No. 156

The Institution of Post Office Electrical Engineers.

Modern Tendencies in the Supply of Power to Telephone Exchanges

By

H. C. JONES, B.Sc. Eng. (Hons.)

A Paper read before the London Centre of the Institution on the 9th October, 1934, and at other Centres during the Session.

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1. Introduction.

It is unnecessary to emphasise to electrical engineers the importance of continuity of service. To those interested in electrical communications this aspect is of paramount importance and one hesitates to imagine the chaos which would result from a big breakdown of such systems. As most routes contain a number of channels, faults on individual circuits are usually relatively unimportant. Power is, however, required for the proper functioning of all circuits and it is, therefore, not necessary to stress the need for a reliable source of power supply for communication services. In this country reliability in performance of power plant in the past has been achieved by

(i) Simplicity of circuit design so as to ensure a power system relatively immune from faults and one where faults could rapidly be localised when they did occur.
(ii) The retention over a long period of years of arrangements which had been found to be satisfactory so that they were well known to the staff.
(iii) Simple maintenance procedure.
(iv) Probably the most important, the provision of plant on a relatively liberal basis.

2. Reason for introduction of new types of Power Plant.

Despite the fact that existing schemes of power plant can be regarded as having given satisfactory service, it has lately been evident that appreciable economies both in capital and maintenance could be effected by different methods of working. Other administrations for some considerable time have used different and cheaper methods of supplying power for large telephone exchanges than has the Post Office. The systems which have been used, however, frequently seemed to have disadvantages, as there is evidence that frequent changes in design have taken and are still taking place.

In this country we have waited until we could see our way to reduce the size and costs of our power plant without sacrificing the reliability and simplicity of the existing schemes. The Department is now in a position to go ahead with the installation of improved types of telephone exchange power plant of all sizes which, whilst having the simplicity and reliability of the existing schemes, have the advantages of appreciably lower capital and maintenance costs. It is the purpose of this paper to indicate the methods used for supplying power to telephone exchanges by other administrations and to describe the schemes which are now being introduced by the Department.

3. Basic considerations in design of Telephone Exchange Power Plant.

At the outset some general principles which will be referred to later should perhaps be mentioned. In these days it is quite possible to serve telephone exchanges direct from generators or rectifiers. This has been done at Holborn exchange although the power plant is not designed specially for such a service. In the *P.O.E.E. Journal,* volume 26, part 2, page 124, reference is made to machines which have been installed in the Witwatersrand Area, South Africa. These machines can themselves maintain the exchange service without the aid of batteries. Units utilising metal rectifiers are frequently used for serving small exchanges direct from the mains.

Most of the schemes to be described incorporate the use of secondary cells and the main reason is, of course, that public electricity supplies are not sufficiently reliable.

In this connection, it is interesting to recall several large breakdowns which have occurred recently and affected a number of exchanges as follows :—

Date.	No. of Exchanges to which Mains Power Supply failed.	Approximate duration of stoppage.
6-12-33	7	1 to 2 hours.
24-1-34	11	¾ hour.
27-2-34	5	¾ hour.
29-7-34	113	1 to 2 hours.

The distribution systems concerned were in each case supplied from the grid system.

Below is a table showing the number of failures of mains power supply to telephone and telegraph installations in this country for 3½ years ending June 30th, 1934.

Year.	No. of Failures.	Average Time of stoppage. Hours.	Period of longest stoppage. Hours.
1931	256	1.3	24
1932	309	0.91	18.5
1933	256	1.5	72
1934 (6 months)	138	1.0	18
3½ years	959	1.2	72

Sufficient has been said to indicate that public electricity supplies in this country have not the same reliability from a continuity point of view as that which seems desirable in a good telephone system. Hence, some form of reserve is necessary to maintain the telephone service during such power supply stoppages. The obvious means to consider for providing a standby are :—

(i) Prime movers.
(ii) Secondary cells.
(iii) Both prime movers and secondary cells.

A single prime mover to be an efficient reserve could not be run continuously. Under such conditions it would require comparatively frequent dismantling for overhauls and at such times would offer no safeguard against a power supply breakdown. Hence, at least two prime movers each capable of dealing with the peakload would be necessary and such provision is hardly a commercial proposition. The prime mover must therefore ordinarily be stationary. It is then practically impossible at a power breakdown to avoid some dislocation of the service as, without extravagant design, the prime mover cannot be started up and take the load before the voltage of the slowing down motor generator sets reaches the allowable minimum for the exchange system. On the other hand, a prime mover would be useful in cases of breakdowns lasting over a lengthy period of several days.

At the same time, the use of secondary cells enables the service to continue without any interruption until the battery is exhausted. If the stoppage lasts longer than the battery can serve the exchange, however, a breakdown occurs unless a prime mover is available.

The use of both a battery and prime mover reserve, however, covers any ordinary contingency, and this is the procedure adopted in this country. The provision of prime movers is not justified at each exchange on account of cost, but transportable charging sets are available at the main centres throughout the country and any individual exchange can obtain the service of such a set within the period of the battery reserve.

4. Systems of working large secondary batteries.

Having indicated the necessity for the continued need of secondary cells the main features of various general methods of working the cells will be briefly mentioned. An appreciation of these methods is essential to a proper understanding of the detailed schemes which will be dealt with later. The methods to be mentioned are :—

(i) Charge-Discharge working.
(ii) Assisted Discharge working.
(iii) Floating.
(iv) Trickle Charging.

Charge-Discharge working is the system which has been used by the Department for a long period of years. Two batteries are required, each being alternately charged and discharged. The discharges should be through a reasonably large proportion of the capacity. Periodically, about once a month, the battery should be brought into a thoroughly charged condition by an extended charge. The other charges should be terminated somewhat before the battery attains a thoroughly charged condition. This method of working has the advantage of giving a constant check of the condition of the battery. Any deterioration is evident during ordinary working. An emergency condition such as a power supply breakdown does not appreciably increase the loading of the battery and therefore does not involve a much more onerous condition than is involved by ordinary working. This is an important argument in favour of this scheme. On the other hand this method of working involves a repeated cycle of increased and decreased volume of the active material of the plates during discharge and charge respectively, a loosening and scouring of active material during the gassing period of charge, and a gradual growth of the positive plates as the underlying lead is changed to active material to make good that lost by gassing, all of which tend to shorten the life of the plates.

With the Charge-Discharge method of working may be incorporated what is termed Assisted Discharge working. This consists of running a generator in parallel with the battery to take a proportion of the load. The discharge thus lasts a longer period than would otherwise be the case and the number of cycles of charge and discharge is reduced.

Floating consists of running a generator or generators in parallel with the battery connected to the load, with the machine arranged to take practically all the load. The intention, with such a system, is usually to keep the battery continuously in a fully charged condition so that the maximum reserve is always available.

The capacity of the battery is therefore determined by the amount of reserve which it is considered advisable to provide. This is a distinct advantage so far as capital cost is concerned, compared with a cycle method of working, such as the Charge-Discharge scheme, where the frequency with which it is convenient and economical to charge, largely determines the capacity to be provided. For instance, with the Charge-Discharge scheme, it has been usual at a fully-equipped exchange, to charge a battery each day. Each battery had therefore to be sufficiently large to last for 24 hours, irrespective of the question of reserve capacity, which meant the provision of a total capacity at least twice the ultimate daily load. Assuming, however, that requirements from an emergency point of view are only 12 hours' reserve, a total battery capacity of little more than this is required for a properly designed floating scheme. Batteries are by far the most costly item of large exchange power plants, and a saving in provision of battery capacity to the extent mentioned is an attractive proposition from the point of view of capital cost.

The adoption of floating schemes further offers big advantages from the point of view of life of the secondary cell plates. The elimination of a regular system of charge and discharge prevents that continual wear and tear of plates which tends to shorten their life under Charge-Discharge working, and twice the life at least is to be expected under floating conditions. With the floating system, the battery is always in a charged condition so that the number of records of specific gravity, etc., can be considerably reduced with consequent saving of maintenance time. Gassing is also almost eliminated and much less water is used, which means that appreciably less topping-up is required.

It is an inherent characteristic of secondary cells that when standing idle they tend to discharge slightly by local action. The extent of the discharge is not a definite value and depends on the particular conditions at each installation. It may, however, reach 2% per day although normally it is probably of the order of 1% per day.

In order to keep an idle or stand-by battery in good condition it is essential that this self-discharge be counteracted by charging. A convenient way of doing this is by a continuous charge at a very low rate, just sufficient to nullify the effects of the self-discharge. Such a charge is termed a trickle charge. Assuming that a battery of say 1,000 Ah. capacity loses 1% of its charge per day, that is 10 Ah. when standing idle, this can be nullified by a continuous charge of 0.4 amps.

