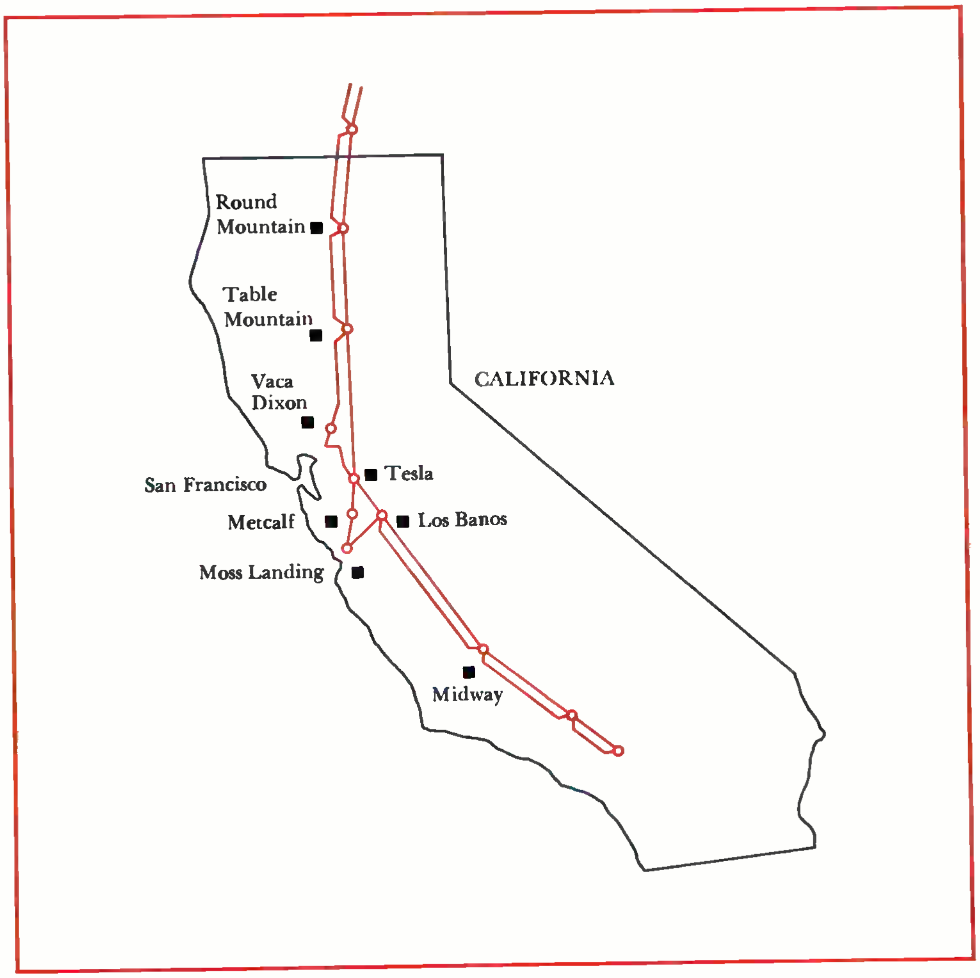
it occurred. Protective-relay and circuit-breaker contacts are connected to 70 high-speed contacts; messages printed out for those contacts are in order of their occurrence to a resolution of ¼ cycle (4 milliseconds).

Every five seconds, the computer also scans each of 56 points and converts the analog data received to digital information. (The analog data represent watts, vars, volts, amperes, and frequency.) Each analog quantity is then checked against preset high and low limits and an alarm message is given if the limits are exceeded. The message states the exact time of the occurrence, indicates whether the reading is high or low, and gives the value of the reading in engineering units.

The computer prints a sequence of events on occurrence and an hourly log that includes all analog inputs, a record of tie-line flows, and calculated values of megawatthours and transmission line losses. Accuracy of calculated values is within 0.25 percent of the signals received from transducers.

The post-disturbance analysis program provides a detailed record of system conditions immediately before and after any disturbance, evidenced by excessive frequency deviation or other criterion. The computer maintains two tables of 20 selected analog variables for the program. One is a historical record of each variable recorded every minute for a 10-minute period; the second is a record of the same variables recorded every five seconds for the most recent one-minute interval. The tables are continuously available.

If a system disturbance occurs, the tables are "frozen" and transferred immediately to auxiliary storage locations for later printout. The emptied tables continue to collect data every five seconds for the next minute and every minute for the next ten after the disturbance. Utility personnel thus get complete information on system conditions leading up to the disturbance and on the effects of each disturbance on total system operation. The program is not intended to be a fault recorder, since its fastest input speed is just five seconds; however, the program performs a function similar to that of 20 strip-chart recorders, and it



2—Pacific Gas & Electric Company's EHV intertie (*top*) has eight 500-kV substations, each monitored by a satellite computer. The system's central computer, located at the operation center, consolidates the substation monitoring and alarming and performs other supervisory tasks. Control room at one of the substations (*left*) has microwave antennae for transmission of data to and from the operation center and for other communication functions. In the control room (*right*), the substation operator reviews the computer output log.

a

SEQUENCE-OF-EVENTS RECORD

Time (hrs., min., sec., CPS)		Condition	
6:33:22:10	LINE A-B	LINE RELAY-C	ALM
6:33:22:11	LINE A-B	LINE RELAY-A	ALM
6:33:22:17	BRK #237	TRIP	ALM
6:33:22:18	BRK #497	TRIP	ALM
6:33:22:27	BRK #497	RECLOSE	ALM
6:33:22:35	BRK #497	TRIP	NRM

b

ANALOG ALARM PRINTOUT

Time	Point	Condition		
01:36	LINE C-D	A PHASE	ALM HI	870 AMP
01:39	LINE C-D	A PHASE	NORM	516 AMP
11:06	TRANSF. 12	SEC	ALM HI	241 KVOLTS

c

HOURLY LOG

Date	Time					
MAY 14, 1967	1:00P					
	MW	MVAR	IA	IB	IC	KV
LINE E-F	650	32	975	975	975	236
LINE G-H	1224	167	1026	1027	1026	496
TRANSF #96	402	68				238

LINE LOSSES	IN	3.7 MW		OUT	0.4 MW
MWH	IN	654	OUT		642

d

POST-DISTURBANCE REVIEW

DATE MAY 14, 1967 TIME 2:02 P

Time	A05	A06	A07	A08	A09	A14	A15
-10M	652	651	282.5	60.00	130.4	653	653
-9M	655	655	283.9	60.00	131.1	656	656
-8M	652	652	282.5	60.00	130.4	651	651
-7M	652	652	282.5	60.00	130.4	651	[illegible]
-6M	656	656	[illegible]	[illegible]			
-15S	655	655	283.9	60.00	131.0	655	655
-10S	655	655	283.8	60.00	131.0	654	653
-5S	654	654	283.6	60.00	130.9	655	655
0S	653	653	283.0	60.00	130.6	654	654

Time	A05	A06	A07	A08	A09	A14	A15
0S	654	654	283.3	60.00	130.8	654	654
5S	[illegible]	646	[illegible]	[illegible]	129.8	[illegible]	653

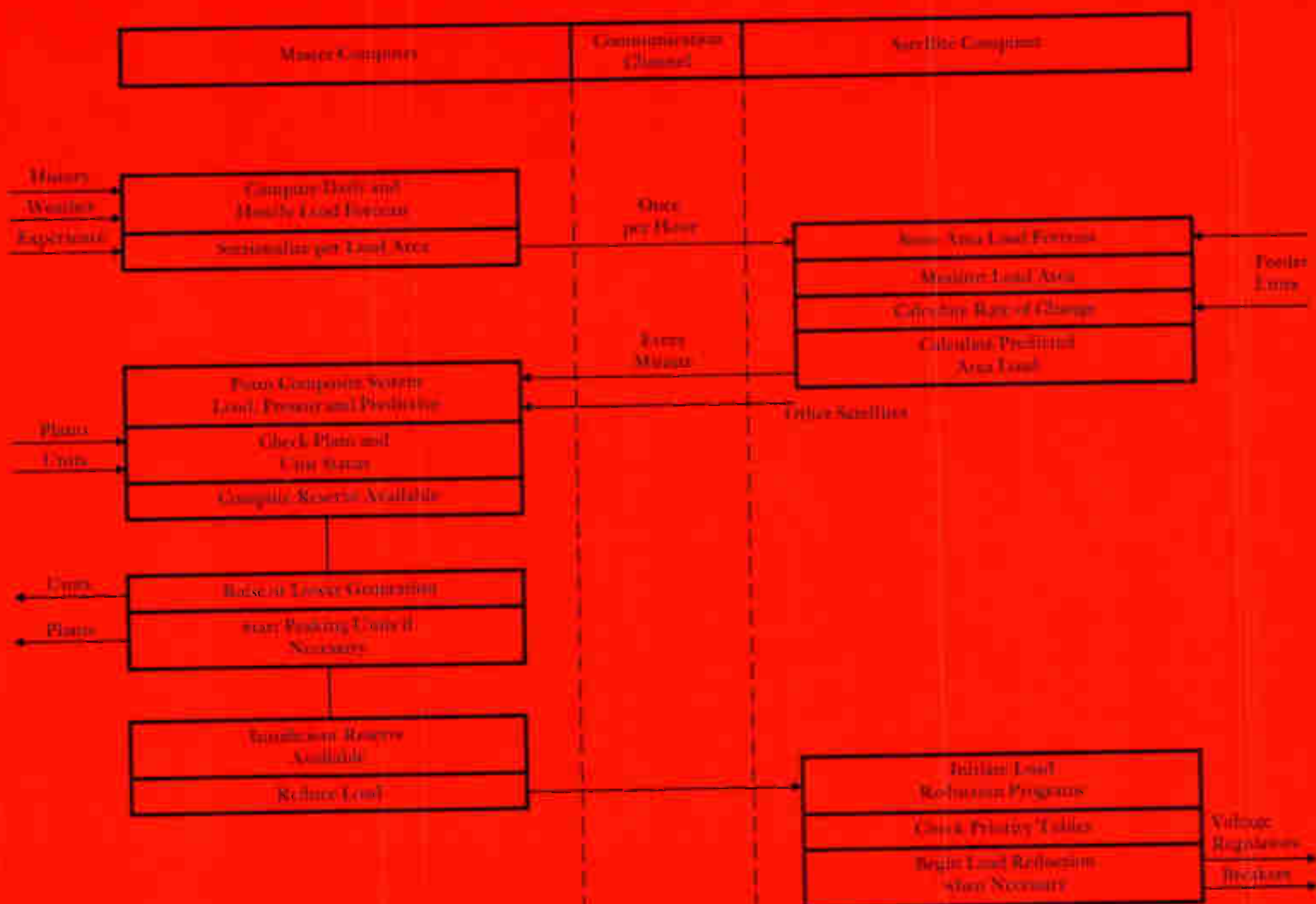
3—Computer printouts are illustrated by these typical samples: *(a)* sequence-of-events record, with every event timed to the cycle in which it occurred, *(b)* analog alarm printout, *(c)* hourly log, and *(d)* post-disturbance review, which records events for ten minutes before and after a system disturbance.

operates only when necessary and without the additional cost of installing and maintaining recorders.

At present, the eight PG&E substation computers are used not only to supply the substation operator with data on which to base operating decisions but also to report abnormal conditions to the system dispatchers. A ninth Prodac 50 computer, installed in the system operation center, consolidates the substation monitoring and alarming. Thus, any abnormal conditions, disturbance, or change in power system status is brought to the immediate attention of the system dispatchers as well as the substation operators. The central computer also performs the load frequency control, economic dispatch, and economy interchange functions and provides a substation hourly log on demand. The central and substation computers communicate with each other by two-way data links.

Now a more powerful computer, a Prodac 250 system, is being incorporated in the dispatching complex, and the Prodac 50 computer there will become a completely independent backup system. Many other dispatching functions will now be available. The operator's console has three high-speed cathode ray tubes for rapid information displays, for example, and the computer will continuously update a multicolor wall map showing the status of all EHV breakers.

Peripheral equipment such as a line printer, card reader, and card punch will provide extremely high-speed computer input and output and will permit the running of many study programs and program compilation in Fortran IV language. A complex scheduling program will be used to optimize the available sources of generating energy; it will consider hydro power, with available water storage and flows, on an economic basis against thermal generating units to



4—Predictive load control, diagrammed here, is one of the system operating improvements made possible by the multicomputer approach. Each satellite computer would collect local data, analyze it, and transmit predicted local load to the central master computer. The master computer would correlate the data from all substations, along with other information available, and determine what control action was necessary. The arrangement would reduce communication between central and satellite computers to a minimum.

arrive at the most economic combination that will meet the daily loads.

Additional Functions Considered

Because computers are extremely fast logical devices with stored program characteristics, they have already usurped many of the functions of conventional wired logic systems and will continue to do so. Similarly, the multicomputer systems will undoubtedly take over some of the functions now done with relay-type equipment. Some additional functions being considered in the industry are:

Breaker Reclosing—When any breaker trips, the substation computer can check all contacts and, after a suitable time delay, make one or more attempts at reclosing. All steps of the operation and the results would be recorded on the log.

Breaker or Switch Failure Sensing—The substation computer can sense the failure of contacts that should trip a breaker. After a suitable time delay, it can then make certain the breaker did trip. Should the breaker fail to trip, the computer can trip the next breaker in line or cause some remote breakers to trip to safeguard the equipment.

Sectionalizing or Load Distribution—After a failure or outage, the substation computer can be used to rearrange electrical distribution to maintain or reinstate critical loads.

Load Reduction or Optimization—The substation computer can be used to sense system approach to peak load capacity and begin to drop nonessential loads selectively. The computer's fast reaction could be useful in keeping total demand within system capacity under emergency conditions or when power sources or tielines are lost.

Voltage and VAR Control—By sensing voltages and by controlling capacitor banks, reactors, or transformer tap changers, the substation computer can regulate line voltage or reactive power level at desired values.

Backup Relaying—Although it may not be practical to rely on the substation computer for normal protective relaying functions, it can monitor the performance of conventional protective devices and initiate emergency procedures in case of relay or breaker failure.

Load Survey Computations—The substation computer can calculate the value of watts, vars, volts, and amperes for any period of time to arrive at integrated demand. It can determine and print out the maximums of these values for different time intervals (5 minutes, 30 minutes, 1 hour), as well as retaining the peak instantaneous values of any quantity for load survey engineering. It can check phase balance, power factor, bank loading, temperatures, and voltage variations and retain the extremes of all those conditions.

System-Wide Central Control Possible

Since the computer is a stored memory device, all of the functions just discussed can be coordinated from a central location as shown in Fig. 1. A large central or master computer is connected via data links to small satellite computers in transmission substations and major distribution substations. Those computers, in turn, can be linked to even smaller computers in the distribution substations. The system would then be integrated both in terms of its electrical equipment and in terms of its control equipment.

Data collection and reduction is thus performed at its source. Only results need be transmitted to the master location, and that need not be done continuously but only when information is needed. The condensation of raw data keeps down the burden on communication equipment, so transit delays in data transmission do not limit real-time operation.

The master computer, knowing entire system conditions, directs local action by transmitting changes in control parameters or restructuring the decision programs. Control action, when it is needed, still occurs at the local level, in effect preprogrammed by the central computer or operators.

An example of the improvement possible in system operation with this multicomputer configuration is in the load control area (Fig. 4). Instead of just correcting for frequency error to match generation with load, another important control parameter could be added: predispatching or predictive load control. The master computer would establish a daily load forecast for determining the generating unit schedule. The forecast would incorporate many conditions based on past experience, predicted weather, and other factors; it would be updated hourly or on any selected periodic basis from known system conditions. Sectionalized portions of load requirements would be transmitted to each satellite computer.

The satellite computer would continually monitor load conditions from sensors on line or feeder circuits. By analyzing load change, calculating rate of change, and incorporating the stored load forecast, it could determine an anticipated load level for its area, both for the next few minutes and for longer time periods. It would transmit the present load requirement and the predicted load to the master computer.

The master computer would form a composite picture of present and future loads from information telemetered from all satellite locations. Knowing generation plant status, spinning reserve, and interconnection reserve, the master computer could determine what control action was necessary. It could then begin moving thermal units, signal peaking units to come on line, and prepare other units, such as hydro plants, to start up in anticipation of increased load.

This approach reduces the dialogue between master and remote to a minimum, as shown in Fig. 4. Even without central communication, many functions are still possible. Since the remote computer is monitoring incoming lines and power transformers at the substation, it can make logical decisions if one of those is lost. Knowing load conditions, it can decide whether the remaining equipment can safely carry the load or load shedding on a priority basis must be started. It can rearrange the substation configuration to restore load service when that is possible.

In summary, the installation of substation computer systems may be first justified by the demands of local conditions, but the result will be improved operation of the entire system.

Aircraft Generator Weight Reduced by More Effective Cooling

R. L. Gasperetti

Besides great weight reduction, spray oil cooling in the new Integrated Drive Generator System will enhance reliability and lengthen overhaul intervals.

The design goal in aircraft generator cooling as recently as the 1950's was to limit insulation temperatures to levels that would permit a life of 1000 hours at maximum continuous rating. Now, however, a new 60-kVA brushless ac generator has been developed for an insulation design life of 12,000 hours at maximum continuous rating (equivalent to about 25,000 hours of normal service). Moreover, the new generator's ratio of weight to kVA output is dramatically lower and its reliability dramatically higher than those of even the latest generators now in use.

The reason for the increase in life and capability is partly in the better insulation materials now available but mainly in a new cooling method. The generator, developed for the new Integrated Drive Generator System (IDG), is cooled by oil brought into intimate contact with the sources of heat (chiefly the conductors, iron, and bearings).

Evolution of Generator Cooling

Air cooling, the first method used for aircraft generators, brings the coolant into intimate contact with the heat sources, but it has severe limitations. Air has low specific heat, and it also has low density and therefore a low heat-transfer coefficient; both factors result in a high temperature differential between coolant and heat sources. Moreover, in supersonic aircraft the ram effect (compression of air in the cooling-air intake) produces such high inlet air temperatures that air cooling is impractical.

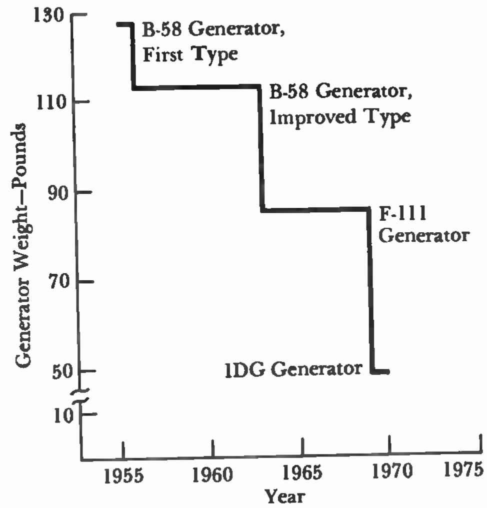
That last limitation, high ram air temperature, required development of environment-free cooling when the first supersonic aircraft were being built. Westinghouse pioneered in the field in the early 1950's by applying, for the B-58 aircraft, engine fuel as a heat sink and oil as the transfer medium. The generators were cooled by circulating oil through passages to carry their heat to heat exchangers, where it was transferred to the fuel (or to the air at low aircraft speeds). Oil was selected for the coolant because it was readily available from the constant-speed drive (a mechanical drive commonly used to provide constant generator speed, and thus constant ac frequency, from the varying aircraft engine speed). Those first practical oil-cooled aircraft generator systems are still in service on B-58 aircraft.

