Cable Power Facility

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Submarine cable system power supplies must be designed to provide an uninterrupted flow of precisely controlled, transient-free operating power for a time interval equal to the service life of the cable system. Heavy reliance on redundancy along with conservative application of semiconductor and magnetic circuit elements form the basis for the circuit design. The equipment design emphasizes the techniques required to withstand high voltages, provide ease of maintenance and insure personnel safety.

Saturable reactors operated in the constrained mode serve as the basic power control element. AC power for the saturable reactors is obtained from a transistor inverter fed from a continuously floated storage battery. Metering-type magnetic amplifiers are used to isolate the regulation, metering and alarm circuits from the high-voltage output. Transistor amplifiers and temperature-compensated silicon reference diodes complete the regulating loop.

I. INTRODUCTION

The power supplies for the SD submarine cable system[1] must be designed to provide an uninterrupted flow of precisely controlled, transient-free operating power if the long life and stable transmission characteristics inherent in the submerged repeater design are to be obtained. Ideally, the power system should be capable of providing this power without interruption for the life of the cable system. Equally important is the need for reliable automatic alarm and shutdown circuits. These signal the presence of abnormal cable currents and voltages and turn down the power if hazardous levels are reached, whether the cause of the trouble is within or external to the power plant.

II. DESIGN REQUIREMENTS

Fig. 1 illustrates the basic power feeding arrangement used. Nominal current and voltage for a 3600-nautical mile (nm) system are shown.

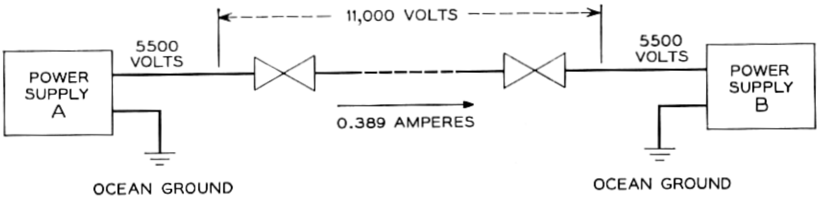

Fig. 1 — Basic power feed arrangement.

Power is normally applied from both ends to minimize the applied voltage stress. For systems shorter than 1800 nm, power may be applied optionally from both ends or one end only.

Complete electrical design requirements are given in Table I. These values apply for supplying power at one end of the cable.

TABLE I — ELECTRICAL DESIGN REQUIREMENTS

Normal voltage	5500 v
Normal current	0.389 a
Ripple	1 v rms maximum
Noise	−120 dbm maximum (0.1 mc–1.1 mc) referred to transmission input
Normal accuracy of current control	±0.4% absolute
Load current regulation	
1000-v change	1.0%
Rectifier failure	−0.5%
Output resistance above 6500 v	2500 ohms

External alarms:

Power plant output

Minor alarm	Major alarm
current ±2%	current ±5%
voltage ±5%	voltage ±10%

Rectifier output

Minor alarm	Major alarm
current −5%	current +5%
less than 500 v	more than 7500 v

Protective shutdowns:

Rectifier

5% over-current
over 7500 v

Plant

over 9000 v

III. DESIGN PHILOSOPHY

Redundancy was considered the key to achieving the required degree of reliability. To fully exploit this approach, three basic principles were felt to be essential: minimum interdependence of one functional element upon another, use of static components only, and minimization of the number of components which could not be made redundant directly connected to the power plant output. Fig. 2 illustrates the basic power system. Two identical power plants are used, independent of each other except for the sharing of the ac input power source and cable terminating equipment.

Power for the battery charging rectifiers is normally obtained from commercial sources. When commercial power failure occurs, these rectifiers are fed from the emergency power system of the station. The batteries are normally maintained on continuous charge with their outputs fed directly to the inverters. The inverters are designed to operate over the normal battery voltage range without end-cell switching or other voltage adjustment means.

Regulation of the cable current is done by the high-voltage rectifiers. These, along with their associated inverters, are designed to have full

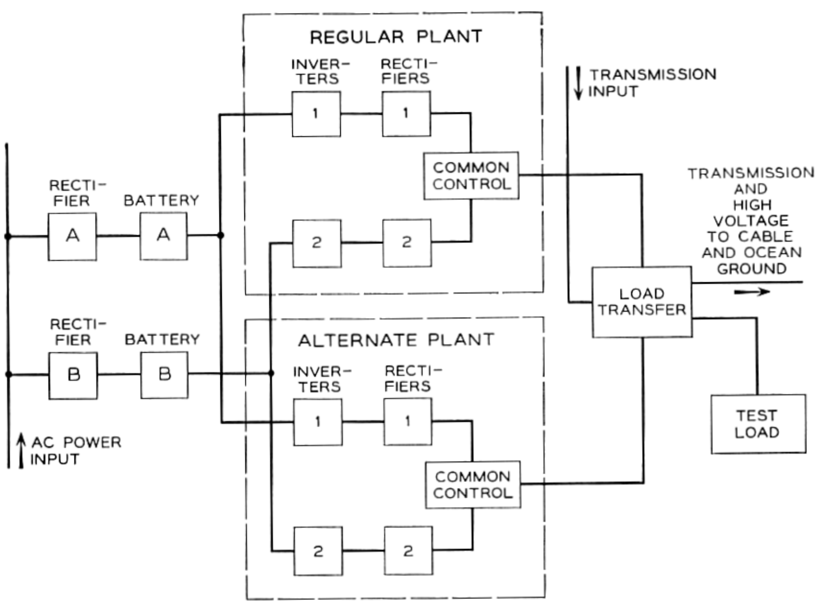

Fig. 2 — Power system functional block diagram.

load capability. In normal operation they are connected in series and adjusted to share the load equally. If the output of one of the rectifiers fails, the remaining rectifier assumes the cable load. When this occurs, it is normal practice to transfer the power feed to the standby power plant. The load transfer is designed to permit such a transfer without disturbance of the cable current.

An adjustable test load is provided to permit testing of both individual rectifiers or a complete power plant. A precision calibrating circuit is included as an integral part of the test load to permit periodic calibration of the cable current meters.

IV. EQUIPMENT DESIGN OBJECTIVES

The equipment design objectives were as follows:

(a) to provide an equipment arrangement capable of withstanding the high voltages present without dielectric breakdowns or corona for extremely long service periods,

(b) to give easy access to apparatus for repair or maintenance operations

(c) to guarantee personnel safety and proper operation of the plant by design features,

(d) to provide mechanical integrity to withstand 3-g shock loads due to atomic blasts when installed in hardened sites,

(e) to require a minimum of installation effort, and

(f) to provide a distinctive, pleasant appearance.

V. GENERAL DESCRIPTION

5.1 *Equipment Design*

The power plant is composed of a number of seven-foot-high cabinets, the exact number and arrangement being a function of the specific application. Among the considerations involved are the length of cable being powered, the type of installation (hardened or nonhardened), and the degree of redundancy desired. An arrangement of cabinets for a regular supply is shown in Fig. 3. An alternate power plant does not include a load transfer. A test load cabinet is furnished with each regular supply.

The power plant equipment cabinets are 7 feet high, with split rear doors. Two widths are available. The cabinets are of welded aluminum construction. A different type of cabinet is used for the test load and is available with wheels or for direct mounting to the floor. A number of slide-mounted equipment units of a generally similar mechanical configuration are incorporated in the cabinets. Typical units are shown in Fig. 4.