The same condition applies to a floating battery. If the machines are adjusted to take the load the floating battery is really in a stand-by condition and will deteriorate unless it receives some charge.

The normal condition of both the purely stand-by and floating battery is therefore that they are in a fully-charged condition and receiving a small charge. Fig. 1 shows the voltage which typical fully-charged cells attain when charged at various rates. The minimum rate which is likely to keep any cell from deteriorating is about the 2,500 hour rate. It will be seen that at this rate the voltage is 2.15 and that it increases with the current.

When a cell is normally floating its voltage should be of the order of 2.15. When it is discharging its voltage drops to between 2 and 1.8.

These voltage characteristics of secondary cells are the main factors controlling the design of floating systems of power plant for automatic exchanges where the voltage limits are somewhat critical.

5. Principle of Design of a Floating System for Automatic Exchanges.

Many floating systems have been based on the use of one set of cells. As it is necessary to maintain a voltage of 2.15 per cell, as described above, and the allowable limits for the power supply are 46-52, it is obvious that the floating battery must comprise either 22, 23 or 24 cells. 24 cells gives a voltage almost on the limit of 52 and does not allow much tolerance for the functioning of the automatic voltage control apparatus. 22 cells gives a voltage rather close to the bottom limit. Further, if the floating generator shut down, the voltage of a 22 cell battery would immediately drop below the minimum allowable limit for the exchange working. 23 cells at 2.15 volts give a voltage reasonably midway between the bottom and top limits. This number of cells has been selected as the standard by a number of administrations.

The voltage characteristics of secondary cells at various rates of discharge are shown in Fig. 2. It will be seen that very early in the discharge, the voltage drops to below two volts per cell, and hence very little capacity of a 23 cell battery is effective for supplying an automatic exchange system. In fact, allowing for the drop of voltage through leads and fuses, the voltage from a 23 cell battery applied to

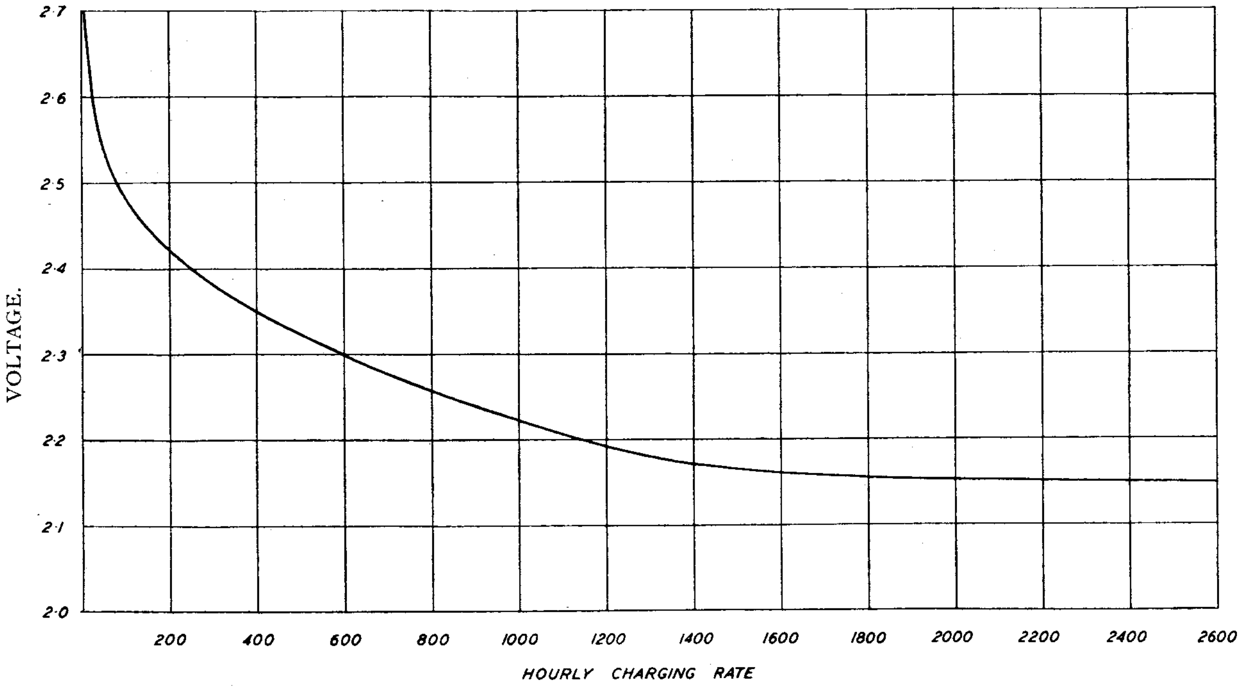


Fig. 1.—Variation of Voltage of Fully Charged Lead Acid Cell with Charging Rate.

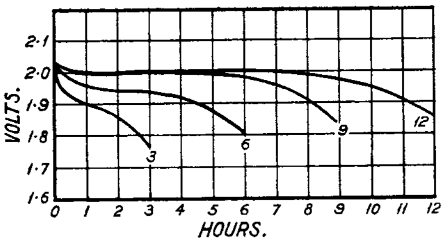


FIG. 2.—TYPICAL CURVES SHOWING VARIATION OF VOLTAGE DURING DISCHARGES COMPLETED IN 3, 6, 9 AND 12 HOURS.

the actual equipment will probably be below the allowable minimum immediately it commences to discharge. In order to use the battery capacity effectively, it is necessary, therefore, to increase the number of cells, whilst the battery is discharging. In the various systems, either 2, 3 or even 4 cells have been used for this purpose. These are switched into circuit either singly or in groups as required. As the discharge circuit must not be broken whilst this is being done, the cells are short-circuited during this process, and whilst due to the infrequency of the operation, the cells will not suffer unduly, heavy switch gear is necessary, which increases the cost, size and complexity of the power board. The end cells being separate from the floating battery and being very little used, make it necessary to have proper facilities for maintaining their condition. This is usually done by means of a trickle charge.

So far then, the scheme is quite simple, but the conditions which arise when emergencies occur, must be considered. Assuming the power supply to fail, and the main battery and its end regulating cells to be discharged to an appreciable extent, they must be re-charged again as early as possible. Fig. 3 indicates the voltage of secondary cells during charge. At whatever the rate of charge, it is impossible to prevent the voltage of the 23 cells rising to well above the maximum allowable limit of 52. To overcome this difficulty, there are two possibilities. The first is to introduce counter E.M.F. cells into the discharge circuit, and the second is to work the exchange direct from machines whilst the battery is being re-charged. The counter E.M.F. cell scheme has been widely used, but this arrangement again increases the cost and complexity of the plant. Due to the comparatively little use the counter E.M.F. cells get the question of maintaining their condition arises, and this is usually done by means of a trickle charge.

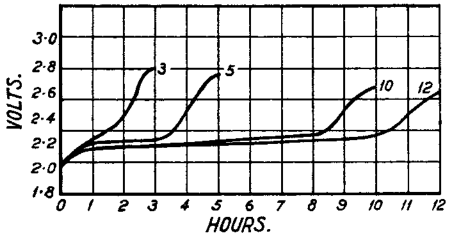


FIG. 3.—TYPICAL CURVES SHOWING VARIATION OF VOLTAGE DURING CHARGES COMPLETED IN 3, 5, 10 AND 12 HOURS.

The other possibility, of disconnecting the battery from the exchange, obviates the provision of counter E.M.F. cells, but leaves the exchange without any reserve whatever whilst the battery is being recharged, and makes a breakdown of the service inevitable in the case of a failure of the power supply during the re-charging process.

Schemes involving the principle just mentioned have recently been installed at a large number of exchanges in the Witwatersrand Automatic Area, South Africa, many exchanges controlled by the United River Plate Telephone Co. in Argentine, and also in the U.S.A.

However satisfactory a power system may be from a maintenance point of view, the secondary cell plates are likely to require renewing occasionally during the life of the exchange and such work is most effectively done by taking the battery out of commission. If this is done with the systems just considered, the exchange will be left without reserve. The alternatives are to provide a portable emergency battery which is impracticable in the case of big installations or to do the work plate by plate whilst the battery is in service. This can be done, but is a complicated and dangerous operation. It will be seen, therefore, that there are appreciable disadvantages with the single battery floating scheme, particularly from the point of view of reliability.

