Power Feed Equipment for the North Atlantic Link

By G. W. MESZAROS* and H. H. SPENCER*

(Manuscript received September 20, 1956)

Precise regulation of the direct current which provides power for the undersea repeaters in the new transatlantic telephone cable is necessary to maintain proper transmission levels and to assure maximum repeater tube life. The highest possible degree of protection is needed against excessive currents and voltages under a wide variety of possible fault conditions. Furthermore, to minimize the dielectric stresses, a double-ended series-aiding power feed must be used and the balance of these applied voltages must be maintained in spite of substantial earth potentials. This paper describes the design features which were employed to attain these objectives simultaneously, while eliminating, for all practical purposes, any possibility of even a brief system outage due to power failure.

INTRODUCTION

The principal objectives in the power plant design for the Transatlantic cable system were as follows:

1. To stress reliability in order to guarantee continuous dc power to the electron tubes that form an integral part of the submerged repeaters. This is essential, not only to be able to maintain continuous service, but to prevent cooling and contraction of the repeater components, especially the tubes.

2. To provide close dc cable current control to ensure constant cathode temperature and regulated plate and screen potentials for the repeater tubes. These operating conditions are essential both for obtaining maximum life from these tubes and for maintaining constant transmission level.

3. To control and limit the applied dc cable potentials in order to minimize the dielectric stresses. The life of certain capacitors in the repeaters is critically dependent upon these stresses. Moreover, momen-

* Bell Telephone Laboratories.

tary high potentials increase the chances of corona formation and insulation breakdown.

4. To protect the cable repeaters from the excessive potentials or currents to which they might be subjected after an accidental open or short circuit in the cable.

5. To compensate for earth potentials up to 1,000 volts, of either polarity, that may develop between the grounds at Oban and Clarenville during the magnetic storms accompanying the appearance of sun spots and the aurora borealis.

6. To provide adequate alarms and automatic safety features to ensure safe current and voltage conditions to both the cable and the operating personnel.

DESIGN REQUIREMENTS

Reliable Cable Power

The first basic problem of design was to select a reliable source of dc power for energizing the cable repeaters. Although a string of batteries, on continuous charge, is perhaps the most dependable source of direct current, such an arrangement is not attractive here. A complex set of high-potential switches would be required for removing sections of batteries for maintenance and replacement purposes. Protection of the repeater tubes from damage during a cable short circuit would be difficult. Facilities to accommodate changing earth potentials would be cumbersome. Furthermore, the problem of hazards to personnel would be serious.

The use of commercial ac power with transformers and rectifiers to convert to high potential dc would expose the cable to power interruptions even with a standby diesel-driven alternator, because of the time required to get the engine started. A diesel plant could be operated on a continuous basis, but this prime power source would also present a considerable failure hazard even with the best of maintenance care. The two-motor alternator set, used so successfully in the Bell System's type "L" carrier telephone system, was adopted as representing the most reliable continuous power source available. This set normally operates on commercial ac power, but when this fails, the directly-coupled battery-operated dc motor quickly and automatically takes over the drive from the induction motor, to prevent interruption of the alternator output. Here the storage battery is still the foundation for continuity, but at a more reasonable voltage.

As described later, the possibility of a system outage resulting from failure of this two-motor alternator set has been essentially eliminated by using two such sets, cross-connected to the rectifiers supplying power to the two cables, with a continuously operating spare for each set, automatically switched in upon failure of the regular set.

The regulating features of the rectifiers will be described in a later section. In the present discussion of reliability it is sufficient to note that series regulating tubes are used, which are capable of acting as high-speed switches, through which two rectifiers can be paralleled. Thus either rectifier can accept instantaneously the entire load presented by the cable. In each regulator the series tubes carrying the cable current are furnished in duplicate and connected in parallel to share the cable load, a single tube being capable of carrying the entire load. These current regulators are operated from separate ac sources to protect against loss of cable power because of failure of one of the sources of ac power.

Cable Potentials

To minimize the cable potentials, half of the dc power is supplied at each end of each cable, the supplies being connected in series aiding. With this arrangement, as shown in Fig. 1, the dc cable potential at one end of each cable is positive with respect to ground while at the other end the potential is negative. This places the maximum potential and risk on the repeaters near the shore ends, which are more readily retrieved, while the repeaters in the middle of the cable, in deeper water, have potentials very near to ground. The power equipment would be simpler with a single-ended arrangement, but at the penalty of doubling the dielectric stresses in the entire system, which would be prohibitive. A balanced power feed could have been attained at the expense of power separation filters in the middle of the cable or a shunt impedance of appropriate size at the midpoint. The resulting complications, in-

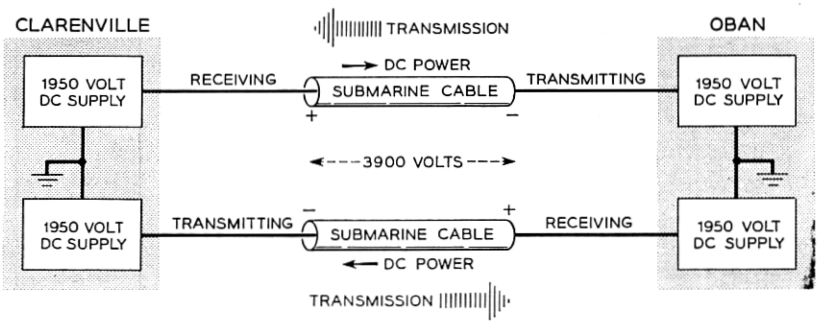

Fig. 1 — Cable voltage supply.