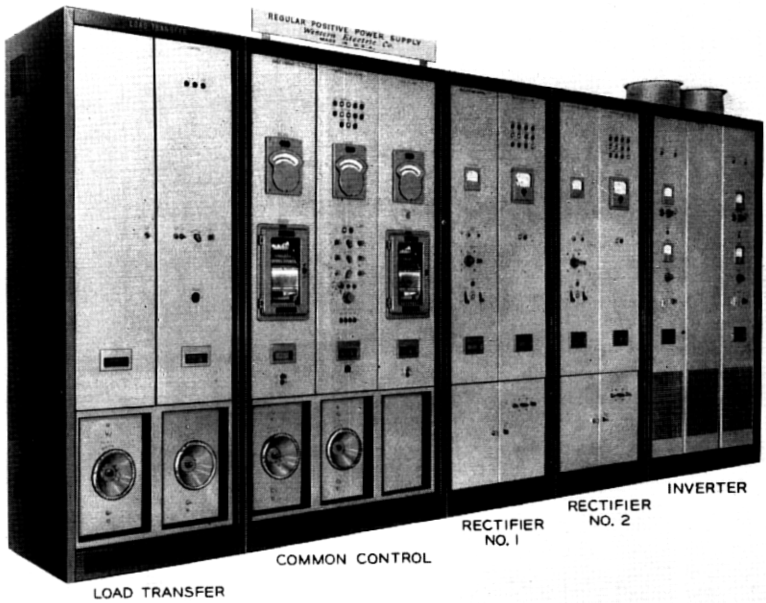

Fig. 3 — Terminal plant — regular power supply.

5.2 *High-Voltage Rectifier Circuit Design*

A series-connected saturable reactor,[2] operated well into the constrained mode, is used as the main power-control element in the rectifiers. This device electrically approximates an ideal current source by virtue of its ability to maintain an output current whose magnitude is proportional to the control current but is virtually independent of supply and load voltage variations. When appropriately designed with a control circuit having a long time constant, it behaves as a current source under dynamic as well as static operating conditions.[3]

Fig. 5 shows the circuit schematically with typical wave shapes. The rectangular wave shape of the load current is independent of supply and load voltage wave shapes in the linear operating range, as shown. Typical saturable reactors used in this system exhibit only a 2 per cent change in load current for a 25 per cent change in supply voltage and a load voltage change equivalent to 6500 v.

The principal reasons for the use of the saturable reactor were:

(1) it is inherently a current source, requiring only a nominal amount

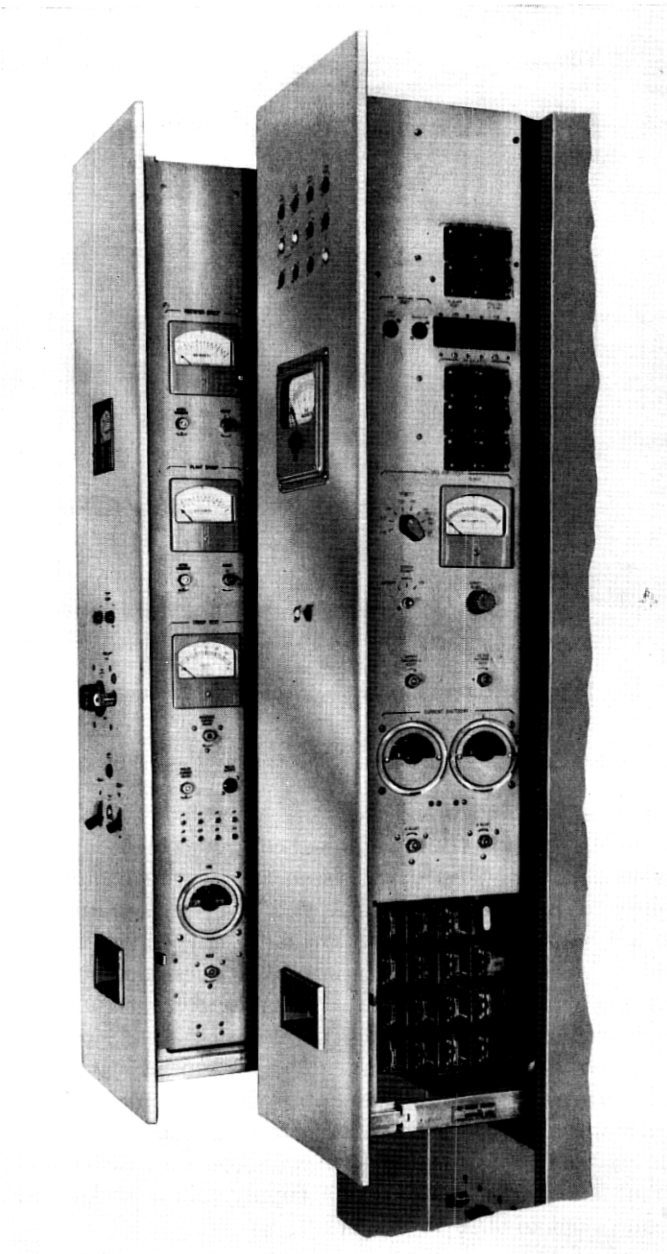

Fig. 4 — Typical slide-mounted units.

of over-all regulating circuit loop gain to meet both static and dynamic performance requirements;

(2) the rectangular load current wave shape is ideal for rectification, giving a small percentage output ripple;

(3) a long control circuit time constant prevents sudden and rapid change in the rectifier output, providing ample time for detection and turndown of a runaway rectifier before significant changes in cable current can occur; and

(4) insensitivity to supply voltage variations permits use of an unregulated ac power source.

The practical problems associated with designing a saturable reactor circuit for operation at these power levels virtually rule out the use of commercial power frequencies. A 60-cycle design would be impracticably large in volume and weight. The attractiveness of the saturable reactor

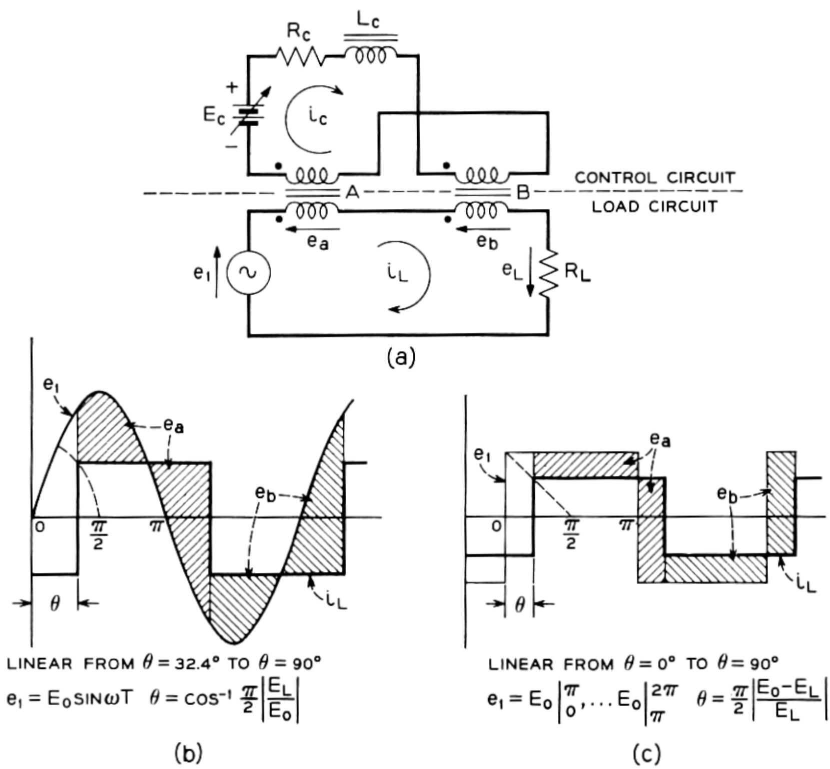

Fig. 5 — Saturable reactor regulator circuit: (a) schematic, (b) waveforms with sinusoidal excitation, (c) waveforms with square-wave excitation.

approach, however, was sufficiently great to justify the use of higher supply frequencies.

