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The Institution of Post Office Electrical Engineers.

Power Supplies for Telegraphs

G. N. DAVISON, B.Sc. (Eng.), D.I.C., A.M.I.E.E.

A Paper read before the London Centre of the Institution on the 4th June, 1945

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SUMMARY.

Power Supplies for Telegraphs

INTRODUCTION.

The story of the solid achievements of the last twenty years in the development of telegraph transmission and mechanisation has been told elsewhere. Suffice it here to say that, not twenty years ago, practically all landline telegraph transmission in this country was by direct current signalling, with power supplies at ± 40V, ± 80V and ± 120V, according to the length and type of circuit. The very small office was equipped with primary batteries, or worked to its parent office on a central battery basis. The large office was provided with a so-called " universal battery " installation, giving line power supplies at all the above voltages, together with a local supply at ± 24V, and operating on a charge-discharge basis. The types of telegraph instrument in use were many and varied and each required its own special handling by skilled operators.

The technique of telegraphy has undergone such a complete change in less than a generation, that little of the equipment which is now commonplace would have been familiar to an operative of twenty years ago. The main-line portion of a long circuit now consists, in general, of one or more channels in multi-channel voice frequency systems, with its standard terminal instrument the teleprinter. The only important exception is the Tariff " A " type of long private wire, which is sometimes set up on a by-product circuit and which then employs direct current signalling, as also do short teleprinter circuits and the local ends of voice frequency circuits. On the more lightly loaded short links in the public system the messages are sent by telephone instead of by teleprinter.

In addition to these changes in technique there has taken place, in the war years, a phenomenal increase in the scale of provision of teleprinter circuits to supply the needs of the Defence Teleprinter Network. (D.T.N.).

All this has not happened without attendant changes in power supply requirements, and this paper has been written with a view to presenting some of the facts concerning modern telegraph power plant for public and private services in this country.

2. EQUIPMENT REQUIRING POWER SUPPLIES.

Notwithstanding the broad standardisation of methods referred to above, there are, of course, several types of installation with varying needs to be considered. These are briefly the following:—

2.1. Public service instrument rooms with teleprinter, phonogram, telephone-telegram and printergram equipment.

2.2. Teleprinter switchboard and teleprinter ancillary installations for the public service.

2.3. Multi-channel V.F. telegraph terminals.

2.4. Terminal equipments for Tariff " A " by-product private wires.

2.5. Teleprinter and teleprinter switchboard installations for the D.T.N. and for commercial renters.

A future development will be the supply of power to automatic equipment for a public service teleprinter automatic switching network.

3. THE NATURE OF THE POWER SUPPLIES REQUIRED.

The following is a statement of the power supply needs of the various types of equipment listed above. The ways in which these supplies are provided will be described in later sections, except where, on account of their slight interest, they can be disposed of shortly here.

3.1. Public Service Instrument Rooms.

3.1.1. *Teleprinters.*

A supply at a nominal ± 80V, which has come to be known as the " eighty plus eighty volt " supply, is always required for signalling. This is standard. It may be thought that ± 80V is an unnecessarily high voltage for D.C. signalling over the comparatively short underground circuits now worked in this way. Actually, research showed that if relay reception were to be dispensed with on the shorter teleprinter circuits and extensions, and the teleprinter electro-magnet connected direct to line, then transmission at ± 60V resulted in materially better reception than did transmission at any lower voltage. The reason is that the teleprinter electro-magnet armature, unlike that of a relay, has to perform an appreciable amount of work, the energy for which is not adequately provided by a low voltage supply. The experiments showed that there appeared to be no advantage in increasing the supply voltage beyond ± 60V and, since every increase brings greater risk of interference between circuits, the nearest of the then existing universal supplies above ± 60V, namely ± 80V, was chosen as the new standard.

The teleprinter motors need a D.C. supply, which may be derived from D.C. mains, from a rectified A.C. mains supply, or from the 80 + 80V supply when this is a battery supply of sufficient capacity.

It is at present standard practice to operate an installation on an all-mains basis when it comprises less than eight working teleprinters, and to provide batteries at offices with eight or more teleprinters, and a programme for the installation of floating battery plants at all offices with the above qualifications is now nearing completion. The battery reserve is normally made sufficient to drive half the full complement of teleprinters for 24 hours, but it may be slightly more than this at a few highly important offices and it may be less where standby engine set facilities exist. The Teleprinter No. 3 takes on the average a current of approximately 0.3A from an 80 + 80V supply.

3.1.2. *Phonogram and Telephone-Telegram Equipment.*

The phonogram and telephone-telegram services are essentially telephone services and, in order to make the maximum use of existing power supplies, the equipment can be arranged to work from 22/24V, 40V, 50V or 60V battery supplies. Frequently the supply can be obtained from an exchange battery in the same building, but when a special power installation has to be provided, the batteries are normally 24V and designed for 24 hours reserve. On many installations a single stage valve amplifier is associated with each operator's position equipment; it derives its filament current from the supply already mentioned, while the anode supply can be taken from any convenient battery between 100V and 150V or even from the + 80V telegraph battery.

Looking ahead, it is probable that at all large offices provision will be made for an automatic distribution system for incoming phonograms and telephone-telegrams. The equipment for such a system would be standardised for 50V operation.

3.1.3. *Printergrams.*

The requirements for printergrams are firstly a teleprinter motor D.C. supply as already described, secondly an A.C. or D.C. supply for the V.F. telegraph converter, and thirdly a −80V relay supply.

An ordinary telephone speech circuit is used in the printergram service, and the V.F. converter has a function to perform both in the sending and in the receiving of messages. Thus it generates the 1500 c/s carrier tone which the teleprinter signals modulate during transmission, and converts the modulations of the tone incoming from line to the D.C. signals required for the operation of the teleprinter, during reception.

Two types of V.F. converter are available, one suitable for A.C. mains supplies and the other for D.C. mains, each type including its own power pack. By using the D.C. type of V.F. converter, the whole equipment can be supplied from an 80 + 80V battery supply, and thus given freedom from interruptions due to mains failure.

3.2. Public Service Teleprinter Switchboards and Teleprinter Ancillary Equipments.

Teleprinter intercommunication switchboards, which have been installed at Birmingham, Leeds, Manchester and Bristol, require an 80 + 80V supply with battery reserve, to cover all requirements save that of the switchboard lamps. For the latter a 6V supply is necessary, and this also requires reserve against possible mains failures.

The teleprinter ancillary switchboard, which is a terminating switchboard for concentrating lightly-loaded circuits, requires the usual 80 + 80V supply, and, again, a 6V supply, which may be either A.C. or D.C.

3.3. Multi-Channel V.F. Telegraph Terminals.

There are two standard types of M.C.V.F. telegraph equipment, a four-channel equipment for minor routes and a main-line eighteen-channel equipment.

3.3.1. *Power Supplies for the Four-channel Equipment.*

The four-channel type of equipment has not, as yet, been used on a large scale for the provision of public service telegraph circuits, but it has been in very considerable demand for the D.T. Network. The out-station terminal of the four-channel system works on an all-mains basis from single phase 50 c/s A.C. at 200/250V or 100/125V, the load being approximately 0.5 kVA. The only standby against mains failure is normally a mobile engine-alternator, but, in one or two exceptional installations, a standby motor-alternator has been provided, to be run from an existing battery.

In the rare installations at which the mains supply is D.C., duplicate motor-alternators or rotary converters are provided, and, as the stations are usually unattended, automatic restarting after mains failure is necessary.

As the in-station end is installed in a main station, it utilises the same battery supplies as are required for 18-channel equipment.

3.3.2. *Power Supplies for the 18-channel Equipment.*

The 18-channel type systems form the backbone of the public service long-distance network and are also used on a very large scale for the D.T. Network and for other rented circuits. Both ends of these systems are normally situated in offices with battery supplies; exceptions to this rule have only rarely been made in permanent stations, but batteries are, of course, dispensed with when this equipment is installed in mobile vans. The supplies required are the filament, anode and signalling supplies, which have come to be known respectively as the LT, HT and "80 plus 80 volt" supplies. The LT and HT supplies have mean values of approximately 21.5V and 130V respectively, measured at the input to the equipment. The great majority of terminals have floating battery plant, details of which are described later in this paper. Some of the older stations have not been brought up to date in this respect, but it is planned to complete the conversion to full float working during 1945/6.

3.4. Terminal Equipments for Tariff "A" Private Wires.

The main line portion of Tariff "A" circuits, as originally conceived, consists of a phantom or double-phantom by-product channel. The steady signalling current on the main line is limited to 10 mA and the signalling voltage is ± 20V, although the original intention was to employ ± 40V, such as is used on the local end between the terminal and the home renter. The ± 20V and ± 40V batteries were originally installed on a charge-discharge basis, and the negative battery cells were made the larger, to cater for the greater daily drain on them. Whenever a standard 80 + 80V supply becomes available in a building housing a Tariff "A" terminal, opportunity is being taken to recover the "local" 40 + 40V batteries, and to make the simple conversion of the local ends to 80 + 80V signalling. The 20 + 20V supplies for the main line signalling have perforce to be retained, but these are being converted to single battery float working at the same time as 80 + 80V is introduced for the local supply. The loads are very small and the 20 + 20V rectifiers for floating have no special regulating devices.

When a Tariff " A " circuit is routed on a V.F. channel, the Tariff " A " terminal equipment requires only the standard 80 + 80V supply.

3.5. Renters' Installations.

A renter's installation may be anything from a single teleprinter at a business house to a large D.T.N. installation comprising a multiple type teleprinter switchboard of up to 24 positions, and perhaps upwards of 200 teleprinters. Most D.T.N. installations also include M.C.V.F. telegraph equipment and audio equipment.

3.5.1. *Simple Installations for Tariff " A," Tariff " D " and D.T.N. Private Wires and for Telex Subscribers.*

Installations of this type do not require power plant in the usually accepted sense, as the teleprinters are operated as units on an all-mains basis.

The standard Tariff " A " private wire installation for a by-product circuit requires a D.C. supply for the teleprinter motor and nothing more. If the mains supply is A.C. a rectifier is provided as part of the unit table equipment to supply the motor power. The transmission is normally on a single-current central battery basis, and only if the local line is exceptionally long (of the order of 10 miles), or if the circuit as a whole lacks adequate margin, does it become necessary to install either a rectifier or a rotary converter at the renter's premises, to provide 80 + 80V signalling power and so enable double-current transmission to be employed.

An 80 + 80V supply is also required for Tariff " A " terminations of M.C.V.F. circuits and for all D.T.N. terminations. The latter type, in which the local record during transmission is taken from the send-receive switch of the teleprinter, can also be regarded as the modern tendency for Tariff " A " development.

For a Tariff "D" or Telex teleprinter installation, the arrangements for the teleprinter motor are the same as those for a Tariff " A " or D.T. teleprinter, but the transmission is required to be an alternative to speech and, as already described for printergrams, consists of a modulated 1500 c/s tone. A V.F. Telegraph Converter is therefore required, of either the D.C. mains or the A.C. mains type.

3.5.2. *Larger Teleprinter Installations.*

Where there are five or more teleprinters in a renter's office or D.T.N. station which has an A.C. mains supply, it becomes economical and convenient to supply all the motor (160V) and signalling requirements from a common rectifier. Such a unit is the " Westat " 80 + 80V rectifier, which will be dealt with more fully in later sections. When it is considered essential for the sake of security to have the common rectifier in duplicate, then the economical limit becomes approximately 10 teleprinters as a minimum. The Teleprinter No. 7B takes a current of approximately 0.4A from an 80 + 80V supply.

3.5.3. *Switchboard Installations.*

Switchboard installations for renters' (notably D.T.N.) use were fully described last session in a paper read before this Institution by Messrs. Martin and Freebody.[1] One of the smallest types of switchboard requires only 80 + 80V power, but all the others require, in addition, a 6V lamp supply. The smaller installations are commonly supplied with power on an all-mains basis, while for the larger switchboards floating battery supplies are the rule. Further details will be found elsewhere in this paper.

4. HOW THE POWER SUPPLIES ARE PROVIDED.

It is now proposed to describe the types of plant which are installed to provide the supplies detailed in the last section.

4.1. The small all-mains Teleprinter Office.

In a public service instrument room with less than eight teleprinters operated on an all-mains basis, each teleprinter position is separately equipped to derive its own supplies from the mains.