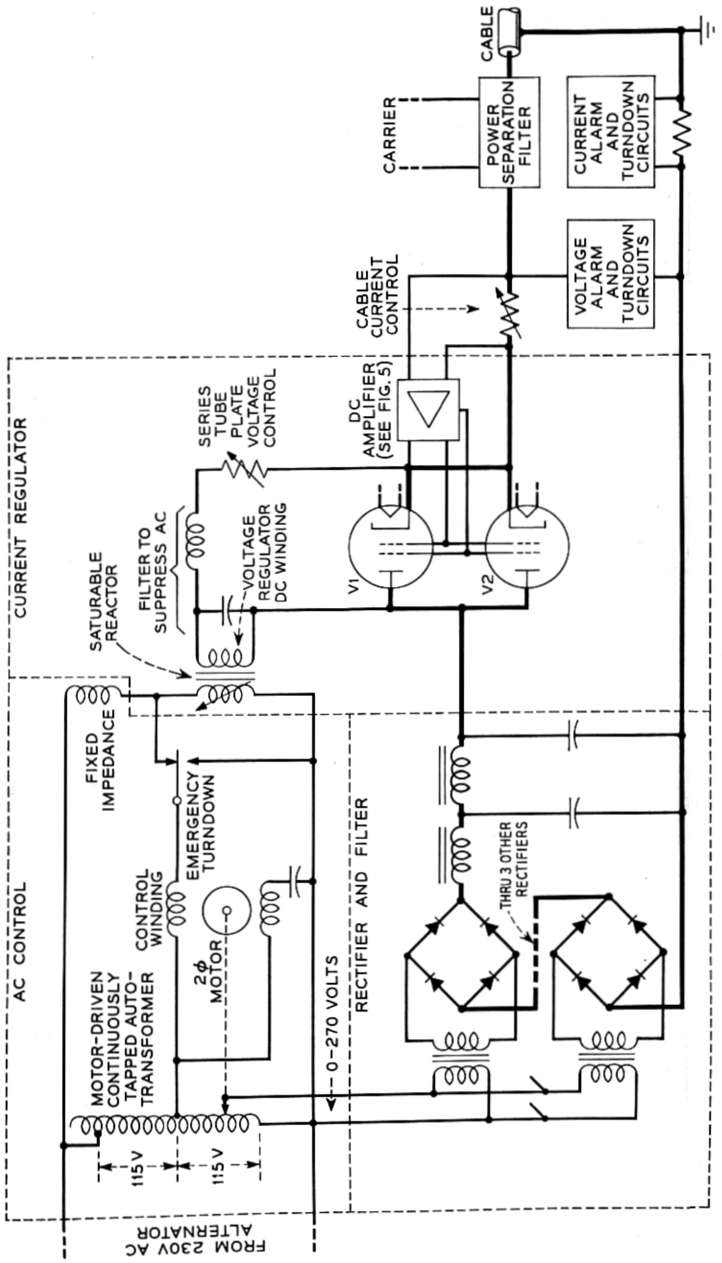

Fig. 2 — Simplified circuit of the regulating system.

cluding difficulty in the location of a cable fault, could not be justified for the sake of simplification of power-plant design and operation.

The requirement that minimum cable potentials be maintained during and after severe earth potential disturbances necessitates variable output voltages from the supplies at both ends, and this introduces problems in continuous voltage balance and regulation stability. The design features which yield the required performance are described in a later section.

DC Cable Current Regulation

The salient requirements in performance of the constant current regulator are listed below:

a. The regulator must have extremely fast response to hold the cable current within a few milliamperes of its nominal value should a short circuit develop in the cable. Thus damage to the heaters of the repeater tubes, as well as excessive induced transient voltages in the repeater transformers is avoided. The probability of a short circuit is higher near the shore ends where the water is shallow and sea traffic a factor. The regulator must be capable of absorbing the reduction in power to the cable, while maintaining current control under normal conditions. This sudden exchange in power from cable to regulator may be as much as 2,000 volts at 0.25 ampere.

b. The cable current should be maintained constant within 0.2 per cent of its nominal value for normal variations in ac supply, gradual earth potential changes, and ambient temperature changes. This degree of regulation allows an adequate safety factor in maintaining a constant transmission level.[1]

c. The regulators, in conjunction with the power separation filters and the rectifier filters, must limit the power supply noise at the cable terminals to a peak-to-peak value less than 0.02 per cent of the dc supply potential.

d. The cable current must be adjustable over a range of 225 to 245 milliamperes to compensate for repeater tube aging.[2]

e. The regulators must operate in parallel in such a way as to ensure continuity of power should one fail or be removed from service for maintenance. This of course implies that regulators can be switched in and out of service without causing surges in the cable current or voltage.

f. The series-aiding arrangement, with rectifiers at each end of the same cable, must be stable.

