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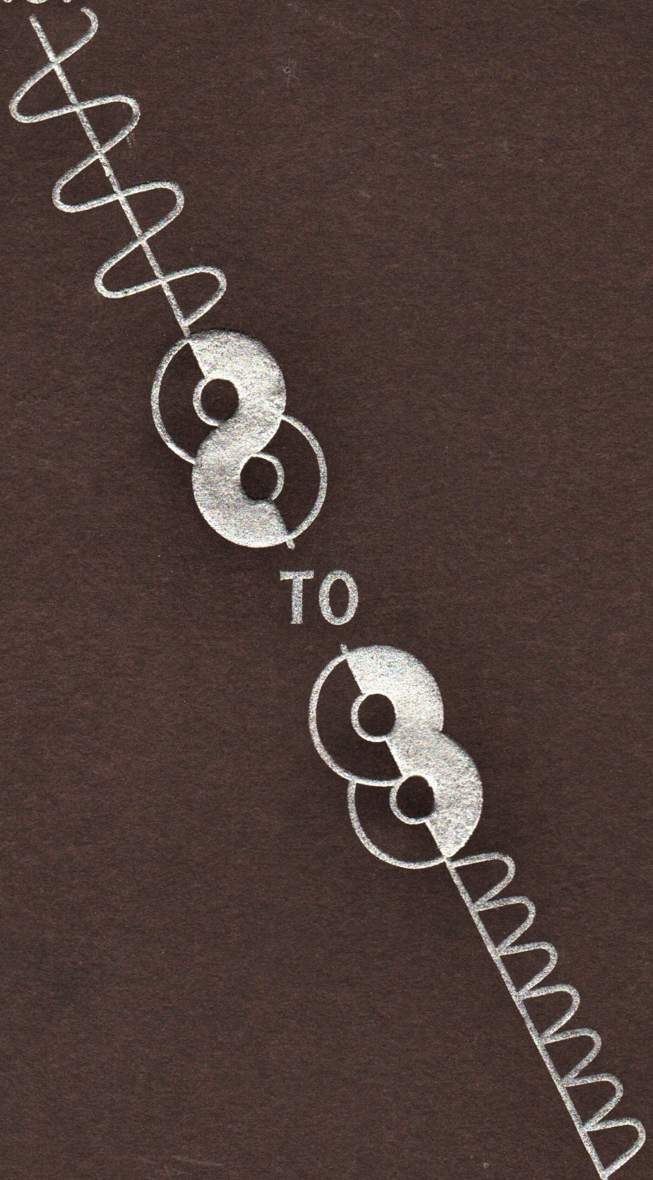

TO

D.C.

BY

WESTINGHOUSE

METAL RECTIFICATION

WESTINGHOUSE BRAKE & SIGNAL CO. LTD.
82, York Way, King's Cross, London, N.1.
Telegraphic Address : Westinghouse, Nordo, London.
Telephone No. : TERminus 6432.

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AC to DC

BY

WESTINGHOUSE

METAL RECTIFICATION

General instructions for the use and application of Westinghouse copper-oxide and Westalite rectifiers.

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1. INTRODUCTION

A reliable and efficient static device for converting alternating current power to direct current had been sought for many years and it was not until this Company introduced the copper-oxide rectifier on a commercial scale in 1927 that the demand was met. During the next few years the production of the Westinghouse copper-oxide rectifier proceeded far beyond the original expectations, with improvements in manufacture and developments in utilisation; the rectifier was manufactured under licence in several countries and equipments were built ranging from extremes of half-a-million volts at a low current to 12,000 amperes at a low voltage.

Selenium rectifiers were being developed in the late 30's, but these tended to suffer from reverse instability. The problem was solved in the Research Laboratories of the Westinghouse Company by the development and introduction in 1939 of their " Westalite " rectifier. This is a selenium-compound type which differs from others in having a better forward characteristic and reverse stability and is produced by more efficient methods. It replaced the copper-oxide rectifier for power conversion purposes, being smaller, cheaper and more efficient. At the same time the copper-oxide rectifier remains unchallenged for instrument applications and for use in higher-frequency circuits.

Research continued, however, and a natural development was the Double-Voltage Westalite rectifier, which has an efficiency of about 90% and has enabled much higher power rectifiers to be built. The actual economic limit is dependent upon a number of factors, and ranges from outputs of about 50 kW at medium voltages to 500 kW at low voltages. A further development is the Quadruple-Voltage Westalite rectifier, specially designed for high-voltage, low-current applications.

A range of Germanium Crystal rectifiers has also been introduced for use in high frequency circuits.

As manufacturers of all these types, and with over 25 years of experience in the development and application of rectifiers, the Company is in a unique position to offer the most suitable rectifier equipment, whether it be a miniature component for telecommunication purposes, or an automatically-controlled power unit for an electroplating process.

This publication describes the various forms of rectifier, the circuits in which they are used, and their main applications. Detailed particulars of the range of rectifier units for incorporation in manufacturer's apparatus, or complete rectifier equipments for such purposes as battery charging, the power supply to large lifting magnets, plating baths, etc., are given in other Publications and Data Sheets issued by the Company, some of which are referred to in this booklet.

Rectifiers are now used by thousands of manufacturers in hundreds of different aspects of the electrical industry, yet new applications are still arising. It is not possible to cover more than the main uses in this booklet. Any enquiry submitted to the Company will have the fullest investigation by engineers who have experience second to none in the application and design of metal rectifiers.

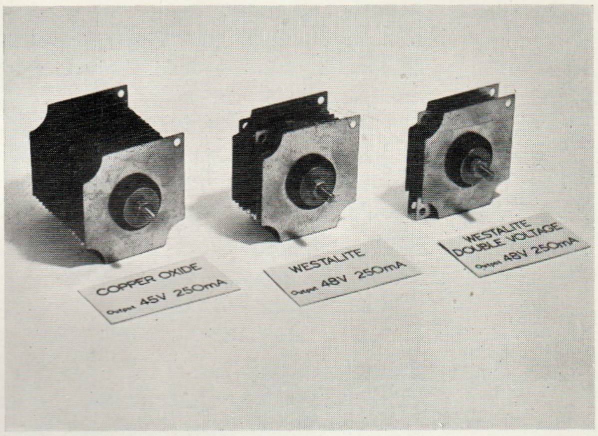


Fig. 1.—Comparison in the size of Copper-oxide, Westalite and Double-Voltage Westalite rectifiers giving the same output.

2. RECTIFICATION

A rectifier is an electrical device which permits current to pass more freely in one direction than in the other. By connecting a number of rectifiers in various ways, as explained later in this book, alternating-current energy may be transformed to direct-current energy, which is suitable for operating apparatus normally requiring a DC source of supply.

The symbol for a rectifier is a half-arrow indicating that current may be assumed to flow readily in the direction of the half-arrow, but with difficulty in the opposite direction. There is a small voltage drop in the " go " or " forward " direction, and there is also a minute current leakage in the " stop " or " reverse " direction. These values depend on a large number of independent variables and make it impossible to express the internal resistance of the rectifier in terms of ohms as it has no constant value.

Further particulars will be found in a paper by A. L. Williams and L. E. Thompson, published in the *Journal of the Institution of Electrical Engineers*, Part I, October, 1941.

2.1. Forward and reverse characteristics

The four types of metal rectifier described in the following pages all exhibit the same shape of voltage-current characteristics described here ; the scale of the voltage and current characteristics differ, but their relative shapes can be seen on Fig. 2.

If the forward current through the " go " direction of a metal rectifier is plotted against voltage, it will be seen that no current flows until the voltage has built up to a certain minimum figure, largely dependent on the type of metal rectifier under test. Above this point the current rapidly increases until the voltage-current characteristics becomes a straight line with a steep slope. This straight line may be continued indefinitely, there is no saturation point as in the case of the thermionic valve, which has, up to this point, a similarly shaped characteristic.

If the rectifier is allowed to heat up and the test is repeated, it will be found that above the point at which current begins to flow, a given applied voltage will produce a higher current. Thus the rectifier has a negative temperature coefficient in the forward direction.

An examination of the reverse characteristic reveals the same trend as the forward characteristic (see Fig. 3).

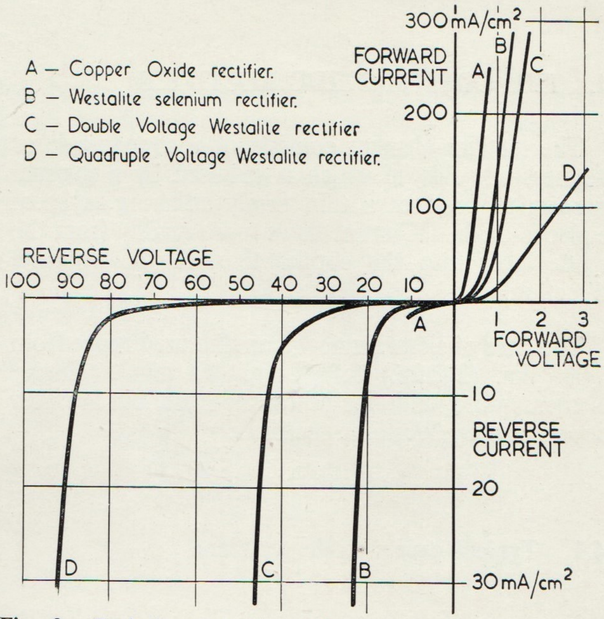


Fig. 2.—Typical comparative voltage-current characteristics of copper-oxide, Westalite and double voltage Westalite rectifiers.

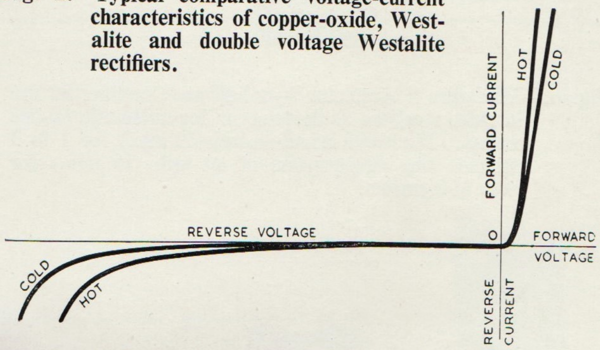


Fig. 3.—Typical voltage-current characteristics of a metal rectifier under cold and hot conditions.

3. GERMANIUM CRYSTAL RECTIFIER

Fig. 4.—Germanium crystal rectifier.

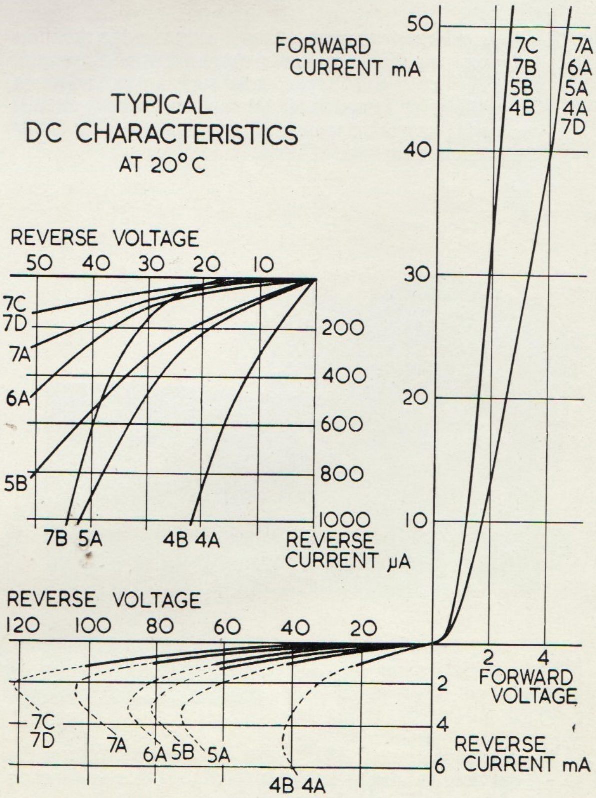


Fig. 5.—Characteristics of Germanium crystal rectifier.

4. THE COPPER-OXIDE RECTIFIER

The rectifier element consists of a copper disc or washer, one side of which is oxidised by a thermal process to produce a thin firmly adhering layer of cuprous oxide. Current flows more readily from the oxide layer into the copper than in the opposite direction.

The sizes of elements now manufactured range from 0·08″ dia. (2 mm.) to $\frac{3}{4}$″ dia. (19 mm.). Larger elements were made for power rectifiers, but are now superseded by Westalite rectifiers.

It is necessary to apply pressure to the oxide surface which is faced with gold to obtain a low contact resistance. A compression spring is included in the assembly of the elements, the disc type being fitted into a tube of insulating material, while the larger washer type is assembled on a spindle over which an insulating sleeve has first been placed. Protection from moisture is obtained, where necessary, by dipping the assembly in paint or by incorporating a hermetic seal in the design of the housing.

Further details are to be found in Data Sheets Nos. 31 and 47 and Publications MR. 3 and MR. 14, Suppt. 3.

4.1. Typical copper-oxide rectifiers

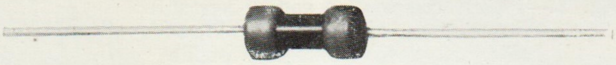


Fig. 6.—Miniature " Westector "—a half-wave rectifier for use in radio receivers as detector or for automatic volume control. The length is half-an-inch (12 mm.) for 1 to 9 elements and threequarters of an inch (19 mm.) for 10 to 15 elements.

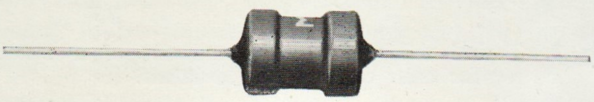


Fig. 7.—A very important application of copper-oxide rectifiers depends on their non-linear characteristic, a group of " KH " or " KG " type units such as these form a modulator or demodulator for carrier telephony circuits allowing several channels of conversation to be transmitted over one pair of lines.

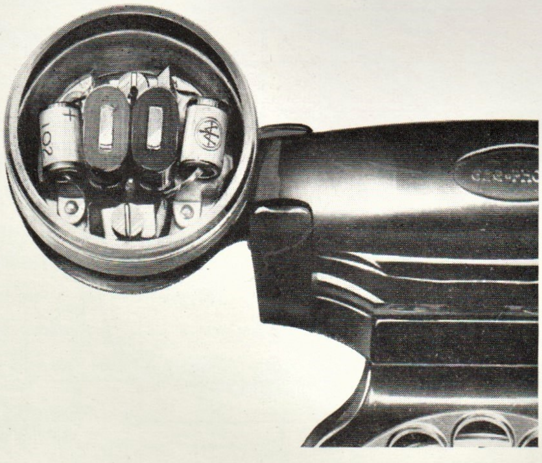


Fig. 8.—These two type " 101 " units are connected across the earpiece to absorb acoustic shock, another application of the non-linear characteristic.

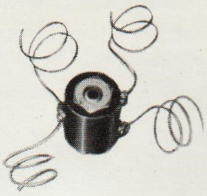


Fig. 9.—Full-wave rectifiers for use in moving-coil instruments to enable AC values to be read. These are rated at 0·25, 1, 5 and 10mA full-scale deflection.

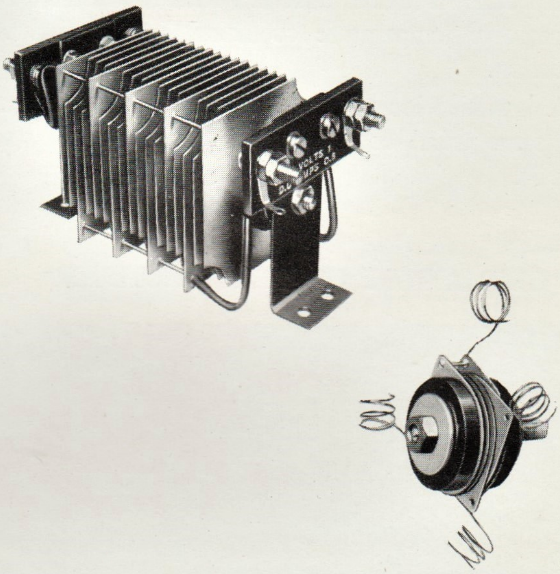


Fig. 10.—These larger rectifiers, type M.9 and M.11, are rated at 100 and 500mA and are generally used in recording instruments or those incorporating a current transformer.

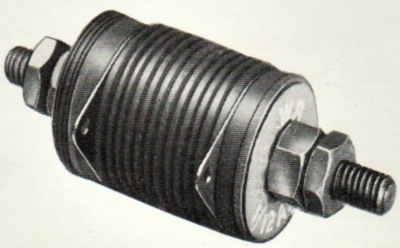


Fig. 11.—Many applications are found in telephone line circuits, such as polarising of relays and suppression of inductive discharge. These units bear codes allocated by the G.P.O., who have some millions in use.

5. THE WESTALITE RECTIFIER

The element consists of a layer of a selenium compound formed on a steel plate which acts as a support; on the selenium is sprayed a thin layer of a special alloy containing tin and cadmium. Current will be found to flow readily from the selenium to the alloy film, but is restricted in the opposite direction.

The elements range in size from discs of about $\frac{1}{4}''$ diameter (6 mm.) to rectangular elements $12'' \times 3''$ (304 mm. $\times$ 76 mm.), with several intermediate sizes which are either circular washers with a central hole, or rectangular or square plates.

Again, pressure is required to minimise the contact resistance and similar forms of construction are employed for both copper-oxide and the smaller Westalite elements. The larger elements are mounted on one or more spindles over which an insulating sleeve has been placed. Cooling fins are added to these power rectifiers to enable their output to be increased. The assembly is then dipped in a heavily-loaded paint for protection, or the unit may be immersed in transformer oil.

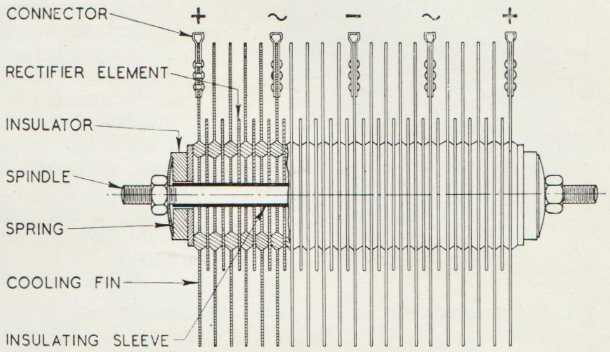


Fig. 12. Sectional view of typical Westalite rectifier unit.

5.1. Typical Westalite rectifiers

Further details are to be found in Data Sheets Nos. 40, 41, 42, 43, 49, 60, 61 and M.R. 14 Suppts. 1, 2 and 4.

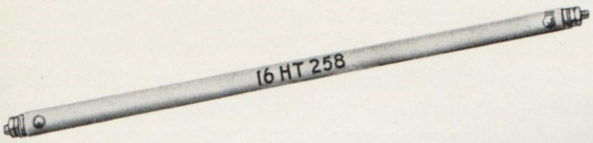


Fig. 13.—These units, assembled with double-voltage elements, are used in DC pressure testing sets for cables and for surge generators. They will withstand a peak inverse voltage of 10,836.

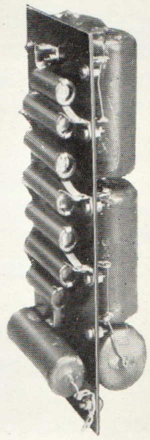


Fig. 14.—Another application is in the "Westeht" power unit for television receivers and any other equipment incorporating a cathode ray tube. This design employs a voltage multiplier circuit and delivers 5,500 volts from a 350–0–350 volt transformer.

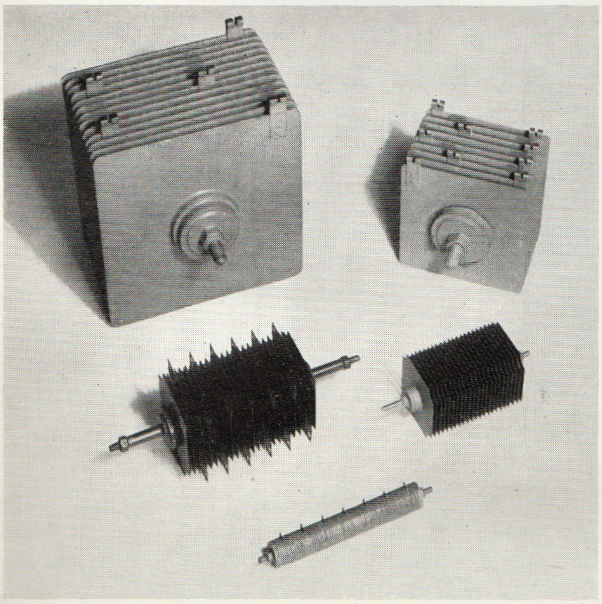


Fig. 15.—This group of rectifier units covers a range of 0·15 to 5 amperes and is used for operating contactors, battery charging and hundreds of other applications.

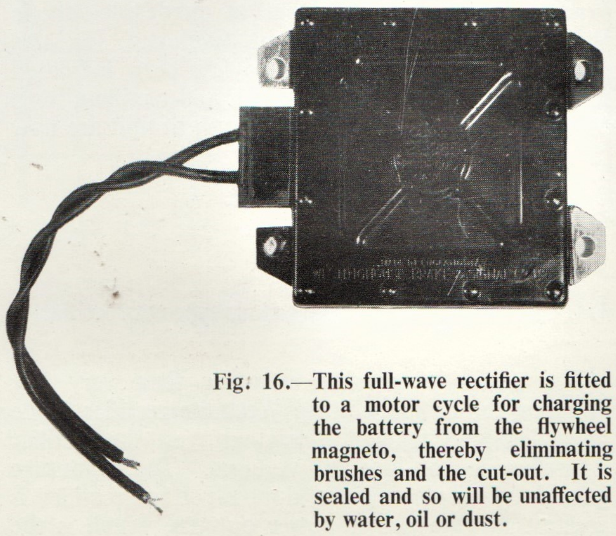


Fig. 16.—This full-wave rectifier is fitted to a motor cycle for charging the battery from the flywheel magneto, thereby eliminating brushes and the cut-out. It is sealed and so will be unaffected by water, oil or dust.

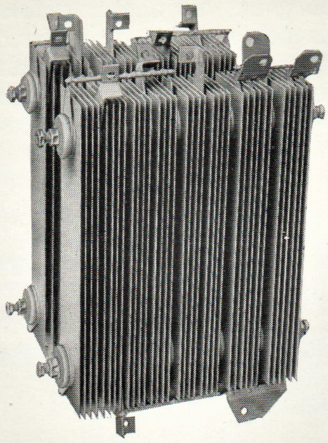


Fig. 17.—The power supply in modern aircraft is obtained from alternators and rectifiers. This arrangement is lighter than the alternative generator and avoids commutation and brush troubles. This assembly delivers 15·8 kW and is blast-cooled, the weight of the rectifier is only 2 lbs. per kW (0·9 Kg per kW).

Latest developments with a more compact assembly give a weight to power ratio of 1·67 lb. per kW with a rectifier efficiency of 82% at full load.

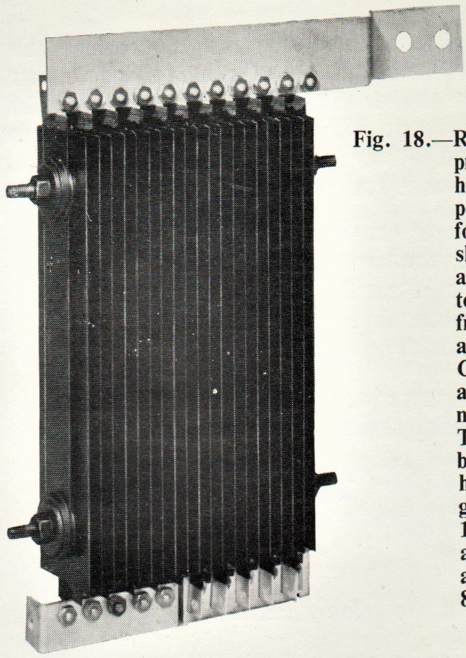


Fig. 18.—Rectifiers for providing the heavy - current power supply for a plating shop are operated under oil to protect them from the shop atmosphere. Cooling fins are thus unnecessary. Three assemblies as shown here will together deliver 1,000 amperes at 7 volts with an efficiency of 85%.

5.2. The double-voltage Westalite rectifier

The elements are identical in appearance to those of the ordinary Westalite rectifier, but the composition of the selenium, the spray for the counter-electrode, and the manufacturing process, are different. The assembly is then dipped in a heavily-loaded paint for protection, or the unit may be immersed in transformer oil.

5.3. The quadruple-voltage Westalite rectifier

The demand for a high-voltage, low-current rectifier for cathode ray tubes has increased enormously with the developments in television. Hitherto valve rectifiers have been used, but the design of a reliable transformer, with the filament winding insulated for working at several thousand volts above earth is expensive. The 36 EHT range of quadruple-voltage Westalite rectifiers has been developed for this purpose; the reverse resistance has been increased so that less elements are required, and rectifiers for a peak voltage of 2,000 per inch length of unit are now in operation.

5.4. Relative merits of the various types of rectifier

For power conversion at other than very low voltages, the double-voltage Westalite rectifier is the most desirable, while the original Westalite rectifier is preferable for low DC voltages. The advantage gained by employing the double-voltage rectifier is greatest for the higher power outputs, which is the first demand on the Company's production capacity. As this is increased, the double-voltage rectifier will gradually supersede the original type for the lower-power applications.

Copper-oxide rectifiers are most suited for use in voice-frequency and higher-frequency circuits where their smaller self-capacitance is advantageous. They are also used with moving-coil measuring instruments where their lower voltage drop introduces a minimum of distortion from a linear scale.