The B-58 generator system also was the first with intimate coupling between generator and constant-speed drive for space and weight saving. Connected to the drive by oil-lubricated splines, the generator and the drive share one bearing and have a common oil supply and sump. The drive and generator package was developed mutually by Westinghouse and the constant-speed drive manufacturer, Sundstrand Aviation, a division of Sundstrand Corporation.

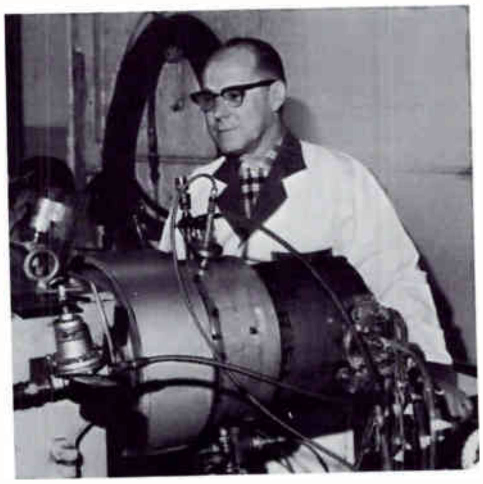
The B-58 generator operates at 8000 r/min and is continuously rated at 40 kVA with 4 to 5 gal/min of cooling oil at maximum inlet temperature of 150 degrees C. Design life is 1000 hours, with insulation temperature and rotating oil-seal wear the limiting factors. (The oil seal was needed to keep the drive's oil out of the generator cavity, because the generator insulations used at that time would contaminate the oil.) The generator weighs 90 pounds; uprated to 60 kVA for comparison purposes, it would weigh 127 pounds, or just over 2 pounds per kVA (Fig. 1).

The most advanced system in operation today is the Westinghouse 60-kVA generator in the F-111 aircraft, which weighs 85 pounds (1.4 pounds per kVA). It is essentially the same as the B-58 generator except for having Westinghouse Hiperco 27 magnetic steel instead of high-silicon steel, and a thermosetting insulation system of polyimide enamel with a diphenyl-oxide resin impregnating varnish instead of teflon-treated glass fiber insulation with no varnish impregnation.

In those conduction-oil-cooled generators, coolant temperature rise is low (10

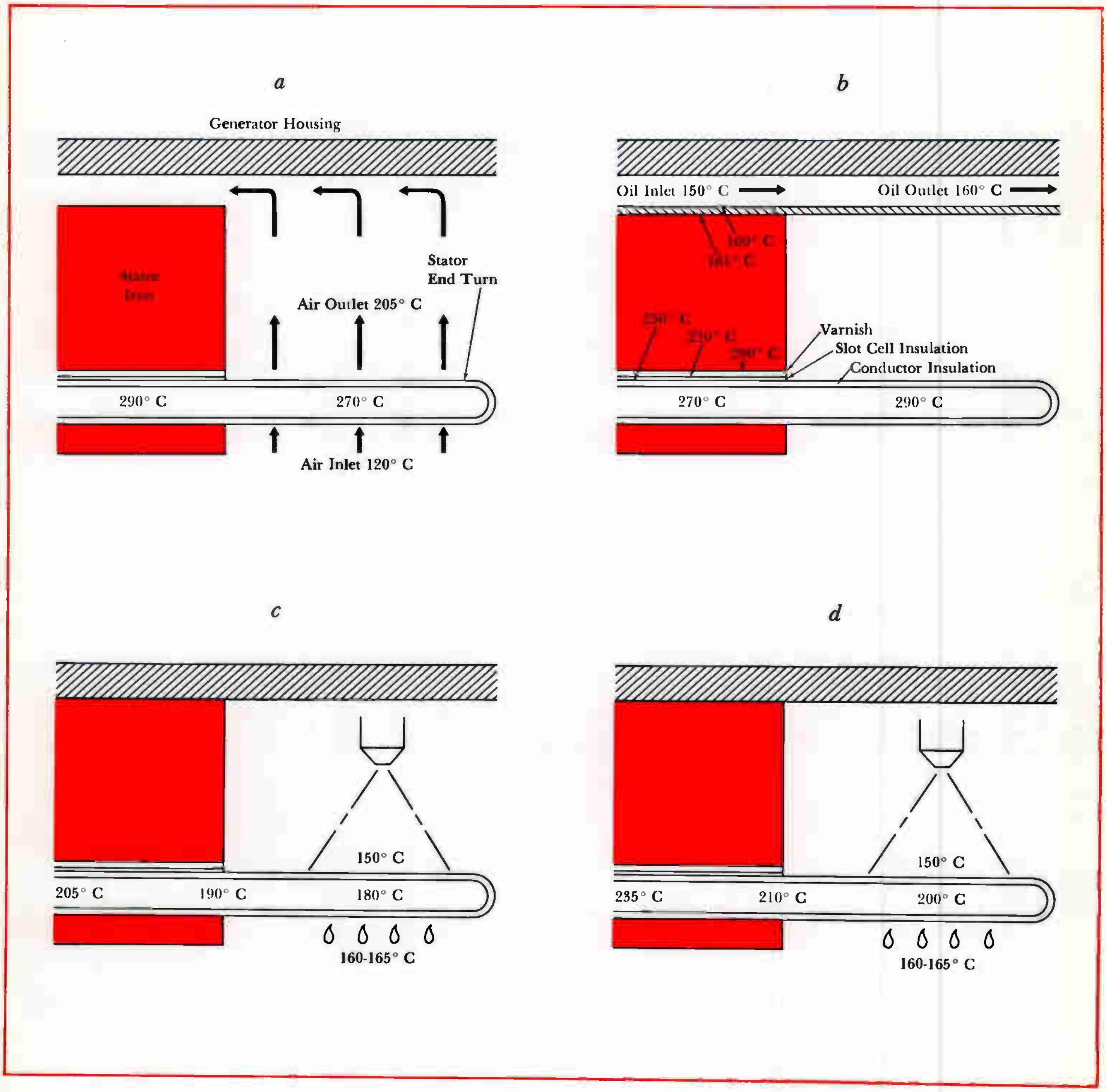


1—Brushless ac generators for aircraft have steadily decreased in weight with the development of better materials, better designs, and, in the IDG machine, dramatically better cooling by use of oil spray. The F-111 generator and the IDG generator are 60-kVA units; the B-58 generator is rated at 40 kVA, but for comparison purposes it is uprated here to 60 kVA. Cooling oil flow for the comparison is 4 to 5 gal/min, and oil inlet temperature is 150 degrees C.



Brushless ac aircraft generator for the Integrated Drive Generator System (IDG) was photographed while being run on a test stand in the engineering development laboratory. Performance exceeded specified requirements, and spray oil cooling was so effective that insulation design life was calculated at about 25,000 hours of normal service. As a result of the tests, a more advanced IDG generator will be manufactured.

R. L. Gasperetti is Manager, Generator Systems Section, Aerospace Power Systems Department, Aerospace Electrical Division, Westinghouse Electric Corporation, Lima, Ohio.



2—Conductor temperature determines the insulation life of a generator. Air cooling (*a*) brings coolant into direct contact with windings, but it is limited in effectiveness because of air's relatively low specific heat, low heat-transfer coefficient, and the limited mass flow rate available. Conduction cooling with oil forced through passages in the generator (*b*) provides better heat transfer, but it is limited by the necessity to conduct heat across electrical insulating materials, which are also thermal insulators. Spray oil cooling (*c*) combines the best features of both methods to such effect that, even with high current density (*d*), conductor temperature remains low enough for long insulation life. Use of high current density in the IDG generator is the main factor in size and weight reduction.

to 15 degrees C) compared with that for air cooling (75 to 85 degrees C) because the specific heat of oil is more than twice that of air and because of the greater mass flow rate available. Equally significant is the much higher heat-transfer coefficient between the oil and the wall of the coolant passage, making the temperature differential across the oil film only 10 degrees C. Moreover, the designers tried to maximize cooling efficiency by keeping the thermal conductive path short and making it of the best heat conducting materials feasible.

However, electrical insulations unavoidably form part of the thermal conductive path, and they are also *thermal* insulators. Therefore, the total temperature differential in the conductive path is high, so again (as in air cooling) the conductor temperature and its effect on insulation life is the limiting design factor (Fig. 2, *a* and *b*).

The new IDG concept combines the best cooling features of the two previous methods. Coolant oil is sprayed on windings and other parts to bring the coolant into direct contact with the sources of heat (as in air cooling), and the oil's good heat capacity and heat transfer capability result in low temperature rise between coolant and heat source. Thus, the concept is valuable for all applications where constant-speed drives are required —not just for supersonic aircraft.

A typical spray-cooling temperature distribution for what can be considered normal current densities is shown in Fig. 2c. The cooling is so much better that conductor temperature is no longer the limiting design factor; instead, the temperature at which the oil would deteriorate is the prime consideration. Present synthetic oil can withstand average winding temperature of 240 degrees C, so, obviously, higher stator wire current densities than the normal values of Fig. 2c can be used. Representative temperature distributions with high current density are shown in Fig. 2d.

High current density is used in the IDG generator to reduce generator size and weight. Even so, winding temperature is much lower than in air-cooled or conduction-oil-cooled generators that have

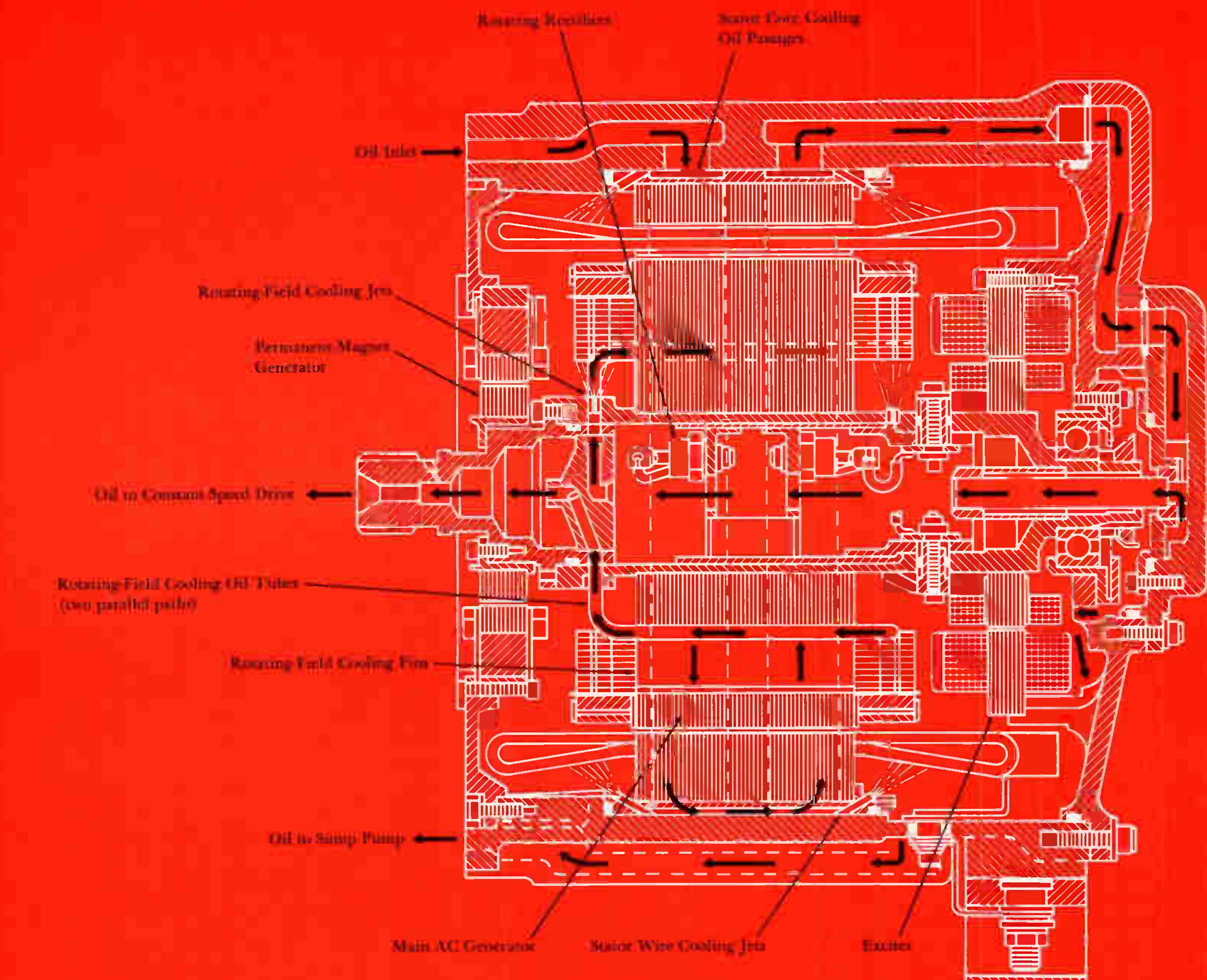
Table I. Comparison of F-111 and IDG Generators

Main Features	*F-111*	*IDG*
System Rating	60/68 kVA, 115/200 V, 3 phase, 400 Hz	60/90 kVA, 115/200 V, 3 phase, 400 Hz
Operating Speed	8000 r/min	12,000 r/min
Weight	85 lb	48 lb
Maximum Continuous Rating (with 150-degree-C oil inlet temperature)	60 kVA	90 kVA
Insulation Design Life at Maximum Continuous Rating	1900 hr	12,000 hr
Electrical Performance Specification	MIL-G-21480	MIL-G-21480
Magnetic Material	Hiperco 27	Hiperco 50
Number of Rotating Seals	1	0
Inherent Mean Time Between Failures (MTBF) (calculated)	13,000 hr	19,200 hr
Achieved MTBF (calculated)	10,000 hr	15,000 hr
Time Between Overhauls	3000 hr	On condition*

*Generator contains no parts with predictable wearout.

Table II. Main Design Requirements for Demonstration IDG Generator

Rated Speed	12,000 ± 120 r/min
Rated Frequency	400 ± 4 Hz
Rated Voltage (3 phase wye connected)	120/208 V
Rated Current	174 A
Rated Power Factor	0.75 lagging to 0.95 leading
Overloads	75 kVA for 10 min 90 kVA for 5 min 120 kVA for 15 sec
Fault Capacity (3 phase, L-N, L-L, L-L-N)	3 PU current min for 12 sec
Phase Balance	4% voltage unbalance with 2/3 single phase current unbalance
Wave Form	Distortion factor 3.5% max Single harmonic 2.5% max
Rotation	CCW viewed from drive end
Overspeed	14,000 r/min for 5 min 15,000 r/min containment
Efficiency	84.8% at full load, 0.75 PF 89.9% at full load, 1.0 PF
Oil Inlet Temperature	150 degrees C
Oil Inlet Pressure	240 psi above case pressure (1000 psi above case pressure during starting)
Oil Flow Rate	4 to 5 gal/min



3—Sectioned view shows how demonstration IDG generator is cooled both by oil spray and by oil flow through passages. Testing revealed the spray cooling to be so effective that most of the conduction-cooling passages can be omitted. The generator couples directly to a constant-speed drive.

lower current density. In the latter, such as the F-111 generator, the average winding temperature of 280 degrees C limits generator life to 1900 hours when operated continuously at full rated load. The IDG generator winding temperature is limited (by oil coking) to 240 degrees C, a temperature at which insulation life is 12,000 hours at full rated load.

Increasing the current density to take advantage of the better cooling diminishes the fault capacity of the generator somewhat. However, it still meets the requirements of the governing military specification (MIL-G-21480) for minimum fault capacity of three per unit for five seconds. Time to failure in a generator is a function of the current density in the copper and also of the mass of the copper, since much of the heat generated in a fault must be stored in the copper.

IDG Generator

Design and performance features of a 60-kVA Westinghouse IDG generator built for demonstration are compared with those of the F-111 generator in Table 1. The IDG generator weighs only about 48 pounds, or 0.8 pound per kVA. Like the B-58 and F-111 generators before it, it is the result of close design cooperation between Westinghouse and Sundstrand Aviation.

Essentially, the generator's low weight was achieved by use of oil-resistant insulation, greater current density made possible by spray oil cooling, improved magnetic materials, and higher operating speed. The greater reliability and longer service life were achieved by operating the windings at lower maximum temperature, by making the generator cavity integral with the drive housing and thus eliminating the need for a rotating seal between them, and by employing drive oil for generous lubrication of generator drive splines and bearings.

More specifically, the 43-percent weight reduction (from the F-111 generator) stems from the following design and material changes:

1) Use of Westinghouse Hiperco 50 magnetic steel provides higher flux density at lower excitation, so the volume of iron can be reduced and hence less copper and structure are required. This factor accounts for about 12 percent of the weight reduction.

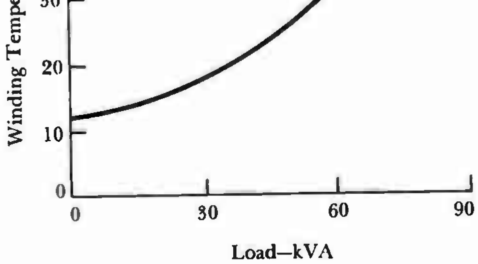
2) The speed increase from 8000 to 12,000 r/min reduces weight in two ways. First, the weights of the exciter and permanent-magnet generator are reduced by allowing frequency to increase with speed. Second, the rotor configuration for a four-pole 12,000-r/min generator has 33 percent more volume for copper than does a configuration with six poles at 8000 r/min; with ample rotor cooling provided, a smaller rotor diameter can be used. Speed increase thus accounts for about 13 percent of the weight reduction.

3) The improved removal of losses achieved by spraying oil directly on the windings and other generator parts permits current density to be increased by decreasing wire size. Both copper and structural weight are reduced as a result, accounting for about 18 percent of the weight reduction.

The IDG concept extends the evolution of environment-free rotating equipment by making the generator cavity and drive sump a single cavity and letting the generator run with its housing flooded with oil spray and mist (Fig 3). The demonstration IDG generator was designed to a Sundstrand specification, the basic requirements of which are listed in Table II. Testing has demonstrated that the generator meets or exceeds all of the requirements.

In fact, the test cooling data indicate that the generator can carry 90 kVA continuously with an insulation life of more than 25,000 hours (Fig. 4). However, electromagnetically the generator is a 60-kVA design, so its true rating is 60/90 kVA. It was designed with redundant conduction-cooling passages to provide latitude for optimizing such factors as flow rates, nozzle openings, and relative amounts of spray and conduction cooling. Tests have shown that most of the conduction cooling paths can be eliminated and still have satisfactory cooling.