6. The Divided Battery Float System.

In the floating scheme which the Department is standardising these disadvantages, however, are eliminated. The Department's scheme is known as the Divided Battery Float System and, so far as is known, the principles on which it is based are unique so far as telephone exchange practice is concerned. The scheme will be described as it was originally proposed, for a single-unit 50-volt automatic exchange. Two small 25 cell batteries are used; the batteries are of equal capacity and the total capacity of the two is equal to the maximum reserve capacity it is desired to provide. This is sufficient to last the busiest twelve hours of the day. As regards machines, two main generating sets, the total output of which is equal to the ultimate peakload, and a trickle charging unit are necessary. The charging units are of different sizes. By far the greater part of the exchange load occurs between 9 a.m. and 6 p.m. and the load during the remainder of the 24 hours is comparatively light. In order to float economically during this time it is desirable to use a comparatively small machine and it is for this reason that machines of different sizes are used. The size of the smaller machine is determined by the fact that it should be able, in case of a breakdown on the other set, to work the exchange itself at the ultimate date. In these special circumstances, the Charge-Discharge method of working would be resorted to and the small machine would run continuously. The size of the larger machine is the difference between the ultimate peakload and the output of the small machine. The large machine has actually about 2½ times the output of the small one.

Each of the main generating sets is provided with an automatic voltage regulator to keep the voltage of the battery terminals between the limits of 50.25 and 51.75 during the floating. Each machine is also provided with a choke coil.

The circuit arrangement is shown in Fig. 4 and the normal method of working is as follows :—

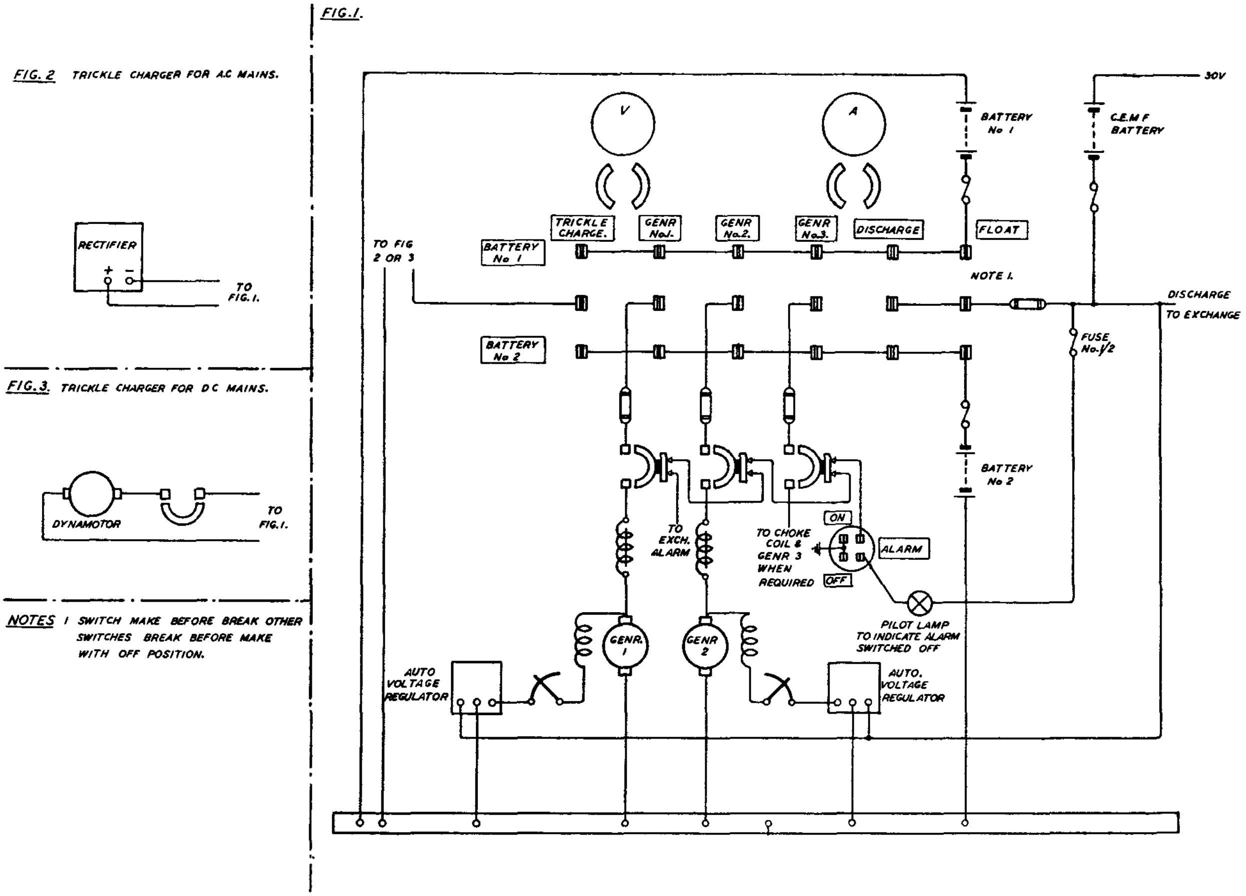


Fig. 4.—Divided Battery Float Power Plant. Schematic Diagram.

Either one or both generators are floated on one of the main batteries. During periods of light load as at night or week-end, the smaller machine is used whilst during the periods of heavy load, either the larger or both machines are required. Each main battery is used as the floating battery alternately for periods of a week at a time. The voltage limits of 50.25 and 51.75 are the highest values which can be worked to having in mind the allowable limits for the exchange apparatus, but nevertheless a 25 cell battery working continuously at such a voltage would gradually deteriorate as such values represent a voltage of less than 2.15 per cell, the minimum at which cells may be kept in good condition indefinitely. During the alternate weekly periods when the batteries are not floating they will, therefore, be given a continuous trickle charge at a rate sufficient to make good the small losses which occurred during the floating period and those due to local action which tend to occur during the idle periods. If necessary, they can also be given a refreshing charge at an ordinary charging rate during this period.

Assuming a power supply failure to occur, the floating generator will be disconnected from the battery. As the battery contains 25 cells, however, it can itself maintain the service for several hours, even though there may be no engineering officer available at the time. When convenient, however, the second battery which is on its trickle charge period , can be switched on to the exchange. Thus the exchange service is maintained without interruption. When the main power supply is reconnected, normal working is resumed and as soon as the exchange load can be taken by a single machine, the idle battery is charged by the second motor generator set. There is, therefore, no difficulty with the charging process as there is in the single battery float schemes. After completion of the charge the batteries are changed over, the fully charged battery being floated on the exchange and the other being charged.

When major repairs to the batteries are required, each battery would be out of commission for a period of about two weeks. The exchange service would be in no way interfered with though, of course, the reserve capacity would be reduced to half the normal amount.

In the event of the generating set being out of commission, Charge-Discharge working is resorted to so that the full-load output of the remaining machine can be utilised continuously, to charge up the batteries in turn. The size of the machines mentioned will enable the service to be properly maintained under such conditions though, of course, with the expenditure of some overtime.

The Divided Battery Float System, has, therefore, the advantages of being both a simple scheme and enabling all ordinary emergency conditions to be met without interfering with the power supply to the telephone equipment.

The following information is supplied for those interested in the detail of the scheme to show the method of arriving at the rating of the various items of plant :—

Batteries. It has been decided, in future, to provide batteries on a basis of 12 busy hours reserve. A scrutiny has been made of the load curves of various typical exchanges to ascertain what percentage of the day's load occurs in certain periods of busy hours. The figures can be taken as typical of the usual large exchange in this country and details are as follows :—

Busiest 12 hours—9.30 a.m. to 9.30 p.m. 90% of the day's load.
,, 8 ,, —9.30 a.m. to 5.30 p.m. 76% of the day's load.
,, 4 ,, —9.30 a.m. to 1.30 p.m. 44% of the day's load.

As a general basis capacity equivalent to 0.9 of the day's load will be provided. Usually each battery will, therefore, have a capacity of 0.45 of the day's load.

Machines. The sum of the outputs of the charging sets is required to be equal to the ultimate peak-load. It is found that one sixth is a safe value for the numerical relationship between the daily load in ampere-hours and the peak exchange load in amps.

Hence, if D be the ultimate daily load, then $\frac{D}{6}$ or 0.17D is the sum of the outputs of the two charging sets. The minimum size of the small machine is determined by the fact that in case of emergency it must be capable, by running on full load continuously, of supplying sufficient power to work the exchange itself, the batteries being worked on a Charge-Discharge basis. Allowing for the battery efficiency the machine must, therefore, be capable of supplying 1.15D ampere-hours at 57 volts in 24 hours, *i.e.*, its minimum output must be 0.048D or, say, 0.05D.

The output of the large machine is therefore $0.17D - 0.05D = 0.12D$, *i.e.*, the large machine has about $2\frac{1}{2}$ times the output of the small one.

The trickle charge unit will be based on supplying 2% of the battery capacity to cover local action whilst the battery is standing idle, 2% to cover possible loss of capacity during the previous floating period and 1% for marginal purposes. It will, therefore, be based on supplying up to 5% of the battery capacity per day.