Except when there is a D.C. mains supply for the teleprinter motors, a separate rectifier (Rectifier No. 43A) is provided for each teleprinter. This is a simple bridge-connected selenium rectifier (a simplified schematic of which is shown in Fig. 1) with an output

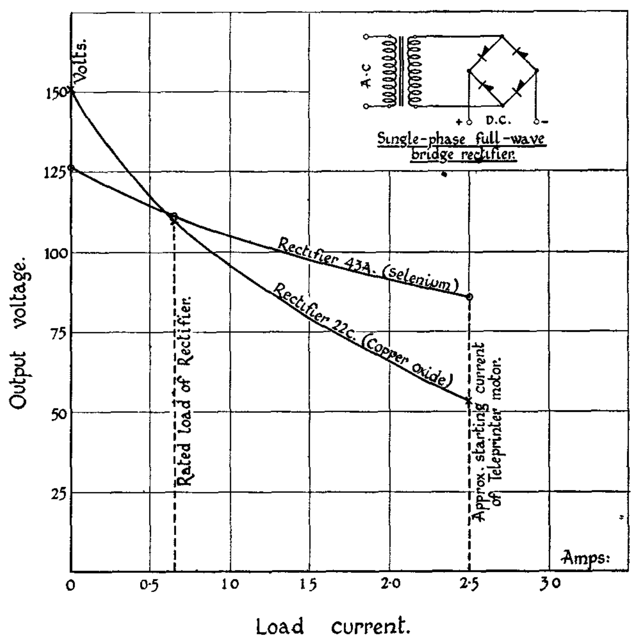

FIG. 1.—COMPARATIVE VOLTAGE REGULATION CURVES FOR COPPER OXIDE AND SELENIUM TYPE RECTIFIERS.

approximately 0.65A at 110V D.C., and suitable for rectifying any 50 c/s 100/110V or 200/250V A.C. supply. The selenium elements give it much closer voltage regulation with varying load than was obtainable with its forerunner fitted with copper oxide elements, namely, the Rectifier No. 22A or 22C. As

[1] This paper will be issued as an I.P.O.E.E. Paper in the near future.

the teleprinter motor sometimes has to start against a torque some five times as great as the average running torque, the value attaching to close voltage regulation in the rectifier, which results in higher starting current and torque, is apparent.

Fig. 1 clearly demonstrates the superiority of the selenium rectifier in this respect. The two rectifiers were adjusted to deliver approximately the power required by a No. 7B teleprinter motor operating at 110V. Then, without further adjustment, the rectified voltage was recorded at no-load and at a load of 2.5A which approximates to the starting current of the motor.

Each teleprinter is also provided with its own source of 80 + 80V signalling power. At offices with A.C. mains a rectifier (Rectifier No. 26B) is employed. This is a copper oxide rectifier operating on the voltage-doubler principle and suitable for 100/110V, and 200/250V, 50 c/s A.C. supplies. Some of these rectifiers have been fitted with selenium elements for tropical work, and it is probable that the use of such elements may be made standard. However, for use in this country there would be no special gain such as accrues from the use of selenium elements in the Rectifier No. 43A. The ± 80V D.C. supplies with respect to earth, required for line transmission, are obtained from a condensered potential divider forming part of the rectifier and which has its centre point earthed; when a relay local supply is also required, a separate potentiometer unit is added (known as Unit A.A. T.G. 4505), which, of course, has its centre point not earthed in order to avoid interference.

If the mains supply is D.C. the 80 + 80V signalling power is obtained from a small rotary converter (Rotary Converter No. 4). It is a very small machine, enclosed and flexibly mounted in a metal case for silence. The potential divider for deriving the ± 80V line supplies from the 160V output of the machine is incorporated in a separate unit (known as Unit A.A. TG. 1020). The local supply which is required for a relayed circuit is obtained from the D.C. mains supply.

The arrangements at renters and D.T.N. installations equipped on a unit basis are generally similar in principle. It is impossible, however, to lay down for renters' and D.T.N. installations a hard and fast line beyond which power supplies cease to be provided on a unit " per teleprinter " basis, since so many factors are involved.

4.2. The use of 80+80V Westat Rectifiers on an all-mains basis.

4.2.1.

The names (*a*) " Noregg " and (*b*) " Westat " are trade names of Messrs. Westinghouse for rectifying equipment with constant output voltage. " Noregg " is for use without batteries, whereas " Westat " is for use with batteries. The general practice in the Department, which is used throughout this paper, is to refer to both types of equipment as " Westat " rectifiers.

The use of 80 + 80V Westat rectifiers without batteries for supplying teleprinters and teleprinter switchboards, is described in this paragraph.

Considerable use has been made of this arrangement for D.T.N. and renters' installations, with from say 5 to 35 (or even more) teleprinters and often including also a teleprinter switchboard of the No. 8, No. 13 or No. 15 type.

The need for non-battery Westat installations has not so far arisen at public service offices, since battery supplies are now being provided for as few as eight teleprinters, and most smaller installations had started to grow up on a unit supply basis before the introduction of Westat rectifiers.

4.2.2.

The Westat rectifier is manufactured in a number of standard sizes, defined by their output wattage rating. The Post Office 80 + 80V rectifiers are of two types, the first consisting of two 300 watt Westat rectifiers mounted in a single cubicle, and the second consisting similarly of two 600 watt Westat rectifiers, which are the largest available.

4.2.3.

The first type was designed specially for all-mains operation, and therefore includes two banks of electrolytic condensers, each 1,750 microfarad capacity, connected one across each 80V output. This provides a satisfactory degree of smoothing and decoupling, such that the motor and signalling current requirements of about ten teleprinters or of an equivalent load made up of a teleprinter switchboard and teleprinters, can be supplied, without an objectionable degree of interference between circuits. In its first form (Rectifier No. 54A) it was wall-mounting, but its weight proved to be unexpectedly high, and the later model (Rectifier No. 55A) was therefore made floor-mounting. The teleprinters are usually bench-mounted and the 80 + 80V power is distributed to each position separately from a conveniently mounted iron-clad distribution board and earth bar.

4.2.4.

The second type of 80 + 80V Westat rectifier (Rectifier No. 56A) is intended primarily for battery float operation in conjunction with a manually-controlled standby rectifier and power board, and its use in this way is dealt with in the next section.

Provision is, however, made for adapting it to all-mains operation by fitting a standard voltmeter and key in the spaces provided on the front panel, as well as electrolytic smoothing condensers. For teleprinter and teleprinter switchboard operation the complement of condensers is 1750 + 1750, or 2000 + 2000, microfarads, depending upon whether 250, or 1000 microfarad units are used. In the past, when the load has necessitated the use of two of these rectifiers, it has been customary to parallel the rectifiers instead of using them as two separate units. This effected a saving of one set of electrolytic condensers and a voltmeter, and also, by pooling the load and increasing its diversity factor, enabled the two rectifiers to supply safely a larger number of teleprinters. However, a breakdown can be fairly troublesome with this arrangement, and it has therefore been decided, in all-mains installations, not to parallel the rectifiers in future.

4.3. 80 + 80V Floating Battery Installations.

4.3.1. 80 + 80 *V battery supplies may be required to serve*:—

(*a*) Teleprinter switchboards and teleprinter motor and signalling supplies, whether in public offices or D.T.N. and other renters' offices.

(*b*) Multi-channel V.F. telegraph equipment.

4.3.2. *Conditions to be fulfilled.*

The conditions to be fulfilled are briefly:—

(*a*) The positive and negative supplies should not differ by more than 4 volts, as beyond this limit excessive signal distortion may be caused.

(*b*) The maximum and the minimum voltage of the 80 + 80V supply must both be within the governing range of the teleprinter motors and of the motors of the M.C.V.F. telegraph frequency generators. These ranges are:—

	Upper Limit Volts	Lower Limit Volts
Public Service Teleprinter (3X) Motor	172	150
Renter's Teleprinter (7B) Motor	265	150
M.C.V.F. Telegraph Frequency Generator	184	150

(*c*) The supplies should be free from interruptions.

(*d*) The specified battery reserve should be catered for and the batteries should be maintained in good condition.

4.3.3. *The Characteristics of Single Battery Float and Divided Battery Float Working.*

The meaning of the terms "single battery float operation" and "divided battery float operation" are well known and need little explanation in this paper, but the following statement, which is generally true of the more important features, will serve to show why both types (Fig. **2**) are in use for telegraph 80 + 80V supplies.

(*a*) Single battery float plant is the simpler.

(*b*) The batteries occupy less space in a single battery float scheme.

(*c*) The range of voltage is less with divided battery float operation.

(*d*) The divided battery float plant is the more satisfactory for handling batteries which are large for the load, that is, which are designed to give a long period of reserve.

For single battery float operation a floating voltage of not less than 2.15V per cell is necessary and a voltage a few per cent. higher will do no harm. It is desirable to be able, occasionally, to boost the voltage to 2.3V per cell, without disturbing the equipment connected to the bus-bars. For divided battery float working it is never necessary to float the batteries at a higher voltage than 2.06V per cell.

4.3.4. *Divided Battery Float Operation for Public Service Installations.*

For public service installations, divided battery float plant is standard, using four batteries, each of forty cells, the mean floating voltage being 82.5 + 82.5V, which satisfies the requirements of the Teleprinter No. 3X motor. The batteries are designed to give 24 hours reserve for any M.C.V.F. equipment and miscellaneous loads in full and for half the maximum teleprinter load, without their voltage falling below 76 + 76V. The two batteries are paralleled in the event of mains failure, sometimes automatically, to use the available capacity as economically as possible.

It is occasionally economical to use 41 + 41 cells when the discharge leads are exceptionally long and heavily loaded.

4.3.5. *Single Battery Float Operation for D.T.N. Installations.*

For D.T.N. installations, in which economy in the space occupied by plant is of prime consideration, and in which a standby engine supply is usually available to replace the mains, single battery float plant, providing only two hours reserve at the maximum rate of discharge, has been standardised. With the smallest standard plant, however, it so happens that the limitations imposed by using standard battery sizes has resulted in appreciably more than two hours reserve being provided. Two batteries, each of 40 cells, are floated as nearly as possible at 86 + 86V, with occasional float-charges, if necessary, at up to 92 + 92V. The renter's type of teleprinter (No. 7B) and the motors of M.C.V.F. multi-frequency generators are both capable of accepting this maximum voltage. At the high rate at which the batteries are discharged in the event of mains failure, their efficiency is only some 76% of that at the nine-hour rate, and, furthermore, the batteries can only be partially discharged before their voltage falls to the permissible minimum of 76 + 76V. These two factors together make it necessary for the ampere-hour capacity of the battery, at the nine-hour rate, to be numerically equal to approximately 3.5 times the discharge load in amps, in order to give two

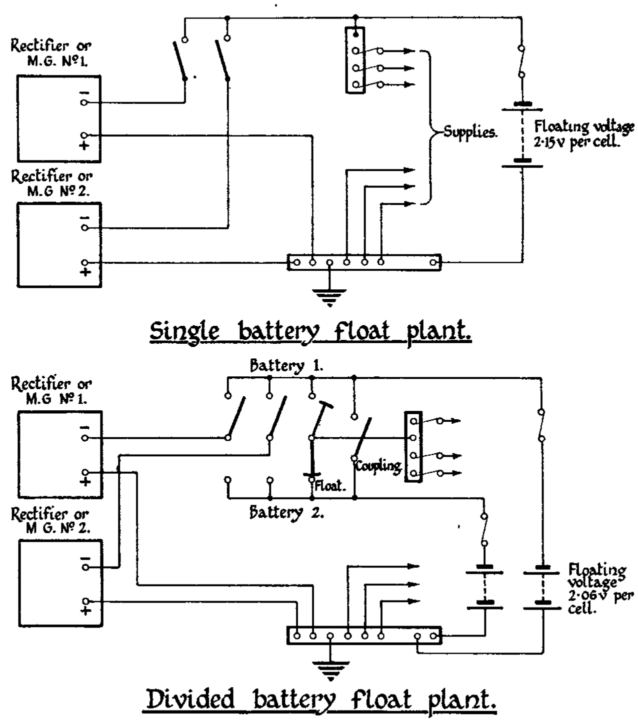

FIG. 2.—SIMPLIFIED SCHEMATICS OF SINGLE AND DIVIDED BATTERY FLOAT PLANTS.

hours reserve. The use of 41 + 41 cells is sometimes necessary when power has to be supplied over external cables to a distant teleprinter room.

4.3.6. *Standard 80 + 80V Single and Divided Battery Float Plants.*

The following are now the standard equipments for operation from A.C. mains supplies. Alternative switchboards are available for single and divided float working.

(*a*) *Westat Rectifier Plants.*

These plants operate from single phase, 50 c/s A.C. supplies and their ratings are approximately 7A and 14A.

(*b*) *Motor-Generator Plants.*

These are normally used for loads heavier than those covered by the Westat Rectifier plants, the rating of the two standard sizes being approximately 24A and 48A. The standard plants operate from 3 phase, 50 c/s A.C. supplies. (Larger sizes are occasionally required. It should also be added, that before the Westat type of rectifier was introduced, motor-generators were also standard in the smaller outputs now covered by the rectifiers.)

4.3.7. *Standard 80 + 80V Rectifier Plants.*

The type of plant referred to under (*a*) of Section 4.3.6 will now be more fully described. The table shows the main items required to make up either a single, or divided, battery float plant of approximately 7A or 14A rating.

	Single Battery Float		Divided Battery Float	
Approx. max. load (amp)	7	14	7	14
No. of 600+600 Watt Westat Rectifiers (Rectifier No.56A)	1	2	1	2
No. of 15 amp Standby Rectifiers (Rectifier No.57A)	1	1	1	1
Switchboard (Panel Power No.15A)	1	1	–	–
Switchboard (to Diag. TG.2037)	–	–	1	1
No. of batteries, each 40 cells	2	2	4	4
Standard capacity of cell (Ah)	50	50	*	*

* Varied to suit needs.