6. PERFORMANCE OF RECTIFIERS

The following information applies to both Copper-Oxide and all types of Westalite rectifiers, except where stated to the contrary. Further information regarding the characteristics of Copper-Oxide rectifiers, as applied to measuring instruments, is given in Publication MR. 3.

6.1. Life

From experience gained during more than 25 years, it appears that the copper-oxide and Westalite rectifiers have a very long life; several of those installed in 1928 and 1929 are known to be still in service without any repairs having been carried out on them. The available experience of the Westalite rectifier in service is limited to twelve years, but this indicates that many more years of life are to be expected.

The initial settling-down period, in which the forward resistance of the rectifier increases slightly, is common to both the copper-oxide and the various types of Westalite rectifier, but the change in resistance is so small that it may be ignored in the case of the Westalite rectifier. While the current output from a copper-oxide rectifier, feeding, say, a magnet load, might drop by up to 6% during the first year or so of use, after which little or no change would occur, the drop in output is only some 2% for a Westalite rectifier, which is generally far less than the change due to the increase in resistance of the magnet windings due to their self-heating. This ageing affect can be compensated by increasing the applied voltage correspondingly and all rectifier equipment built by the Company incorporates means of so doing, where possible, although the drop in output nearly always passes unnoticed, if it occurs at all.

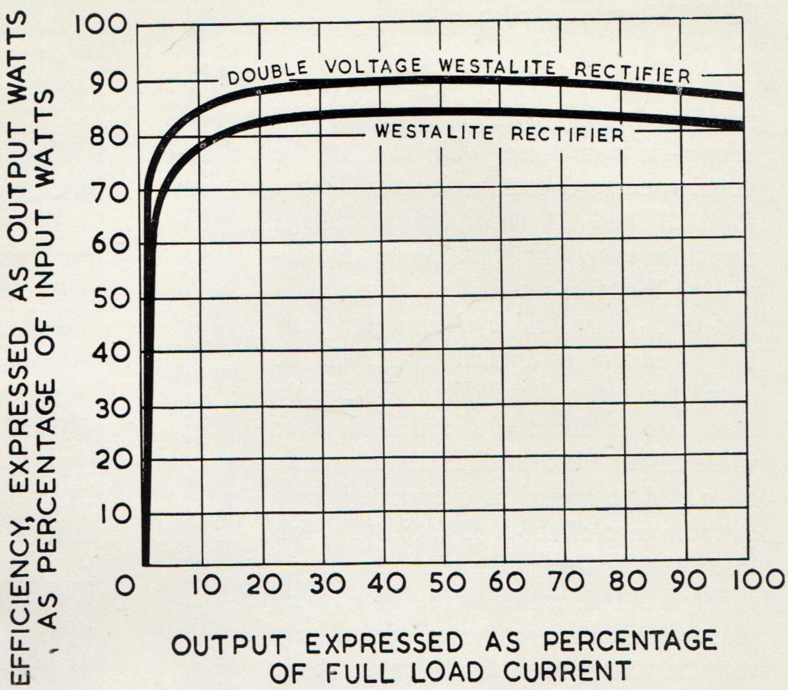


Fig. 19.—Typical efficiency curves of Westalite and double-voltage Westalite rectifiers, operating in single-phase circuits into an inductive load.

6.2. Efficiency

Both copper-oxide and Westalite rectifiers have not only a high efficiency at full load, but what is often more important, the efficiency remains high as the load is decreased. The economy is revealed in the case of plants of larger outputs which may not always be loaded to capacity.

Fig. 19 illustrates the efficiency of a Westalite and a double-voltage Westalite rectifier operating on a single-phase system and feeding a magnet load. These curves are based on each rectifier operating at its full rated load based on temperate climatic conditions. The shape of the efficiency curve should be studied; the efficiency reaches 90% and remains above 80% even down to about 8% full load in the case of the double-voltage design.

Fig. 20 illustrates the same performance curves for a three-phase rectifier. It will be noted that the efficiency is slightly higher, nearly 92%. Such excellent performance may be obtained at DC voltages of 12 or less.

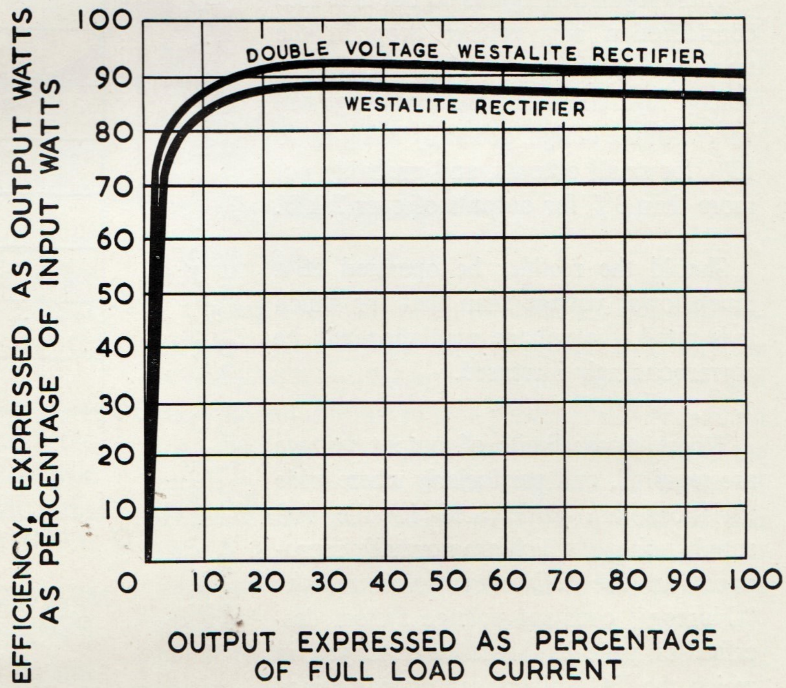


Fig. 20.—Typical efficiency curves of Westalite and double-voltage Westalite rectifiers, operating in three-phase circuits into an inductive load.

6.3. Voltage regulation

The voltage regulation of the Westalite rectifier is an improvement on that of the copper-oxide rectifier, while that of the double-voltage Westalite is even better. Figs. 21 and 22 show typical voltage regulation curves for Westalite and double-voltage Westalite rectifiers, used in single- and three-phase bridge circuits, the load being resistive or inductive. It will be noted that the voltage drops appreciably from zero to about 15% full load, after which the curve becomes linear with a gentle slope. Most apparatus operates within a current range of about 15% to 100% full load; the no-load voltage of the power supply is of little consequence. Thus for all practical purposes we are concerned only with the voltage regulation between about 15% and 100% full load. From the two regulation curves it will be seen that this value is about 7% for the Westalite rectifier, and less than 5% for the double-voltage Westalite rectifier.

These regulation figures do not take into consideration any voltage drop in the transformer, if used; the transformer voltage regulation over this load range will vary with the design, generally being up to 10% for small outputs, and probably not more than 3% for outputs of over 2 kW.

Should the rectifier be operated at a much lower voltage than that for which it is rated, the voltage regulation will be correspondingly increased.

Where closer limits of output voltage are required, and particularly where wide variations are anticipated in the AC supply voltage, which are normally reproduced in the DC output voltage, the "Noregg" constant voltage system described on page 21 should be employed, in which the DC voltage can be maintained within limits of ± 4% of its mean value, allowing for the effects of current variation from zero to full load, and also of variations in the AC supply voltage of ± 6% from the declared value. Under the same conditions the variation in DC voltage from a simple transformer and double-voltage Westalite rectifier would be of the order of ± 15%.

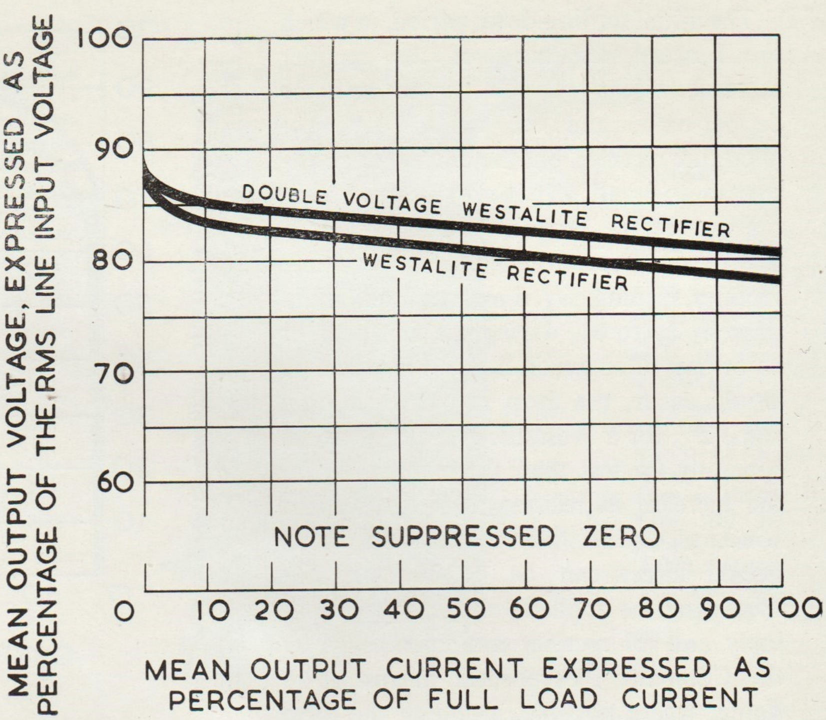


Fig. 21.—Voltage regulation characteristics of single-phase rectifiers with a resistive or inductive load.

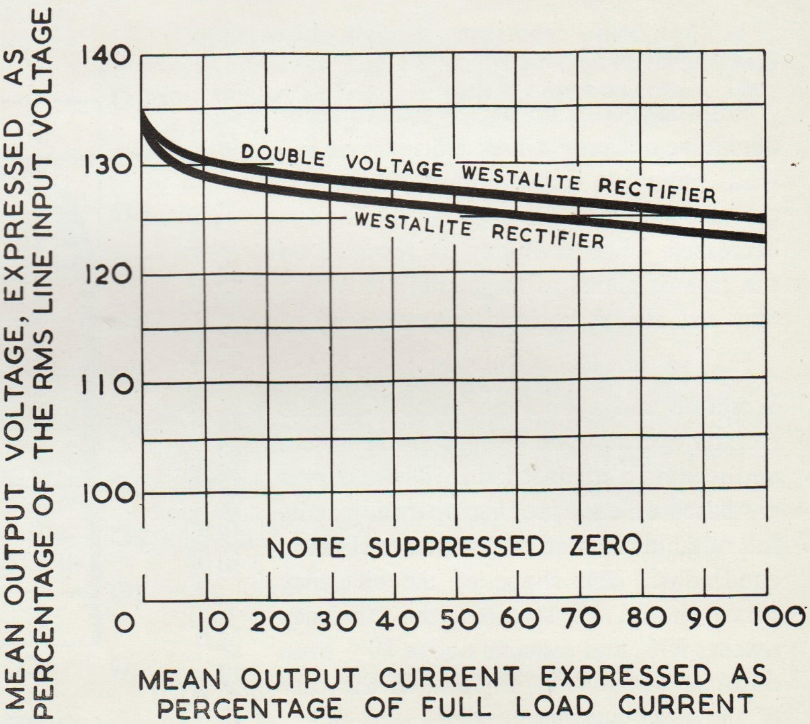


Fig. 22.—Voltage regulation characteristics of three-phase rectifiers with a resistive or inductive load.

6.4. Effect of climatic conditions

6.4.1. *Temperature*

Westalite and double-voltage Westalite rectifiers are usually designed to operate so that the temperature of the elements does not exceed 70° C. (158° F.). Rectifiers for use at 70°C ambient temperature are being developed at the time of going to press. The current rating is determined by the available difference in temperature between the rectifier elements and the surrounding air or other cooling medium, thus, compared with temperate conditions, the available difference in temperature under tropical conditions is less, hence the current rating must be reduced. The maximum ambient temperature at which a Westalite rectifier may usefully be operated continuously is about 55° C. (131° F.) although operation at a slightly higher temperature for a short time may not produce very serious deterioration. Element temperature can be measured only by embedding a thermocouple in the rectifier unit during assembly, tests taken with a thermometer may show a temperature about 5° C. (9° F.) lower than the true element temperature, even when precautions are taken to obtain good contact.

Rectifiers may be rated to operate under the following four conditions:

Temperate—implying an average temperature of the air immediately beneath the rectifier which does not exceed 25° C. (77° F.), with occasional peaks of short duration, not exceeding 35° C. (95° F.).

Sub-tropical—implying an average temperature of the air immediately beneath the rectifier which does not exceed 35° C. (95° F.), with occasional peaks of short duration, not exceeding 45° C. (113°F.).

Tropical—Implying an average temperature of the air immediately beneath the rectifier which does not exceed 45° C. (113° F.), with occasional peaks of short duration, not exceeding 55° C. (131° F.).

Sustained Tropical—applicable when the air temperature may be maintained at 55° C. (131° F.) for prolonged periods, but higher peaks do not occur.

Copper-oxide rectifiers as a rule are used in circuits where there is little self-heating and may be used under all of the above conditions. In some cases it is necessary to reduce the rating.

6.4.2. *Protection against moisture*

Westalite rectifiers may be protected against the effects of moisture by a painting process in which the rectifier unit is dipped in a heavily loaded paint, the process being repeated three times, or more if the operating conditions are severe.

Heavy-current rectifiers are immersed in transformer oil, which provides an efficient means of transferring the heat developed within the rectifier unit to the surrounding air; at the same time the rectifier elements are safely protected against any corrosion.

Air-cooled rectifiers may be used under damp tropical conditions, but are not generally suited to outdoor use; for this purpose oil-immersed rectifiers are employed, the tank being suitably designed so that the terminals are protected against the weather.

Copper-oxide rectifiers now incorporate an improved form of contact which is unaffected by moisture; so effective is this that it is actually possible to operate the rectifier under distilled water, it is not of course suggested that this should be done in practice. Many designs are sealed so that their operation is unaffected by the external conditions.

Most types of rectifier have been granted Type Approval by the Inter Services Radio Components Standardisation Committee and by the Air Registration Board.

6.5. Overload capacity

6.5.1. *Current overload*

Current overloads of up to about ten times normal may be applied without damage provided the duration of overload is insufficient to overheat the rectifier, and the overload is followed by a period of rest or reduced load during which the rectifier may cool. Due to the relatively small mass of the rectifier, the period of overload must be a matter of seconds, while the rest period must be several minutes. The rectifier is unaffected by these overloads and is thus admirably suited for closing solenoid-operated switchgear, dynamic braking of AC motors, repeated starting of DC motors, etc.

An estimation of the voltage drop in the rectifier under overload conditions may be obtained by extending the voltage regulation curves, Figs. 20 and 21. In practice, due to voltage drop in any transformer feeding the rectifier, and, in the cable runs, it is not economical to exceed about ten times full load, or the DC output wattage will fall off with increasing current. Rectifiers used in DC circuits may be loaded beyond this point provided the rectifier is not overheated.

6.5.2. *Voltage overloads*

An examination of the reverse voltage-current characteristic in Fig. 2, page 5 shows the sharp bend in the curve. At voltages below this bend the reverse current is negligible, but above the bend the reverse current increases very rapidly. The characteristic is so stable that it is safe to operate the rectifier near the limit, but no appreciable increase in the reverse voltage is permissible.

Thus, while all rectifiers are rated to withstand a temporary rise of 6% in the applied AC voltage to allow for mains fluctuations, any further voltage overload is liable to cause damage.

The voltage regulation of the transformer feeding a rectifier should be taken into consideration in the selection of the rectifier if it is possible for the DC load to be disconnected, as the rectifier must be capable of withstanding the full open-circuit voltage. The same conditions apply to a low-voltage rectifier which is permanently connected to a load, the mains voltage being broken down by means of a resistor. Should the DC load be inadvertently disconnected, the rectifier will be subjected to the full mains voltage and may be destroyed. Further, if the load is highly inductive, there will be an instant before current is established in the load and the full mains voltage will be impressed on the rectifier and this must be allowed for.

6.6. Voltage surges and peaky reverse wave-forms

The normal voltage and current ratings of rectifiers assume that the rectifier derives its power supply from a low impedance source, so that the AC current wave-form, as influenced by the nature of the load and the rectifier circuit employed, will not be affected by any impedance in the AC supply. If there is appreciable impedance in the AC supply, severe voltage stresses may be developed across the rectifier which may result in its destruction. The choice of a different rectifier, and modifications to the circuit, generally result in a satisfactory and reliable design. The manufacturers will be pleased to make recommendations on receipt of details, in any such cases which embrace rectifiers connected to current transformers, or in series with the output of small alternators, or choke-ballasted rectifiers supplying choke input filter.

Surges, such as those generated when transformers are switched on the line, or when inductances are switched out of circuit, or by nearby lightning strokes, may often be absorbed by means of a Westalite rectifier specially designed for the purpose. The sharp bend in the reverse characteristic is utilised, the current rising at about the twelfth power of the applied voltage.

It should be noted that the surge produced by switching off an inductive DC load does not damage the rectifier. If the switch is on the DC side of the rectifier, the surge voltage occurs across the switch and is not applied to the rectifier. If, on the other hand, the switch is on the AC side of the rectifier, the rectifier provides a low-resistance path for the inductive energy in the load, and this effectively limits the surge voltage.

Copper-oxide rectifiers are less affected by surges as their reverse characteristic has a higher initial slope and the bend is less pronounced.

6.7. Choice of single- or three-phase rectifiers

A single-phase bridge-connected rectifier is the most economical for low outputs, while for high outputs a three-phase circuit is preferable as it is cheaper and also enables the loading of the AC supply to be balanced. The economic line of demarcation between single- and three-phase is around 1 to 2 kW output, but is influenced by the standard frame sizes available, whether any tapping switches are associated with the transformer, the cost being higher for switching three-phase lines, and whether a smoothed output is necessary, which is simpler if a three-phase unit is used.

7. ECONOMIC RANGE OF OUTPUT

Which form of conversion equipment is best for any project depends not only on the first cost and running costs, which take into account efficiency and maintenance, but such other problems as reliability, ease of control, floor-space available, etc. Thus, while it can be stated that one or other form of converter is the best to employ for certain outputs and conditions, it is difficult to draw the line as to when some other converter is preferable.

There are three other methods of converting AC to DC which constitute practicable alternatives to the Metal Rectifier within the limits of its application, each having its advantages and its drawbacks. The thermionic valve, largely used in radio apparatus for the HT supply, has a limited life, is fragile and requires a power supply to heat the filament, which is often at a high voltage to earth. Hence the filament transformer introduces further problems in insulation above those involved in the centre-tapped winding commonly used with a full-wave rectifier valve.

Against these criticisms must be weighed the advantages of low initial cost and small space.

The glass-bulb mercury-arc rectifier has some of the disadvantages associated with the thermionic valve, but is used for higher power outputs. Its efficiency is lower than that of the rectifier at voltages below about 150. By means of grid control the output from the mercury-arc rectifier may be readily controlled.

The motor generator does not seriously compete with the Westinghouse metal rectifier since, in addition to appreciably lower efficiency, the generator has the disadvantages associated with rotating machinery, such as the need for periodical brush replacements, occasional attention to commutator and bearings, while there are restrictions as to where the machine may be installed.

The Westinghouse metal rectifier is unchallenged for heavy-current outputs at low voltages. There is no economic limit of output at voltages of up to 50 volts; a 16,000 ampere 7 volt rectifier is in service, while the total current output of all the low voltage Westinghouse rectifiers built in this country alone exceeds six million amperes. A Westalite rectifier has been built for an output of 16,000 amperes at 33 volts. This is an exceptional application, but illustrates what can be achieved.

For voltages above 50 the Westalite rectifier is usually economical for outputs of up to 50 kW, although circumstances may justify a much larger output, as, for instance, 3,000 amperes at 120 volts for which a rectifier has been constructed. Higher power outputs may be justified if the power supply is required for electro-static precipitation processes where reliability and ability to stand up to continuous service for months on end are essential.

8. RECTIFIER CIRCUITS AND THE EFFECTS OF DIFFERING LOADS

This section is written for Engineers who purchase rectifier units for incorporation in apparatus of which the rectifier is a component; it is of lesser interest to those who purchase a complete rectifier equipment such as a battery charger, or transformer-rectifier set for magnet or motor operation, although the section devoted to the effects of differing loads is of importance regarding the method of measurement of current and voltage. Further detailed information for the purchaser of Westalite rectifier units is available in data sheets Nos. 40 and 41, while publication MR. 3 details the performance of copper-oxide rectifiers for measuring-instrument use, and data sheet No. 47 and publication MR. 14, Suppl. 3, gives details of Westectors for use in high-frequency circuits. Additional information, where necessary, is provided in correspondence.

8.1. Method of measurement of DC voltage and current

There is an essential difference between the output of any type of rectifier and that of a battery or DC generator, in that while the voltage and current supplied by the latter are steady, the rectifier provides a pulsating output, which, however, is uni-directional. The effect of these pulsations is not noticeable as regards the operation of the equipment, except in a telephone or radio communication power plant, where a background noise may be produced unless a smoothing circuit is added to reduce the level of the pulsations below the response of the human ear. Misunderstanding may result from measurements of voltage and current taken by differing types of instrument, which justifies a brief explanation. Moving-coil instruments should always be chosen for measurements of rectified AC voltage and current ; moving-iron and dynamometer instruments should not be used. All AC measurements should be made with moving-iron or dynamometer instruments ; rectifier ammeters are liable to introduce errors in a few circuits where the current wave form is distorted.

8.2. Fundamental rectifier circuits

8.2.1. *Assuming a non-inductive resistance load*

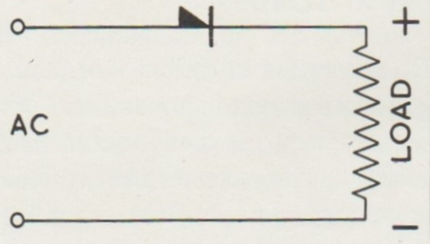
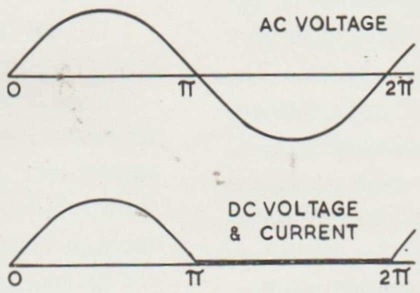
<table>
<tr><th>Circuit</th><th>Waveforms</th><th>Applications</th></tr>
<tr><td>Half-wave.


Fig. 23</td><td>
</td><td>Not used with a non-inductive load.

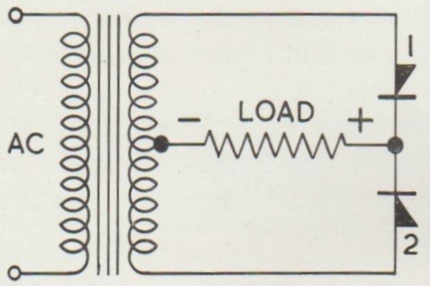
Used extensively with an inductive load, the magnet driving a vibrating screen tuned to the frequency of the half-wave impulses.</td></tr>
<tr><td>Centre-tap.


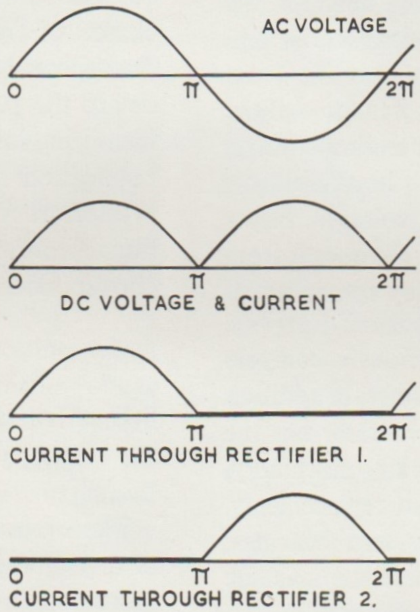
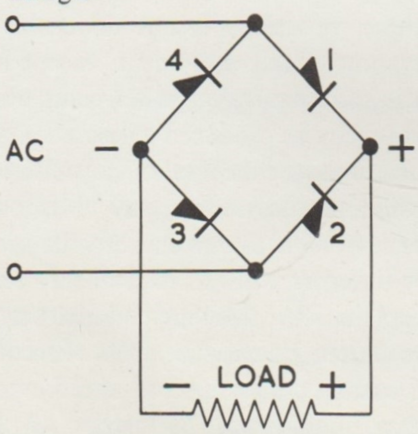
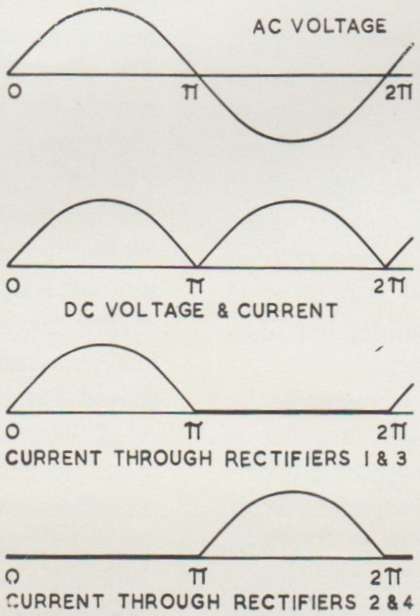
Fig. 24</td><td>
</td><td>Used with valve rectifiers where the two anodes and single cathode are accommodated in one envelope. Rarely used with Westalite Rectifiers, and only where low regulation and high efficiency are required at very low DC voltage. Transformer essential. Transformer design is uneconomical, each winding is in use only half the time, while insulation for twice the voltage of each half-winding is necessary.</td></tr>
<tr><td>Bridge.


Fig. 25</td><td>
</td><td>The standard circuit for Copper-Oxide and Westalite Rectifiers. Impracticable with valve rectifiers as 3 or 4 valves and several transformer windings required.