Cooling oil enters the housing at the mounting face (Fig. 3). About 60 percent of the oil is sprayed on the ac stator end turns from nozzles in the stator conductive cooling circuit. The remainder is routed into the hollow shaft, where the rectifiers are located. Some is sprayed out through nozzles onto the rotating field end turns, and some is conducted through finned oil tubes to conduction-cool the rotating field windings. What remains returns through the shaft to lubricate the drive parts. The oil in the generator housing is extracted by sump pumps in the drive assisted by pressurizing air provided by the drive.



4—Cooling test results with a demonstration generator show that winding temperature rise (above oil inlet temperature) is low enough for the generator to carry 90 kVA continuously. Oil flow was 4.5 gal/min at inlet temperature of 150 degrees C; the winding temperature shown is stabilized maximum.

Continuing Development

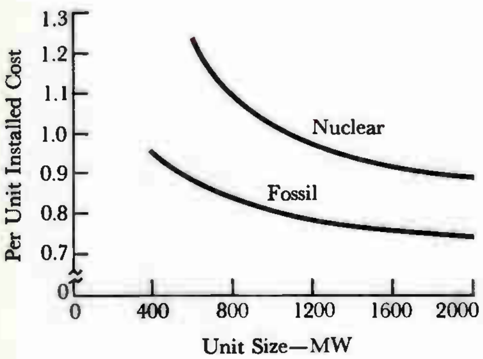
A more advanced design of the IDG generator in a 60/90-kVA rating is being built. It has a new arrangement of spray and conduction cooling optimized in the test program. The unit weighs less than 48 pounds, yet it meets all the performance requirements of specification MIL-G-21480. In addition to comprehensive testing at Westinghouse, generators will be supplied to Sundstrand Aviation for laboratory and flight test programs.

Forecasting Unit Size Patterns for the Seventies

An estimate of the turbine-generator unit sizes that will be installed from 1970 to 1980.

A manufacturer's capability to supply the electric utility industry's needs for new generating equipment requires both correct estimates of the need for new sizes of generating units and correct estimates of the numbers of all sizes required. The former assures that development efforts will be completed as required; the latter, that manufacturing facilities will be properly planned. This article describes the Westinghouse estimate of the industry's needs through 1980, from which our plans are being formulated.

The maximum unit size that will be required by utilities during the next decade is a function of several interrelated factors. Chief among these is the extent to which operating systems will grow through increased pooling. That growth, however, has an economic limit that depends on the relationship between unit size and unit cost, and the relationship between unit size relative to system size and reserve requirements to maintain adequate system reliability. We have analyzed these complex relationships in order to estimate the largest size unit that will be required for operation by 1980.



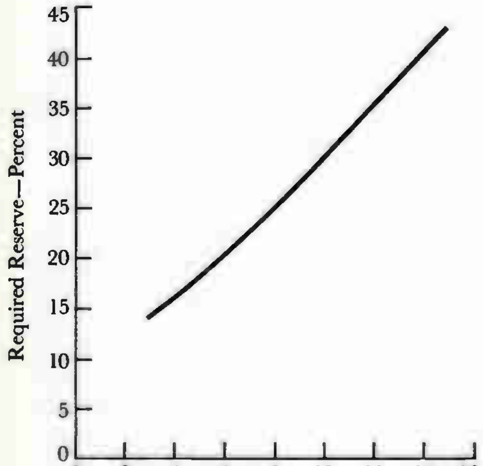
1—Installed cost as a function of turbine-generator unit size in per unit of the cost for an 1100-MW nuclear unit.

Cost Versus Size

Fig. 1 shows cost per kilowatt versus unit size relationships (in per unit of the cost of an 1100-MW nuclear unit) which are basic to the study. We expect continuing reductions in cost per kilowatt for nuclear units as their sizes increase to about 1800 MW. Beyond that point we do not foresee much further reduction due to the scale effect. In contrast, the effect of size on fossil unit costs disappears at about 1400 MW.

Reserve Requirements

A generalized estimate of the effect of unit size on the installed reserves required to maintain consistent system reliability is shown in Fig. 2. It embodies an assumption of slightly increased forced-outage rate with unit size and an estimate of the increased impact on reserve requirements caused by abrupt changes in percent unit size.



2—System installed reserve requirements as a function of unit size.

Maximum Unit Size

By combining these two factors—economy of scale and reserve requirements—we determined the economic maximum unit size as a function of pool size, first considering only *nuclear units* in sizes from 800 to 2000 MW. The results, as shown in Fig. 3a, indicate that:

1) The range of pool size for optimum economic application of each generating unit increases rapidly as sizes increase from 800 to 1000 to 1500 to 2000 MW;

2) Pools greater than about 35 GW will be required to fully realize the expected benefits of scale in nuclear plant costs.

The economic maximum *fossil unit* size as a function of pool size, shown in Fig. 3b, is seen to be significantly lower than for nuclear units, reaching only 1500 MW for pools up to 55 GW.

In other words, the generation savings available to offset the costs of creating larger pools decrease rapidly. This is illustrated in Fig. 4, where we see a dramatic rise in savings to about a 15-GW pool size with either fossil or nuclear generation. Thereafter, the savings begin to flatten out and essentially saturate at pool sizes of about 60 GW. Clearly, as pools get larger than about 25 GW, the $/kW savings show diminishing returns, so the impetus to pool, at least from a generation point of view, decreases. The generation savings from pooling with fossil units will be substantially less than those from nuclear units.

How Many Large Units?

To determine what portion of the generation requirements will be made up by large units, and to develop a timetable for these large units, it is necessary to estimate the number of systems large enough to justify them. Our estimate of the number of major power systems or pools in the various size ranges by 1975 and by 1980 is shown in Fig. 5.

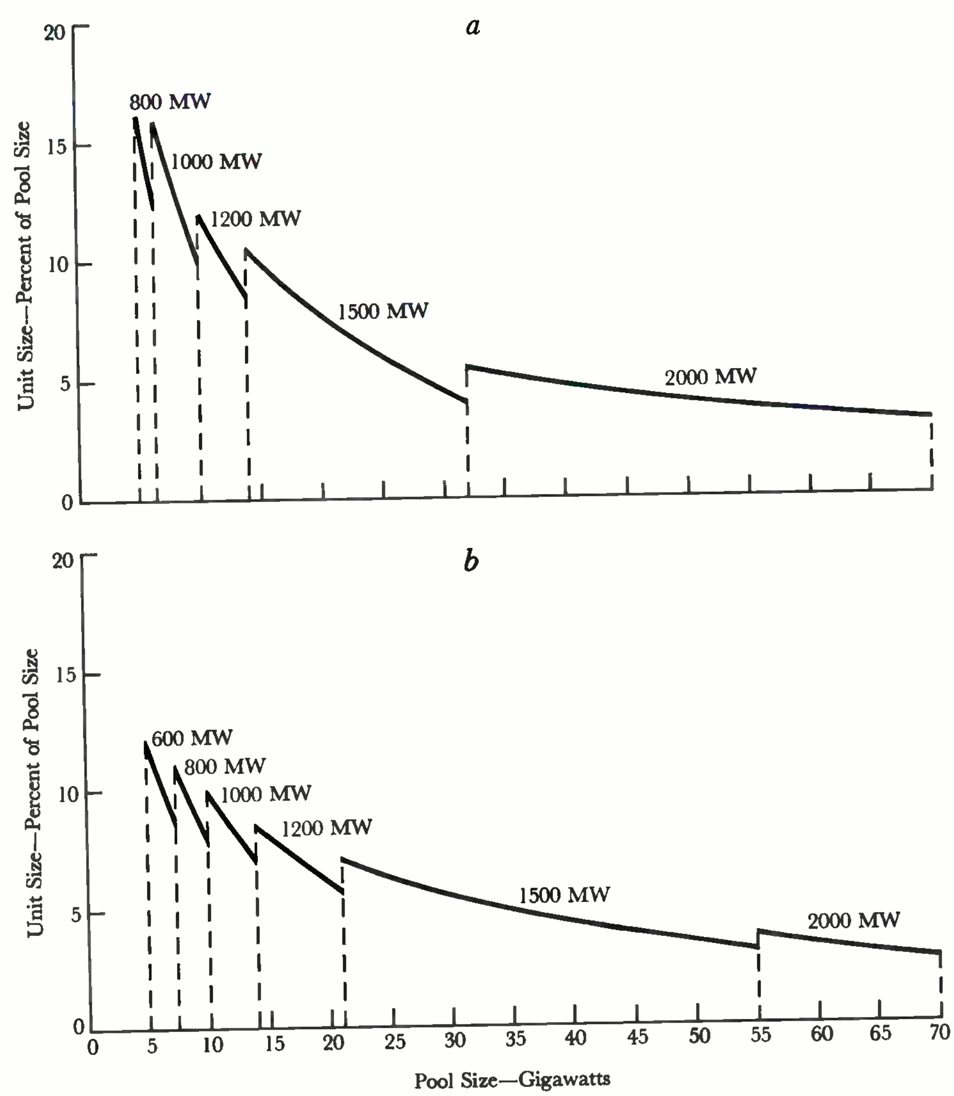
The number of units in sizes greater than those being bought today, which can

H. G. Houser is a generation engineer and J. A. Reker is a business planner in Generation, Power Systems Planning, Westinghouse Electric Corporation, East Pittsburgh, Pennsylvania.

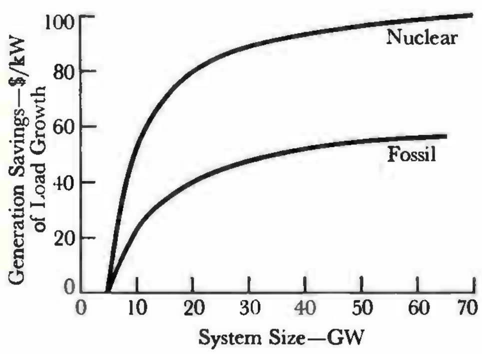
be economically justified, can be estimated from these system size estimates and the economic unit sizes shown in Fig. 3. However, there can be other reasons for increased sizes, such as a utility's desire to put into operation a constant number of units per year. Therefore, in an effort to base our plans on the most realistic course of events, and to determine the extent of the market in each turbine-generator size class, analysis was made of each major system's past generation additions and projected requirements. The forecast market requirements for units of 1500 MW and larger are shown in Fig. 6. The first generating unit in the 1500- to 1699-MW size range is expected to be installed in 1976. A 2000-MW unit will be needed about 1980. The timing of our development programs is tied to those years when the first unit of a class is expected to be needed.

It may seem that the advances in unit size are slowing in the late 1970's, and that is true relative to the 1960 to 1972 period. But viewed over the 20-year span from 1960 to 1980 (450 MW to 2000 MW), the size attained in 1980 represents a little better than the normally expected doubling in size every ten years.

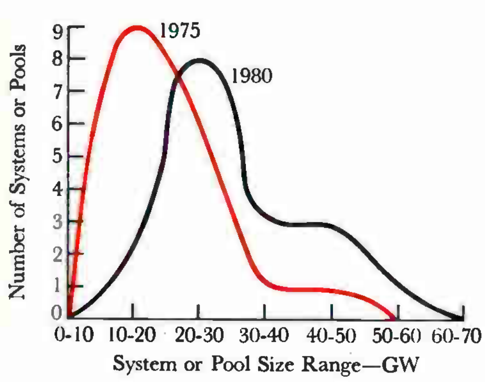
Turning to factory requirements, our manufacturing planning must be based not only on the sizes to be produced but also on the number of units in each size class. From a manufacturing viewpoint then, Fig. 6 shows that there will not be a very large aggregate need for units of 1500 to 2000 MW through 1980. Within that category, the smaller units (1500- to



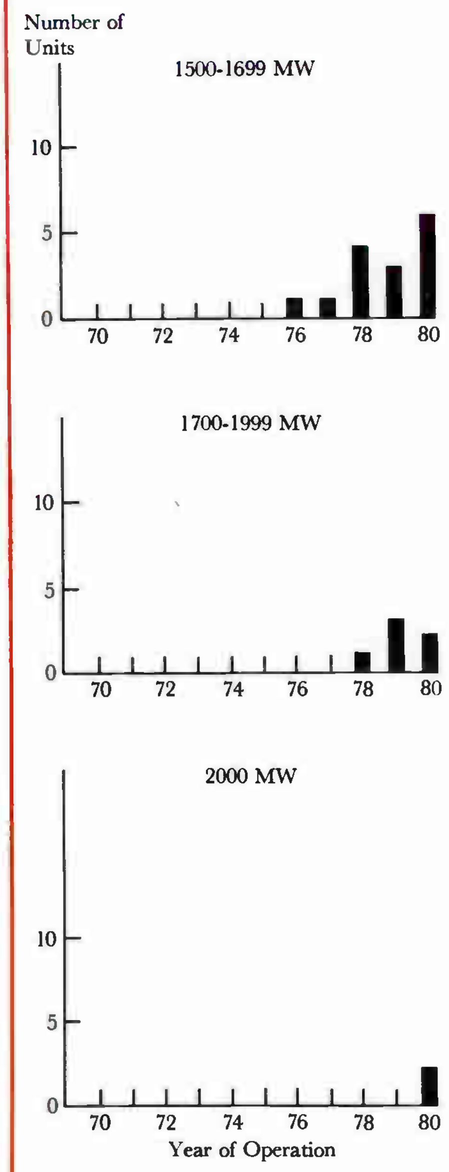
3—(*a*) Economic nuclear-unit size versus pool size assuming all nuclear additions. (*b*) Economic fossil-unit size versus pool size assuming all fossil additions.



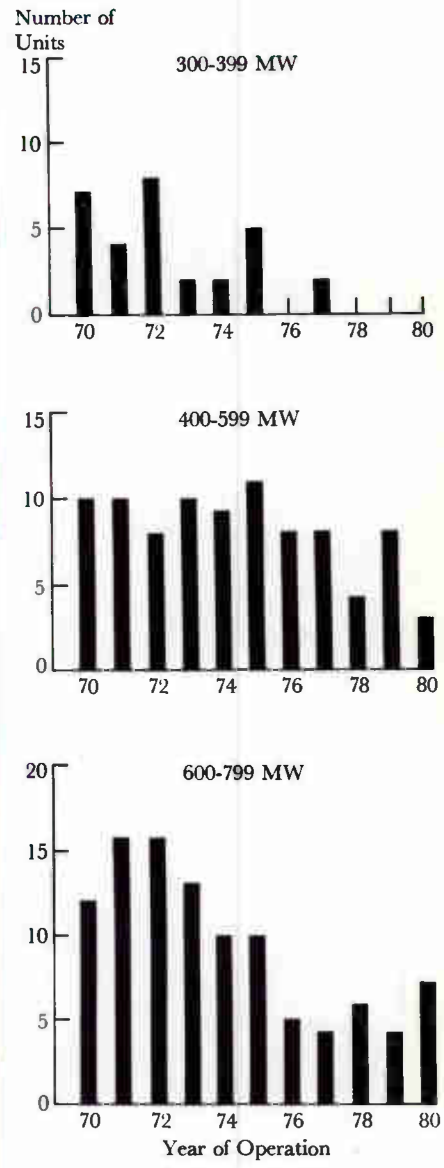
4—Generation savings from pooling with nuclear or with fossil units.



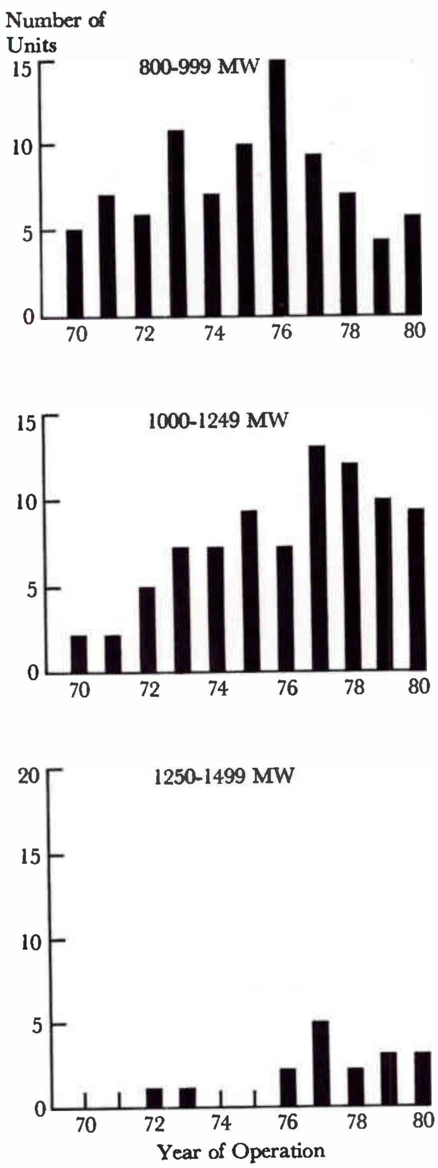
5—Size distribution of major power systems in 1975 and 1980.



6—Time distribution of new turbine-generator unit sizes by size class.



7—Time distribution of turbine-generator unit sizes by size class.



1699-MW) account for about two-thirds of the units. This finding substantiates the conclusion drawn from the generalized studies that 1500-MW units will satisfy the needs of most pools for larger units.

Smaller Units

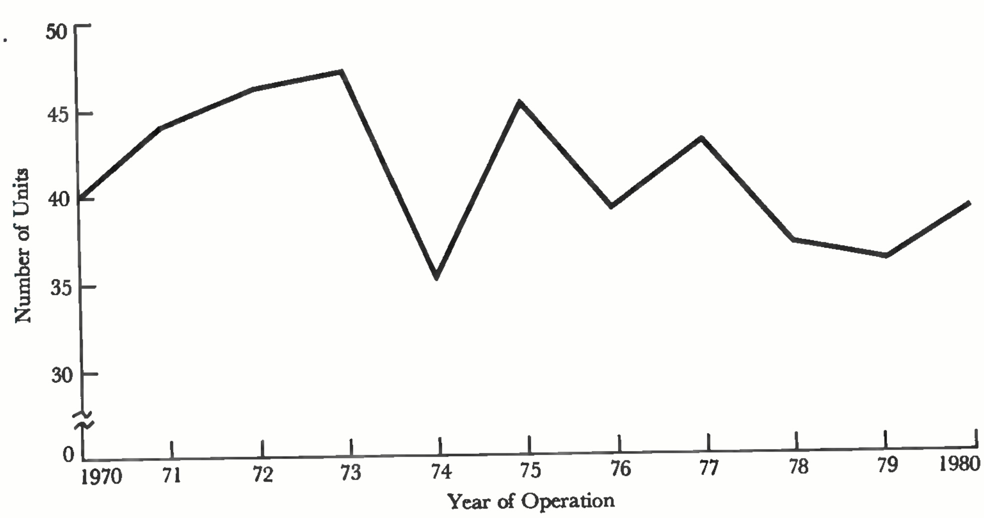
Although 1500- to 2000-MW units are important from a development standpoint, it is evident that most of the units to be installed through 1980 will be in sizes already available and most of the manufacturing capacity will be required for these sizes. The system-by-system analysis already mentioned yielded historical as well as forecast data for analysis of existing size ranges (Fig. 7). The various bar charts show the time distribution of the number of units to be installed in the size classes in demand today. When supplementary historical data are included, the peaks of the bar charts for the 400- to 599-MW, 600- to 799-MW, and 800- to 999-MW classes move forward approximately four years from class to class. However, the 1000- to 1249-MW class peaks only a year later than the preceding 800- to 999-MW class. A primary cause for this near overlap is the emergence of nuclear power. The substantial nuclear economies of scale attracted many buyers to the 1000- to 1100-MW units, thus accelerating the growth in the class.