Hence its output will be

$$\frac{0.5 \times 0.45D}{24} = 0.00094D, \text{ say } 0.001D \text{ amps.}$$

Fig. 5 shows curves indicating the efficiency of the system from a power point of view when an exchange is fully loaded. One curve shows the exchange discharge in amperes during a typical period of 24 hours. The relative outputs of the two machines are shown by horizontal lines. It is assumed that the large machine carries the exchange load between 9.30 a.m. and 7 p.m. and that during the other period of the 24 hours the small machine is running. Taking into account the varying loading of the machines the top curve shows how their efficiency varies during the 24 hours. The input curve is derived from the load and efficiency curves and shows the power being taken from the mains at any time.

The load of the average new exchange is about 50% of the ultimate load. The following table, which summarises information derived from curves such as Fig. 5, indicates the power efficiency of the system initially, ultimately and part way through the life of the exchange :—

	Conditions when load is		
	50% of ultimate load.	80% of ultimate load.	Ultimate load.
kWh from mains per day ...	0.045D	0.062D	0.072D
kWh used by Exchange per day	0.025D	0.041D	0.051D
Over-all efficiency mains to Exchange	56%	66%	71%

Where D is the numerical value of the ultimate day's load in ampere-hours.

It is interesting to compare the power efficiency of the floating system with that of the Charge-Discharge system. The method of charging in the Charge-Discharge scheme is to use the full output of the charging unit until the voltage of the 25 cell battery reaches 59 and then to reduce to the 12 hour rate. For the first three-quarters of the charging period the machine is working at its full load and full efficiency for which a good average figure is 78%. During the last quarter of the period it is working at about 60% of its load and 75% efficiency. The efficiency of the machine for the whole of the charge can, therefore, be taken as

$$0.75 \times 78 + 0.25 \times 75 = 76.4\%$$

A good average working figure to take for the watt-hour efficiency of the battery is 70%. The over-all efficiency of the system is therefore about $70 \times 76.4 = 53.5\%$. It will be seen, therefore, that there is not a great deal in favour of the floating scheme so far described from the point of view of power costs when the exchange is first installed.

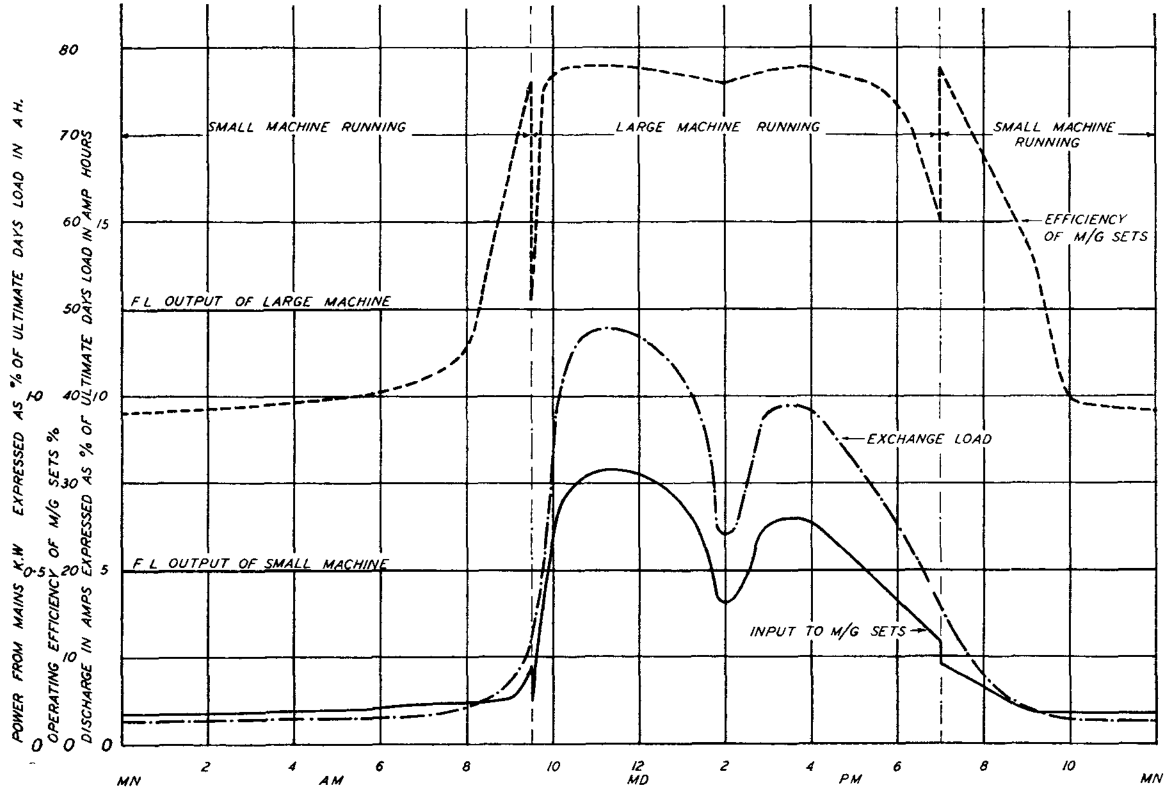


FIG. 5.—EFFICIENCY AND POWER PERFORMANCE OF DIVIDED BATTERY FLOAT SCHEME. (EXCHANGE FULLY LOADED).

Later on the machines become more heavily loaded, however, and the saving in power is appreciable.

[NOTE.—Since the paper was read it has been decided to modify the two machine arrangement so far described. Six sizes of plant have been standardised, the battery and machine equipment for each being as shown below :—

Ultimate load in Ahs per day.		Capacity of each of the two batteries. Ah.	Number of Motor Generator Sets of under-mentioned outputs required at ultimate date.				
Exceeding	Not exceeding		100 amps.	200 amps.	300 amps.	400 amps.	500 amps
2000	3000	1200	1	2	—	—	—
3000	4000	1650	1	—	2	—	—
4000	5000	2100	1	—	—	2	—
5000	6000	2600	—	1	—	2	—
6000	8000	3000	—	1	—	—	2
8000	10000	4000	—	1	—	—	3

It will be seen that the full complement of machines will be either 3 or 4 and of these one will be of relatively small output for dealing with the night load. The small machine and such others of the large ones necessary all working together to cope with the peakload 5 years after the opening of the exchange will be provided initially and the others later when required.

By using a larger number of smaller machines it is possible to work the machines at a higher efficiency than with the two machine scheme previously described. The 3 or 4 machine scheme, also has obvious advantages during the periods when one of the machines is out of commission.

It will be seen from the table that it is intended to use the divided battery float scheme for exchanges estimated to require upwards of 2000 Ah. per day ultimately.]

In passing, it is interesting to note that the floating systems which have recently been provided in several large exchanges in the U.S.A. incorporate the use of two batteries. Each main battery, however, contains only 23 cells and it is, therefore, necessary to introduce end cells to maintain the voltage during discharge. The switching allows of either two or four cells being added for this purpose. The end cells are normally kept in condition by a trickle charge. They are associated with the discharge circuit and the only means of charging them is to place them in series with the battery floating on the exchange and to control the floating generator by hand. There is no doubt that the system is far more complicated and less flexible than that adopted by the British Post Office.

7. All Mains Units for C.B.S. and Magneto Exchanges at present served by Primary Cells.

There are about 1500 exchanges of the C.B.S. and Magneto type served by Primary Cells They are, of course, small exchanges requiring a comparatively small amount of current, but power supplied in this way costs upwards of £1 per kWh. The performance of primary cells leaves much to be desired as the PD of a battery may fall from of the order of 36 to 16 volts during its life and close attention is necessary to cleaning and refreshing. In many country areas where Primary Cells have been used of necessity in the past, A.C. power supplies are becoming available. In such places it is proposed to replace the primary batteries by an all-mains unit which will, of course, be entirely automatic in operation and require practically no attention. Two schemes are being tried.

One is as shown in Fig. **6**. The apparatus consists essentially of a main full-wave rectifier unit, a filter, a small capacity battery containing 10 secondary cells and an auxiliary rectifier, which acts as a valve, in series with the battery. Normally the current required for the exchange will be supplied direct by the rectifier which is so adjusted that with the minimum mains voltage applied to the primary of the transformer and with the maximum load the rectifier is likely to experience, its output voltage will not be less than 20. This proviso ensures that when the main rectifier is operating, the battery will not discharge to any appreciable extent. When the load is lighter and the mains voltage higher the voltage across the exchange is higher than 20, and the battery receives a charging current. Under these conditions the auxiliary rectifier in the battery circuit offers a high resistance to the charging current, and but little current flows through the battery. When, however, the mains are disconnected and the output of the rectifier ceases, current is immediately fed to the exchange from the battery. The current through the rectifier valve having reversed the latter now acts in its low resistance direction. The current to the exchange is thus not interrupted.