Transformer unnecessary except for voltage adjustment. Rectifier efficiency and regulation as that of centre-tap without the disadvantages imposed by the centre-tap transformer design.</td></tr>
</table>

Circuit | **Waveforms** | **Applications**

Three-phase half-wave.

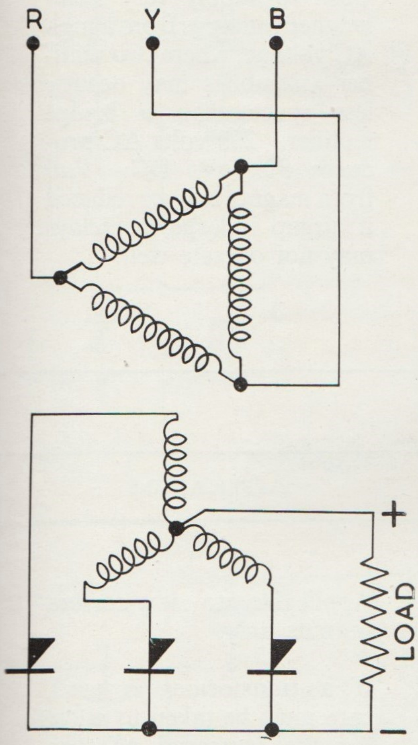
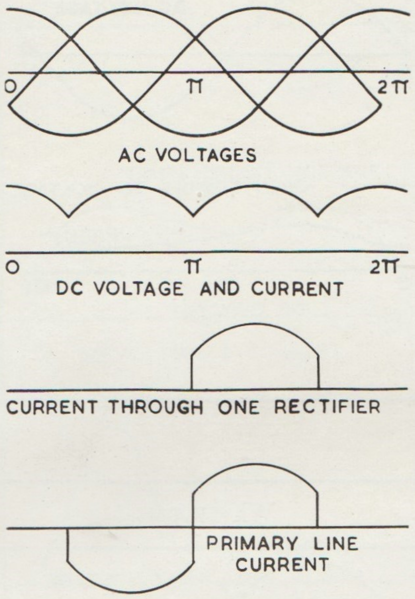


Fig. 26



Extensively used for low-voltage Westalite rectifiers for plating, also valve and mercury-arc rectifiers for higher voltages. At voltages of half or less of the voltage obtained from a single element assembly in a three-phase bridge circuit, the efficiency and regulation are improved, but the transformer design is complicated and the utilisation factor of the windings is low.

A star-interconnected star transformer connection is preferable to avoid DC flux in the core.

Three-phase bridge.

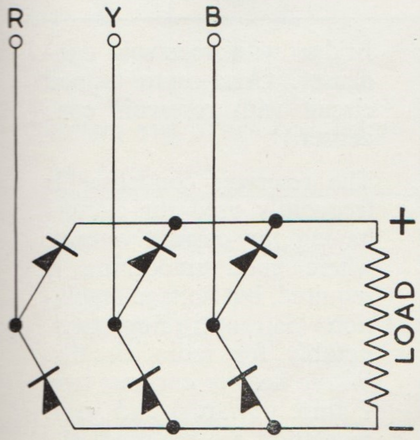
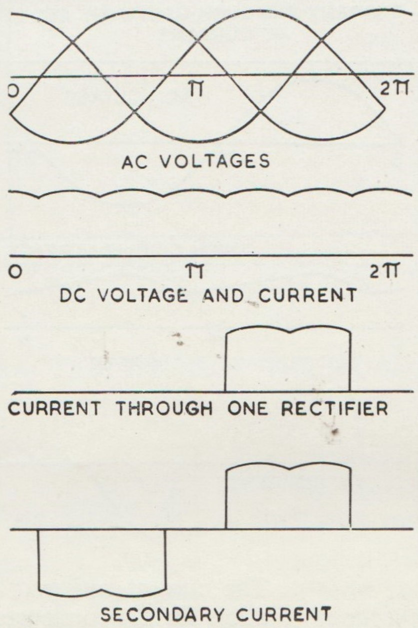
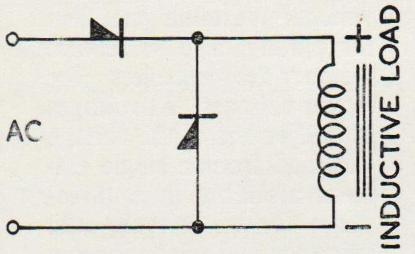
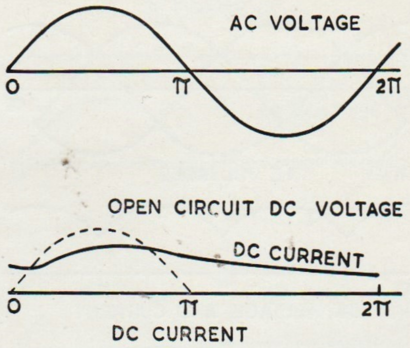


Fig. 27

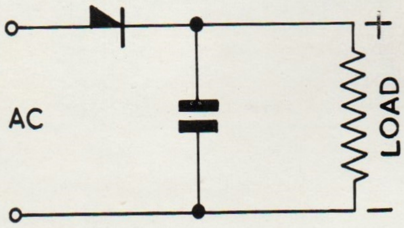
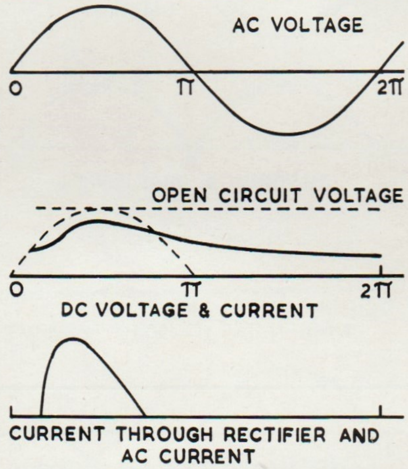
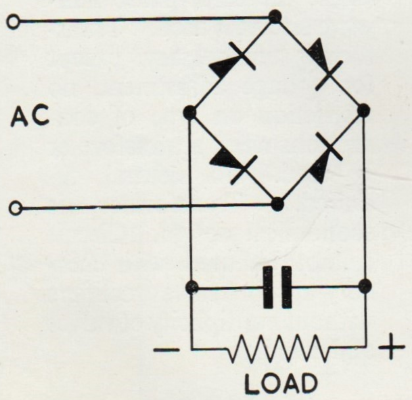
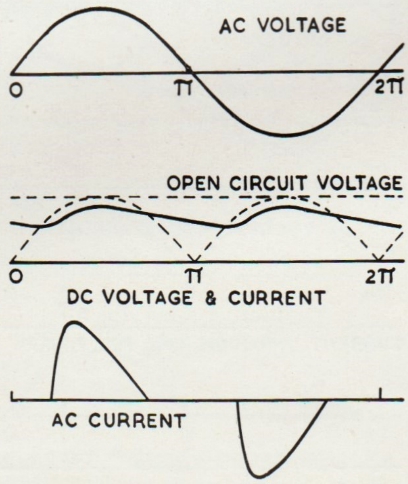


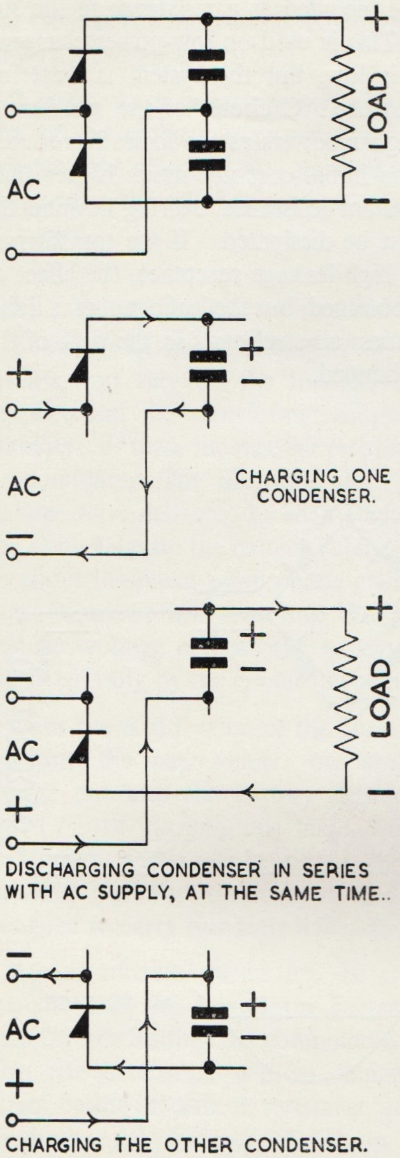
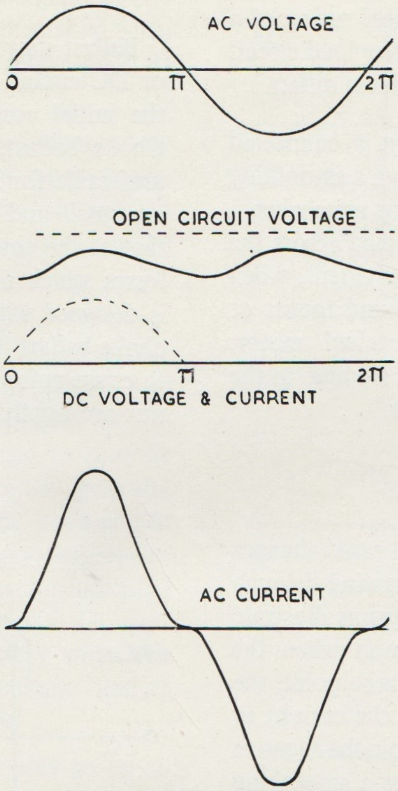
Employed in all high-power Westalite rectifiers, except for very low voltage outputs, where the three-phase half-wave circuit is used. Transformer unnecessary, except for voltage adjustment, no restriction on type of connections when a transformer is used. No neutral required. Transformer is economical design. Circuit cannot be used with mercury-arc or valve rectifiers without multiplicity of valves and windings.

8.2.2. *Circuit applicable only to highly inductive loads*

Circuit	Waveforms	Applications
Series shunt or current doubler.  **Fig. 28**		Used to supply very small magnet windings from a high AC voltage, where two rectifier assemblies may occupy less space than a bridge rectifier. 230 volts AC produces 80 volts DC. Pull from magnet may be reduced if airgap is large, so relays may not operate well.

8.2.3. *Circuits involving condensers*

Circuit	Waveforms	Applications
Half-wave with reservoir condenser.  **Fig. 29**		Applicable to low-current outputs only. If a transformer is used, care must be taken to allow for the increased effective voltage regulation caused by the peaky current waveform.
Bridge with reservoir condenser.  **Fig. 30**		Bridge with reservoir condenser. (Also centre-tapped circuit with reservoir condenser.) The reservoir condenser is frequently used for circuits having low-current output, where good smoothing is required, but voltage regulation is not important, notably for radio circuits. Where heavier currents (say 1 amp. upwards) and good regulation are required, the choke input filter is preferable.* The current rating of the rectifier must be reduced to allow for the condenser charging current. * Also used for DC injection in vibrating-screen circuits.

Circuit	Waveforms	Applications
Voltage-doubler.  Fig. 31.		Commonly used for low currents at high voltages where the steep voltage regulation, caused by the impedance of the series capacitor, is no disadvantage. The limited short-circuit current is sometimes an advantage. The circuit operates by charging one condenser, which is discharged in series with the AC supply, during the following half-cycle, when the other condenser is charged for the subsequent half-cycle.

9. THE EFFECT OF THE CHARACTERISTICS OF THE LOAD ON THE RECTIFIER

9.1. Performance

The single- and three-phase bridge circuits are employed for the majority of power rectifiers. The single-phase full-wave circuit produces a voltage waveform which results in widely varying current wave forms for different types of load; the three-phase circuit with its smoother output is not appreciably affected by differing loads.

The characteristics of the load fall into one of the following categories:—

Inductive load, which includes magnet windings and series motors and circuits incorporating a choke input filter. This type of load does not allow for rapid changes in the instantaneous value of DC current.

Non-inductive resistive load is rare; it is approached in electro-plating, but even then there is a small back EMF from the bath which in practice can generally be ignored. The electrical rating of a rectifier for an inductive or a resistive load circuit is the same, only the current waveform differs.

Battery load, in which the rectifier is connected direct to the battery and not through a smoothing choke. The same general problems arise when a large reservoir condenser is connected across the rectifier terminals, and, to a lesser extent, when the rectifier is feeding a shunt-wound motor or the armature of a separately excited motor. This type of load allows for rapid changes in the instantaneous value of DC current.

9.2. Inductive load

The effect of inductive load is to resist rapid changes in the instantaneous value of current passing through the windings. The accompanying diagrams illustrate how the current continues to flow even when the applied voltage is passing through the zero point, the energy stored in the inductance causes the current to continue flowing through the rectifier from the negative to its positive terminal. This produces a smoothing effect on the current and hence the flux it produces, (in practice the ripple component is reduced to about 10% of the mean value of current). This circuit must not be employed without precautions if there is appreciable impedance in the AC circuit (such as may occur if the power is derived from a small alternator, or a current transformer, or there may be a choke in the AC feed to the rectifier). The AC circuit must be of low impedance, and this applies to a lesser extent to a three-phase rectifier.

9.3. Battery load

The charging current is determined by the excess of voltage of the rectifier or other source of supply over that of the battery, and is restricted by the impedance of the circuit. The rectifier voltage reflects the small changes in value of the AC supply mains, and, while these changes may be small, they may be large compared with the excess voltage to force current through the internal resistance of the battery, and so they will produce large changes in the charging current. A rise in mains voltage of 2% could easily result in doubling the charging current. Additional impedance is added to the circuit to reduce the effect of mains voltage variations on the charging current; this is known as BALLAST. As a general rule, the impedance is increased to the extent that a 6% rise in mains voltage results in an increase in the charging current of not more than 25%.

Ballast may be included as a resistance in the AC or DC circuit. This is used on low-power chargers; the initial cost is low, but the system is wasteful. Choke ballast, in the AC circuit of the rectifier, is preferable for higher powers as the losses introduced are small and the initial cost not much higher than that of the equivalent resistance, bearing in mind the losses which must be dissipated. If the transformer is designed with high leakage reactance, the effect of choke ballast is obtained, but the leakage flux is liable to cause noise unless all steel parts in the path of the flux are tightly clamped.

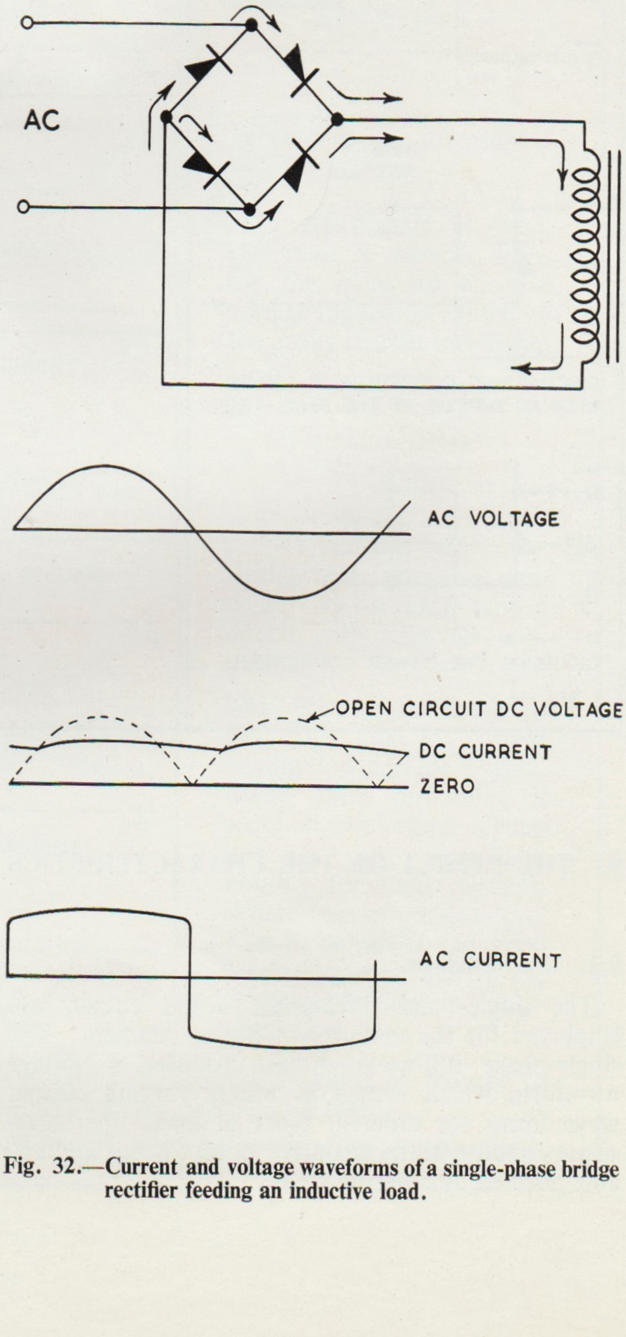


Fig. 32.—Current and voltage waveforms of a single-phase bridge rectifier feeding an inductive load.

The ballast impedance also reduces the effect of changes in the forward resistance of the rectifier with temperature and with age. With inadequate ballast the charging current will increase appreciably when the rectifier has warmed up, due to the reduction in its internal resistance.

The degree of ballasting may also be influenced by the battery maker's requirements of a taper-charge, whereby the charging rate must not exceed a certain value when the cells begin to gas or the plates may be damaged.

9.3.1. *Battery charging without ballast.*

Some cheap battery chargers do not include any ballast, but rely on the forward resistance of the rectifier and the transformer impedance to provide stability; of these the rectifier resistance will generally predominate. The diagrams show the open-circuit voltage wave delivered by such a battery charger; on the same diagram the battery voltage level is indicated as about the mean value of the open-circuit DC voltage. Current will flow into the battery when the rectifier voltage exceeds the battery voltage, and is restricted only by the circuit impedance.

Thus the RMS value of the current may be up to 1·8 times the mean value : but since the amount of charge put into the battery depends on the mean value of the current, this large ratio is undesirable, resulting in additional heating of the battery and the necessity for the transformer and rectifier to be designed to carry this high RMS current.

As the rectifier warms up, the charging rate will increase and the wave-form becomes more peaky, thus further heating the components and the battery. This rise in current will be compensated to some extent by the increase in resistance of the transformer windings. An increase of 6% in the AC supply voltage, as may occur during the night when the mains are lightly loaded, may more than double the charging rate and this overload has often destroyed an unballasted battery charger.

All battery chargers made by the Company include adequate ballast.

9.3.2. *Battery charging with resistive ballast*

The problems arising in the battery charger without ballast may be overcome by adding additional resistance. As already explained, this may be unnecessary with low-power chargers, as sufficient resistance may be included in the transformer winding without overheating. The resistance may be in the primary or secondary circuit, or on the DC side of the rectifier.

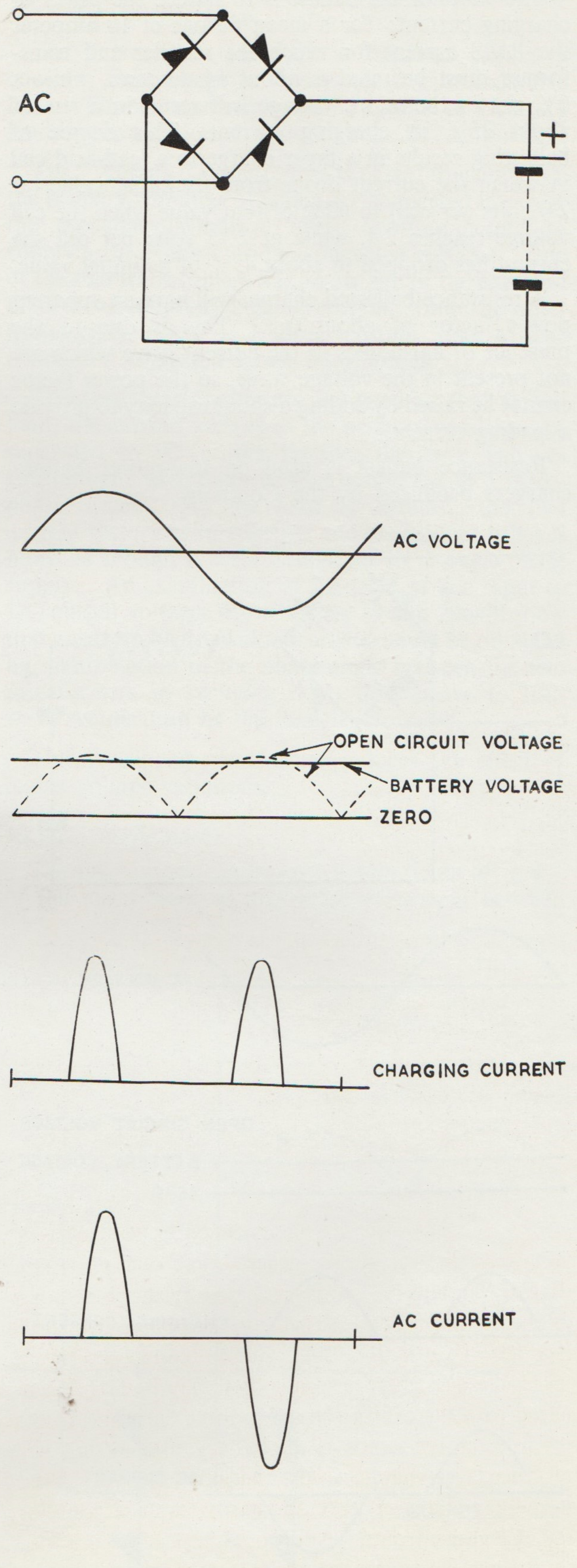


Fig. 33.—Current and voltage waveforms of a single-phase bridge-connected rectifier supplying a battery load without ballast.

The effect of the ballast is to reduce the peaks of charging current; for a mean output of 10 amperes the RMS current for which the rectifier and transformer must be rated is about 14 amperes, while a 6% rise in the mains voltage will result in a rise of about 25% in charging current. This degree of ballasting results in a taper charge to a lead-acid cell in which the current drops from its initial value (at 2·0 volts per cell) to 60% of that value when the cell voltage reaches 2·4, while at 2·75 volts per cell the current has dropped to about 45% of its initial value.

A resistance-ballasted charger will have an apparent power factor of about 0·8. This is due to the presence of harmonics in the current wave which are not present in the voltage wave, so the power factor cannot be raised by adding a shunt capacity to provide a leading current.

Resistance ballast is used on low-power battery chargers produced by the Company.

9.3.3. *Battery charging with choke ballast*

This principle is used on battery chargers with an output of 1 kW or more. It has the advantage over resistive ballast of eliminating the loss in the ballast resistor, while the peaks of charging current are reduced, so, for a mean output current of 10 amperes, the rectifier and transformer need be rated to carry only 12 amperes RMS. This degree of ballasting gives the same stability against mains fluctuations, and the same taper rate, as obtained by resistive ballast and described in that paragraph. The AC current wave is nearly sinusoidal.

Choke-ballasted chargers have a power factor of about 0·75, lagging. This can be raised to about 0·9 by adding a shunt condenser, but, as the current wave is not quite sinusoidal, the power factor cannot be corrected beyond this figure.

Choke ballast is employed on all the larger battery chargers made by the Company.

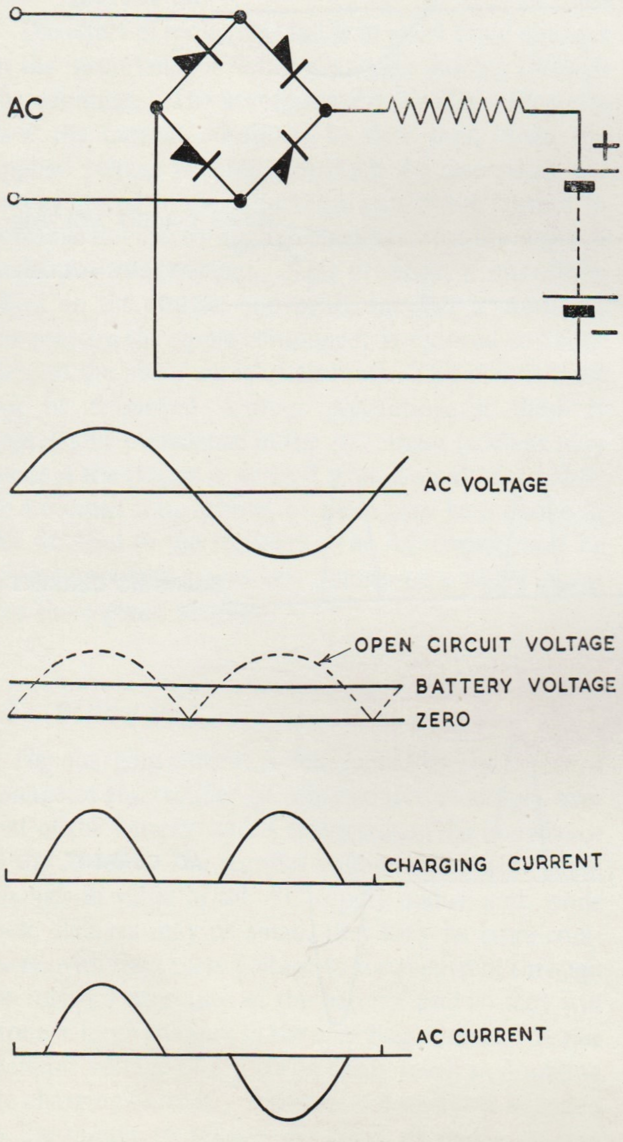


Fig. 34.—Current and voltage waveforms of a single-phase bridge-connected rectifier supplying a battery load with resistive ballast.