Another influence in the relatively high growth of the 1000- to 1249-MW class is the presence of discrete size offerings of nuclear steam supply systems for reasons of economy and licensability. Substantial numbers of units in the 1000- to 1249-MW class are expected to be installed in the late 1970's, whereas the next higher class (1250- to 1499-MW) will provide considerably fewer units.

Total Volume

The total number of units needed per year is fundamental to planning manufacturing capacity requirements. An overall examination of unit volume anticipated through 1980 was made, and the total number of units of 200 MW or larger to be installed each year from 1970 to 1980 is shown in Fig. 8. On a total unit basis, the trend is a constant number of units per year.

In summary, the overall market demand through 1980 for turbine-generator units seems well defined. Engineering and manufacturing plans are being based on the consistent results found in our analyses so that production capability can proceed in parallel with the needs of the utility industry.



8—Forecast of total number of units to be installed each year from 1970 to 1980.

Static Sensor Makes Compact Circuit Breakers More Capable and More Flexible

R. O. D. Whitt
Thomas W. Slebodnik

A line of compact circuit breakers rated from 100 to 2000 amperes employs a unique solid-state current sensor instead of the conventional thermal-magnetic tripping devices. The resulting trip action is highly selective and readily adjusted to alter performance curves as needed.

Compact molded-case circuit breakers are widely used throughout the electrical industry in switchboards, control centers, panel boards, combination starters, and separate enclosures to protect and control lighting, distribution, and other power circuits operating at up to 600 volts. Although such breakers have been improved continually to meet the constantly growing need for dependable circuit protection, their basic design and operating characteristics have changed little.

Now, however, a completely new type of breaker has been developed to provide power system designers with a degree of flexibility previously unknown in compact circuit breakers. The new breaker is called the Westinghouse Systems Circuit Breaker (SCB) because it makes possible, for the first time at a modest cost, coordinated system protection. Systems Circuit Breakers fill the application gap between thermal-magnetic molded-case breakers and conventional power circuit breakers; that is, system designers can now have protective features not available in molded-case breakers without paying the premium for the more expensive power circuit breakers.

The Systems Circuit Breakers are available in three frame sizes having frame continuous current ratings of, respectively, 600, 1200, and 2000 amperes (Fig. 1 and Table I). Trip ratings (current monitor ratings) range from 100 to 2000 amperes, and the breakers can be applied at up to 600 volts ac.

Systems Circuit Breaker Innovations

The protective features not previously found in molded-case circuit breakers but available in Systems Circuit Breakers are:

1) Adjustable continuous current setting (long-time-delay pickup). (Continuous current setting defines the lowest current at which the breaker will trip.)

2) Adjustable long-time-delay tripping (the relatively long inverse time delay portion of the trip characteristic).

3) Short-time-delay tripping to regulate trip time on fault currents.

4) Instantaneous tripping adjustable over a greater range than previously possible—especially to lower values.

5) Self-contained ground current tripping.

6) Accuracy and repeatability in all of the time-current characteristics.

7) Selective trip operation. Several breakers can be applied in series, set so that the one nearest the fault opens first to isolate the faulted circuit from the system.

8) Tripping characteristics easily checked and verified in the field.

9) A 100-percent continuous current rating.

10) Mechanical emergency trip button.

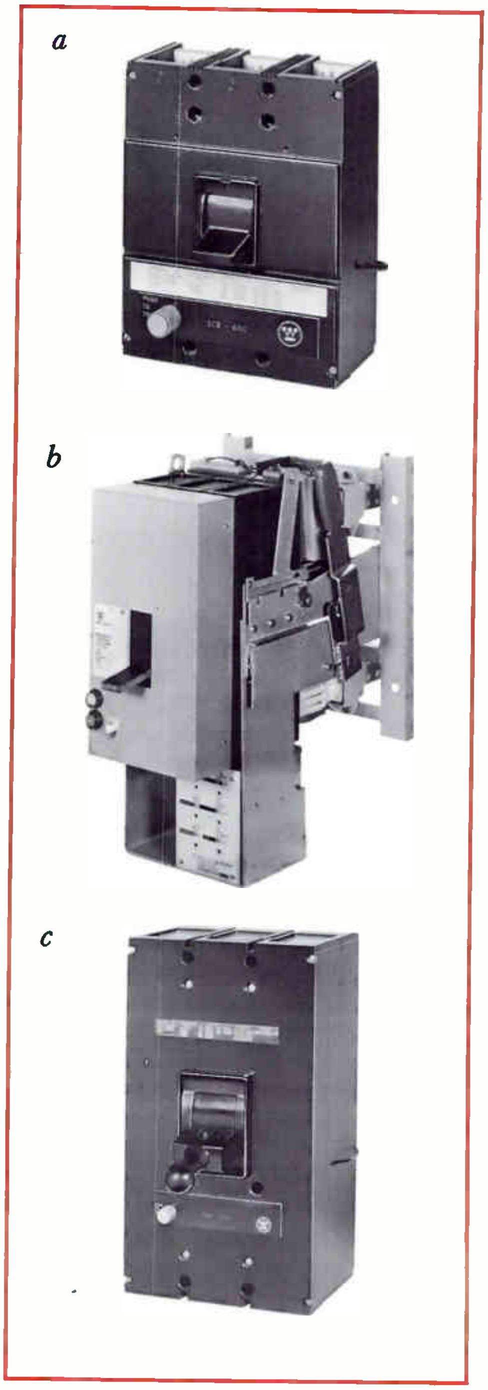
11) Three-position drawout mechanisms and motor operating mechanisms.

Application of recent advances in solid-state circuitry coupled with design innovations in contact structures and shunt trip devices made the new breakers possible. The principal advance is an adjustable electronic trip action provided

R. O. D. Whitt is Consulting Engineer at the Low Voltage Breaker Division, Westinghouse Electric Corporation, Beaver, Pennsylvania, and Thomas W. Slebodnik is a Supervising Engineer there.

Table I. Standard Ratings of Systems Circuit Breakers

AC Voltage Rating (volts)	*Breaker Type Designation*	*Max Frame Rating (continuous amperes)*	*Asymmetrical Interrupting Rating (amperes)*		*Symmetrical Interrupting Rating (amperes)*		*Current Monitor Ratings (amperes)*
			Instantaneous	*Short-Delay*	*Instantaneous*	*Short-Delay*	
240	SCB-600	600	50,000	—	42,000	—	100, 250, 400, 600
240	SCB-1200	1200	50,000	25,000	42,000	22,000	100, 250, 400, 600, 800, 1000, 1200
240	SCB-2000	2000	150,000	50,000	125,000	42,000	600, 800, 1000, 1200, 1600, 2000
480	SCB-600	600	35,000	—	30,000	—	100, 250, 400, 600
480	SCB-1200	1200	35,000	25,000	30,000	22,000	100, 250, 400, 600, 800, 1000, 1200
480	SCB-2000	2000	100,000	50,000	85,000	42,000	600, 800, 1000, 1200, 1600, 2000
600	SCB-600	600	25,000	—	22,000	—	100, 250, 400, 600
600	SCB-1200	1200	25,000	25,000	22,000	22,000	100, 250, 400, 600, 800, 1000, 1200
600	SCB-2000	2000	75,000	50,000	65,000	42,000	600, 800, 1000, 1200, 1600, 2000



1—Systems Circuit Breakers fill the application gap between molded-case breakers and power circuit breakers. The three type designations (which represent maximum frame ratings in continuous amperes) are, top to bottom, SCB-600, SCB-1200, and SCB-2000. The SCB-1200 is shown in a drawout mounting, with an optional motor operator, and with its static sensor attached.

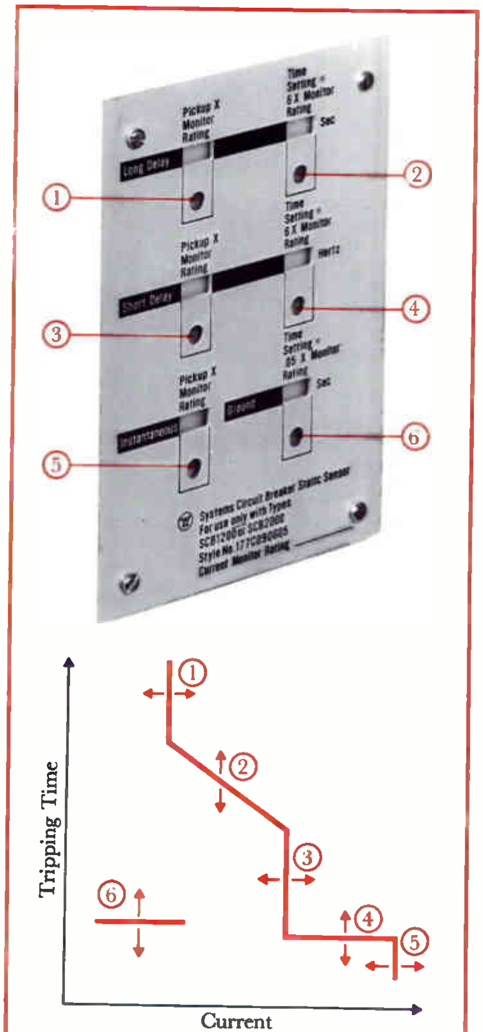
by a solid-state static sensor that replaces the standard thermal-magnetic tripping device. The sensor makes possible, in a compact package, selective tripping, ground fault protection, and excellent coordination with other breakers or protective devices in an electrical system. Instead of the one limited performance curve characteristic of conventional molded-case circuit breakers, each Systems Circuit Breaker has an almost unlimited number of potential performance curves because its sensor can easily be adjusted at the time of installation and later readjusted to meet altered system requirements.

The static sensor is a highly reliable device containing proven solid-state circuits that analyze the output currents from the current monitors and transform the intelligence into tripping signals that open the breaker at the preset time and current point. (See *Static Sensor Operation*, p 82.)

The sensor is the key to the Systems Circuit Breaker; indeed, its few simple adjustments make the new breaker possible. Several combinations of adjustments are provided, depending on the degree of protection desired. The maximum number of adjustments available on any one sensor is six (Fig. 2).

Adjustment *one* sets the long-delay pickup current, establishing the lowest load current at which the breaker will trip. The pickup point can be varied between 0.5 and 1.2 times the breaker's current monitor rating. Moving adjustment *two* varies the time it takes the breaker to trip—from 2 to 20 seconds at six times the current monitor rating of the breaker. When used together, the two adjustments make it possible to match the breaker to the distribution system's overcurrent conditions to prevent overheating of transformers, cables, and other components on the load side of the breaker.

Short-delay time-current characteristics are determined by adjustments *three* and *four*; they enable the SCB to be set for coordinated tripping on fault currents. Adjustment *three* establishes the lowest current at which the breaker will trip on short delay. It is adjustable from one through seven times current monitor



1. Long-Delay Pickup Point
2. Long-Delay Tripping Time
3. Short-Delay Pickup Point
4. Short-Delay Tripping Time
5. Instantaneous-Trip Pickup
6. Ground-Current Time

2—Static sensor has up to six adjustments to provide great variety in overload trip curves and ground current trip times, as indicated. A Systems Circuit Breaker can be adjusted at installation for the kind of protection desired, and then readjusted later if system requirements change. The adjustments also permit selective trip operation in a system for maximum service continuity.

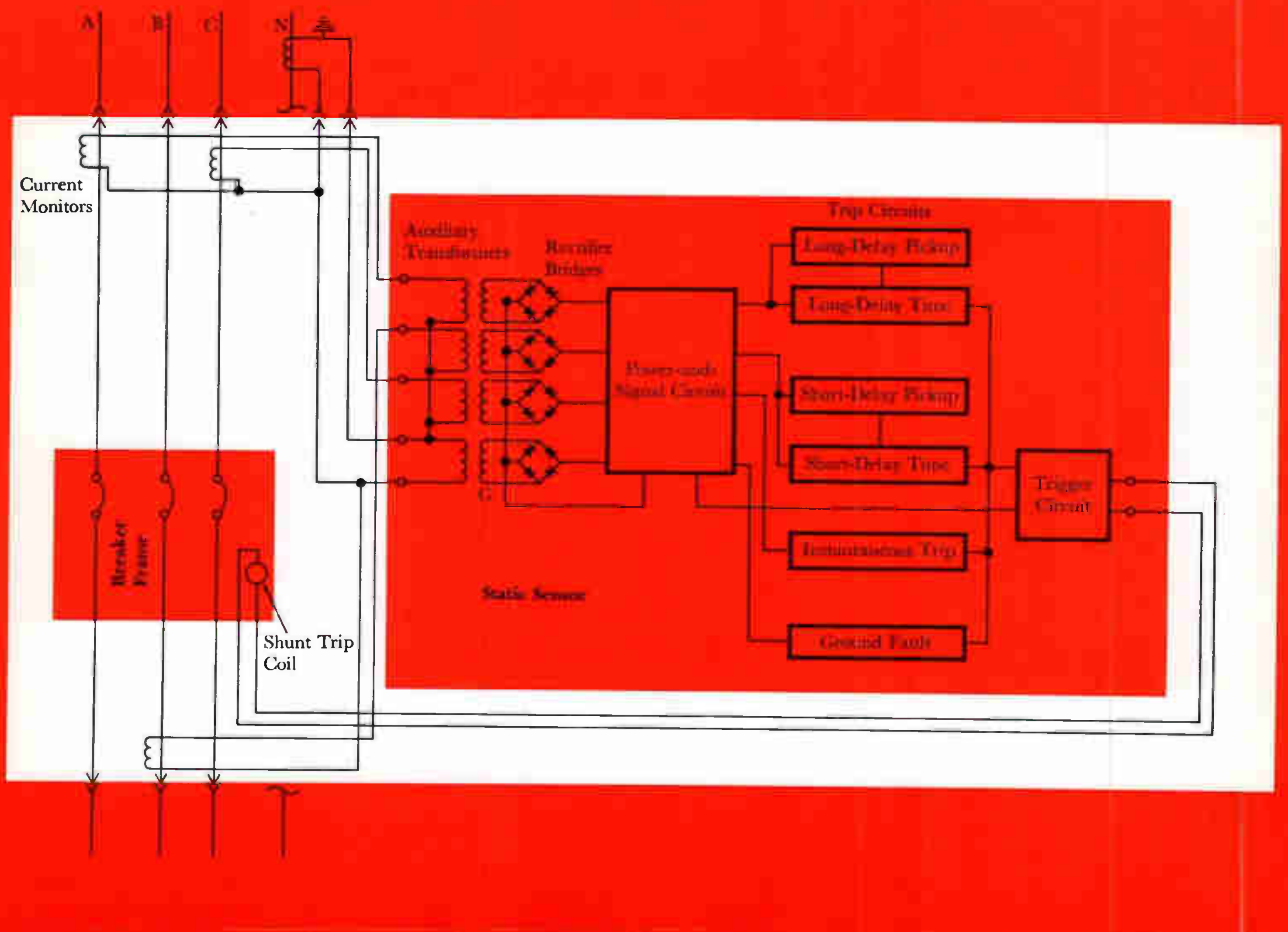
Static Sensor Operation

Signal current from the current monitors goes to the static sensor's auxiliary transformers, where it is stepped down to milliampere levels, and then to the rectifier bridges to be converted into dc power for use by the other circuits of the sensor. (See figure, which shows a Systems Circuit Breaker in drawout construction as applied in a four-wire distribution system.) The power and signal circuit serves two purposes. First, it supplies a signal for the sensing and triggering circuits. Second, it is the power supply for energizing the shunt trip coil. It does that job by charging a capacitor with direct current from the rectifier bridges; when tripping is called for by the sensing circuits, the capacitor discharges to the shunt coil, which opens the breaker contacts. The other sensor circuits also draw operating power from the capacitor and the rectifier bridge.

Overload Operation—When an overload current passes through the breaker, the voltage from the rectifiers increases proportionally to the overload current and acts as a signal to operate timing circuits in the trip circuits. These timing circuits, which signal the trigger circuit to discharge the capacitor through the shunt trip coil, cause the breaker to trip according to the curve established by the settings on the static sensor. Operation of the long-delay, short-delay, and instantaneous trip parts of the sensor is the same in both three-wire and four-wire three-phase distribution systems.

Ground Fault Operation—In a three-wire system, normal load currents flowing through poles *A*, *B*, and *C* of the breaker induce proportional currents in three current monitors. All those currents pass through the primary of the auxiliary transformer *G*. There is no output from transformer *G* because the currents of a three-phase system cancel each other completely, even when the circuit load is unbalanced and the current is not equal in all three phases. However, when a ground fault occurs on one phase of the three-wire system and one of the other phases is already grounded, the ground fault current flows in auxiliary transformer *G*. There is then an uncanceled current in the secondary of the transformer, resulting in a dc signal to the power and signal circuit. If the fault current is higher than five percent of the breaker's nominal rating, the ground-trip circuit signals the trigger circuit to trip the breaker.

In a four-wire power system, current flows in the neutral bus even with no ground fault whenever an unbalanced load causes the three-phase currents to be unequal. That neutral-line current would escape detection by the three current monitors on the power lines, so total current in auxiliary transformer *G* would not be zero and the sensor would falsely report a ground fault. Consequently, a fourth current monitor is added, on the neutral bus (see figure). It reflects any neutral-line current to auxiliary transformer *G* so that all current components cancel when the load is unbalanced but there is no ground fault. When a ground fault does occur, fault current in the neutral line appears in the primary of auxiliary transformer *G* only, and tripping occurs.



rating. Adjustment *four* varies tripping time from a minimum of two cycles to ten cycles in a 60-Hz system. (It is not available with the SCB-600.)

Adjustment *five* permits selection of the fault current at which the breaker will trip instantaneously (no intentional delay). The pickup point can be varied from 1 to 12 times the monitor current rating. For all practical purposes, the static sensor provides instantaneous tripping at a fixed time, and tripping time is essentially the same for all fault currents above the pickup setting.

Ground fault protection also is made possible by the static sensor. Never before has it been available for compact circuit breakers without the use of additional transformers, shunt trips, and relays. Pickup load current for ground fault tripping is fixed at five percent of the breaker's current monitor rating. However, tripping time can be varied by adjustment *six*, from 0.1 to 0.5 seconds, to coordinate ground fault protection among several circuit breakers.

Each adjustment is easily varied with a screwdriver. The exact setting selected is illustrated in the viewing window as a percentage of current monitor rating for current settings and in cycles or seconds for time settings. Current settings are ±10 percent and time settings are ±20 percent. Once set, accuracy and repeatability are ±1 percent.

System-coordination breaker tripping characteristic curves are easily prepared with these adjustments. Typical coordination curves are illustrated in Fig. 3 for the hypothetical system defined in Table II.

Because only low operating-signal currents are required for the static sensor, Systems Circuit Breakers can be field tested easily with a minimum number of instruments and a low current supply. The points on the time-current tripping characteristic curve are verified or adjusted to insure proper coordination.