Since a reliable source of ac operating power is essential to fulfillment of the design objectives, careful consideration must be given to its selection. The availability of power transistors having collector dissipation ratings of 250 watts makes possible static inverter designs capable of meeting the power requirements for this system. These inverters, in their simplest form, generate rectangular output voltage wave shapes (although sinusoidal outputs can be obtained by appropriate techniques). Saturable reactors as used here are inherently insensitive to supply voltage wave shape, within broad limitations, and a single design can be made to give satisfactory performance with either wave shape. The rectangular wave shape offers the advantage of the widest possible linear operating range for a given reactor, as may be seen by reference to Fig. 5, permitting the most economical design for a given set of requirements. Where operation with both wave shapes is required, this economy cannot be obtained.

Proven schemes for generation of reliable ac power based on the use of rotating machines are widely used. Because of the availability of reliable 400-cycle rotating machines and the broad experience gained with this frequency in military systems, a decision to use nominal 400-cycle power was made (although even higher frequencies would have been more suitable from a size standpoint).

The advantages of the static inverter, including freedom from routine maintenance, make it the preferred ac power source for this system. Although a suitable proven design did not exist at the outset of this project, the availability of rotating machines as a back-up approach permitted ample time to prove in an inverter design. This was accomplished, and static inverters are used at all terminal installations.

To obtain the full potential of saturable reactor regulation, it is necessary to connect the outputs of the rectifiers in series. This stems largely from the desire to maintain a constant cable current under all operating conditions. If the rectifier outputs were connected in parallel, for example, loss of output from one of the rectifiers would require a sudden increase in the output current of the remaining rectifier if a significant dip in cable current were to be avoided. The relatively long time constant of the saturable reactor circuit precludes rapid adjustment of rectifier output current. A second disadvantage would be the need for a greatly increased regulator loop gain in order to provide the required gross changes in control current without a significant change in cable current. While this approach represents a departure from past practices, it is not entirely without precedents. A dual of this method may be found in the parallel operation of voltage sources in the commercial power industry. This arrangement permits addition or removal of supplementary sources without significant disturbance to the load.

Fig. 6 shows the basic interconnections within a plant. Shunt diodes are connected across the output of each rectifier. Under normal operating conditions these diodes are reverse biased and conduct a negligible current. If the output current of a rectifier should fail, its voltage will drop to zero and attempt to reverse polarity as a result of current flow from the remaining rectifier. The shunt diode, becoming forward biased, provides an alternate path for the current, permitting the remaining rectifier to supply the load. Only two rectifiers are shown in the illustration, but the technique can be extended to any number of series-connected rectifiers.

To insure stable load voltage sharing between rectifiers, two steps must be taken. The first is a reduction of the nearly infinite rectifier output resistance to a finite stable value. The second is provision of a highly stable regulating circuit.

While any desired amount of rectifier output resistance could have been obtained by a combination of both current and voltage feedback, the complexity of this approach was felt to be excessive when contrasted with the simplicity of an equivalent physical resistance connected across the output. To limit the change in cable current to less than 0.5 per cent following failure of a rectifier, this resistance must have a value of 1.5 megohms. The less than 3-watt power consumption is insignificant.

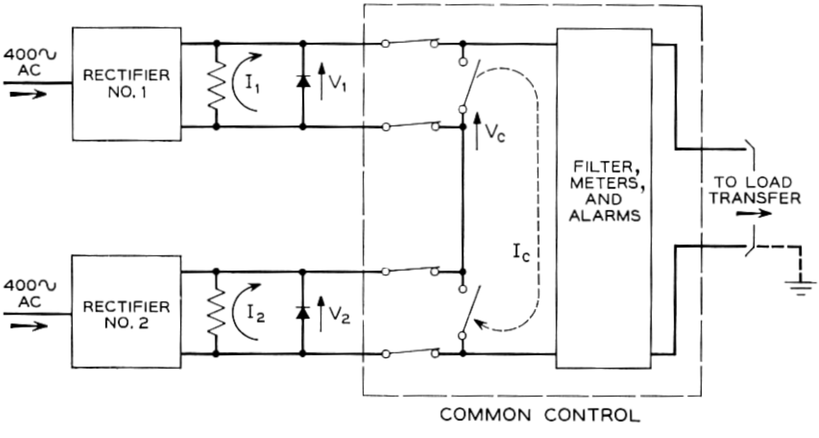

Fig. 6 — Power plant interconnections.

If the drift in voltage between two rectifiers is to be held to less than 75 volts for long periods of time, the drift in rectifier output current must be held to less than about 0.025 per cent for equivalent periods of time. Achievement of this high level of stability requires careful regulator circuit design. The availability of temperature-compensated silicon reference diodes and matched transistors permitted meeting this requirement with direct-coupled transistor amplifier circuits.

No special precautions were found necessary other than compliance with accepted feedback stability criteria to insure freedom from oscillation and hunting. The rectifiers are designed to be stable for both open- and short-circuit conditions.

5.3 *Common Control Circuit*

By virtue of its relationship to the over-all system, the common control is one of the more critical parts of the system. Either terminal-to-terminal short circuits of shunt-connected apparatus or a grounding failure of apparatus connected to the high-voltage conductor will result in immediate loss of cable power. Great care was therefore taken to minimize the likelihood of such failures. This was done largely by keeping the number of such components to a minimum and by paying special attention to the design and manufacture of these components to insure the highest possible quality.

While an open-circuit failure of series-connected components will also result in immediate loss of cable power, series-connected components are limited to magnetic amplifiers and filter inductors. With suitable design and manufacture the probability of an open-circuit failure in these can be made virtually zero.

VI. DETAILED DESCRIPTION

6.1 *Inverter*

The design of the inverter was based on the use of 250-watt silicon power transistors developed by Westinghouse Electric Corporation.

The inverter is designed to operate from a 42 to 52-vdc source. Two outputs are provided. The main output, rated at 4.5 kva, is unregulated and supplies power to the saturable reactor in the rectifier. A second output, rated at 0.3 kva, supplies regulated operating power to the rectifier feedback amplifier and the metering magnetic amplifiers in both the rectifier and common control. The regulated output voltage is held statically to within ±1 per cent for combined input voltage and load current changes. No special speed of response requirements was necessary, however, because of the type of regulating circuit used in the rectifier.

Special attention was given to the design of the main power stage to insure reliable operation with the saturable reactor load. The inverter must perform satisfactorily with a load current whose magnitude and phase angle describe the region bounded by 0 to full-load current and 0 to unity power factor. For example, a rectifier delivering rated current into a short circuit will draw full-load kva at nearly 0 power factor from the inverter.

With the exception of the oscillator, each inverter stage is of the bridge configuration. The oscillator uses a center-tap circuit to permit simple application of series *LC* timing.

Provision is included in the oscillator circuit for frequency synchronization of all inverters in a power plant. The synchronizing circuit is loosely coupled, so that faults on the synchronizing bus will result only in loss of synchronization. Synchronization is provided to eliminate possible beat frequency interference between the combined outputs of the rectifiers in a plant.