g. The regulators should be capable of being serviced at low poten-

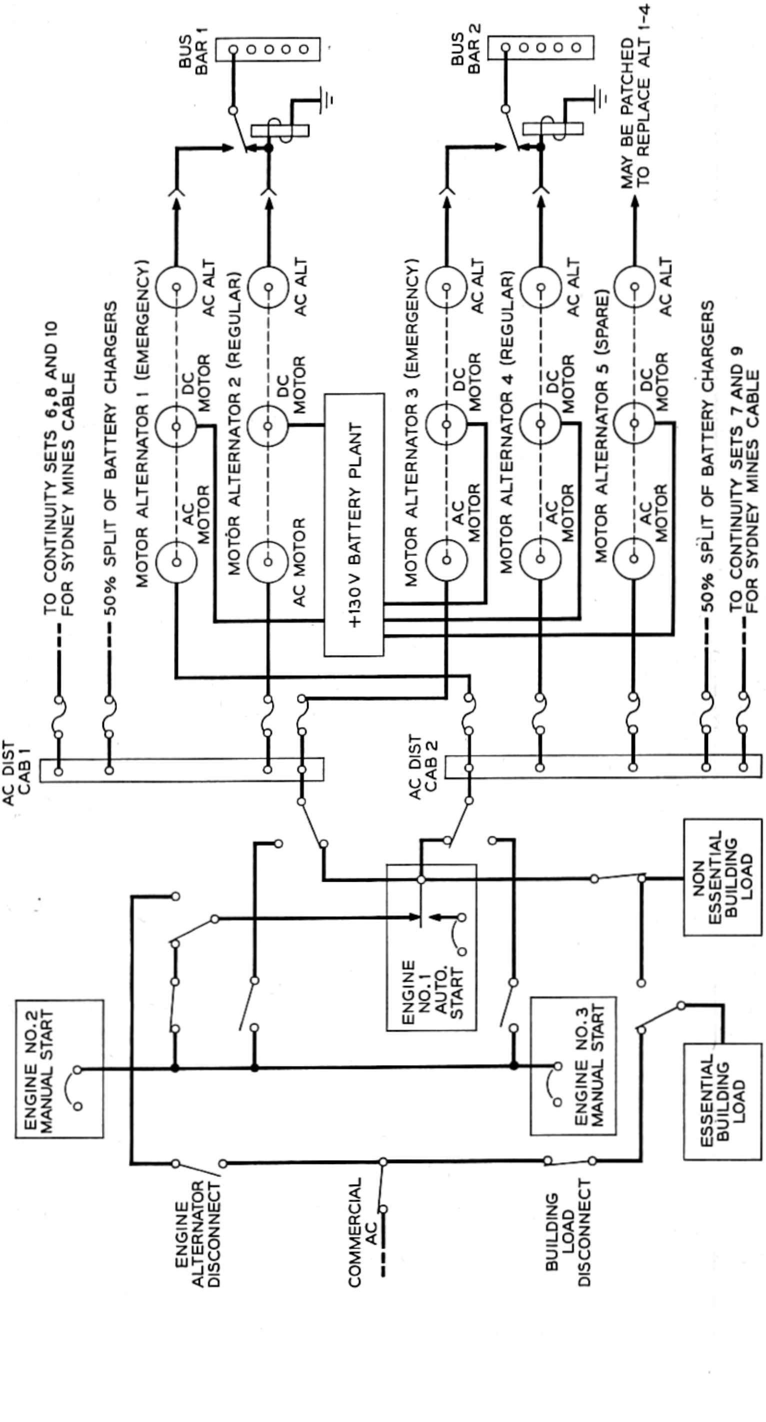

Fig. 3 — Continuous ac power.

tials, when in the test position, in order to protect maintenance personnel.

h. The current regulator should be of the fail-safe type so that impairment of any of the regulator components will not permit excessive rise in cable current. In the event of component trouble, an aural or visual alarm should occur.

It was decided that a high speed electronic constant-current regulator backed up by a slower speed servo system, as shown in Fig. 2 and discussed in detail later, would best meet the above requirements. In this way, fast response with high gain is combined with wide regulating range, yet the efficiency is high and the load-handling capacilities of the various components are held to a minimum. With regard to simpler alternatives, the electromechanical type of current regulator, using relays and a motor-driven rheostat, is too slow to protect the repeater tubes from a cable short circuit and its accuracy is insufficient to meet the regulation requirements. The all-magnetic type of regulator is possibly most dependable but it does not readily provide either the speed of response or the wide regulating range needed.

GENERAL DESCRIPTION

Prime and Standby Power Source

Commercial service is considered the normal prime source of power for the cable, although at the Clarenville terminal commercial power was not available at the time of installation. Anticipating this condition, a reserve plant consisting of three 60-kw diesel alternators was installed and the distribution circuits were arranged, as shown in Fig. 3, to provide partial or total use of the commercial service. Initially all cable power was supplied by diesel operation, alternating the prime movers on a weekly basis. These sets are paralleled manually when they are interchanged, to prevent an interruption in the 60-cycle supply. It may be noted that Engine No. 1 is arranged as an automatic standby whether prime power is provided by diesels or by commercial service.

The switching and distribution arrangements are designed to be essentially failure-proof. At Clarenville, for example, two ac distribution cabinets, each capable of being fed from two sources, were provided in separate locations. The normal source through Engine No. 1 control bay can be readily by-passed directly to the manual diesels, should Engine No. 1 control bay be disabled. Furthermore, allocation of charging rectifiers, control circuits, ac motors for continuity sets, etc., has been made in such a manner that loss of one cabinet alone will have minimum effect on the cable power supplies or office loads. At Oban, where 50-cycle commercial service is normally used, special distribution arrangements have been provided to give maximum power supply reliability, with three manually operated 50-cycle, 90-kw, diesel-alternator sets arranged for standby service. The diesels at this terminal are larger to care for greater local power loads.

Continuous AC Power From Two-Motor Alternators

At both cable terminals, two reliable ac buses supply power to the dc cable regulating bays. Each of these buses is fed from a continuously operated, self-excited, single-phase, 230-volt alternator normally driven by a 3-phase induction motor on the same shaft with a 130-volt dc motor. Each regular alternator is backed-up by a similar emergency alternator running at no load. A fifth motor-alternator is provided which can be used whenever any other set is out of service for routine maintenance or repair.

As alternator loads are essentially constant, and since induction motor speeds are fairly insensitive to power supply voltage variations, alternator outputs are set by fixed adjustments of their field rheostats. Supply voltages are monitored to control automatic transfer to dc motor drive whenever the supply voltage drops below 80 per cent of the normal value. Fig. 4 shows the normal running circuit for an alternator set, with the dc motor connected to the battery through a resistance of 75 ohms inserted in the armature circuit. The field resistance FR is preset so that when the battery is driving the set, the speed matches that of

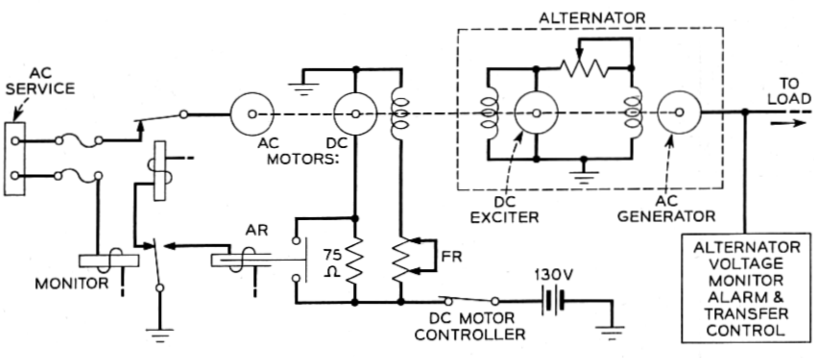

Fig. 4 — Two-motor alternator set.

the ac drive when the battery voltage is at the mean discharge value. During ac drive, the EMF generated in the dc motor armature is a few volts below that of the battery. Accordingly, when the fast acting contactor AR shorts the 75-ohm resistance in the armature circuit, the motor finds itself essentially at the desired operating flux condition and a smooth pickup of drive occurs. Oscillograms indicate that the interval between failure of ac power and operation of contactor AR is less than 0.1 second. During the transfer from ac to dc drive, the change in the nominally 230-volt output is less than 5 volts.