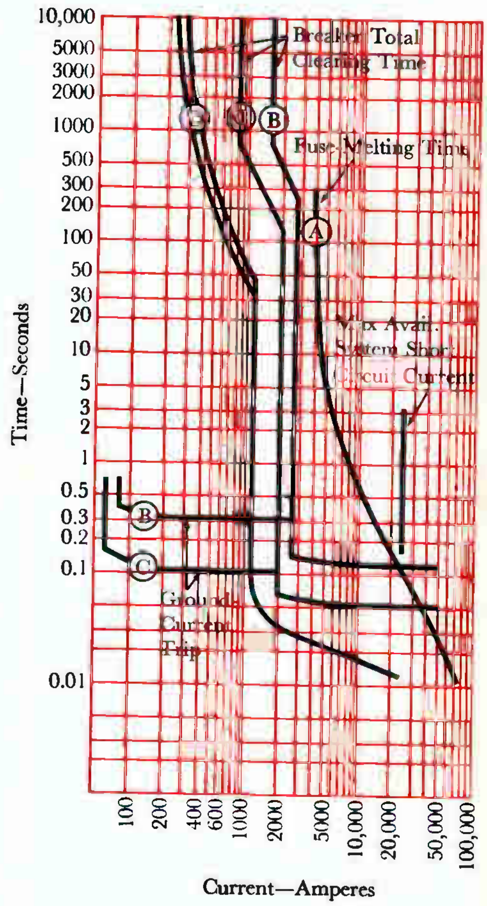
Each breaker has a 100-percent continuous current rating equal to its type designation regardless of the rating of the current monitor applied with it. (For example, the SCB 1200 has a 1200-ampere continuous rating.) However, the trip rating is a direct function of the rating of the current monitor applied with the breaker. Several current monitor ratings are available within each frame size, as shown in Table I.

All Systems Circuit Breakers have a mechanical emergency trip pushbutton (which operates independently of the manual operating handle) to open the breaker by releasing the energy stored in the breaker mechanism's springs. The button can be padlocked in the tripped position for safety.

Systems Circuit Breakers are mechanically versatile: they are available in fixed mounted or three-position drawout construction, either manual or motor operated (Fig. 1b). In the drawout construction, the intermediate position opens the power circuits but leaves the signal circuits connected for testing the static sensor.

The manual operating mechanism is the same reliable, high-speed, spring-charged overcenter mechanism used for years on service-proven AB De-ion circuit breakers. The action is completely independent of the speed or force with which an operator moves the handle. Position of the operating handle gives positive indication of the breaker contact position: on, off, or tripped.

Secondary contacts are available for remote accessories and control. For remote operation, a front-mounted motor operator is supplied. The motor is housed in a shallow enclosure that enables the switchboard assembler to utilize the same bus construction, with a change in front doors, for manual or motor-operated devices. The motor mechanism is ex-



3—The kind of selective tripping possible is illustrated by this example of system characteristic curves. The system illustrated is defined in Table II; it has a primary fuse, two Systems Circuit Breakers with different current monitor ratings, and a molded-case breaker.

Table II. System Ratings and Settings for Selective Tripping Example

Curve	*Breaker or Fuse*	*Long Delay*	*Short Delay*	*Instantaneous Trip*	*Ground-Current Trip*
A	BA-200 65E standard refill fuse	—	—	—	—
B	SCB-2000, 1600 A	100% pickup 20-sec delay	180% pickup 8-cycle delay	—	0.3 sec
C	SCB-2000, 800 A	100% pickup 20-sec delay	250% pickup 4-cycle delay	—	0.1 sec
D	AB De-ion 225-A Type JA molded-case circuit breaker	—	—	500%	—

tremely fast (less than 12 cycles opening or closing) and operates on the principle of a ball-bearing screw drive.

Standard accessories include an undervoltage trip, alarm switch, auxiliary switches, and kirk key interlocks.

Construction and Operation

The Systems Circuit Breaker consists of four basic components: breaker frame, flux-transfer shunt trip, current monitors, and the static sensor described in the preceding section. Each represents years of engineering research and design effort, and each possesses a portion of the innovations that make the new breaker possible.

Breaker Frame—The frame contains the breaker contacts, De-ion arc quenching grids, a three-pole operating mechanism, and the associated moving parts that open and close the contacts. All are enclosed in a glass-polyester case for maximum safety.

A new design in contact construction permits, for the first time in a compact breaker, a short-time current rating (the amount of fault current a breaker can successfully carry for a short interval).* The SCB 1200 and SCB 2000 can be used with static sensors having short-time delay settings up to 10 cycles.

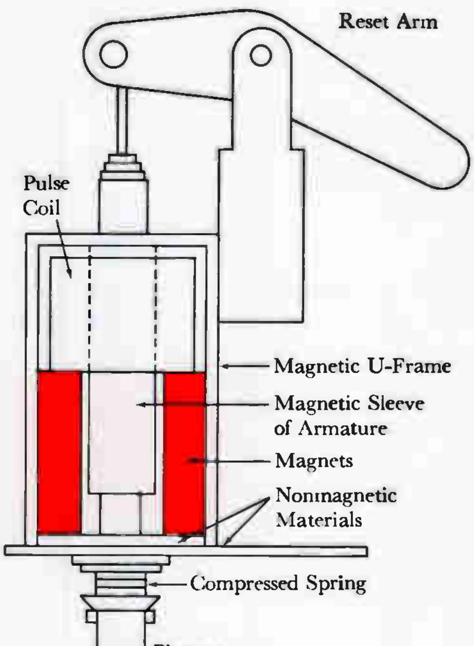
Flux-Transfer Shunt Trip—The flux-transfer principle employed in the shunt trip makes the breaker independent of outside power sources; it requires only a low-energy signal from the static sensor to operate. The term "flux transfer" refers to the magnetic principle on which the shunt trip operates (Fig. 4).

The two permanent magnets are oriented so that their flux lines go into the U-frame, up and over the coil into the magnetic sleeve of the armature, and thence back down to the magnets, with their flux adding to hold the armature upward against the force of the spring. When a pulse of direct current from the static sensor passes through the coil, the coil develops a flux field that opposes the permanent-magnet field and thus weakens the holding force on the armature. Stored energy in the spring then overcomes the weakened flux holding the armature, driving the armature downward to strike the breaker tripping mechanism. As the breaker contacts open, the reset arm engages the breaker operating mechanism, automatically resetting the armature and compressing the spring in readiness for a subsequent tripping operation.

Current Monitors—Four current monitors are included in each Systems Circuit Breaker used in a three-phase four-wire system—one on each phase bus and one on the neutral bus. In a three-wire system, three current monitors are used.

Each monitor is a transformer that produces a current proportional to the current flowing in the bus. At overloads in the bus, the current monitor's output to the static sensor rises in close proportion to the overload current; if the current rises above a predetermined level as determined by the static sensor, a signal is initiated that causes the breaker to trip.

Current monitors for a given type breaker are interchangeable, although they are not interchangeable from, say, a type SCB-600 to a type SCB-1200.



4—Flux-transfer shunt trip device is illustrated in the "reset" position. Permanent magnets hold the armature in this position until the pulse coil receives a signal from the static sensor. The signal develops a flux field that opposes the permanent-magnet field so that the spring can drive the armature downward to trip the breaker. Only a low-energy signal is required, so the Systems Circuit Breaker requires no auxiliary power source.

Application

Systems Circuit Breakers enable distribution system designers to provide complete protection in a fully coordinated distribution system. This coordinated protection can be obtained in either of the two most common types of distribution systems, depending on the degree of final coordination required and, to some extent, the initial cost of the installation. Those two types are the fully rated nonselective system and the selective tripping system.

All ratings of Systems Circuit Breakers can be applied in fully rated nonselective distribution systems, up to their interrupting ratings as outlined in Table I, when used with static sensors having long-time and instantaneous tripping adjustments. System designers thus can take advantage of the high interrupting ratings available.

The system designer who requires the utmost in coordination can design selective-tripping distribution systems, which provide maximum service continuity. Several breakers are applied in series, set so that the breaker closest to the fault always trips first to isolate the fault and disrupt service in the smallest part of the system (Fig. 3). Both the SCB 1200 and SCB 2000 breakers can be applied in this type of system up to their interrupting ratings. The breakers would be equipped with static sensors having short-time pickup and short delay adjustments.

Systems Circuit Breakers provide system coordination at a cost approximately 10 to 30 percent less than that of conventional power circuit breakers capable of doing the job. Consequently, many system designers who had previously sacrificed system coordination for cost savings can now include it.

*The duty cycle for this rating consists of maintaining rated short-time current for two periods of 10 cycles (on a 60-hertz system) with a 15-second interval of zero current between the periods.

Spot Networks Can Improve Service Reliability to Suburban Load Centers

D. R. Smith
W. Paul Matty

With properly relayed network protectors and, in some cases, balancing transformers, spot networks can be operated reliably from nondedicated feeders.

Many of today's suburban load centers require service with a level of reliability equal to that provided by conventional secondary network systems to downtown areas. Large shopping centers, hospitals, airports, large office and apartment buildings, and digital computer facilities are typical of suburban loads that are often remotely located and cannot be fed from existing secondary networks. For such loads, spot network systems can supply power with the same reliability provided by the secondary network.

The spot network system is designed so that primary circuits will not be seriously overloaded when one or two primary feeders are out of service. Traditionally, spot networks have been supplied through at least two *dedicated* feeders (feeders that supply no other load or only network load), fed from the same electrical bus (Fig. 1). A fault on a primary feeder or in the primary winding of the network transformer is disconnected from the system by tripping the circuit breaker at the supply end of the feeder and opening the associated network protectors. Isolating the fault in this manner does not cause an interruption to any network customer.

When it is necessary to use *nondedicated* primary feeders (feeders that also supply other non-network loads or originate from different electrical buses), the reliability of the spot network can be maintained with careful attention to network system design.

Network Protectors

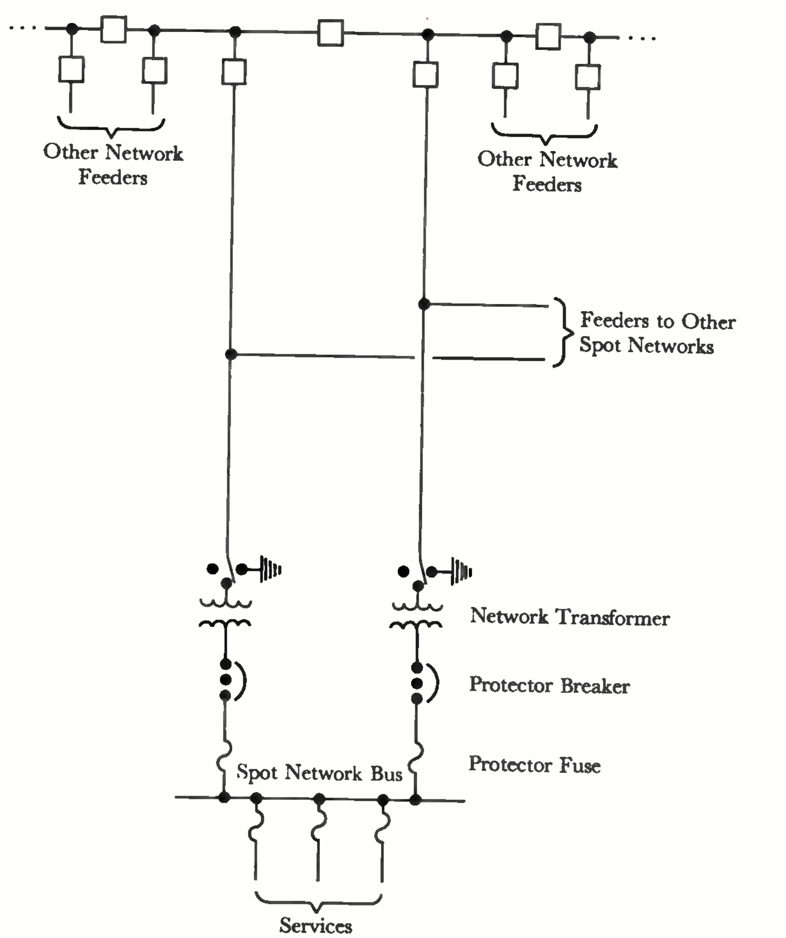
Key to the reliability of the spot network system is the network protector, an electrically operated low-voltage air circuit breaker with self-contained relays for controlling its operation.

The electric power used to close and trip the protector breaker is obtained from the network system which it protects. No external power sources such as batteries or capacitor trip devices are required. In a normal application, the protector trips any time the net three-phase power flow is from the energized secondary network toward a fault in the network transformer or on the primary feeder. The protector trips even for relatively small values of reverse power, such as that required to magnetize the network transformer. Consequently, when a primary feeder breaker is opened, all protectors associated with the feeder will open. A sensitive reverse-power trip also assures proper protector operation for a single phase-to-ground fault on a primary feeder even when primary windings of the network transformer are delta connected.

The other major function of the network protector is to close automatically when system conditions are correct. When a primary feeder associated with a given network protector is energized, the protector closes only if voltage conditions will cause power flow into the secondary network.

In addition to the operating convenience of being able to restore a network feeder to service merely by closing the feeder breaker at the substation, the network protector does not close *automatically* if primary phases have been crossed accidentally during maintenance or installation work.

D. R. Smith is a distribution engineer in the Power Systems Planning Department, Westinghouse Electric Corporation, East Pittsburgh, Pennsylvania. W. P. Matty is an assistant product manager in the Switchgear Division, Westinghouse Electric Corporation, East Pittsburgh, Pennsylvania.



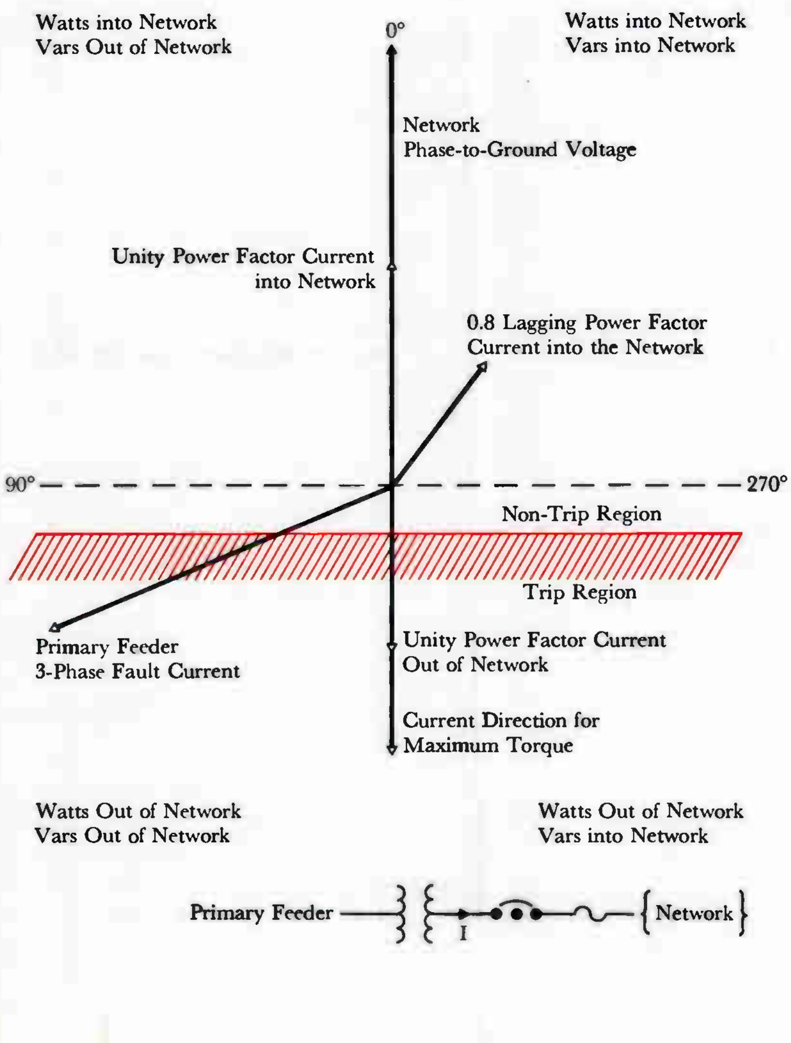
1—Typical spot network fed from dedicated network feeders that originate on the same electrical bus. Primary feeder faults are isolated by opening of the feeder breaker and protectors on the faulted feeder.

Network Protector Relays

In conventional grid and spot network systems, the network master relay (Westinghouse CN-33), which controls protector operation, has a polyphase directional characteristic with both a tripping and a closing contact. The relay trip characteristic during balanced three-phase conditions can generally be considered a straight line perpendicular to the network phase-to-ground voltage, as shown in Fig. 2. With the network phase-to-ground voltage at an angle of zero degrees considered the reference vector, current in the protector during balanced three-phase conditions can be in any of the four quadrants. (The reference direction for phase current is shown on the sketch below the phasor diagram.) A current vector which is within plus or minus 90 degrees of network phase-to-ground voltage corresponds to watt flow into the network, and it provides electrical closing torque in the relay element.

When the protector current leads the network phase-to-ground voltage by more than 90 but less than 270 degrees, watt flow is out of the network to the primary feeder. If reversed watt flow is of sufficient magnitude to actuate the relay element, the relay trip contacts close and the protector opens. For example, when the primary feeder breaker is opened to de-energize the feeder, the network transformers connected to the feeder remain energized from the low-voltage network. The watt relay detects the core loss component of the reverse magnetizing current and opens the protector to de-energize the feeder from the network side.

2—Trip characteristic of the watt relay during balanced three-phase conditions.