6.1.1 *Reliability*

Conservative transistor operation was considered essential in obtaining reliable inverter performance. To achieve this, not only must the average and peak transistor power dissipation be held within conservative limits, but also the locus of the product of instantaneous collector current and voltage must be maintained within the reliable operating region for the transistors used.

The peak collector power dissipation of the transistors has been held to less than their rated average power dissipation. With the exception of the power stage, average collector power dissipation has been held far below ratings. The heat sinks provided are capable of maintaining collector junction temperatures below 100°C under all operating conditions.

Economic considerations required that the transistors in the power stage be operated much closer to their ratings, in order that the total number of devices be held within reasonable limits. The power stage design permits failure of up to one transistor in each of the four circuit legs before catastrophic inverter failure becomes imminent. This is accomplished by the use of 8 parallel-connected individually-fused transistors in each leg of the power stage. The fuses are of the fast acting current limiting type. Sufficient overload current capacity is available in

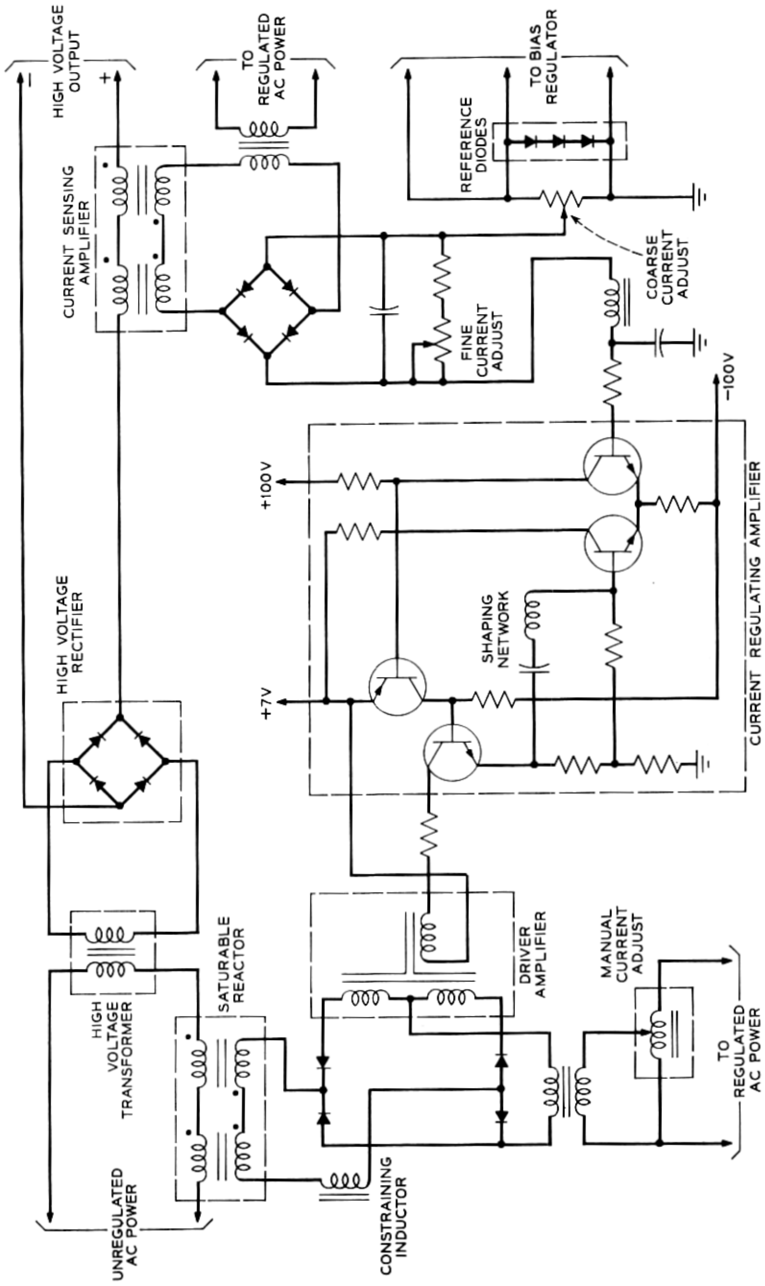

Fig. 7 — Current regulating feedback circuit.

the circuit to blow a fuse following a transistor failure without serious overload of the remaining transistors. The circuit has been designed to operate at rated load for at least 8 hours with only 7 transistors per leg.

An automatic fuse failure alarm is provided to signal the presence of a blown fuse. A manually operated metering circuit is provided to permit in-service measurement of individual transistor currents, permitting detection of low-gain or open-circuited transistors.

6.2 *Rectifier*

It was shown earlier that output failure of one of the rectifiers—resulting from a terminal-to-terminal short circuit, for example—while undesirable, does not result in loss of cable power. Grounding failures within the rectifier directly connected to the high-voltage power plant output conductor will result in immediate loss of cable power. As in the common control, it again becomes important to minimize the likelihood of grounding failures.

Metering-type magnetic amplifiers, which functionally exhibit at dc all the attributes of a high-quality ac current transformer, are used to isolate the metering, regulating and alarm circuits from the high-voltage part of the circuit. This approach offers the dual advantage of materially reducing the number of components directly subjected to high voltage and permits use of conventional devices and circuit techniques for metering, regulation and alarms. Only those components which by their basic function must be connected to the high-voltage conductor are so connected.

6.2.1 *Current Regulation*

The current regulating circuit is shown in Fig. 7. Negative feedback is provided around the 3-stage transistor amplifier to reduce the effects of unit-to-unit variations in transistor parameters and to provide a convenient point for applying the shaping network required to insure adequate gain and phase stability margins for the regulation system.

A reference voltage of about 20 v obtained from temperature-compensated silicon diodes is required to obtain the required regulator dc stability. Bias current for the reference diodes is obtained from a single-stage transistor regulator.

The output of the transistor amplifier controls a self-saturating magnetic amplifier (driver amplifier) which in turn drives the main regulating saturable reactor.