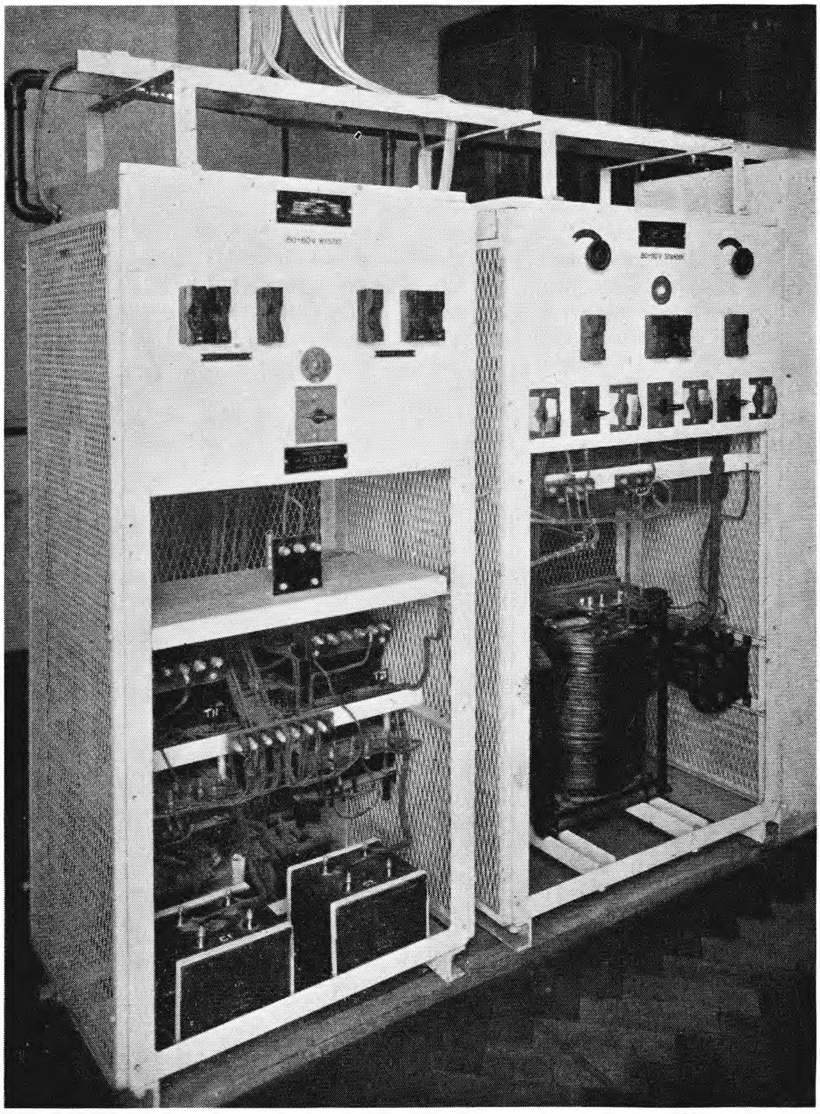

Fig. 3.—80 + 80V Westat and Standby Rectifier Cubicles.

The rectifiers, which are manufactured by Messrs. Westinghouse, are floor-mounting and include rectifier elements of the Westalite selenium type.

The Westat rectifiers (Fig. **3**) are received from works adjusted for operation from 230V 50 c/s A.C. supplies, and to give an output voltage varying between approximately 86 and 90V from full-load to 1/10th load at constant normal input frequency and voltage, as illustrated in Fig. **4**. This is the

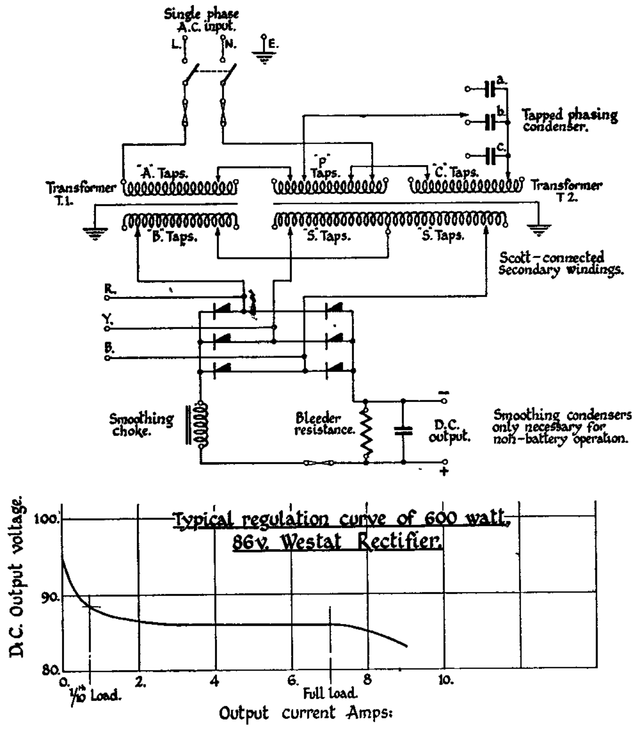

FIG. 4.—SIMPLIFIED SCHEMATIC OF THE WESTAT RECTIFIER—AND VOLTAGE REGULATION CURVE.

setting required for single battery float operation. Mains voltage variations, within the statutory limits of ± 6% from the declared voltage, add little to the output voltage variations produced by load changes, such that from 1/10th load to full load, with a simultaneous variation of input voltage from 6% above to 6% below normal, the output voltage varies only about 5V. The rectifiers are, however, sensitive to supply frequency changes, and the output voltage varies approximately linearly by 1.5% to 2% for every 1% change of frequency. The transformer and condenser taps within the cubicle can be re-adjusted for any declared input voltage from 200 to 250V, and for a mean output voltage of 82.5V for divided battery float working. There are no manual controls on the Westat rectifier. When two Westat rectifiers are provided, they are permanently paralleled to form what is, for all practical purposes, a single float unit.

The standby rectifier cubicle (Fig. **3**), made in one rating only, will deliver any output from 3A at 80 + 80V to 15A at 110 + 110V, and has transformer input tappings adjustable for any input voltage from 200 to 250V. The positive and negative rectifiers, which are simple single-phase bridge rectifiers, have independent controls in the shape of transformer output tapping switches and variable resistors, which together give a very fine control.

The single battery float power board is wall-mounting, while the divided battery float type can be either wall-mounting or floor-mounting, both types being very simple and requiring little comment.

The Westat rectifier (or rectifiers) is normally on continuous floating duty. The manually controlled rectifier can be used as a standby in the event of a failure of the Westat rectifier, it being then necessary to make occasional adjustments to cater for load and mains voltage variations. The standby rectifier is also available for use after a mains failure, to give control of the recharging of the batteries, and, in divided battery float installations, for recharging weekly the battery that has come off floating duty.

It is true that, when the mains are restored after a failure, a partially loaded Westat rectifier can be safely allowed to re-connect automatically to the batteries, but, in general, it is safer to restore connection on the standby rectifier, to avoid the risk of the Westat rectifier overloading itself beyond the safe limit of about 20% overload. The voltage output of the Westat type of rectifier begins to collapse with overload, giving a measure of self protection, but the model in question will supply quite a heavy overload before this collapse commences.

It may be mentioned that where a very light load has to be supplied, as for example at a small M.C.V.F. telegraph terminal, a simplified form of installation is sometimes provided, consisting of one Westat cubicle and a single battery of 39 + 39 cells, with sufficient capacity to provide 24 hours reserve without the P.D. per cell falling below 1.95V. In such circumstances the Westat rectifier is fully capable of maintaining the battery in good condition, and of restoring an adequate proportion of the full charge within reasonable time of the power being restored after an emergency discharge.

4.3.8. *Standard* 80 + 80*V Motor-Generator Plants.*

The following table shows the plant required for single, or divided, battery float installations with approximately 24A and 48A output.

	Single Battery Float		Divided Battery Float	
Approx. max. load current (amp)	24	48	24	48
Number of 2+2 kW 80+80V Motor-generators	2	–	2	–
Number of 4+4 kW 80+80V Motor-generators	–	2	–	2
Switchboard (Diag. TG.2038)	1	1	–	–
Switchboard (Diag. TG.1095)	–	–	1	1
Number of Batteries, each 40 cells	2	2	4	4
Standard Capacity of Cells (Ah)	125†	250†	*	*

* Variable to suit local conditions.
† 2 Hours reserve.

The rating of each plant is the full output of one motor-generator.

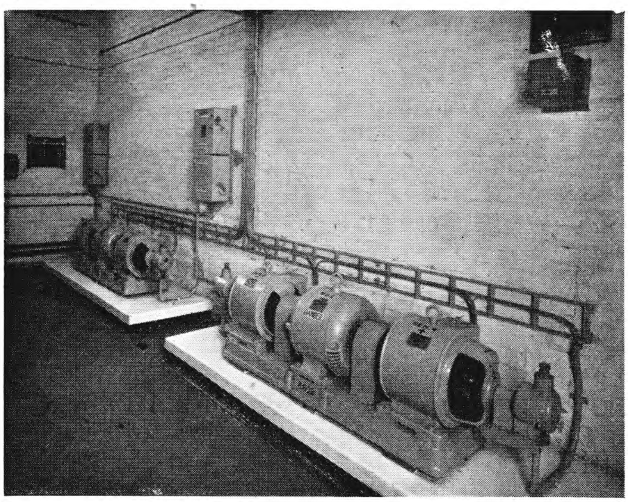

Fig. 5.—Standard 80 + 80V Motor Generator Set (Capacity 2 + 2 kW).

Figs. **5** and **6** show the motor-generator plant and associated switchboard respectively for a 24A output single battery float plant.

Each motor-generator consists of a 400V, 3 phase, 50 c/s induction motor, running at approximately 1440 r.p.m. and driving, at each end, a direct-coupled shunt-wound D.C. generator. The motor has a squirrel-cage rotor and is started by a star-delta switch. The output of each generator is only nominally 80V, the actual voltage being, of course, approximately 86V for single battery floating and 82.5V for divided battery floating. It is desired to stress that in speaking, for instance, of a 2 + 2 kW, 80 + 80V motor-generator, or, more loosely, of a 2 kW 80 + 80V motor-generator, it is intended to imply that each generator is rated at 2 kW or approximately 24A. Each generator is provided with an individual automatic voltage regulator of the Isenthal vibrating contact type, direct-coupled by spring coupling to the commutator end of the generator, as well as with a manual shunt field regulator. The machines are somewhat larger than the equivalent industrial machines on account of the absence of fans, which are prohibited in order to keep noise down to a minimum, though small fins are allowed on the squirrel-cage rotors.

The switchboards are floor-mounting and have a standard height of 6 ft. 6 in. The four generator circuit-breakers give over-current and reverse-current protection of 25% and 5% respectively, the latter perhaps appearing unnecessarily stringent, but being in fact, necessary as the generators will often motor with a very small current input. The type of circuit-breaker provided on some of the switchboards employs a contact ammeter to energise the shunt trip coil, giving a neat arrangement in which the over-current and reverse current contacts are easily set and in which the meters can also be used as indicating meters if mounted on the front of the switchboard.

The Isenthal regulator (Fig. **7**) has two pairs of contacts, which operate successively, and these can be arranged to control the generator field current in two ways. In the first arrangement, which has come to be known as the "Parallel Contact" arrangement, each pair of contacts in turn short-circuits the whole of the field series resistance. This gives the closest possible control of the generator voltage, namely, regulation to within $\pm$ 1% of the nominal value from no-load to 25% overload, with simultaneous variation of the A.C. input voltage and frequency over the range $\pm$ 6% and $\pm$ $2\frac{1}{2}$% respectively. The limitation to the use of this method is a maximum field current of 2A under automatic control. In the second arrangement each pair of contacts short-

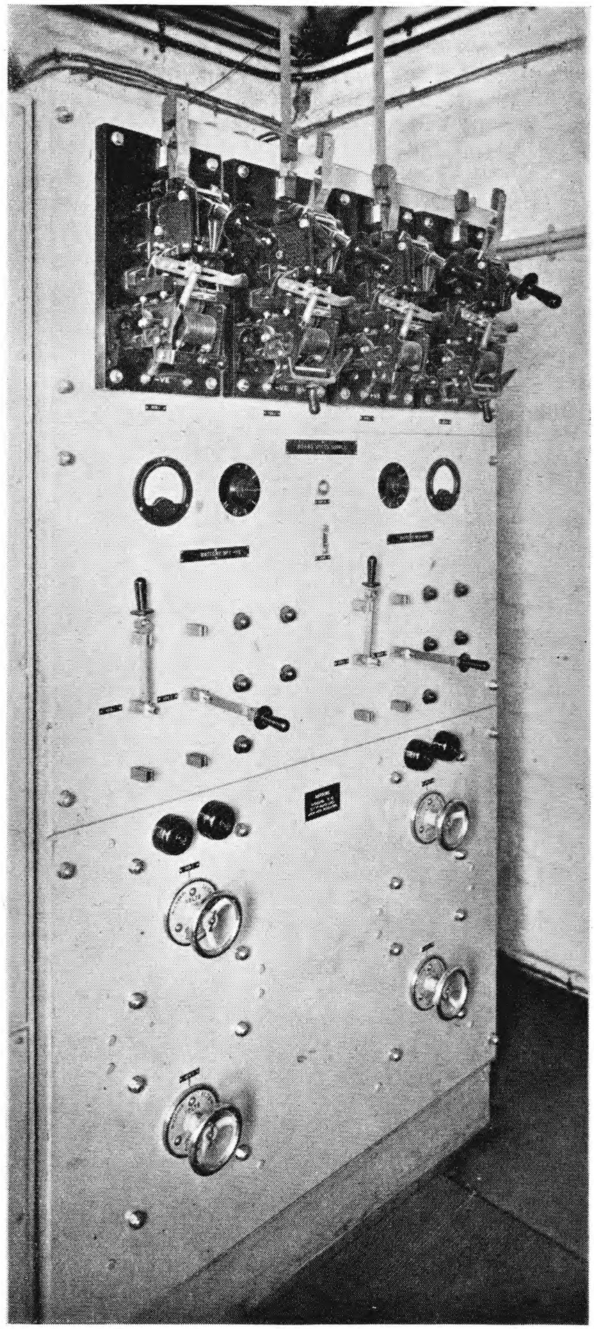

Fig. 6.—Standard 80 + 80V Power Switchboard—Single Battery Float Operation.