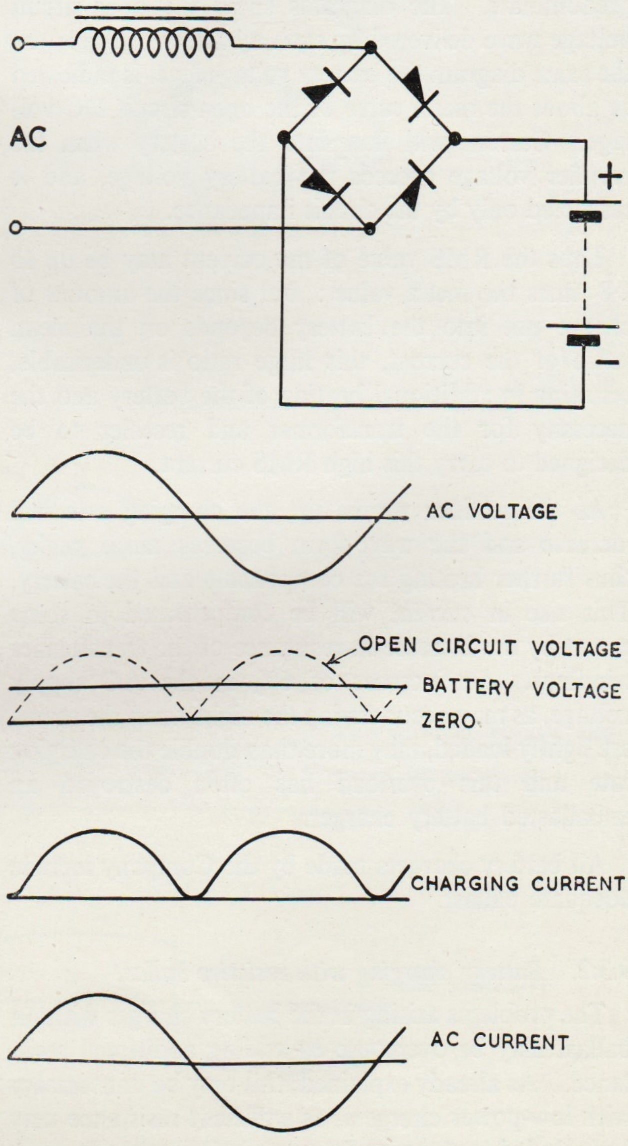


Fig. 35.—Current and voltage waveforms of a single-phase bridge-connected rectifier supplying a battery load with choke ballast.

10. CONSTANT VOLTAGE SYSTEMS

Closer limits of voltage may be required than are obtained from a rectifier and its associated transformer, particularly for the operation of telephone equipment direct, or whenever a floating battery system is used and the load current fluctuates. It may be necessary to hold the DC voltage within limits of ± 4%, or even less, of its average value, while there may be variations in the AC supply voltage of ±6% in addition to varying load and the effect on the output voltage to be compensated.

A new transductor system called the "Transbooster" is under development which will provide very close control of voltage with no moving parts and be more efficient in the use of materials than the orthodox transductor.

Two basic schemes have been developed to meet these needs. The first is a static device consisting of special transformers, a condenser and a rectifier, which has been given the trade names " Noregg " and " Westat," and is applicable to outputs up to about 4 kW; the other scheme includes a voltage relay connected across the DC terminals of the rectifier, the operation of the relay causing a motor-driven voltage regulator to operate and so adjust the voltage. The degree of accuracy with which the voltage may be held constant depends on the limits of operation of the relay and the associated voltage regulator. There is no upper limit to the output which can be regulated in this manner; below about 4 kW the Westat is usually cheaper, while above 4 kW the voltage relay principle is the cheaper.

10.1. The " Noregg " constant voltage rectifier system for resistive loads

The " Noregg " principle is used to obtain a constant DC voltage to feed a resistive or inductive load. The same principle can be applied to a battery load by the addition of a choke in the DC output line.

The " Noregg " system consists of two transformers, the primary windings of which are connected in series, the secondary windings being Scott-connected to supply a three-phase bridge-connected rectifier. One of the two transformers has an air gap in the core and takes a substantially lagging current, while the other transformer takes a leading current due to the condenser connected across its windings.

The two transformers are designed so that at full load, the current vectors in the primary windings are separated by 90%; the rectifier therefore behaves substantially as though it were connected to a three-phase system. As the load is reduced, the two current vectors swing together and the rectifier behaves more as though it were connected to a single-phase supply. An examination of the ratio of line input to DC output voltages from Figures 19 and 20 will show that a reasonably level characteristic could be obtained by manipulation of the phase angle between the two transformers in swinging from three-phase to full-wave rectification as the load is decreased.

The air-gapped transformer reduces the effect of mains voltage variations.

10.1.1. *Performance*

The DC voltage can be kept within limits of ± 4% of the mean value at any value of current between

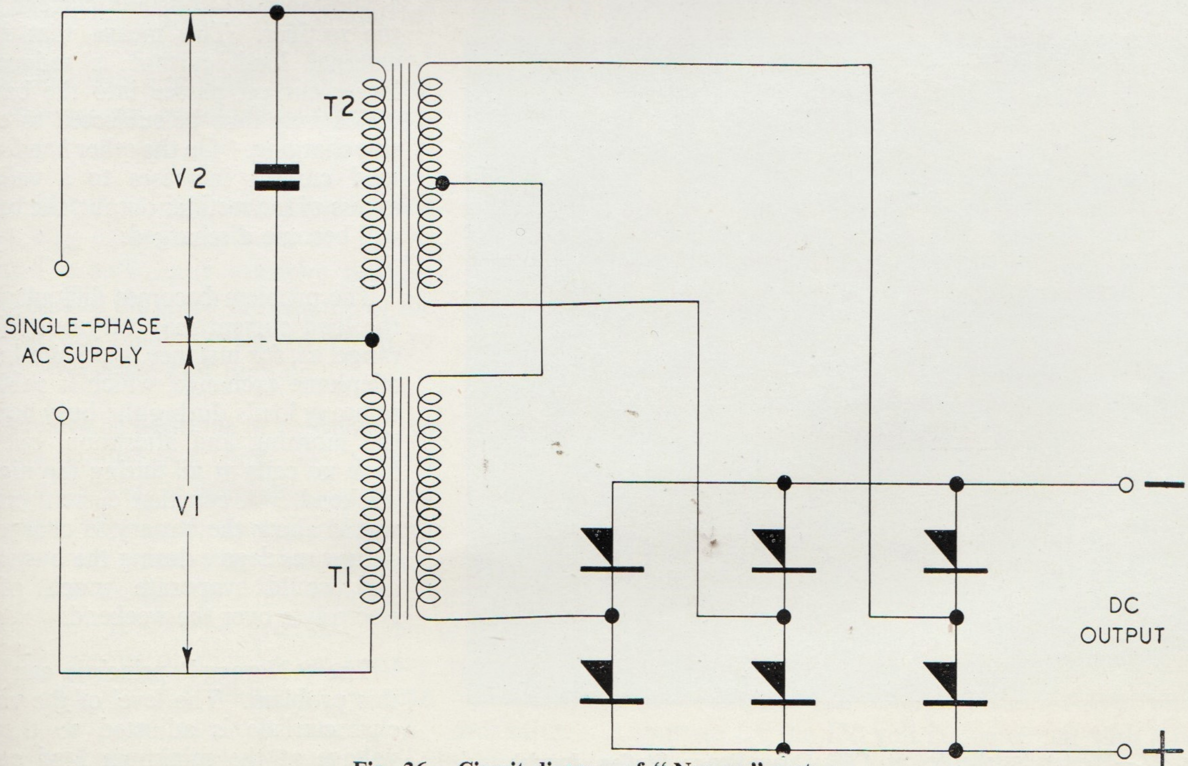


Fig. 36.—Circuit diagram of " Noregg " system.

zero and full-load, with simultaneous variations in the AC supply voltage of $\pm 6\%$. If either the load current, or the AC supply voltage, is not varied, the DC voltage will be maintained within much closer limits.

While it is usual to adjust the equipment to a level voltage characteristic, the voltage can be made to rise with increasing current, thus providing an over-compensating effect to allow for the voltage drop in any smoothing chokes. A falling characteristic can be obtained if desired.

The ripple component is considerably less than that of a single-phase rectifier, thus the additional filter circuit to provide a very smoothed output is less elaborate.

There is no appreciable time lag in the operation of the Noregg system, which corrects the output voltage within a few cycles. A range of these sets with outputs from 40 to 600 watts, and thereafter multiples of 600 watts, is available, for any DC voltage of 6 or higher.

10.2 The " Westat " constant voltage rectifier system for battery loads

Batteries are generally employed as stand-by power supplies so that the operation of equipment may not be effected by short interruptions in the AC power supply. The batteries must be maintained in a fully-charged condition to ensure that the stand-by supply is available in an emergency. If the load current is constant, it may be balanced by connecting the battery in parallel with a rectifier having a high degree of ballast, so that fluctuations in the AC supply voltage have little effect on the rectifier output current.

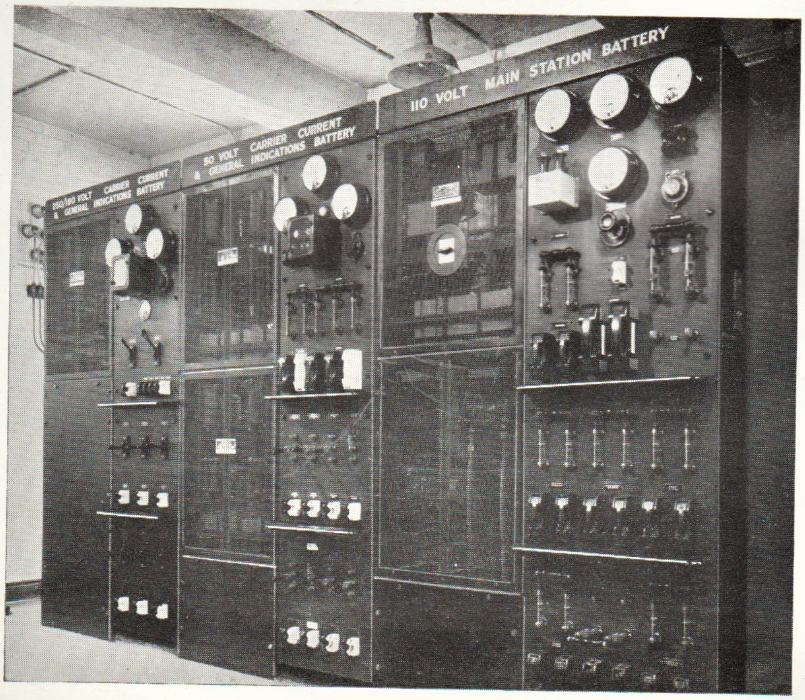


Fig. 37.—Westat installation at Cliff Quay Power Station, Ipswich.

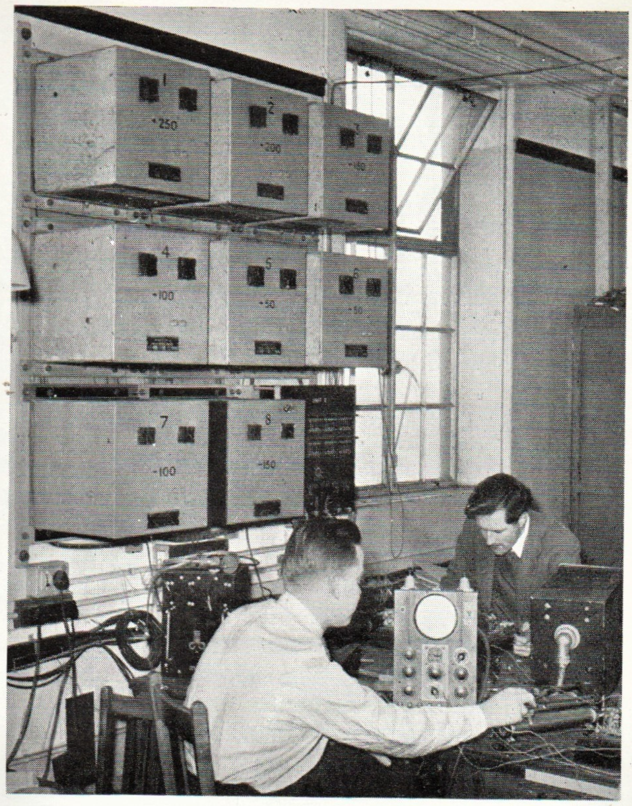


Fig. 38.—Installation of Westats at the G.P.O. Research Station at Dollis Hill.

Variations in the load current, if small in comparison with the battery capacity, may be tolerated for short durations. The heavy ballasting results in a substantially constant current from the rectifier. This means that if the external load current is reduced, a larger current passes into the battery, which may thus be subjected to excessive charging. On the other hand, if the load current increases to a value in excess of the rectifier output, the battery will become discharged.

The problem becomes difficult where the load current may vary over a wide range, as, for instance, a private branch telephone exchange, which is subjected to heavy loads during the busy hours of the morning and afternoon, but may have no calls at all during the night or weekend. A constant current charger would allow the battery to charge to a dangerous degree during the busy hours and would evaporate much of the electrolyte over the weekend.

The " Noregg " principle can solve this problem. The level of the voltage characteristic is adjusted so that the voltage at the minimum load current corresponds to 2·35 volts per cell for a lead-acid battery, the voltage at the full-load capacity of the rectifier being 2·15 volts per cell. The "Westat," as this automatically-controlled battery charger is called, is selected so that its maximum continuous current rating is about 50% more than the maximum load current to allow spare capacity for recharging the battery after a supply interruption, at the same time meeting the demands of the load. The battery will normally float at a voltage between 2·20 and 2·35, depending on the load current; it will remain in a fully charged condition and as the evaporation loss will be very small, topping up need rarely be done.

Thus, the battery will float without any adjustment or attention and will be unaffected by variations in the load current or of the AC supply voltage. If the AC supply should fail, the battery may be assumed to be fully charged and in a healthy condition for the discharge. When the supply is restored, the Westat will meet its normal load demand and recharge the battery, automatically reducing the charging current until the battery is fully charged and a steady condition prevails.

10.3. Voltage-relay controlled systems

The "Westat" system cannot economically be extended to outputs much over 4 kW at which point the rectifier voltage is best controlled by a reliable voltage relay which operates the drive circuit for some form of voltage regulator, such as a transformer with a multiplicity of tappings or a moving-coil or induction-type regulator.

The output voltage may be controlled within very close limits such as ± 1%, provided a sufficiently sensitive relay is employed and the speed of response of the motor-driven regulator slowed down to prevent over-drive and hunting.

It may not be desirable or convenient to build the rectifier as a single set. Several sets, each complete in themselves, including their own regulators, transformers and rectifier, may need to be operated either individually or in parallel with other similar sets. It may be necessary then to provide automatic means of sharing the current evenly to prevent any one set taking more than its share of the load and possibly causing its protective gear to operate and trip it out, when the average load of the sets in parallel approaches full load. Current balance can be effected to within limits of ± 5% of the mean value, irrespective of whether there are two or more rectifier sets on load. As an example, rectifier equipment has just been completed to provide a total load of 16,000 amperes at a nominal 25 volts, there being four 4,000 ampere rectifiers which may be used either for floating the load, at a maximum of 16,000 amperes, or charging the stand-by battery at 8,000 amperes. Unless some means of current balance were instituted, it would not be possible to obtain 16,000 amperes from four rectifiers, as the one having the highest level of voltage would take more than its share of the load, which would cause it to trip out on overload, whereafter the remaining three sets would follow in quick succession.

Very close control of voltage and current is required when rectifiers are used to supply the filament and anode power for amplifier valves for long-distance telephony. Several such installations have been made, the largest being for the terminal of most of the long-distance calls converging on London, requiring 12,000 amperes for the 24 volt filament circuit with a further 4,000 amperes for charging the battery, and 960 amperes for the 130 volt anode circuit with a further 320 amperes for charging the battery.

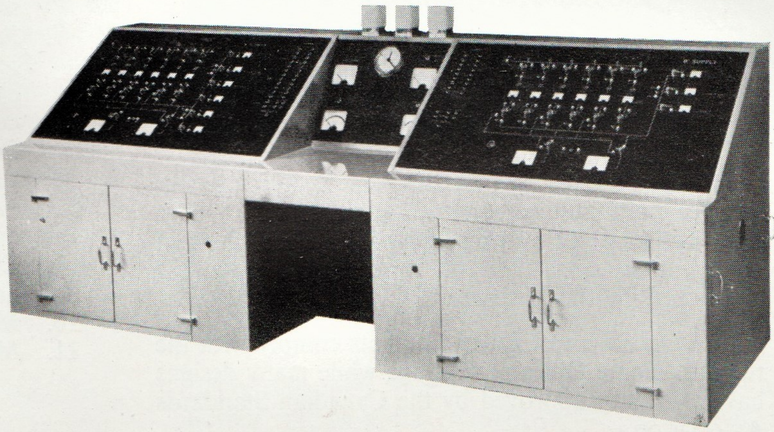


Fig. 39.—Control desk for six 4,000 ampere and six 320 ampere rectifiers for telephone amplifier valves.

(Courtesy of G.P.O.).

10.4. Automatically-controlled rectifiers

The Company have always been interested in the construction of automatically controlled rectifiers. The most important field of application for automatically controlled rectifiers is in electro-deposition and allied processes.

Automatic control is employed on rectifiers for chromic-acid anodising of aluminium components, a process requiring very accurate control in which the rectifier voltage is raised against a strict time cycle and a check made that the film on the aluminium which the current produces has no weak areas. The current and voltage are recorded on a chart so that a permanent record exists of the process.

Automatic control of current into a large plating bath based on area of work to be plated can be obtained by means of a Westinghouse Constant Current Density Controller, several of which are in operation.

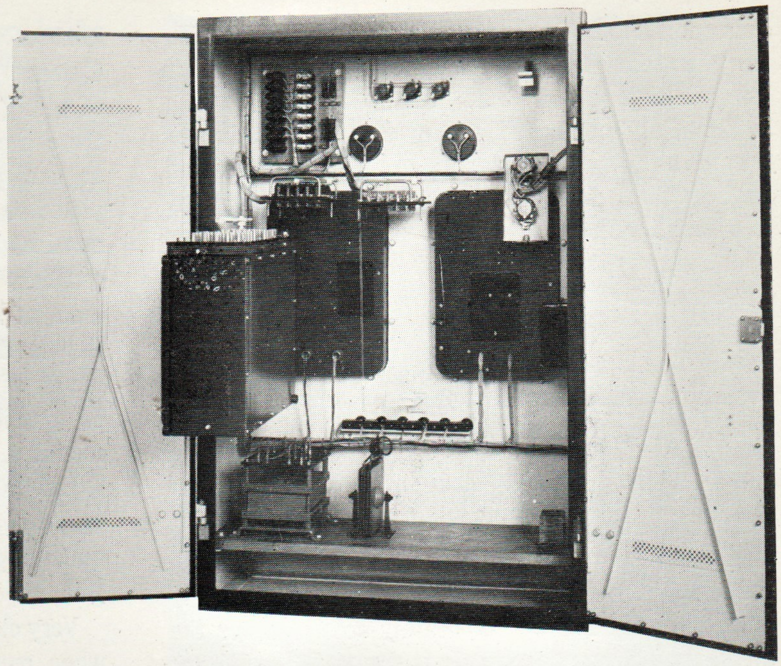


Fig. 40.—Automatic control unit for chromic-acid anodising process for a 60 volt 1,500 ampere rectifier.
(by courtesy of Rolls-Royce Ltd.)

11. APPLICATIONS OF METAL RECTIFIERS

Rectifiers are used in such a wide variety of apparatus that a classification of their applications can only be achieved under the various types of load; individual applications covered by each type of load are listed in the appropriate section.

The dimensions, performance and specification of rectifier units and complete equipments which have been designed for various applications are given in other publications of the Company, which are mentioned in this Section.

Westinghouse rectifier equipments comply with the relevant Home Office regulations while many designs have also been approved by the Canadian Standards Association.

11.1. Classification of applications

1. Energisation of magnets, ranging from miniature pattern relays to large solenoid-operated circuit breakers requiring up to 50 kW.
2. Motor applications, including running of DC motors for variable speed drive, DC/AC changeover, starter motors and dynamic braking of AC motors.
3. Electro-deposition, including electroplating, anodising and power supply to electrolytic cells.
4. Battery charging.
5. Extra high-voltage applications—such as electrostatic precipitation, DC pressure testing, supply for surge generators.
6. Electric arcs, including projector arc power supply for cinemas, and spectrographic analysis.
7. Radio power supply for transmitters and receivers. Rectifiers for use in high-frequency circuits as detectors and for automatic volume control. Cathode ray tube supplies. Radio frequency heating.
8. Surge absorber applications, for DC and AC circuits, including protection of instruments and safety system for series-lighting circuits.
9. DC stopper applications, such as polarising of neutral relays and reverse current cut-outs.
10. Moving-coil measuring instruments.
11. Modulators for carrier transmission.

11.2. Energisation of magnets

Applications :

Adjustment of trip value of circuit breakers and operating value of acceleration relays.
Brake magnets.
Carbon-pile regulators for controlling AC circuits.
Contactors.
Magnetic chucks.
Magnetic clutches.
Field excitation for alternators.
Ignition coil power supply for engine test.
Lift control gear, including brake magnet.
Lifting magnets.
Relays.
Magnetic separators.
Solenoid-operated circuit breakers.
Vibrating screens.

Other publications :

D.S.23. Specification and dimensions of complete rectifier equipments, with or without transformer.

DS.50. Specification of oil-immersed rectifier equipments for industrial power supply.

D.S.40. Details of rectifier units for inclusion in control gear maker's panel.

11.2.1. *Features of magnetic applications*

While the closing coils of many contactors operate on alternating current, the coil and armature of a DC-operated contactor have the advantages of being smaller and generally cheaper, the contactor is quieter and there is less risk of coil failures due to the lower voltage per turn and the coil current being affected by the air-gap. Rectifier-operated DC contactors are standardised throughout the lift control industry for these reasons.

11.2.2. *Relays* are generally operated by individual rectifiers. Where a group is operated, such as for an electro-pneumatic organ, the voltage change with load and with varying AC mains voltage may be troublesome. This is overcome by using the Noregg constant-voltage system described on page 21.

11.2.3. *Contactor coils* should be wound for the voltage delivered by the rectifier when connected to the AC supply without any transformer. A single-phase rectifier is satisfactory, when the coils should be designed to operate at a voltage of approximately 75% of the AC line voltage. Three-phase rectification is usually unnecessary and results in a DC voltage of about 125% of the AC line voltage, so that a step-down transformer would be required to reduce the voltage to a value more suited to the contactor coil.

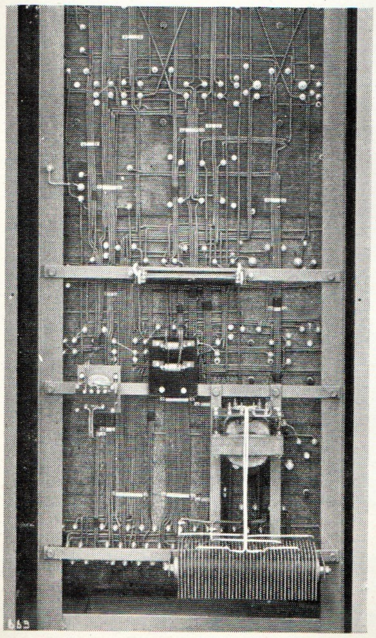


Fig. 41.—Rear view of a 4 H.P. 4 floor lift control panel showing rectifiers for operation of brake magnet and control contactors (by courtesy of Dewhurst & Partner, Ltd.).

The output current from a single-phase rectifier is sufficiently smoothed. The rectifier can be designed to carry the heavier momentary current for closing contactors fitted with economy resistances.

11.2.4. *Solenoid-operated circuit breakers,* with latched-in mechanism, may require up to 50 kW or so, during the closing operation. Rectifiers for this duty are usually rated for 10 or 20 seconds consecutive duty during a 20-minute period, which allows a generous margin of safety over normal operating and test conditions. At this rating the rectifier may be loaded to about ten times its continuous current rating and can be economically designed so that it need not be switched off the AC line during the rest periods.

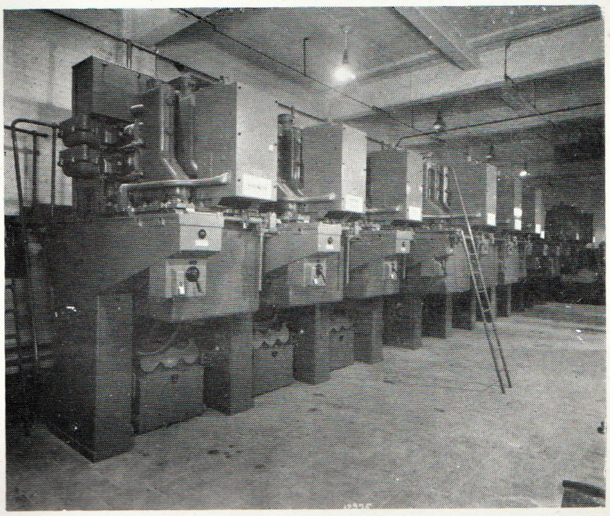


Fig. 42.—These 11kV 750mVA circuit breakers are closed by Westalite rectifier equipment.

(by courtesy of A. Reyrolle & Co. Ltd.).

The solenoids should be wound for the natural output voltage of the rectifier, or the rectifier may be designed to deliver a specific voltage such as 110 or 230. This generally necessitates the use of a transformer and so increases the cost.

Full particulars of these rectifier equipments, or rectifier units, are available to manufacturers and users on request.

