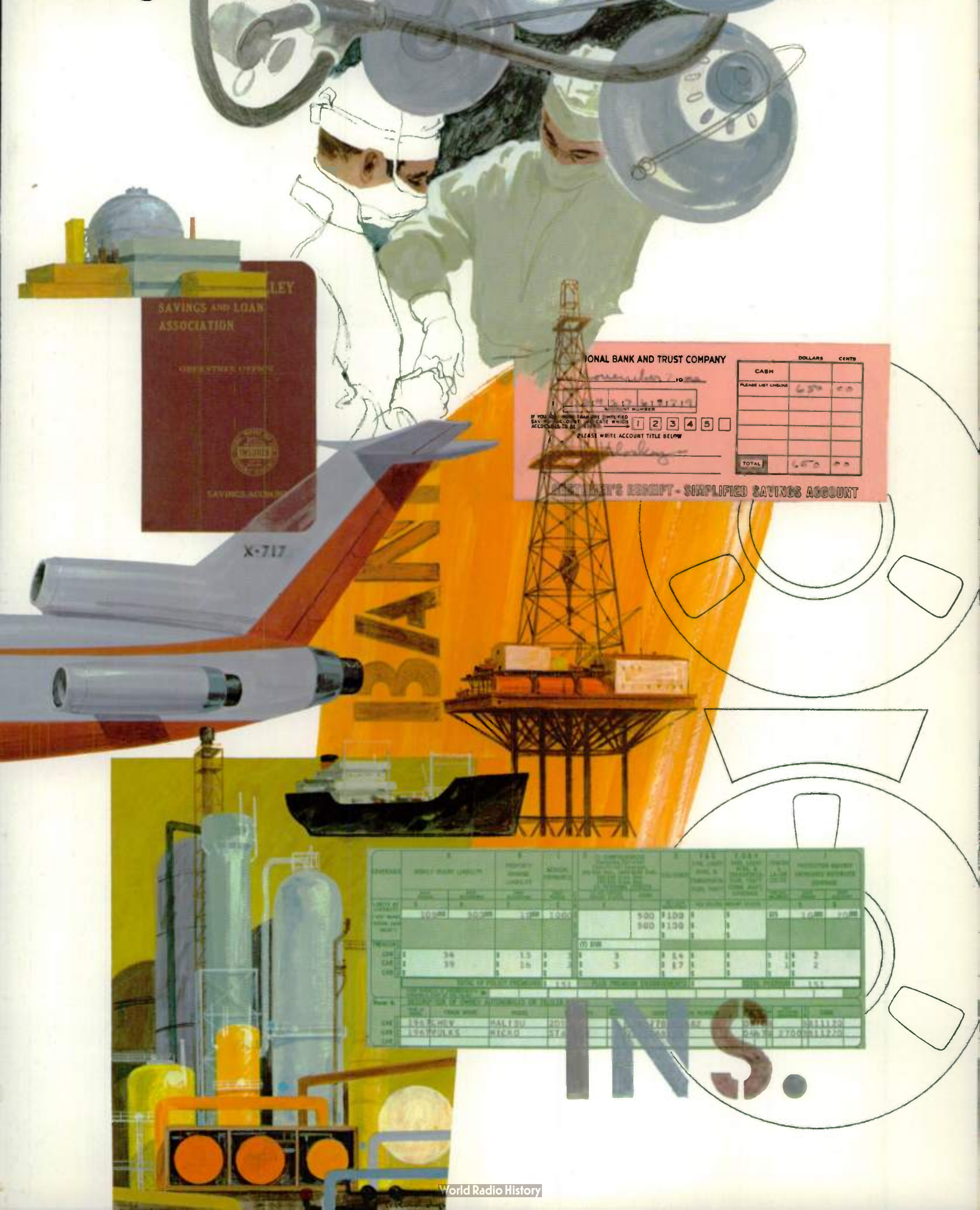
Westinghouse ENGINEER

November 1973



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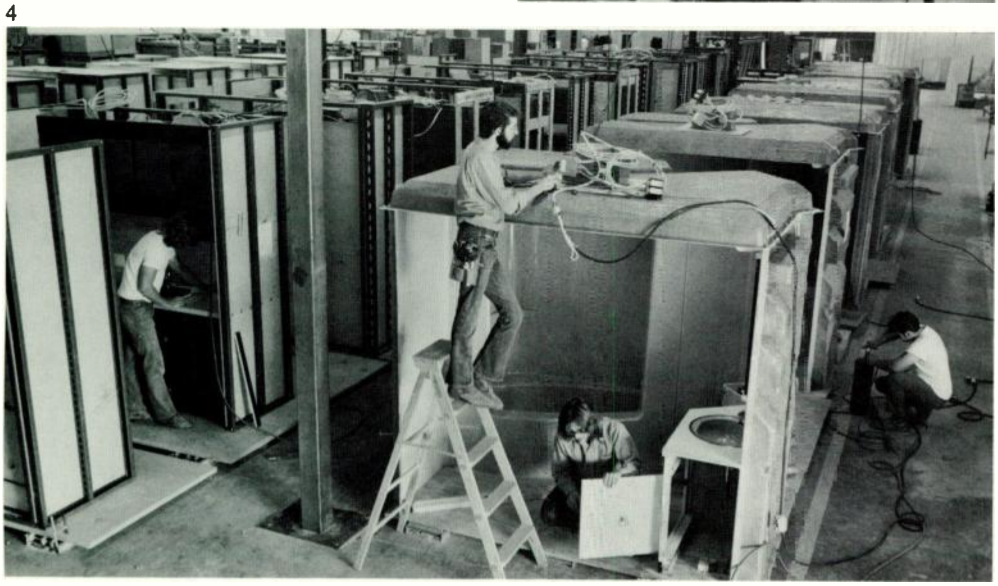

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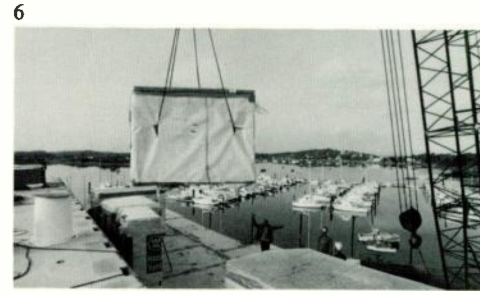

Everything Including the Kitchen Sink

Use of factory-built interior subsystems is speeding construction of Weymouthport, a residential and recreational complex near Boston, Massachusetts. The Westinghouse subsystems include kitchens, bathrooms, and utility centers (Figs. 1, 2, and 3).

The full and half bathrooms being used are completed off the job site, down to mirrors and towel racks (Fig. 4). So are the galley and L-shaped kitchens, each of which has a range with hood, refrigerator, dishwasher, waste disposer, cabinets, countertops, and undercounter lighting. The utility centers include water heater, stacked washer and dryer, electrical load center, and a combined heating/ventilating/air-conditioning module.

The subsystems are loaded onto trucks at the factory to be hauled to the job site (Fig. 5). As framing for a floor nears completion, the subsystems are hoisted into place (Fig. 6). They are connected to utility lines, finishing work is done, and construction is started on the next floor.

The Westinghouse subsystems are used by the developer with the Echo Module System of concrete multistory construction, which involves manufacture of two-dimensional elements that are assembled in the factory into three-dimensional building modules. The Echo system is licensed to developers and architects by Echo Module Systems, Inc., Quincy, Massachusetts.

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Front Cover: Applications of electronic controllers and data-processing computers suggested in this month's cover design include power plants, hospitals, banks, airlines, offshore drilling platforms, insurance businesses, and refineries. Although the applications differ greatly, the electronic equipment for all of them has a common requirement—a reliable supply of high-quality ac power. Static uninterruptible power supplies that provide such power are described in the article beginning on the following page. The cover design is by Tom Ruddy.

Uninterruptible Power Supplies Provide Insurance for Critical AC Loads

C. G. Helmick

Computers and other critical ac loads are vulnerable to fluctuations in input voltage and frequency as well as to complete power outages. The problem is solved by inserting a UPS system between the critical load and the commercial power supply.

Many of the functions and services that people have come to depend on are provided by sophisticated and interconnected electronic systems. Examples of such systems are data-processing computers and process controllers of various kinds and sizes. A common factor in all is the need for a class and reliability of power that is beyond the ability of commercial power systems to supply.

For example, most large computers require that input voltage never exceed plus 10 percent or minus 8 percent of nominal voltage for even a millisecond. Otherwise there is probability of data errors, protective shutdown, loss of real-time information, or upsetting of important system operations. The economic consequences of errors and loss of service can be incalculable in such applications as banking, airline operations, the insurance business, industrial processes, and other large data processing areas.

However, it is impossible for commercial power sources to provide such service so long as they must supply common power to many customers. Even the best utility is exposed to the fault transients of its customers, lightning surges, operating switching surges, and the like. Adding to those problems are power shortages in some areas, which reduce reserve margins and can result in brownouts that aggravate the transient problem.

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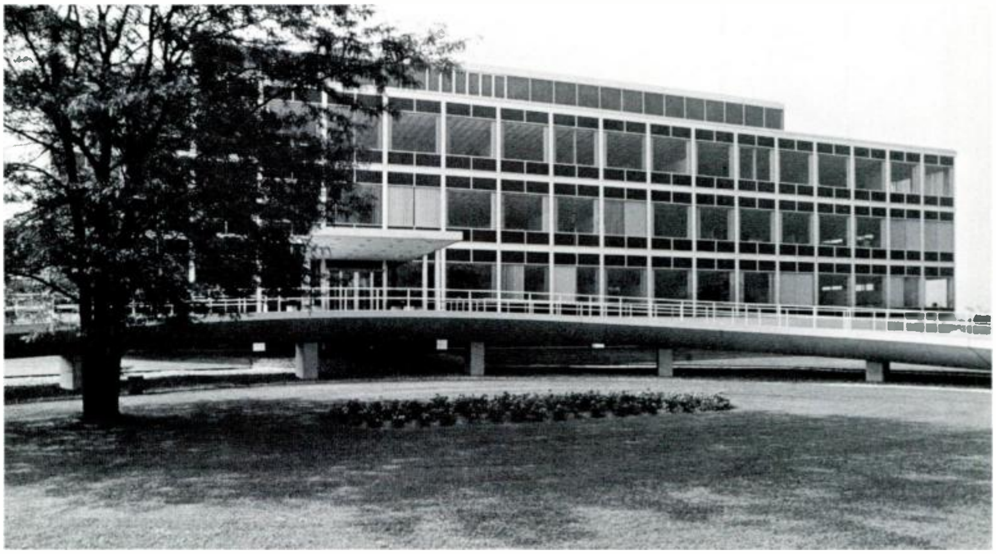
For many users of critical loads, a static uninterruptible power supply (UPS) system solves the problems. Although various forms of flywheel m-g sets have been used in the past, the static UPS system has emerged as the system most capable of satisfying the demands of performance, reliability, and total cost effectiveness. A wide range of applications has been successfully met by static UPS systems of all ratings, from small ones for boiler flame detectors, fossil and nuclear power-plant instrumentation, offshore drilling and production platforms, and petrochemical process controls to larger systems for instrumentation and data processing in hospitals, banks, insurance companies, airlines, communication systems, electric utility systems, etc. Sizes range from less than 1 kVA to more than 1 MVA.

Several case histories are given in this article to illustrate how static UPS systems are used and justified in different applications. The system configuration of each is tailored to the specific needs of the application, so the case histories illustrate the flexibility of the basic UPS system in solving specific problems. First, however, the operating principles of the static UPS system are reviewed.

Operating Principles

The basic static UPS system consists of an inverter, a rectifier-charger, and a stor-



The home office of Connecticut General Life Insurance Company, Bloomfield, Connecticut, includes a computer facility. To prevent data errors and processing interruptions, power is supplied to the computers by way of a Westinghouse uninterruptible power supply system. The system includes a battery and static electronic equipment that converts commercial ac power to the precisely controlled ac power required by computers.

age battery (Fig. 1). Circuitry and system configurations change for different applications, but those main elements are always present.

The inverter operates from a source of dc power and produces an output of precisely controlled computer-grade ac power. Normally, the dc power for it is furnished by a regulated rectifier/charger supplied from the commercial ac power line. The battery is the alternate source of dc power; it is connected to the dc bus at all times.

If the commercial source of power goes outside normal limits or fails altogether, the battery immediately takes over the dc load with no switching. The inverter operates from either source of dc power without disturbing its output ac voltage. When the commercial source returns, the rectifier-charger resumes its normal role of feeding the inverter and at the same time recharging the battery.

Small Westinghouse UPS systems, such as the one described in the fourth case history here, employ single-phase inverters. The larger ones have AccurCon three-phase inverters.

The AccurCon three-phase inverter has a unique circuit concept that gives unmatched reliability and the ability to isolate internal faults safely. Its individual single-phase inverter stages are combined in such a way as to produce a three-phase output with true 120-degree phase separation, permitting achievement of large power ratings with superior waveform even before power filtering.[1,2] The design results in very fast response to any transient disturbance. It also provides a form of internal redundancy that yields higher reliability than other types of inverter that have fewer devices.

For larger power ratings than can be supplied from a single inverter (about 250 kVA with present semiconductor devices), several inverters are paralleled and rigorously controlled to share load properly. Such paralleling provides UPS system ratings up to 2000 kVA and more. Systems with paralleled inverters often have a fully redundant configuration, as described later, to reduce the economic consequences of a failure in any part of the UPS system.

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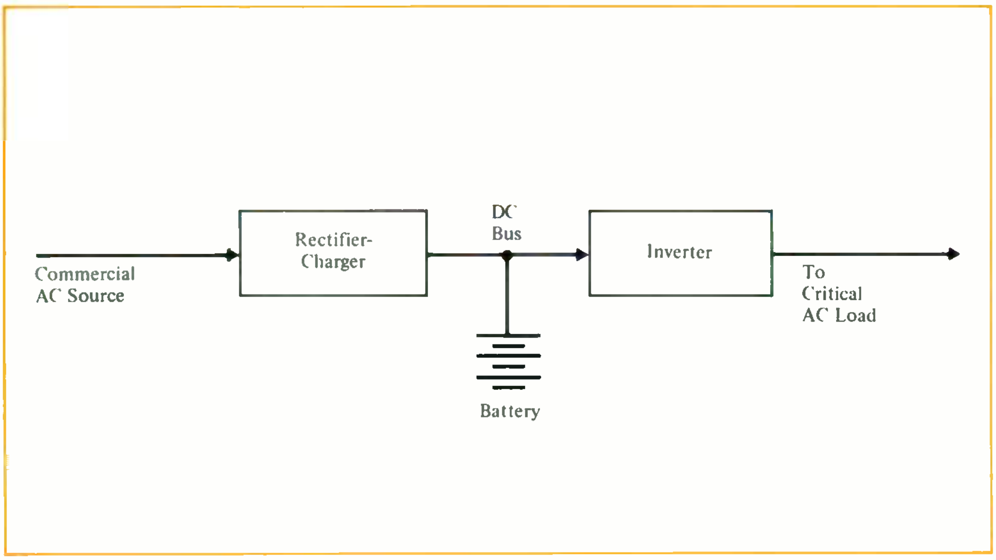

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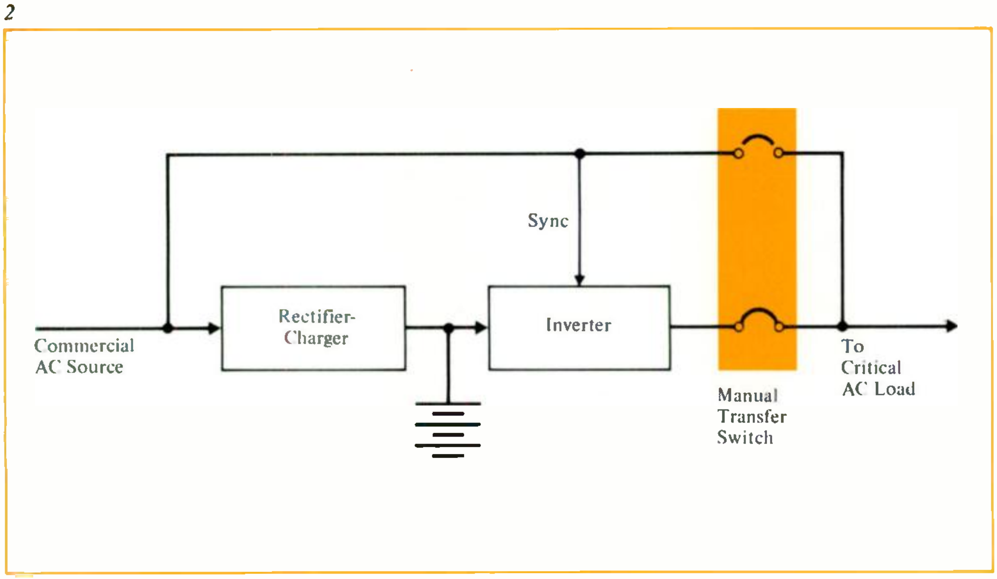


Case Histories

Manufacturing Plant—A data-processing computer schedules and monitors production throughout the Westinghouse transformer plant at South Boston, Virginia. Production status is updated in a real-time on-line fashion via 20 data-collection units strategically placed in the plant, and immediate inquiry is available via 10 other terminals. The system measures reported progress from order entry to shipment against a plan and isolates deviations for corrective action.

The computer receives its power from a relatively long transmission line exposed to many transient disturbances. At certain times of the year, the frequency of line disturbances caused by lightning is intolerable. The computer manufacturer recommended use of a static UPS system, leading to the installation discussed here.

1—Essential elements of a static UPS system are a rectifier-charger, an inverter, and a battery that supplies power if the commercial source fails or goes out of limits.

2—A UPS system with a manual make-before-break transfer switch is illustrated by this simplified schematic diagram. The switch, which consists of two circuit breakers, is used to take the UPS system out of service for maintenance. The inverter's output frequency is synchronized with the frequency of the commercial power source.

The 75-kVA UPS system is diagrammed in Fig. 2. A manual transfer switch in the output of the system permits uninterrupted transfer of the critical load to the commercial source in the event it is desired to take the UPS out of service for maintenance.

The system has eliminated computer shutdowns, damage, and other problems (such as data errors) arising from the commercial power source. Since such problems can cost many thousands of dollars, the economic payout from the investment was realized in the first year.

Banking—Another operation needing protection is bank data processing, illustrated by an installation at San Diego Federal Savings and Loan. Reliability of system operation was the foremost goal, and the main hazard was the high level of lightning disturbances through the year in that geographical area.

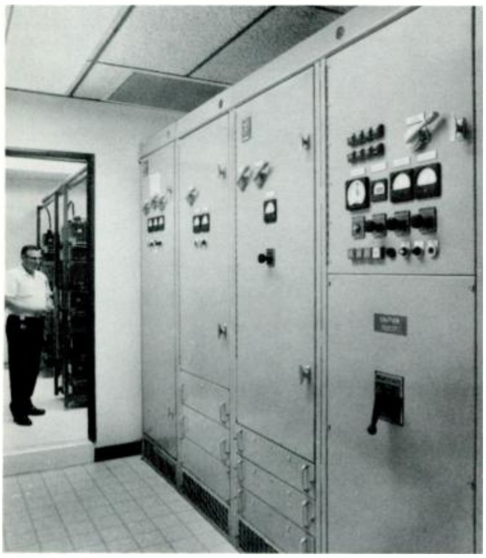
To protect the vital data-processing operations, a 75-kVA UPS system was installed (Fig. 3). The system is augmented by a static transfer switch (Fig. 4). The purpose of the switch is to protect the UPS system itself, as well as the critical load, in the event of internal failure or overloads beyond the capacity of the system. (See *Static Transfer Switch*, p. 165.) In either event, the critical load is transferred automatically to the commercial source while maintenance or corrective action is taken. Load transfer is almost instantaneous and causes practically no system disturbance (Fig. 5).

During the short repair time required, the critical load is exposed to the possibility of disturbances occurring on the commercial power system. However, the probability of a simultaneous utility-system disturbance and a UPS-system overload or failure is statistically remote, making this system configuration a practical and economical choice for supplying a critical load. Economic payout in this application depends on the intangible (but invaluable) customer confidence factor that all banks encounter when utilizing computer-aided transactions.

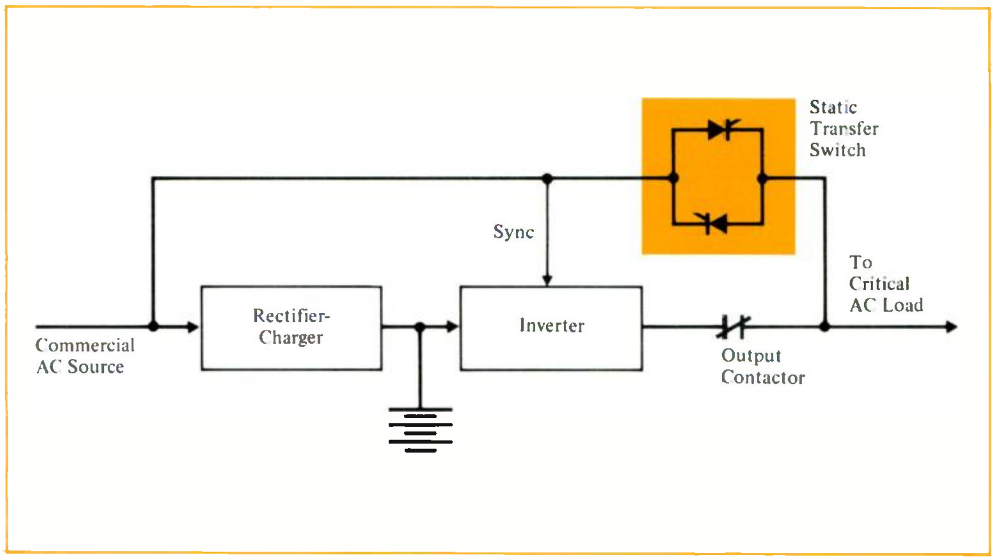
Insurance Business—An enormous volume of data processing is required in many insurance operations. To perform it, the home office of Connecticut General Life Insurance Company employs powerful data-processing computers (see photographs on p. 162). The computers are backed up by 500 kVA of static UPS power.