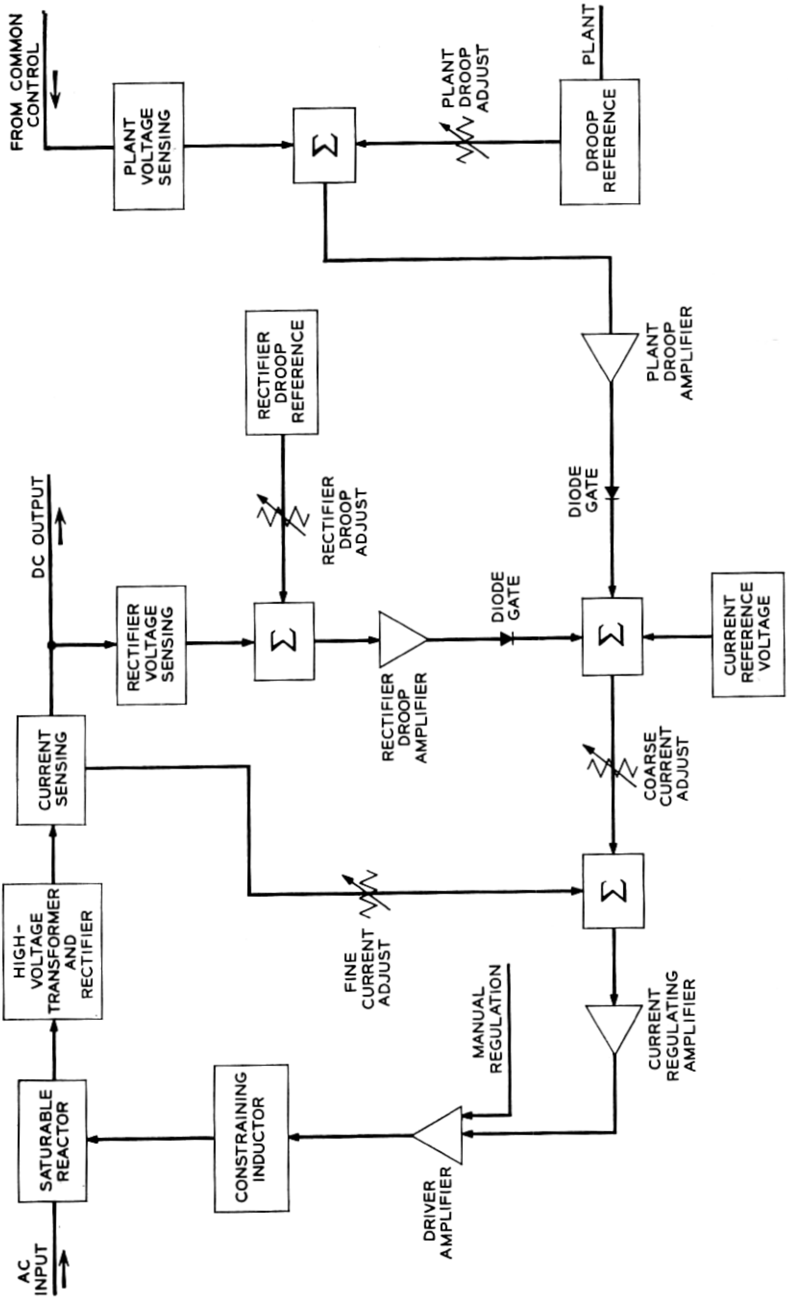

Fig. 8 — Rectifier feedback regulator functional block diagram.

6.2.2 *Current Droop*

Voltage limitations in the repeater power separation filter capacitors make it preferable, when the applied cable voltage exceeds 6500 volts (as might occur with abnormally high earth potentials), to reduce cable current rather than allow further voltage increase. A transition from current to voltage regulation is obtained by the addition of a second feedback path to the regulator, responsive to plant output voltage. This feedback path is coupled into the first path at the current regulator reference. The circuit is so designed that in the current droop region the magnitude of the reference voltage is reduced in direct proportion to the increase in output voltage. Since the current regulator acts to maintain the rectifier output current accurately proportional to the magnitude of its reference (voltage), effective control of current is possible.

The gain of the droop circuit is adjusted to produce a 100 per cent reduction in cable current for a 1000-v increase in cable voltage (normally from 6500 to 7500 v). A 3-stage single-ended transistor feedback amplifier provides the controlled gain and power required to modulate the current regulator reference voltage. A functional block diagram of the over-all rectifier feedback regulating circuit is shown in Fig. 8.

Two separate droop circuits are provided with each rectifier. The first, as described above, responds to plant output voltage. The second, functioning in a similar manner, responds to rectifier output voltage and serves as back-up protection. It is normally adjusted to act at the same voltage as the plant droop circuit. Since the voltage of an individual rectifier is normally about one-half the plant voltage, the rectifier droop circuit will function only if one of the plant droop circuits fails.

6.2.3 *Droop Circuit Test*

Under normal circumstances, the occurrence of large earth potentials is infrequent, but it is important that the droop circuits function properly when required. Confidence in these circuits can be obtained if an in-service test can be performed. To be meaningful, this test should involve as much of the droop circuit as possible.

A second control winding (test winding) is provided on each of the metering magnetic amplifiers. The output of these amplifiers is proportional to their net control ampere turns. By passing a dc current through the test winding, it is possible to either increase or decrease the amplifier output while in no way affecting normal system output.

The input and output of each droop amplifier is metered during test. The input meter indicates either the plant or rectifier voltage; the output meter indicates the voltage difference between the droop amplifier output and the current regulator reference voltage. This voltage indicates the amount of margin existing before droop action takes place. By adjustment of the test winding current, this margin can be brought to zero. The indication on the input meter then corresponds to the voltage at which droop will occur.

Selector switches are provided to permit application of an adjustable current to each of the test windings. Normal droop action of the circuit is inhibited during test.

Fig. 9 illustrates the voltage-current characteristic of a power plant when the effects of the current droop circuit are included.

6.2.4 *Manual Regulation*

The main regulating saturable reactor is sufficiently stable over time intervals of 10–15 minutes to permit usable rectifier operation on a manually controlled basis. This provides a back-up operating mode. Operation in this mode involves only the driver magnetic amplifier and a continually adjustable autotransformer, the latter serving as the manual current adjust control. In this mode of operation, control current is removed from the driver magnetic amplifier. It then behaves purely as a passive element, delivering a dc output voltage proportional to input voltage obtained from the manual current adjust control. Input

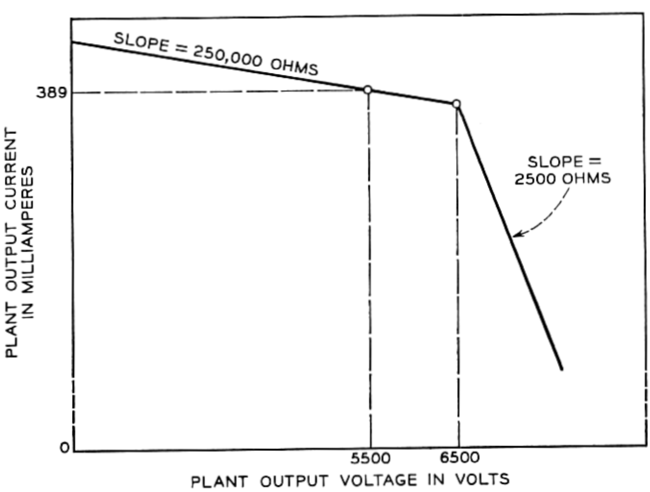

Fig. 9 — Power plant voltage-current characteristic curve.

power for the driver amplifier is taken from the regulated ac output of the inverter.

6.2.5 *Rectifier Alarms and Shutdown Circuits*

To meet the over-all design objectives, the rectifiers must provide automatic alarm and shutdown protection when abnormal currents or voltages exist. These abnormal conditions can occur as a result of malfunction of a rectifier, operator error, excessive earth potentials or faults on the cable system.

Two classes of alarms are provided. Those designated "minor" imply the presence of an abnormal but tolerable current or voltage. Those designated "major" imply the presence of hazardous current or voltage and require shutdown of the offender.

Two independent sensing circuits feeding separate, permanently adjusted, meter-type relays provide the current alarms. Each relay responds to both high- and low-current conditions. When the high-current contact on either relay makes, shutdown as well as an alarm indication takes place. Shutdown is produced by release of the main ac input contactor. A second fast-acting electronic shutdown circuit, fed along with one of the meter relays from one of the sensing magnetic amplifiers, is provided. This circuit produces shutdown by interrupting the dc input to the inverter oscillator. Power flow from the inverter ceases within about 15 msec after the shutdown level is reached. The shutdown circuits are all adjusted to operate at the same current. The electronic circuit, being faster, operates first. The relays provide back-up protection.

A single sensing circuit feeding both an adjustable contact indicating meter relay and a fast-acting electronic circuit is provided for the voltage alarm. Shutdown is accomplished in the same manner as for the current alarms, with both circuits adjusted to operate at the same voltage. The meter relay serves also as the rectifier output voltmeter.