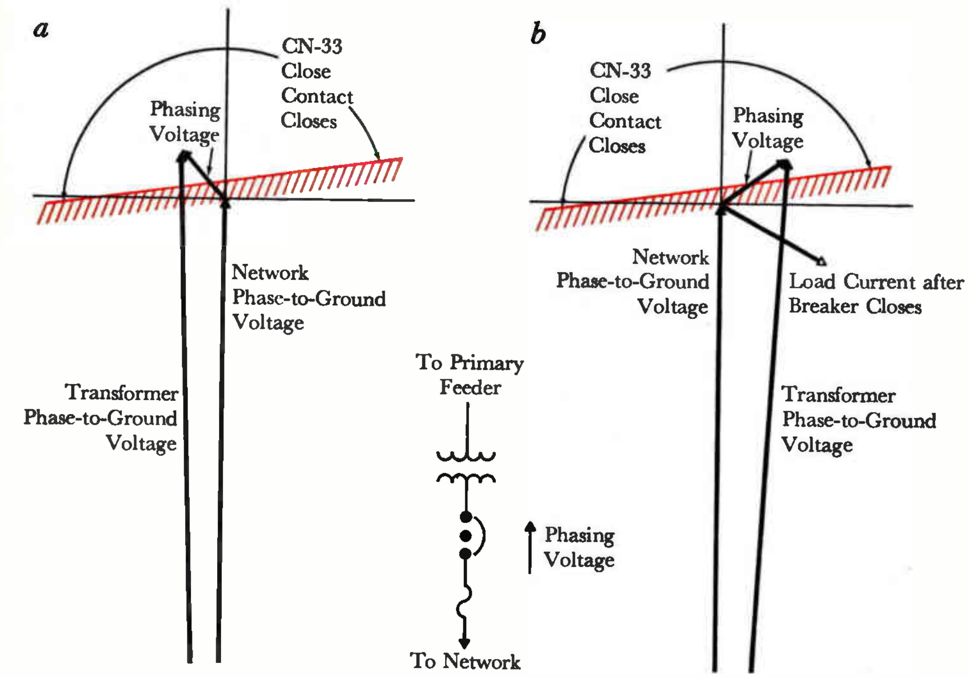


For protector closing, the watt relay (CN-33) is energized by network phase-to-ground voltage and phasing voltage (voltage across open breaker contacts). Under balanced three-phase conditions, the closing characteristic of the watt relay is shown in Fig. 3a. It can be seen from the figure that the watt relay will make its close contact when the transformer voltage magnitude is slightly greater than the network voltage magnitude. The load current that flows after the protector breaker closes will lag the phasing voltage by approximately the impedance angle of the system. However, if network phase-to-ground voltage and phasing voltage have the phase relationship shown in Fig. 3b when the network protector breaker is open, the watt relay will allow the protector to close; but upon closing, watt flow is from the network to the primary feeder and causes the watt relay to trip the protector. To prevent "pumping" that can then occur, a phasing relay (Westinghouse CN-J) close contact can be put in series with the watt relay (CN-33) close contact. The phasing relay is similar in construction to the watt relay, but has the closing characteristic shown in Fig. 4a. With the two relay contacts in series, the net closing characteristic is a composite of the two relay characteristics, as shown in Fig. 4b. In most cases, this composite characteristic prevents the protector from closing when network and phasing voltages are of a phase position that can cause pumping.

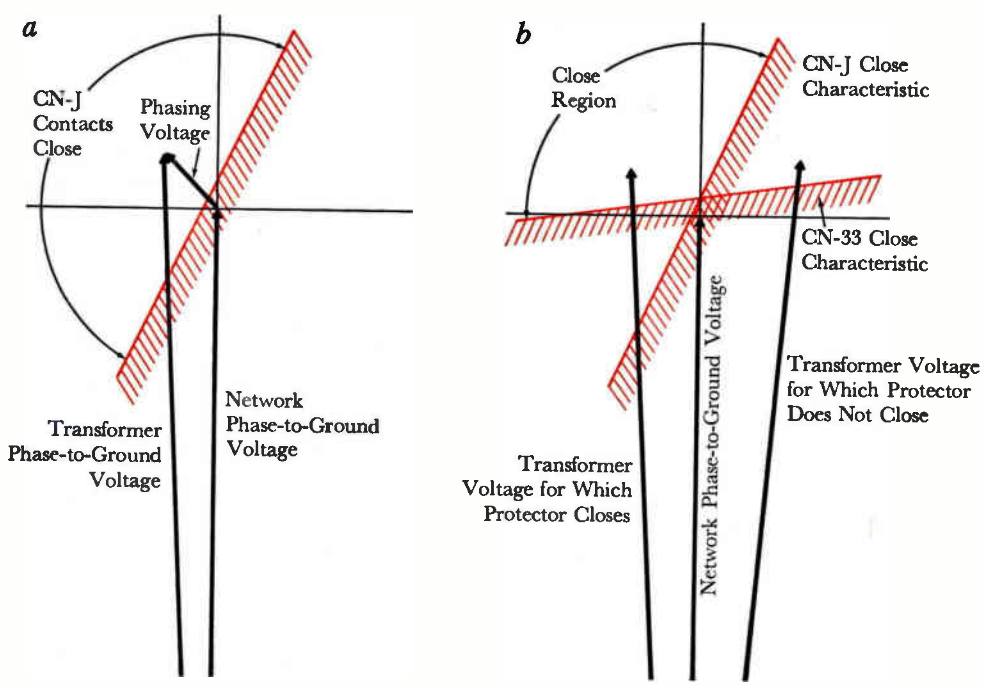
If currents and voltages are not balanced, the trip characteristics for the watt relay (Fig. 2) cannot be used to evaluate the relay's performance. However, the direction and relative magnitude of the electrical torque developed in the watt relay *can* be estimated for fault conditions with the equation:

$$T_E = K\,[V_A I_A \cos(\theta_{VA} - \theta_{IA}) + V_B I_B \cos(\theta_{VB} - \theta_{IB}) + V_C I_C \cos(\theta_{VC} - \theta_{IC})], \quad (1)$$

where V_i is phase-to-ground voltage magnitude, I_i is phase current magnitude, θ_{Vi} is the angle of phase i voltage relative to the system reference vector, θ_{Ii} is the



3—(*a*) Closing characteristic is shown for the network protector watt relay. Contact closes when phasing voltage is above shaded line. (*b*) Phasing voltage in this position can result in pumping if only the watt relay is used to control protector closing.



4—(*a*) Closing characteristic of a network protector phasing relay is similar to that of the watt relay, but rotated counterclockwise. (*b*) Composite close characteristic of the network protector when the close contacts of the watt and phasing relays are in series.

angle of phase *i* current relative to the system reference vector, and *K* is the relay torque constant. Thus, the electrical torque developed in the relay element during fault conditions is proportional to the real component (watts) of total volt-ampere flow in the protector. A positive sign indicates electrical torque in the closing (or non-trip) direction; a negative sign indicates electrical torque in the tripping direction.

Balancing Dedicated Feeders

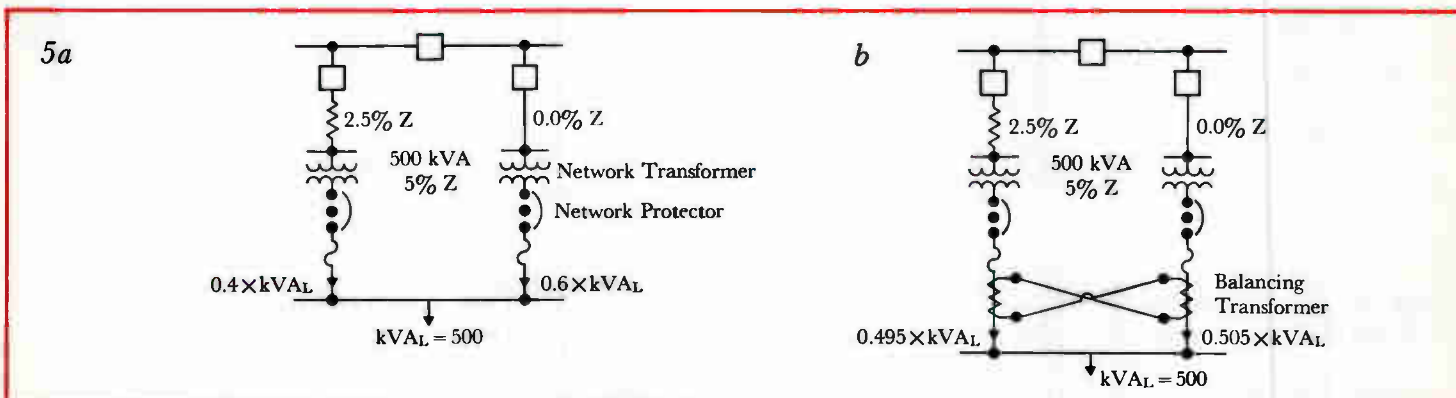
A single line diagram of a simple two-unit spot network supplied from the same electrical bus through two dedicated feeders is shown in Fig. 5a. If the feeders and transformers have equal impedances, power never flows in the reverse direction in a protector for any network load (except if the network load is regenerative). The total load kVA will divide equally between the protectors in service. If a two-unit spot network is supplied from the same electrical bus through dedicated feeders of unequal length (which results in unequal feeder impedances), the load carried by each protector will be different.

For example, for the conditions illustrated in Fig. 5a, one feeder normally carries 40 percent of the total load and the other feeder carries 60 percent of the total load. If more equal load division between the two network units is desired, balancing transformers can be added to the circuit (Fig. 5b). This is the "classical" application of balancing transformers to a spot network. In this example, balancing transformers are used to equalize load division between the two network units, but they are not required to keep the protectors closed for most network load conditions. Either with or without balancing transformers, the network transformer voltage magnitude at an open protector is always equal to or greater than network voltage, and transformer voltage always leads network voltage in phase position for lagging power factor network loads. Therefore, standard watt (CN-33) and phasing (CN-J) network relays can be applied. If either protector is open for any reason, it closes automatically when the feeder is energized if the network load is large enough to cause the phasing voltage magnitude to exceed the closing setting of the watt relay. The magnitude of load required to close a protector depends upon feeder and transformer impedances, and upon the closing voltage setting of the watt relay. Thus, if the feeders are dedicated to the spot network and come from the same electrical bus, standard network protectors and relays can be used either with or without balancing transformers.

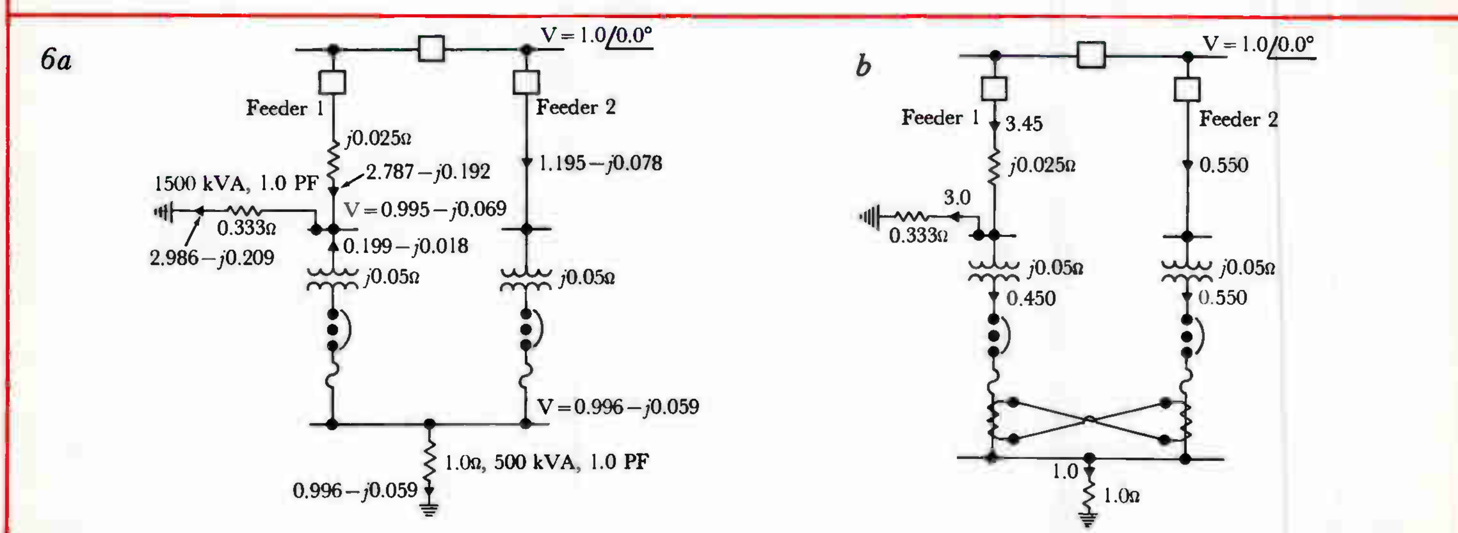
Balancing Nondedicated Feeders

Although the conventional spot network with dedicated feeders is desirable, the remote locations of many of the new suburban load centers often render the dedicated-feeder spot network economically impractical. For these situations, a spot network must be fed from existing nondedicated feeders and, in some cases, the feeders are served from different substations. The spot network system should not interfere with the normal design and operation of the nondedicated feeders or substations. Thus, the problem is to satisfy the overall reliability and operating requirements of the utility system and at the same time provide reliable, economic service with the spot network.

A typical spot network served from nondedicated feeders of unequal impedance is shown in Fig. 6a. The circuit is identical to the circuit shown in Fig. 5a, except that a load of 1500 kW is fed at the spot network transformer primary from the feeder. The currents in the different line sections and bus voltages are given in per unit (500-kVA base). As indicated, normal power flow in this system will be in the *reverse* direction through the network protector on the loaded feeder. Therefore, this protector will trip from reverse power flow, even when the watt relay trip setting is at its highest value (10 percent of protector rating). Thus, if both the network load and feeder load have the same or similar load cycles, the system shown cannot be operated as a spot network with both protectors closed. At best, this system could only provide good secondary throwover operation with the



5—(*a*) Single-line diagram illustrates load division in spot network with feeders of unequal impedance. (*b*) Balancing transformers can be used to equalize load division in feeders.

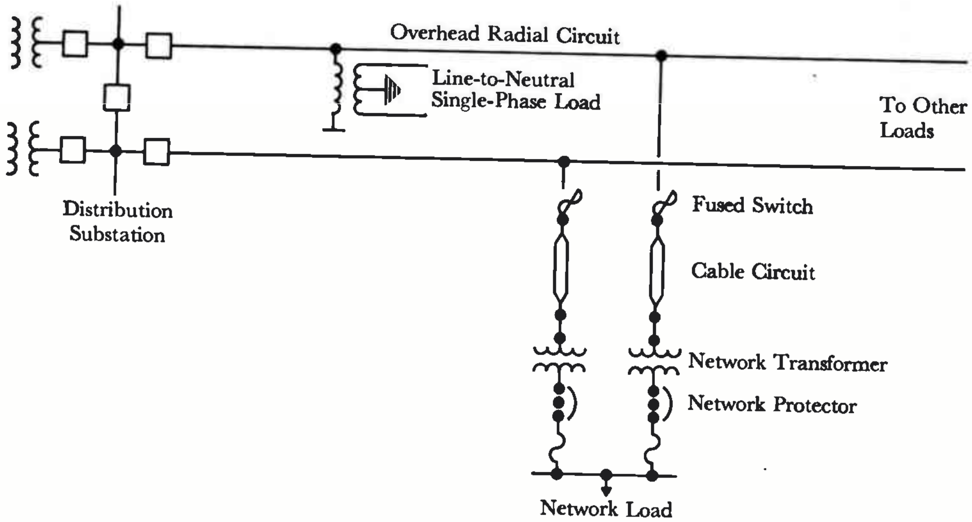


6—(*a*) Spot network fed from nondedicated feeders. All impedances and currents are in per unit on a 500-kVA base. Balancing transformers are required for this spot network if both protectors are to stay closed. (*b*) With balancing transformers, power flows to the network from both feeders.

protector fed from the unloaded feeder being normally closed.

If balancing transformers are placed in the secondary of the network units as shown in Fig. 6b, the power flow in each network protector is now into the network. The unit fed from the loaded feeder carries 45 percent of the network load and the other carries 55 percent.

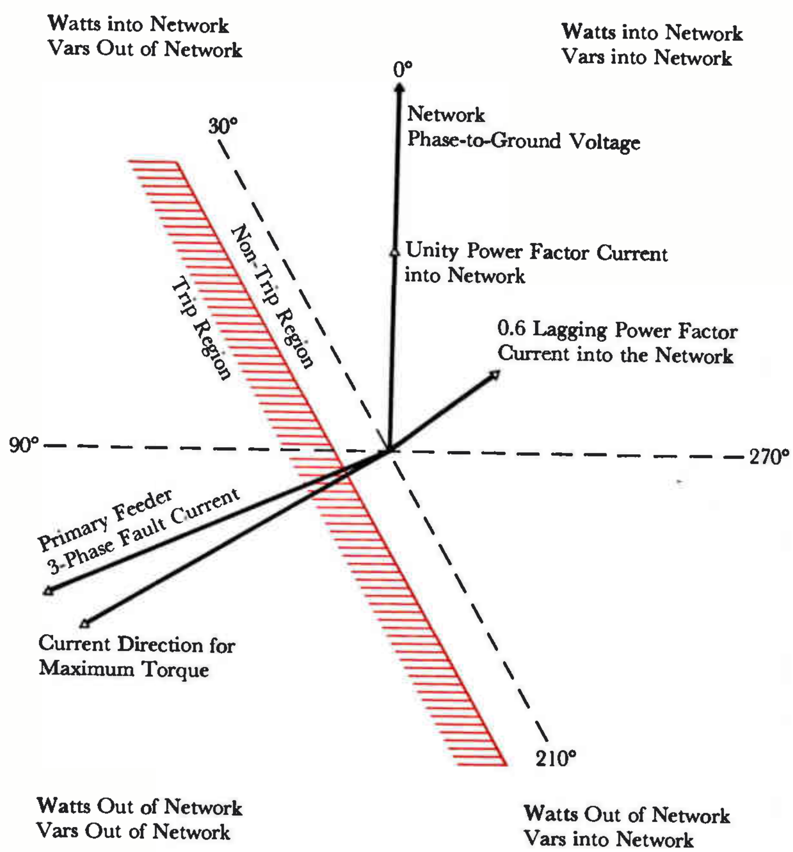
Although load balancing of nondedicated feeders is readily accomplished in most all cases with balancing transformers, protector relaying may become more involved. If the protector fed from the loaded feeder opens, the voltage conditions at the network transformer when the feeder is re-energized may not allow standard watt and phasing relays to make their close contacts. In this situation, special relays can be used to close the protector and fully utilize the capability of balancing transformers.



7—Two-unit spot network fed from nondedicated overhead primary circuits. Balancing transformers may be required if the total load on each overhead circuit differs by a large amount, or if the overhead circuits originate at different substations.

Protector Relaying for Nondedicated Feeder Applications

A typical system used to supply a remote spot network where primary feeders are not dedicated is shown in Fig. 7. Each spot network transformer is fed through a cable circuit, supplied from an existing overhead feeder through fused cutouts or switches. Other loads in addition to the network are served from the overhead feeders. If a permanent fault occurs on an overhead feeder, the faulted-feeder circuit breaker and network protector open to isolate the fault. If a fault occurs on one of the cable circuits, fault current is interrupted by a fuse or fuses blowing at the tap point and by opening of the network protector. The fuses in the faulted phases of the cable circuit will usually blow before the network protector opens, creating the condition of a fault and a blown fuse or fuses. However, balanced currents and voltages do not exist at the protector when one or two fuses are blown, so the trip characteristics of the conventional CN-33 watt relay may no longer insure immediate network protector operation. To accommodate this situation, a network relay has been developed that is better suited to the unbalanced conditions that can develop when primary circuits are fused.



8—Trip characteristic of the watt-var relay during balanced three-phase conditions.

The new relay has a watt-var tripping characteristic rather than the conventional watt characteristic. The advantage of the watt-var relay is that it develops much larger electrical tripping torques than the watt relay for the most common primary feeder faults, both with and without blown primary fuses. Since the spot network should not interfere with normal operation of the overhead feeder, the network protector should open as quickly as possible. This objective can be achieved with a watt-var relay trip characteristic.