Four 125-kVA inverters are paralleled to give the total capacity of 500 kVA (Fig. 6). Of that total, 375 kVA is needed by the load. The system configuration therefore carries a fully redundant rating of 375 kVA, meaning that any one unit can be removed from service for any reason without impairing system performance. This arrangement eliminates dependance on a commercial bypass source of power for the critical load, keeping operations completely isolated from the commercial source at all times. An internal fault in any one unit is isolated by that unit removing itself from the critical bus, with negligible output disturbance (Fig. 7).

The economic justification for such installations is easily established since downtime of computer centers like this is



3—*This 75-kVA UPS system protects a data-processing computer at San Diego Federal Savings and Loan. Its battery room can be seen in the background.*

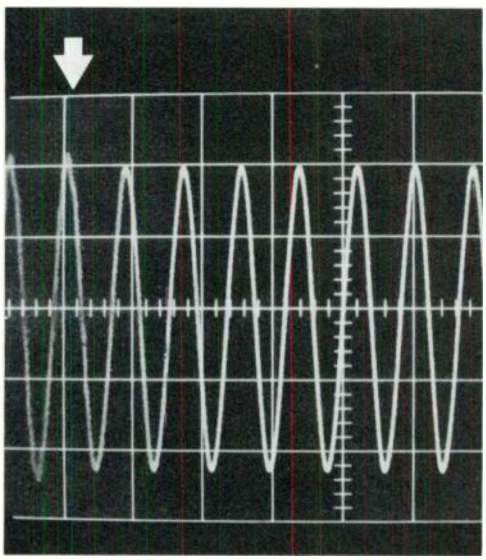


4—*A static transfer switch is used with the UPS system shown in Fig. 3 to provide additional protection for the computer. It automatically switches the critical load to the commercial power source in the event of overloads, load faults, or trouble in the UPS system.*

measured typically in terms of $100,000 and higher per occurrence. Moreover, even a momentary disturbance can upset the computer interrelationships, leading to hours of reprocessing and "catchup" expense.

Petrochemical Plant—At the other end of the power spectrum is the small single-phase UPS system. It has countless applications of a wide and varied nature, with a long list of potential users. Present users include petrochemical plants, electric-utility plants (nuclear and conventional), offshore platforms, department stores, hospitals, instrumentation systems, microwave communication systems, and many more. The UPS system is utilized in those applications to prevent interruption of critical functions, where such an interruption could cause severe economic loss or even jeopardize human life.

An installation at one large petrochemical plant is typical of the trend toward small UPS systems of exceptionally high reliability (Fig. 8). The need and the economic justification for this kind of UPS



5—This oscillograph shows the negligible effect of opening the inverter output circuit breaker, in the UPS system of Figs. 3 and 4, to automatically transfer the load to commercial power by means of the static switch. The inverter output was at 208 volts at the time of transfer (indicated by arrow), and the commercial supply was at 197 volts. Load was 130 amperes.

Static Transfer Switch

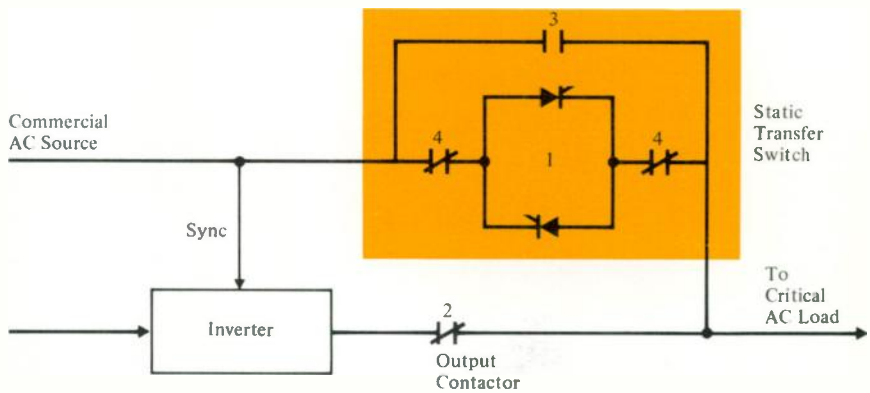
The Westinghouse static transfer switch complements and takes advantage of the AccurCon inverter's unique fault-isolating properties. It has a simple "normally open" static switch (number *1* in the diagram) that puts the UPS system and commercial power in parallel at the moment of transfer. A conventional ac contactor (*2*) completes the transfer by removing the UPS system from service. The UPS system is operated in synchronism with the commercial source at all times, so the transfer is made with only minimum disturbance.

Conventional UPS systems, in contrast, must have in addition a "normally closed" static switch to prevent high circulating currents under conditions of internal failure in the UPS system. The simplicity achieved in the Westinghouse system by having only the "normally open" static switch further improves system reliability and makes testing of the switch itself a very simple procedure.

While the UPS system is operating in synchronism (phase-locked) with the commercial source, the thyristors of the static switch are in the blocking (ungated) state. A sensing panel continually monitors operation of the UPS system and its output with high-speed logic; if voltage goes out of limits, the gates are energized instantaneously, triggering the static switch closed. In three-phase systems, the total sensing and clearing time may be as fast as one millisecond. Because sensing must take place over each fraction of one cycle, sensing time is the predominant factor, with actual turn-on requiring only a very few microseconds. For single-phase switches, sensing time limits the transfer time to 4 milliseconds.

The gating for transfer also initiates a signal to open the UPS system's output contactor, which takes about 50 milliseconds. During the overlap time, the commercial power source determines the voltage to the load. Because the commercial source has much greater fault-clearing capacity, the switch thyristors are furnished with a very high surge rating to take advantage of that capacity for clearing downstream faults. Fuses that are carefully coordinated in type and speed with the semiconductor devices protect the switch if a downstream fault persists.

A "bypass mode" switch (*3*) enables the static switch to be removed electrically from the system for testing or maintenance. Disconnects (*4*) provide further isolation for operator safety during servicing or testing of the switch.



Mode	Switches			
	1 (static)	2 (magnetic)	3 (manual)	4 (manual)
Normal	—| |—	—|/|—	—| |—	—|/|—
Bypass UPS	—|/|—	—| |—	—| |—	—|/|—
Bypass Static Switch	—| |—	—|/|—	—| |—	—| |—
	—| |—	—| |—	—|/|—	—| |—

system stem from the fact that interruption of the critical instrumentation and process controls can result in complete shutdown of the multimillion-dollar operation with consequent loss of time, loss of important work in process, and high expense of restarting.

In this installation, the basic elements of a conventional UPS system are augmented by a static transfer switch and a second UPS system running in a state of readiness (Fig. 9). This configuration is referred to as a "Normal/Standby" UPS system. It is capable of achieving the highest degree of system reliability, comparable to that of the fully redundant configuration discussed earlier.

However, the two 5-kVA UPS systems are not operated in power parallel; one is in a "Normal" role and the other only in a running "Standby" role. Thus, a failure in one UPS cannot propagate to the other and jeopardize its performance as well. The arrangement eliminates the need for the static fault isolators required for units in power parallel, thereby eliminating a major cost and reliability problem.

This system simplification is made possible by use of the static transfer switch, which immediately transfers the critical load to commercial power in the event of overload or failure of the Normal UPS. After the uninterrupted transfer to commercial power, the load is transferred to the Standby UPS, which now assumes the role of the Normal unit. Exposure of the load to any disturbance of the commercial system is reduced to a negligible level.

The critical load is not switched directly from Normal to Standby because it is safer to take advantage of the fault-clearing capability of the commercial power source during the interim period in the transfer process. Small inverters have very limited ability to clear downstream faults, which can cause the UPS system to go into a self-protecting current-limiting mode of operation that adversely affects the critical load. However, the static transfer switch with its very high surge capability instantly transfers any downstream fault to com-

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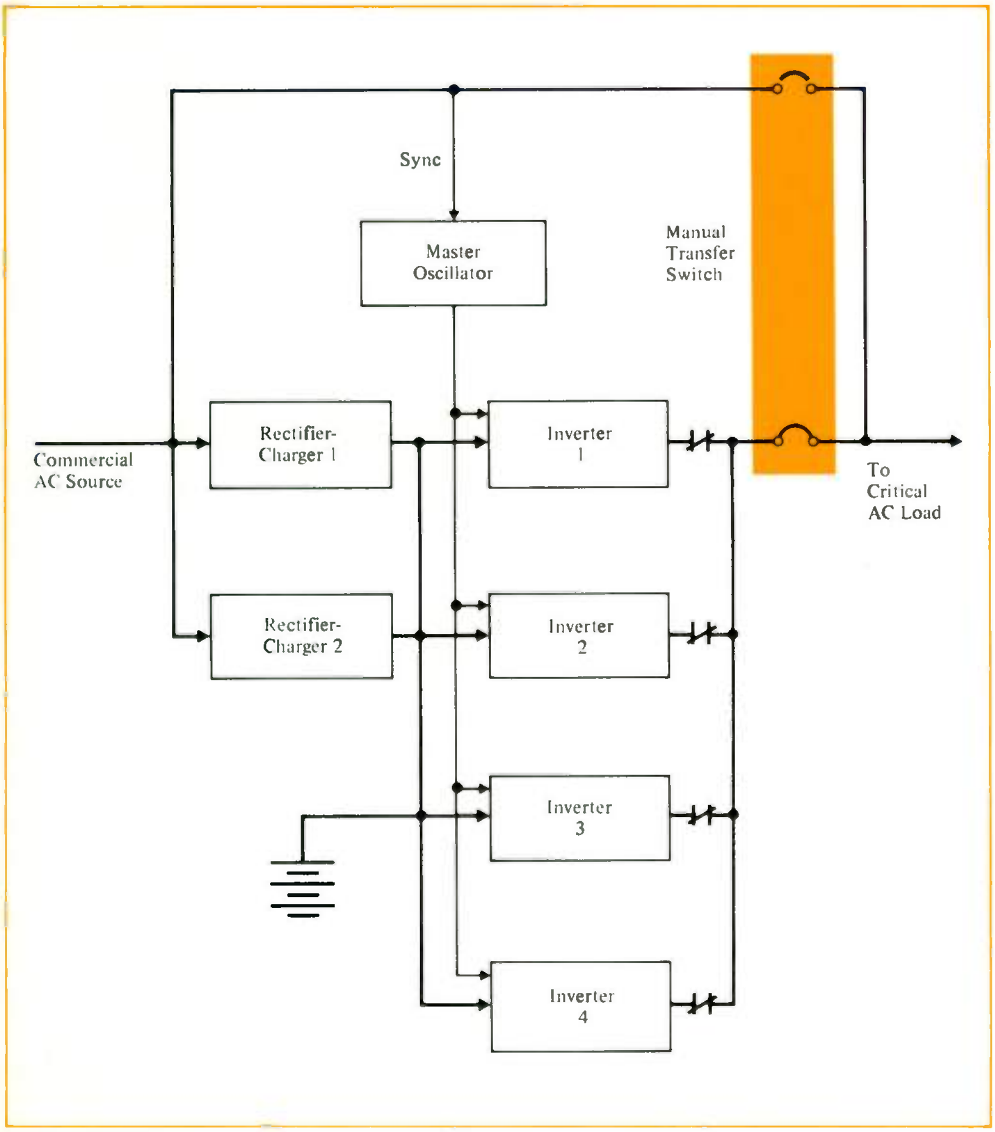

6—A redundant UPS system has one more inverter than is needed to supply the critical load. Therefore, any inverter can be removed from service without leaving the critical load dependent on commercial power. This system includes a manual make-before-break transfer switch to take the entire system out of service if necessary.

7—The effect of a fault in one inverter of a redundant UPS system is shown here. The first arrow indicates when the fault occurred and a thyristor fuse blew; the dip is 3.2 percent. The second arrow indicates removal of the faulted inverter from the critical bus by its ac contactor.

8—This small single-phase UPS system was supplied to a petrochemical plant to protect instrumentation and process controls against power interruptions. It consists of two units, one normally carrying the load and the other on standby to take over the load instantly if necessary.

9—The Normal/Standby UPS system includes a static transfer switch that transfers load, when necessary, from the Normal unit (the one carrying load at that time) to the commercial source. Then the load is transferred to the Standby unit.

mercial power, which is an "infinite bus" by comparison with the UPS. After clearing of the downstream fault, the critical load is retransferred to the Standby UPS system. That transfer is made either manually or automatically, according to the system design.

The roles of the Normal and Standby unit are completely interchangeable. As in all UPS systems using the static transfer switch, UPS output voltage is synchronized with the voltage of the utility line to minimize the disturbance when actual paralleling takes place. Logic inhibiting can be provided to prevent transfer when the utility source is unavailable or out of specified limits.

Conclusion

Not all electronic applications require static UPS systems. Many computers and instrumentation systems are doing less critical work whose interruption is merely a nuisance, resulting in only minor economic loss. For such applications, no protective system may be required or, at most, just a simple m-g set to isolate the load from utility disturbances but with virtually no protection against complete power interruptions.

However, with larger and larger electronic systems doing more and more critical work, the number of systems requiring a static UPS is increasing rapidly. The important consideration is to evaluate critical ac loads and determine how any unscheduled interruption would affect the user economically.

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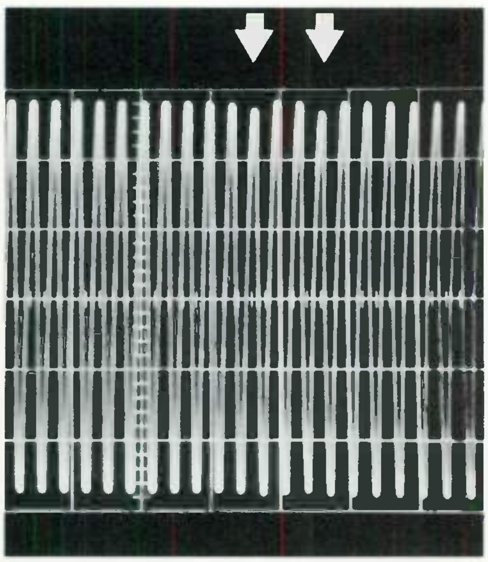

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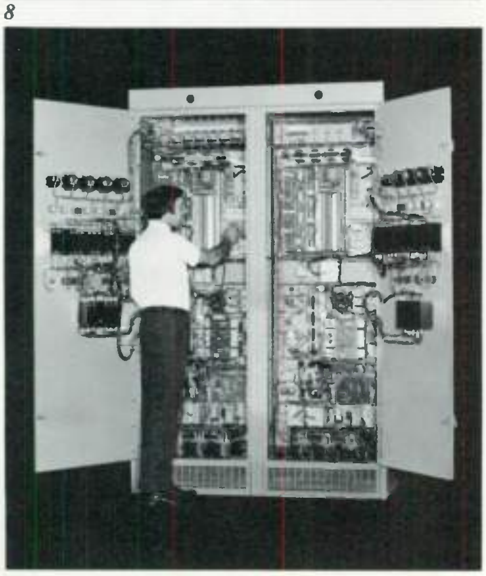

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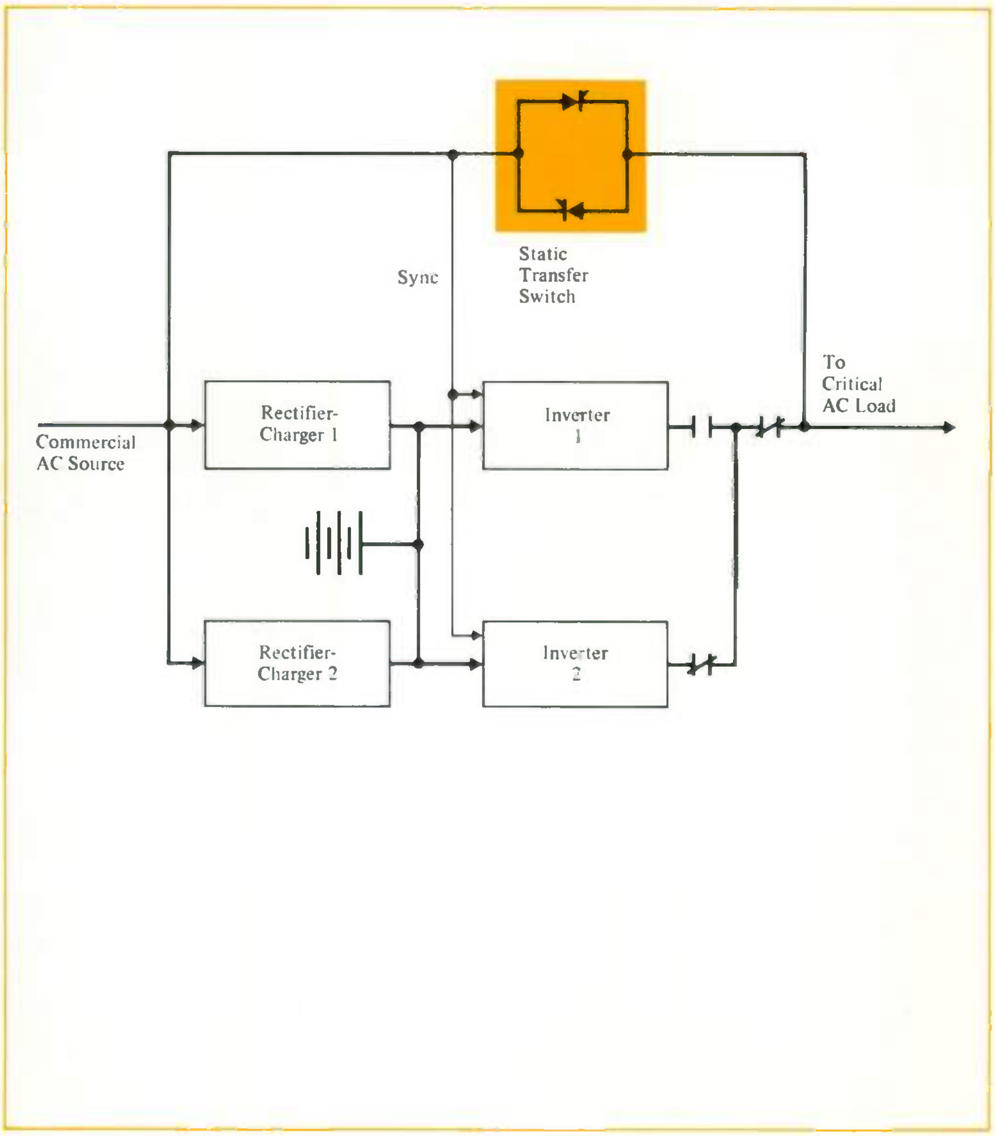

Pole Disagreement Relaying for Independent-Pole Circuit Breakers

C. L. Wagner
E. A. Udren

The benefits of independent-pole-operated circuit breakers to system stability performance were discussed in the first article of this series[1]. Independent-pole operation must be accompanied by pole-disagreement relaying to avoid self-inflicted damage to the breaker by pole disagreements during non-fault situations. The SLB relay has been developed primarily for that purpose.

As discussed in the first article in this series[1], separate pole mechanisms are a requirement for independent-pole operation of breakers, a mode of operation that obviates the most serious threat to system stability—a three-phase fault in combination with a three-pole "hung" breaker. Since it is virtually impossible for more than one pole to fail to interrupt fault current with independent-pole operation, the most serious faults involving two or three phases will always be downgraded by circuit breaker operation, if not entirely cleared.

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Separate pole-operating mechanisms for each phase were originally developed for power circuit breakers operating at voltages of 345 kV and above because of their large operating components and wide phase spacing requirements. Because of the advantages provided by independent-pole operation, however, some 230- and 345-kV oil and dead-tank gas breakers that have previously utilized a single operating mechanism are also being offered with separate pole-operating mechanisms.

Field experience with independent pole mechanisms has shown that it is also necessary to consider the possibility of unsymmetrical operation during nonfault situations. Electrical or mechanical failures have left one phase open when the others are closed, and vice versa. Malfunctioning mechanical systems have occasionally allowed contacts to move to a partially open position, shunting the circuit through opening or closing resistors. Unless such pole disagreements are detected and corrected or isolated, they can evolve into hazardous situations where the affected breaker head arcs internally or externally, resulting in serious damage to itself and failure of insulating support columns.

Even breakers with a single operating mechanism have experienced pole disagreements. For example, lightning or switching surges can cause flashover of an open phase, or a linkage to one phase could malfunction. Some of the following discussion will apply to those situations for single-mechanism breakers, but the emphasis will be on the three-mechanism breaker. For this case, the three complements of trip coils, close coils, and auxiliary contacts are wired together so that all poles operate in unison, unless single- or selective-pole tripping[1] is used. (Selective-pole tripping will be discussed in the third article of this series.)