While great care has been taken in the design of the rectifier and inverter, a malfunction is likely to result in abnormal output. Where low current occurs, the shunt diode automatically bypasses the output. When high output occurs, the alarms will provide immediate warning, and if the output is over 5 per cent above normal will result in immediate shutdown. When sudden failure of the feedback regulator occurs, resulting in maximum output, the long (0.3-second) time constant of the main saturable reactor control circuit provides ample time for detection and shutdown before the current can climb appreciably above the shutdown level.

Alarm lamps are provided for each specific alarm function. These lamp indications persist for any alarm that signals the office alarm. An approximately 2-second time delay is provided on all minor alarms. If the alarm comes in and clears before the delay has elapsed, the alarm clears automatically and no office alarm is transmitted.

6.2.6 *Alarm Testing Circuits*

Under normal conditions, the frequency of alarm indications is very low. It is important, however, as with the droop circuits, that these circuits function properly when abnormal conditions occur. Additional positions are provided on the magnetic amplifier test selector switches to permit in-service testing of these circuits. Where the function to be tested includes shutdown, shutdown is inhibited. All other aspects of the alarm and shutdown circuits are unaffected by the inhibiting action. Through application of the test signal to the magnetic amplifier, confidence in the integrity of the alarm circuits is maintained, since the complete alarm path is tested. Inhibiting involves bridging of normally closed relay contacts.

The design of the alarm test circuit does not permit accurate adjustment of the alarm operating points, but rather is intended solely as a functional check. The design of the meter-type relays insures that they will hold their calibration over long periods of time. Accurate calibration of these relays is possible by taking the equipment out of service and operating it with the test load. Fig. 10 shows the test circuit used.

6.2.7 *Spark Gap*

A protective spark gap is connected across the dc output of the rectifier to limit the maximum instantaneous voltage which can be developed. This is done to protect components in the rectifier against damage resulting from excessively high voltage. A resistor and a current sensing relay are connected in series with the spark gap. Operation of this relay results in rectifier shutdown. The resistance is provided to limit the peak current in the protector circuit.

6.3 *Common Control*

The basic functions of the common control are:

(1) connect and disconnect means for the individual rectifiers in a plant,

(2) voltage and cable current metering,

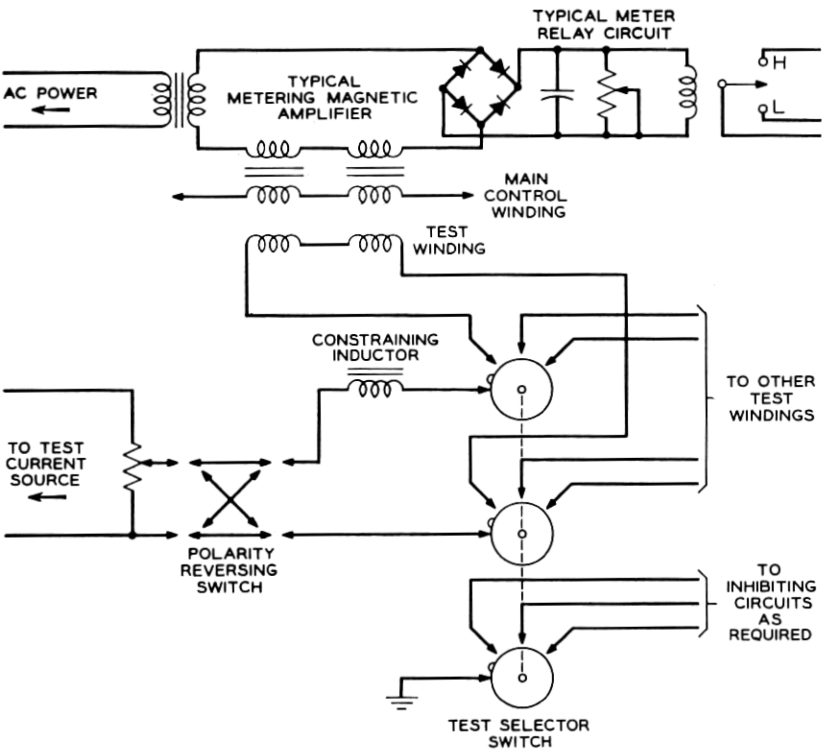

Fig. 10 — Magnetic amplifier test circuit.

(3) monitoring of cable voltage and cable current by means of alarms,
(4) final power supply output ripple filtering, and
(5) means for surge voltage limiting.

As in the rectifier, metering magnetic amplifiers are used to isolate the alarm circuits from the high voltage circuit. Since one side of the plant output is at ground potential, indicating voltmeters are operated directly with high-resistance multipliers.

A suppressed-zero meter (300 to 450 ma), operating from a metering magnetic amplifier having exceptional stability, is used for precision cable current metering. The magnetic amplifier is connected in the high-voltage conductor at the output of the common control. AC power for these magnetic amplifiers is selectable by means of a selector switch so that power can be obtained from any of the rectifiers.

Since none of these alarms results in shutdown, their failure results only in loss of alarm capability. Alarm failure resulting from loss of ac

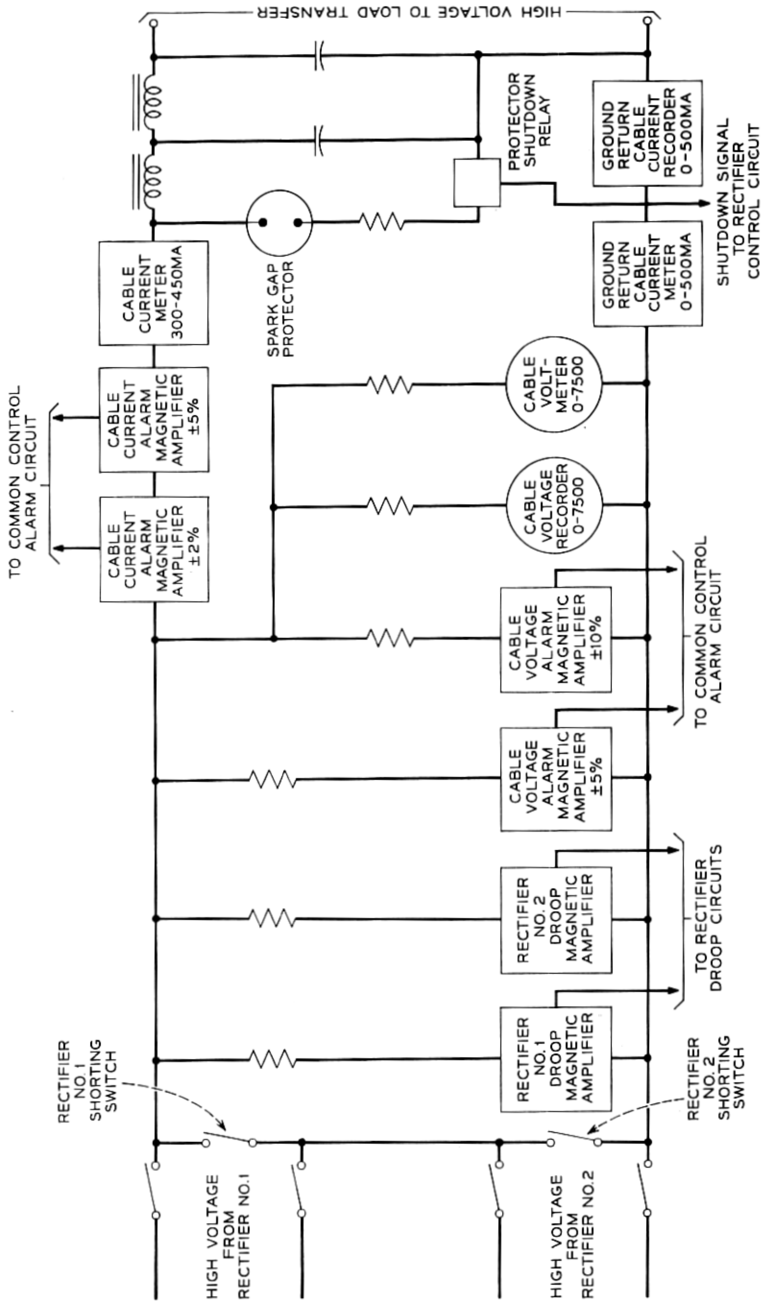

Fig. 11 — Common control functional circuit.

power produces immediate transmission of low-limit major alarms to the office alarm system.