It is desirable that whenever the main rectifier ceases to function a warning should be given, as otherwise a failure of the rectifier, due to, say, a blown fuse, might pass unnoticed, until the power supply to the exchange failed as a result of the battery becoming exhausted, and a relay is therefore placed across the secondary of the transformer for this purpose. On releasing, one of its contacts gives an alarm condition and a second short-circuits the auxiliary rectifier so as to reduce to a negligible value the voltage drop of about 1.5 to 2 volts which otherwise takes place across it while it is carrying the peak exchange load. The voltage characteristics of the main rectifier unit and filter are shown in Fig. **7**. Three curves are shown. The centre one for a certain declared mains voltage, the lower one for a supply 6% less than the declared supply and the higher for a supply of 6% higher than the declared value. The ±6% curves are shown because these represent the limits between which power supplies are allowed to vary by Electricity Supply Regulations, 1934.

With this unit the maximum voltage is being

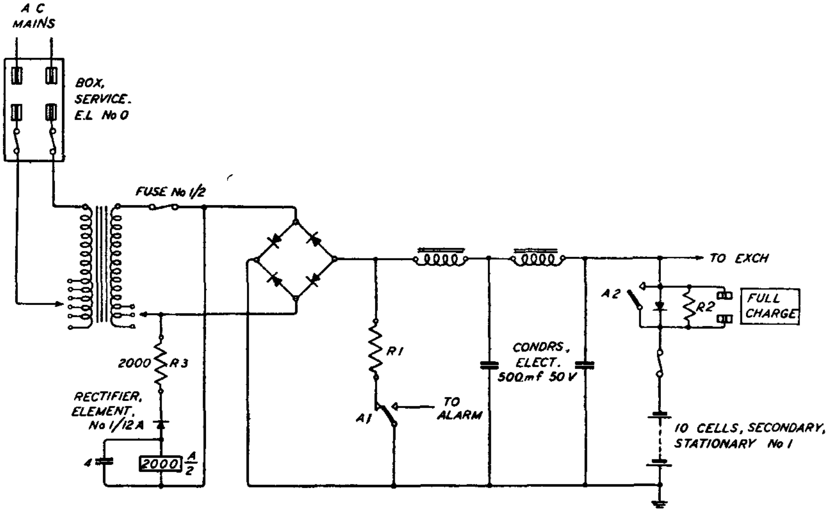


FIG. **6**.—MAINS UNIT FOR C.B.S. AND MAGNETO EXCHANGES WITH SECONDARY CELL RESERVE BATTERY.

NOTE :—Relay " A " is normally operated and its contacts are shown accordingly.

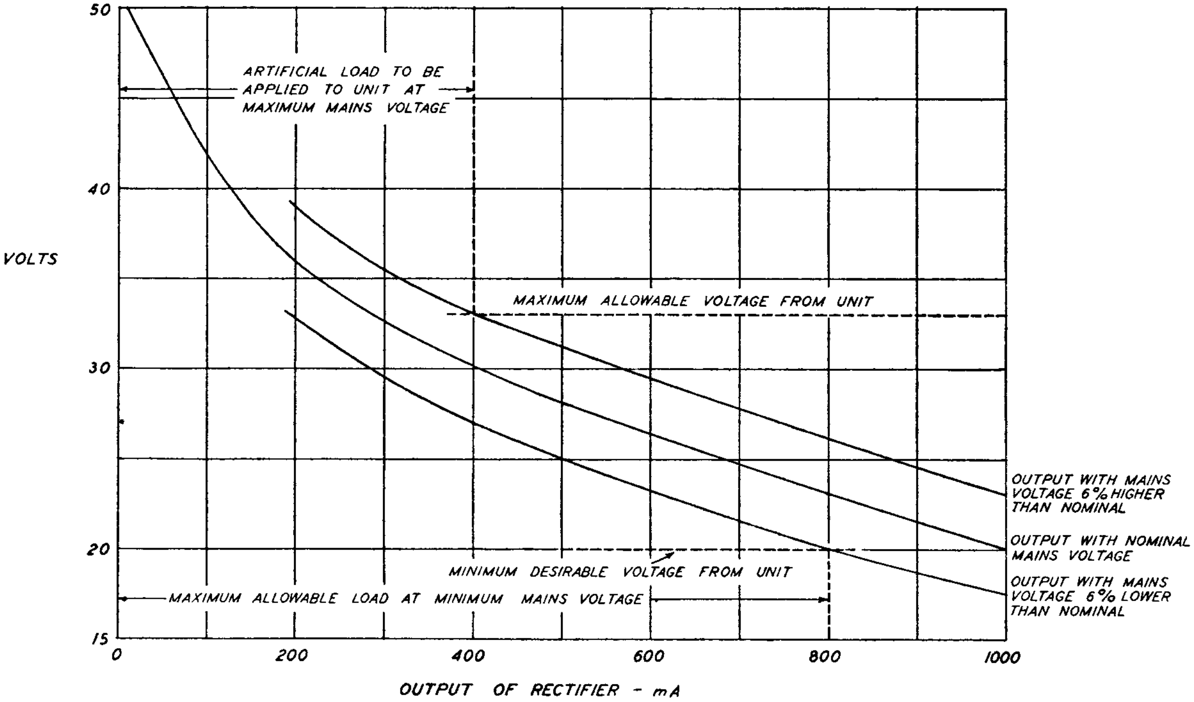


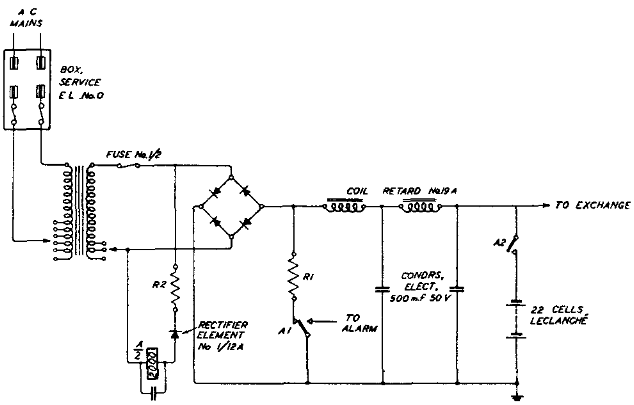
FIG. 7.—VOLTAGE CHARACTERISTICS OF MAINS UNITS FOR C.B.S. AND MAGNETO EXCHANGES.

limited to 33. It will be seen that, with the mains voltage 6% above the declared value, the voltage of the unit is 33 when a load of approximately 400 milliamperes is applied. Hence in order to ensure that the voltage of the rectifier does not, under any circumstances, exceed 33, it is necessary to place a resistance of about 80 ohms across its terminals, so that even when there is no exchange load the unit will be loaded to 400 milliamperes. When the mains voltage is at its lowest limiting value, it will be seen that a load of 800 milliamperes can be applied before the output voltage decreases below the limiting minimum value of 20. The total resistance of the load under these circumstances is therefore $\frac{20}{0.8} = 25$ ohms. As the permanent load is 80 ohms, the equivalent minimum resistance of all the exchange apparatus in use at one time can be 36 ohms. The maximum exchange load can therefore be $\frac{20}{36}$ or 0.55 amperes. Whilst it is essential that the 80 ohm load be connected to the unit when it is operating from the mains, it is desirable that it be disconnected when for any reason the rectifier unit ceases to function, as otherwise it will represent an additional and undesirable load on the reserve battery. A contact on the alarm relay which has been mentioned earlier is, therefore, arranged to disconnect the 80 ohm resistance when it releases, and conversely to apply the load when it operates.

The reserve battery is of secondary cells which require a trickle charge to keep them in good condition. The auxiliary rectifier does not allow sufficient current to pass for this purpose, and it is therefore necessary to place a resistance across its terminals. The average voltage at which the apparatus functions, allowing for the light night load, is about 29 volts. The battery when on trickle charge will be about 22 volts. It is of 8 ampere-hour capacity. A liberal trickle charge rate will be sufficient to supply 2% of the capacity per day, that is 0.16 ampere-hours per day, or a continuous current of 0.07 amperes. Hence the combined resistance of the auxiliary rectifier and resistance across its terminals, must be about $\frac{29 - 22}{0.007}$, *i.e.,* 1,000 ohms. The auxiliary rectifier is of very high resistance, and the resistance across its terminals can very well be 1,000 ohms.

It is necessary to provide facilities for charging the cells should they for any reason become discharged. This is done by providing a tumbler switch to short-circuit the auxiliary rectifier and connect the battery direct to the main rectifier unit. The charging current will start at about 1 ampere, and will gradually taper off as the charge progresses, to about $\frac{1}{2}$ ampere. There is, of course, no objection to the exchange being connected to the circuit during the charging operation.