Breaker Pole Disagreements

Pole disagreements can be grouped into three general categories:

1) A phase trip coil or mechanism, or a close coil or mechanism, malfunctions and, as a result, one circuit breaker pole does

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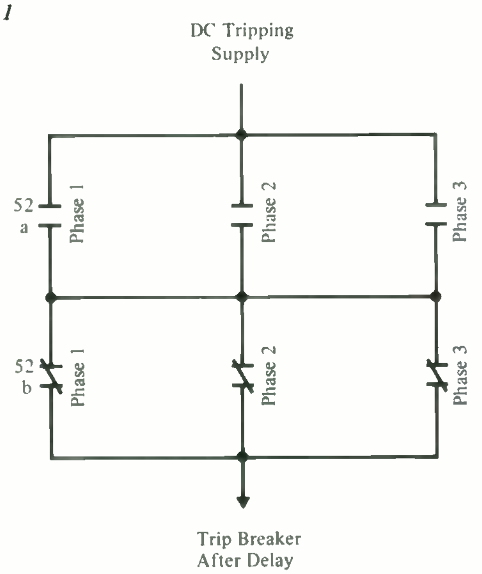

1—Certain unsymmetrical pole closures can be detected by auxiliary contacts. If a pole is closed (a contact closed) at the same time that another pole is open (b contact closed), a path is provided to initiate tripping.

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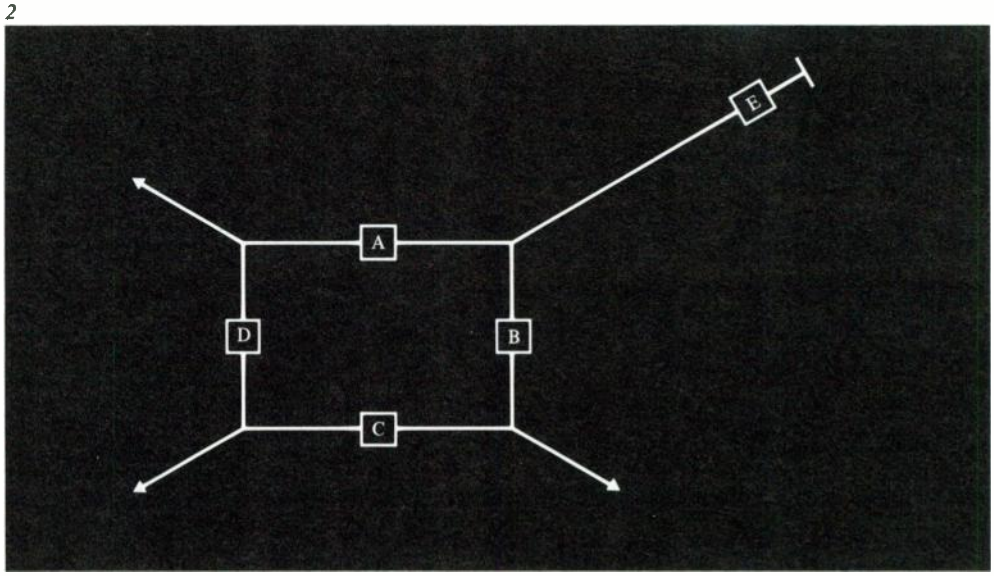

2—A ring bus connected to a remote terminal by a transmission line provides a typical situation where disagreement relaying is needed to prevent unsymmetrical operation of breakers.

not respond to an operating signal.

2) An operating rod or other mechanical component of the operating mechanism malfunctions, leaving the interrupting head stuck in the open, closed, or some partially open position. The preinsertion resistor in the breaker, whose purpose is to reduce transient overvoltages during closing, may or may not be inserted into the circuit. Conversely, if a trip is initiated, a pole may not open or may open only partially and the circuit may still be completed through the interrupting resistor (if such a resistor is used).

3) An open or partially open mechanism may flash over and arc due to lightning, switching surges, or loss of air or gas pressure in an interrupter or pressurized insulating system.

For certain unsymmetrical pole closures in category (1), the breaker can be protected by an interconnection of auxiliary contacts. As indicated in Fig. 1, if any pole is closed at the same time that another pole is open, a path is provided to initiate tripping. A short time delay precedes tripping to allow sufficient time for a sluggish pole to close and avoid unnecessary retripping of the breaker. Backup trip coils are provided with a duplicate interconnection for redundancy.

Disagreements that are not protected by the auxiliary contacts can sometimes be detected during faults by conventional local breaker-failure relays and remote backup relays, which sense a failure to interrupt fault current and initiate tripping of adjacent and/or remote breakers. In the past, however, no automatic means has been provided for detection of disagreements in categories (2) and (3) during non-fault situations. Even if the trip results from relay action, resistor current may continue to flow in one or more poles without being detected or cleared, depending on relay settings. The operator can monitor phase ammeters, but he may not detect all of these conditions or react quickly enough to prevent damage to the breaker.

Pole-Disagreement Detection

When a pole disagreement occurs, both the seriousness of the operating hazard and the behavior of ac relaying quantities that might be used to detect the condition are heavily dependent on the status of adjacent lines and breakers. Consider, for example, a ring bus connected to a remote terminal by a transmission line, as shown in Fig. 2. If all breakers are closed and breaker *A* has an incorrectly open pole, disparity of current flow among the three phases is readily detected on the breaker ammeters. In the meantime, breaker *B* will carry the total phase-A load current. However, if breaker *B* is open, *A* becomes the only source from the bus, and the line will operate unsymmetrically. Significant voltages, which vary with load flow, will appear across the open phase of breaker *A*.

If the remote breaker *E* is also open, shunt capacitive coupling between the live phases and the open phase will result in approximately 1.12 per unit voltage across the failed pole contacts. This condition can be detected only by sensing the difference between line-charging current in the

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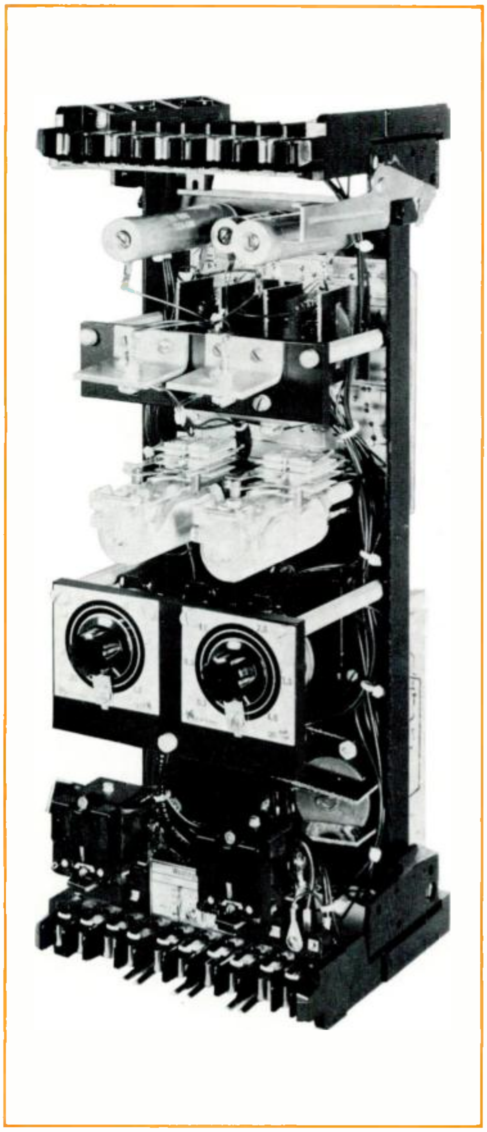

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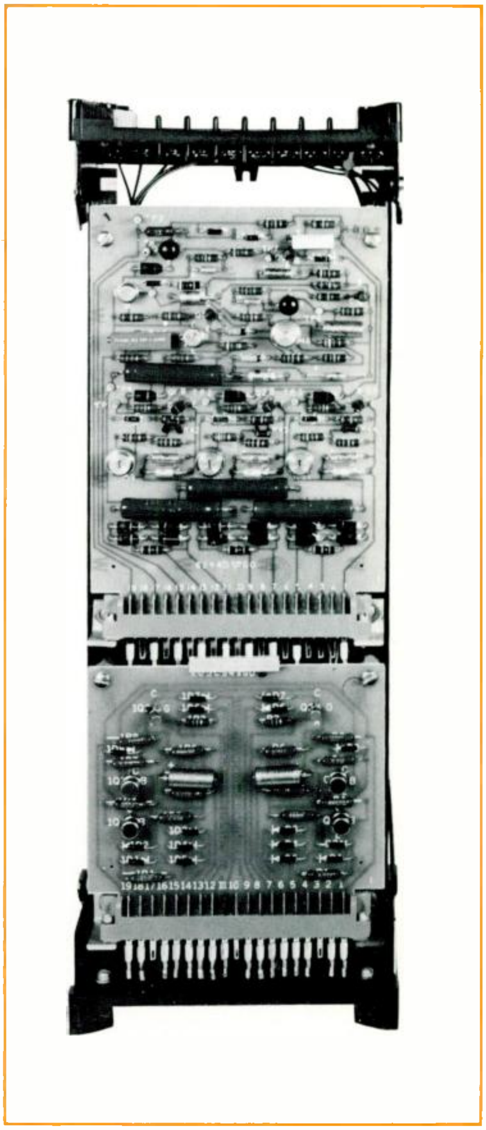


3—Front (a) *and rear* (b) *views of SLB relay illustrate its solid-state construction. Sensitive current sensors differentiate between an open pole and a closed pole carrying line-charging current.*

closed phases and zero current in the open phase. Should arcing occur in the open head, or if it is closed through a resistor, the current flow is balanced and the condition is undetectable. Serious damage to the pole may result.

Consideration and analysis of all possible nonfault pole-failure situations points to three categories into which they can be divided, with regard to means of detection:

1) Those that cannot be detected by any reasonable use of local ac relaying quantities;

2) Those that can be detected by making a sensitive comparison of the phase current values in the breaker;

3) Those in which the obvious disparity of phase currents can be seen on the breaker ammeters. However, this last form of detection requires operator diligence and is only satisfactory for nonhazardous situations where prolonged unsymmetrical operation won't harm the breaker.

Monitoring residual voltage or current

SLB Relay Logic

Three phase-voltage signals, proportional to phase current inputs (I_A, I_B, and I_C), are each connected to a current sensor I_L. The output of each sensor changes from a logic 1 (high) to logic 0 (low) if the respective phase current exceeds 20 mA (note the inverted output).

The three current-proportional voltage signals are also connected together through a maximum-voltage network (*OR 1*) to the I_H level detector, whose output changes from logic 0 to 1 if any of the three phase currents exceeds 65 mA.

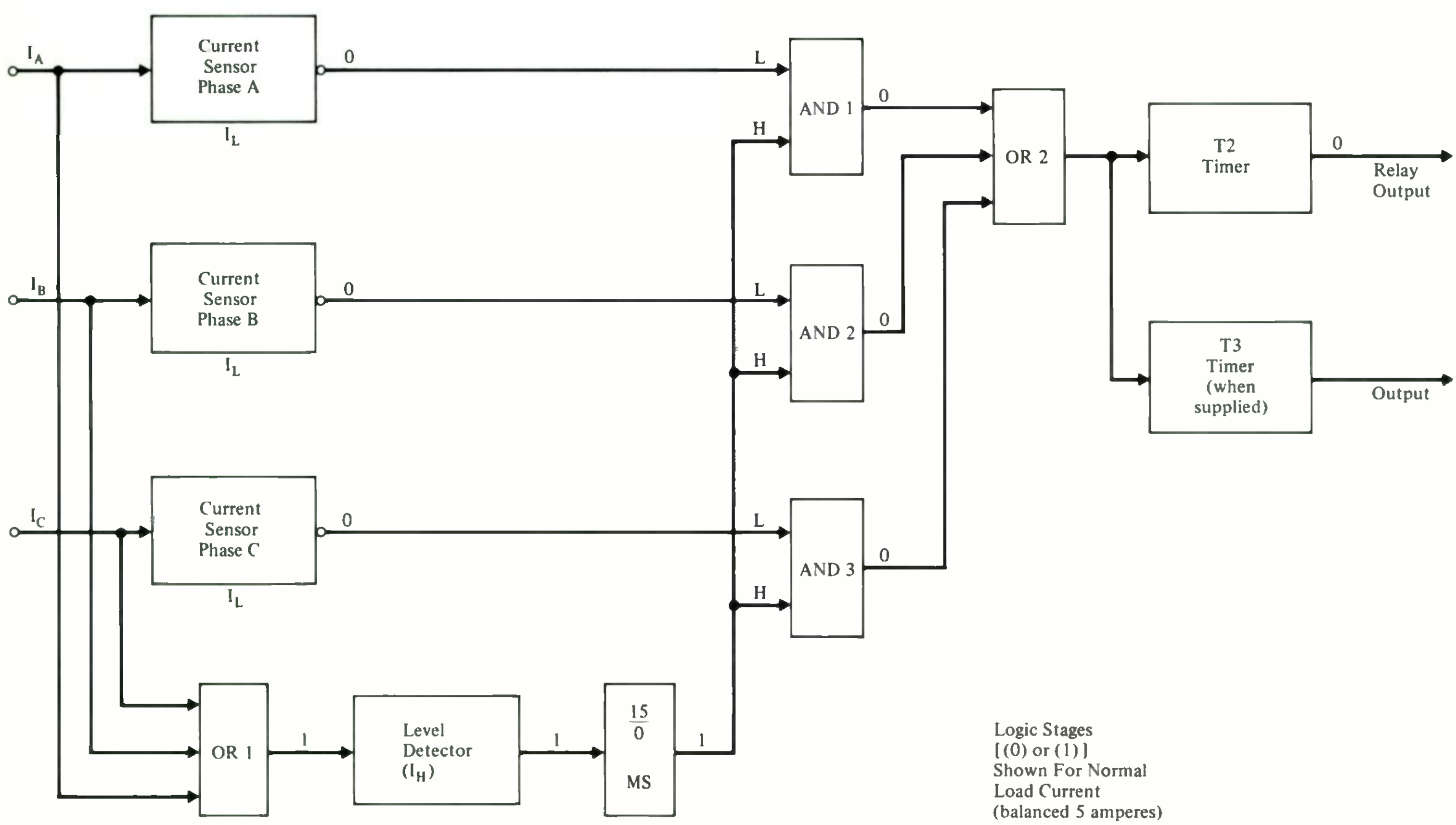
After a 15-millisecond delay, the I_H detector output is ANDed with each of the three inverted I_L outputs (*AND 1, 2, 3*). A logic 1 output from any *AND* gate will start, through the *OR 2* gate, one or two pole-disagreement timers (*T2, T3*). The 15-ms delay prevents energization of the main timer(s) because of a temporary pole disagreement created by a lagging but operative breaker pole during closing.

Consider the behavior of the circuit under balanced and unbalanced current conditions: If the breaker to which the relay is connected is open so that all phase currents are below 20 mA, all three I_L sensors will present a logic 1 to the "L" inputs of their respective *AND* gates. But none of the currents will be sufficient to operate the I_H level detector (65 mA), so input "H" of all three *AND* gates will be logic 0 and the relay will not generate an output.

Next, suppose the line is symmetrically energized and is carrying charging or load current in excess of 65 mA secondary per phase. Now the I_H detector will be picked up and, after a 15-ms delay, a logic 1 will be present at the "H" inputs of the *AND* gates. However, all three I_L sensors will have a logic 0 output so that the pole disagreement timers (*T2* and *T3*) will not be energized.

Finally, consider a pole failure such that one phase, say I_A, is below I_L (20 mA), while another, such as I_B, is above I_H (65 mA). I_B will pick up the I_H level detector through *OR 1*, and input "H" of all *AND* gates will be a logic 1 after 15 ms. The I_L sensor for phase *A* will not be picked up, so input "L" of *AND 1* is also logic 1. The output of *AND 1* will start the pole disagreement timer(s) through *OR 2*, and, after the user-set time delay expires, the relay will close its contacts.

Note that so long as one phase current is above I_H and another is below I_L, the relay will operate regardless of the value of the third.



allows detection of some dissymmetries, but these quantities are not consistent indicators nor are they unique in their ability to detect any particular condition.

SLB Pole Failure Relay

A protective device, the type SLB relay shown in Fig. 3, has been developed for sensitive detection of pole disagreements in nonfault situations. It monitors the three current-transformer secondary phase currents, sensing whether any is below a low threshold I_L (20 mA, which indicates an open pole) at the same time that any other is above a substantially higher threshold I_H (65 mA, which indicates a closed pole carrying line-charging current).

The use of two detection levels (described in *SLB Relay Logic*, p. 170) provides a dead band between 20 and 65 mA so that phase currents in this range can be ignored. That dead band effectively prevents tripping due to current imbalances that result from phase dissymmetries. By requiring a clear disagreement, security is vastly improved.

The I_L (20 mA) and I_H (65 mA) detection levels are factory calibrations, not intended to be changed by the user except as noted under *Error Current Considerations* below. The relay is available with one or two pole disagreement timers (*T2* and *T3*), each with its own telephone relay output, and each having a delay adjustable from 0.05 to 1 second or from 0.2 to 4 seconds.

Use of SLB Relay Output

The contact outputs of the SLB relay may be used to alarm the operator, trip or retrip the local breaker, or trip adjacent breakers to isolate the protected breaker.

A single timer relay will suffice for users who prefer only to alarm for a pole disagreement, as well as those who wish to initiate only one tripping function. Two timers must be used to sequence the tripping of the protected breaker and adjacent breakers if both functions are to be attempted. The second timer can also alarm if protected-breaker tripping, initiated by the faster timer, is unsuccessful (see Fig. 4).

Timer setting is not critical because the pole failures that occur during attempted fault clearing, which could jeopardize system stability, will be isolated by high-speed breaker-failure relays.[1] Thus, pole-disagreement timers can be set substantially longer because the only concern is minimizing or preventing breaker damage in nonfault situations. A suggested setting for timer *T2* is one-half second. If timer *T3* is provided, a suggested setting is one second.

If single- or selective-pole tripping is used, the breaker may trip unsymmetrically for faults. However, the SLB relay should still be applied because prolonged operation of the line with one phase open during nonfault situations must be avoided. However, the minimum time-delay setting should exceed the maximum time needed for fault clearing and reclosing by a comfortable margin.

Behavior in Pole-Failure Situations

With the operating characteristics of the SLB relay established, its behavior and limitations with respect to the pole-failure situations mentioned earlier can be reviewed.

For the bus arrangement shown in Fig. 2, assume that all breakers are closed and that breaker *A* has an incorrectly open pole. For this case, the SLB relay protecting breaker *A* will immediately detect the obvious difference between load current in the sound phases and zero current in the failed pole.

If breaker *B* is open, the relay protecting *A* will still operate as long as the failed pole is completely open. If the pole is closed through an opening or closing resistor, however, all three phase currents will exceed I_H, and relay detection will be delayed until the resistor opens as a result of its thermal rating being exceeded.

If breaker *E* at the remote terminal is open, the SLB relay will distinguish between zero current and closed-phase charging current and will operate. However, if a pole is closed through its resistor, the resistor will pass virtually full line-charging current and the condition is undetectable. In time, the resistor will heat and open the circuit, but the rather severe voltage stress could conceivably cause internal flashover and arcing in the head with resumption of virtually full charging current flow; this is also undetectable and can, if prolonged, cause serious damage to the interrupting head or support column. However, exposure to this hazardous situation can be minimized by observing the reasonable precaution of not operating transmission

*Table 1—Line Length Limitations for Single Pole Closed**

	Single Conductor			Bundled Conductors			
Voltage (kV)	*115*	*161*	*230*	*230*	*345*	*500*	*765*
Current in Closed Phase per Mile of Line	0.32	0.45	0.63	0.82	1.23	1.78	2.7
Min Length (miles)							
2000/5 CT	81	57	40	32	21	14	10
800/5 CT	32	23	16	13	8	6	4

*Table 2—Line Length Limitations for Single Pole Open**

	Single Conductor			Bundled Conductors			
Voltage (kV)	*115*	*161*	*230*	*230*	*345*	*500*	*765*
Current in Closed Phase per Mile of Line	0.34	0.49	0.69	0.88	1.33	1.9	3.0
Min Length (miles)							
2000/5 CT	75	54	38	29	20	13	9
800/5 CT	30	21	15	12	8	5	3.5

*The positive- and negative-sequence shunt impedance values are assumed to be 0.18 megohm/mile for single-conductor lines and 0.14 megohm/mile for bundled conductors; the corresponding zero-sequence values are 0.27 and 0.21 megohm/mile.

lines with one end open for long periods.

Now consider the case of breaker *A* open, except for one phase which is incorrectly closed or partially closed, possibly through the resistor. With remote breaker *E* closed, and regardless of whether adjacent breaker *B* is open or closed, the presence of load, resistor, or arcing current in the closed phase, as compared to zero current in the others, can be detected readily by the SLB relay. Even if breaker *E* is open, the SLB relay will see charging current flow into the shunt capacitance of the closed or arcing phase and operate to prevent severe damage.