An alarm test circuit similar to that used with the rectifiers is provided for in-service testing of all alarms. Fig. 11 illustrates the common control functional circuit.

6.3.1 *Surge Voltage Protection*

The series connection of the rectifiers results in an asymptotic open-circuit voltage greater than 15,000 v. Application of such a voltage to filter capacitors within both the power plant and the repeaters will severely shorten their life. Because of the constant-current nature of the power plant, such voltages are possible following an open-circuit cable break. The rate of rise of voltage can be as high as 120 v per msec depending on the location of the break. This rate of rise is too fast to control by direct overvoltage sensing and turndown circuits. Instead, a spark gap, designed for fast triggering and capable of carrying the full plant output current indefinitely, is used for surge voltage protection.

A current limiting resistance and current sensing relay is included in the spark gap circuit to limit the magnitude of the surge current and to produce shutdown of the power plant.

6.4 *Load Transfer*

The purpose of the load transfer is to permit transfer of power from the working power plant to the standby power plant without interruption or disturbance of the cable current. Fig. 12 illustrates the circuit used. The transfer operation consists of energizing the standby plant through the connected path (A) into the test load; then simultaneously adjusting the standby plant and test load until the current and voltage equal that of the working plant; then closing the presently open contacts (B) and opening the formerly closed contacts (A). It may be seen at this point that the former working plant is now feeding the test load and the standby plant is now feeding the cable.

Alarm transfer relays synchronized with the high-voltage contacts connect the office alarm to the working plant.

6.5 *Test Load*

The test load is designed to dissipate the full power output of either an individual rectifier or a complete plant. Load voltage is adjustable to permit operation at any voltage from 0 to 7500 v. This flexibility is

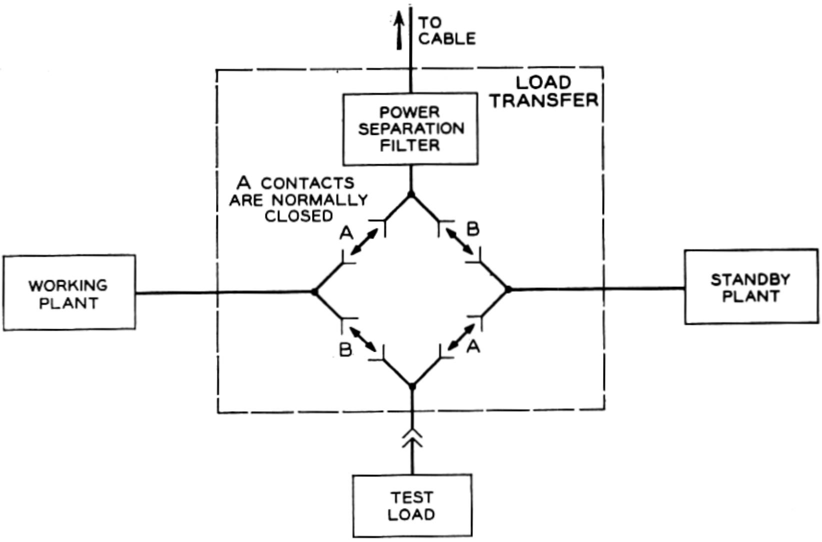

Fig. 12 — Load transfer circuit.

required to accommodate all possible lengths of cable systems. Meters accurate to 0.25 per cent are provided for current and voltage measurement.

6.5.1 *Ripple Measurement*

An attenuator is provided to permit rectifier or plant output ripple voltage to be measured at a safe potential with respect to ground.

6.5.2 *Precision Current Meter Calibrator*

Two sets of shunts and standard cells are provided to permit an accurate calibration of the power plant cable current meters. The shunts have a resistance which gives a voltage equal to the nominal standard cell voltage at 0.389 ampere of current. The voltage drop across the shunt is compared to the voltage of the standard cell by means of a sensitive galvanometer. Switches are provided to permit comparison of the voltage drop across each shunt to the voltage of each standard cell and permit cross comparison of calibrating circuit elements to reveal a drift or aging in any of these elements.

VII. DETAILED EQUIPMENT DESCRIPTION

7.1 *Appearance*

In the equipment development the aim was to design a distinctive, pleasant-appearing, and functional set of equipment. A distinctive blue color was selected for the exterior of the cabinets and the rear doors. Light gray panels are used for ease of legibility, readability and maintainability. Panels which are adjacent to one another have rounded edge contours to minimize the effects of assembly tolerances. An effort was made to provide an up-dated appearance for components such as meters recorders, etc. The number of cables, conduits and other appurtenances to the equipment bay tops is minimized in order to achieve a clean, uncluttered look.

7.2 *Voltage Isolation, Personnel Protection and Key Interlock System*

Hazardous voltages over 600 volts within the power supply are isolated so that access to components with these potentials is restricted when the equipment is energized. These voltages are isolated in locked units or in locked compartments. Fig. 13 demonstrates the isolation within the equipments. The high- and low-voltage sections within the cabinets are defined by vertical or horizontal partitions. The tops of the cabinets are enclosed with sheet-metal covers. The foregoing is generally applicable to all equipment cabinets except the inverter cabinet, which has no potentials above 600 volts and is therefore unlocked.

Operating procedures designed to minimize any interruptions to service or injury or damage to equipment were developed to allow access to high-voltage portions of the equipment only when the potentials had been removed. Each step in the procedure requires the operation of a key or number of keys wherein the key is released, captured or exchanged.

The key interlocks are used to control the operation of switches, the opening of doors, the operation of variable autotransformers, the operation of the patch panels, the operation of patching facilities for testing, etc.

7.3 *Maintenance*

A number of maintenance features have been included. The major feature is the provision of regular and alternate power supplies which are in either the working or standby condition. This permits testing and main-

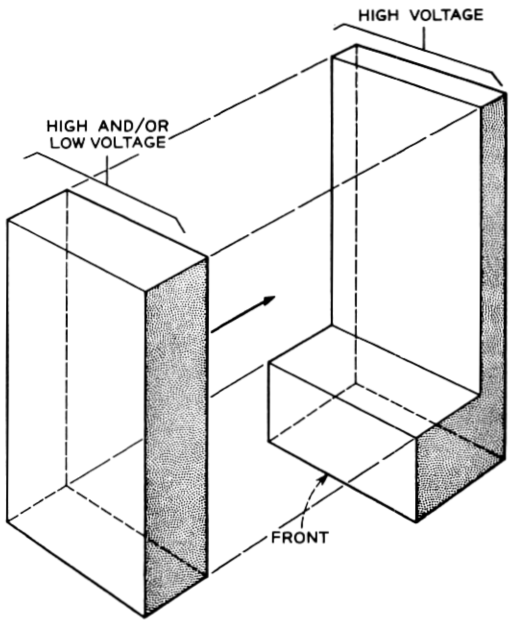

Fig. 13 — Voltage isolation in equipment.

taining the standby plant without concern, since there is no effect on the submarine cable system.