Return to ac drive is delayed approximately 20 seconds after the ac supply voltage has returned to normal to allow time for the ac to stabilize. Fixed field settings for both dc motor and alternator fields provide simple control arrangements without the overspeed or overvoltage hazards which automatic regulators might add. Alternator output is monitored, however, to give alarms for voltage changes exceeding ± 5 per cent and to control transfer to dc drive if the output should drop more than 10 per cent for any reason. When the latter occurs, the machine locks on dc drive. This feature guards against ac motor failure or low ac drive speed because of low supply frequency without low supply voltage.

Failure of the alternator output after transfer to dc drive causes the set to stop and automatically transfer the load to its emergency alternator. This transfer causes a break in the alternator supply to its bus, but cable power is maintained constant by the parallel dc regulating bay fed from the other alternator bus.

Battery Plants and Distribution

Battery power for dc motor drive is supplied from a 66-cell, 1,680-ampere-hour battery at Clarenville and from two 68-cell, 1,680-ampere-hour batteries at Oban. The latter station has double capacity to provide stand-by power for the ac supplies to the inland transmission equipment.

At both cable terminals, control battery for the small alternator plants and the cable dc regulating equipment provides 24 volts and is split so that a fuse or a battery failure on either supply will not interrupt cable power. To guard against so remote a hazard as loss of a common battery for this vital control, two separate 24-volt power plants have been provided with one half of the critical control circuits furnished from each plant.

In addition to supplying dc motor power, the 130-volt battery at Clarenville supplies current to the carrier terminal and test equipment which the voltage holds within 2,600 ± 200 volts as the turndown relays operate and release to maintain the ceiling voltage. A fourth magnetic-amplifier voltage detecting relay provides an alarm for ±5 per cent excursions in cable voltage from the normal value. Other alarms are provided to indicate low output in either of the two parallel regulating bays, relay troubles, loss of magnetic amplifier ac control voltage, and fuse failures.

To limit the rate of change in the cable current under short circuit conditions and to reduce the rise in voltage at the repeaters on open circuit failure, an inductance of about 36 henries is connected in series with the cable circuit, and physically close to the cable termination, so that any failure in the power supply would have the advantage of this surge-limiting element.

Metering

Metering of the cable current is a very important part of the power plant design. Not only are the cable current ammeters needed to set the value of current desired, but their ability to indicate absolute current values assists in obtaining stable regulation between the two ends of the cable. The meters provided for this purpose are suppressed-zero, magnetically and statically shielded 150–300 milliampere, large scale ammeters, with 0.5 per cent accuracy. One of these meters is connected in the ungrounded side and another in the grounded side of the cable supply circuit to provide an accuracy check and to indicate any ground leakage current in the supply circuit. They are connected to highly accurate 1-ohm four-terminal shielded resistors acting as shunts in the cable current circuits with their shunt leads arranged for switching to a calibration box for checking accuracy and for adjustment. This box employs a Weston laboratory standard cell, essentially a single-point potentiometer with the usual galvanometer, acting as a calibration standard at the 225-milliampere point. Meters calibrated at Oban for 225 milliamperes were expected to be within 0.2 per cent or 0.5 milliampere of those similarly calibrated at Clarenville, and at present are within about 0.2 milliampere.

The cable current is also indicated by a recording ammeter. Meters in each regulating bay indicate the division of current between paralleled regulators. These meters have only 1 per cent accuracy but are satisfactory for adjusting load balance between parallel bays and also are used in turnup of power on a particular bay.

Cable voltage is read on a large scale voltmeter reading 0–3,000 volts and having ±0.25 per cent accuracy. Since the accuracy is not critical, this meter is not arranged for calibration. However, the series resistors incorporate 6,000-volt components for an extra degree of reliability. The voltmeter with its series resistor is normally connected across the common cable power supply ahead of the cable current regulating point. It can, however, be switched to read the cable voltage nearer the cable termination. In the latter position, it reduces the cable current by about 1 milliampere, causing an unbalance in cable regulation, and therefore is not normally left in this position. The cable supply voltage is also indicated by a recording voltmeter.

Other meters are provided to indicate series tube plate voltages, dc rectifier voltages, ac input voltages, series tube currents, test currents for adjusting mag-amp operating limits, and the difference in current between the positive and negative power supplies to ground. Since many of these instruments operate at high potential, a special design was used with the operating mechanism and scale depressed in the instrument case approximately 1 inch. This both eliminated possible electrostatic effects on the instrument pointers and served as a safety measure.

DC REGULATION

DC Amplifier

The direct-coupled two-stage amplifier shown in Fig. 5 is characterized by potentiometer coupling and cold-cathode gas-tube voltage stabilizers. The biases are selected high enough so that linear operation is assured even for a short circuit at the cable terminal. As is apt to be the case in a direct-coupled amplifier, cathode temperature in the low-level stage is critical. In this amplifier, a 5 per cent change in heater voltage results in a 0.5 milliampere change in the cable current.

The required precision of current regulation in these power supplies can be expressed as representing a source impedance of not less than 100,000 ohms. To meet this requirement, the gain of the dc amplifier was made as large as practicable with the plate and screen potentials available from gas-tube regulators. Interstage network impedances are high to reduce the shunt losses, and are proportioned to provide the large biases mentioned above. Gain adjustment is provided by a variable resistance in series with the cathode of the first stage.