Line Length Limitations

In a number of the aforementioned situations, the SLB relay must distinguish between charging current flow into the shunt capacitance of the transmission line and zero current in an open phase. For that to happen, however, there must be at least 65 mA of current-transformer secondary current for correct relay operation. The minimum line lengths required to provide sufficient line-charging current for relay operation are listed in Table 1.

Table 1 line-length limits are determined as follows: Since the SLB relay requires at least 65 mA CT secondary current flow for the I_H detector to pick up for a closed pole, and since the CT ratio is known, the primary current flow necessary to induce 65 mA of secondary current can be found. Then, dividing the required primary current by amperes per mile of line yields the minimum line length that can be protected. For Table 1, the values of current inflow per mile of line pertain to a line open at both ends except for one pole of one of the breakers, which is incorrectly closed.

For example, for a 2000/5 CT, 26 A must flow through the primary winding to provide 65 mA in the secondary. For a 500-kV bundled-conductor line, each mile of conductor in use will result in 1.78 A inflow through the single closed pole. Thus, 26 A will flow if the line is 14 or more miles long, as shown in Table 1.

Similar calculations are tabulated for other voltage levels, as well as for an 800/5 CT ratio. Results can readily be obtained for any other CT ratio and line using similar calculations.

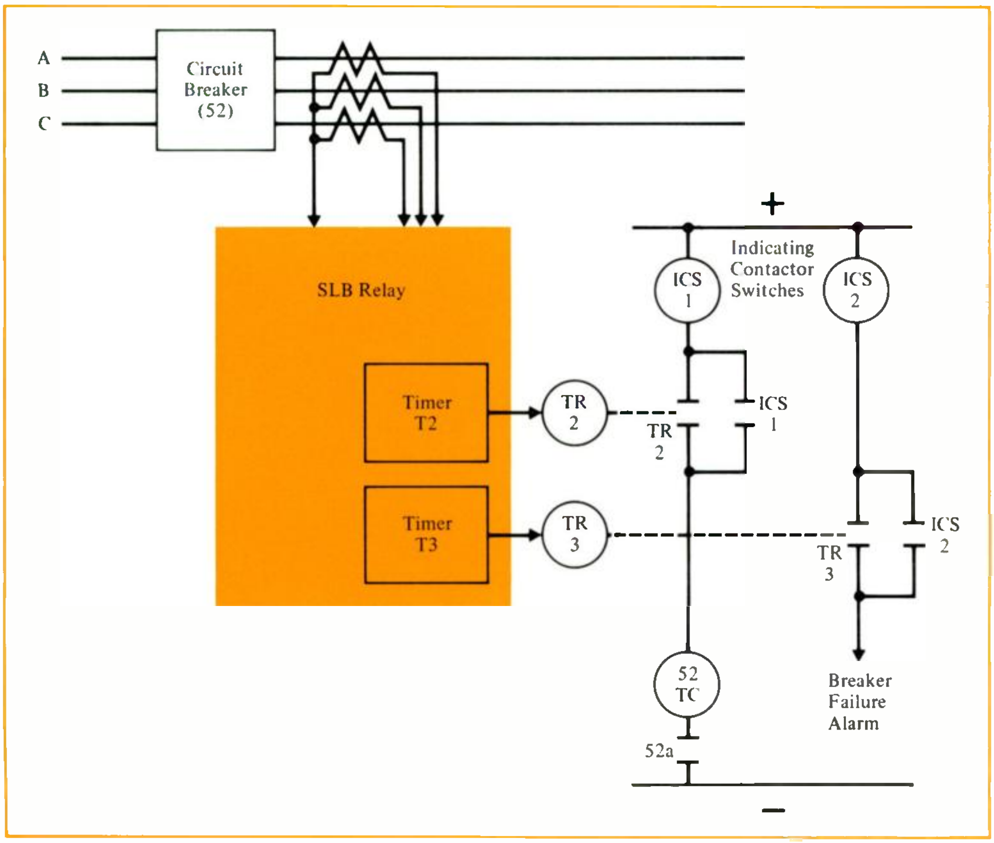
Table 2 repeats these calculations for the case of two poles closed with one pole incorrectly open; again, the line is assumed open at the remote terminal.

Error Current Considerations

In rare installations, the SLB relay may have difficulty detecting open poles due to error currents in excess of I_L (20 mA) in a CT secondary circuit even though the associated pole is open. That condition can arise from two sources:

1) Assume two poles of a breaker are carrying load current and the third is incorrectly open; secondary current from the CT's of the closed phases may be coupled (due to lead proximity) onto the open phase CT lead. Even though this current must be driven through the high exciting impedance of the open CT, 20 mA may be possible in a few installations.

2) Assume a closed bus with two breakers supplying load current to one line (Fig. 5). If breaker *2* has an open pole, all of the load current for that phase must flow through the breaker *1* pole. The CT secondary load current for the breaker *1* pole will produce an IZ drop as it flows through the burden of the current windings of the line-relay complement. The resulting voltage across the line relays V_{NR} may force a small current I_{error} through the current transformer of the breaker *2* open pole. If the line relaying burden is significant with respect to the CT exciting impedance, the error current might exceed 20 mA so that the breaker *2* relay will not detect the open pole. Usually, however, the CT secondary voltage capability needed for accurate re-



4—(Left) *Typical use of SLB relay outputs with two time delays is illustrated. Short delay* (T2) *initiates protected breaker tripping; if unsuccessful, second output* (T3) *actuates operator alarm or trips adjacent breakers.*

5—(Right) *When two breakers are supplying load current to one line, it may be possible in rare instances to develop sufficient voltage drop across line relay burden* (V = IZ) *to generate an error current in an open-pole CT that prevents an SLB relay with standard settings from detecting the open pole.*

laying with a large burden will result in a high exciting impedance, and thus insignificant error current.

To accommodate the few users who will experience significant error currents, the current detector adjustment ranges of the SLB relay can be adjusted so that the I_L detector picks up at 60 mA and I_H at 180 mA. However, factory calibration remains at $I_L = 20$ mA and $I_H = 65$ mA. These values should not be increased unless error currents large enough to affect relay operation are measured or calculated. In any case, the ratio of I_H to I_L should be 3 to 1 or greater.

Loss-of-Conductor Application

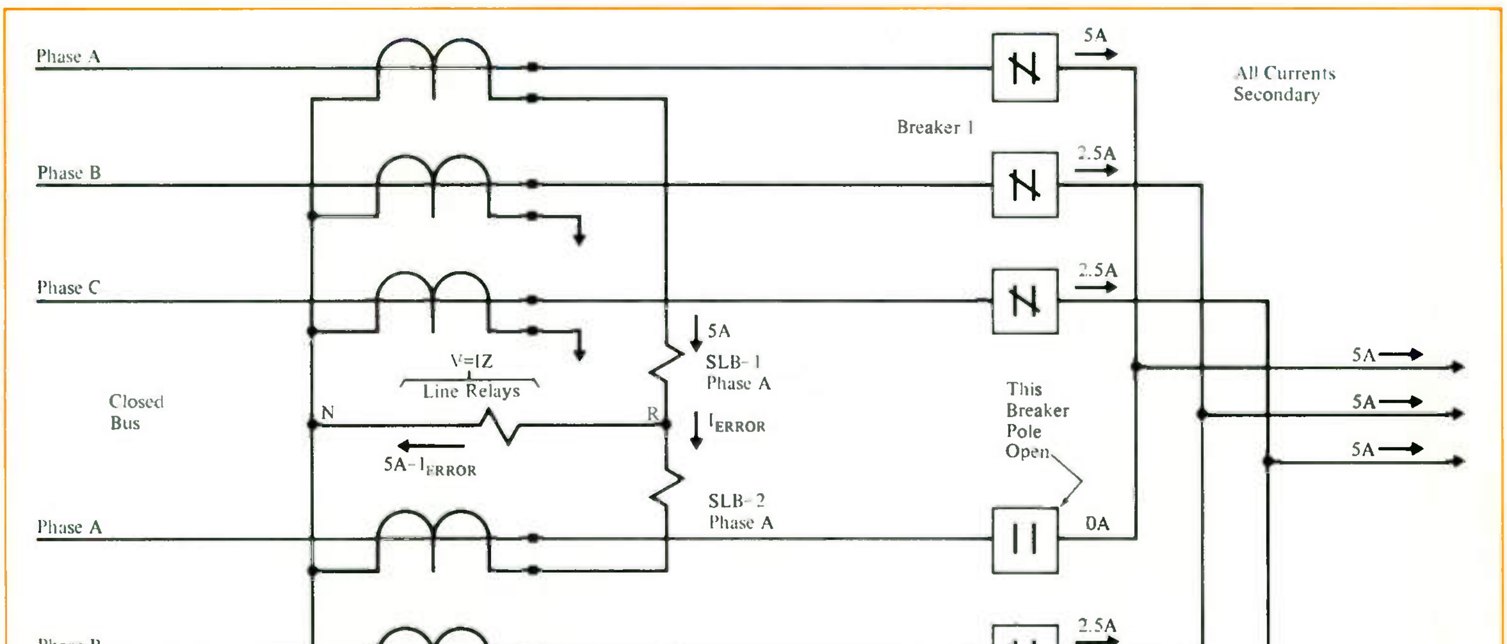
The SLB relay possesses a limited ability to detect and operate for a conductor break even if the establishment of a ground fault is delayed or does not occur at all.

Consider a transmission line whose terminating breakers are protected by SLB relays carrying load current when a conductor breaks due to galloping, ice loading, or aircraft collision. If the charging current for the portion of the line from one terminal to the break is less than the I_L setting, the relay will sense the imbalance just as it would a pole disagreement. For most EHV lines, this means that the SLB relay will respond only to breaks close to one of the terminals. For lower voltage lines whose charging current approaches the I_L setting range, the SLB relay may be specifically applied for loss-of-conductor protection. In this case the timer would be set to trip the breaker with short enough delay so that load current would be interrupted before the broken conductor hits the ground. The risk of personal injury and property damage beneath the break is thus minimized, and a probable ground fault is avoided. Note that in the modified SLB relay, I_L may be set to 60 mA or more.

Conclusion

On certain occasions, circuit breakers can be subjected to unsymmetrical pole operating conditions during nonfault situations. Such pole disagreements could be caused by (1) failures in the tripping or closing systems of breakers having separate phase mechanisms; (2) mechanical linkage failures in single-mechanism or independent-mechanism breakers; or (3) pole flashovers of open breakers due to external lightning or switching surges or loss of air or gas pressure. Such conditions can be hazardous and can result in serious breaker damage, depending on line and bus operating conditions at the time of the failure. The SLB pole-disagreement relay is designed to detect these dissymmetries and reduce or prevent breaker damage by tripping or isolating the protected breaker.

REFERENCE:
[1]C. L. Wagner and H. E. Lokay, "Independent-Pole Circuit Breakers Improve System Stability Performance," *Westinghouse ENGINEER*, September 1973, pp. 130-7.



Skylab Furnace System Provides Precise Thermal Environment for Materials Experiments

J. M. Feret
R. Mazelsky

An electric furnace system enables Skylab crews to perform experiments in materials processing under conditions of weightlessness. The resulting data should tell whether useful manufacturing and processing techniques that are not possible on earth, because of the influence of gravity, can be performed in space.

Materials processing in its broadest sense covers the gamut of modern technology—the production and modification of glasses, ceramics, metals, composites, and crystals. Major advances in techniques and sophistication have been made in the past generation, but until now one parameter could not be controlled. It was the omnipresent effect of gravity on materials.

Skylab now provides the opportunity for long-term studies free from the effects of gravity. (See *Skylab*, below.) Because the vehicle is in orbit around the earth, effectively in a state of free fall, the people and objects in it experience virtually no gravitational pull.

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Skylab

One of the main objectives of the space program, along with exploration, is utilization of the environment of space (especially weightlessness and high vacuum) for scientific investigations. The National Aeronautics and Space Administration (NASA) and its contractors have experimented in a number of technical areas by use of drop towers, parabolic flight, suborbital rockets, and short studies during Apollo missions. Data from the experiments indicated a need for a vehicle in which long-term studies could be made, so Skylab was developed to perform the studies.

Skylab is an orbiting laboratory launched on May 14. It consists of an Apollo Command and Service Module, which ferries crews from and to the earth; a Multiple Docking Adapter, which is an experiment control center and two-port space dock; an Airlock Module to provide an exit for extra-vehicular activity; an Apollo Telescope Mount; and an Orbital Workshop, which is an Apollo S-IVB booster stage modified to serve as living quarters and research area.

Skylab has three crews of three men each, with the crews scheduled to man it successively for a total of five months. They perform a variety of experiments in astronomy, medicine, biology, and materials processing. This article is concerned only with the furnace facilities provided for materials processing experiments.

A special furnace system developed for the vehicle enables the crew to perform experiments in materials processing. The experiments will help determine whether manufacturing and processing techniques not possible on earth (under the influence of gravity) can be performed under the reduced gravity conditions aboard a satellite. (See Table 1.)

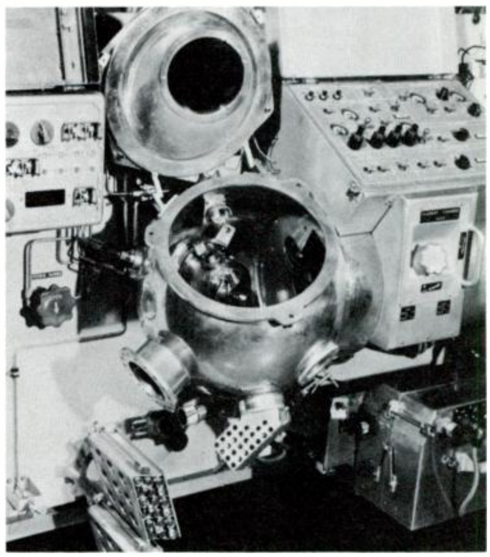
The furnace system includes provisions for the Skylab crew to select temperatures, maintain them for selected intervals, and select cooling rates—all chosen to fit the needs of each experiment. Readouts and telemetry are provided for monitoring and performance evaluation and to enable the astronauts to take corrective measures if a malfunction occurs.

The effects of gravity on materials processing stem from the simple observation that more dense objects sink in a fluid and less dense objects float. For example, if a liquid mixture is kept molten for any length of time, the components segregate; as a result, synthesis of composite materials in a single processing step has been difficult. Similarly, any temperature gradient in a homogeneous liquid causes a small variation of density in the liquid and, under a gravitational field, convection currents result; the currents have considerable impact on solidification processes such as directional solidification, casting, and crystal growth. In free fall, such phenomena do not exist.

To better understand the effects of density-induced convection, and so to produce improved and possibly unique materials, NASA developed the M512 Materials Processing Facility for use in Skylab (Fig. 1). It is essentially a spherical chamber evacuated to space and provided with power for heating, a heat sink for dissipating the heat, and access ports through which cables are run to observe and record data during experiments.

NASA's original plan was to restrict the experiments that require a furnace to a crystal-growth and a solidification experiment, each with its own furnace system functioning within its particular set of parameters. However, the scientific community was interested in performing a variety of experiments to answer more questions. For example, in the absence of convection, could crystals of greater perfection be obtained and impurity distributions be accurately controlled, resulting in new or improved semiconductor devices? Could immiscible materials be processed to yield homogeneous solid mixtures? To answer such questions, NASA defined a new furnace system that would provide the capability to perform many experiments.

The Westinghouse Research Laboratories and Astronuclear Laboratory undertook a joint program to design, develop, and manufacture the new furnace system



1—Skylab furnace is seen here mounted in a simulated M512 Materials Processing Facility, which is the spherical chamber in the middle of the photograph. The furnace system's control package is at upper left, and cartridges containing the materials to be processed in the furnace are in the stowage containers below it.

under contract to Marshall Space Flight Center in Huntsville, Alabama. The system enabled NASA to add 10 materials experiments to this year's Skylab program, increasing the total from 7 to 17.

Furnace System

The new system is designated M518 Multipurpose Electric Furnace System. Its major components are the furnace, a control package, and experiment cartridges.

Furnace—The primary function of the furnace is to provide a programmable thermal environment for the experiments. It has two main sections, the furnace chamber and the instrumentation compartment, joined by flanges (Figs. 2 and 3). The furnace housings are fabricated from stainless steel joined by hydrogen furnace brazing. The instrumentation compartment has a 26-pin hermetic receptacle for electrical power and control connections, and a manually operated vacuum valve.

The furnace accepts three experiment cartridges at a time, spaced 120 degrees apart around its long axis. Access is provided through the instrumentation compartment. Cartridges are inserted and removed by use of access-port cap assemblies that provide positive latching.

Operating requirements included capability to perform experiments requiring up to 1000 degrees C at the hot end, system power consumption of less than 144 watts, and maximum efficiency in transferring the power as heat to the experiment cartridges. Therefore, a primary design consideration was to minimize heat losses.

The heater assembly consists of two resistance heating elements wound on an alumina sleeve that fits around a graphite block called the heat leveler (Fig. 3). Because of the relatively high thermal conductivity of graphite, the heat leveler is essentially isothermal. It is supported by three stainless-steel tubes that connect it to three copper heat-transfer tubes attached to a copper heat-extractor plate. The experiment cartridges are held within the tubes. The transition from the low to high thermal conductivities of the tube materials (stain-

Table 1—Materials Experiments for Skylab M518 Furnace System

No.	*Institution*	*Title and Description*	*Maximum Temperature (degrees C)*
M556	Rensselaer Polytechnic Institute	Vapor Growth of IV-VI Compounds: To determine the degree of improvement that can be obtained in the perfection and chemical homogeneity of crystals grown by chemical vapor transport under weightless conditions.	575
M557	TRW Systems Group	Immiscible Alloy Compositions: To determine the effect of near-zero gravity on the processing of material compositions that normally segregate on earth.	725
M558	NASA Marshall Space Flight Center	Radioactive Tracer Diffusion: To measure self-diffusion and impurity diffusion effects in liquid metal in space flight and to characterize the disturbing effects, if any, due to spacecraft acceleration.	775
M559	Texas Instruments Corporation	Microsegregation in Germanium: To determine the degree of microsegregation of doping impurities in germanium caused by convectionless directional solidification under conditions of weightlessness.	985
M560	University of Alabama at Huntsville	Growth of Spherical Crystals: To grow indium antimonide crystals of high chemical homogenity and structural perfection and study their resulting physical properties in comparison with theoretical values for ideal crystals.	655
M561	National Research Institute for Metals, Tokyo, Japan	Whisker-Reinforced Composites: To produce void-free samples of silver reinforced with oriented silicon-carbide whiskers.	970
M562	Massachusetts Institute of Technology	Indium-Antimonide Crystals: To produce doped semiconductor crystals of high chemical homogeneity and structural perfection and to evaluate the influence of weightlessness in attaining those properties.	795
M563	University of Southern California, Los Angeles	Mixed III-V Crystal Growth: To determine how weightlessness affects directional solidification of binary semiconductor alloys and, if single crystals are obtained, to determine how their semiconducting properties depend on alloy composition.	950
M564	University of California at Los Angeles	Halide Eutectics: To produce highly continuous controlled structures in samples of fiber-like sodium fluoride/sodium chloride and to measure physical properties.	895
M565	Catholic University, Belgium	Silver Grids Melted in Space: To determine how the configurations of perforated silver foils and a porous block of fine silver wires change when melted and resolidified in space.	990
M566	NASA Marshall Space Flight Center	Copper-Aluminum Eutectic: To determine the effect of weightlessness on formation of lamellar structure in eutectic alloys when directionally solidified.	855

less steel to copper) provides a thermal gradient region for the cartridges. The interiors of the heat-transfer tubes are coated with a material of high thermal emissivity to enhance heat transfer.

The furnace is thermally insulated by radiation heat shields. It has eight concentric molybdenum cylindrical shields, eight layers of molybdenum hot-end axial shields, and 16 layers of molybdenum cold-end axial shields.

Most of the heat generated is transferred to the heat leveler by radiation, the remainder being lost through the heat shields. Heat transferred to the heat leveler is either lost by axial conduction through the tubes or transferred to the experiment cartridges by radiation; all of it is ultimately transferred by conduction through the heat-extractor plate to the heat sink of the Materials Processing Facility.

The total power required by the furnace for a given experiment consists of "intrinsic" furnace heat losses (heat that does not pass through the experiment cartridges) plus heat losses through the cartridges. The difference between the furnace power of 144 watts and the intrinsic heat loss is the experiment power available. For a heat leveler temperature of 1000 degrees C, for example, the intrinsic heat loss is 112 watts, thus leaving 32 watts for the experiment cartridges. Intrinsic heat losses vary directly with the temperature of the heat leveler. The lower the heat-leveler temperature required, the less the power needed to reach that temperature and therefore the greater the power available for heating the cartridges.

Six thermocouples are employed in the furnace. Two serve as the sensing elements for temperature control, two measure the thermal environment to which the high-temperature ends of the cartridges are exposed, and two measure the temperature in the region of the furnace in which heat is extracted from the cartridges.

Control Package—The control package employs solid-state techniques to control furnace temperature automatically in response to a preset time-temperature program. Means are provided for manually setting the three main operating parameters for any given experiment—soak temperature, soak period, and cool-down rate (Fig. 4). The package also provides visual display of furnace temperatures and corresponding analog voltage signals for telemetry.