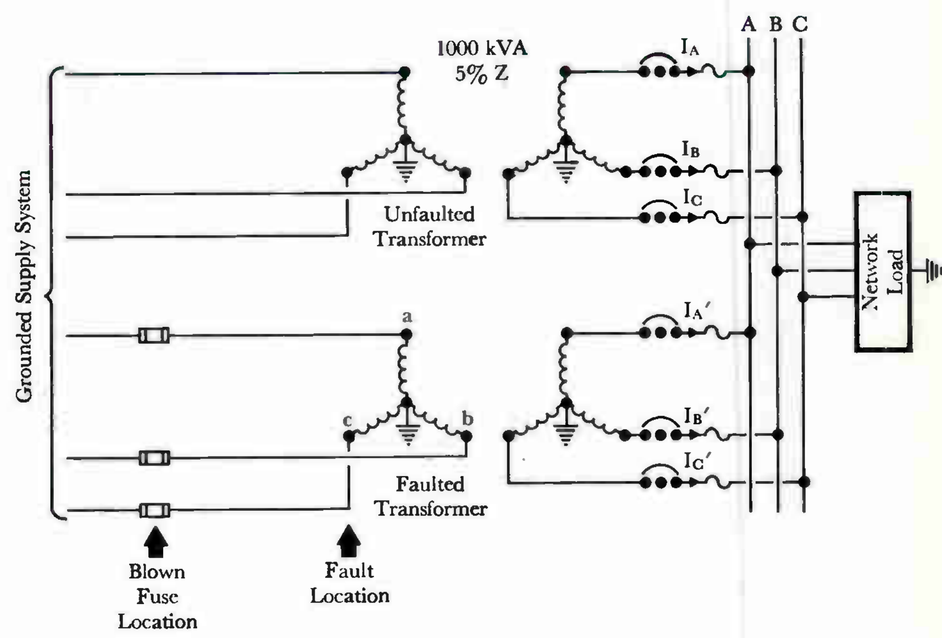
Watt-Var Relay Characteristics

The tripping characteristics of the watt-var relay for balanced three-phase conditions with rated voltage applied to the relay are shown in Fig. 8. The trip curve of the relay is similar to that of the conventional watt relay (Fig. 2) except that it is rotated 60 degrees in the clockwise direction. Thus, the watt-var relay develops maximum electrical torque in the tripping direction when phase current leads network phase-to-ground voltage by approximately 120 degrees. (The watt relay develops maximum tripping torque when this lead angle is 180 degrees.)

When a three-phase fault occurs on a primary feeder, the ratio of vars flowing out of the network to watts flowing out of the network in the protector connected to the faulted feeder is usually greater than two (due mainly to the X/R ratio of the network transformer leakage impedance). Therefore, the watt-var relay develops much greater electrical tripping torque than the watt relay for three-phase primary faults because fault current is closer to the maximum torque line of the watt-var relay than to that of the watt relay. When the primary feeder breaker is opened to de-energize the feeder, the network transformer magnetizing current in a protector leads the network phase-to-ground voltage by an angle of typically 100 to 115 degrees. Again, comparing trip characteristics, the watt-var relay develops greater electrical tripping torque than the watt relay for reverse magnetizing current.

In both cases, the greater tripping torque will result in faster relay action. A network protector should have the fastest possible tripping time when used in a spot network which is fed from nondedicated primary feeders because the protector must coordinate with other primary system protective devices. Since the tripping time of the watt-var relay for most situations, and particularly for primary faults, is much faster than that of the watt relay, use of the watt-var relay usually makes possible the desired level of coordination.

Unbalanced Fault Conditions—With dedicated feeders, a primary circuit fault is immediately cleared on the primary side by three-phase circuit breaker operation and the protector is confronted with a reverse power situation which is easily detected by the watt relay. But with nondedicated feeders protected by fuses, single line-to-ground, double line-to-ground, and line-to-line faults that blow primary circuit fuses create unbalanced voltages and currents in the protector. The watt relay may not detect all of these



9—A two-unit spot network system (*above*) is used to compare the electrical torques developed in watt and watt-var relays for (*a*) single line-to-ground fault, (*b*) double line-to-ground fault, and (c) line-to-line fault, all with a blown fuse or fuses.

The unbalanced phase-to-ground voltages and phase currents at the faulted and unfaulted transformers can be calculated by a method that employs symmetrical component techniques. The method considers all three sequence networks simultaneously. The interconnected sequence networks are represented by node voltage and constraint equations. The sequence voltages in the system are obtained by simultaneous solution, and system currents and voltages are constructed from their respective symmetrical components. With these current and voltage values, the torques (T_E/K) developed by the watt relay are calculated with equation (1) and the torques developed by the watt-var relay with equation (2). Both relays develop tripping torque at the faulted transformer and nontripping torque at the unfaulted transformer, but the watt-var relay develops much greater torques.

conditions if the network load is heavy and the primary breaker ahead of the fuses is closed. However, these unbalanced fault conditions *will* be detected by the watt-var relay. The performance of the watt-var relay during unbalanced fault conditions cannot be evaluated using the trip characteristic shown in Fig. 8. The direction and relative magnitude of the electrical torque developed in the watt-var relay can be estimated with the equation:

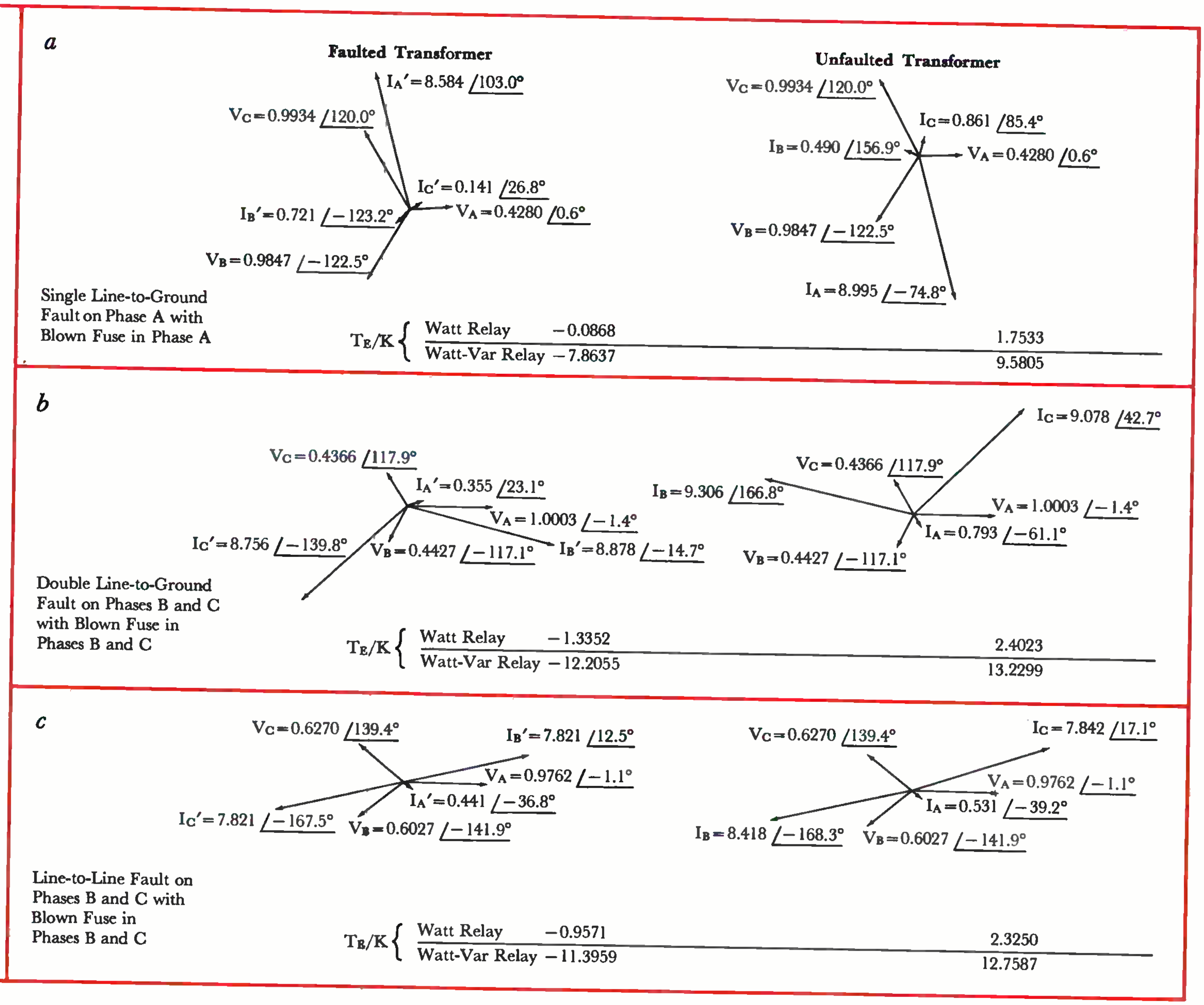
$$T_E = K\,[V_A I_B \cos(180°+\theta_{IB}-\theta_{VA}) + V_B I_C \cos(180°+\theta_{IC}-\theta_{VB}) + V_C I_A \cos(180°+\theta_{IA}-\theta_{VC})], \quad (2)$$

where the quantities are as defined for equation (1). A negative value of T_E corresponds to a relay electrical torque in the tripping direction, and a positive value indicates torque in the closing or nontripping direction. By comparing equations (1) and (2), it can be seen that the watt-var characteristic has been obtained by interchanging the voltage and current winding connections on a basic polyphase CN-33 element.

When phase currents and voltages at the watt-var relay are *balanced*, equation (2) reduces to:

$$T_E = K\,[3 V_A I_A \cos(\theta_{IA}+60°-\theta_{VA})]. \quad (3)$$

The sign of T_E is negative when the protector phase current leads the protector phase-to-ground voltage by more than 30 but less than 210 degrees, which is simply



the characteristic for balanced conditions shown in Fig. 8.

Watt Relay vs Watt-Var Relay

Calculating procedures and a digital computer program have been developed to determine the response of a network system subjected to unbalanced faults, such as single line-to-ground, double line-to-ground, and line-to-line faults with a blown fuse or fuses at another location in the system. These are the fault conditions most likely to occur in a spot network with fused primary feeders. The phase-to-neutral voltages and phase currents at the network protectors for three fault-with-blown-fuse conditions on a typical spot network are shown in Fig. 9. With these unbalanced voltage and current values, the electrical torques developed by watt and watt-var relays can be estimated and compared. For example, substitution of voltage and current values for the single line-to-ground fault condition from Fig. 9a in equation (1) yields the electrical tripping torque developed by a watt relay in the protector connected to the faulted transformer:

$$\begin{aligned} T_E/K = [&(.428)(8.584)\cos(0.6-103.0) \\ &+(.9847)(.721)\cos(-122.5+123.2) \\ &+(.9934)(.141)\cos(120.0-26.8)] \\ = &-0.0868. \end{aligned}$$

Similarly, the electrical tripping torque developed with a watt-var relay can be found with equation (2) to be:

$$T_E/K = -7.8637.$$

Comparison of these tripping torque values clearly indicates that greater electrical tripping torque is developed with the watt-var relay. Similarly, the *nontripping* electrical torque developed by the watt-var relay for the protector fed from the unfaulted transformer can be calculated and it will also be greater than the torque developed by the watt relay (Fig. 9a).

For double line-to-ground and line-to-line faults, voltages and currents were determined, and the torques for the watt relay and the watt-var relay were calculated, as tabulated in Figs. 9b and 9c.

For the fault conditions illustrated in Fig. 9, which are typical when fuses are in the primary circuit, the watt-var relay definitely develops much greater tripping torques than the watt relay. Although the network transformers in the example (Fig. 9) are connected wye-grounded wye-grounded, the watt and watt-var relays' response to faults with blown primary fuses will be similar when the network transformers are connected delta wye-grounded.

During certain balanced-load conditions on a spot network system, the trip characteristic of the watt-var relay may not be desirable. For example, the watt-var relay will false trip a protector for *leading* power factor network loads if the load power factor is less than 0.866. Also, the watt-var relay may fail to trip the protector when the primary circuit is opened if the primary cable-charging current is appreciably greater than transformer reverse magnetizing current.

These limitations to watt-var relay application can be circumvented by using fault detector and auxiliary relays to change the network relay trip characteristics. For normal load conditions where current in each protector phase is less than 100 percent of protector rated current, the connections to the network relay are made to provide the watt characteristic. If the current in any phase of the protector exceeds 150 to 200 percent of rated current, a fault probably exists on the system. This condition is sensed by the fault detector, and auxiliary relays change the wiring connections to the watt relay to give it the watt-var characteristic. Thus, the protector trips for any primary-fault/primary-blown-fuse condition and also functions normally for currents less than 150 percent of rated.

If balancing transformers are required to provide the necessary division of load flow in the protectors, or to prevent reverse power flows, the protector relay close characteristics can be changed to permit maximum utilization of the balancing transformers' capability to limit reverse power. There is no problem making the relays trip on reverse power flow through the protector when balancing transformers are used. When a protector is open, the network voltage may be higher than the transformer secondary voltage, so that conventional network relays would prevent the protector from closing. This, of course, is a desirable close characteristic when balancing transformers are not used because closing for these conditions would initiate a pumping cycle. But with balancing transformers, the protector *can* be closed when the network voltage is higher than, and leads, the transformer voltage and a reverse power or var flow will not occur in either protector. To enable closing when transformer voltage is lower than network voltage, an autotransformer raises the network transformer secondary voltage applied to the watt relay by two, four, or six percent. In addition, the phasing relay is not used in the protector.

Conclusions

Spot networks that are fed from nondedicated primary feeders should be analyzed with a digital load flow program or a calculating board to determine if balancing transformers are required to keep the protectors closed. If the analysis shows that two-unit spot network operation is not possible because of reverse power flow during normal load conditions, balancing transformers, in most cases, will prevent reverse load power and also cause an equal division of the network load in the protectors.

To fully utilize the balancing transformer's capabilities, the normal close characteristics of the protector relays can be modified with auxiliary autotransformers, and if required, a timing relay and an auxiliary loss-of-voltage relay. If fuses are in the primary circuits which supply the spot network or reclosing primary circuit breakers are used, a relay with a watt-var tripping characteristic should be used in the protector. This relay will detect the different types of primary circuit faults with blown primary fuses. In addition, the network protector will coordinate with the primary feeder circuit breaker. Thus, a spot network with balancing transformers and properly relayed protectors will operate satisfactorily from nondedicated feeders, and the high level of service reliability that has been obtained with grid networks is now possible with spot network systems.

Lunar Television Camera Proven in Apollo Flight

The television camera used during the Apollo 9 mission, and scheduled to be taken to the surface of the moon, weighs only 7.25 pounds (earth weight). It can withstand temperatures that will range from 250 degrees F during the lunar day to −300 degrees F at night, and its special image tube can produce pictures even during the lunar night. Moreover, the camera is designed to operate in the vacuum of space as well as in the spacecraft atmosphere. It was built by Westinghouse for the National Aeronautics and Space Administration.

For the lunar landing mission, the camera will be placed on an access hatch of the descent stage of the lunar module. The hatch will open after the lunar module has landed, aiming the camera at the ladder the astronauts will descend. The astronauts will then remove the camera for hand-held operation.

The camera is capable of operating over a light range from 0.007 to 12,600 foot-lamberts. The wide range permits use with low light levels, as during the lunar night when the moon's surface is illuminated dimly by light reflected from the earth. Such sensitivity is accomplished by use of a Westinghouse secondary electron conduction (SEC) imaging tube. The SEC tube converts light into electrical signals much as in a conventional television camera, except that the signals are amplified hundreds of times before they are converted into images.

The camera is so designed that astronauts need make no adjustments other than to change lenses and to switch from slow to fast scan. The four fixed-focus lenses include a wide-angle lens for cabin interior use, a 100-millimeter telephoto lens for viewing the earth and moon during the flight, and two general-purpose lenses—one for lunar day and one for lunar night.

The camera has two interchangeable handles—one with a 9-foot cable for use inside the spacecraft and the other with a 100-foot cable for use outside. The handle also serves as an electrical conductor that can be engaged and disengaged without the contacts welding in the vacuum of space. The cable carries dc voltage to the camera and a video signal back to the transmitter in the spacecraft.

Lightweight television camera was used in the Apollo 9 mission and is scheduled for use in the lunar-landing mission. It is built to operate in atmosphere or vacuum and in the searing heat and intense cold of the lunar day and night. The image tube's wide sensitivity range will enable it to produce pictures during lunar night as well as lunar day.

To achieve the required reliability, performance, and portability, 80 percent of the camera's circuitry is made up of molecular-electronic functional blocks and thin-film circuits. Only 6½ watts of power is required.

Since convection cooling is not possible in a vacuum, heat generated within the camera is conducted to the outer surfaces and radiated away. On the moon, internal operating temperature will range between 0 and 130 degrees F.

(For more information, see "The Lunar Television Camera," E. L. Svensson, *Westinghouse ENGINEER*, March 1968, pages 46 to 51.)

Control Computer Can Be Expanded with Hardware and Software Modules

The basic Prodac 2000 computing control system is made up of only four large plug-in circuit boards such as the one in the foreground. The four boards take the place of the considerably larger number of smaller boards, such as the one the girl is holding, in traditional computer construction. One advantage is that, if something goes wrong, the user can quickly replace the faulty board with a spare instead of having to check dozens of small boards to find the fault.

The user of industrial control computers is understandably reluctant to pay for more computer than he can use. However, the Westinghouse Hagan/Computer Systems Division has found that the user usually underestimates his computer needs and is then faced with the costly task of replacing his relatively new system with a larger one, adding another system, or doing without the needed capacity.

As a result, the division has brought out the Prodac 2000 computing control system, which can cover the area between the upper limits of wired logic capability —such as simple data logging—and the middle limits of large sophisticated computer systems. The user can start with a low-cost but limited capability and easily expand it later with economical modular additions to hardware and software.

The division has been producing three lines of Prodac process-control computer systems: the small low-cost Prodac 50, the larger Prodac 250, and the still larger Prodac 500. Cost and capability of the new Prodac 2000 extends from below that of the Prodac 50 to the mid-range of the Prodac 250.

The Prodac 2000 system is an integrated-circuit, high-speed, random-access digital computer designed for real-time on-line process control applications. Its basic hardware consists of just four large (16- by 25-inch) circuit boards for input/output, memory, and arithmetic functions. Most other computers, in contrast, have many separate circuit boards; to locate a fault in them it is often necessary to check dozens of boards, perhaps resulting in costly downtime for the process. If a fault occurs in a Prodac 2000 system, however, a quick change of one of the four boards eliminates the trouble.

A user can keep spare circuit boards on hand—on a lease basis, if he wishes—and send a faulty board back to the Westinghouse plant, where it will be repaired and the user charged only for the repair work done. Besides eliminating downtime, the user would receive economical and expert factory repair work.

The user expands the capability of his Prodac 2000 system simply by adding additional circuit boards or portions of boards. Software routines are also available if the user does not want to provide his own.

The most important operational feature of the Prodac 2000 system is its ability to use the Westinghouse integrated software package called Progen, making it the first small computer with an on-line real-time compiling capability. First offered with the Prodac 250 computing control system, Progen is a complete on-line Fortran compiler. With Progen, computer time can be shared with the process being controlled to translate Fortran program statements into new control programs—or to debug existing programs—without interfering with the computer's control of the ongoing process. Library programs are available as subroutines, and services of the Westinghouse Information Systems Laboratory are available for special program writing.