Shaping of the loop gain and phase characteristics to obtain margins for stable operation is accomplished by means of the RC shunt (R_9C_1) across the plate resistor for the first stage. The amplifier gain and phase characteristics without this compensation are shown in Fig. 6. These

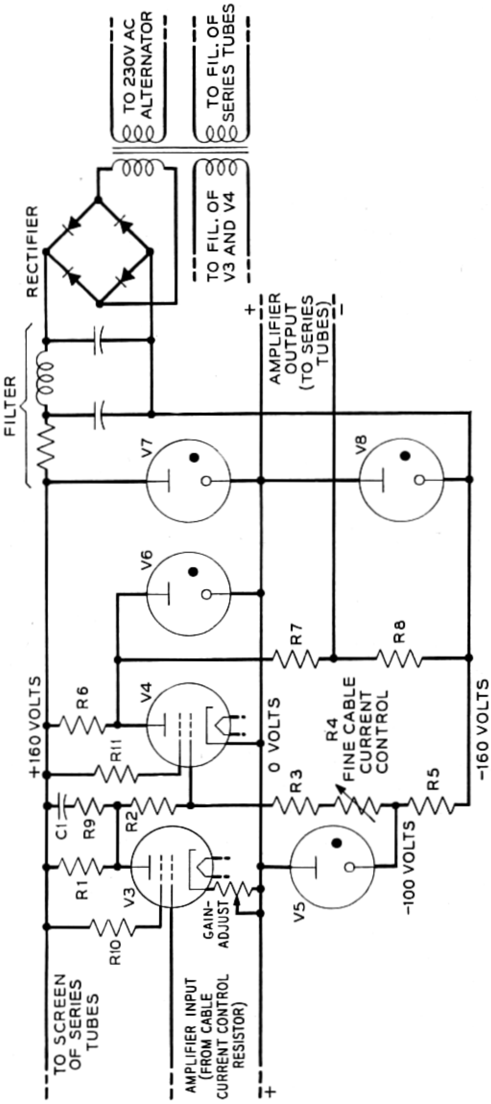

Fig. 5 — Two-stage dc amplifier.

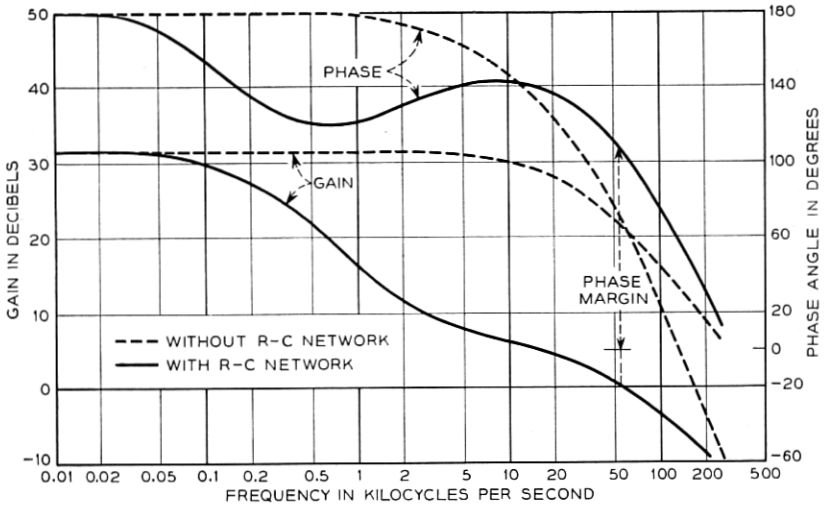

Fig. 6 — DC amplifier gain and phase, experimental model.

data were obtained by opening the feedback loop at the control grid of the first stage, applying normal dc bias plus a variable frequency ac signal to the grid of the tube, and measuring the magnitude and relative phase of the return signal.

The corresponding characteristics with the compensating network in place are also shown in Fig. 6. The compensating network effectively puts a relatively low-impedance shunt across the interstage network at the higher frequencies, resulting in a "step" in the gain characteristic. A secondary effect is the phase shift in the transition region. The calculated "corner frequencies" are 2,800 and 195 cps, respectively, chosen on the basis of the criteria (1) little effect on regulator gain at 100 or 120 cps, the most prominent rectifier ripple frequency, and (2) a gain step of something above 20 db with no appreciable contribution to the phase shift at frequencies above 30 kc. The calculated loss at 120 cps is 1.2 db with a maximum phase shift of about 60 degrees at the median frequency. These results agree quite well with the measured data plotted in Fig. 6.

As indicated in Fig. 6, the phase margin at the gain crossover frequency of 55 kc was somewhat over 100 degrees for the experimental model on which these measurements were made. The gain margin could not be measured readily but is clearly substantial. On production units, larger wire sizes and longer lead lengths resulted in lesser, but still satisfactory stability margins, as shown in Fig. 7, the phase margin being somewhat

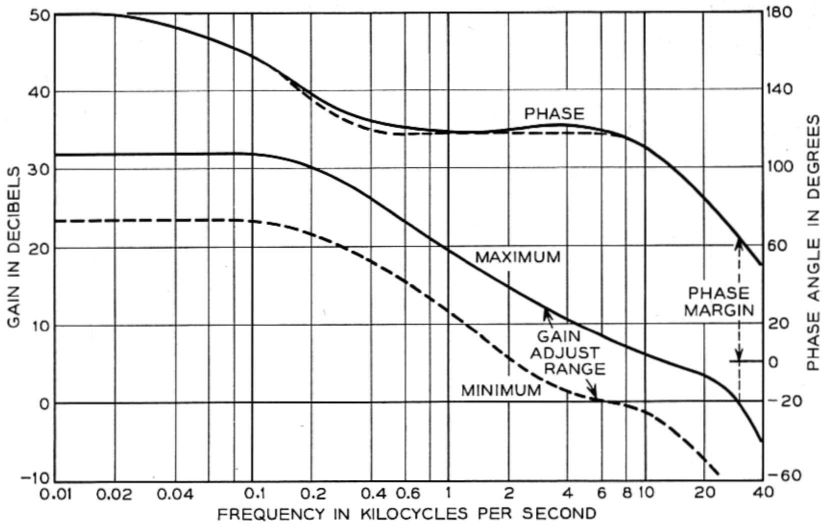

Fig. 7 — DC amplifier gain and phase, production model.