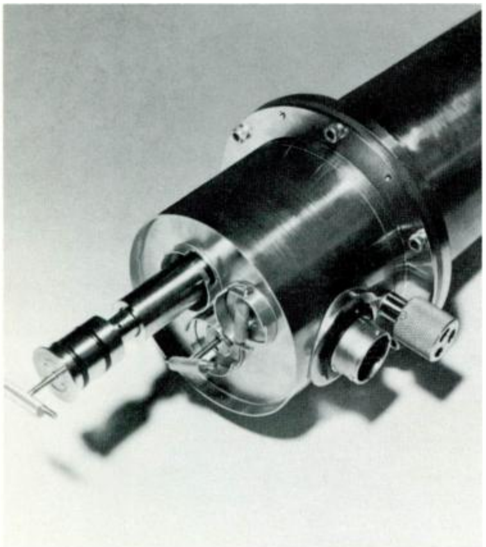
The selected soak temperature is maintained by controlling the voltage applied to the furnace heaters in response to a control signal and a feedback signal (Fig. 5). The control signal is derived from a precision 10-turn potentiometer, while the feedback signal is provided by one of the two control thermocouples located close to the heaters. On-off proportional control of the voltage applied to the heaters is provided by an output switch as a function of error between the temperature control signal and the amplified thermocouple signal. The control accuracy is about ±1 degree C.

The soak period is selected by means of a rotary switch on the control panel. The circuitry provides automatically timed soak periods of 1 to 64 hours and cool-down rates of 0.6 to 2.4 degrees C per minute, with manual override options. The soak-period timer is started when the furnace has heated to the desired soak temperature.

Manual selection of "controlled" or "passive" cool-down rates is provided. If passive cool-down is selected, the control circuitry steps into a "shutdown" or "end" mode that removes all power to the heaters. Controlled cool-down is provided by an integrated-circuit counter and a digital-to-analog converter. The counting rate of the counter is determined by a rate selection switch located on the control panel. The output of the converter is summed electronically with the soak temperature control signal to yield a temperature control signal into the comparator that decreases at the selected rate.

Lamps on the control package indicate the heat-up, soak, cool-down, and end modes. Circuitry is provided to sense an open control thermocouple, overtemperature, or shorted output power transistor.

A separate system provides direct readout of furnace temperature and also dc analog signals for telemetry. Signals from its thermocouples are amplified by precision integrated-circuit amplifiers that yield 0- to 5-volt analog voltage signals. A rotary switch on the control package permits selection of any of the four thermocouple temperatures for display. The four-digit display circuitry provides temperature readout repeatability within ±1 degree C. A switch is used to transmit the



2—The furnace is essentially a cylinder 10.16 cm in diameter and 28.96 cm long. It accepts three experiment cartridges at a time, one of which is partly withdrawn here.

3—(Right) *The furnace has two resistance heating elements surrounding a heat leveler near one end. That arrangement and the radiation heat shields provide an isothermal high-temperature region, a thermal-gradient region, and a low-temperature region. One of the experiment cartridges is shown in this section view.*

amplified thermocouple signals to telemetry channels in the vehicle.

Experiment Cartridges—The cartridges contain ampoules, and inside the ampoules are the experiment samples. Design of the cartridges was a critical part of the program because they do much more than provide the means for handling samples: they help provide the required temperature distributions. The furnace temperature profile is somewhat limited, so the specific profiles required by the participating scientists ("principal investigators") are obtained by controlling heat flow in the cartridges and consequently in the ampoules.

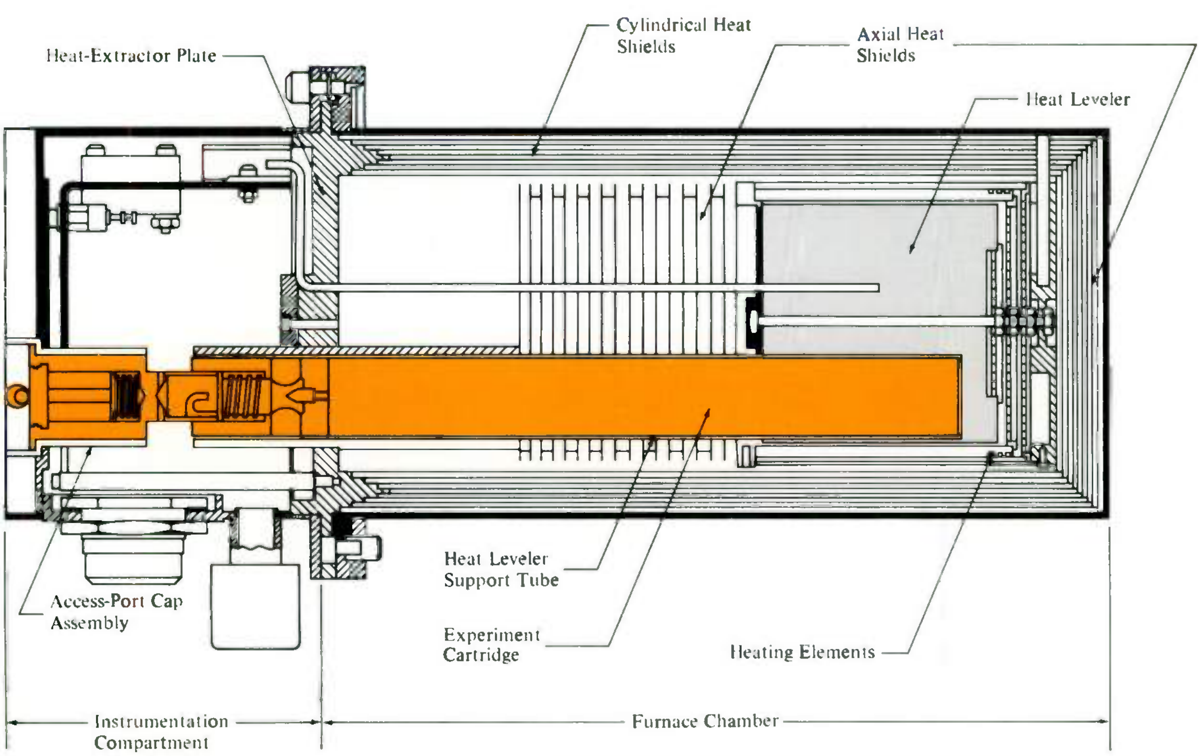
Graphite thermal inserts conduct heat between the cartridge surface and the sample and provide relatively constant temperatures at the hot and cold ends of the cartridge. Thermal insert designs were varied for each experiment, but some features of the experiment cartridges are common to all designs. All consist of a stainless-steel shell 2.06 cm in outside diameter, 0.025 cm in wall thickness, and 20 cm long, which includes a latching and pump-out section 3.51 cm in length. Cartridges are hermetically sealed, and most are backfilled with helium to a pressure of 70 torr to improve heat transfer.

The temperature gradient for each sample is controlled by the thermal emissivity of the cartridge hot end where the heat enters, the axial thermal conductivity along the cartridge, and the emissivity of the cartridge cold end where the heat is transferred to the heat sink. An example of the control that can be exercised is shown in Fig. 6. Further control is possible in the gradient section by encasing the ampoule in an additional heat-conducting sheath.

Each principal investigator supplied the desired temperature distribution and associated ampoule details for his experiment. The design team then made thermal and power analyses to determine if the ampoule design was compatible with the furnace system. After analytic verification, a preprototype model cartridge for each experiment was constructed and tested. Temperatures and heat fluxes measured permitted refinement of the knowledge of thermal properties of all the experiment cartridges and samples.

Test Program

The development test program to demonstrate flight worthiness of the furnace system consisted of five phases: design, construction, and test of a prototype furnace system to demonstrate that a system could be developed that satisfied the requirements; redesign of the prototype system for reproducible construction, using standardized materials, components, processes, etc.; acceptance testing of the first production system to demonstrate that it retained the characteristics of the prototype system; qualification testing of the first production system to demonstrate that it retained its initial characteristics after storage and launch; and acceptance testing of follow-on production systems (for flight and backup) to demonstrate that they had the same initial characteristics as the system subjected to qualification testing. Similar environmental qualification testing was performed on the experiment cartridges.

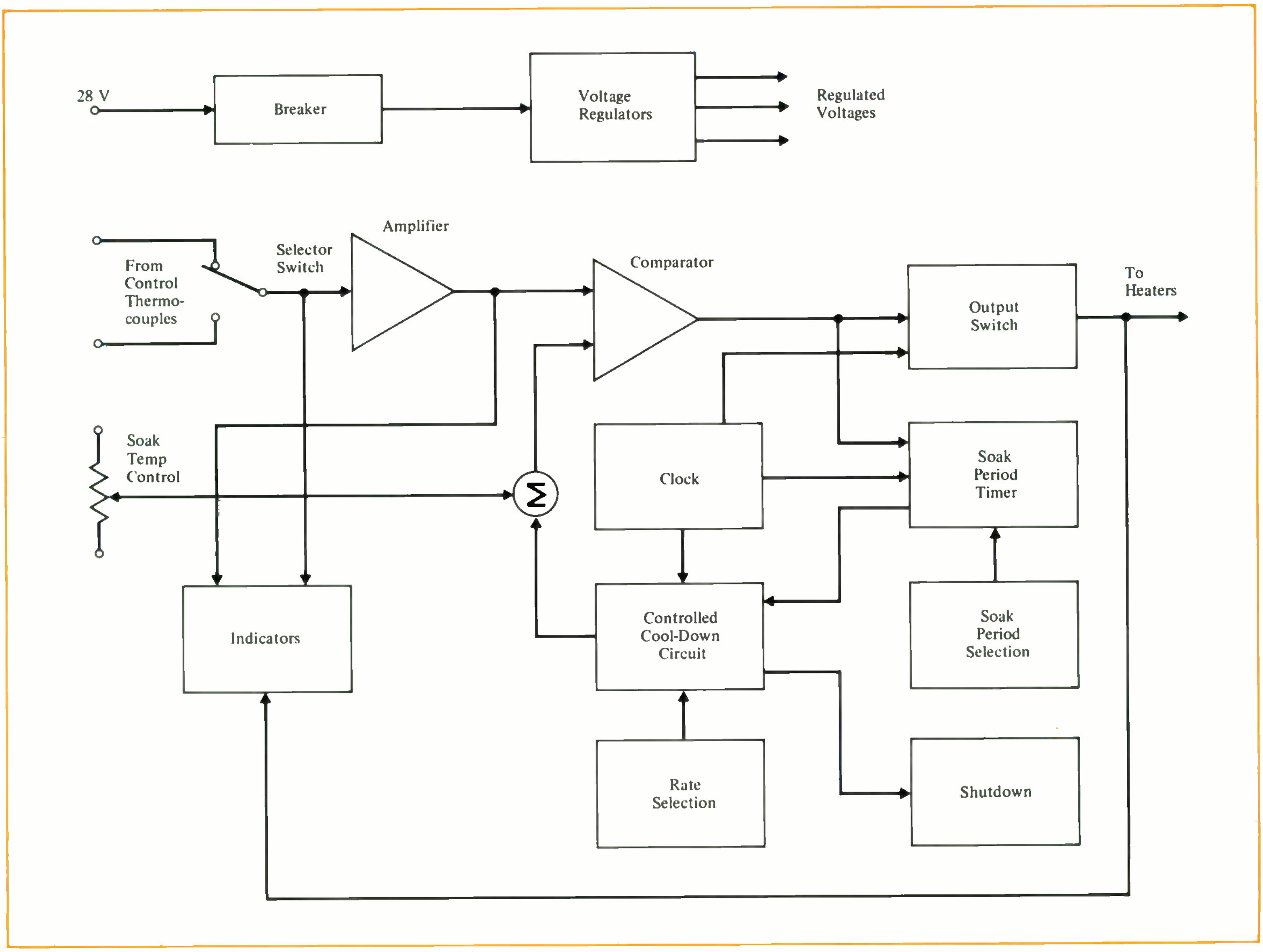


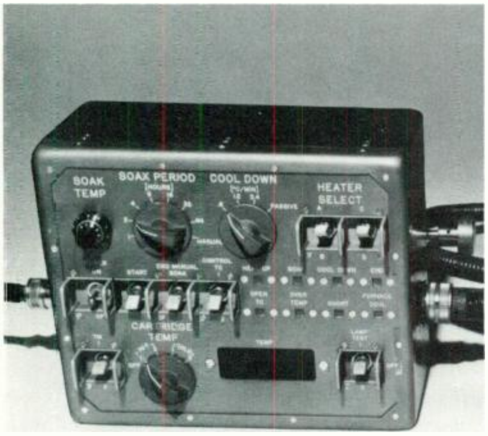
Additional testing designated as Ground Base Testing was performed with the furnace qualification unit by NASA personnel at the Marshall Space Flight Center. Flight experiment cartridges were tested in a simulated M512 Materials Processing Facility to provide operational data under normal gravity. Detailed evaluation of the data resulted in selection of the control-package settings to use in the mission for each experiment.

Flight System

In the launch configuration, the furnace is stowed in the Skylab Multiple Docking Adapter (MDA), while the control package, cables, and the two loaded cartridge stowage containers are stowed in a locker in the Orbiting Workshop (OWS). Experiment setup is initiated by establishing an MDA environment (approximately 5 psia of oxygen) in the Work Chamber and then transferring the furnace from its launch location to the Work Chamber. The furnace's vent valve is opened to equalize its internal pressure with that of the MDA. The control package and the interconnecting cables are transferred to the MDA, where the control package is attached to a panel located adjacent to the Work Chamber. The necessary hermetic lead and power/telemetry cable connections are then made, completing the installation of the system.

Next, the cartridge stowage containers are removed from the OWS locker and attached to a panel near the Work Chamber (Fig. 1). The three cartridges for the first experiment are removed from the stowage container, attached to furnace access-port cap assemblies, and inserted into the furnace. The Work Chamber hatch is then closed and latched to isolate the chamber interior from the MDA, and both the chamber and the furnace are vented to space vacuum. The controls on the panel of the control package are set to the heater combination, soak temperature, soak period, cool-down rate, and selection of control, display, and telemetry thermocouples specified for the first experiment. At the con-





clusion of each experiment, the cartridges for the next one are installed in the furnace and the control package panel is reconfigured to meet the requirements of that experiment.

With the conclusion of the last experiment, the control package, cables, and furnace are returned to their launch stowage positions. The cartridge stowage containers, now filled with tested cartridges, are removed from the MDA and stowed in a locker in the Command Module for return to earth. After recovery, the samples will be examined and compared with samples made of the same materials at the same time on earth under identical conditions except for gravity.

Conclusion

Development of the M518 Multipurpose Electric Furnace System has enhanced Skylab's materials science capability. Besides enabling scientists to explore the possibilities for manufacturing operations in space, the system demonstrates for future space experiments that one set of equipment can be adapted to perform multiple experiments.

ACKNOWLEDGMENT:
The authors acknowledge the important contributions to this article, and to the Skylab furnace program, made by Mr. C. S. Duncan, Mr. R. A. Johnson, and Dr. R. G. Seidensticker of the Research Laboratories and by Dr. J. W. Chi, Mr. R. Flaherty, and Mr. V. H. Hayden of the Astronuclear Laboratory.

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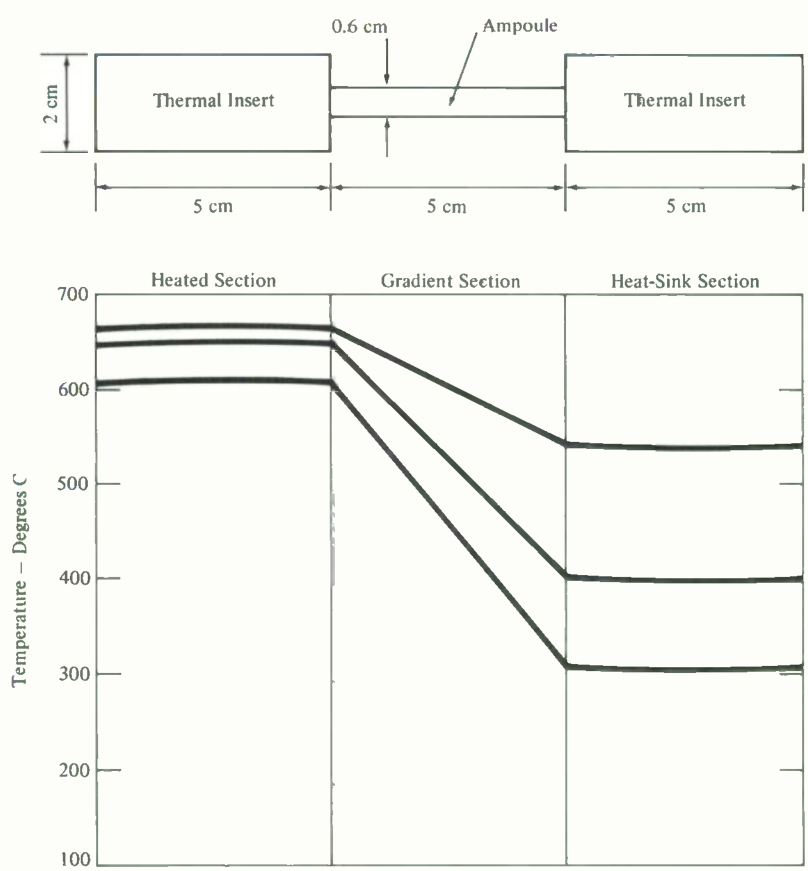
4—(Above) *The control package provides means for setting the desired soak temperature, soak period, and cool-down rate. It also has visual displays of furnace temperatures and circuitry for temperature telemetry. Cables carry controlled electrical power from the control package to the furnace and carry control feedback and temperature-indicating signals from the furnace to the control package.*

5—(Left) *Power for the furnace control package comes from the 28-volt dc bus in the Airlock Module. Voltage regulators generate regulated voltages for the control, timing, and logic circuits that provide the desired soak temperature, soak period, and cool-down rate.*

6—(Right) *The desired temperature gradient for each sample is achieved by selecting the thermal emissivity of the cartridge hot end, the thermal conductivity along the cartridge, and the emissivity of the cold (heat-sink) end. Typical temperature control achievable along the length of a cartridge is illustrated here. (The cartridge, at top, is diagrammed without its outer metal sheath.) Temperatures at the hot and cold ends of the furnace, respectively, are 675 and 100 degrees C in this example, and thermal conductivity of the cartridges is 1 watt per cm-degree. The three curves represent three cartridge designs, all with heated sections having the same thermal emissivity (designated "1"). However, thermal emissivities of the heat-sink sections are all different—from top to bottom, 0.1, 0.4, and 1. Consequently, the respective thermal gradients in the gradient sections are 25, 50, and 58 degrees C per cm.*



Waltz Mill Facility Tests Underground Cables and Also Demonstrates Feasibility of 1100-kV Overhead Systems

C. J. Baldwin
J. W. Bankoske

The Underground Transmission Test Facility at Waltz Mill, Pennsylvania, is designed to perform accelerated life tests and other evaluations on cable samples ranging in operating voltage from 115 kV to 800 kV. Since the facility is capable of transforming and transmitting voltages up to 1100 kV, it is also used in developing UHV equipment.

Placing electric transmission lines underground is a promising concept receiving widespread industry and public attention, but the increased expense has thus far precluded extensive use of underground systems. The need for proven high-voltage underground systems is particularly acute in metropolitan areas, where erection of additional overhead lines is becoming increasingly difficult if not impossible.

To help develop less costly and improved underground transmission systems, a program was initiated in 1966 by the Electric Research Council, a body representing all electric utility companies. The Council's program has the broad objectives of developing commercial HV and EHV systems that can deliver four to ten times the loads of present-day cables, of decreasing installation costs by improved techniques and equipment, and of stimulating work on advanced concepts for underground transmission. More specific objectives include extending the voltage range of existing insulation systems, optimizing their use for underground dc transmission, and improving the power transfer capability of present transmission systems.

Since April 1973, responsibility for the research program has been assumed by the Electric Power Research Institute (EPRI) with financial support from investor-owned and public electric utilities. As the program enters its seventh year, the number of projects authorized for funding has reached a total of 23. The underground transmission program is currently the EPRI's largest research effort; $18 million has been authorized for this work to date.

To meet the needs of the underground transmission research program, a test facility was erected on a 60-acre site near the village of Waltz Mill, Pennsylvania. The facility, completed in 1969, was designed and built by Westinghouse Electric Corporation, which also operates the facility under the supervision and coordination of an EPRI steering committee. Test samples are provided by cable manufacturers and also by research institutes that have made significant contributions to underground transmission research. Tests on the first generation of sample cables are now well under way or completed, and new systems are being engineered for testing. Currently, ten cable systems are being evaluated at the facility; for example, a high-voltage extruded cable splice undergoing tests is shown in Fig. 1. That cable uses a new extruded crosslinked polyethelene insulation.