11.2.5. *Magnetic chucks, clutches and pulleys* are generally designed for a DC voltage of 110. A double-wound transformer is commonly included in the rectifier equipment to isolate the DC circuit from the AC mains. The equipment may be air-cooled and can be fixed on the wall at any height as no attention is required. If the atmosphere is moist due to splashing of coolant, an oil-immersed rectifier may be preferable in which all the electrical componen s are protected.

11.2.6. *Magnetic separators*, for removing tramp iron from material prior to crushing, are commonly designed for 230 volts DC and are operated by a rectifier equipment which includes a double-wound transformer, thereby providing isolation from the AC supply. As these rectifiers often operate under dusty conditions, oil-immersed equipments are sometimes desirable, but air-cooled rectifiers can sometimes be located under better conditions nearby.

11.2.7. *Lifting magnets* may necessitate the rectifier equipment being placed out of doors, possibly on the travelling crane as this arrangement eliminates the need for an extra pair of trolley wires. Weatherproof oil-immersed rectifiers are available for this purpose, designed for crane rating; outputs of up to 25 kW at 230 volts have been constructed. It is possible to take some advantage of the reduction in current as the coil heats up.

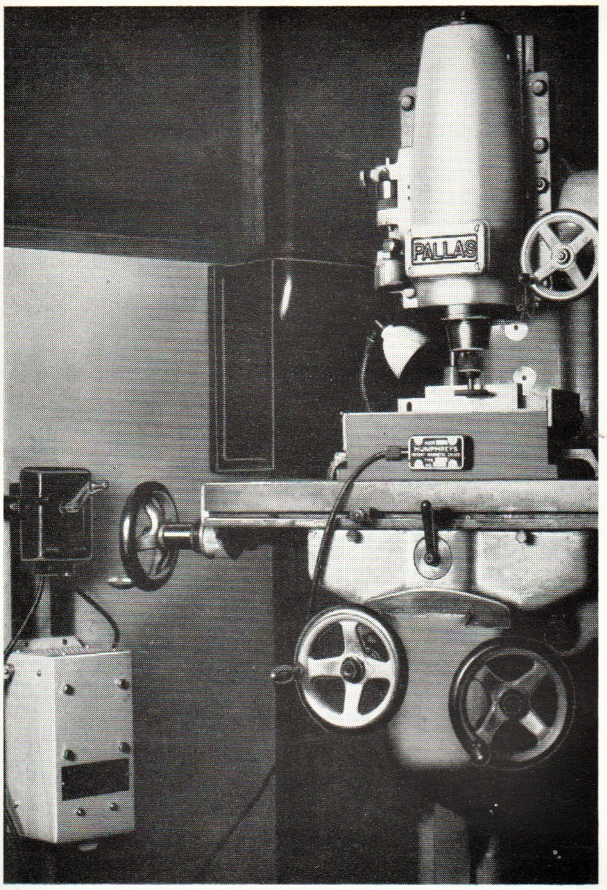


Fig. 43.—Magnetic chuck operated by an air-cooled Westalite rectifier.

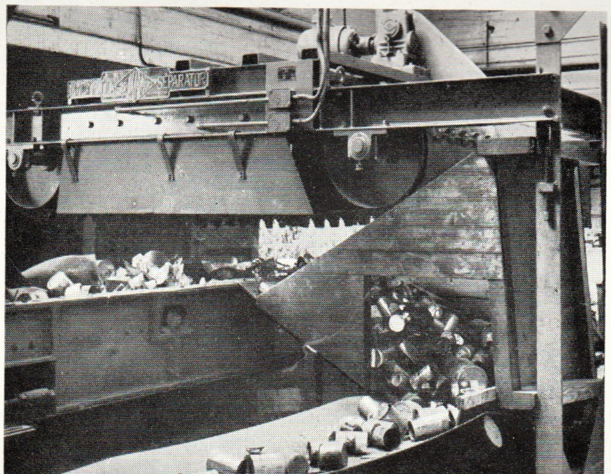


Fig. 44.—Magnetic Overband Separators operated by Westalite rectifiers.

(by courtesy of Electromagnets Ltd.).

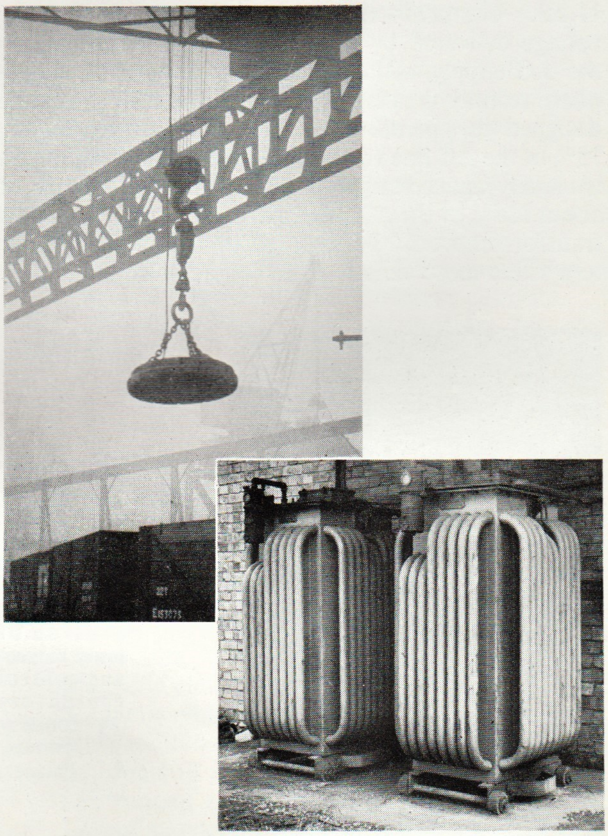


Fig. 45.—Two 25kW outdoor type Westalite rectifiers operating lifting magnets.

(by courtesy of George Cohen Sons & Co. Ltd.).

11.2.8. *Field excitation* by means of a rectifier in place of the customary exciter, saves floor-space and maintenance. The transformer and rectifier are mounted in a suitable case which may include the field rheostat and ammeter.

Self-excitation is possible in this manner, and, with certain precautions, the field may be energised by the output current of the machine, either direct or by means of a current transformer. Such designs should always be referred to the Company's engineers.

The output of the rectifier is sufficently smooth for all purposes, except perhaps motor alternators having a common field when the AC output wave may be influenced by the field ripple current. A choke and possibly a condenser in the rectifier output circuit would avoid this difficulty.

11.2.9. *Carbon pile regulators* are commonly used to control AC circuits when a rectifier is employed to convert to DC for the regulator magnet. The choice of the rectifier is influenced by the circuit in which the regulator is used and designs should be referred to the Company's engineers.

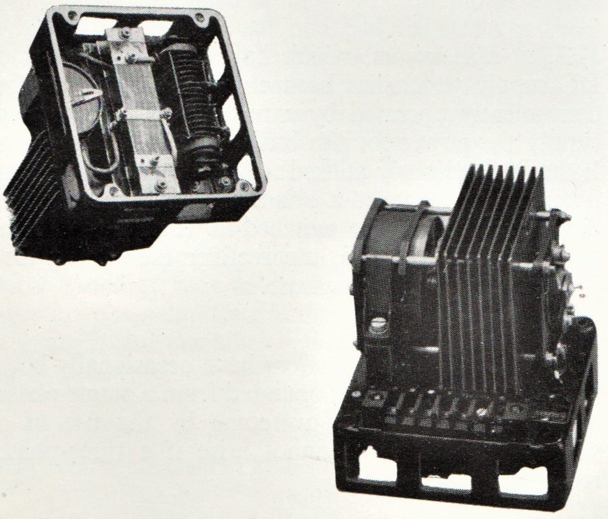


Fig. 46.—Carbon Pile Regulator.
(by courtesy of Newton Bros. (Derby) Ltd.).

11.2.10. *Circuit breaker overload adjustment* often requires a heavy DC current at about 2 volts to allow for lead drop. A short-time rated rectifier with a suitable regulator for current adjustment is ideal for this purpose and may also be used for measurements of the voltage drop and the temperature rise of the contacts. Another similar use is the adjustment of the acceleration relays for electric trains.

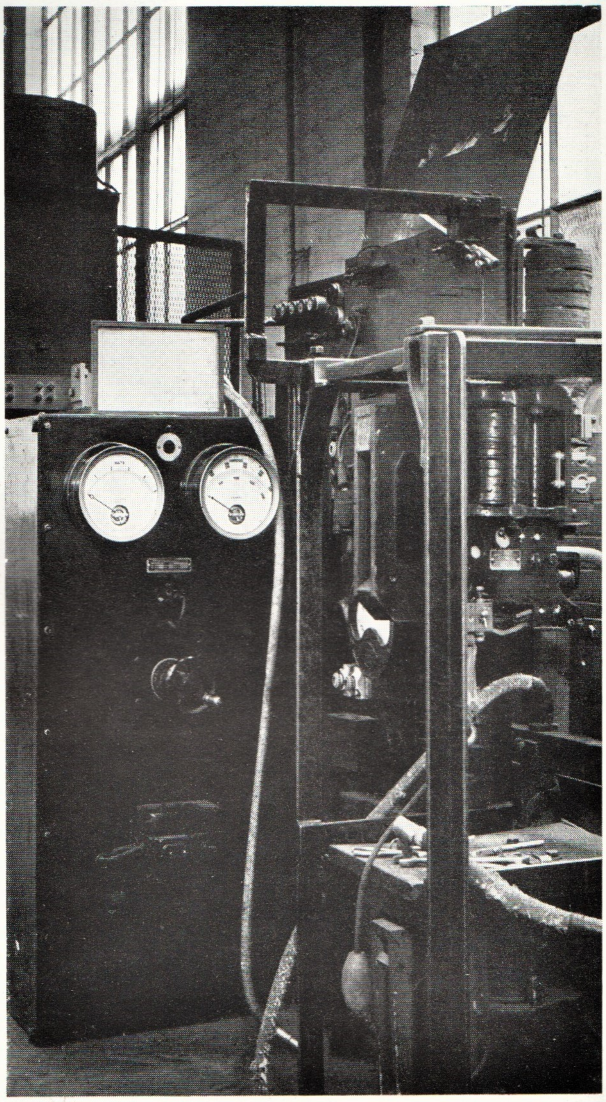


Fig. 47.—Circuit breaker testing up to 2,000 amperes, by a copper-oxide rectifier that has been in continuous service for about 16 years at the Acton Works of the London Transport Executive by whose permission this photograph has been reproduced.

11.2.11. *Vibrating screens*, for sieving material or for hopper and other feeds, are mechanically tuned to the frequency of the AC supply and are actuated by a series of impulses obtained by connecting a half-wave rectifier in series with the winding, springs providing the return action during the ensuing half-cycle. The amplitude of the vibration is controlled by means of a series rheostat.

An alternative method is to inject DC into the AC circuit which provides a bias, the control is simplified and all that is necessary is to regulate the extent of the DC bias. Motor generators have hitherto been employed for the bias, which requires a voltage up to about 15 to overcome the resistive drop of the circulating DC current in the vibrator coil and back through other pieces of apparatus connected across the line.

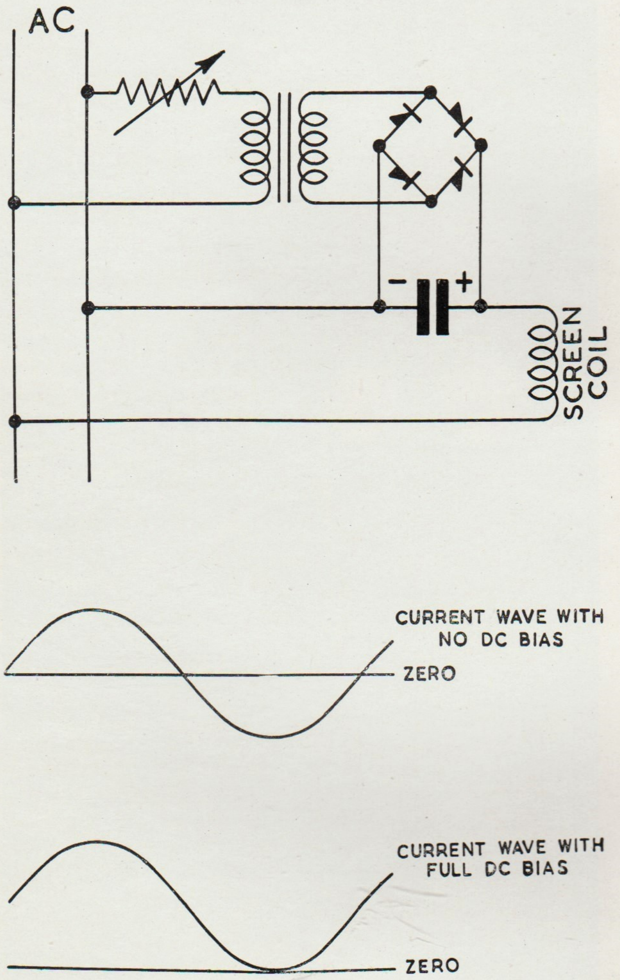


Fig. 48.—Basic circuit of DC bias vibrator system showing current wave through vibrator coil at zero and full bias.

11.3. Motors and generators

Applications :

Alternator excitation.
DC/AC changeover of motors in dental equipment, mincing machines, etc.
DC injection braking of AC motors.
Lift motors.
Organ blower motors.
Remote reversal for DC motors.
Starter motors for vehicles and aircraft.
Separately excited variable speed machines.
Shunt-wound variable speed machines.
Teleprinter motors.
Torque test of starter motors and clutches.

Other publications :

D.S.23. Specification and dimensions of complete rectifier equipments with or without transformer.
D.S.50. Specification of oil-immersed rectifier equipments for industrial power supply.
D.S.40. Details of rectifier units for inclusion in control gear maker's panel.
D.S.46. Rectifiers for operation of starter motors for aircraft and vehicles.

11.3.1. *Features of motor applications.*

11.3.2. *Excitation of alternators*, generators and synchronous motors is already described under the magnet load section, 11.2.8.

A rectifier is ideal for driving a DC motor incorporated in some existing equipment, where difficulties would arise in replacing the machine with an AC motor. The rectifier equipment should preferably include a transformer with a range of tappings to enable the DC motor to be driven under correct conditions, particularly if the machine is shunt-wound, when a lower AC input voltage will be required from the transformer secondary winding to obtain the requisite current, as compared with a machine having a series field which behaves as a magnet load.

11.3.3. *Lift motors*, which have been in use on a DC supply which has been changed to AC, can be conveniently operated by a rectifier which will also supply the power for the brake and contactor coils. If the lift previously utilised regenerative braking, it is necessary to connect a shunt resistance across the machine which can be switched in when the motor is required to be braked, the rectifier then being disconnected from the armature.

11.3.4. *Organ blower motors* have occasionally been found to be noisy when operated from a single-phase rectifier; this may be overcome by the use of a smoothing choke; it cannot arise if a three-phase rectifier is used.

The rectifier is well able to withstand the starting current of a DC motor and the consequent drop in voltage is unlikely to be sufficient to affect the torque or acceleration of the motor.

11.3.5. *Starting of petrol, diesel and gas turbine engines* constitutes a heavy load on batteries. Rectifiers are widely used in place of batteries for starting engines on the test beds in the production factory, while a range of mobile rectifier equipments is available for starting the engines of transport vehicles and aircraft without loading the batteries. These equipments are also suitable for torque tests and the adjustment of friction clutches.

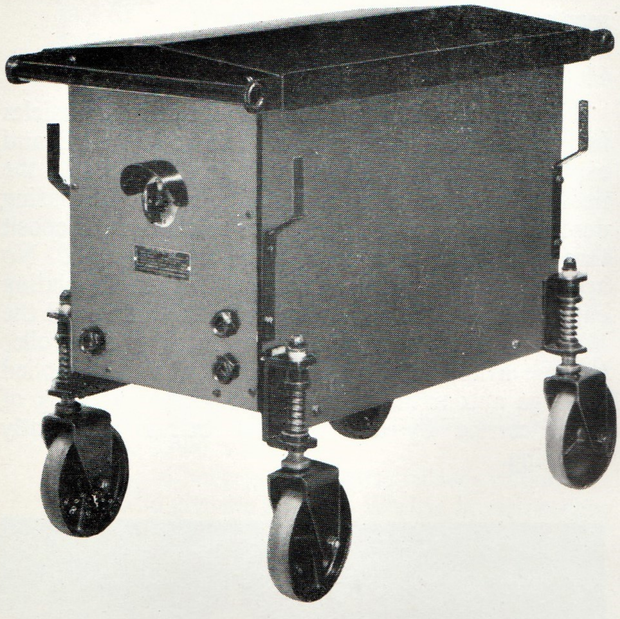


Fig. 49.—Westalite rectifier suitable for starting aircraft piston engines or gas turbines.

11.3.6. *DC injection braking* of AC motors up to several hundred H.P. is widely employed where a motor has to be pulled up rapidly. The motor is first switched off the line, one phase of the stator is then short-circuited to reduce the field induced by the rotor, and a short-time rated rectifier is connected to the two other phases in parallel, being disconnected when the machine is sufficiently slowed down. It is sometimes necessary to introduce a short time-delay to ensure that the induced voltage is sufficiently reduced, otherwise the rectifier, which is rated for a low-voltage output dependent on the resistance of the stator windings, may be damaged. There are advantages in connecting the rectifier to the rotor windings in wound rotor machines and short-circuiting all three stator windings.

11.3.7. *Polarity reversal.* An interesting application is the remote reversal of motors such as those employed for transporting ingots in steelworks where the feed to the motor is through trolley wires. Reversal of the polarity of the supply would not reverse the DC motor, unless the field polarity is unchanged, but if the field is connected to the trolley wires through a bridge-connected rectifier, the field current will not reverse

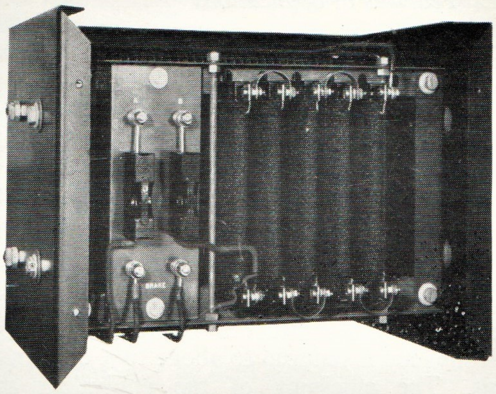


Fig. 50.—Braking panel incorporating Westalite rectifiers
(by courtesy of Igranic Electric Co., Ltd.)

when the polarity of the supply is changed, while that of the armature current will depend on the polarity of the supply, thus remote reversal of the machine by reversal of polarity at the source is achieved.

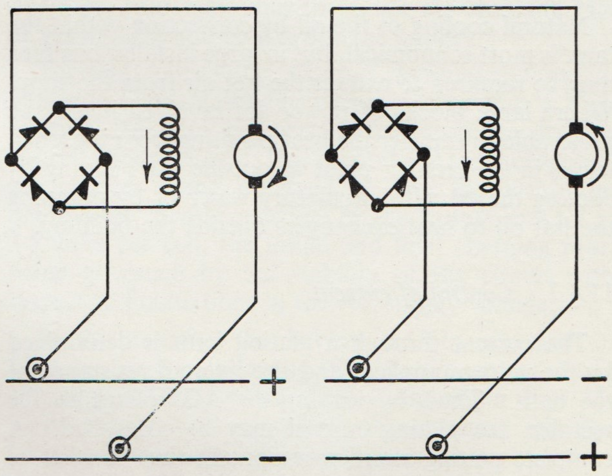


Fig. 51.—Circuit showing remote reversal of DC motor by changing polarity.

11.4. Electro-chemical processes

Applications :

- Anodising.
- Electroforming.
- Electroplating.
- Electro-polishing.
- Electrolytic cells.
- Emergency power supply for nickel plating processes.

Other publications :

Data Sheet No. 44. Power supply for electroplating plant with output up to 10,000 amperes and more.

11.4.1. *Features of applications*

Motor generators supplied the heavy-current power supply for electroplating and similar processes prior to the introduction of the copper-oxide rectifier, which was developed in 1932 for heavy-current outputs. The modern Westalite rectifier has advantages over the fan-cooled copper-oxide rectifier in that it may be oil-cooled, and so protected from the plating-shop atmosphere.

The overall efficiency of the rectifier equipment is of the order of 80%, which is maintained at this level even if the load is reduced to about 10% of maximum current. The efficiency of the equivalent motor generator does not approach 80% even at full load, while at light loads it is very low indeed. While the motor generator requires replacement of the brushes at short intervals, and occasional attention to the commutator and bearings, the rectifier requires no maintenance whatever. The rotary machine requires concrete foundations for the heavy bedplate, the rectifier, having no rotating masses, may be mounted anywhere—even on a gantry over the plating shop if floor space is limited.

Natural cooling of the oil by convection within the tank is most economical, but in large installations fans may be required to extract the hot air from the shop. Where large blocks of power are involved it may be preferable to transfer the heat resulting from the small losses in the rectifier plant to outside the building by cooling the oil with circulatory water or by pumping the hot oil to heat exchangers outside the building.

11.4.2. *Control of current*

The current through a plating bath is determined by the voltage applied, and the internal resistance of the bath. Thus, by varying the AC voltage to the rectifier, the plating current may be controlled. A complete plating rectifier equipment thus consists of some form of voltage regulator to control the voltage, a step-down transformer to convert the AC supply voltage to the low potential required, and a Westalite rectifier to convert the low voltage AC to direct current.

The voltage regulator is generally an auto-transformer with means of adjusting the output voltage by use of tapping switches or a movable contact, the latter may be motor-driven and remotely controlled if required. In this manner the current may be economically adjusted to suit the varying requirements of the plating bath.

11.4.3. *Automatic current control*

The control of current to suit the varying articles in the bath has always been left to the skill and experience of the operator. Rising plating costs, the need to economise in materials and the increasing demands for a certain minimum thickness of deposit throw a great responsibility on the operator. No apparatus was available which could adjust the plating current to suit the area of work in the bath until the Westinghouse Constant Current Density Controller became available, which is most frequently applied to large automatic plating plants where the area of work carried by the conveyor belt is frequently changing.

Fig. 52.—Typical plating rectifier with 63-step control included in the same tank as the main transformer and rectifier. Output 7.5 volts at 1,000 amperes.

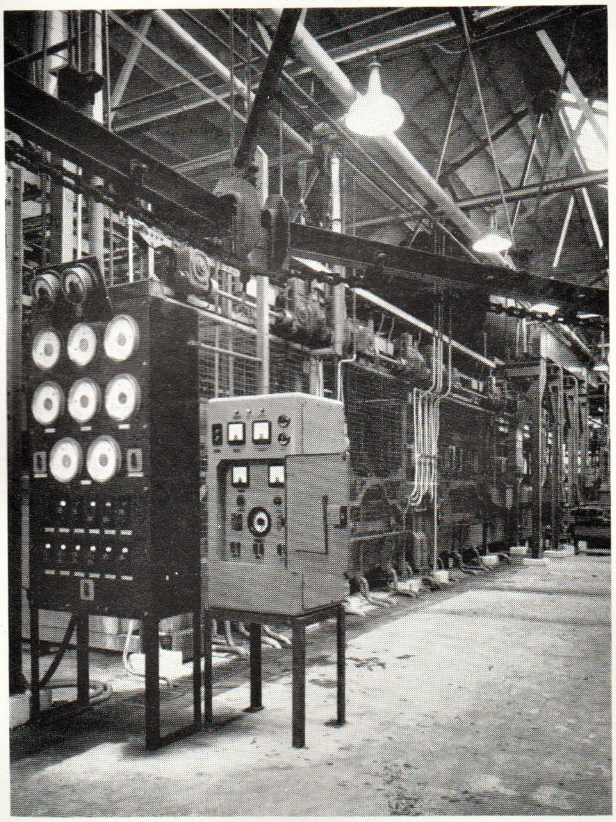


Fig. 53.—Automatic control of current density for large conveyor plating plants is achieved by the Westinghouse Constant Current Density Controller.

(Plant installed at Messrs. J. B. Brooks & Co. Ltd., Birmingham, by Messrs. W. Canning & Co. Ltd.)

11.5. Battery charging

Applications :

All systems of charging from AC mains for batteries used for cars, emergency lighting, fire alarms, switch-closing and tripping, radio receiving sets, telephone and telegraph systems, electric vehicles for road delivery or factory use, etc.

Other publications :

MR.13. "At the Correct Rate," with full details of commercial chargers and charging.
D.S.62. "Westat" automatic battery chargers.
D.S.35. Range of industrial battery chargers.
D.S.33. RT.20 and RT.40 series battery chargers with outputs up to 200 watts.
D.S.53. BC.3 series battery charger with outputs up to 72 watts.
DS.54. BC4 series battery charger with outputs up to 250 watts.
D.S.55. BC.5 series battery charger with outputs up to 570 watts.
D.S.56. BC.6 series battery charger with outputs up to 850 watts.
D.S.57. BC.7 series battery charger with outputs up to 1,250 watts.
D.S.58. BC.8 series battery charger with outputs up to 2,400 watts.
D.S.26. Chargers for electric battery vehicles.
"You did give me a start" Westric home charger for car batteries.

The information concerning battery characteristics on the following pages is liable to small variations depending on the particular type of battery used, and details should in every case be referred to the battery manufacturer if accurate design data is required.

11.5.1. *Charging characteristics of lead-acid cells*

The voltage, after a completely discharged cell has stood for some minutes, is about 1·85 volts, but as soon as any appreciable charging current is passed into the cell, its voltage rises to 2. Thereafter the voltage rises gradually to 2·3 volts, when a rapid rise occurs to about 2·7 volts when the voltage remains constant.