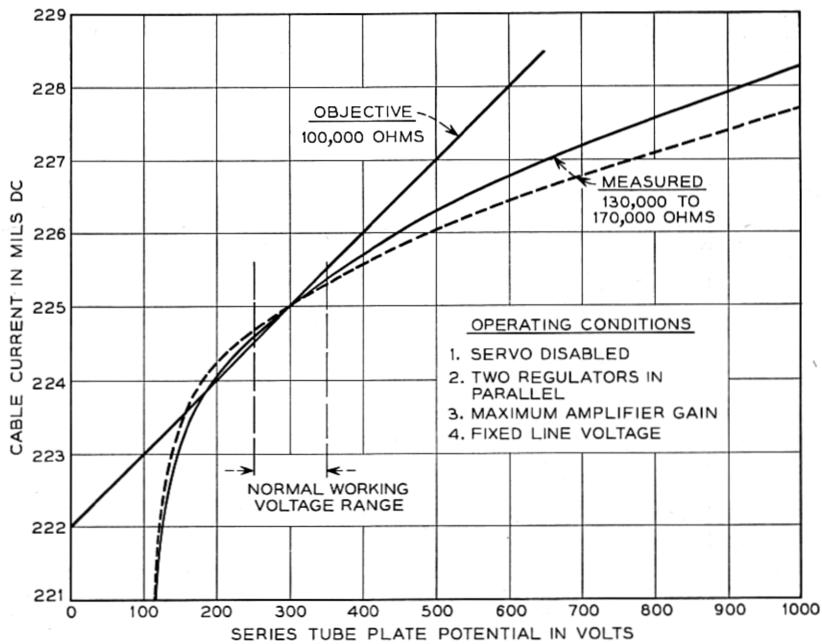

Fig. 8 — Load regulation.

over 60 degrees. Fig. 7 also shows the characteristics at the extremes of gain control, the range of control being about 8 db.

Fig. 8 shows the measured performance of the dc regulators, the servo system being disabled in order to obtain a plot of the performance of the dc amplifier and associated circuits. Twenty-two regulator units were manufactured and measured and the curves of Fig. 8 show the extreme limits observed, the differences between individual regulators being due primarily to differences between electron tubes. The measured range of source impedance, 130,000 to 170,000 ohms, allows margin for regulator tube aging above the 100,000-ohm objective.

AC Servomechanism

As noted earlier, the servo system shown in Fig. 2 is part of the current regulating scheme and holds the series tube plate potential within reasonable limits by adjusting the rectifier input voltage. In an emergency, a "turndown" feature, operated from several remote points, either manually or automatically, will reduce the autotransformer output to zero in less than two seconds. For simplicity, only the manual turndown feature is shown in Fig. 2. It operates simply by switching one end of the motor control winding from one corner of the bridge to the other, thus applying half of the input voltage to the control winding.

Manual operation of the autotransformer tap is provided to raise the cable current slowly, either initially or after a turndown. In manual operation a dynamic brake, consisting of a short circuit on the motor control winding, prevents the motor from creeping or coasting when the operator releases the handwheel, as it otherwise would since the fixed phase of the two-phase motor is always energized. The turndown feature takes precedence over the short circuit of the motor control winding, automatically, to energize the motor should the operator inadvertently cause abnormally high cable voltage or current.

One essential feature of the servo design is the dead band of the series tube plate voltage in which the servo remains stationary, even though there are small changes in the incoming signal. This band can be varied from 10 to 100 volts under control of a gain-adjust potentiometer across the control winding of the two-phase motor. Without this dead band, the servo would be constantly in operation correcting for small random variations in line voltage or earth potentials. Furthermore, since it is extremely difficult to set the current regulators at the two ends of a cable to exactly the same current, the servo dead band permits some margin of error. Otherwise the servo associated with the current regulator trying to regulate for a slightly higher cable current, would drive its rectifier voltage to its stop or maximum output, unbalancing the cable voltages.

*System Stability**

A complete analysis of system stability represents an exceedingly formidable, if not impossible, task. It has been established analytically that for a linear network the two dc regulators in parallel and the system as a whole are unconditionally stable. The details of this proof are too long to be presented here but the line of reasoning with respect to the overall system is as follows. The system of Fig. 1 is symmetrical about a vertical plane through the middle of the figure. Under these conditions, the system will be stable if, and only if, the following three simpler systems† are stable:

(a) A power supply short-circuited;

(b) A power supply feeding an impedance equal to twice that of the half cable short-circuited; and

(c) A power supply feeding an impedance equal to twice that of the half cable open-circuited.

The transfer function of the servomechanism was measured over the frequency range of principal interest, 0 to 1 cps, the behavior near zero frequency being determined from the asymptotic slope of the unit step response.‡ In this frequency range the dc amplifier gain is a real constant, flat gain and negligible delay as previously shown, therefore only the ac servo feedback loop characteristic has to be known to predict the stability of condition (a). The Nyquist loop for this transfer function shows that condition (a) above is satisfied. A similar examination of the Nyquist plot, including the readily computed cable impedance shows that conditions (b) and (c) above are satisfied. Thus the linear analysis indicates stable operation for the system of Fig. 1. This result was confirmed by tests of conditions (a), (b), and (c) individually and by the behavior of the system as a whole, both in the laboratory with a simulated power network for the cable and in the final installation.

One of the most obscure aspects of the power system behavior is that of equilibrium conditions after one or a series of large earth potential

* The analysis briefly summarized here was made by C. A. Desoer.

† In this discussion of simpler systems a power supply consists of only the elements shown in Fig. 2.

‡ In the course of these time-domain measurements, it was quite apparent that the ac control loop could be considered as a linear network only in an approximate sense and thus that the analytical results were primarily useful in interpretation of observed behavior of the system.

disturbances. While the system is stable in the sense that the transient due to a perturbation will disappear in a finite time once the disturbance has been withdrawn, the range of possible equilibrium positions (disregarding the overvoltage protective feature) is extremely wide — from perhaps 1,300 to 2,500 volts at the cable terminals. The upper limit of 2,500 volts is set by the maximum output available from one power plant; this also sets the lower limit of the associate power plant at the far end of the cable. This situation is illustrated diagrammatically in Fig. 9.

The behaviors of the servomechanisms at the two ends of a given cable are nearly enough alike that the repeated introduction of simulated earth potential in the laboratory was found not to disturb substantially the equilibrium point. This was true for earth potentials of either polarity up to 1,000 volts and with these potentials introduced at any point along the artificial cable. A rate of change of earth potential of 20 volts per second was adopted in these tests with the thought that such values would be realistic.