1100-kV Substation

The capability of the Waltz Mill Facility to energize cable samples at test voltages as great as 1100 kV for long periods of time

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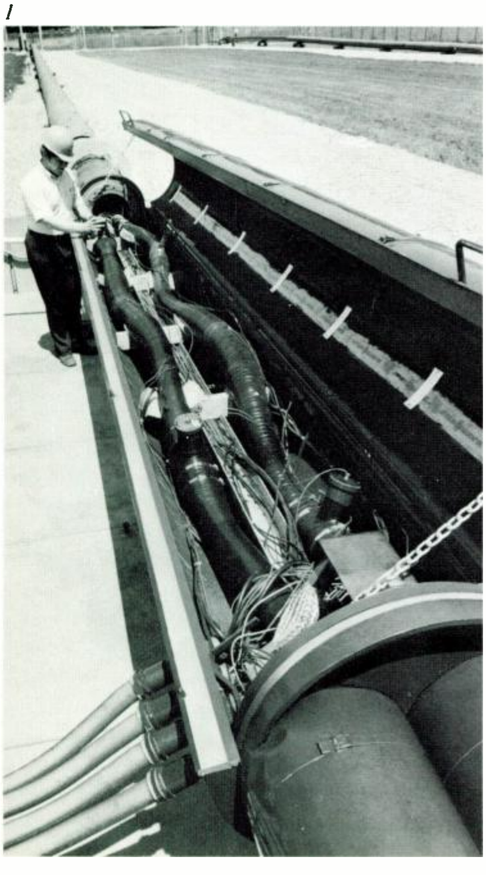

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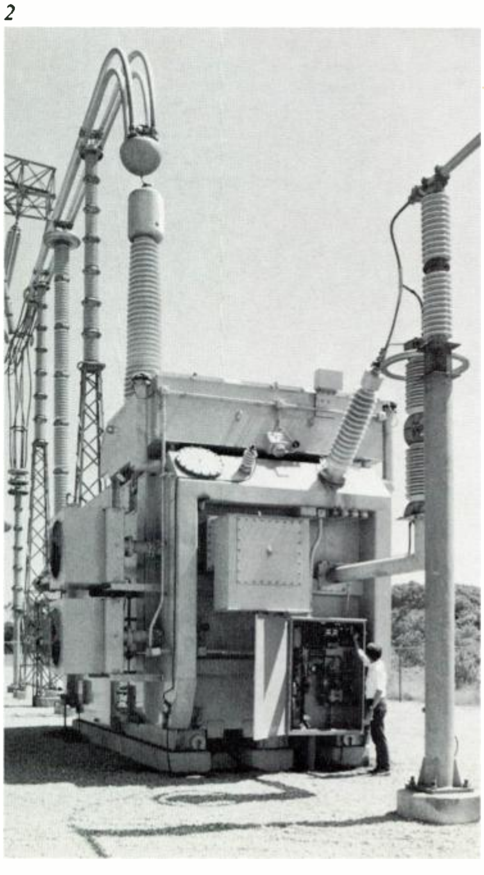

1—A technician inspects two splices on a 138-kV extruded cable undergoing tests at Waltz Mill. The development of reliable splicing techniques is a vital part of a research and development program directed toward demonstration of commercial cable systems.

2—Illustrated is one of the three 1100-kV autotransformers that provide power to cable systems under test in the EHV test area. The three units are the first 1100-kV transformers ever manufactured to commercial standards. Each incorporates different design features to maximize the knowledge gained from operation of the three units.

3—Electrical tests performed on full-scale models enabled these 1100-kV bus structures to be designed to withstand lightning impulse, switching surge, and power frequency voltages.

4—Voltages applied to the test cables are monitored by 1100-kV coupling capacitor potential devices.

provided Westinghouse with the opportunity to develop UHV equipment and operate it under actual utility conditions. That development effort was most timely since some utilities are considering 1100 kV as their next voltage level.

Three-phase voltage up to 1100 kV is provided by three 1100-kV autotransformers (Fig. 2). Each transformer incorporates a different design so that greater knowledge may be gained from operation of the three units. Two transformers employ low-profile construction, which will permit substations to be constructed more compactly with subsequent economies and improvement in appearance. The performance of the three transformers, which all employ low insulation levels, is monitored to help engineers establish the most reliable and economical insulation system. All three units are currently providing voltage and power to the cable systems under test. The transformers have all been successfully operated at 1100 kV, and two units have been operating for long periods at that voltage level.

Construction of the 1100-kV bus structures for the facility required the research and development effort that always precedes adoption of a new voltage level by the industry (Fig. 3). In designing the bus structures, electrical tests on full-scale mock-ups were performed at the UHV Test Center at Trafford[1,2]. Laboratory tests were also performed to determine radio and audible noise generated by the conductors during adverse weather conditions. From those test results the dimensions and configurations of the insulation and conductors were determined for the Waltz Mill Station, and estimates were projected for the design of future 1100-kV transmission lines. The tests also established the direction of future engineering research required for the development of reliable and economical 1100-kV insulation and conductor systems. For example, testing showed that switching surges and atmospheric contamination of the insulators are the two major obstacles to economical UHV transmission.

Test apparatus in the 1100-kV substation includes coupling capacitor potential devices for voltage measurements (Fig. 4), a three-phase 1100-kV disconnect and grounding switch, and two precision capacitors for measurements of insulation dissipation factor.

The disconnect and grounding switch serves a dual purpose. Closing any one of its three phase contacts connects a precision capacitor to the test cable energized by that phase for making dielectric dissipation factor measurements. Closing all three phase contacts in addition to the grounding contact provides a convenient and safe method of draining static charge or induced voltage prior to maintenance work in the substation.

The Waltz Mill Station not only has created the opportunity to develop realistic station and apparatus design for future transmission systems, but it also has provided a location where other fundamental UHV research takes place. One recent test, for example, was to determine the effect of the electric field on the ability of people to work comfortably and safely in a UHV substation.

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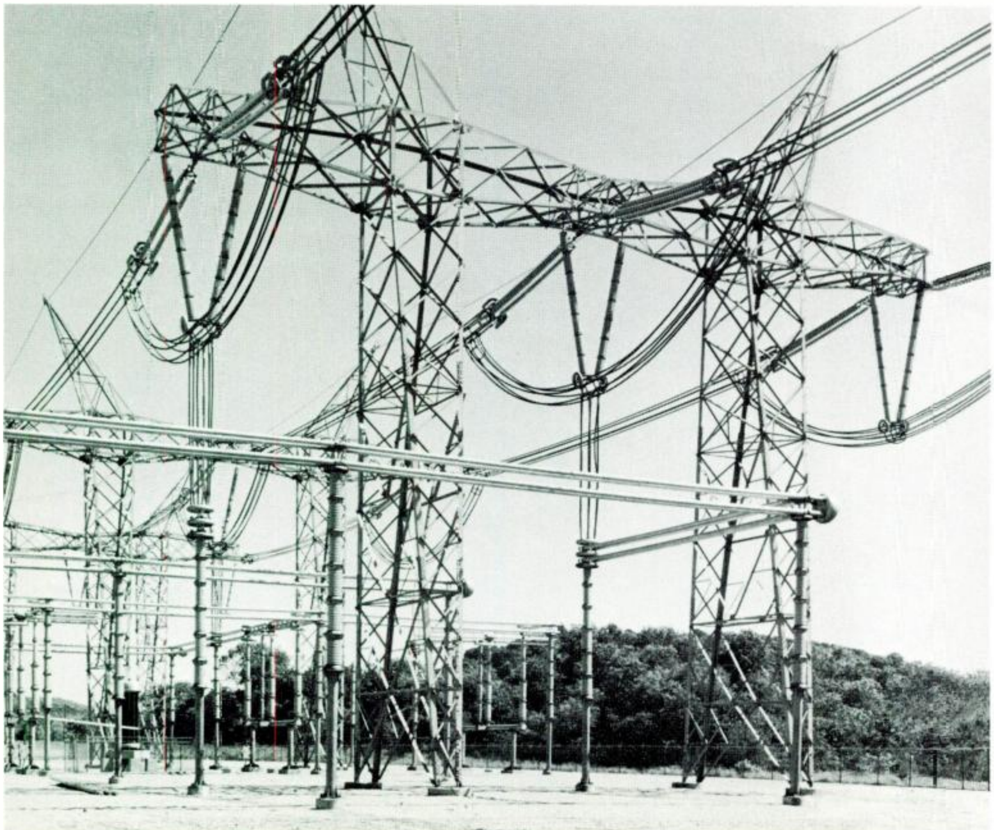

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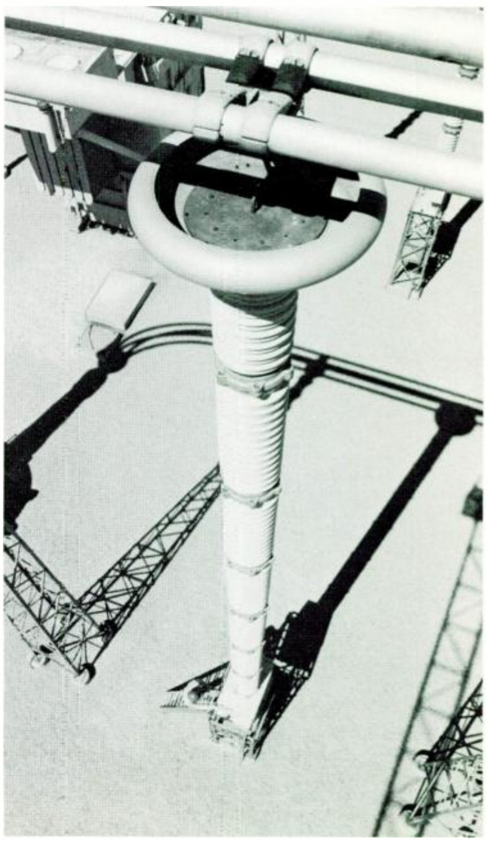

The electric field at ground level is higher than that of lower voltage substations because, to minimize expense, the 1100-kV bus was designed for minimum safe ground clearance. While tests indicate electrostatic voltages can be induced into vehicles, other objects, and workers, no physical dangers exist to the workmen because these voltages result in discharge currents that are well below the safe let-go levels.

Station Features

Although many uses can be envisioned for the test facility, the primary intended purpose is to enable accelerated testing of sample insulation and other evaluations that require a continuous high voltage, circulating load current, and computerized temperature and process control. The facility is currently divided into a high-voltage test area where controlled three-phase voltage up to 345 kV is available, and an extra-high-voltage test area where controlled three-phase voltage up to 1100 kV is available. Each major area is further divided into six test bays for cable testing.

The EHV test area is used for testing underground transmission cable samples rated 362, 550, and 800 kV. Each 1000-foot cable sample is arranged in a loop configuration, with a pothead terminal at each end for applying voltage (Fig. 5). Three-phase 138-kV power is delivered to the station over transmission lines from West Penn Power Company. From the transmission lines, power flows through 138-kV breakers, through three 40-MVA regulating transformers, and into the three 1100-kV autotransformers. Operating voltage to the test area may be varied between 315 kV and 1100 kV by selecting the appropriate no-load tap of the autotransformers. After the circuit is energized, the proper coarse and vernier tap positions are selected for the regulating transformers, which then automatically maintain the voltage within ±0.5 percent of the selected value.

An additional 10-MVA regulating transformer can be switched in series with any of the three 40-MVA regulating transformer and autotransformer combinations to supply voltages below 315 kV to the EHV test area. The 10-MVA regulating transformer has tap switches that enable the 138-kV station input voltage to be stepped down to as low as 11.5 kV before it is applied to the 40-MVA regulating transformer and autotransformer. Reduced test voltage enables base quantities such as power factor of cable samples to be measured at electric gradients below their ionization level.

Cable test conditions are chosen to simulate 40 years of sample life in a two-year test program. Empirical equations have been determined that relate insulation degradation as a function of voltage, exposure time, and most important, temperature. The two-year acceleration aging of insulation is accomplished by operating the samples at voltages up to 150 percent of their nominal rating and at temperatures beyond their emergency rating. A Prodac 250 process control computer and a console (Fig. 6) are used to control and monitor the many test parameters such as temperature, voltage, and exposure time.

Two methods are employed concurrently to apply and control heat in the sample

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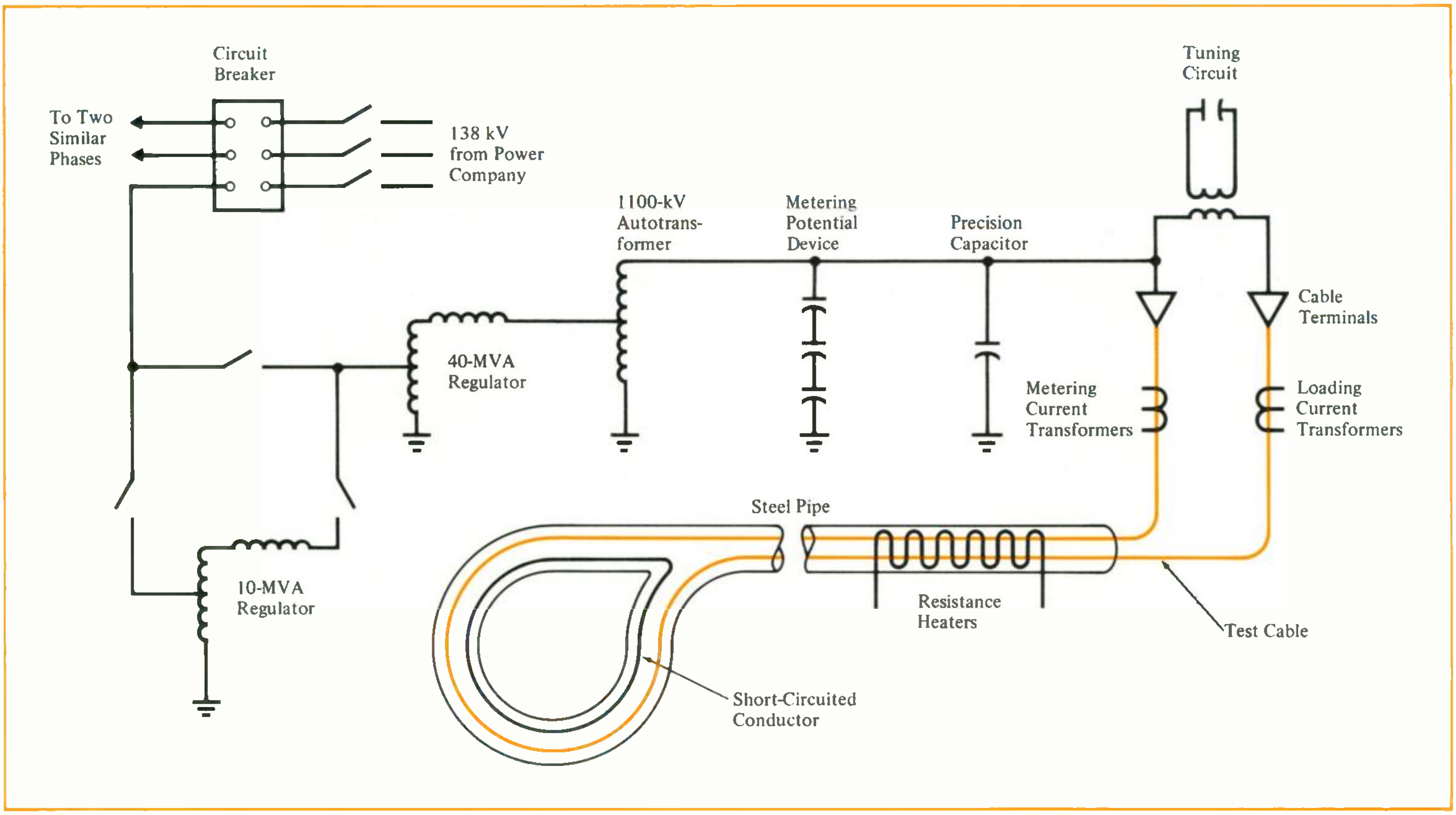

cable loops. The first is inducing load current in the loops by applying a controlled voltage to the primary of loading current transformers, which are installed around one end of the cable loop (Fig. 5). Resistive losses developed by this current flow increase the conductor temperature. By cancelling the cable sample's inductance with carefully tuned capacitors, the loading current transformers can be made to circulate current in excess of 2000 amperes in the loops. Current is controlled by a setpoint controller under direction of either the computer or manual control station. To further elevate the cable temperature, resistance heaters are installed around the steel cable housing, which is enclosed in thermal insulation. The heaters are either computer or thermostat controlled.

The HV test area is designed for accelerated life testing of 138-kV and 230-kV cables. The cables are arranged and energized in a manner similar to that described for the EHV test area. The HV test area includes three 345-kV autotransformers and associated regulating transformers (Fig. 7).

Cable Testing

Approximately 40 computer programs have been developed for the management of accelerated life testing of cable samples. The programs are of four general types: data collecting and processing, alarming and detection of abnormal conditions, reports, and control programs. Most of the information gathered by the computer is in the form of analog voltages from thermocouples and other measurement devices. An analog-to-digital program converts the analog data points every five minutes to engineering units and stores them on disc. Another program uses disc-stored temperature values to calculate average and extreme temperatures at different areas of the test sample. The computer processes about 1000 different measurement points.

Other programs check the analog data and contact closure alarms for abnormal test conditions. Contact closures verify the proper operation of control equipment as well as indicate alarm conditions for remote electrical equipment. Depending on the severity of the abnormal condition, the computer automatically initiates corrective action by printing a message, turning off load current and resistance heaters, or tripping a main circuit breaker.

Test data are automatically printed on an hourly or daily basis. Immediate and concise data printouts concerning the status of the tests can also be requested at any time through the programmer's console. Status reports generated by the computer constitute the main data sent to companies participating in the Waltz Mill Project.

Data processed by the computer and inputs from the test engineer are used by the computer to control the testing. As mentioned earlier, cable conductor temperature is the most important parameter involved in accelerated life testing of cable samples. For each test performed, the computer is capable of controlling load current, pipe heating, and duration of the test necessary to establish the proper test conditions.

The only data not acquired from the main control room are dielectric dissipation factor values and partial discharge levels. These measurements are used to

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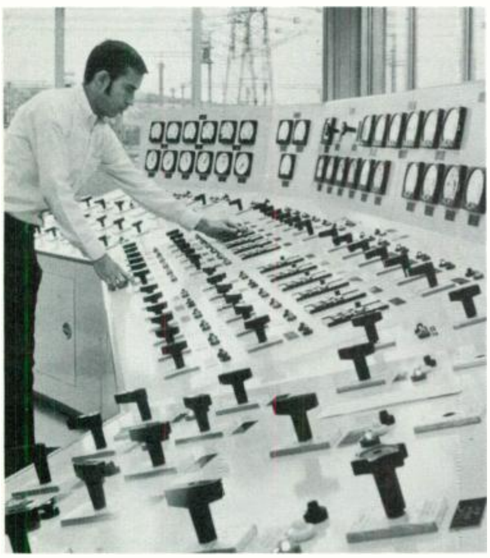

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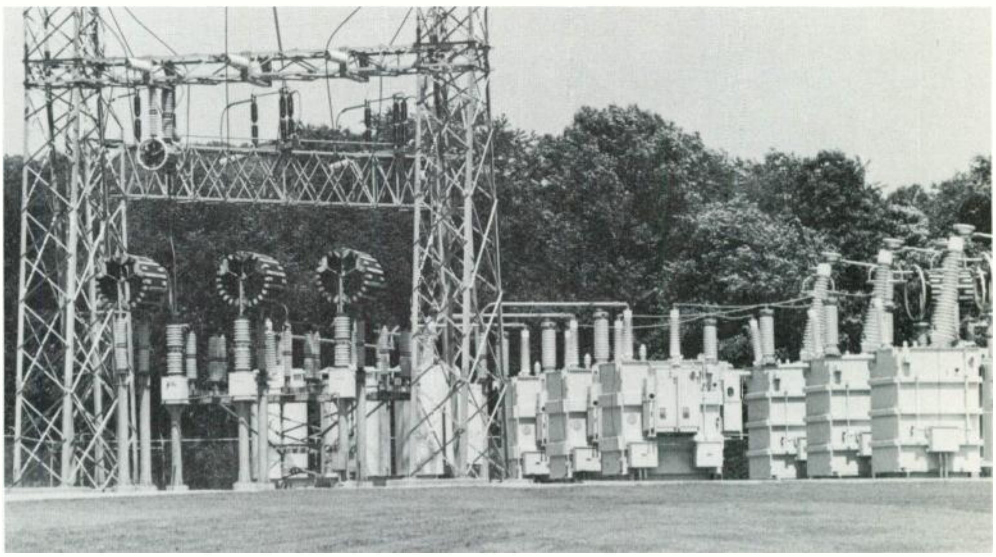


5—Simplified diagram of the EHV test area illustrates a cable sample installation, high-voltage connections, and testing and control features. A short-circuited conductor is included in the loop section of cable testing arrangement to prevent unwanted inductive heating in that section.

6—All testing is directed from the central control console. The computer control systems function from inputs through the main control panel and programmer's console, while the status of the tests is observed on the control console and recorded by computer printout.

7—Three 345-kV autotransformers (at right) and their associated regulating transformers (next to them) are installed in the high-voltage test area. The area is used to test 138-kV and 230-kV underground transmission cable samples.

determine the performance of the cable insulation systems during accelerated aging tests. Since cable insulations are not perfect lossless dielectrics, a small portion of the energy required to charge the cable insulation is dissipated in the form of heat. This energy is called the dielectric loss and is related to the dielectric dissipation factor. For a good insulation, the dielectric dissipation factor is slightly voltage dependent and extremely temperature dependent, but it shows repetitive readings at any time under identical temperature and voltage conditions. Any increase in value with time is an indication that the insulation is being degraded.