The charging current at the start of charge is limited mainly by heating; the temperature of the electrolyte should not exceed 110° F. It should be remembered that the battery may be heated by a heavy discharge, so that the limiting temperature may rapidly be reached if the charging current is very high.

When the cell voltage reaches 2·5 volts, it may be necessary to reduce the charging current to avoid excessive gassing.

The current may be held constant automatically or by the manual operation of the controls to produce the current-time characteristic shown in Fig. 54, which also shows the corresponding battery voltage during charging.

The battery may be recharged in about eight hours with a charger having these characteristics.

A charger having these characteristics is expensive if controlled automatically, while, if manual control is employed to maintain the charging current as the cell voltage rises, the control is dependent on the operator, who may omit to reduce the charging rate at gas voltage and so damage the battery.

The most satisfactory form of charging equipment, which is incidentally the cheapest, provides a high initial charge rate, but permits the current to drop as the cell voltage rises. This is known as taper charging, the charger being designed to give the maximum permissible current specified by the battery makers at 2·5 volts per cell, the initial and final charging rates being governed by the stability of the circuit with respect to fluctuations in the AC supply voltage.

In this manner the battery is fully charged in 12 hours or less, allowing 90% as the ampere-hour efficiency. This characteristic is shown in Fig. 55, which is the basis on which the charging sets for battery electric vehicles are designed.

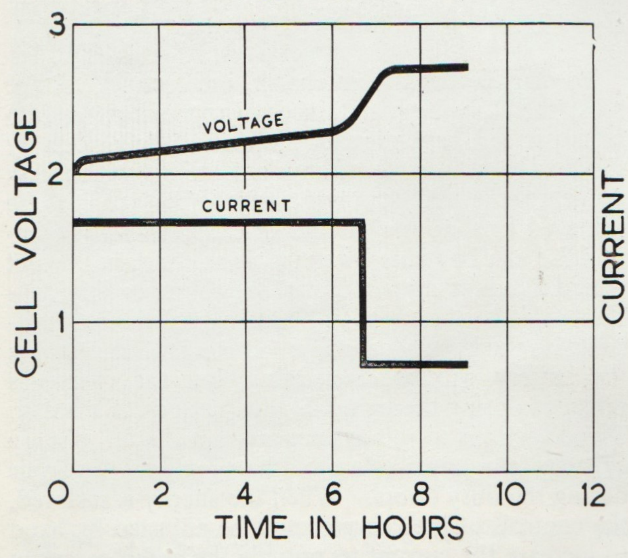


Fig. 54. Ideal voltage-time and charging current-time characteristics for recharge of lead-acid battery.

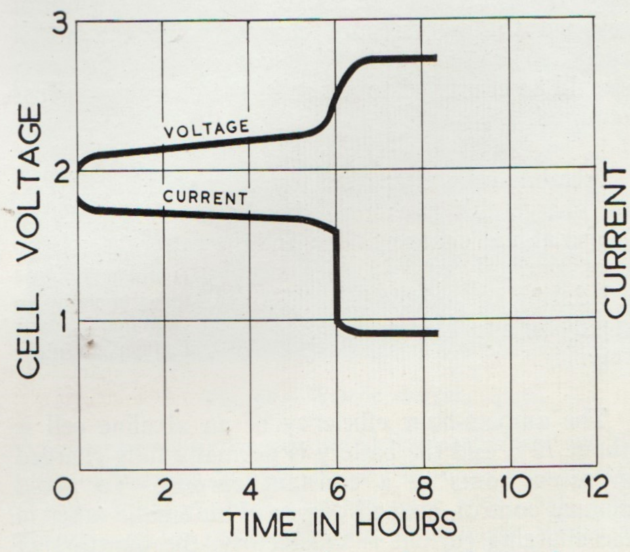


Fig. 55.—Typical charging characteristic of taper charge.

Occasions arise where it is necessary to recharge the battery in about eight hours, or, for instance, where a dockside or factory truck is used 24 hours per day and its battery must be recharged during an eight-hour shift. This may be done by starting the charge at as high a rate as the battery maker permits and allowing it to taper, but at 2·5 volts per cell a voltage relay operates and automatically reduces the charging current to the maximum permitted at this voltage; this value thereafter tapers. The battery charger is appreciably more expensive as it is designed for a much higher initial rate and includes the relay and contactors for the automatic changeover control. The charging characteristic is indicated in Fig. 56.

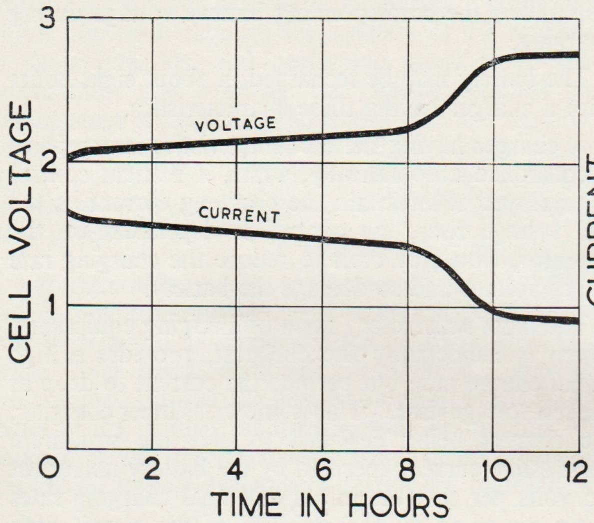


Fig 56.—Typical charging characteristic of two-rate charger.

11.5.2. *Charging characteristics of alkaline cells*

There are two types of alkaline battery which have substantially the same charging characteristics, but they differ in that the nickel-iron battery will not respond to low rates of charge, while the nickel cadmium battery will. The battery manufacturers should be consulted to ascertain the charging current required.

Alkaline cells after discharge may stand at 1 volt; on charge this rises immediately to about 1·3, or higher at high charging rates, and thereafter the voltage rises gradually to 1·45, then steeply to about 1·7 or 1·8 during an hour or less, the top voltage remaining steady for a further two hours if charged at the normal rate.

The ampere-hour efficiency of an alkaline cell is about 70% and the battery is normally fully charged in seven hours at a constant current. To avoid manual control, a small degree of automatic taper in the charging current is satisfactory, the duration of charge is then maintained at seven hours by starting at a higher rate, or, if time permits, a smaller and cheaper charger can be used, which will recharge the battery in 12 hours without affecting the battery performance.

Battery chargers designed for charging lead-acid batteries are not generally suitable for charging alkaline batteries of the same voltage as additional ballast is required to obtain the closer limits of taper recommended by the manufacturers of alkaline cells.

11.5.3. *Trickle charging*

A fully-charged lead-acid battery which is standing idle is subject to internal losses which may be made good by continuously charging the battery at a rate of $\frac{C}{1,000}$ where C is the amp-hour capacity of the battery, the cell voltage being about 2·25. This is termed trickle-charging.

The current may be increased to compensate for any intermittent discharges, such as switch-tripping operations, regular readings of the specific gravity being recorded to see whether the low-rate charge is adequate to compensate for the drain caused by the intermittent loading.

11.5.4. *Float charging*

Where continuity of supply to a load is of special importance, it is common practice to use two separate batteries, one feeding the load while the other is being charged. After a suitable period the batteries are then interchanged.

This duplication can be avoided by using a floating-battery system. In this, a single battery is connected across the output terminals of a rectifier, the latter being designed to feed the load and supply a small trickle charge to the battery. In the event of an interruption in the main supply, the load is immediately supplied from the battery.

To provide the trickle charge, the rectifier voltage must therefore be maintained at approximately 2·25 volts per cell, regardless of the current demanded by the load, and in spite of any fluctuations which may occur to the AC supply voltage. This cannot be achieved in a normal design of charger, but a compromise can be made by charging at constant current where the daily ampere-hour load is reasonably constant and the variations in load are small in comparison with the battery capacity. During the busy hours the battery will be discharging, but the energy is replaced during the lighter-loaded periods of the day. The objections to this system are that the full battery capacity is not available should a supply failure occur during the busy hours. When the supply is restored, the controls of the charger must be adjusted by hand to increase the current to provide the recharge, when charging has been completed the controls must be

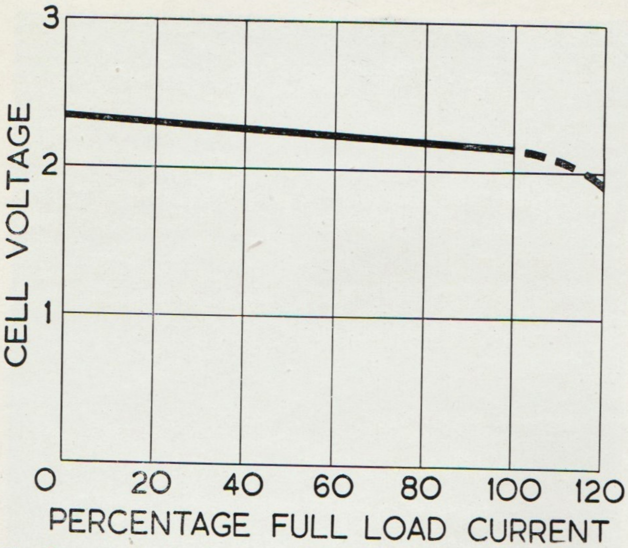


Fig. 57.—Typical voltage regulation characteristics of a Westat automatic float charger.

adjusted again to reduce the output to the floating rate. This system may not be satisfactory when the average daily load varies from day to day—as, for instance, at weekends and holidays.

The " Westat " automatic constant-voltage system, described on pages 22 and 23, entirely overcomes these difficulties.

The " Westat " rectifier automatically balances any load applied to the battery and maintains a trickle charge to keep the battery in a fully-charged state. After a supply failure the battery is automatically recharged and, when fully charged, the current is automatically reduced to the required float value.

11.5.5. *Some applications of Westinghouse battery chargers*

11.5.5.1. *Battery vehicles.* The reliability of Westinghouse vehicle chargers has earned them a name which is jealously guarded in the care bestowed on the design and manufacture of over 20,000 of these chargers, ranging from capacities of 250 watts for " electric barrows " for milk delivery, to several kilowatts for mining locomotives.

Fig. 58.—Typical installation of vehicle chargers at the Tulse Hill Depot of United Dairies.
(by courtesy of Mickleover Transport Ltd.).

11.5.5.2. *Commercial battery charging.* A range of single and multi-circuit chargers is available for the garage and battery service station. The first design of multi-circuit charger was developed by the Company in 1929 and many of these are still in operation. Since then new designs have been introduced to meet the changing conditions.

Fig. 59.—Typical charging station.

11.5.5.3. *Westric charger for home use.* This charger, the pioneer of many imitations, was developed in 1932 for doctors and others whose car journeys were not long and necessitated frequent starts and the use of parking lamps, thereby draining the battery. Over 25,000 of these chargers have been sold, many being used for fire engines and ambulances where the need for a fully-charged battery is obvious.

Fig. 60.—Westric charger.

11.5.5.4. *Power station batteries.* The switching battery usually supplies a small steady load of indicator lamps and is subjected to heavy intermittent loads for switch-closing and tripping, while it is often used for emergency lighting or for compressors in the event of a supply failure. A "Westat" automatic float charger is normally in circuit to balance the varying loads and an additional circuit giving a quick-rate charge is often provided.

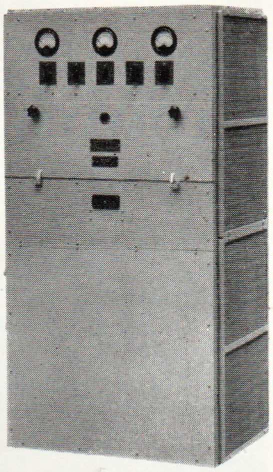


Fig. 61.—Typical Westalite charger for 125 cell 400 A.H. power station battery.

11.5.5.5. *Telecommunications.* A stand-by battery is essential, necessitating reliable charging plant. Some thousands of Westat and manually-controlled chargers are in use for such purposes as telephone, teleprinter and telephone repeater systems for the G.P.O., telephone and cable companies. A Westinghouse rectifier plant is now being installed at a telephone repeater station requiring 16,000 amperes at a nominal 25 volts, with an additional 8,000 amperes for charging the standby battery, while the anode battery requires 1,200 amperes at a nominal 137 volts, with an additional 600 amperes for charging the stand-by battery.

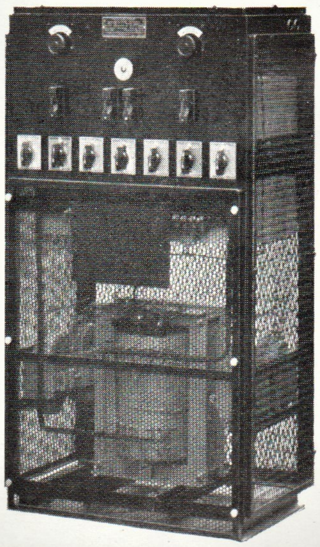


Fig. 62.—Typical Westat as supplied to the G.P.O.

11.6. E.H.T. power supply

Applications :

Cable testing.
Detearing and paint spraying.
Electrostatic precipitation and air-cleaning.
Impulse testing.
X-ray.

11.6.1. *Electrostatic precipitation*

Reliability and ability to operate continuously for many months, without overhaul, are essential for the power plant employed in the electrostatic precipitation of tar from coal gas, smoke from power-station chimneys and the recovery of chemicals which are present in the form of dust or mist. Air-cleaning in the same manner calls for reliable equipment which must operate with the minimum of maintenance.

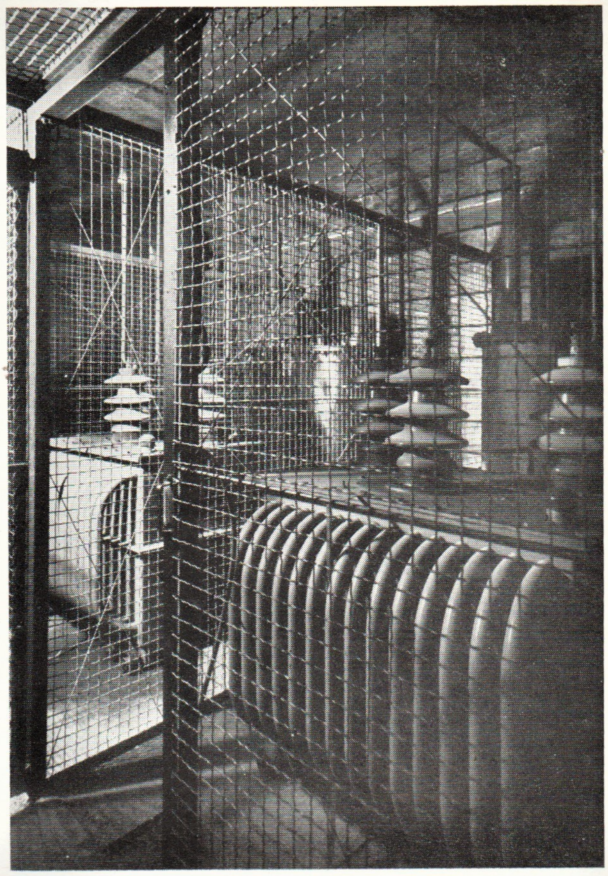


Fig. 63.—40 kV 150 mA Westinghouse rectifiers, some of which were built in 1931 and are still in operation.
(Courtesy of National Smelting Co., Ltd.)

The valve rectifier in its various forms has too short a life to be employed in industrial plant of this type; the rotary commutator, driven by a synchronous motor and operating as a double-pole change-over switch, has been widely used in the past, but requires regular attention and must be well-screened to prevent radio interference.

The Westalite rectifier is ideal for this application, it is oil-immersed and often housed in the same tank as the transformer and condensers so there is only one H.T. bushing.

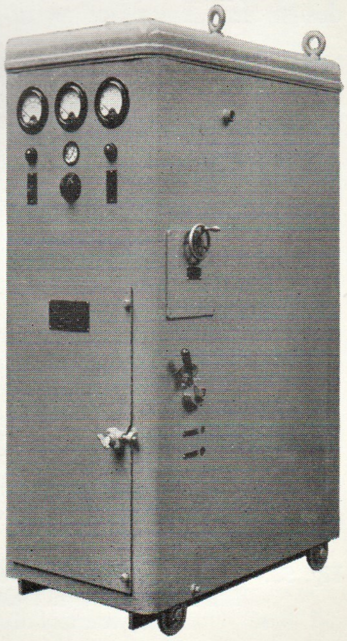


Fig. 64.—30 kV 60 mA equipment built by Ferranti, Ltd., incorporating double-voltage Westalite rectifiers.

11.6.2. *Cable testing*

A DC supply is essential when testing the insulation resistance of underground cables, as the capacity current taken from an AC supply would mask any small leakage current. Portable rectifier equipments have been made for this duty but the most interesting problems arise on higher voltage test apparatus for checking insulator bushings and cables in the factory.

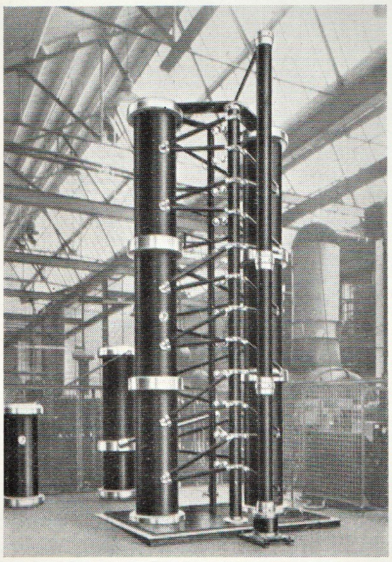


Fig. 65.—1,700,000 volt 30 kW. secs. Impulse Generator, incorporating Westalite rectifier, designed and manufactured by Messrs. Johnson & Phillips Ltd., and installed in their H.V. test plant.

11.7. Projector and spectrographic arcs

Applications :

Cinema-arc lamps.
Printing arcs.
Searchlights.
Spectrographic arcs.
Spot lamps.
Slide lanterns.

Publications :

D.S.48. Cinema-arc rectifiers.

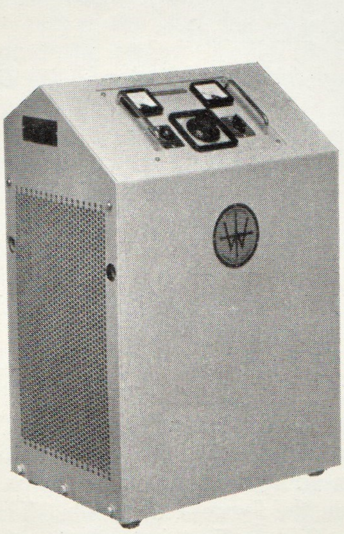


Fig. 66.—Single-phase Westalite rectifier for operating high or low intensity cinema arcs.

11.7.1. *Projector arcs for cinemas and theatres*

The Company developed the first high efficiency rectifier system in which the wasteful ballast resistances hitherto employed were replaced by a choke and condenser, the power factor was very high and the equipment had a constant-current characteristic. The efficiency of this system has not yet been exceeded in practice by any other make.

Designs are available either for mounting out of the operating box, with remote switching, or, if required, alternatives are available for mounting by the lamps in the box.

11.8. Power supply to radio transmitters and receivers

Application :

HT, GB and LT power supply for radio transmitters.
HT and GB power supply for radio and television receivers.
Standby power supply for transmitters.
Public address system power supplies.
Radio frequency heating power supplies.
Cathode ray tube power supplies.

Other publications :

D.S.49. Manufacturers' type HT rectifiers for domestic receivers.
MR.14, Supp. 1. HT rectifiers for receiver power supply for amateurs.
D.S.40 and D.S.41. Manufacturers' type rectifiers for choke input filters.
D.S.43. Manufacturers' type rectifiers for condenser input filters.
D.S.42. Type 16 HT rectifier units for outputs of 8–15mA.
D.S.60. Type 36 EHT rectifier units for outputs of 2mA.
M.R. 14 Suppt. 4. "Westeht" rectifiers for cathode ray tubes.

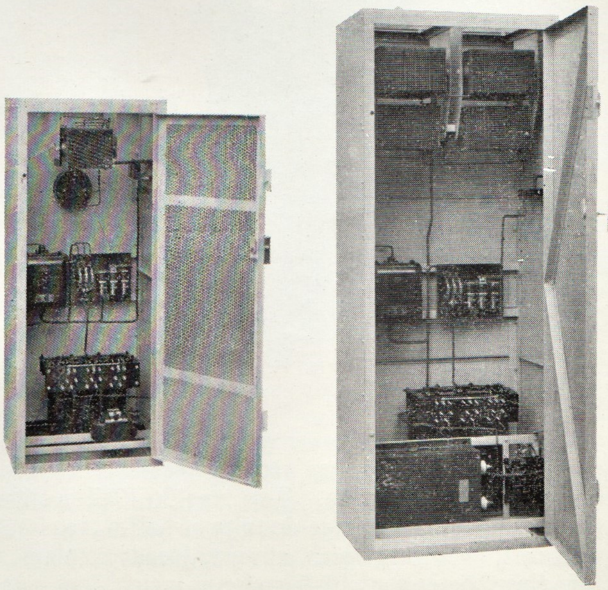


Fig. 67.—Typical GB units as supplied to the B.B.C.

11.8.1. *Radio transmitters*

Westalite rectifiers are ideal for the anode supply and are usually oil-immersed for higher voltages. Voltage regulation over the working range is excellent.

Filament rectifiers are generally oil-immersed and have an efficiency of 85–90%, which is much higher than can be obtained from a motor generator, which also requires brush replacements and other maintenance.

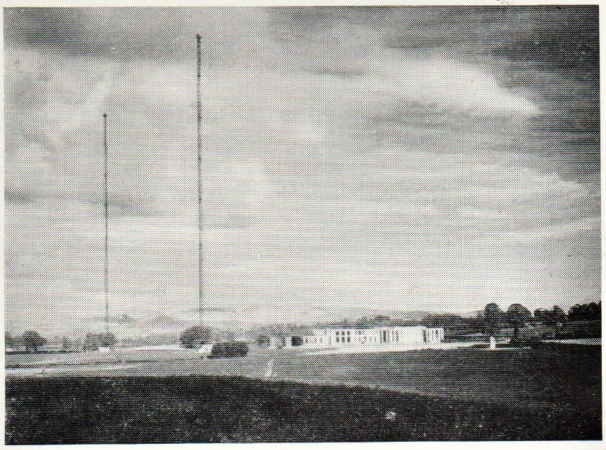


Fig. 68.—Western Regional Station, Washford Cross, Somerset. Westalite rectifiers used there include a 3,000 volt oil-immersed set for H.T. Supply and a Grid Bias unit giving 500 volts.

(By courtesy of the B.B.C.)

11.8.2. *Radio receivers*

In addition to the robustness and long life of the Westalite rectifier, there are additional advantages over the valve rectifier in that no filament winding is necessary on the mains transformer, while in the " live line " set, using a half-wave rectifier, the need for a transformer is eliminated.

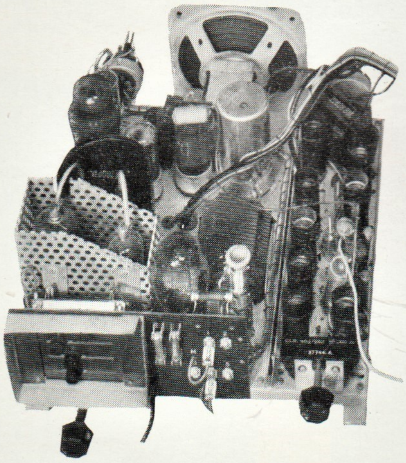


Fig. 69.—Receiver chassis showing Westalite rectifier.

(by courtesy of The Gramophone Co. Ltd.)

11.8.3. *Cathode ray power supply*

A special high-voltage rectifier element has been developed for this duty. This type 36 EHT rectifier is used either in a voltage-doubler or half-wave circuit from a transformer which, however, needs no filament winding; or in a multiplier circuit which does away with the step-up transformer.

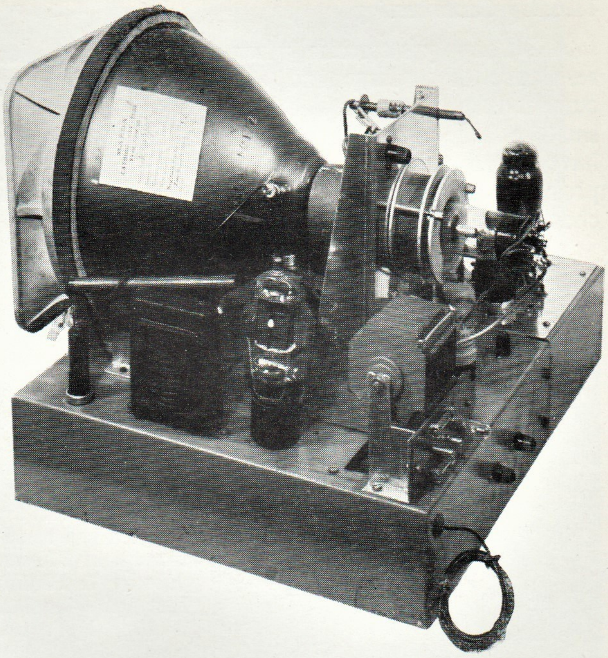


Fig. 70.—36EHT100 operating from line flyback pulse giving 6kV at 100 microamps.

11.8.4. *High-frequency rectifiers*

Miniature half-wave copper-oxide rectifiers have been developed for use at frequencies of 1,500 kilocycles per second, or higher, and are sold under the name " Westector." Their chief use is as the detectors in monitoring sets, second detectors in superhetrodyne receivers and in various automatic volume control circuits. A typical Westector is illustrated in Fig. 6, page 6.

A range of Germanium Crystal rectifiers has now been introduced for use in higher frequency circuits.