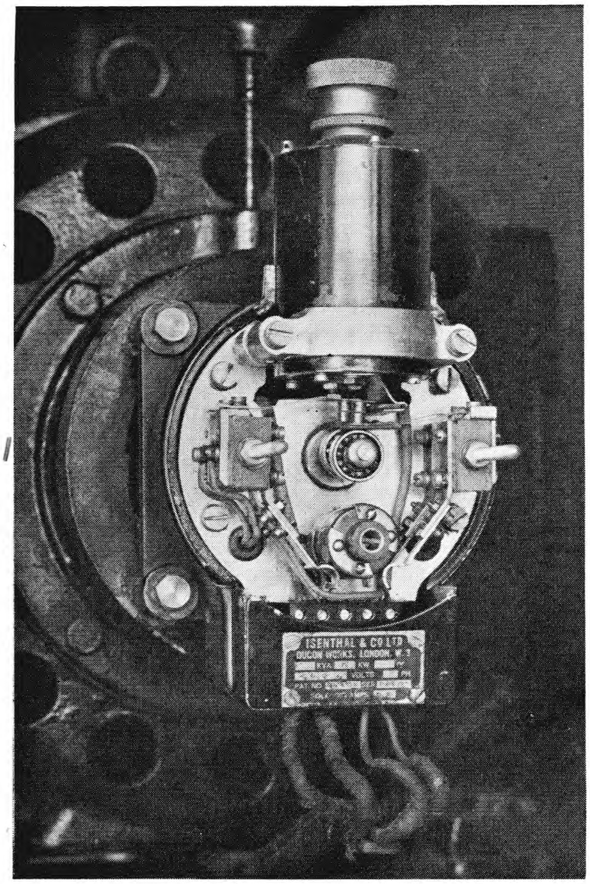

FIG. 7.—ISENTHAL REGULATOR.

circuits only half of the field series resistance, which requires to be centre-tapped, and the voltage regulation obtained is within $\pm 1\frac{1}{2}\%$ of the nominal value under the conditions named above. This arrangement can be used up to field current of 5A under automatic control.

Apart from the automatic voltage control, this standard equipment has no automatic features designed to make attendance unnecessary.

Larger motor-generator installations have from time to time been installed, with generator ratings up to 12 + 12 kW. The only salient difference in these, compared with the standard installations, is in the provision of wound-rotor motors, with rotor resistance starters. Also, when six-pole motors are used, the Isenthal regulators are belt-driven at approximately 1500 r.p.m., instead of being direct-coupled and so running at about 970 r.p.m., because they do not perform so well at this lower speed.

4.3.9. *The use of Compound-Wound Generators for Battery Floating.*

When frequency-controlled A.C. mains are available, it is possible to dispense with automatic voltage regulators, and obtain satisfactorily close voltage regulation for battery floating by compounding the generators and using a separate motor for each generator. One such plant was installed at Cardiff about the beginning of the war and was very satisfactory, but after this it was deemed necessary to concentrate on one type only, this being the standard type described in the last section.

4.3.10. *A Comparison Between the Motor-Generator and the Rectifier for 80 + 80V Supplies.*

It is only within the last few years that much use has been made of rectifiers, other than unit rectifiers, for 80 + 80V supplies. Before this, 80 + 80V loads were purely signalling loads, without the ballasting effect of teleprinter motors, so that the positive load varied widely and rapidly with respect to the negative load. Only the copper oxide type of metal rectifier was available, and there were no specially attractive methods of automatically regulating the voltage of the rectifier to cater for a rapidly varying load. Thus motor-generators held the field for use both with and without batteries. When batteries were not provided compound-wound generators were used, and, for battery floating, shunt generators with automatic voltage regulators were the rule. This was the position until mid-1940 when Westat rectifiers began to be used.

The first change which made the case for the rectifier better was the use of 150/170V teleprinter motors on the 80 + 80V supply. The motor load is large compared with the signalling load, so that the percentage variation in total load due to signalling is much reduced. Next the selenium rectifier became available, with its superior natural regulation, and finally, the simple and effective type of voltage regulation embodied in the Westat rectifier made it a keen competitor of the motor-generator for loads within its power.

When batteries are not provided, it becomes necessary to provide a fairly substantial smoothing condenser with a rectifier, whereas no such provision is necessary when using generators.

While it is difficult to make direct cost comparisons between rectifier and motor-generator installations, the following are estimated figures for 24 hours reserve floating battery installations, employing typical modern plant and giving standard facilities.

Ratio.	14A Plant.	24A Plant.
$\frac{\text{Cost of Rectifiers Plus Switchboard}}{\text{Cost of M.Gs Plus Switchboard}}$	0·76	1·14
$\frac{\text{Cost of complete rectifier installation}}{\text{Cost of complete M.G. installation}}$	0·82	1·13

Thus the present standards in which rectifiers are used for loads up to 14A are logical so far as first cost of installation is concerned.

Of course, the first cost of an installation is not the real measure of its worth ; it is the comprehensive annual charge that matters. In computing the annual charges, account is taken of maintenance and of the cost of power consumed. There is little doubt that rectifiers of as simple a type as the Westat require less maintenance than the equivalent motor-generators. Concerning cost of power consumed, the following figures show, approximately, how the

Westat rectifier compares with equivalent motor-generators as regards watt-efficiency and power factor:—

	7 A Westat	6 A M.G.	12 A M.G.
Full load watt efficiency	69%	48 to 60%	58 to 65%
Full load power factor	0·95	0·78 to 0·86	0·8 to 0·87

At half load the Westat rectifier still has a slightly better watt efficiency and power factor than the best 12A motor-generator.

4.4. Floating Battery Supplies for Phonogram and Telephone-Telegram Equipment.

When an exchange supply is not available for the phonogram and telephone-telegram equipment, the standard plant provided at an office with an A.C. supply is a single battery float plant, with twelve cells of sufficient capacity for a 24-hour discharge.

In the smaller installations, to supply single-panel phonogram equipment, a rectifier (Rectifier No. 38A, B or C) is used to float the battery.

For larger offices with more positions, and these of the single or double-tier continuous type, which impose a greater load per position than the single-panel type, a wall-mounting 600W, 26V Westat rectifier and associated switchboard (Diagram TG. 2033) are available.

When D.C. mains only are available, a charge-discharge arrangement is provided for the smallest offices.

At all but the smallest offices in which the mains supply is D.C., and also at the largest offices with A.C. mains, it is now standard to employ motor-generators on a floating basis (Diagram TG. 2021).

It used to be customary to employ batteries on a charge-discharge basis, with a rectifier or a single motor-generator for charging purposes, and several such installations are still in use.

It sometimes becomes necessary to provide a 30V dialling supply, and this is done by supplementing the main battery with three additional small cells with a trickle-charge rectifier.

The following table shows the approximate 24V loadings of the equipment:—

	Max. Demand Amp.	Daily Load Ah.
Separate Panel, per position	0·3	3
Continuous-Panel, per position	1·0	10
Position amplifiers, per position	0·1	0·5

4.5. Six volt supplies for Teleprinter Switchboards Lamps.

Except for one type of small cordless switchboard for renters' use, in which the 6V switchboard lamps are supplied from the 80V supply through dropping resistors, a 6V supply is required.

For the smaller types of switchboard installed at renters' premises, both the 80 + 80V supply and the 6V supply are normally without battery reserve, the 6V supply being merely an A.C. supply from a transformer. If battery reserve is required, because the switchboard has importance out of proportion to its size, the transformer supply can still be used normally and a change-over switch operated on the switchboard in the event of it being necessary to resort to battery; or the battery supply can be on a floating basis, the rectifier being the same type that is used for dialling batteries in phonogram installations.

For the larger switchboards for D.T.N. Stations and for the public service, battery reserve for both the 80 + 80V and 6V supplies is a standard provision. The arrangement first adopted for the 6V supplies to these switchboards was similar to that just described for the smaller switchboards, with the exception that an automatic change-over panel was provided as part of the switchboard apparatus. A combined 5A or 12.5A charging and trickle-charging rectifier and wall-mounting power panel were provided. At a few large installations, however, rectifiers with greater output were provided and the wall-mounting panel was replaced by a small section lining up with the main power switchboard for the L.T., H.T., and 80 + 80V supplies. (Diagram TG. 2009 shows a typical circuit of this type.) Later it was decided to abandon the above arrangement in favour of a simple floating battery scheme, in which the type of rectifier used has been kept absolutely simple, having no automatic voltage control devices but being designed for the best possible natural regulation. Between one fifth rated load and full load, with simultaneous mains voltage variations of + 6% to – 6% from normal, the output voltage does not vary outside the limits 7V to 6V. The rectifiers have been standardised, to date, in two ratings, namely, 15A and 30A. It sometimes becomes necessary to parallel two of the 30A rectifiers and, in one installation, three in parallel are in use.

The F.L.S. lamps constitute a large part of the load, their variation being, to some extent, compensated for by the calling lamp load. Nevertheless, the load varies considerably over the 24 hours, and the nature of the load varies greatly from one switchboard to another, due to the quite different types of traffic.

The 6V rectifier and battery need to be as near to the load as possible, in order to minimise voltage drop difficulties, and it is therefore the practice to install both of them near the switchboard apparatus racks. To this end the cells are always of the enclosed type, two or three sets of the largest size being paralleled if necessary. They are generally hidden away in cupboards, so as to be unobjectionable in the switchboard apparatus room. The batteries may require either 24 hours or 2 hours reserve, but in the latter case they are made considerably larger than is barely necessary, thus reducing the voltage variations arising from abnormally heavy or light loads persisting for only a short time. With the increasing size of public service teleprinter switchboard installations, it is evident that it will not always be possible to provide 24 hours reserve in a battery to be installed near the switchboard rack equipments. It will then be arranged for a reserve 230V A.C. supply to be obtained from a machine run from the 80 + 80V battery, the 6V supply being always obtained direct from transformers. This problem has not arisen at D.T.N. stations, where only two hours reserve is needed.

It may, perhaps, be questioned why the 6V battery supply is not taken as a tap from the 80 + 80V battery. The answer is that the 6V load is often much heavier than the 80 + 80V load, and always comparable with it, so that the arrangement would obviously be a bad one.

4.6. Power Supplies for Multi-Channel V.F. Telegraph Equipment.

4.6.1. *Some General Points.*

It will be recalled that the supplies required are the 21.5V L.T. or filament supply, the 130V H.T. or anode supply and the 80 + 80V supply. The L.T. and H.T. supplies often come from Repeater Station power plant, and the M.C.V.F. equipment is suitably equipped to prevent electrical noise at an objectionable level from being injected by it into such batteries.

On the other hand, a great many M.C.V.F. terminals have been provided with L.T./H.T. power plant designed primarily for this purpose, and, in all but a few of the earliest installations, such plant has been deliberately designed to be suitable also for repeaters and other transmission equipment. The conditions to be met consist of regulating the voltage to prescribed limits, namely, $\pm 1\%$ H.T. and ± 0.25V L.T., and also of ensuring that the psophometric noise on the batteries, due to the power plant, does not exceed specified limits (see para. 3 of I.P.O.E.E. Paper No. 173).

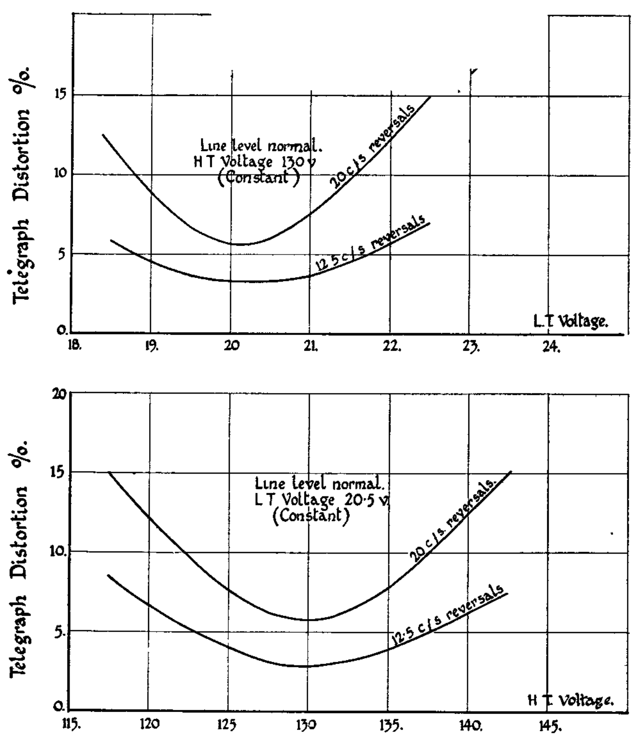

FIG. 8.—M.C.V.F. TELEGRAPH EQUIPMENT—EFFECT OF SUPPLY VARIATIONS ON TELEGRAPH DISTORTION.