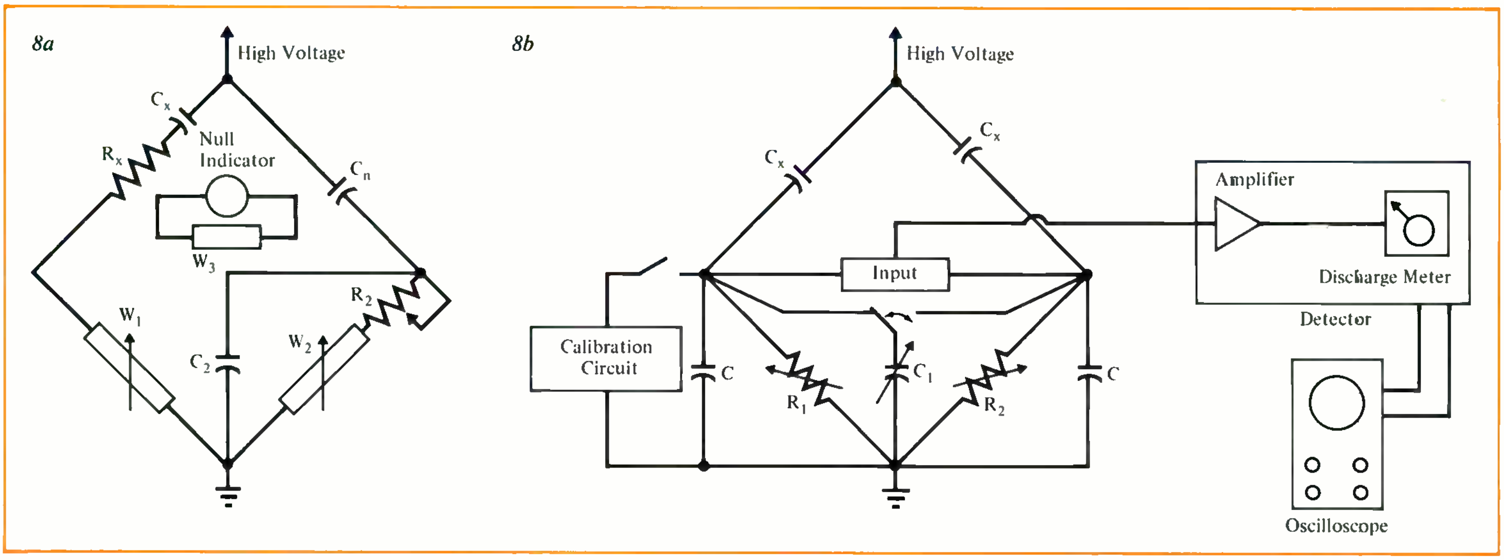
Dielectric dissipation factor is the primary quantity monitored to verify the performance of paper-insulated cables. A transformer ratio-arm bridge and a modified Schering bridge system are used to measure dielectric dissipation factor and cable capacitance (Fig. 8). Three EHV precision capacitors are used as the reference standard during these measurements. Coaxial leads from the cable sections to be measured terminate at switch consoles in the HV and EHV measurement houses. This switching arrangement permits the measurements to be made quickly and safely. The measurements have been shown to be accurate within $\pm 1 \times 10^{-5}$.

Partial discharge measurements are particularly useful for solid-dielectric cables, which can develop insulation voids or inclusions during manufacture or service life. Under high electric fields, these imperfections result in ionization that can severely shorten service life. A differential corona bridge was chosen to measure partial discharge because that instrument can reject small discharges or noise that may be present at the high-voltage terminals or voltage supply (Fig. 8). To further reduce noise pickup while making corona measurements, lead lengths are minimized by the use of an instrument truck containing the differential corona bridge system (Fig. 9). The truck is positioned adjacent to junction boxes at the ends of the cable sample. Short coaxial leads from the bridge are connected to the junction box, and ground connections are made to the bridge and truck. The truck is equipped with a heat pump to maintain proper temperature conditions for the instruments.

The corona instruments indicate the partial discharges of the cable on a discharge meter, and the voltage waveform from the detector is also displayed on an oscilloscope to help discern different types of discharges and interference. Equipment is also available for continuous recording of discharge levels during long time periods.

Test Results

The rigorous investigation of four 550-kV underground cable systems installed in the EHV area was successfully completed in the third quarter of 1972. The two-year series of accelerated life tests provide documented proof that these systems can be expected to operate in commercial service with a minimum life expectancy of 40 years. The ERC has announced that the completion of this program is a long step forward in the development of higher voltage underground cables.



8—A transformer ratio-arm bridge (a) *is used to measure the dielectric dissipation factor of cable sample insulation, whose equivalent circuit is represented by* R_X *and* C_X. *The basic components of the instrument include a variable resistor,* R_2, *a precision capacitor,* C_n, *and an electromagnetically screened difference transformer, whose windings are indicated by* W_1, W_2, *and* W_3. *By adjusting* R_2 *and the number of turns of* W_1 *and* W_2, *the bridge can be balanced as shown by the null indicator. The cable capacitance can then be calculated as* $C_X = C_n W_2 / W_1$, *and the dielectric dissipation factor as* $DF = \omega C_X R_X = \omega C_2 R_2$, *where* ω *is the radian electrical frequency. The differential discharge detector* (b) *is also a balanced measurement circuit. The elements* C_1, R_1, *and* R_2 *are adjusted to balance the bridge circuit, which includes two cable samples of equal capacitance,* C_X. *Capacitors* C *represent the capacitance between the shield of the samples and ground. Discharges in either sample result in a momentary unbalance, which causes voltage impulses over the bridge elements. The impulses pass through the input circuit and amplifier and are measured on the discharge meter. The impulses are also observed with an oscilloscope to help discern different types of discharges and interference. The detector is calibrated by injecting discharges of known magnitude into the circuit.*

Some of the six 138-kV cables currently under test in the HV test bays have completed 90 percent of the scheduled test program. Various failures of other 138-kV cable systems have provided valuable direction to the cable industry's research and development program. Improved cable shield designs and modified splice and terminal construction are a few areas where improvements have already been made. The tests have also provided data about the influence of partial discharges on the life expectancy of solid dielectric cables.

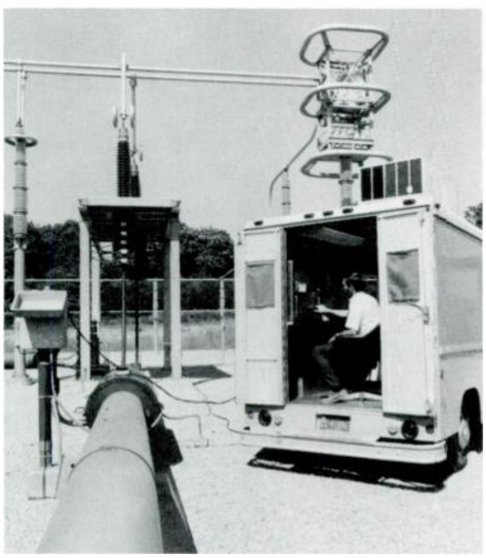
Future Work

Following successful conclusion of the scheduled 550-kV tests, a supplementary project has been instituted by the ERC steering committee. The 550-kV cable systems will be subjected to higher voltages and temperatures than originally contemplated in order to establish their ultimate capability. Demonstration of the cable systems for 800 kV is a prime objective. Additional experiments involve raising the voltage in steps to 930 kV, with current loading at each voltage step to produce conductor temperatures of 90 degrees C and 100 degrees C. Other tests will explore the effects of operating 550-kV cables at temperatures up to 130 degrees C.

When the supplemental test program is completed, the effects of forced cooling on the 550-kV cable insulation will be studied. Westinghouse has recently received a contract for this project from the Edison Electric Institute and the U.S. Department of the Interior. Forced cooling involves the limiting of the internal cable temperature by circulating the cable oil through heat exchangers located in a refrigeration plant. If it is demonstrated that cable insulation can successfully operate under forced cooling conditions, this technique promises to economically increase the power-carrying capability of pipe-type cable systems.

A 1200-foot three-phase 138-kV cable system that employs forced cooling is also being engineered for installation at Waltz Mill. Data acquired from that installation will permit verification of thermal-hydraulic parameters such as heat transfer coefficients and optimum Reynolds numbers, which are necessary for efficient design of forced cooling systems. Both the 550-kV and 138-kV forced cooling tests are essential to widespread commercial acceptance of forced cooling techniques.

Another area that will soon be explored is cable operation at cryogenic temperatures, which appears to be an effective method for transmitting large blocks of power underground. Cryogenic cables would operate at very low temperatures to greatly lower the resistance of the conducductor, thereby reducing its heat production and extending its current carrying capability. A contract has been obtained to carry out field trials on a 138-kV liquid nitrogen cryogenic cable system at Waltz Mill beginning the latter part of this year. The contract outlines a three-year test program in which equipment will be tested in three stages: first a single-phase pothead, then a short single-phase loop, and finally the complete three-phase system. The tests will require construction of a new test bay with substantially different instrumentation than that currently in use. Equipment will include a corona discharge meter for measurements of discharges that occur in the cryogenic cable during conditioning and full-voltage tests. A surge generator will also be required to superimpose lightning impulses on the test sample while it is simultaneously energized from the 60-Hz source.



9—Partial discharge measurements on solid-dielectric cables are recorded with instruments mounted in an instrument truck. Connections are made to the test cable at junction boxes located at each end of the sample.

Research on the effects of high intensity electric fields on plants, animals, and soils is also planned. A test building will be constructed next year for environmental studies to be performed by Westinghouse with the cooperation of the College of Agriculture, Pennsylvania State University. The research will be carried out in a two-phase program. Phase 1 is designed to determine if any effects exist. Depending on the results of Phase 1, a second phase will be structured to explore thresholds of effects, biological mechanisms of effects, and remedial measures.

Conclusion

The Waltz Mill Underground Transmission Test Facility is a unique laboratory in which a wide variety of underground cable samples can be tested up to a maximum voltage of 1100 kV. The facility's instrumentation and control systems provide for accurate data collection and precise control of experiments. The present and proposed tests at Waltz Mill represent a continuing effort by the EPRI and the ERC's Underground Transmission Steering Committee to solve the technical and economic problems presented by underground transmission. The construction of this facility has also facilitated the timely development of 1100-kV equipment for the electric utility industry.

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Technology in Progress

Aircraft Generator Improvements for High Temperature, High Altitude

A lightweight aircraft generator that can operate without special cooling in an ambient air temperature of 300 degrees C at 100,000 feet altitude has been shown to be feasible. The generator is cooled mainly by radiation, since air at that altitude is too thin (8.29 torr) for much help in cooling. Such a generator is especially desirable for advanced supersonic aircraft, in which the accessory environment gets hot but cooling systems must be kept small to minimize weight and drag.

Use of advanced insulation and other materials and components makes radiation cooling feasible by allowing the generator to operate at internal temperatures far higher than present generators can withstand. Winding temperature in the generator built for evaluation has been measured at 400 degrees C; in contrast, the best insulation commercially available can withstand winding temperatures of about 240 degrees C. The studies are being conducted for the U. S. Air Force by the Westinghouse Aerospace Electrical Division, which is subcontracting part of the work to the Research Laboratories and the Astronuclear Laboratory.

The generator built for evaluation is conventional in design, being a salient-pole synchronous alternator with a wound rotor and a rotating rectifier assembly (Fig. 1). However, it has special high-temperature electrical insulation, silicon-carbide diodes, and dry-lubricated ball bearings. It is an 8000-r/min 400-Hz generator rated at 5 kVA, 120 volts. Cooling is by radiation, with heat flowing from the rotor hot spots through the main generator and exciter air gaps, through the stator punchings, and through the steel frame to a heat-radiation jacket made of zirconium-copper alloy.

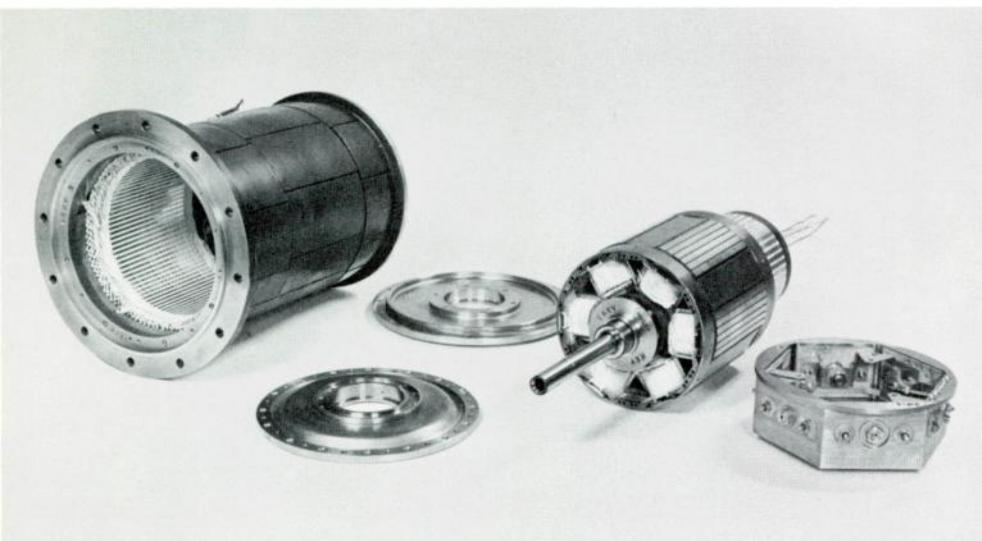
The silicon-carbide rectifiers have junctions prepared by doping during crystal growth. They are capable of operating at case temperatures up to 430 degrees C; conventional silicon diodes, in contrast, are limited to about 190 degrees C.

The ball bearings are conventional in appearance but have ball retainers fabricated from a solid lubricant made of tungsten diselenide, gallium, and indium. The balls acquire a film of solid lubricant from contact with the retainer, and they transfer the film to the races.

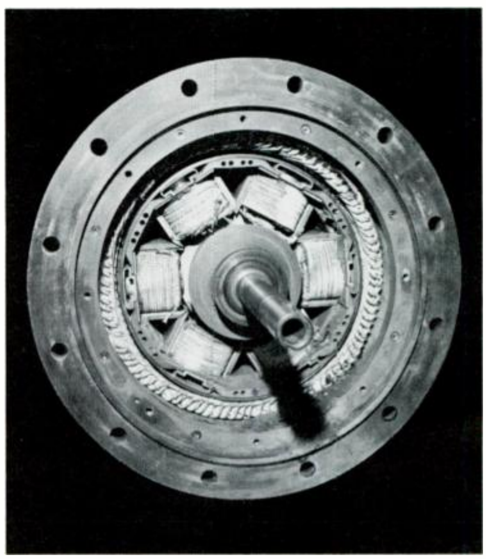
Wire insulation is glass. It was applied by coating the wire with a special frit (ground glass), wrapping it with high-strength glass filaments, and baking the windings to fuse the frit. Slot liners are alumina. The magnetic material is Hiperco-27 alloy, and conductors are nickel-clad silver.

The generator was tested for performance at an ambient temperature of 300 degrees C and a simulated altitude of 80,000 feet. Next, it was endurance tested at a simulated altitude of 50,000 feet and an ambient temperature of 300 degrees C. It ran at those conditions for 482 hours, at which time one bearing failed—232 hours beyond expected bearing life. The generator was then disassembled (Fig. 2). All components except the bearing were found to be in serviceable condition.

With the basic feasibility of the design



1—Main assemblies of the demonstration generator are the stator, end bells, rotor, and diode bridge. They are shown here before the generator was operated.



2—When the generator was disassembled after test, the components were found to be in generally good condition. It had been operated for 482 hours at ambient temperature of 300 degrees C and simulated altitudes of 50,000 feet and more.

Right—*American Electric Power's 1300-MVA transformer is shown on test before it was shipped.*

approach proved, the development effort has turned to refining the generator design and improving the materials and components. The Research Laboratories' part in that effort includes work on magnetic steels, insulation systems, and dry-lubricated bearings. Magnetic steels tend to become brittle at high temperature in air, posing the danger of laminations breaking when stressed by rotation. The investigation is aimed at finding the embrittling mechanism and overcoming it. The main effort in insulation is development of a suitable encapsulating medium to keep windage from abrading the insulation. For the bearings, new dry lubricants are being formulated and evaluated.

At the Astronuclear Laboratory, the packaging of the silicon-carbide diodes is being improved. Although the diodes in the demonstration generator performed satisfactorily, the new packaging should improve their temperature capability and their ability to withstand rotational stresses. The Laboratory also is working on techniques to increase the rating of the diodes from the present 1.5 amperes to 3.0 amperes (half-wave average).

Future objectives, pending successful completion of the component development program, include building and testing a 60-kVA flight-rated generator. The goal for that unit is a rating of 1000 hours between overhauls and 5000 hours total life.

1300-MVA Transformer Goes to American Electric Power

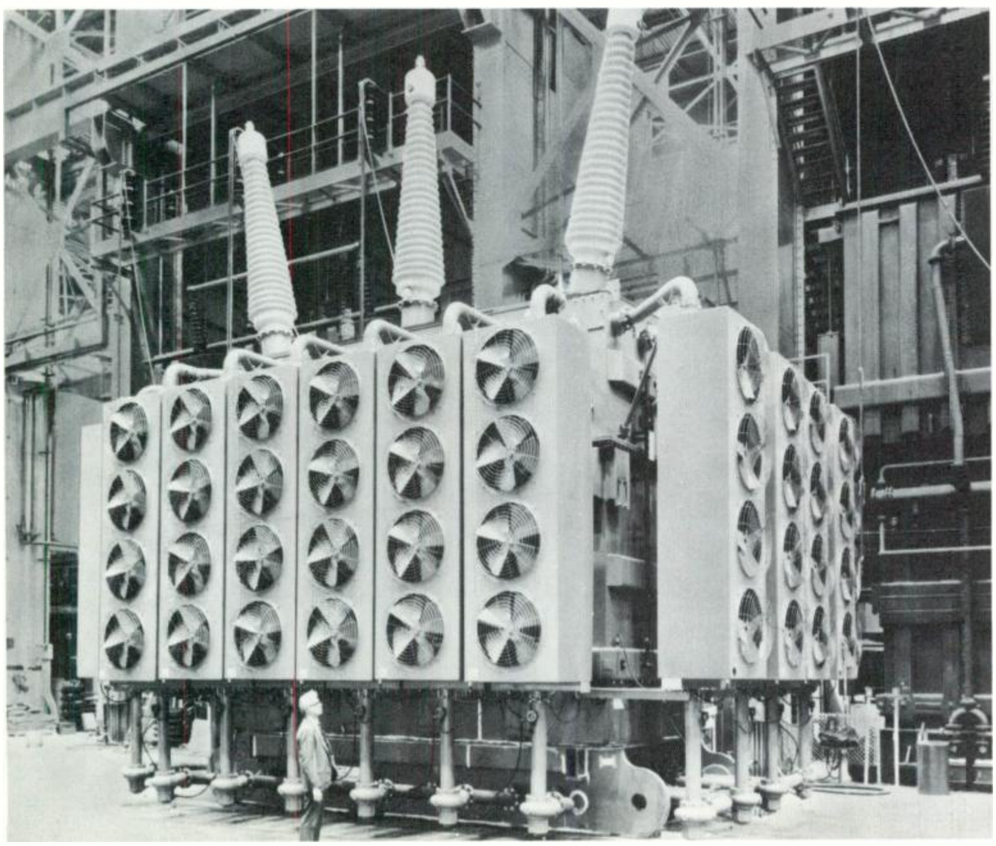
A 1300-MVA power transformer, the highest rated transformer ever designed and built in the United States, was shipped recently from the Westinghouse Large Power Transformer Division to American Electric Power Company's Donald C. Cook nuclear power plant at Bridgman, Michigan. The Cook plant is owned and operated by the Indiana and Michigan Electric Company, a subsidiary of American Electric Power.

The transformer is more than 34 feet high, 44 feet long, and 23 feet wide, and it weighs 531 tons. Its weight was reduced to about 435 tons by partial disassembly for shipment to the power plant on a Westinghouse Schnabel railroad car.

Equipment Being Supplied for Navajo Project Switchyards

Electrical apparatus for the switchyards of the Navajo Project in Arizona is being shipped and installed. Scheduled to be energized next year, the Project will provide power for parts of Arizona and southern California. Westinghouse is supplying all electrical apparatus for the switchyards under a turnkey contract, and it is responsible for construction of the switchyards. Arizona Public Service Company is project manager.

Equipment being supplied by the Westinghouse Large Power Transformer Division includes ten 500-kV single-phase generator step-up transformers, eleven 500-kV autotransformers, and thirteen 500-kV shunt reactors. The autotransformer shown on test in the photograph has been installed at the Westwing Substation near Sun City, and the shunt reactor at the Navajo Substation near Page.



This 500-kV single-phase autotransformer (left) and shunt reactor (right) were tested together before being shipped to Arizona Public Service Company for the Navajo Project. The autotransformer is rated 200/266/333/444 MVA, 525/230 kV, 1425/825 kV BIL, and it has a load tap changer to regulate voltage. The shunt reactor is rated 70 MVAR, 525 kV, 1550 kV BIL.

Airport Expansion Will Include Passenger Shuttle System

A passenger shuttle system will be part of the expansion under way at Miami International Airport. The Dade County Port Authority has selected the Westinghouse Transportation Division to provide an automated shuttle system to link the airport's main terminal with a new satellite international complex, which is scheduled to begin operations in mid-1975.