The alternative to the scheme just described is generally on similar lines, except that it utilises a primary cell reserve battery. This consists of 22 Leclanché cells. Due to the difference between the open and closed circuit voltage of these cells, it is not practicable to have the battery permanently connected across the exchange, as in the secondary cell case. The circuit arrangement is shown in Fig. **8**. The circuit utilises the alarm relay in the same way as does the last scheme. The release of the relay on cessation of the A.C. supply to the rectifier unit, switches into circuit the primary cell battery. During the releasing period of the relay the condensers in the filter discharge to the exchange so that, although there is a momentary drop in the voltage applied to the exchange, the power supply is not actually interrupted.



NOTE :—Relay " A " is normally operated and its contacts are shown accordingly.

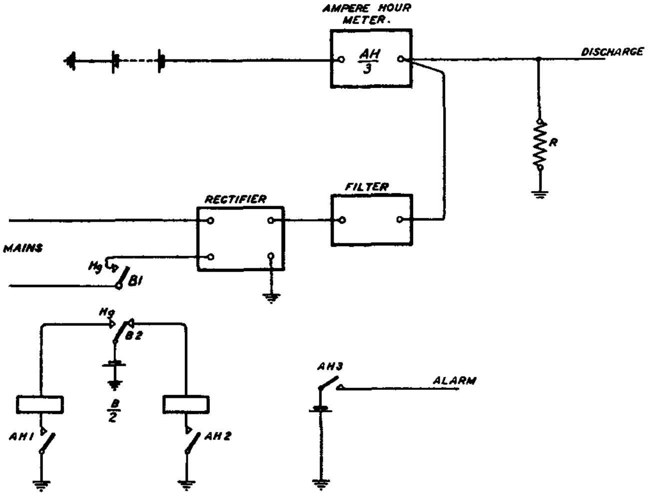
FIG. **8**.—MAINS UNIT FOR C.B.S. AND MAGNETO EXCHANGES. WITH PRIMARY BATTERY RESERVE.

Both the schemes are simple and cheap to install. Their initial cost is very little more than that of the annual requirements of primary battery material for renewal purposes at the average small exchange of the type mentioned, and the advantages from a maintenance point of view need no emphasis. Both schemes are being tried out and are likely to be provided extensively in the country districts in the near future.

8. Automatically Operating Single Battery Scheme with ampere-hour meter control.

It will have been appreciated that the scheme just described requires a comparatively large rectifier. In the first place only about half the rated output is used effectively, due to the poor voltage characteristics, and further the output which is used must be large enough to cater for the peak load of the exchange. This means, that when the exchange is lightly loaded the rectifier unit is also lightly loaded, and is therefore not being used to the best advantage. For instance, a 1 ampere rectifier is capable of supplying 24 ampere-hours per day, but, in the circuits just described, it would serve no larger an exchange than one requiring about 3 ampere-hours per day. This is not important when small sized installations are concerned and the output of the rectifier is comparatively small, but it becomes important as the size of the installation increases. In the schemes now to be described the rectifier is used always at its maximum output. Using the example just quoted a 1 ampere rectifier will, with this scheme, actually serve an exchange requiring at any rate 20 ampere-hours per day.

Fig. **9** shows the principles of the scheme. The essential features are a single battery, a charging unit and an ampere-hour meter, the dial reading of which is approximately equal to the capacity of the battery, through which the battery is charged and discharged. The meter is arranged so that discharge current from the battery to the exchange turns its pointer in a clockwise direction, whilst charging current turns it in the reverse direction. To allow for the efficiency of the battery, about 20% more ampere-hours are required to turn the meter a given distance in the charge than in the discharge direction. The ampere-hour meter has three contacts, the first AH1 closes when the pointer indicates zero, the second, AH2, when the pointer indicates 4% of the dial reading and the third, AH3, when the pointer indicates about 33% of the dial readings.



NOTES :—
AH1 closed when ampere hour meter indicates 0
AH2 ,, ,, ,, ,, ,, ,, 4% of dial reading
AH3 ,, ,, ,, ,, ,, ,, 33% ,, ,,

FIG. **9**.—PRINCIPLE OF AUTOMATICALLY OPERATING SINGLE BATTERY POWER PLANT.

Assume the battery to be in a fully charged condition, and discharge to commence. The pointer of the ampere-hour meter rotates in a clockwise direction and in due course the contact AH2 operates the relay B, by which the mercury switch B1 connects the charging unit to the mains. Depending on the value of the discharge current as compared with that from the charging unit, the cells will either still discharge, but at a lesser rate than before, or receive a charging current. In any case, in due course, they will be charged and the pointer will return to zero. The contact AH1 then causes the charging unit to be disconnected from the battery. The cycle of events is then repeated.

A definite though small current is required to start the meter and a current below this value will not operate it. Consequently at times when the charge is disconnected, it would be possible for small discharges, such as insulation losses, to occur without operating the meter. A progressive deterioration of the cells might, therefore, result, and to guard against such an eventuality, a permanent load is connected to the battery so that the meter is always operating. The value of this resistance R is such that the permanent load is just greater than the minimum operating current of the ampere-hour meter, and is usually about the 1,000 hours rate of the battery.

In the event of a failure of the power supply, or the charging unit, the battery discharges to a greater extent than normally, and in order that the continuity of the service may be maintained, arrangements are made for an alarm to be given when the ampere-hour meter indicates 33% of its dial reading, *i.e.,* when the battery is about a third discharged. As will be seen later, the battery will then still be capable of maintaining service for an appreciable time so that there is adequate opportunity to apply remedial measures.

9. Automatically Operating Single Battery Scheme with both Ampere-Hour Meter and Voltage Control using Mercury-Tube Switches.

In the scheme just described the voltage at the battery terminals varies between wide limits. During discharge, the voltage of each cell drops to slightly less than 2.0, whereas during charge it rises to possibly 2.5. Such an arrangement is suitable only when a wide voltage variation can be tolerated. The biggest field for this type of equipment, is, however, in connection with Unit Automatic Exchanges where a supply within the limits of 46-52 is required. A battery of 24 cells is suitable for these cases, as even at the end of a complete discharge, the peak load is unlikely to be such as to cause the voltage to drop below 1.92 per cell or 46v for the battery. For the voltage of a 24 cell battery not to exceed 52 on charge, the voltage of each cell must be limited to 2.16.

Referring again to Fig. **1**, it will be seen that for the voltage not to exceed 2.16, the charging current must not be greater than the 1440 hour rate. Hence, for the voltage of a 24 cell battery to remain within the stated limits throughout the whole cycle of charge and discharge, its capacity would at least be $\frac{1440}{24} = 60 \times$ the daily discharge. Quite apart from the question as to whether the discharge could be made good at such a low rate, such a large battery is obviously impossible on grounds of cost and space and in order to use cells of a reasonable size, it has been necessary to elaborate the scheme in the manner shown in Fig. **10.**

The further development consists of an arrangement by which counter E.M.F. cells are switched into or out of the main battery circuit under the control of a contact voltmeter. When the main battery voltage rises to 52, two counter E.M.F. cells are switched into circuit and reduce the voltage applied to the exchange to approximately 47.5. As charging proceeds, the battery voltage continues to rise, and when it reaches 52 a second time, the operation of the contact voltmeter results in two more counter E.M.F. cells being switched into circuit. While the counter E.M.F. cells are connected, they are charged by the exchange discharge current and their voltage rises to about 2.5 per cell. When the four cells are in circuit, the main battery may, therefore, be allowed to rise to about 62.0 or 2.58 volts per cell without the voltage on the exchange equipment exceeding 52.

Starting with the ampere-hour meter indicating zero the operation of the circuit is as follows :—

The battery discharges to about 4% of its capacity when the ampere-hour meter contact AH2 operates relay B thus connecting the charging unit to the mains through the mercury tube B1. If the discharge is more than the output of the charging unit the battery will continue to discharge, but in any case in due course the discharge current will be exceeded and the battery will commence to charge. Its voltage then rises and on reaching 52 the top limit voltmeter contact will close and operate relay H. Relay HH is then operated through H1 and contact HH1 provides a subsidiary earth to hold relay H in place of the contact voltmeter, whose contact can then break without sparking. HH2 then operates relay C and its four mercury tubes, C1 switching the first two cells into circuit with the main battery. It will be seen that the counter E.M.F. cells are short-circuited during the change-over and the resistance R2 of about 0.1 ohms is inserted to limit the current. Assuming charging to continue the voltage may again rise to 52. If so, relay HH will again operate, but its contact HH2 will this time cause relay D to change over its four mercury tubes through the following circuit, Earth, HH2, C4, relay D, D3, C3 battery. The mercury tube D1 will switch two more counter E.M.F. cells into circuit with the main battery. Charging will then continue until the pointer of the ampere-hour meter returns to zero, when the closing of AH1 will cause relay B to cut off the main charge. It should be mentioned that the relative size of the charging unit and the cells is such that the voltage does not again rise to 52 during the completion period of the charge. At the end of the charge the voltage of the 24 cells in the main battery is of the order of 60. In series and in opposition to it are 4 cells with an over-all voltage of about 10 which thus reduces the voltage applied to the exchange to about 50.