11.9. Surge Arrestors

Applications :

Absorption of inductive discharge in DC circuits.
Crash limiters for V.F. circuits.
Lamp cut-outs for series lighting circuits.
Spark quench.
Surge arrestors for AC circuits.

11.9.1. *Absorption of inductive discharge in DC circuits*

The asymmetric characteristic of the rectifier is employed in this circuit which has a very wide application ranging from telephony to the field windings of large machines. The principle is illustrated in Fig. 71, top diagram, which shows a solenoid connected to a battery, a half-wave rectifier being connected across the winding such that it opposes the flow of current from the battery.

The lower diagram indicates the conditions immediately the switch is opened. The inductive energy stored in the solenoid attempts to maintain the flow of current, hence the polarity of the voltage across the solenoid is reversed and current passes freely through the rectifier in the forward direction. Thus the voltage rise across the windings is limited to that

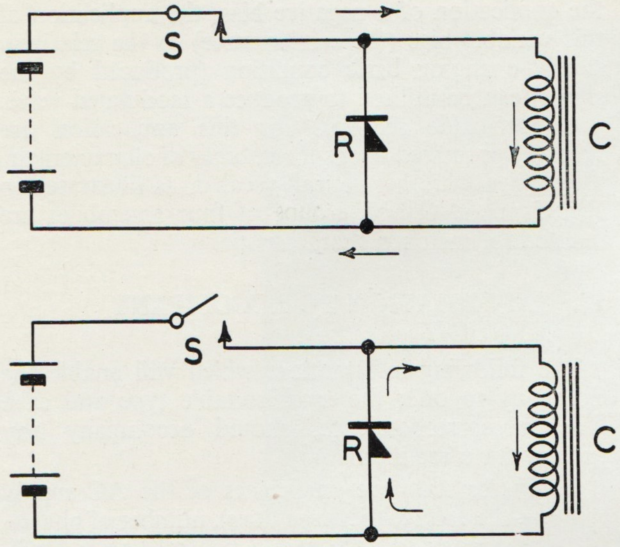


Fig. 71.—Absorption of inductive discharge in DC circuits.

necessary to force the current through the forward direction of the rectifier—a matter of some 10% of the normal voltage across the windings.

The circulating current through the solenoid windings and rectifier gradually diminishes as the inductive energy is dissipated as heat. The gradual drop in current through the winding may be used as a time delay of short duration for a relay or contactor; it may be objectionable when it may be necessary to add a resistor to the rectifier circuit to increase the rate of decay of the solenoid current—this, of course, also increases the peak voltage generated across the windings at the instant of switching off.

11.9.2. *Crash limiters*

As the forward voltage-current characteristic of the rectifier is non-linear, as shown in Fig. 2, page 5, it will be seen that a rectifier may be used as a variable shunt if connected in parallel with, say, a telephone earpiece and the rectifier is selected so that the current by-passed by it at normal level is negligible, but an increase in the level will direct an increasing proportion of the current through the rectifier, thus relieving the earpiece of the full shock. Two such rectifiers are used in parallel, connected in opposition.

This principle has been adopted by the G.P.O. for the operators' headphones.

11.9.3. *Surge arrestor for AC circuits*

The reverse voltage-current characteristics of a Westalite rectifier is shown in Fig. 2, page 5, and if extended beyond the scale it will be found that the current increases as a very high power of the applied voltage.

This aspect of the characteristic is employed in the triple path surge arrestor, illustrated in Fig. 73. A range of these arrestors is available for use on 110, 250 and 440 volt circuits, either AC or DC in which the peak voltage between lines or between either line

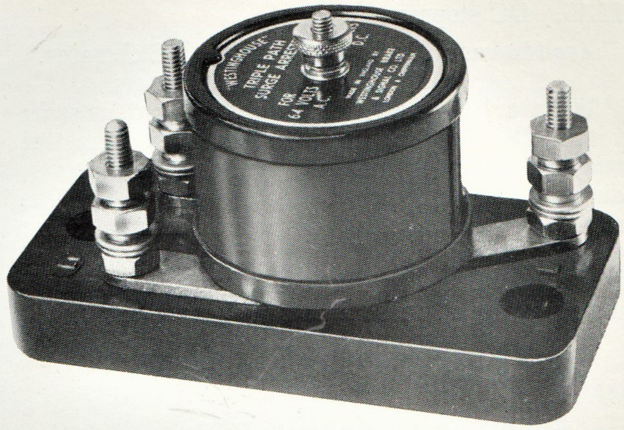


Fig. 72.—Triple path surge arrester for limiting the potential between two power lines, and from either to ground. This employs a Westalite rectifier.

and ground cannot rise beyond about twice the normal RMS voltage. It will be seen that the star arrangement reduces the number of rectifier elements as each may be stressed by surges from two sources.

The arrestor is capable of dealing with surges of short duration, but not prolonged over-voltages as the surge energy would then cause the rectifier to overheat. If the surge energy is beyond the capacity of the arrestor, the rectifier elements are destroyed and the rectifier assembly, which is of the plug-in type, is replaced.

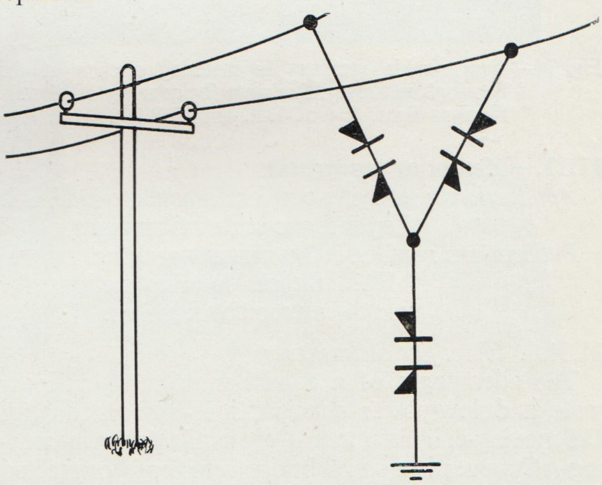


Fig. 73.—Circuit of triple path surge arrestor.

11.9.4. *Lamp cut-outs for series lighting*

The surge arrestor principle is carried a stage further and applied to the protection of series-lighting systems, as for instance those used for illuminating runways on air-fields. Should a lamp filament break, the rest of the lamps in that series circuit will go out, unless precautions are taken. If two rectifier elements are connected back-to-back, with a fusible element between, across the filament, the breakage of a filament throws the full line voltage on to the rectifier, which fails to a short-circuit immediately, fuses the soft metal which produces a low-resistance joint and then solidifies. The pair of rectifier elements and fusible element are included in the lamp cap.

11.10. DC stoppers

Applications : Battery cut-outs for DC charging.
Polarising of neutral relays.

When a half-wave rectifier is connected in series with a DC relay, operated from a DC source, the relay will operate when a potential is applied in one direction, but the non-conducting property of the rectifier when the polarity is reversed does not allow the relay to operate. This principle is widely used in telephone-line circuits, as for instance in the metering circuit for all subscribers in automatic exchanges.

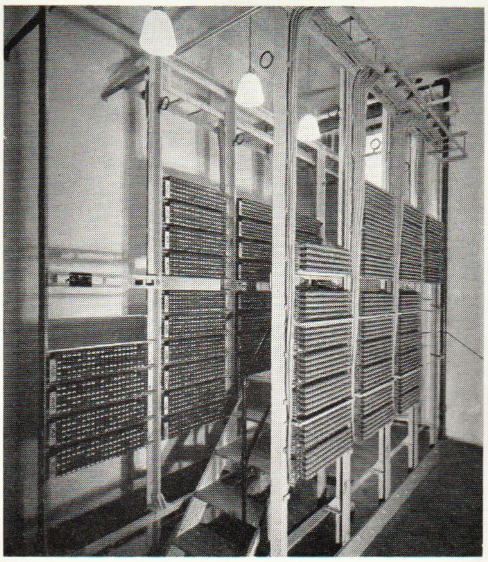


Fig. 74.—Copper-oxide rectifiers in metering circuits at the Birmingham Central Exchange (by courtesy of Messrs. Siemens Bros. & Co., Ltd. and G.P.O.).

11.11. Measuring instruments

Applications : Moving-coil instruments to read AC.
Logarithmic-scale instruments.

Publications : MR.3. Instrument rectifier.
MR.3, Suppl. 1. Instructions for use of instrument rectifiers.

11.11.1. *Rectifier instruments*

The advantages of a robust movement, a linear scale and low-power consumption, associated with DC moving-coil instruments, are available for measuring AC values if a small bridge rectifier is connected directly across the instrument coil.

Copper-oxide rectifiers are used for this purpose and retain first-grade accuracy over a wide range of temperature and frequency. Allowance may have to be made for distorted wave-forms as the instrument is calibrated on the assumption that the wave is sinusoidal.

Examples are shown in Figs. 7 and 8, page 6.

11.12. Modulators and demodulators

A very important part is played by copper-oxide rectifiers in carrier frequency transmission systems where a group of rectifiers is used as a modulator, usually for single-side band transmission. The non-linear characteristic of the rectifier in the forward direction is employed; the resistance of an element is reduced by applying a positive bias and increased by the application of a negative bias, the application of this variable bias (the carrier wave) to the relatively slowly changing basic condition (produced by the signal) can be utilised to produce a modulated wave.

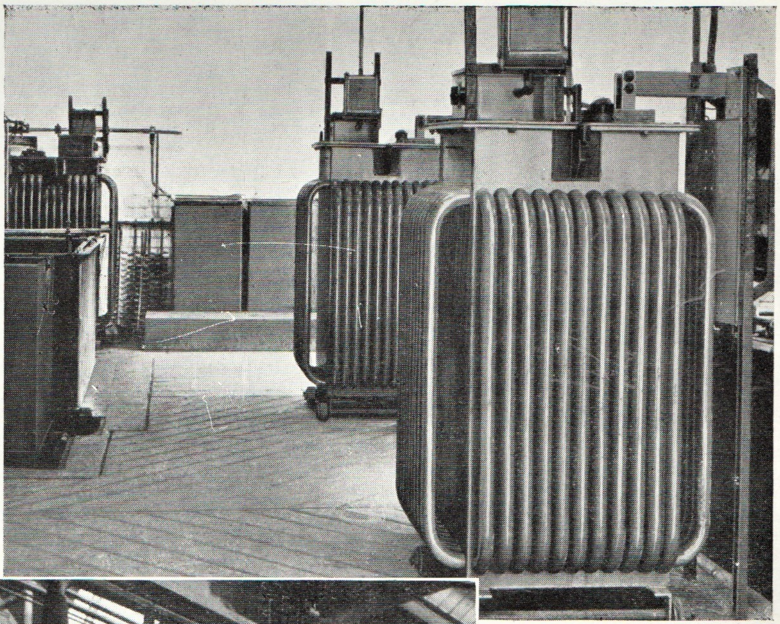
Copper-oxide rectifiers for this application are specially processed to ensure stability of characteristic, the elements are hermetically sealed, as illustrated in Fig. 5, page 6, and groups of four assemblies are selected for matched characteristic.

12. INFORMATION TO ACCOMPANY ENQUIRY

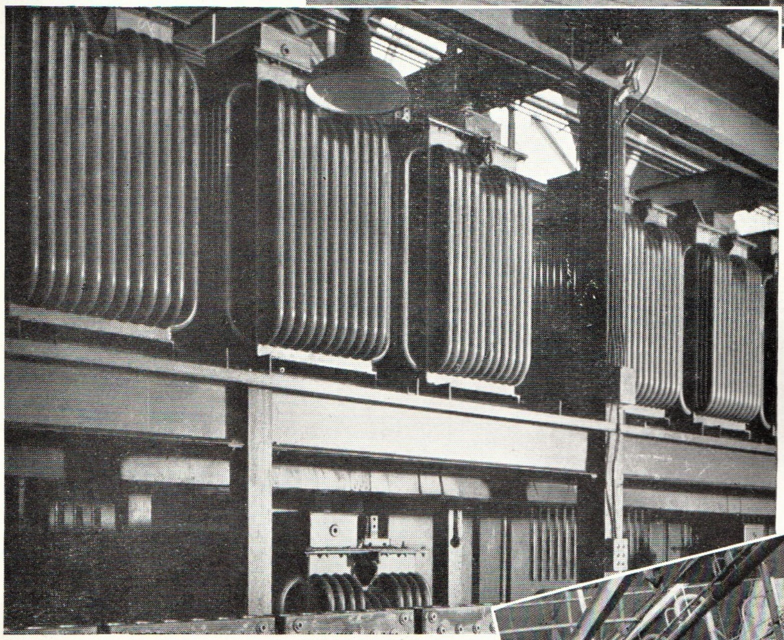
The following information, which will enable the Company to offer the most suitable type and save time in correspondence, should accompany any enquiry for a rectifier.

1. Please state the particulars of the AC supply —the voltage (between lines), number of phases, frequency and whether a neutral line is available. If the power is not derived from the AC supply, but from a small alternator which may have appreciable impedance, its open-circuit voltage should be stated. If the rectifier is energised by a current transformer, or there is any impedance between the rectifier and the AC supply, this should also be stated.
2. The type of DC load is of importance; please state if it is a magnet winding, a motor (if so, state whether series, shunt or compound or separately excited), a battery (if so, please state number and ampere-hour capacity of cells and whether lead-acid or alkaline), or a plating bath (if so, please state the metal to be deposited), or if there is a condenser in series or in shunt with the rectifier output (if so, please state its capacitance).
3. The required DC voltage and current must be known; please state these values. If a magnet load designed for a high temperature rise, state the resistance cold and hot. If a battery load, state whether the current is to be maintained throughout the range of voltage during charge, or may be allowed to be reduced as the battery voltage rises.
4. State if any control of voltage or current is required and the range.
5. If not continuously rated, state the time on load, in seconds, and the time of rest, in minutes.
6. State the maximum likely temperature of the air surrounding the rectifier. If the rectifier is required for use outside the British Isles, the destination should be stated.
7. State whether a complete rectifier equipment is required, or whether only the rectifier units.
8. If a complete rectifier equipment is required, and a design already exists, this will be, in general, cheaper and more readily available than a special design. Any special requirements as regards switchgear, fuses and indicating instruments, should be mentioned, however, as it is likely that the standard design may already include them.

TYPICAL INSTALLATIONS OF OIL-IMMERSED WESTALITE PLATING RECTIFIERS



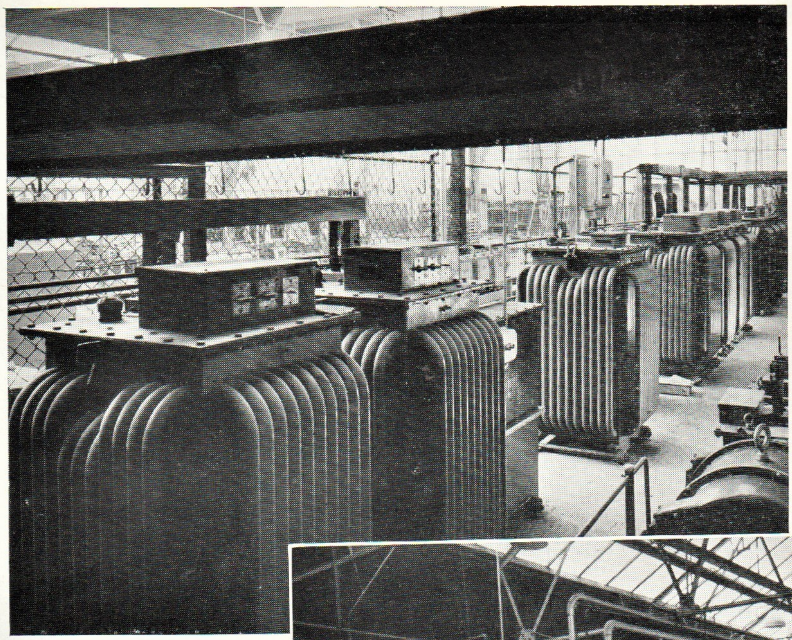
Part of an installation at Triumph Motors, Ltd., Coventry.



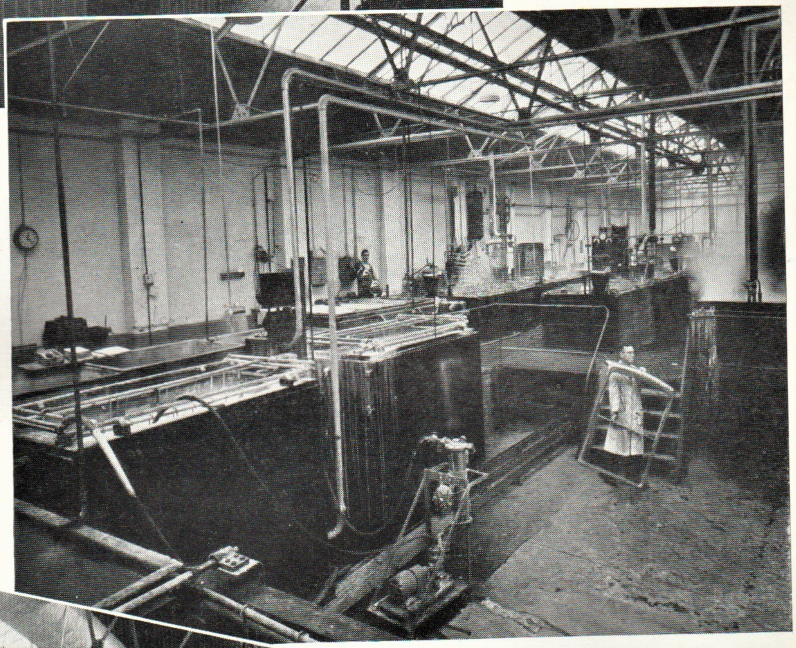
Part of the installation at the Rootes Group Manufacturing Division, Humber Ltd., Coventry.

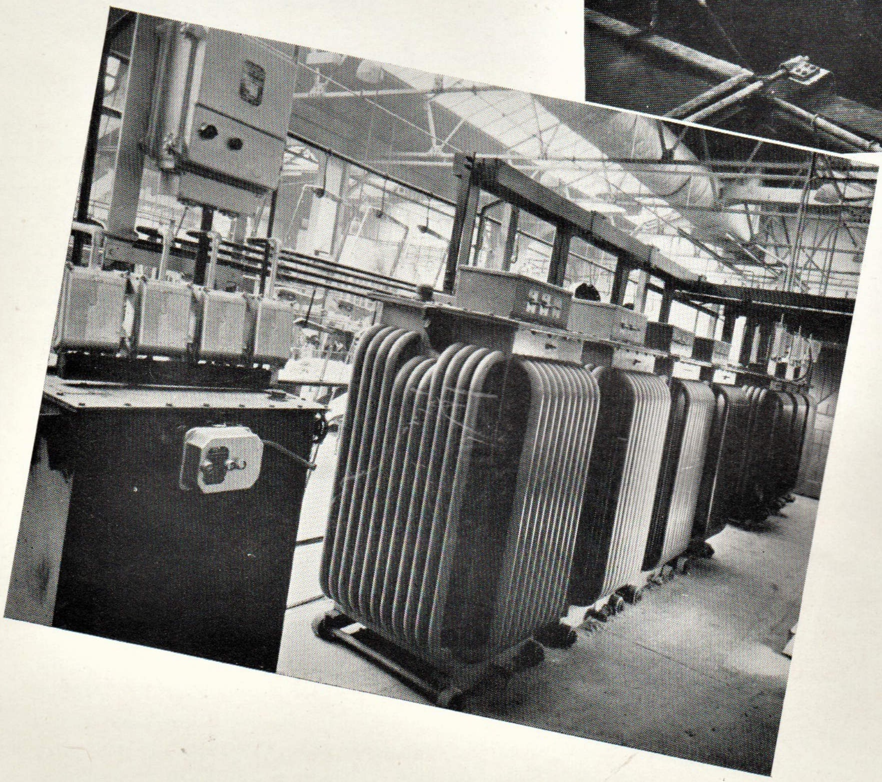
16-volts, 15,000 amperes for anodising at Altones Ltd., Glasgow.

TYPICAL INSTALLATIONS OF OIL-IMMERSED WESTALITE PLATING RECTIFIERS



CAR RADIATORS



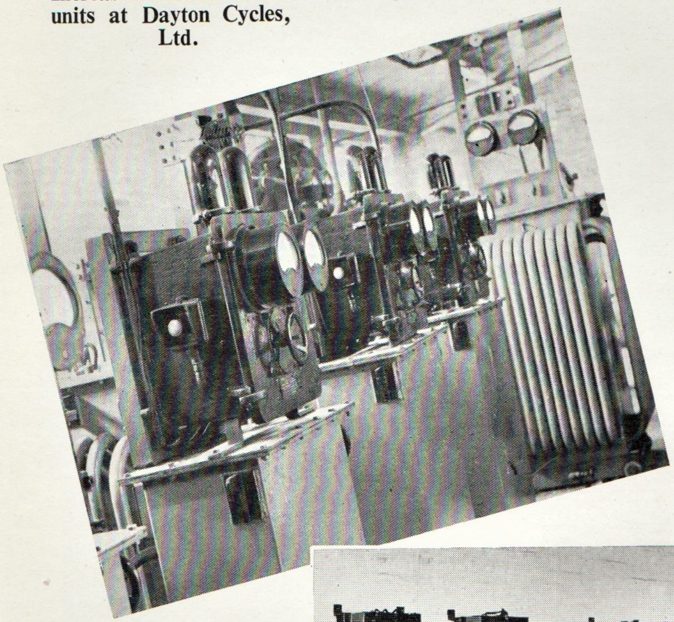


Plating car radiators at Coventry Radiator Co. Ltd.

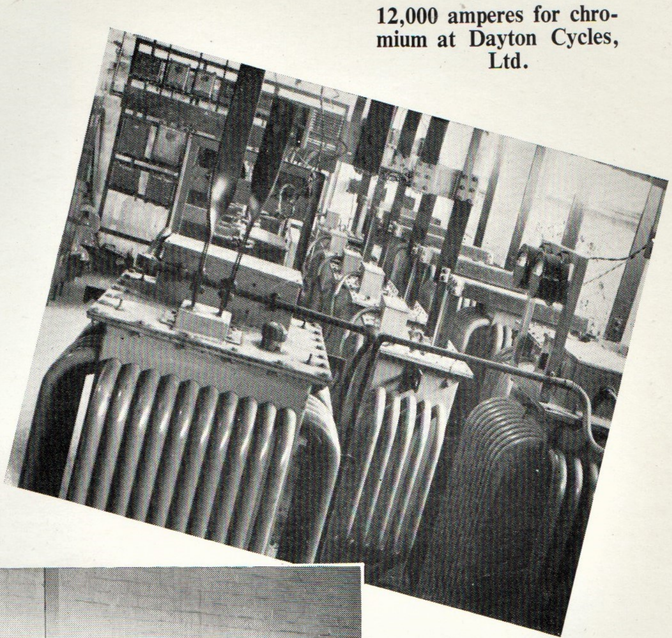
TYPICAL INSTALLATIONS OF OIL-IMMERSED WESTALITE PLATING RECTIFIERS

OVERLOAD PROTECTION

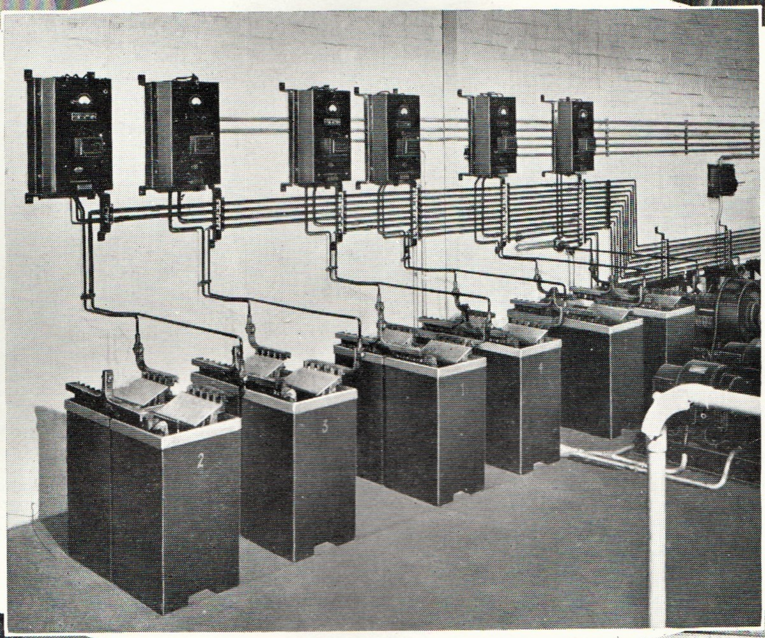
Increased current alarm units at Dayton Cycles, Ltd.



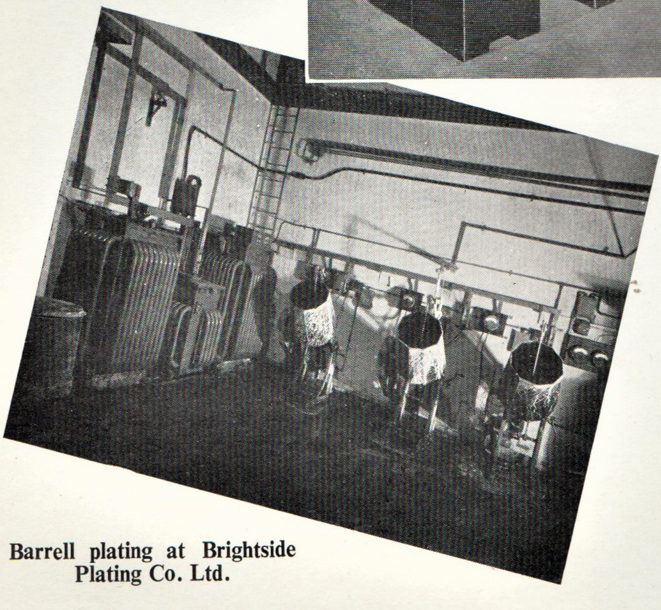
12,000 amperes for chromium at Dayton Cycles, Ltd.