It often happens that the major portion of the load on a telegraph power plant is that of audio equipment.

The M.C.V.F. telegraph equipment is less susceptible to noise than repeater equipment, but in respect at least of the anode supply is more affected by voltage variations. It has, perhaps, not always been fully appreciated to what extent H.T. supply variations affect telegraph signal distortion, compared with the same percentage variations in the L.T. supply, and there are many public service installations in which the L.T. supply is closely regulated by load carbon pile regulators, while the H.T. supply is not, which cannot be regarded as a logical arrangement for M.C.V.F. telegraph equipment. The effect of supply variations is clearly shown by the curves given in Fig. **8**.

Any L.T. load carbon pile regulators for M.C.V.F. telegraph equipment are connected in the negative lead (Fig. **9**), and not in the earthy lead as has been

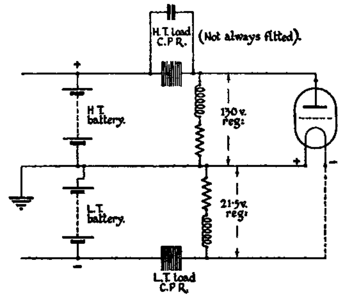

FIG. 9.—L.T. AND H.T. SUPPLIES FOR M.C.V.F. TELEGRAPH EQUIPMENT. THE POSITION OF THE LOAD CARBON PILE REGULATORS.

the custom in repeater practice. There is a good reason for this, because an L.T. regulator in the earthy lead in effect causes variations in the H.T. supply voltage, equal to the variations across the L.T. pile. The standard telegraph practice is adhered to when supplying audio equipment from a telegraph power plant. It will be appreciated that the load carbon pile regulators are normally mounted on the equipment racks (Fig. **10**) and are connected in the supply lead between the battery and the load.

Absolute continuity of supply at M.C.V.F. terminals is of great importance, because of the number of through channels that may be affected, for while a short break in a power supply may cause little or no trouble on speech channels, it will cause errors, false calls, etc., on telegraph circuits.

4.6.2. *The Supply Requirements for M.C.V.F. Telegraph Equipment.*

The precise mean value of the L.T. and H.T. supplies is not critical, but the variation about these mean values is important. The normal limits are 21.5V $\pm$ 0.25V for the L.T. supply and 130V $\pm$ 1.3V for the H.T. supply.

The requirements for the 80 + 80V supply have already been stated in Section 4.3.2.

It will be clear that the supply requirements can best be met by the use of floating battery installations, and only in 4-channel outstations and mobile equipments is operation without batteries tolerated.

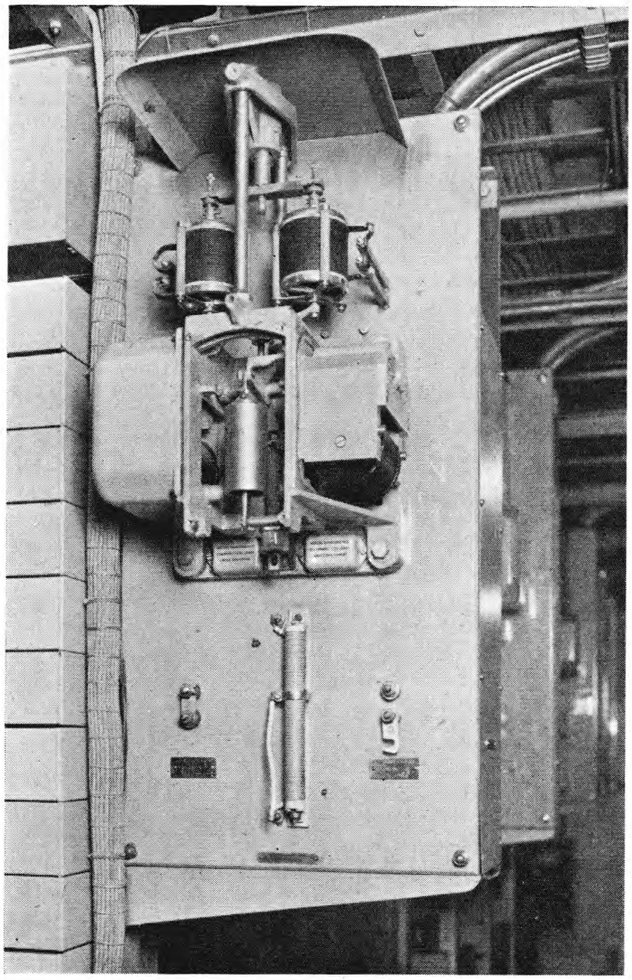

FIG. **10**.—CARBON PILE AUTOMATIC VOLTAGE REGULATOR.

4.6.3. *Standard M.C.V.F. Telegraph Power Plants for Public Service Installations.*

Present-day plants employ floating batteries for all supplies. They are of two types, in the first of which (*a*) each supply has its own 24 hours reserve divided battery float plant, and in the second of which (*b*) the reserve is wholly in the 80 + 80V batteries. The second type is an economical proposition only for a M.C.V.F. terminal associated with a large telegraph instrument room which imposes a heavy 80 + 80V teleprinter motor load.

(*a*) In this type of installation divided battery float plant is provided for all supplies, using rectifiers for all but the largest A.C. mains plants and motor - generators for D.C. and very large A.C. plants. Various types of L.T. and H.T. rectifiers have been used, but the type of cubicle that has been employed for recent installations incorporates selenium elements and a three-phase Ferranti moving-coil regulator with manual press-button control of its reversing disc-type control motor. This gives a superlative manual control of the floating voltage, which has been considered sufficient for batteries with 24 hours reserve. It has been found, however, that a variation of 6% in the mains input voltage has sometimes caused a variation of as much as 11% in the output voltage. This might result in a lot of manual readjustment being necessary to maintain the correct floating voltage, and automatic control of the regulator will therefore be used in future. This can be accomplished at slight extra expense by the use of, what is called by the makers, an astatic relay, which is a simple form of voltage relay. The L.T. cubicles of this type have been made with 50A and 100A outputs, and the H.T. cubicles with 7.5A and 15A outputs.

For motor-generator installations, duplicate machines are provided, each consisting of a motor driving an L.T. and an H.T. generator, direct-coupled to the motor at either end. The generators are provided with automatic voltage regulators of the Isenthal or Brown-Boveri types.

A complete installation comprises two L.T. and two H.T. cubicles, or two LT/HT motor-generators, one L.T. smoothing filter, one H.T. smoothing filter, a switchboard, two L.T. batteries each of 12 cells and two H.T. batteries each of 63 cells. Load carbon pile regulators are used for the L.T. supply, but not for the H.T. supply. (In the foregoing, diagrams TG 1094 and TG 2036 refer for A.C. mains and TG 2018 for D.C. mains.)

The standard divided battery float 80 + 80V motor-generator plant (Diagram TG 1095) is used for the largest installations, while for smaller installations the Westat type of divided battery float plant (Diagram TG 2037) is employed.

Illustrations of a medium-sized plant employing rectifier cubicles for divided battery float operation are given in Figs. **11** and **12**, from which the association of the L.T., H.T., and 80 + 80V equipments will be noted.

(*b*) This plant, which has been employed at a number of large D.T.N. stations as well as in public service M.C.V.F. terminals, has the reserve for the whole station in the 80 + 80V batteries, the voltage of which can be allowed to vary over a wide range as already defined. The reserve is two hours at a D.T.N. station and 24 hours at a public service terminal. The 80 + 80V plant is the standard public service type of motor-generator divided float plant (Diagram TG 1095), with the automatic paralleling contactor for the batteries provided.

The L.T. and H.T. plants are operated on the single battery float principle, the L.T. battery having 10 cells floated at approximately 21.75V, the H.T. battery 60 cells floated at approximately 130V, and each battery having an Ah capacity numerically equal to twice the rated ampere load. (Diagram TG 2022 refers.)

The main L.T. and H.T. generators are driven by a common mains-supplied motor, and run continuously excepting during periods of maintenance or mains failure. When the mains supply fails, or if a fault occurs in the motor-

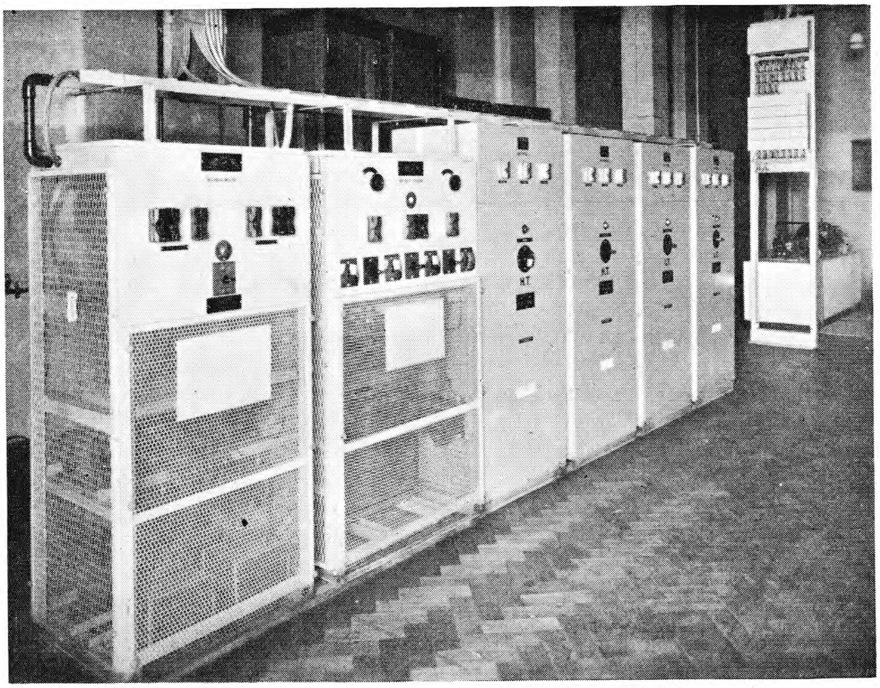

Fig. 11.—Standard M.C.V.F. Power Plant employing Rectifier Cubicles.

Fig. 12.—Standard L.T., H.T., and 80 + 80V Power Switchboards for M.C.V.F. Terminals.

generator, an automatic change-over is effected to a second motor-generator which has a 150/170V motor supplied from the 80 + 80V batteries. Fig. **13** illustrates the plant concerned. The two 80 + 80V batteries are auto-

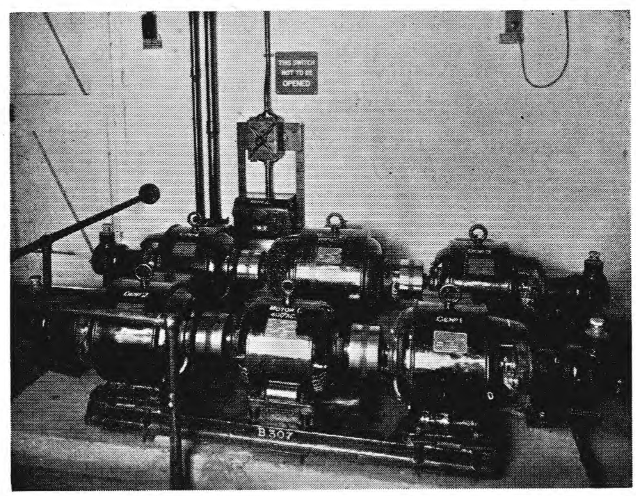

Fig. 13.—M.C.V.F. Power Plant. Mains and Battery-driven Reserve LT/HT Motor Generators.

matically paralleled before the starting condition is applied to the automatic starter of the reserve LT/HT machine.

The H.T. generators are controlled by Isenthal automatic voltage regulators, and the L.T. generators by Brown-Boveri or Isenthal regulators according to their rating.

The loads are connected direct to the bus-bars without the interposition of load carbon pile regulators, with quite a useful saving in power consumed at a large station. The L.T. and H.T. supply voltages fall to about 18V and 110V, respectively, during the few seconds between the occurrence of a mains failure and the connection of the reserve motor-generator to the load, but this has proved to be tolerable. During these few seconds of change-over, also, the small L.T. and H.T. batteries discharge sufficiently to take a considerable current surge from the incoming generators, and mechanical delays on the circuit-breakers have been found better able to handle this surge than the oil-dashpot type.

4.6.4. *Some Special War-time Single-battery Float Installations for D.T.N. Stations.*

A large number of special single-battery float L.T., H.T. and 80 + 80V power installations have been provided just before and during the war, to supply M.C.V.F. telegraph equipment, audio equipment and teleprinters at D.T.N. stations. The stations were divided into three broad types, which were called "Small," "Group" and "Main" stations respectively, while larger stations were referred to as "Special" stations. In the earlier years two types of equipment were produced—

(i) The Small Station Equipment.

(ii) The Group, Main and Special Equipments.

These plants, which were designed before the war, were made semi-automatic in operation, as it was thought that they would require to be left unattended for long periods. On restoration of the A.C. supply after a period of failure the power plant is automatically re-connected to battery and load. Selenium rectifiers are used for the L.T. and H.T. supplies and motor-generators for the 80 + 80V supply. The installation programme employing these plants is believed to have been one of the first large scale projects in this country in which selenium rectifiers were used, the manufacturers being Messrs. Standard Telephones & Cables.