Recording ammeters and voltmeters monitor the output voltage and current of the regular and alternate power supplies. These recorders serve as an invaluable aid in maintenance procedures in the event of an unscheduled shutdown of the power supply. Alarm lamps and indicators have been furnished to assist trouble shooting or adjustment. Test jacks have been provided for in-service checks of low-potential circuits. A major maintenance tool is the test load.

Human engineering principles have been applied wherever possible in the location of controls, meters, switches, etc.

Equipment units on pull-out ball bearing slides are used for better packaging and also to improve maintenance access. Units with only low-voltage circuitry have an interior secondary control area for controls and apparatus required for maintenance adjustments. These are exposed when the slide unit is extended. A typical arrangement is shown in Fig. 4. Indicators of system performance are front panel mounted and are visible at all times. This approach eliminates the vast clutter of instrumentation controls, switches, etc. which might otherwise appear on the front of the equipment panels, and has simplified maintenance and training.

7.4 *Corona and Dielectric Tests*

For system reliability the power plant must withstand corona and dielectric voltage test requirements. Portions of the equipment must pass 19,000-vac or vdc dielectric test requirements and 10,000-vdc corona tests. Workmanship items which include elimination of sharp projections, loose strands of wire and the achievement of smooth, round solder joints are important in passing these dielectric and corona requirements. Ceramic standoff insulators required baked silicone varnish surface treatments to pass corona requirements.

7.5 *Apparatus*

7.5.1 *Patch Panels*

Since the power plant includes redundant rectifiers and provision for regular and alternate supplies, it was necessary to incorporate a suitable disconnect and voltage isolation means whose mechanical operation could be visually verified. The term "patch panel" has been applied to this piece of equipment, which is seen in Fig. 3 in the lower part of the common control cabinet.

The patch panel is essentially a mechanically operated jumper cable. When a handwheel is turned clockwise, specially designed male and female molded high-voltage cable assemblies are connected. The patch panels are locked in the connected and in the disconnected position by means of key interlocks.

7.5.2 *Vacuum Relays*

Vacuum relays are used as shorting switches and control relays. Their operation is associated with the operation of the key interlock system. Vacuum relays were selected rather than mechanical switches because of their superior voltage breakdown characteristics and small size. Relays are normally used in pairs with paralleled contacts. The relays are designed to fail-safe in the event that the coil power is lost.

7.5.3 *Semiconductor Devices*

Semiconductor devices have been extensively employed in the equipment. No tubes, other than gas tubes which will be described later, have been used. In the high-voltage portion of the rectifiers, encapsulated silicon diode sticks with capabilities far in excess of operating conditions have been specified. The diode-encapsulated sticks are mounted using ceramic standoffs to further improve their voltage capability to ground.

7.5.4 *Gas Tubes*

In order to further assure personnel safety and plant reliability, gas tubes have been used which are counterparts of the gas tubes used in the submarine cable repeaters. These gas tubes protect power supply high-voltage meters and recorders if their ground side opens. The tubes will fire and clamp the instruments to ground. Another gas tube, which can carry full cable current, is shunted around the current recorder and the direct-reading ground current return meter to protect against an open in the meter shunts.

7.6 *Hardening*

For protection of communications facilities, most submarine cable terminal stations are installed at hardened sites. In order to achieve a minimum usage of floor space for the power supply, a design with the equipment cabinets arranged in two rows, facing each other, was developed as shown in Fig. 14. The equipments are placed on a platform mounted on rubber shock mounts.

VIII. SPECIAL EQUIPMENT

8.1 *Ground Supply*

The ground supply bay is primarily designed to act as a ground and transmission termination for a cable system powered from one end. A power separation filter is included to permit insertion and removal of transmission circuits. The ground supply bay can be connected to a second ground supply bay to serve as the through connection at an intermediate point on the submarine cable system. It is also possible, on an emergency basis, to patch in a high-voltage power plant to the ground supply to power a part of a submarine cable system.

8.2 *Shipboard Power Plant*

During the laying and repair operation in the submarine cable system it is necessary to provide power to the cable from both land and ship or possibly from one source alone. For these situations a shipboard power

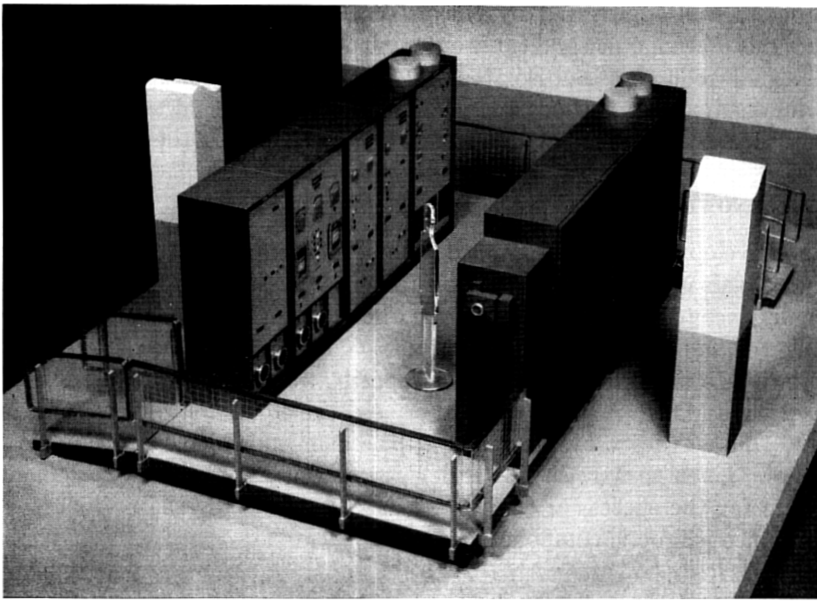

Fig. 14 — Hardened site installation.

supply has been designed and is installed on C. S. *Long Lines*. The shipboard power supply is available for cable laying operations and powering the cable stored on a ship. It is also possible during cable laying operations to power from the shore end and apply a ground to the cable aboard the ship. The shipboard power supply is designed to operate on 400-cycle ac power supplied by a pair of motor alternators. Its design includes several options permitting use with existing foreign or domestic submarine cable systems.

8.3 *Power Plant for Short Cable Systems*

A small power plant similar in design to one of the main power plants has been developed to supply operating power for distances less than 300 nm with double-end power feed or 150 nm with single-end power feed. The major differences are the use of only a single two-rectifier power plant, 1200 cycles ac power, and elimination of key interlocks.

IX. ELECTRICAL NOISE

Some difficulty has been found with electrical noise interference, both from sources within and external to the power plant equipment. This problem was aggravated by the presence of three distinctly different grounds (ocean, office and cable outer conductor) which must be common at signal frequencies but isolated at dc. A satisfactory solution was found after on-site investigations and involved minor equipment wiring changes and the addition of capacitors at appropriate points in the circuit.

X. ACKNOWLEDGMENTS

A development of this complexity obviously required the work of many individuals in order to bring the project to successful completion. Special credit goes to Mr. B. H. Hamilton, who formulated the basic approach followed and supervised the circuit design; to Mr. V. B. Boros, who contributed to the concept and was responsible for a portion of the circuit design; to Mr. R. R. Gay, who supervised the equipment design; and to Mr. D. E. Trucksess, who managed the over-all project. Credit should also be given to Mr. A. D. Hasley's magnetic apparatus development group for the successful design of a large number of reliable high-performance magnetic components.

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