Standby power supply units and batteries at Bristol Aeroplane Company

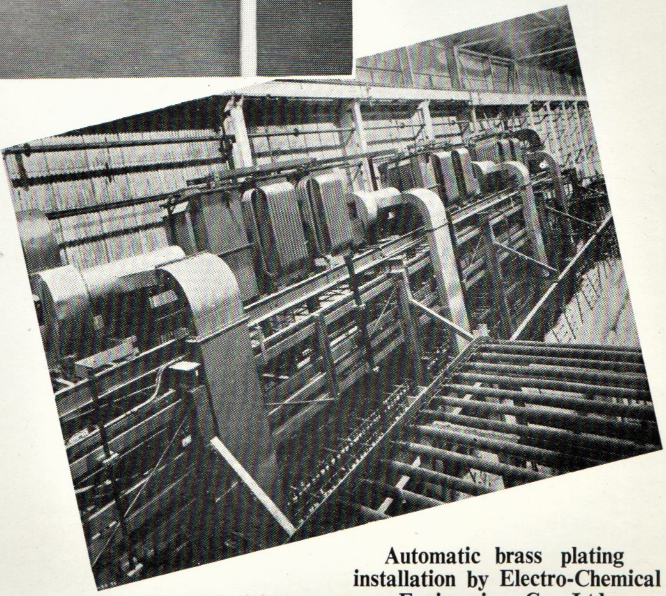


STAND BY POWER SUPPLY



Barrell plating at Brightside Plating Co. Ltd.

BARRELL PLATING



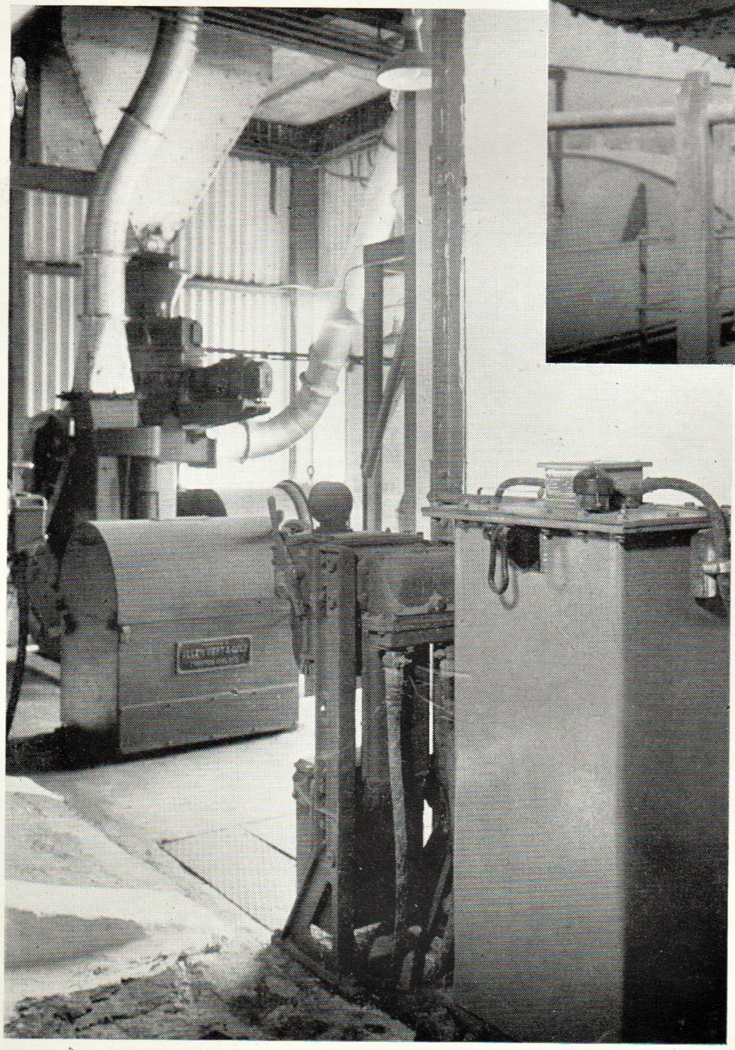
Automatic brass plating installation by Electro-Chemical Engineering Co. Ltd.

AUTOMATIC PLATING

INSTALLATION OF OIL-IMMERSED WESTALITE RECTIFIER FOR DC POWER SUPPLY

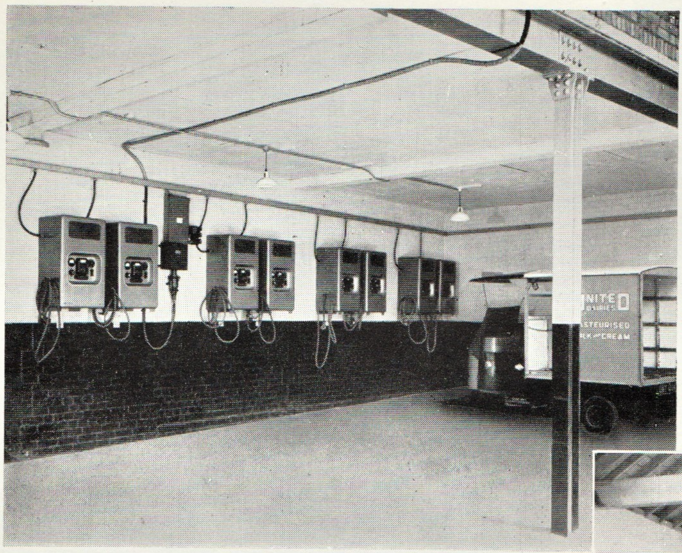
CEMENT MAKING

A Westinghouse oil-immersed rectifier operating a coal pulverizer. The pulverized coal is blown into the furnace of the rotating kiln in which the cement is baked.

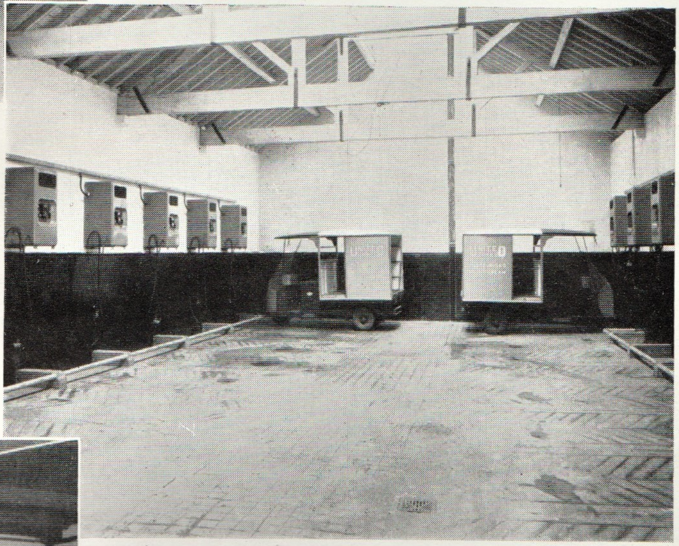


(Photographs reproduced by the courtesy of the Associated Portland Cement Manufacturers Ltd.).

TYPICAL INSTALLATIONS OF WESTALITE VEHICLE CHARGERS



" Westalite " Chargers at the United Dairies Depot at Tulse Hill, London, S.W.

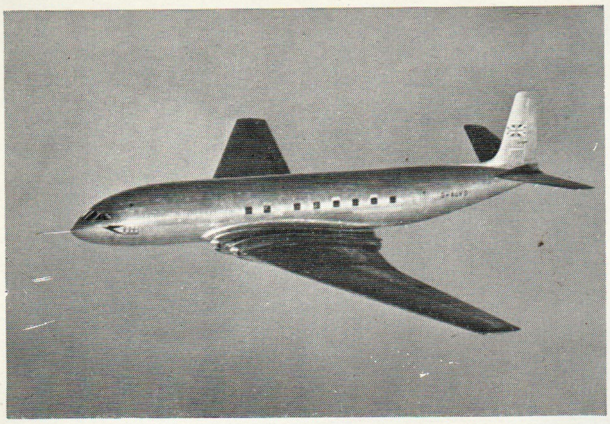


" Westalite " Chargers at the Peckham Depot of United Dairies, London, S.E.

" Westalite " Chargers at the Station Parade, Edgware Depot of Express Dairy Co.

" Westalite " Chargers at the Northcote Road, Wandsworth Depot of Express Dairy Co.

SPECIAL LIGHTWEIGHT RECTIFIERS FOR AIRCRAFT DC POWER SUPPLY



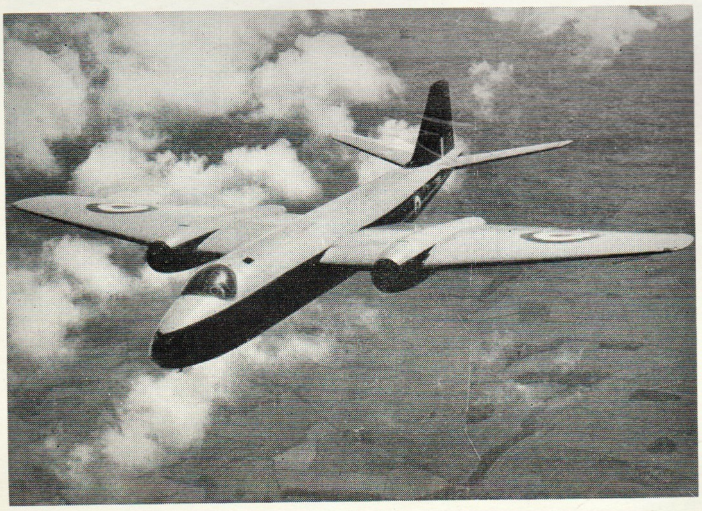
" **Comet** "
(by courtesy of The De Havilland Aircraft Co. Ltd.)

" **Brabazon** "
(by courtesy of The Bristol Aeroplane Co. Ltd.)

" **Hermes IV & V** " **Aircraft**
(by courtesy of Handley Page Ltd.)

These famous aircraft are included in the aeroplanes receiving their main DC power supply from forced cooled special lightweight Westalite rectifiers.

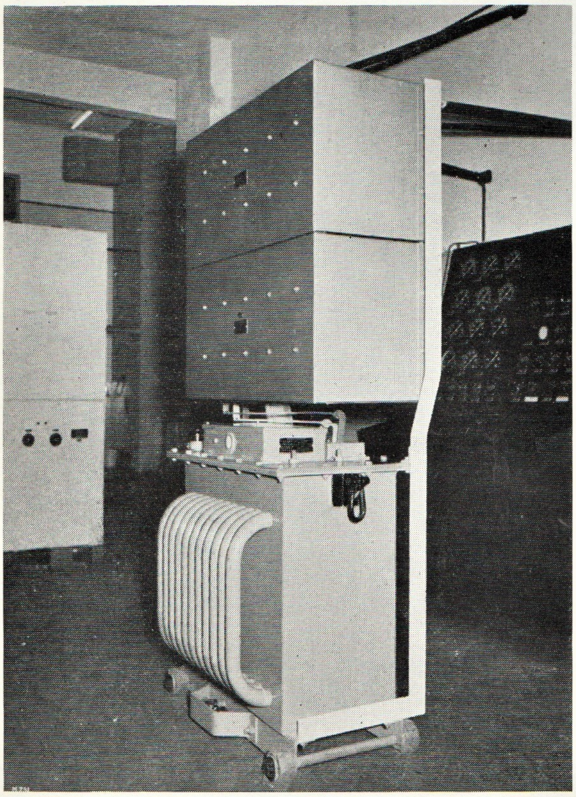
OTHER APPLICATIONS OF RECTIFIERS TO AIRCRAFT



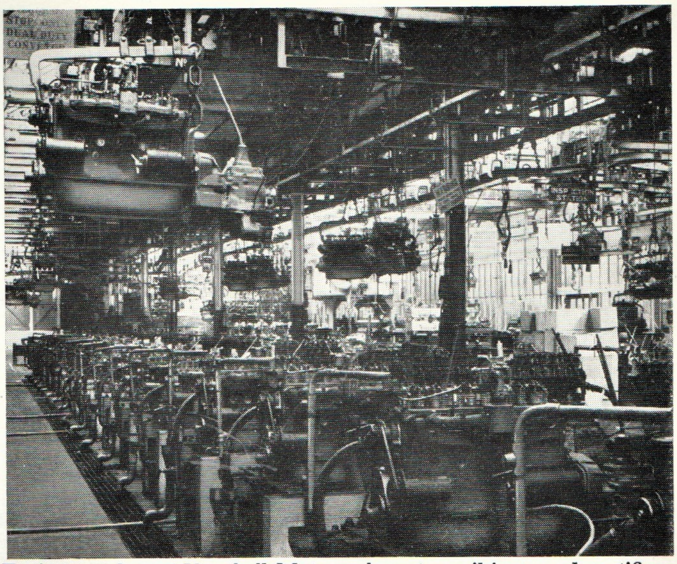
The " Canberra " with engine control by Ultra magnetic amplifier using Westalite rectifiers.

(by courtesy of The English Electric Co. Ltd.)

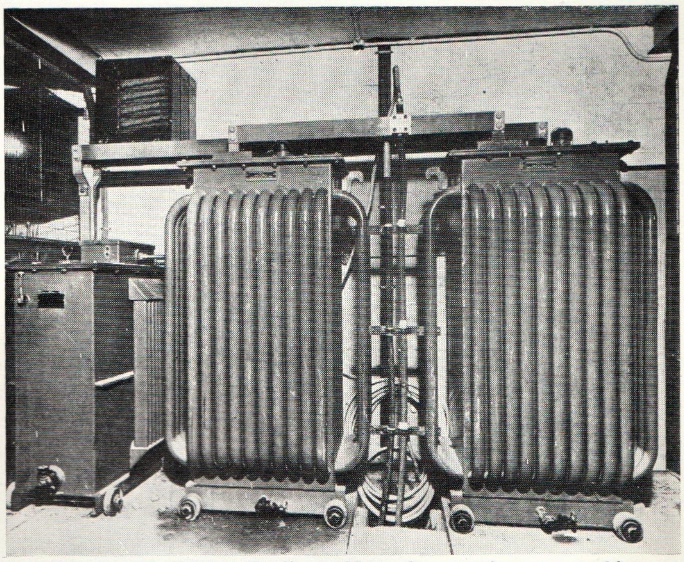
WESTALITE RECTIFIERS FOR STARTING ENGINES



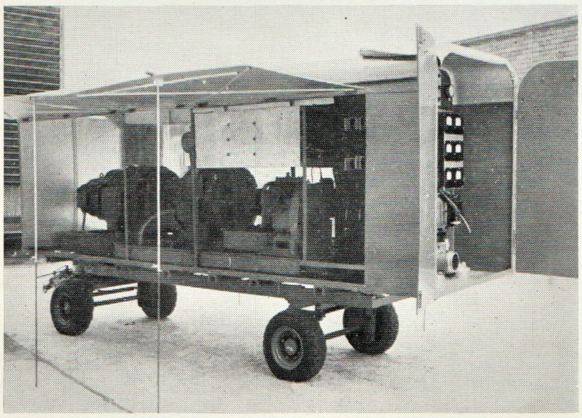
Westalite rectifiers and oil-immersed transformer used for starting Proteus propeller jets on test beds.
(by courtesy of The Bristol Aeroplane Co., Ltd.)



Engine test bay at Vauxhall Motors where two oil-immersed rectifiers are used for starting the engines.
(by courtesy of Vauxhall Motors, Ltd.)



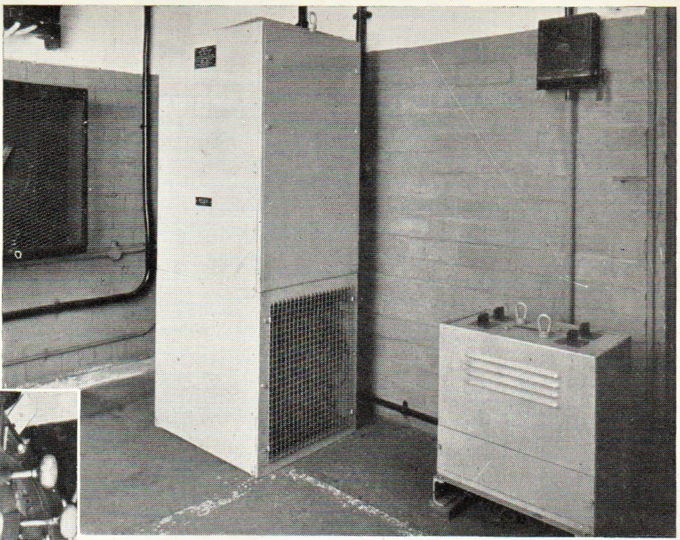
Oil-immersed "Westalite" rectifiers for starting gas turbines.
(by courtesy of Messrs. Rolls-Royce Ltd.)



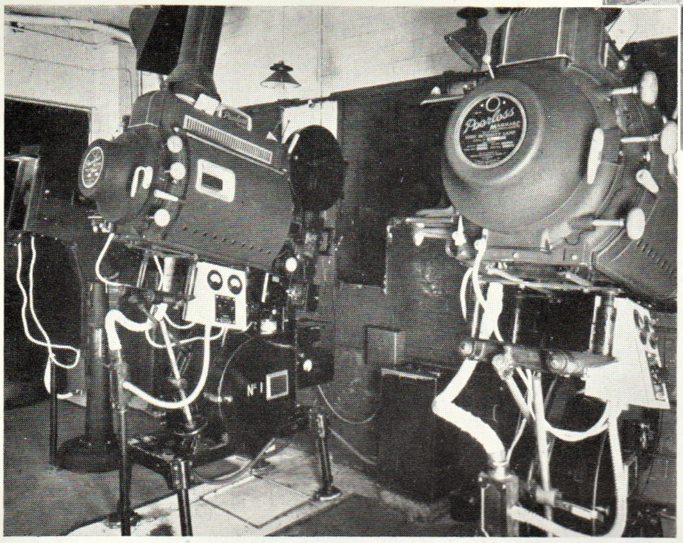
A mobile multi-output electric supply unit giving three outputs one of which is 112 volts 200 amperes obtained from Westalite rectifiers.
(by courtesy of The Bristol Aeroplane Co., Ltd.)

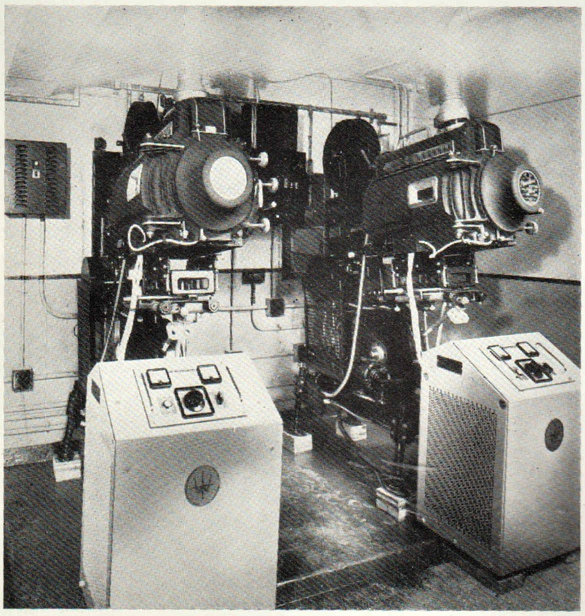
"Westalite" engine starter for 'buses.
(by courtesy of Rochdale Corporation.)

WESTALITE THREE-PHASE AND SINGLE-PHASE RECTIFIERS FOR CINEMA ARCS

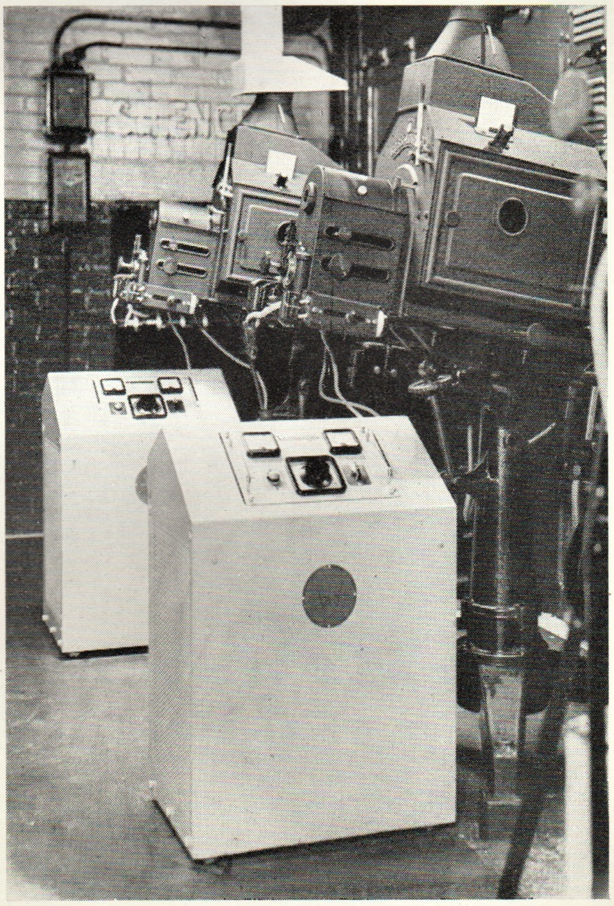


Three-phase " Westalite " rectifier installed at the Futurist Cinema, Birmingham.



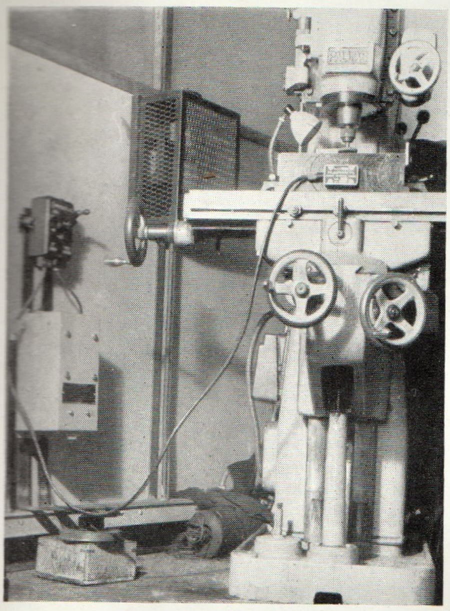


Single-phase cinema arc rectifier installed in the Projection Room of the Rex Cinema, Lewisham.

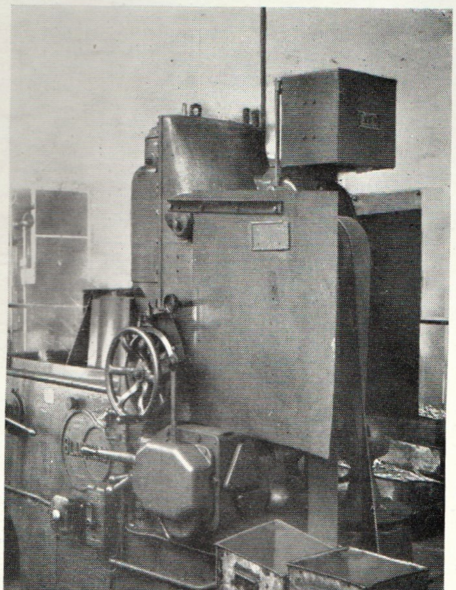


Single-phase cinema arc rectifier installed in the A.B.C. Regal Cinema, Caversham, Reading.

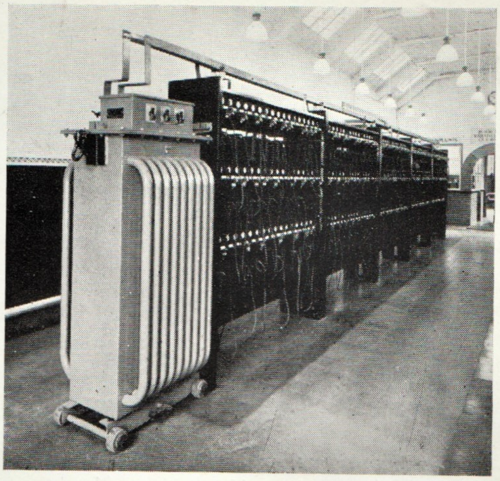
THE VERSATILITY OF WESTALITE RECTIFIERS



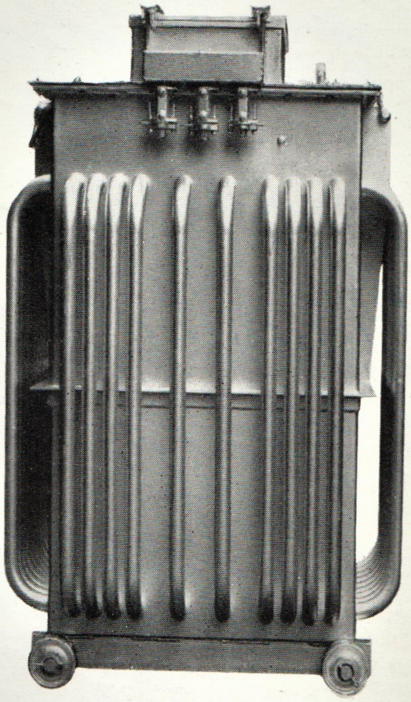
" Westalite " rectifier operating a Humphrey's Magnetic Chuck.



" Westalite " rectifier operating a Blanchard magnetic circuit table.



Oil-immersed " Westalite " rectifier feeding a 500 miners' cap lamp installation.



Oil-immersed " Westalite " rectifier for constant current cathodic protection of buried pipe lines and structures.

" Westalite " hermetically sealed rectifier fitted underneath petrol tank for charging motor cycle batteries.

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