During the later years of the war the above two types were superseded by two fresh types, in which automatic features other than voltage regulation were eliminated, as being no longer necessary now that stations were fully attended, and in which as a result, a useful measure of simplification was achieved. These fresh types are:—

(iii) The "A" type plant having slightly greater LT/HT output than the "Small Station" plant.

(iv) The "B" type plant having slightly greater LT/HT output than the "Main Station" plant.

All of the four types of plant have batteries designed to give two hours reserve, comprising 13 L.T. cells, 71 H.T. cells, and 40 + 40 cells for the 80 + 80V supply. The batteries are floated at 28, 153 and 86 + 86V respectively, within limits of ± 2% with mains voltage variations of ± 10%, and provision is made for occasional float-charging at 30, 163 and 92 + 92V respectively, that is at 2.3V per cell. The automatic regulation of the floating voltage within these close limits is considered to be essential with small batteries giving only two hours reserve. Carbon pile load regulators are used for both the L.T. and H.T. supplies, but not, of course, for the 80 + 80V supplies.

(i) *The Small Station Plant.*

The following table shows some particulars of this plant:—

	L.T.	H.T.	Earlier 80+80V	Later 80+80V
A.C. Mains	200-250V	200-250V	230V	400V 3 phase
Max. Auto-regulated output, (amp)	16	1·5	6	13
Min. Auto-regulated output, (amp)	7	0·75	NL	NL
Max. output manual control, (amp)	25	3	6	13
Battery capacity, Ah	50	10	20	50
Full-load watt-efficiency, auto-control, %	43	54	57	66·5
Full-load power factor, auto-control	0·89	0·84	0·78	0·86

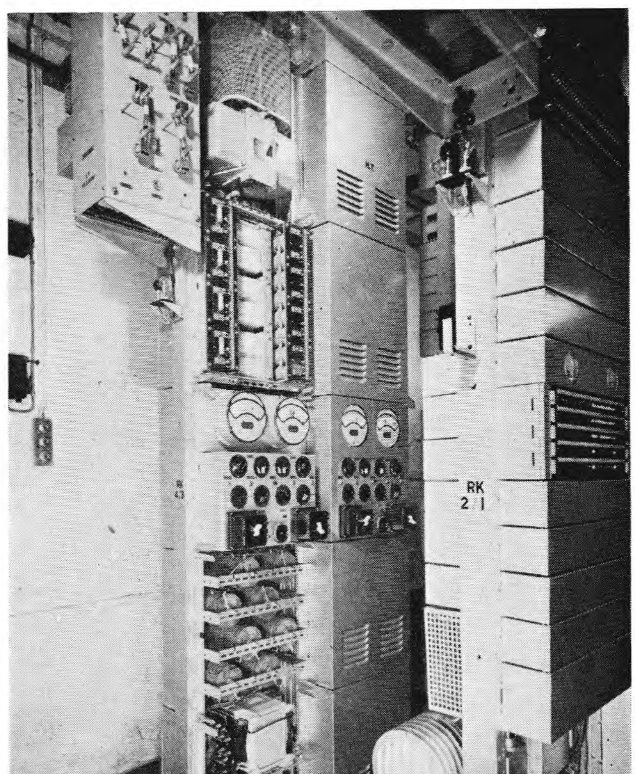

FIG. 14.—D.T.N. SMALL STATION L.T. AND H.T. POWER BAYS.

The L.T. rectifier equipment and the H.T. rectifier equipment each occupies a bay 10 ft. 6 in. high by 1 ft. 8½ in. wide, which line up with M.C.V.F. telegraph or audio equipment bays. This feature is clearly illustrated in Fig. **14**, which shows the L.T. bay (cover removed), H.T. bay adjacent to it, together with a normal telegraph apparatus bay in the foreground. The transformers and selenium bridge rectifier units are provided in duplicate. Either rectifier can be selected for floating, with automatic or manual control, and they can be operated in parallel under manual control to give the maximum float-charge output referred to above. Only one smoothing filter and automatic voltage regulator are provided, the latter being a carbon pile regulator, referred to as the battery regulator, to distinguish it from the external load carbon pile regulator. The arrangements employed to obtain the automatic voltage regulation are shown in Fig. **15**.

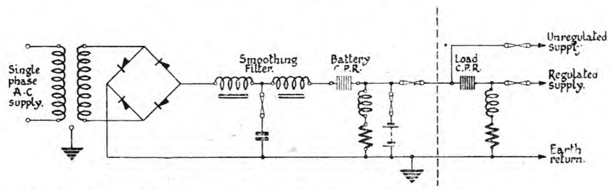

FIG. **15**.—D.T.N. SMALL STATION BAYS—PRINCIPLES OF AUTOMATIC VOLTAGE REGULATION.

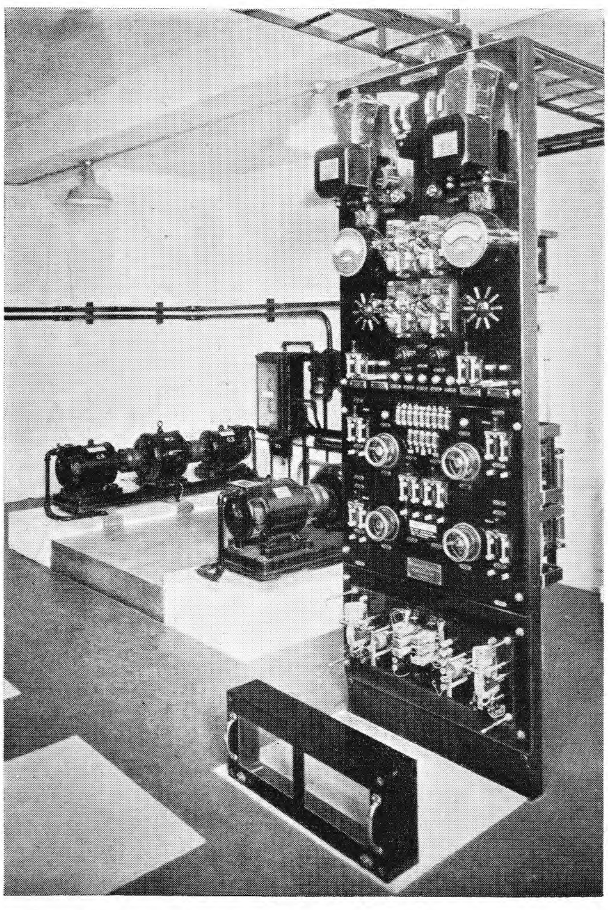

FIG. **16**.—D.T.N. SMALL STATION 80 + 80V POWER PLANT.

When, after a mains failure, the supply is restored, the rectifiers are automatically reconnected to battery and load with a reduced voltage setting of the battery regulators equivalent to 2V per cell and, in addition, with a resistor connected in series with the rectifier output. In this way there is no overloading of the rectifiers due to the batteries taking a heavy charging current. Pilot lamps on the bays indicate that an "emergency float" condition exists, and the attendant eventually restores normal conditions. A manual regulator is provided, which can be switched to replace either the battery regulator or the load regulator, being used in the former case in conjunction with tapping switches on the transformer.

The disadvantage of this plant, as shown in the above table, is its low efficiency, caused by the voltage drop in the battery carbon pile regulator.

The 80 + 80V plant (Fig. **16**) comprises two motor-generators with automatic starters, and a switchboard. When the mains supply is restored after a failure, the motor-generator in service is automatically restarted and the generators are connected to battery and load, with the generators still adjusted for their normal output but with surge-limiting resistors in the generator output ; normal conditions are restored by the attendant. There are two generator carbon pile regulators mounted on the power board, one for the two positive 80V generators and the other for the two negative 80V generators. When the motor-generator starts up, the carbon pile oscillates for a while, and would cause overload release due to surges of battery current were precautions not taken to prevent this. Therefore, after the generator voltage has risen 4V above the battery voltage, there is a delay of 20 to 30 seconds to allow time for the auto-starter (Fig. **17**) to

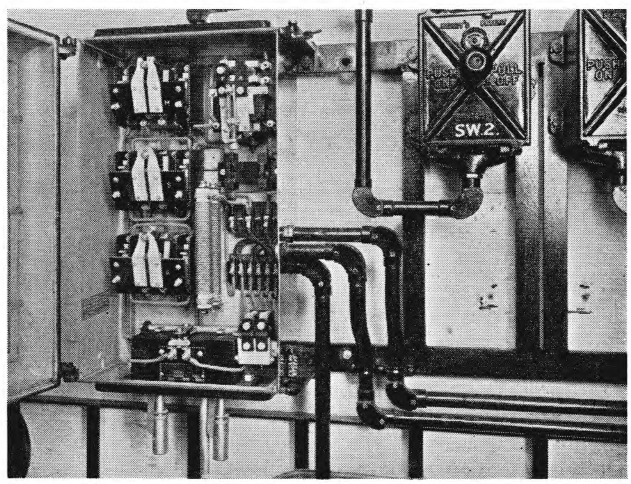

FIG. **17**.—AUTO-STARTER ASSOCIATED WITH 80 + 80V SMALL STATION POWER PLANT.

switch to its running position and for the carbon pile to stop swinging. The generator output of 6A or 13A includes battery charging at the 10 hour rate, only the balance, *i.e.*, 4A and 8A respectively, being normally available for load.

(ii) *Group, Main and Special Plant.*

These plants give the same performance as that described under (i). The 80 + 80V plant is almost identical in type but has greater output. The LT/HT rectifier equipment, however, incorporates a type of tap-changing regulating transformer (Fig. **18**), manu-

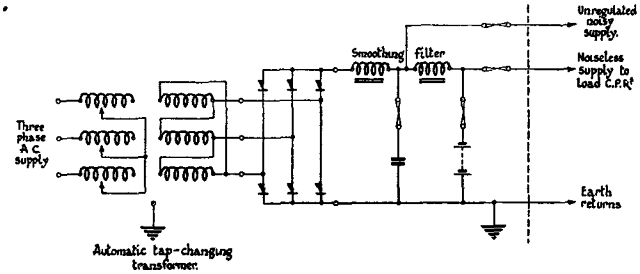

FIG. **18**.—D.T.N. GROUP OR MAIN STATION POWER PLANT—PRINCIPLES OF AUTOMATIC VOLTAGE REGULATION.

factured by the Foster Engineering Co., controlled via relays and contactors by two moving-coil meters, one giving voltage control and the other current control. The following are some particulars of the plants:—

one smoothing filter for each supply, mounted in the automatic cubicle, and a link mounted on the terminal panel in the main cubicle enables either the main or standby rectifier to be switched to the filter input.

The transformers are immersed in petroleum jelly in closed steel tanks.

When the cubicle is switched on, or when the mains supply is restored after a failure, connection is first made to the lowest transformer taps before connecting the rectifier to A.C. supply and battery. The taps are then raised under control of the contact ammeter and voltmeter. The automatic current control is devised to keep the rectifier operating near its full output until the battery voltage rises within the regulating range of the contact voltmeter, when the latter takes control. In this way the battery is recharged as quickly as possible without overloading the rectifier. By the operation of a key, the rectifiers can be made to regulate at 2.3V per cell for float-charging.

LT/HT PLANTS.

400V. 3 phase A.C. supply	Group		Main		Special		Special	
	L.T.	H.T.	L.T.	H.T.	L.T.	H.T.	L.T.	H.T.
Max. auto-regulated output, (amp)	60	7·5	110	15	150	20	250	25
Min. auto-regulated output, (amp)	15	1·2	32	3	30	5	25	2·5
Battery Capacity, Ah.	125	20	300	50	500	50	700 to 1000	75
Full-load watt efficiency, %	71	70	72	74	72	76	73·5	76
Full-load power factor	0·95	0·93	0·95	0·96	0·96	0·96	0·97	0·97

80 + 80V PLANTS.

400V. 3 phase A.C. supply	Early Group	Early Main	Later Gp and Main	Special
Max. auto-regulated output, (amp)	17·5	23	42	60
Min. auto-regulated output, (amp) ...	NL	NL	NL	NL
Battery capacity, Ah.	50	75	125	200
Full-load watt efficiency, %	72	72	72·5	74
Full-load power factor	0·85	0·86	0·86	0·875

It should be observed that the maximum automatically-regulated output always includes a proportion, equal to one-tenth of the battery capacity, for battery charging. Thus, for instance, the 110A output of the L.T. cubicle shown above is apportioned 80A to load and 30A to battery recharging. Each standby rectifier has the same rating as the main floating rectifier, and the main and standby rectifiers are not intended to be paralleled.

The largest LT/HT plant comprises four cubicles, two L.T. and two H.T., one of each being the main automatically-controlled floating cubicle and the other a manually-controlled standby cubicle. The other three equipments each comprise only three cubicles, as the two manually-controlled rectifiers are combined in one cubicle. Figs. **19** and **20** show front and rear views respectively of such a typical equipment. Except for the lack of automatic control, the transformers for the standby rectifiers are identical with those for the main automatic rectifiers. There is only

This type of cubicle has given excellent service, but the complication of the circuit is, perhaps, some disadvantage on the rare occasions when faults do occur.