The electronically controlled shuttle system will consist of two trains, each with two rubber-tired cars, operating on a quarter-mile aerial roadway. Each train will carry 128 passengers comfortably, and the system will be able to handle 3000 passengers an hour. Traveling at about 30 miles an hour, the cars will make the run between terminals in less than a minute.

Electronic equipment on the cars and along the wayside will provide automatic control to make the passenger shuttle system operate smoothly, efficiently, and safely. Similar passenger transfer systems are in operation at Tampa International Airport and at Seattle-Tacoma International Airport. All are based on the Transit Expressway technology developed for such applications and urban rapid transit.

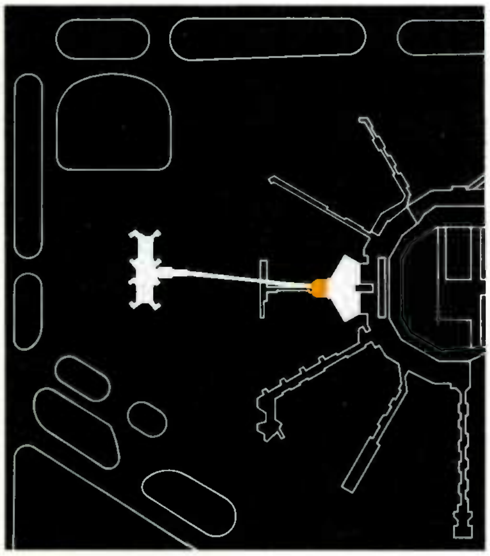
The Miami system, however, posed some unusual design problems. It had to accommodate international travel and fit into the design of the existing airport.

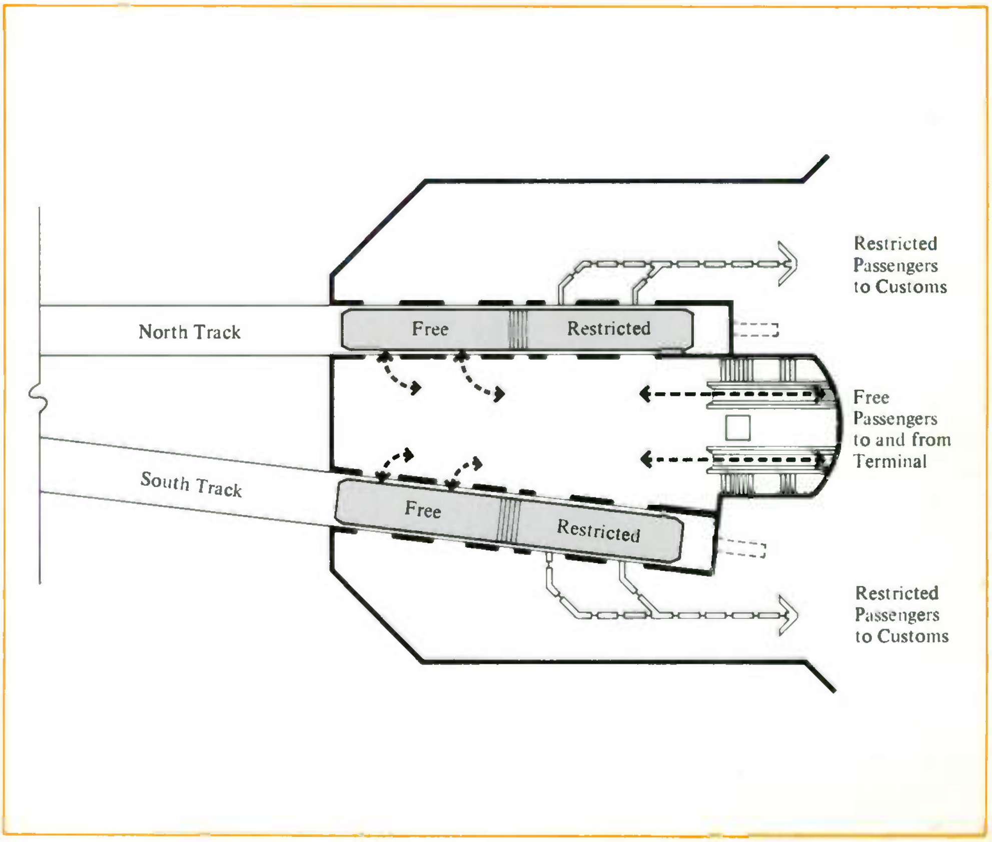
Lobby areas in both the main and satellite terminals will be divided into free and restricted zones. The free zones are for departing passengers and nontravelers, while the restricted zones are for passengers arrived from overseas who must go through customs. The system is so arranged that a train will stop at each station with one car in the free zone and the other in the restricted zone, saving passengers, their guests, and airport workers considerable time and inconvenience.

Generation and Transmission Information Goes into Automated Data Bank

An automated data bank is being developed by Westinghouse Advanced Systems Technology in conjunction with the Northeast Power Coordinating Council (NPCC). Its purpose is to provide for storing, maintaining, accessing, processing, and retrieving large quantities of technical data relating to the generation and transmission facilities of NPCC member companies. It will contain the basic data needed for conducting system load flow and transient stability studies; in addition, other data will be stored for compiling reports.

The initial loading will consist of 20 years of information. The first six years will include six load levels for each year, and the remaining 14 will include two load levels for each year. The bank will accommodate a system size of 4000 buses and 8000 lines, with 4000 shunt devices, 1200 generators, and 1200 transformers. It allows for easy expansion or revision if necessary. In addition to the data-bank program and the file managers, three application programs will be available initially: load flow, network reduction, and generation dispatch.



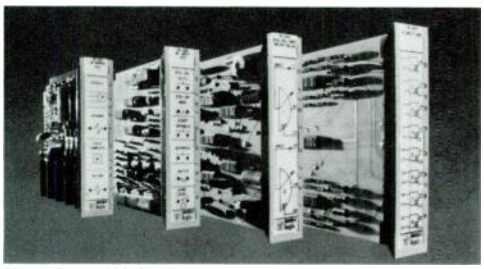


A new satellite international complex with a passenger shuttle to the main terminal, shown in solid white in the left view, will expand the capacity of Miami International Airport. The enlarged view (right) shows how use of two-car trains will make it easy to keep "free" and "restricted" passengers separate.

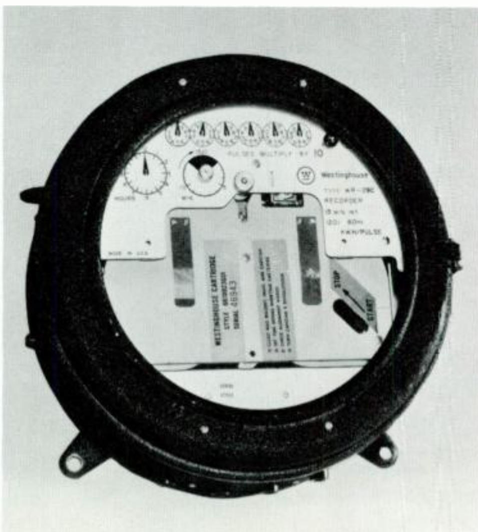
Lead-mount rectifier diodes in a new 1-ampere series are diffused silicon devices available in ratings from 50 to 1000 volts, with surge current capacity of 30 amperes (JEDEC Types 1N4001 to 1N4007). Physical dimensions and cost are about the same as many similar diodes with lower current ratings, so the new series can be used for all needs up to one ampere without changing circuit configurations. The epoxy-encapsulated devices measure 2.7 mm by 5.2 mm long with 28-mm leads. *Westinghouse Semiconductor Division, Youngwood, Pennsylvania 15697.*

Multicolor cathode-ray tube generates displays in as many as four colors with the resolution, light output, and contrast of black-and-white tubes. The multicolor capability is a simple and economical means of displaying different classes of information simultaneously and intelligibly. Uses include computer-based applications involving complex graphics or systematic interaction between the viewer and the computer, as in process control, air-traffic control, computer-assisted instruction and design, information-retrieval and management-information systems, and text-editing and document-generation systems. Red, orange, yellow, and green displays are generated simultaneously by switching anode voltages to vary electron-beam penetration of the phosphor layers. The spot size of 15 mils gives a sharp image. Light output is 25 footlamberts. Tubes can be tailored for specific applications with up to four colors and diagonal face dimension up to 21 inches, using either magnetic or electrostatic focusing. (See back cover for a display pattern generated by a computer for demonstration purposes.) *Westinghouse Electronic Tube Division, P.O. Box 284, Elmira, New York 14902. (In Europe, Compagnie Westinghouse Electric, 41 Avenue George V, 75 Paris 8e, France.)*

Numa Logic 300-Series wired-logic controls incorporate troubleshooting circuitry to substantially reduce electrical downtime of the controlled machine tools and automated processing equipment. Key element in the troubleshooting scheme is a pictorial lens, on the front of each module, that lines up with light-emitting diodes used to monitor machine operation. Each lens is marked by the user with the type and location of the mechanical motion and the symbols of the devices controlling the motion. Each circuit location displayed is also coupled to a test point, where voltage and continuity probes can be applied for quick circuit testing and isolation of the inoperative process or motion. Extensive use of integrated circuits, light-emitting diodes for indicating lights, and completely "burned-in" solid-state components make the Numa Logic controls especially reliable. Unlike some solid-state controls, Numa Logic requires no ac/dc or 440/120-volt segregation of wiring because it is immune to electrical power line interference and transients. The controls incorporate safety interlocking and broken-wire protection systems to protect personnel and equipment. They use a simple English logic format with a full range of plug-in general-purpose input, output logic, and timer modules so that the controls can be tailored to specific applications. *Westinghouse Control Products Division, Tuscarawas Road, Beaver, Pennsylvania 15009.*



Numa Logic 300-Series



Magnetic Tape Recorder

Magnetic tape recorder is conveniently and economically substituted for graphic recorders presently installed in revenue billing applications. It is designed to mount in existing enclosures, with all hardware and a new wiring harness included. Circuitry of the WR-29C recorder is compatible with existing pulse initiators; a latching relay is included so that either mechanical or photoelectric pulse initiators can be used. The recorder uses a standard tape cartridge that can accept 6000 pulses per hour. This pulse rate substantially improves resolution compared with the capabilities of graphic recorders. A battery carry-over circuit, having a solid-state inverter rather than the conventional vibrator, is optional. *Westinghouse Meter Division, P.O. Box 9533, Raleigh, North Carolina 27603.*

Solid-state underfrequency relay, Type SDF-1, is for use in automatic load saving schemes. When a system overload occurs, it disconnects load to arrest frequency decline. Diode set plugs on the front panel are used to set the relay for underfrequency trip at 54 to 60 Hz in increments of 0.05 Hz, with ±0.007-Hz accuracy. Smaller increments are available for unusual applications. The relay operates at 48 to 125 volts dc with no settings or adjustments required. Digital logic and setting techniques are used, with time delay setting made from digitally set rotary step switches. Several SDF-1 relays can be set in successively lower steps for highly selective load shedding. An optional test module allows testing at any frequency with no external test equipment required. *Westinghouse Relay-Instrument Division, 95 Orange Street, Newark, New Jersey 07101.*

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Author Index

Author biographies appear on the inside back cover of each issue.

About the Authors

C. G. Helmick began his Westinghouse career designing and applying industrial drive and control systems, an activity that led to his present responsibility for static uninterruptible power supplies. He joined Westinghouse on the graduate student training program in 1951 and went to the former Industrial Engineering Department. There he worked on development and application of drive and control systems for the chemical fiber industry.

Helmick transferred to the General Control Division in 1964 as product line administrator for adjustable-frequency inverters, a responsibility that included systems engineering and coordination. The inverter group was moved to the former Industrial Systems Division in 1970, with Helmick as Product Line Manager. He retains that position in the new Industrial Equipment Division.

Helmick earned his BSE in electrical engineering at the University of Michigan in 1950 and his MSE there the following year. He has since completed the Business and Management Program at the University of Pittsburgh.

Charles L. Wagner received his BSEE from Bucknell University (1945) and his MSEE from the University of Pittsburgh (1949). He joined Westinghouse in 1946, and after completing the graduate student course was assigned to the Engineering Laboratories where he helped develop the analog computer Anacom.

In 1950, Wagner moved to the Electric Utility Engineering Department to become a Sponsor Engineer. His work there consisted of assisting electric utility and industrial customers with equipment application, system planning, and design. In 1962, he became Project Manager of the VEPCO 500-kV project and also Engineer-in-Charge of the Relaying and Metering Groups for the other Westinghouse EHV study projects. He is presently Manager of Transmission Systems Engineering in the Transmission and Distribution Systems Department.

Wagner is a Fellow in the IEEE, chairman of the IEEE Switchgear Committee, member of the IEEE Power Systems Relaying Committee, and chairman of the ANSI C37 Committee on Power Switchgear. He is an instructor in the University of Pittsburgh Graduate School and a Registered Professional Engineer in the State of Pennsylvania.

Eric A. Udren earned his BSEE degree from Michigan State University (1969), and he is presently pursuing an MSEE at the Newark College of Engineering. He joined Westinghouse on the graduate student program and, after completing Design School, was assigned to the Relay-Instrument Division.

Udren is presently a Relay Systems Consulting Engineer, responsible for application of existing protective relays and relay systems as well as the conception and specification of new products. In the latter area, Udren was a codeveloper of the experimental Prodar 70 computer relaying system (described in the September 1972 issue of the *ENGINEER*), now in service at PG&E. He was responsible for major portions of the system's software.

J. M. Feret is Manager, Skylab Program, at the Astronuclear Laboratory. He was responsible for the design, development, fabrication, and testing of the flight-qualified M518 Multipurpose Electric Furnace System described in this issue.

Feret earned his BA degree in mathematics in 1961 at St. Vincent College and his BS in mechanical engineering at the University of Pittsburgh in 1962. He joined the Westinghouse Astronuclear Laboratory to work in design of test-assembly support equipment for the NERVA nuclear rocket. He was appointed lead design engineer in 1964 for development of the test car (used to transport the NERVA reactors between the assembly and testing facilities) and associated equipment required for testing the reactors. He later performed system malfunction and safeguard studies on various systems and components for the NERVA engine test-stand facility.

Feret has progressed through positions of increasing responsibility, such as Project Manager, NERVA Test Support Equipment, and Manager, NERVA Program Administration. He contributed to development of much of the test-assembly support equipment for the NERVA reactor tests, including the reactor support stand, radiation and thermal shields, personnel stands, and hydraulic, cryogenic, and gaseous piping systems. He was appointed to his present position last year.

Robert Mazelsky graduated from Hofstra University in 1954 with a BA degree in chemistry. He went on to the University of Connecticut, where he received his PhD degree in chemistry in 1958.

Dr. Mazelsky joined the Westinghouse Research Laboratories in 1958. There he has worked on thermoelectric materials, solid oxygen electrolytes, luminescence and lasers, and crystal growth. He was appointed Manager, Inorganic Preparation and Crystal Growth, in 1964. Dr. Mazelsky's achievements include development of laser and optical crystals for defense systems. He has been awarded five patents and has published some 30 technical papers.

C. J. Baldwin is an electrical engineering graduate of the University of Texas, where he earned a BSEE degree in 1951 and his MSEE the following year. He also received a professional Electrical Engineer degree from Massachusetts Institute of Technology in 1957. He graduated from the Program for Management Development at Harvard Graduate School of Business in 1969.

Baldwin joined the Electric Utility Engineering Department of Westinghouse in 1952, where for several years he was a Sponsor Engineer dealing with system engineering problems of utilities in the Ohio River Valley area. In 1956, he was awarded the B. G. Lamme Graduate Scholarship by Westinghouse for his year of study at MIT. Following this, he headed a team that developed new techniques of power system economic planning by digital simulation. In 1962, he assumed management responsibilities for consulting work and development of power system planning techniques for utility and industrial customers. He is currently Manager of Research and Development, Advanced Systems Technology, Power Systems Planning. He is responsible for development of new technology for power systems and products, being primarily concerned with bridging the gap between research and application. Present projects include the Waltz Mill 1100-kV Underground Test Facility, the Apple Grove 775-kV Overhead Test Facility, the mobile switching surge laboratories, the oscillography laboratory, and the Anacom facility.

Baldwin served for six years as a lecturer at the University of Pittsburgh and the Westinghouse Advanced Design Course, teaching graduate courses in transients in linear systems and engineering applications of field theory. For seven years he lectured on engineering economics at the Graduate School of the U. S. Department of Agriculture in Washington, D.C.

J. W. Bankoske graduated from Pennsylvania State University with a BSEE degree in 1964, and he is currently completing work toward his MSEE at the University of Pittsburgh.

Bankoske joined Westinghouse on the graduate student training program in 1964. Following completion of training assignments and Engineering School, he was assigned to the Electric Utility Engineering Department at East Pittsburgh, where he worked as an Assistant Sponsor Engineer. The group conducted technical investigations of electric utility systems and provided guidance regarding product development to various Westinghouse divisions. In 1966, he was assigned to the Underground Transmission Section, which was responsible for designing, supervising construction, and operating the 1100-kV Waltz Mill Underground Transmission Test Facility. He has worked on all facets of the project's design and operation, with particular responsibility for instrumentation of the project. In 1972, he was appointed Supervising Engineer of the facility.

Bankoske has contributed to design and specification of equipment for detection of corona discharges and power factor of cables at voltages up through 1100 kV. He was also responsible for application of a digital process control computer for control of the Waltz Mill Facility.

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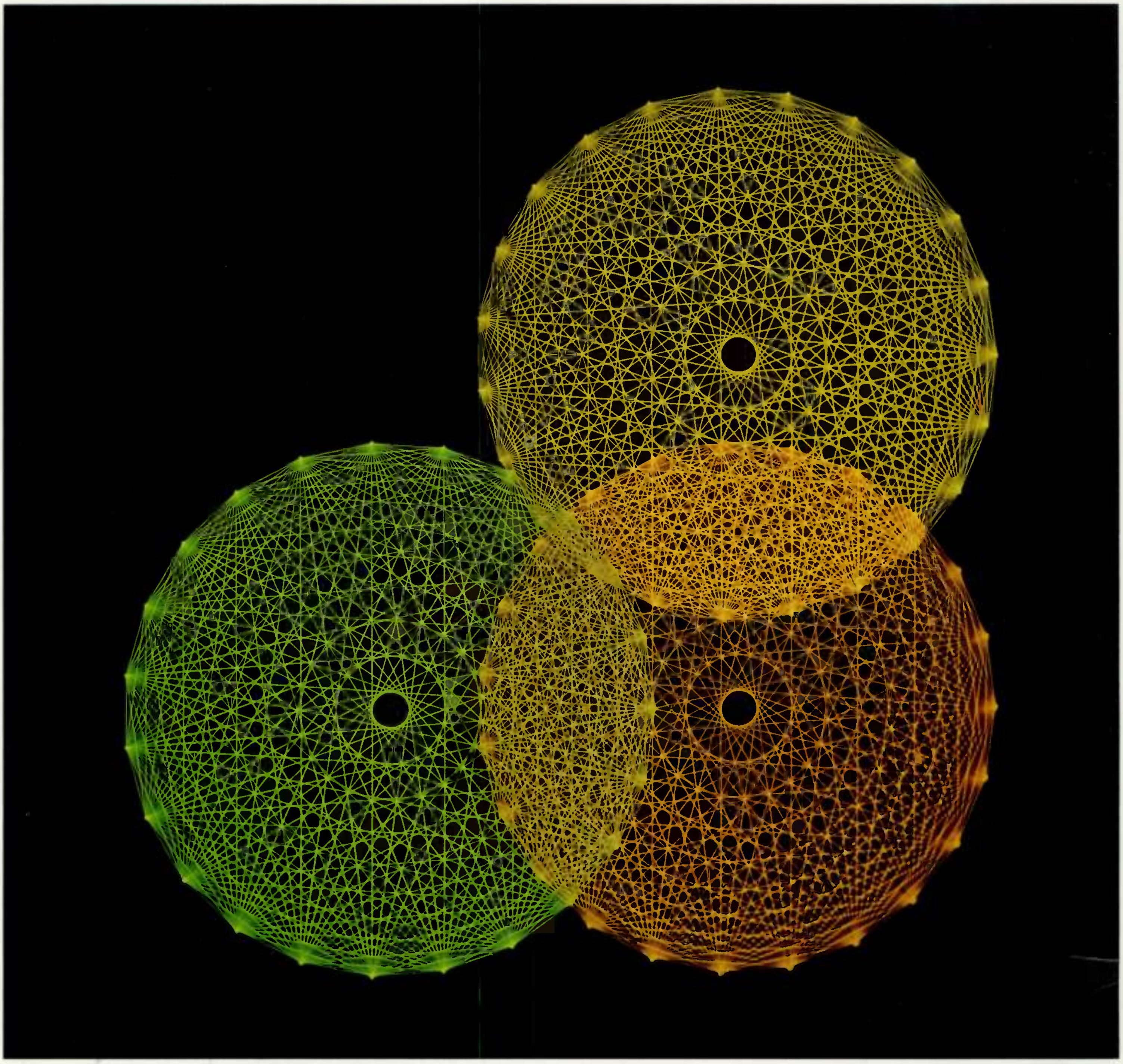
Pittsburgh, Pennsylvania 15222



This is the face of a Westinghouse cathode-ray tube that generates displays in as many as four colors simultaneously. For more information, see "Multicolor cathode-ray tube," page 189.