After the charging current has been cut off the voltage applied to the exchange will decrease and, on reaching 46, the bottom limit voltmeter contact will operate relay L whose contact will operate relay LL. Contact LL2 will cause relay D to change-over its four mercury switches and cut out the two counter E.M.F. cells controlled by D1. The exchange voltage will thus be raised by approximately 5 volts, but will then gradually decrease until it again reaches 46. This time relay C and its four mercury tubes will change over, C1 cutting out the remaining two counter E.M.F. cells. The main battery of 24 cells will now be connected direct to the exchange and its voltage will continue to decrease until it reaches about 48. The discharge current registered after the

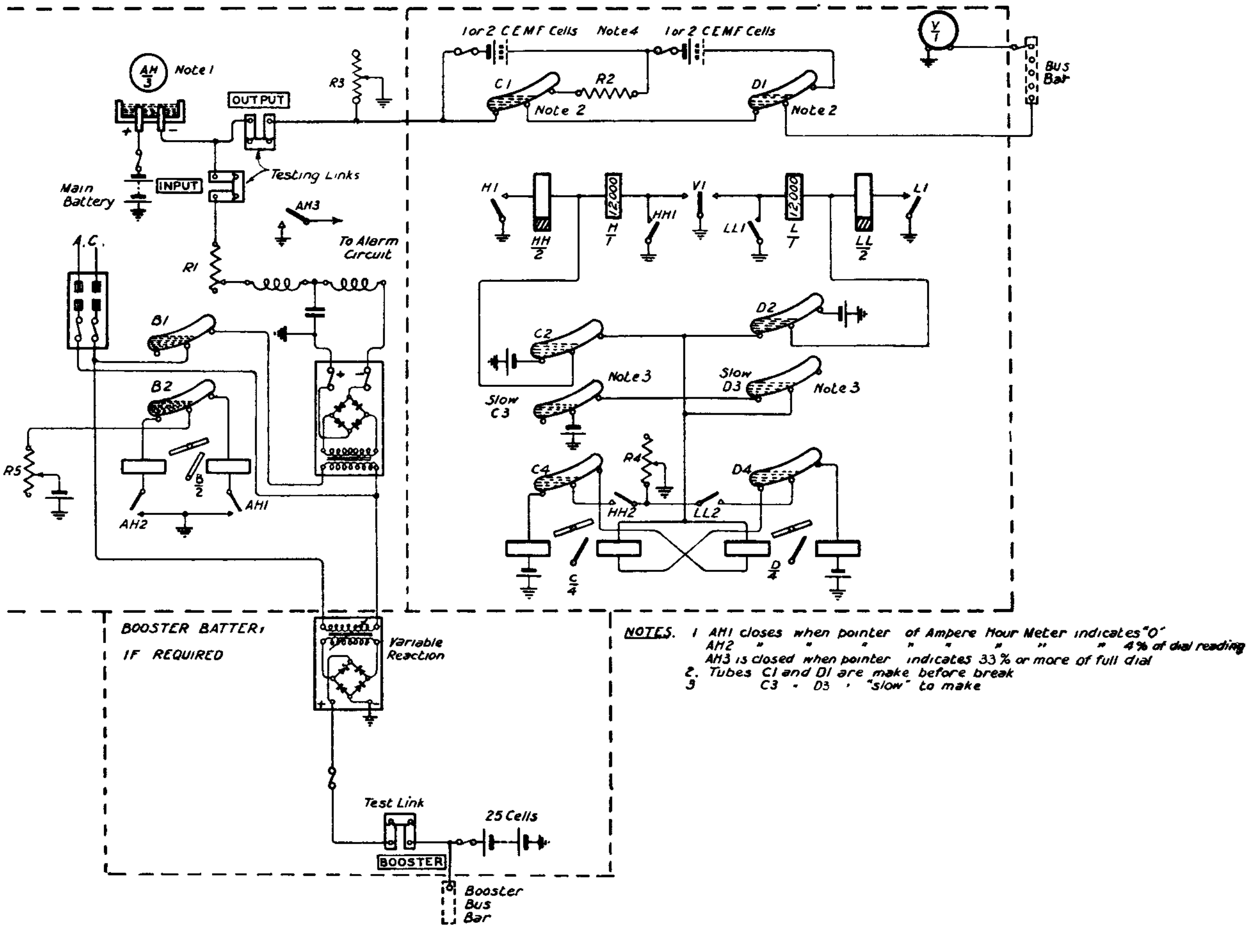


Fig. **10**.—Single Battery Power Plant with Voltage Control. (Schematic Diagram).

charging unit is cut off will in due course cause contact AH2 to close and re-connect the charge when the sequence of operations will be repeated.

Although facilities are available for switching in two sets of counter E.M.F. cells, both sets are not necessarily switched in on each cycle of operations. Examination of the circuit will show that the arrangements will allow of the first set being switched in and out without the second set. It will be seen that when the first group of counter E.M.F. cells is in circuit alone the current to the exchange is fed through the low resistance R2. The counter E.M.F. cells, can, however, only be cut into and stay in circuit when the main battery is charging, *i.e.*, when the exchange load is less than the output of the charging unit and the voltage drop through the resistance is therefore negligible.

Fig. **11** shows graphically the operation of the equipment when serving a telephone exchange over a typical period of 24 hours. The exchange load is assumed to be about 70 ampere-hours a day, the output of the rectifier 5A, and the capacity of the battery 300 ampere-hours. The period starts at 8 a.m. when it is assumed the ampere-hour meter indicates zero. The battery discharges until the pointer indicates 12 ampere-hours at A when the charge of 5 amperes is connected, thus reducing the rate at which the battery is discharging. At B the exchange load for the first time becomes less than the output of the charging unit. The battery, therefore, receives a charging current and its voltage increases. On reaching 52 at the point C, the first set of two counter E.M.F. cells is cut in, thus reduc-

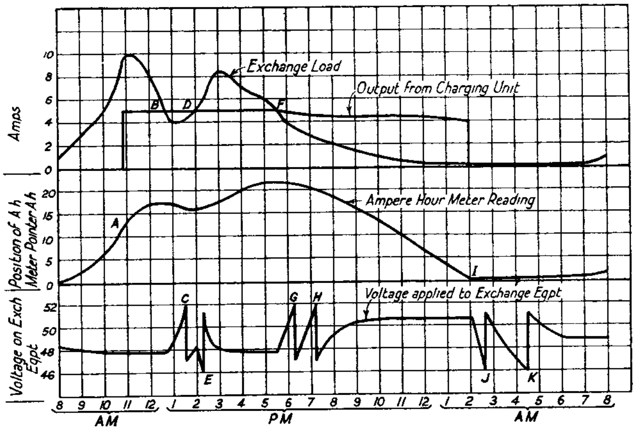


Fig. **11**.—Graphical Performance of Automatically Operating Single Battery Scheme.

ing the voltage to about 47. The voltage continues to rise, but at D the exchange load which is increasing, again exceeds the output of the charging unit, and discharge current is taken from the main battery, the voltage of which decreases. When the voltage on the exchange reaches 46 at E, the two counter E.M.F. cells are cut out and the exchange voltage is stepped up to about 51. The exchange voltage continues to decrease until it reaches a steady value of about 48. The main battery continues to discharge until several hours later when the exchange load falls below the output of the charging unit at F and charging of the battery again commences. The voltage rises to 52.0 at G when the first two counter E.M.F. cells are switched in. As the charging current is increasing in value, the voltage continues to rise and shortly again reaches 52 at H, when it is again reduced by the second set of counter E.M.F. cells. The voltage then continues to rise until it attains a steady value about 50. In due course the ampere-hour meter will return to zero at I when the output of the charging unit will be disconnected. The exchange voltage will then decrease to 46 at J when the second group of counter E.M.F. cells will be cut out. The voltage will thus be increased by about 5.0 volts, but will then gradually fall until on again reaching 46.0 at K the first group will be cut out. The exchange voltage thus stepped up to about 51.0 will then gradually settle down to about 48.0 until several hours later when the charging unit is reconnected to the circuit.