The hardware includes features that give the Prodac 2000 system much more control capability than other small computers. Among them are 16-bit word length (rather than the more common 12-bit length), 128 input/output channels (4 or 8 is common), up to 65K core memory (16K maximum is common), mass memory, and built-in multiply and divide functions. A typical system measures about 87 inches high by 53 inches wide by 33 inches deep and weighs about 1500 pounds.

Analog-to-digital conversion is performed by a voltage-to-frequency converter and counter. Analog signals are treated by integration for exactly one cycle of the ac line, thereby canceling line-induced noise; 40 such conversions are made per second per converter. Digital input is provided by isolated and filtered 48-volt coupling circuits, while output is by means of mercury-wetted 100-VA relays. Up to 64 individual external interrupts can be obtained in blocks of 16. Process interrupts are classed as external. Buffering the input or output is done by both hardware and software, permitting use of full memory as a single buffer or any combination or division. Priority is by software for all central processor functions.

Typical application functions of the Prodac 2000 system include data logging, monitoring and alarming, operator guidance, analog loop set-point control, direct digital control, feedback and feedforward control, and sequence control.

Primary Distribution Metering Goes Underground

The ever increasing use of underground distribution to serve commercial and industrial customers has created a need for a primary metering service that is fully compatible with the underground distribution system. Such a service was recently installed in Erie, Pennsylvania, by the Northwestern Division Engineering and Meter Departments of the Pennsylvania Electric Company (Penelec). The installation is at Erie Brewing Company. It has two Westinghouse VMP metering units that, because of their compact size and completely sealed construction, provide a practical means of locating 15-kV-class metering transformers below ground level.

The VMP metering unit is designed for use in a standard 36-inch bituminous cylinder, although in the Erie installation a concrete vault was used. A nine-pound magnesium anode was placed beside and connected to the ground lugs of the units to help protect the tanks from possible electrolysis. Cost is comparable to the total cost of individual transformers assembled in an above-ground enclosure.

Two 15-kV primary metering units were installed in a concrete vault for an underground distribution system.

The VMP metering unit consists of three potential transformers and three current transformers located under oil in a stainless-steel tank. The potential transformers are rated 7200 to 120 volts with 0.3 accuracy through Z burden. Current transformers are 150- to 5-ampere ratio with rating factor of 1.5 and 0.3 accuracy through B2.0 burden.

The welded tank cover mounts six plug-in receptacles for incoming and outgoing primary cables. Also located on the cover are a 5-kV-class neutral bushing, nameplates, and oil filling plugs. Secondary color-coded cable leads extend from the tank wall through an oil- and water-tight connection.

Radioisotope Thermoelectric Generator Employs Heat Pipe

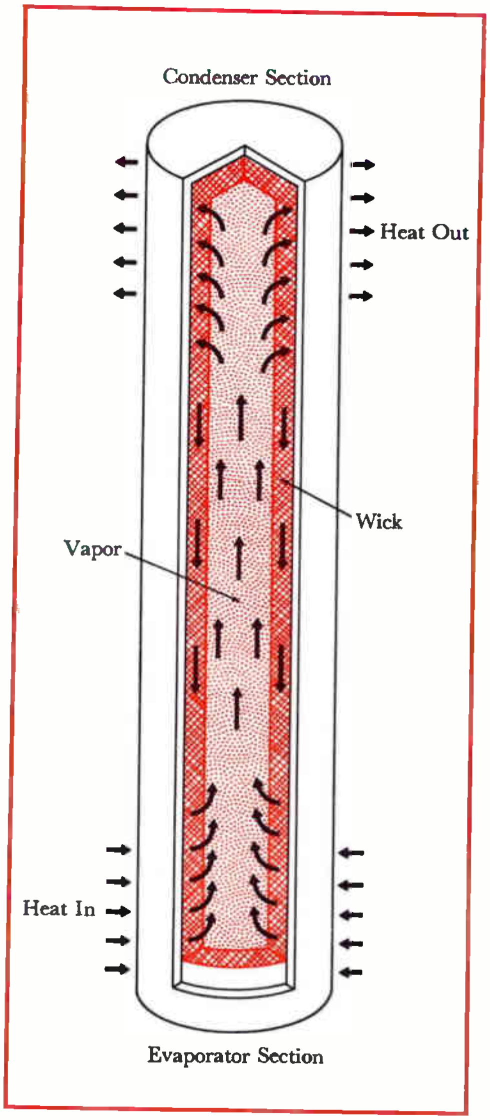
A thermoelectric power generation system developed for the California Institute of Technology's Jet Propulsion Laboratory is the highest power radioisotopeheated device built to date for the space program. It also has the highest efficiency of any such device built so far. Output of the unit is about 120 watts (3.5 volts at 34 amperes), and efficiency is nearly six percent.

The generator consists of a heat source, a heat pipe, a thermoelectric module, and a radiator. Thermal energy produced by the radioisotope heat source is transferred to the interior of the tubular thermoelectric module by the heat pipe and flows outward through the module to the radiator. The interior of the module is the hot side of the thermoelectric couples, and the radiator is the cold side.

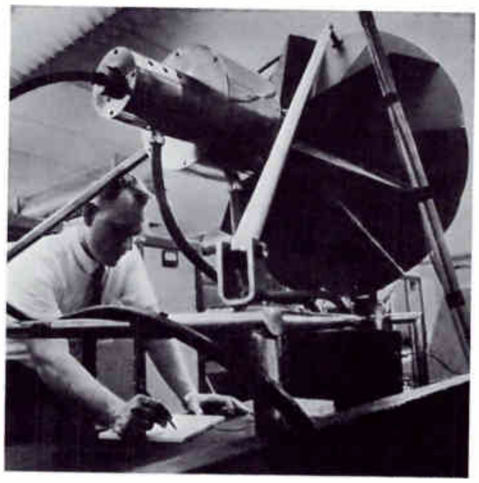
The generation system puts to use the heat transfer capability of the heat pipe, which up to now has been confined largely to laboratory development. The heat pipe is highly efficient, transferring almost 100 percent of the heat applied to its evaporator section at one end to the condenser section at the other end. (See photograph of heat pipe on outside back cover.)

The tubular thermoelectric module used can operate in air, inert gas, or even submerged in liquids. Tests show that it can resist impacts as great as 10,000 g and is not sensitive to thermal cycling or moderate overheating.

The power generation system was developed by the Westinghouse Astronuclear Laboratory.



Top Right—**Heat pipe is a closed evacuated tube with a wire mesh wick around its inner surface. The wick is saturated with a liquid that has a low vapor pressure (sodium in the unit shown in the photo). Heat applied to one end of the pipe vaporizes the liquid. The vapor travels rapidly to the other end, where it condenses and releases its heat of vaporization. The liquid is drawn back to the evaporator end by capillary forces in the wick.**



Right—**Prototype radioisotope thermoelectric generator consists of a heat source, a heat pipe to conduct thermal energy from the source, a thermoelectric module, and a radiator that dissipates heat from the cold side of the thermoelectric module. In the test shown, electrical heaters were used in place of a radioisotope power source; the power line for the heaters enters the unit's hot end at upper left. The radiator is on the right.**

Carbon Dioxide Monitor Is Simple and Reliable

A new kind of carbon dioxide monitor has been developed to warn of dangerous levels of carbon dioxide in diving systems, undersea craft, and other closed environments. The instrument runs continuously, forcing air through a cylinder of lithium hydroxide granules. Carbon dioxide in the air reacts with the alkali to form water vapor, and the concentration of water vapor is measured electrochemically with a dewcell hygrometer. Readings appear on a scale that converts water concentration to carbon dioxide concentration.

The monitor requires less attention and maintenance than do the continuous monitors now in use, which employ schemes based on heat conduction or infrared radiation effects to measure carbon dioxide concentration directly. It is also expected to cost much less, and it is more accurate under high pressure. Moreover, its accuracy is virtually unaffected by inconstancies—such as changing pressure and composition of an artificial atmosphere, or fluctuating power supply—that tend to cause serious errors in other monitors. The monitor was developed at the Westinghouse Research Laboratories. Its initial use will be in the Westinghouse Cachalot diving system.

Products for Industry

Computer-room air conditioner has solid-state modular humidity and temperature controls for automatic and precise environmental regulation. It filters the room air and controls air temperature to 72 (plus or minus 2) degrees F and relative humidity to 45 (plus or minus 5) percent. The close humidity control minimizes static electricity and provides consistent texture and dimensional stability of cards and paper; temperature control reduces malfunctions in the computer electronics and provides a consistently comfortable atmosphere. Air filtering protects tapes from dirt and dust. All major components are doubled—two compressors, two condensers, and dual electrical and protective devices. If one unit fails, the air conditioner continues to operate at half capacity until the defective unit is repaired. *Westinghouse Architectural Systems Department, 4300 36th Street, S.E., Grand Rapids, Michigan 49508.*

High-frequency arc stabilizer enables owners of ac or dc arc-welding power supplies designed for standard coated-electrode welding to add tungsten-inert-gas (TIG) welding capability. The stabilizer gives the required stability to arcs struck with the noncoated TIG electrodes, keeping the arc alive on ac and avoiding contaminating touch starts on both dc and ac. TIG capability allows welding of aluminum, magnesium, stainless steel, brass, copper, and other hard-to-weld metals. Moreover, arc stabilization can raise the quality of standard coated-electrode welds. The stabilizer is rated 500 amperes at 60 percent duty cycle. *Westinghouse Welding Department, P.O. Box 300, Sykesville, Maryland 21784.*

Cleaning and packaging facility for small parts consists of a three-stage ultrasonic cleaner mounted in a bench-type clean work station. The station uses vertical laminar air flow to help isolate the working surface from outside contamination and thus permit handling and packaging of equipment immediately after cleaning without recontamination. The ultrasonic cleaning stages include a solvent degreaser and a vapor degreaser with boil sump area for vapor rinsing. Each five-gallon tank has a 20-Hz Magnapak transducer powered by a 300-watt Magnaline generator, both mounted beneath the work area. *Westinghouse Industrial Equipment Division, 2519 Wilkens Avenue, P.O. Box 416, Baltimore, Maryland 21203.*

Services for Industry

Oil testing and gas analysis help prevent in-service breakdown of oil-filled transformers. The oil testing service determines whether contaminants known to cause transformer failure are present and recommends either replacement of the oil or the preferred method of cleaning it. The gas analysis service detects gases in the oil that are related to specific transformer malfunctions, and it tells the user where to look for possible trouble. *Westinghouse Electric Service Division, Chatham Center Office Building, P.O. Box 1017, Pittsburgh, Pennsylvania 15230.*

Pressure facility for testing deep-submergence undersea equipment can achieve 13,500 psi, equivalent to 30,000-foot depth. Its pressure chamber's test volume is 30 inches in diameter by 60 inches long. The test medium is simulated seawater, and a high-capacity heat exchanger in the chamber controls temperature. Electrical penetrations permit operation of the equipment being tested under pressure. The chamber's control system is completely instrumented and has provisions for automatic temperature and pressure cycling. *Advanced Systems Marketing, Westinghouse Aerospace Electrical Division, P.O. Box 989, Lima, Ohio 45802.*

High-Frequency Arc Stabilizer

Cleaning and Packaging Facility

CAMPTURN, a Westinghouse computer-based CAMP service, reduces the costs, errors, and lead time required for manual programming and punching of control tapes for numerically controlled lathes. The service employs an easy-to-learn conversational programming language. It gives parts programmers direct access to large computers that converse with the programmer, make all the necessary calculations, detect errors, optimize machining operations, and then punch out the control tapes at the programmer's terminal. *Westinghouse Manufacturing Information Systems Department, 2040 Ardmore Boulevard, Pittsburgh, Pennsylvania 15221.*

New Literature

All In One (SA 8850-2) is a comprehensive guide to meter and instrument-transformer application in both single-phase and polyphase systems. It also contains a condensed watt-hour meter course that describes the operating principles and test procedures for the various types of meters. The guide outlines calibration and testing procedures, with the aid of test-connection diagrams and internal-wiring diagrams. In addition, it defines standard meter constants and gives equations for deriving those constants as well as for calculating meter accuracy. The guide is published by the Westinghouse Meter Division. Price, $1.25. Order from *Westinghouse Electric Corporation Printing Division, Customer Service Department, Forbes Road, Trafford, Pennsylvania 15085.*

About the Authors

Paul E. Couture graduated from the University of Notre Dame in 1962 with a BS degree in electrical engineering. He joined Westinghouse on the graduate student training program. His first permanent assignment was in the Electric Utility Control Systems Division, first as a design engineer in analog circuitry and then as a project engineer in analog dispatching systems. He continued with the division when it became the Power Control Division in 1963, serving as a project engineer in communication and control systems for the Bay Area Rapid Transit test project. He contributed to the design and development of automatic train control systems both for the BART project and for the Transit Expressway demonstration near Pittsburgh.

Couture became part of the former Computer Systems Division, when it was formed in 1965, as a development engineer for computer analog input systems. He is now an application engineer at Hagan Computer Systems Division, applying computers and control systems for the electric utility industry (primarily in the area of power systems operations).

Jerry C. Russell earned his BSEE at Iowa State University in 1956 and has since done graduate work in electrical engineering at the University of Pittsburgh. As an undergraduate, he worked summers for Iowa Power and Light Company as an engineering trainee. He joined Westinghouse Apparatus Service in 1956 as a supervisory field service engineer.

Russell transferred to the Power Control Division in 1962 to do design engineering on automatic dispatching equipment. He moved to the former Computer Systems Division in 1965 as an application engineer for power system control equipment. The following year, he was made District Engineer in the San Francisco District Electric Utility Sales Office. He returned to Hagan Computer Systems Division early this year, where he works on computer applications for power systems. He has contributed to the development and use of computers for substations, automatic power dispatching, and data acquisition.

R. L. Gasperetti graduated from New Mexico State University with a BS degree in electrical engineering in 1951, and he has since completed the requirements (except for the thesis) for an MSEE at the University of Pittsburgh. He joined Westinghouse on the graduate student training program and went to the Aviation Engineering Department (now the Aerospace Electrical Division). Gasperetti served until 1960 as a design engineer, responsible for design and development of aircraft voltage regulators and electric power system controls. He was then appointed Supervisory Engineer with responsibility for control and conversion apparatus, including variable-speed constant-frequency systems.

Gasperetti became Manager, Power Conditioning Systems, in 1963, a post that included supervising the development of the static inverter system for the Apollo spacecraft. In 1965 he was made Manager, Generator Systems Section, with engineering responsibility for ac and dc aerospace generators.

Hugh G. Houser and **John A. Reker** both work in the Westinghouse Power Systems Planning Department, evaluating long-range trends and needs of the electric utility industry.

Houser, a graduate of the University of Pittsburgh with both a BS and a BSEE, joined Westinghouse in 1960. After completing the company's advanced design school in 1961, Houser worked on the development and application of digital computer programs for electric utility long-range economic planning. He was transferred to his present position in the Power Systems Planning Department in 1967, where he is concerned with determining the technical needs of the electric utility industry and developing methods for improved economic analysis of electric utility generation problems.

Reker graduated from Yale University in 1961 with a BEME. He came with Westinghouse on the graduate student training program and, after completing engineering school, was assigned to the engineering section of the Elevator Division.

In 1962, Reker took military leave to serve three years in the U.S. Navy. He returned to Westinghouse in 1965 to join the generation marketing section of what is now the Power Systems Planning Department. He has worked on studies concerning marketing organization and on analyses of the electric utility industry. In addition, he has organized and conducted five training seminars in electric utility economics. Reker was in charge of a one-year forecasting and electronic data processing project to develop in detail the future generation equipment needs of the electric utility industry. The data developed provide much of the background for the article in this issue.

Ray Whitt earned his BSEE degree at Auburn University in 1951 and joined Westinghouse on the graduate student training program. His first permanent assignment was at the Manufacturing and Repair plant at Atlanta, Georgia, where he served first as a draftsman and then as a switchgear engineer. He moved to the Aerospace Electrical Division in 1962 as a senior design engineer.

Whitt was made Engineering Manager of the Low Voltage Distribution Equipment Division facility at St. Louis later that year, and in 1964 he was transferred to division headquarters in Pittsburgh as Supervisor, Switchboard Development. His next assignment, in 1965, was as Manager, Standard Development, at the division's Chicago facility, a post that included responsibility for development of motor control centers and distribution switchboards. In 1968 he became Consulting Engineer at the Standard Control Division (now the Low Voltage Breaker Division), carrying out liaison between the main plant and other plants, foreign licensee contacts, and liaison with the Marketing Department on technical publications.

Thomas W. Slebodnik joined Westinghouse in 1944 in the Small Design Breaker Department, Switchgear Division. He earned his BS degree in electrical engineering at Carnegie Institute of Technology in 1948 and then worked as a design engineer on molded-case circuit breakers at the Standard Control Division. In 1955 he received his MS in electrical engineering from the University of Pittsburgh.

Slebodnik became Section Manager, Circuit Breakers, in 1960. He was made Section Manager for the High Power Laboratory at the Standard Control Division in 1963, and since 1966 he has been Supervising Engineer, Design and Development, Circuit Breakers.

Slebodnik has been responsible for development of large molded-case circuit breakers and the Tri-Pac breakers, and he was instrumental in the design and construction of the High Power Laboratory. He is the liaison man between the Low Voltage Breaker Division and the Research Laboratories for projects relating to molded-case circuit breakers.

David R. Smith and **W. Paul Matty** join forces to discuss the spot network system in this issue. Smith concentrates on system design, and Matty's interest is the network protector.

Matty graduated from the University of Pittsburgh with a BSEE in 1951. He came with Westinghouse on the graduate student training program. After attending sales school early in 1952, he was assigned to the Distribution Apparatus Department and given product engineering responsibilities for distribution equipment, working with Westinghouse field salesmen and utility engineers. In 1958, Matty moved to the Switchgear Division. He assumed his present position of Assistant Product Manager, responsible for network protectors, power fuses, and indoor air switches, in 1968.

Smith graduated from Penn State with a BSEE in 1963 and came to Westinghouse on the graduate student program. He earned his MSEE from the University of Pittsburgh in 1968. After attending the company's advanced design school in 1964, Smith went to the Electric Utility Headquarters Department (now Power Systems Planning Department) to work as a distribution engineer. A year later, Smith transferred to the advanced development section to work on utility short-circuit, load-flow, loss-formula, and stability studies. In early 1967, he returned to distribution engineering and presently works on the design and application of spot and grid networks.

The "heat pipe" being demonstrated here glows uniformly along its full length, illustrating its unique heat-transport properties. Temperature along the length of the heat pipe is uniform, unlike a solid rod's large reduction in temperature with length. The device transfers more than 500 times as much heat as any solid rod of the same diameter. Operating temperature for this unit is about 1350 degrees F; for the demonstration, the heat was provided by an induction coil. Only a laboratory curiosity until recently, the heat pipe has now been put to use by the Westinghouse Astronuclear Laboratory in a radioisotope thermoelectric generator. For more information, see page 94.