With regard to the long-term stability of the equilibrium condition described above, it is, of course, important that the controls which establish the cable current at the two ends of the same cable be adjusted for very nearly the same value. Unless this is done, the cable voltage at one end will gradually increase or decrease and the voltage at the other end will move equally in the opposite direction. This would eventually

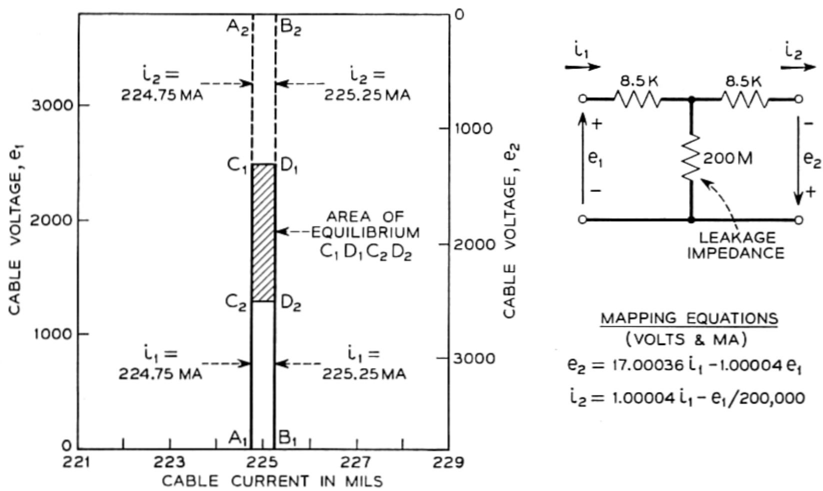

Fig. 9 — Equilibrium diagram.

bring in alarms and necessitate manual readjustment. In this connection, the voltmeters which indicate the drop through the series regulating tubes provide a very convenient magnification of any drift in cable current. The multiplying factor is the effective dc impedance of the regulated system, that is, more than 100,000 ohms. Thus 25 volts, which is an appreciable fraction of the nominal 300 volts across the series regulating tubes, is equivalent to less than 0.25 ma., which is of the order of 0.1 per cent of normal cable current. As a matter of fact, the behavior of this voltage provides the final criterion for precise adjustment of cable current to assure long-term stability.

EQUIPMENT DESIGN

Description

Fig. 10 shows the complete dc equipment for supplying one polarity of power to one cable. Similar equipment provides the opposite polarity to the other cable. The two equipments are located facing each other across a common aisle with their common control bays directly opposite. Regulator 1 on the right is normally operated in parallel with Regulator 2. Regulator 3 on the left is the spare regulator, normally off. The common bay, between Regulators 1 and 2, includes the cable

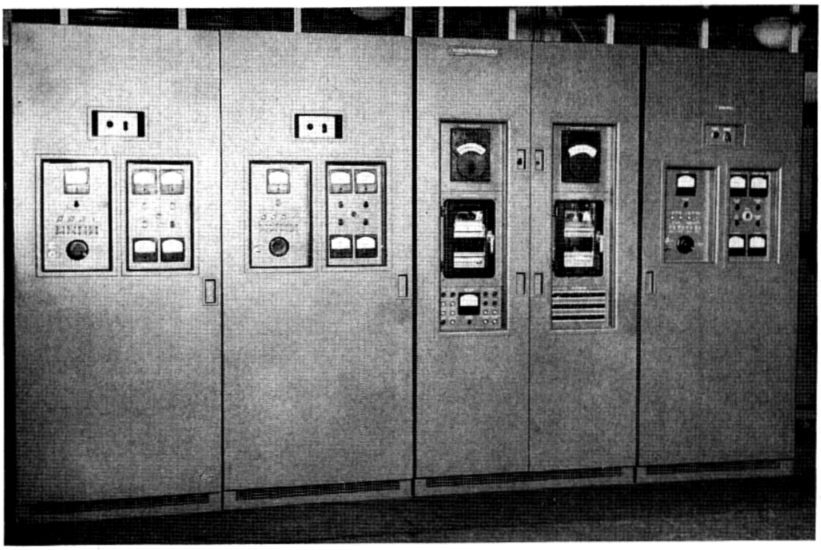

Fig. 10 — DC regulator and common control bays.

termination and power separation filter. This equipment and all the live parts of the circuit, back to the common point to which the switches in the individual regulator bays are connected, is enclosed in a high voltage compartment.

The paralleling control switches are mounted in high voltage compartments in their respective regulating bays and must remain completely enclosed, as their common cable connections are alive during cable operation. These switches have an interrupting capacity of 1 ampere at 3,000 volts, thus providing a large safety factor over the 0.245 ampere maximum load current.

Fig. 11 illustrates some of the special design features built into the equipment to facilitate maintenance. The high voltage compartment shown open at the top is locked whenever the cable is in operation and this protection feature will be described below. Pull-out drawers at the bottom contain metering shunts, a test unit for adjusting voltage and current protection limits, a voltage protection unit, a current protection unit, and an alarm unit. While only one of these compartments is to be pulled out at a time, they are arranged so as not to endanger personnel or to affect service during adjustment when open. Doors are provided on all bays to prevent accidental disturbance of adjustments and to protect against damage to controls.

Corona

The high voltage ac elements of the complete regulator bays were tested for corona with 4,000 volts ac applied, and furthermore, if corona was observed on increasing the applied rms voltage to 5,000 volts, it was required to extinguish when the voltage was reduced to 3500 volts. The maximum acceptable leakage was 20 microamperes at 4000 volts across the circuit (200 megohms). A dc corona requirement of 4000 volts was applied to the dc elements of the regulator bays and 5000 volts for the common bay, with a maximum permissible leakage of 5 microamperes. The higher corona requirements on the common bay were intended to eliminate the necessity for turning down the entire system for repair. A high standard of workmanship is required to provide such performance. There can be no sharp projections and no loose strands of wire. Solder must be applied in such a manner as to obtain a rounded smooth joint and high voltage wiring must be dressed away from exposed grounded metal, bus bars, etc., so that the outer braid (other than polyethylene) does not come in contact with metal.