(iii) *The " A " Type Plant.*

When the need for semi-automatic plant no longer existed, the " Small Station " plant described under (i) was superseded by an all-rectifier plant of slightly larger capacity. The 80 + 80V portion of the plant is the single-battery float Westat plant already described. The LT/HT plant also employs Westat rectifiers. The complete LT/HT plant is built into a single cubicle (Rectifier No. 58A) which includes L.T. and H.T. Westat float rectifiers, L.T. and H.T. manually - controlled standby rectifiers, and one smoothing filter for each supply. The Westat rectifiers are normally in use on floating duty, and their full output is available for load, as the standby rectifiers have a margin above this for battery charging. The principle of automatic voltage regulation

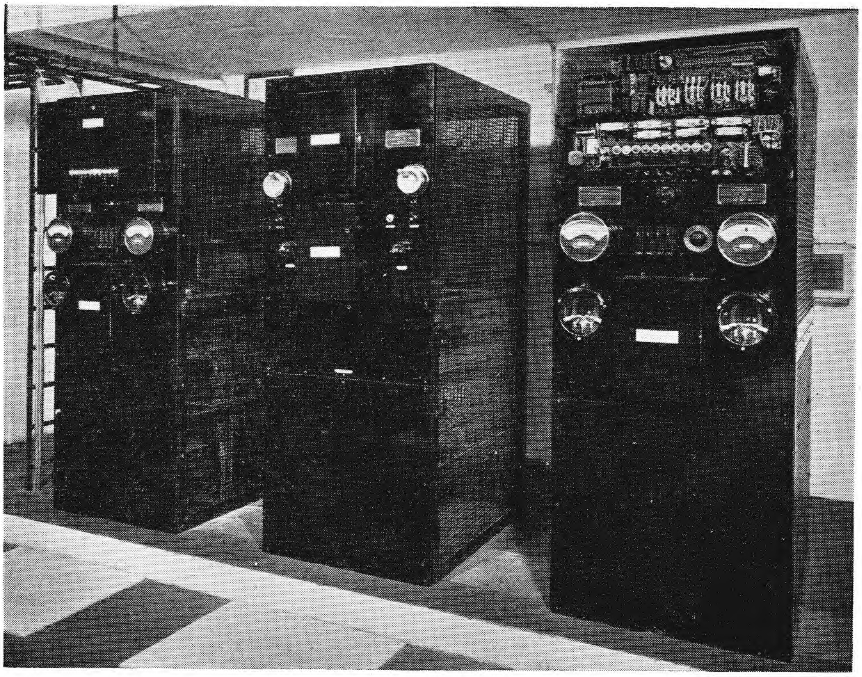

Fig. 19.—D.T.N. Main Station L.T. and H.T. Power Cubicles.

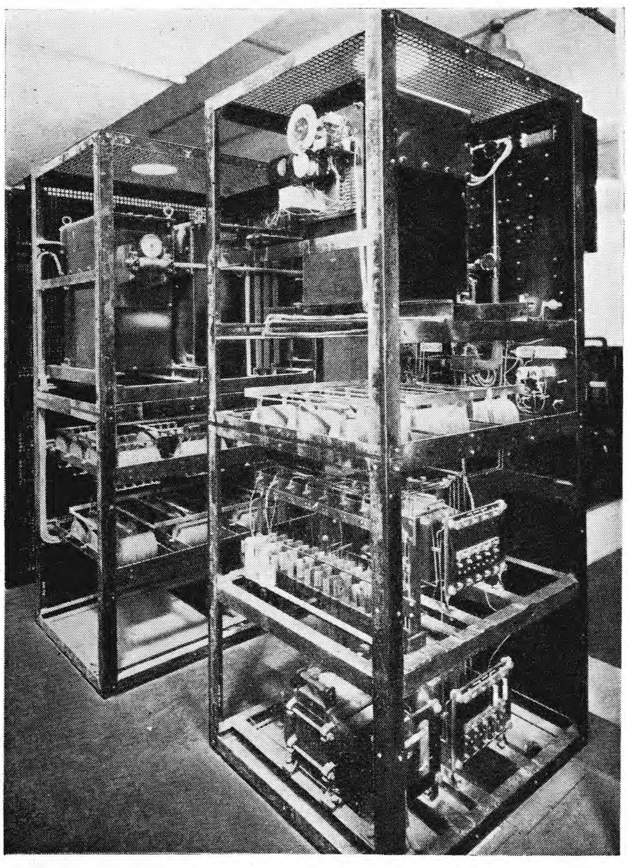

Fig. 20.—Rear View of D.T.N. Main Station L.T. and H.T. Power Cubicles.

employed with this type of plant is shown schematically in Fig. **21**.

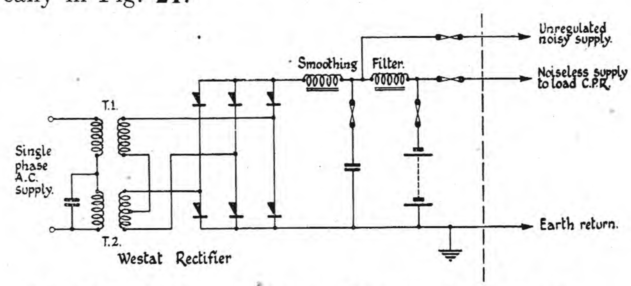

Fig. 21.—D.T.N. " A " Type Cubicle—Schematic of Westat Rectifier (L.T. Supply).

The following table gives some particulars of the LT/HT plant:—

	L.T.	H.T.
Rating of Westat float rectifier, (amp)	20	2
Rating of manually-controlled rectifier, (amp)	30	3
Min. output of manually-controlled rectifier, (amp)	5	0·5
Range of voltage output of manually-controlled rectifier	26/30	142/163
Battery capacity, Ah.	75	10
Full-load watt efficiency of Westat rectifier, %	66	62
Full-load power factor of Westat rectifier	0·96	0·97

The complete L.T., H.T. and 80 + 80V plant operates from a single-phase 50 c/s A.C. supply of 200 to 250V.

Although this type of plant was not designed for automatic reconnection on restoration of A.C. supply, it can be allowed to operate in this way if the interruption in the supply is short, or if the load is well

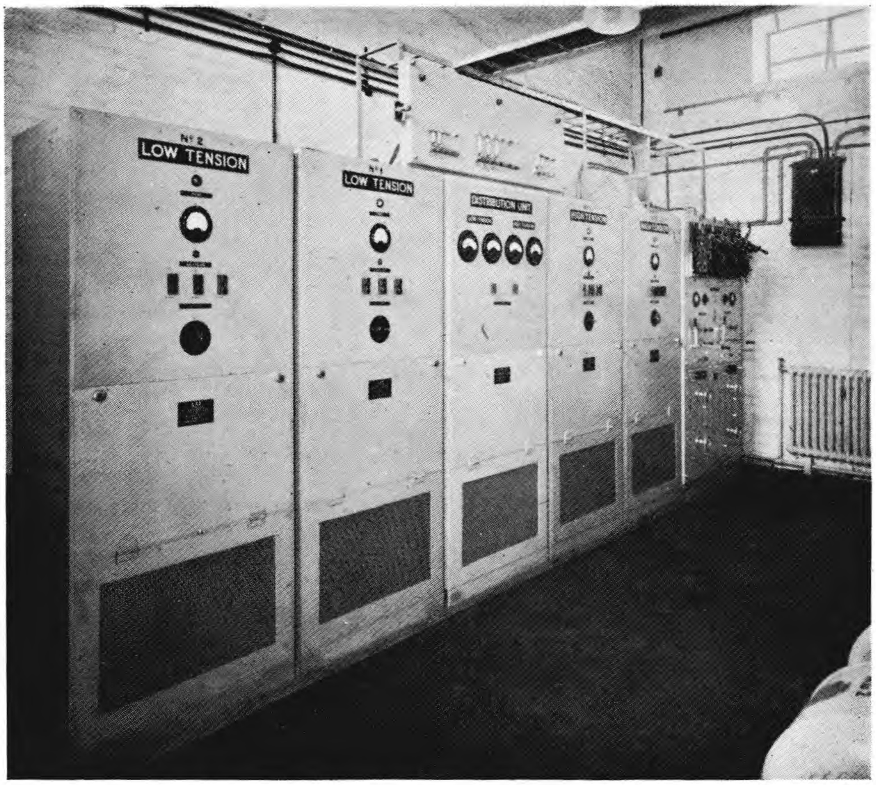

FIG. 22.—D.T.N. " B " TYPE LT/HT RECTIFIER CUBICLES AND 80 + 80V SWITCHBOARD.

within the capacity of the Westat rectifiers, such that the initial battery charging current does not overload the rectifiers by more than 20%. The only deficiency in this type of rectifier equipment is that it does not compensate for frequency variations in the supply.

(iv) *The " B " Type Plant.*

This type of plant, which superseded the "Group" and " Main " types described in (ii) for the larger stations, was not designed for automatic reconnection on restoration of the A.C. supply. However, the L.T. and H.T. rectifiers can be allowed to reconnect automatically provided the rectifiers are not overloaded by the battery charging current, but the 80 + 80V plant is the standard single-battery float motor-generator plant described in section 4.3.8, and is not provided with automatic starters.

The LT/HT equipment, manufactured by Messrs. Standard Telephones and Cables, normally comprises five cubicles, two L.T., two H.T. and a smoothing and distribution unit (Fig. **22**) ; but provision is made to extend the equipment by the addition of one more L.T., and one more H.T. cubicle. The two L.T. cubicles are similar, as are the two H.T. cubicles. The distribution unit contains a single L.T. smoothing filter and a single H.T. filter, together with a distribution panel, alarm relays, voltmeters and ammeters. To provide for automatic voltage regulation of the floating battery each rectifier is supplied from a Ferranti 3-phase moving-coil regulator as shown schematically in Fig. **23**. The regulator is controlled by an astatic voltage relay which can be seen in front of the moving-coil regulator in Fig. **24**. The function of this combination is to regulate the voltage on the input side of the rectifier, hence, unlike the three types of plant so far described, this one does not compensate automatically for the variations in voltage drop in the rectifier units caused by varying load. However, the normal load is virtually constant, and it is only necessary to readjust the taps of the auto-transformer feeding the astatic relay when a permanent change of load occurs, or when it is desired to charge the batteries following an emergency discharge. Like the Westat rectifier the A.C. astatic relay is sensitive to supply frequency variations. (Since this plant was designed, Messrs. Ferranti have developed, in conjunction with officers of the Equipment Branch of the Engineer-in-Chief's Office, a D.C. version of the astatic relay, which can be used to control the output voltage of the rectifiers.) The rectifier units are fitted in funnels, to improve their rating by inducing a better draught. The standard provision of two cubicles of each type allows one

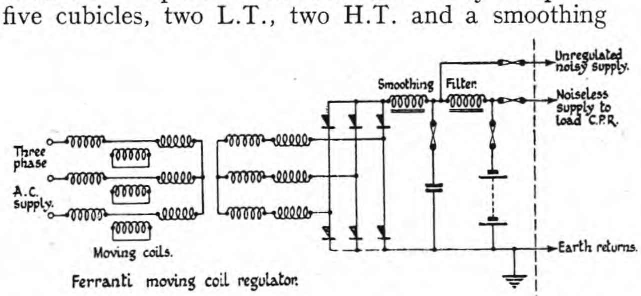

FIG. 23.—D.T.N. " B " TYPE L.T. CUBICLE—AUTOMATIC VOLTAGE-REGULATION USING FERRANTI MOVING-COIL REGULATOR.

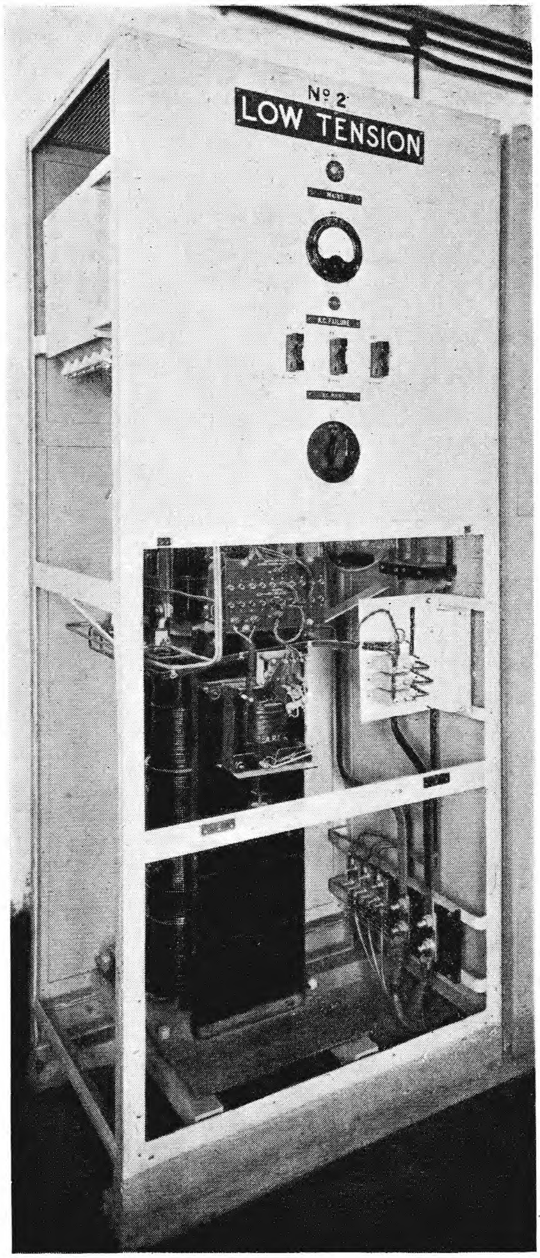

FIG. 24.—D.T.N. " B " TYPE L.T. CUBICLE—FERRANTI MOVING-COIL REGULATOR AND ASTATIC RELAY.

rectifier to be used up to its rating for supplying load, the second being available as standby and for paralleling with the first when it is required to charge the battery. The rectifiers work well in parallel, each with its own automatic voltage control, sharing the load admirably despite mains voltage variations.

The following are some particulars of this type of plant:—

A.C. supply 400V 3 phase	L.T.	H.T.
Rating of each rectifier, (amp)	100	10
Minimum current, (amp)	20	2
Battery capacity, Ah.	400	50
Full-load watt efficiency %	71	72
Full-load power factor	0·68	0·63

It will be observed that the power factor is disappointingly low.

A very interesting plant, similar in principle to the above, has been installed at one station. This was designed for a 400 amp L.T. load and a 40 amp H.T. load and it has, therefore, three 200 amp L.T. cubicles and three 20 amp H.T. cubicles. Messrs. Ferranti required the regulators to be oil-cooled and, actually each has been mounted above the associated rectifier units in a common tank, with pipe cooling. The astatic relay is accommodated in an ironclad box on the front of the tank. With this plant the average full load watt efficiency and power factor were 73% and 0.8 respectively for the L.T. rectifiers, and 72% and 0.8 respectively for the H.T. rectifiers. An illustration of this plant is given in Fig. **25**. The H.T. cubicles to be seen in the background are of similar construction to the L.T. cubicles, but of smaller dimensions.

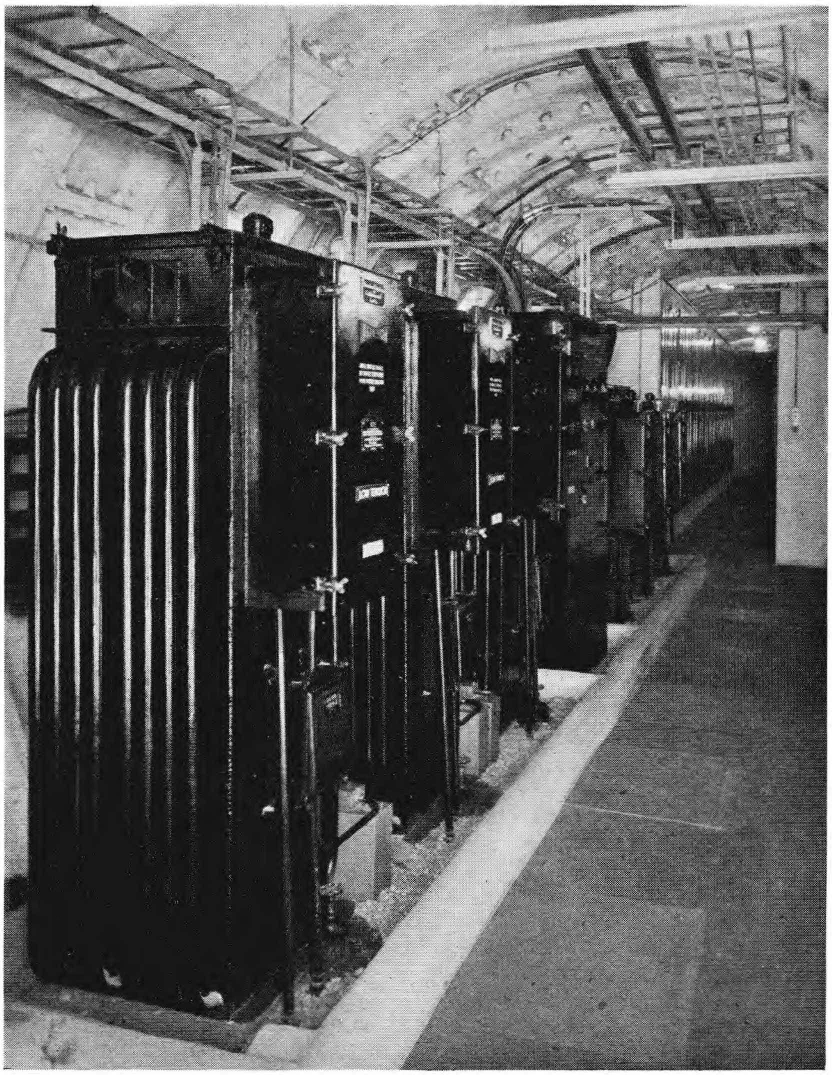

FIG. 25.—D.T.N. SPECIAL OIL-COOLED RECTIFIER POWER PLANT.

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APPENDIX I.

A BRIEF DESCRIPTION OF THE PRINCIPLE OF THE WESTAT RECTIFIER.

The Westat rectifier requires only a single-phase A.C. supply, and, without the use of any moving parts, it will give a closely regulated D.C. output voltage with varying load and A.C. supply voltage ; it will not compensate, however, for supply frequency variations, and, in fact, the D.C. voltage varies approximately linearly with, but somewhat more than in direct proportion to, the supply frequency. With a single-phase full-wave bridge rectifier the mean D.C. voltage, while falling with increase of load, is always less than the r.m.s. A.C. input voltage throughout the range no-load to full-load. On the other hand, with a three-phase bridge rectifier, the mean D.C. voltage, while again falling with increase of load, is always greater than the r.m.s. A.C. voltage between any pair of lines, throughout the range no-load to full-load. Thus, for any given r.m.s. A.C. voltage applied single-phase to a single-phase full-wave rectifier, and three-phase to a three-phase full-wave rectifier of similar current rating, the D.C. output voltage of the three-phase rectifier at full-load is greater than that of the single-phase rectifier at no-load. It will, therefore, be clear that, given a three-phase full-wave rectifier unit and a three-phase supply, by connecting only one phase of the supply at no-load, but all three phases at full-load, there is, compared with the no-load condition, a margin at full-load to counteract the voltage drop in the rectifier elements. An approximation to a constant voltage output has therefore been achieved at these two points on the load curve. This is the principle of the Noregg and Westat rectifiers. Referring to Fig. **4**, of two transformers which have their primary windings in series across the single-phase A.C. supply, one (T1) has an air gap in its magnetic circuit, whilst the other (T2) is a normal transformer, shunted on its primary winding by a condenser and having its secondary winding centre-tapped. The secondary windings of the two transformers are Scott-connected to a three-phase bridge rectifier, so that if an approximation to a normal two-phase supply were connected, one phase to each primary winding, an approximation to a normal three-phase supply to the rectifiers would be obtained.. By careful design of the transformer magnetising currents and condenser current, and by adjustment of numerous tappings on the transformers and condenser, it is arranged that at full-load the line current leads the voltage V2 (developed across T2 primary) by approximately 45°, and lags behind the voltage V1 (developed across T1 primary) by approximately 45°. V1 and V2 are approximately 90° out of phase, so that the output from the Scott-connected secondary windings is three-phase. From full-load to no-load a progressive change occurs, resulting in the voltage developed across T1 primary becoming smaller, until, at no-load, the supply to the rectifier is virtually single-phase, from T2 only. Overload causes reversion towards single-phasing with consequent fall of D.C. voltage. The steepest part of the regulation curve is that very near to no-load, and this can readily be cut off by the use of a bleeder resistance sufficient to impose a very light load.

Changes from normal in the mains voltage also cause deviations of the voltages V1 and V2 from their normal phase relationship, so that some degree of compensation is again given. This is necessarily far from a complete treatment, but it is hoped that the principle will have been indicated.

APPENDIX II.

A BRIEF DESCRIPTION OF THE PRINCIPLE OF THE FERRANTI MOVING COIL REGULATOR.

The regulators used in the power equipments that have been described are designed for three-phase operation. The three-phase regulator merely consists of three single-phase regulators operating together, and therefore a description of the principle of a single-phase regulator will suffice. The regulator (Fig. **26**) is essentially a transformer with (in principle) a long two-limbed core, on one limb of which are wound two primary windings "a" and "b" and two secondary windings "c" and "d." (The second limb may actually be in two or more parts.) Winding "a" is towards one end of the limb and winding "b," which is wound in opposite sense, is towards the other end of the limb. The two coils are connected in series across the A.C. supply, and over them a short-circuited coil "s" is free to move. The short-circuited coil behaves as a barrier to magnetic flux, and its position with respect to coils "a" and "b" decides their relative impedance ; it also decides the voltage across each, since they are in series across the A.C. supply. In similar positions to coils "a" and "b," and also surrounded by the moving coil, are respectively windings "c" and "d" which, again, are wound in opposite sense to each other and connected in series to the rectifier elements. Clearly if the turns ratio of "c" to "a" were the same as that of "d" to "b" then, as the moving coil "s" traversed the length of the limb, a more or less constant output voltage would be obtained across the two secondary windings in series. By suitable choice of the number of turns on a, b, c, and d, and by making the turns ratio $\frac{c}{a}$ and $\frac{d}{b}$ different, the desired range of output voltage can be obtained. A numerical illustration of the functioning of the regulator is given towards the end of this appendix.

The moving coil is driven through a lead screw by an A.C. disc-type split-phase induction motor. The motor will drive the coil over its complete range in approximately $1\frac{3}{4}$ minutes.

The motor is controlled by an A.C. voltage relay, known as an astatic relay to indicate that its plunger has no tendency to return to any one particular position, this being so because the design gives a

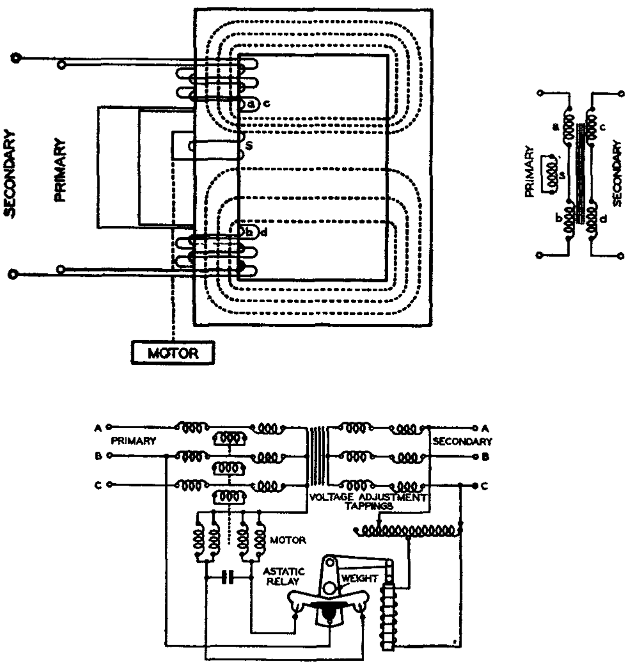

FIG. 26.—FERRANTI MOVING-COIL REGULATOR.

virtually constant magnetic pull over a wide range of movement of the plunger. The weight of the plunger balances the magnetic pull equivalent to normal voltage, so that the armature floats in its guides. The armature controls the position of a three-contact mercury tube in the motor circuit. With changes of voltage the plunger takes up new balanced positions, in which the change of magnetic pull is balanced by the pendulum action of the tube assembly, deviated from its normal position. If the voltage change is as much as the sensitivity setting of the relay, the mercury contact is made and the motor drives in the appropriate direction to compensate for the voltage change. To allow the relay to regulate at any chosen voltage over a given range, that is to enable load changes and battery charging to be catered for, the relay is fed from a tapped auto-transformer connected to the supply to be regulated, and the tap chosen determines the regulated voltage. The relay is affected by frequency changes, such that the regulated voltage varies approximately in direct proportion to the frequency. As stated earlier, a D.C. type of astatic relay has now been perfected.

The first table following shows how, with a constant voltage input to the regulator, and presuming constant load, the output voltage varies with the position of the short-circuited coil, two hypothetical designs being illustrated.

The second table shows how, with an input voltage varying ± 10% from normal, and presuming constant load, the astatic relay causes the moving coil to take up varying positions such that the output voltage from the regulator remains constant. It will be realised that, for simplicity, it is assumed that the voltage transformation ratio is equal to the turns ratio of the coils.

(I) VOLTAGE OUTPUT VARIED BY POSITION OF MOVING COIL, WITH CONSTANT INPUT VOLTAGE.

Moving Coil Position	Primary Voltages			Design No. 1. Turns Ratios $\frac{c}{a}=\frac{1}{5}$ $\frac{d}{b}=\frac{1}{2}$ Secondary Voltages			Design No. 2. Turns Ratios $\frac{c}{a}=1$ $\frac{d}{b}=\frac{1}{2}$ Secondary Voltages		
	Supply	Va	Vb	Vc	Vd	Output	Vc	Vd	Output
1	230	30	200	6	100	106	30	100	130
2	230	50	180	10	90	100	50	90	140
3	230	100	130	20	65	85	100	65	165
4	230	150	80	30	40	70	150	40	190
5	230	200	30	40	15	55	200	15	215

(II) COMPENSATION FOR INPUT VOLTAGE VARIATIONS BY VARYING THE POSITION OF THE MOVING COIL.

Moving Coil Setting	Primary Voltages			Design No. 1. Turns Ratios $\frac{c}{a}=\frac{1}{5}$ $\frac{d}{b}=\frac{1}{2}$ Secondary Voltages		
	Supply	Va	Vb	Vc	Vd	Output
3+	253	138·5	114·5	27·7	57·3	85
3	230	100	130	20	65	85
3–	207	61·5	145·5	12·3	72·7	85

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