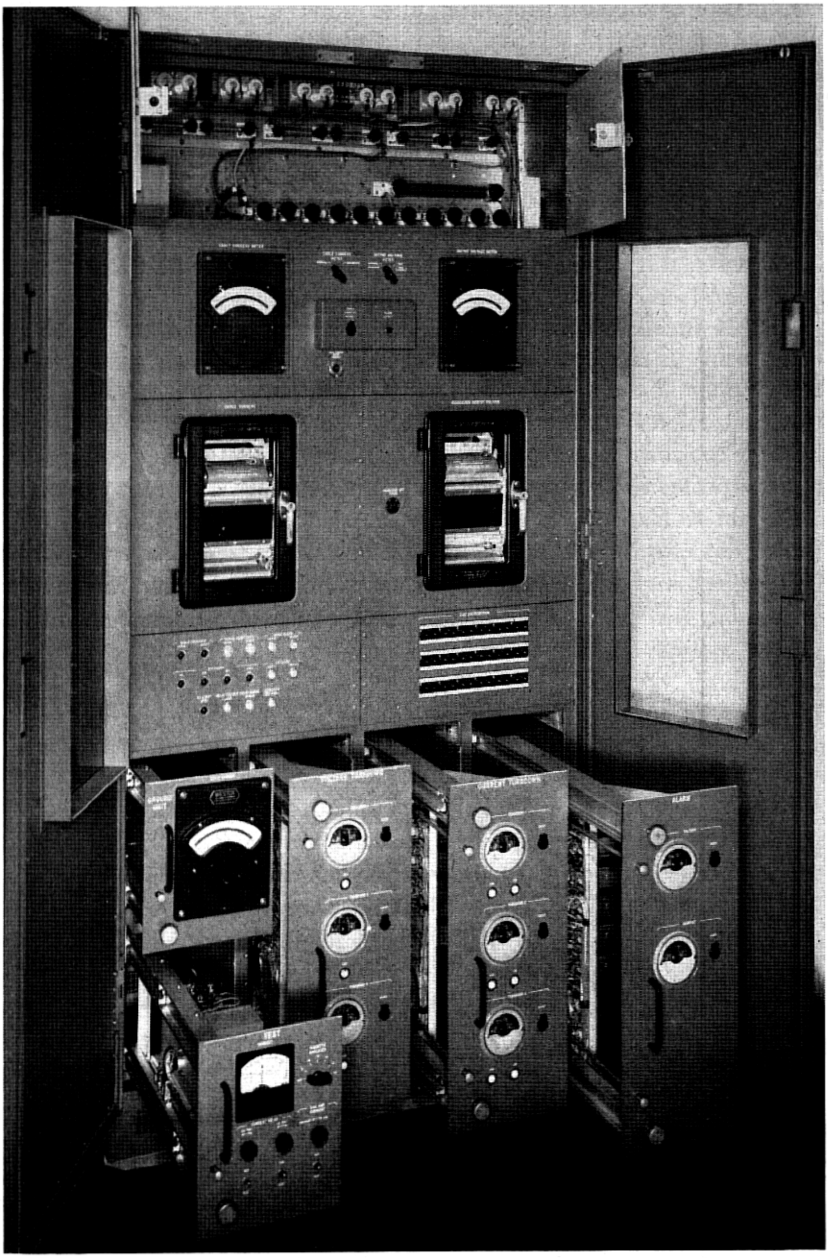

Fig. 11 — Common control bay.

Crosstalk and Outside Interference

In order to meet the severe crosstalk requirements between receiving and transmitting circuits and to guard against feeding office noise potentials into the carrier transmission system, arrangements were made so that office grounds are carefully separated from the outer conductor of the cable and from all circuit elements within the power separation filter. Pickup of external radio-frequency fields by the power separation filters was greatly reduced by completely enclosing in a copper shield the cable terminal and the power separation filter elements nearest to the terminal. The shielding itself and the cans of PSF capacitors and oil-filled coils are connected to the return tape of the cable which is insulated from office ground until it reaches sea water, thus reducing the coupling to the other cable as compared to tying both tapes together at the office or bay frame ground.

Protection of Personnel

A key locking system is provided to safeguard against any hazard to personnel from high voltages. In the common bay, the high voltage compartment can be entered only by operating a switch which shorts the cable to ground and releases a key for the compartment doors. In each regulating bay, the key system assures that the bay is disconnected from the cable and hence from the paralleling power supplies. Where access is required to the interior of any compartment, the key system insures that the ac power to the bay also be switched off.

The test compartment contains pin jacks, provided for maintenance operations which are always performed with the regulator bay connected to a low resistance load. Access to this compartment can be obtained with ac power connected to the bay. However, for such access, the key system enforces the operation of the output disconnect switch, which also transfers the bay to a low-resistance load. Moreover, a mechanical interlock with the autotransformer assures that the test voltages are reduced to safe values.

In addition to its function in protecting personnel, the key system also insures that no more than one regulating bay is disconnected at one time so that continuity of service is protected at all times by two parallel regulators.

FACTORY AND SHIP CABLE POWER

In addition to the above cable power supplies at the ocean terminals, similar dc cable current regulating equipment was designed for use at the cable factory and abroad the cable ship *Monarch*. Well protected and closely regulated reliable power was considered essential during the cable loading and laying operations. It was necessary to have power on the cable continuously, except when splices were made, in order to detect a fault immediately, to measure transmission characteristics for equalization purposes and finally to alleviate the strain on the glassware and tungsten filaments of the repeater tubes during the difficult laying period.[3]

REFERENCES

1. H. A. Lewis, R. S. Tucker, G. H. Lovell and J. M. Fraser, System Design for the North Atlantic Link. See page 29 of this issue.
2. T. F. Gleichmann, A. H. Lince, M. C. Wooley and F. J. Braga, Repeater Design for the North Atlantic Link. See page 69 of this issue.
3. J. S. Jack, Capt. W. H. Leech and H. A. Lewis, Route Selection and Cable Laying for the Transatlantic Cable System. See page 293 of this issue.