It was mentioned earlier that if the voltage of the 24 cells comprising the battery did not rise above 62 on charge, the exchange voltage would be unlikely to rise above the limit of 52. Owing to the various factors, such as temperature, variation of specific gravity, possible ageing of the plates and power supply variations which might increase the voltage, a liberal tolerance of 2 volts is allowed, that is, it is arranged that the rate at the end of the charge is such as will keep the maximum voltage under ordinary circumstances to about 60 or 2.5 volts per cell. It will be seen that the final charging rate must therefore be about the 75 hour rate. The output current of the rectifier, however, decreases as the battery voltage rises and it is found that if the current output is equivalent to the 75 hour rate at 60 volts it is about the 46 hour rate at 48 volts.

These facts may now be used as a basis for deciding the relative sizes of battery and charging unit for a given installation. Assuming the plant is designed on a basis of 20 hours operation of the charging unit per day at the ultimate period, the remaining 4 hours being allowed as a factor of safety, the exchange load, D, in terms of the ampere-hour capacity of the battery A, would be approximately

$$D = \frac{7A}{46} + \frac{0.83 \times 13A}{60}$$

$$i.e., \quad A = 3.0D$$

In obtaining the above expression it is assumed that for 7 hours the exchange load exceeds the output of the rectifier, during which time the output of the latter would be at the 46 hour rate. During the remaining 13 hours the battery would be charging at an average of the 60 hour rate. As the ampere-hour meter is 20% slower in the charge than in the discharge direction only 83% of this amount will in due course be supplied to the exchange.

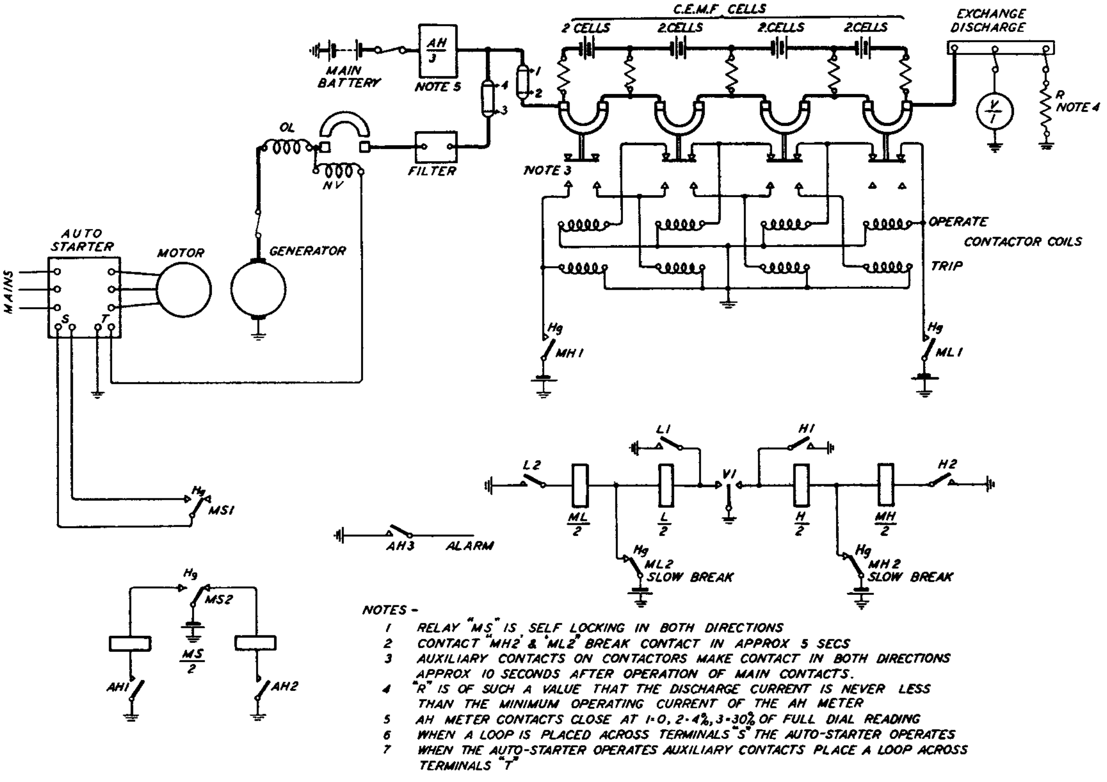
The advantages of the single battery scheme from the point of view of capital expenditure will be appreciated by the fact that whereas an installation requiring 6 ampere-hours per day is usually served by batteries of 72 ampere-hours capacity and a 12 ampere charging unit under double battery conditions, one battery of 40 ampere-hour cells and a charging unit with 0.5 ampere output is all that is necessary for the single battery scheme.

10. Automatically Operating Single Battery Scheme with Ampere-hour Meter and Voltage Control using Contactors for Switching.

The single battery scheme just described is suitable for installations requiring up to 100 ampere-hours per day. The maximum practicable size is limited by the fact that the scheme involves the use of mercury tubes which it is not considered advisable to use beyond a certain size. This is, however, no reason why automatic plants should be limited to small exchanges, in fact, there is a definite requirement for automatic schemes for exchanges considerably larger than that mentioned. Arrangements for week-end working are frequently a source of difficulty under the Charge-Discharge scheme, but full floating systems, involving as they do continuously running machines and automatic voltage regulators, are obviously not desirable at the smaller exchanges. The single battery scheme just described has, therefore, been further developed to allow of its use at installations requiring up to about 2,000 ampere-hours per day. The ampere-hour meter control described in the mercury tube scheme is again used and the voltage is again controlled by switching counter E.M.F. cells in and out of the discharge circuit. The switching is, however, done by contactors which can handle up to 300 or 400 amperes. Whereas the mercury tube scheme is intended for use in connection with metal rectifiers, the contactor scheme can be used in conjunction with either A.C. or D.C. mains supplies. The charging unit can be either an A.C. or D.C. generator set or a rectifier.

The circuit is shown in Fig. **12**. It will be noticed that each group of counter E.M.F. cells is normally short-circuited by a contactor. As this is rather unusual practice it should be explained that the cells are of the nickel iron type and specially designed for counter E.M.F. purposes. They have a negligible capacity and can be short-circuited with impunity. When a short-circuit is applied there is a rush of current, but this is not sustained for more than a few seconds, after which the cells reach zero voltage. When the short-circuit is removed the voltage of the cells rises to about 1.5 in two or three seconds with even a small charging current. Within a minute the voltage attains a value of the order of 1.9 to 2, which value is reasonably constant irrespective of the value of the charging current.

The operation of the circuit, which shows a motor-



NOTES -

1 RELAY "MS" IS SELF LOCKING IN BOTH DIRECTIONS
2 CONTACT "MH2" & "ML2" BREAK CONTACT IN APPROX 5 SECS
3 AUXILIARY CONTACTS ON CONTACTORS MAKE CONTACT IN BOTH DIRECTIONS APPROX 10 SECONDS AFTER OPERATION OF MAIN CONTACTS.
4 "R" IS OF SUCH A VALUE THAT THE DISCHARGE CURRENT IS NEVER LESS THAN THE MINIMUM OPERATING CURRENT OF THE AH METER
5 AH METER CONTACTS CLOSE AT 1-0, 2-4%, 3-30% OF FULL DIAL READING
6 WHEN A LOOP IS PLACED ACROSS TERMINALS "S" THE AUTO-STARTER OPERATES
7 WHEN THE AUTO-STARTER OPERATES AUXILIARY CONTACTS PLACE A LOOP ACROSS TERMINALS "T"

FIG. 12.—AUTOMATICALLY OPERATING SINGLE BATTERY POWER PLANT FOR EXCHANGE OF MEDIUM SIZE USING CONTACTORS FOR SWITCHING.

generator set as a charging unit, is as follows :—

Assume the ampere-hour meter to be indicating zero and the main battery to be discharging. The pointer of the ampere-hour meter will move round and when in due course it indicates about 4% of its dial reading its contact AH2 closes and operates relay MS which changes over its two mercury tubes. MS1 closes the first operating coil of the automatic starter which then starts up the charging unit. When the starter is operating, auxiliary contacts inside it close the operating coil of a contactor in the output side of the charging unit. This coil is across the generator terminals and when the voltage of the latter rises to a value slightly more than the battery voltage the contact closes and connects the generator to the battery. According to the relative value of the machine output and the exchange discharge, the battery may then either continue to discharge or to be charged, but in any case, in due course charging of the battery will commence. When this occurs its voltage will rise to the maximum allowable limit for the exchange apparatus, which, assuming the plant we are discussing to be used for a 50 volt automatic system, is 52. The contact voltmeter V1 then makes contact on the high voltage side. Relay H operates and locks in through its contact H1 and operates relay MH with its contact H2. Relay MH carries two mercury tube contacts, the first MH1 energises the trip coil of the contactor which is short-circuiting the first set of counter E.M.F. cells, thus introducing these cells into the discharge circuit and lowering the voltage applied to the exchange by about 3 volts. The second tube MH2 is of the slow break type. It takes about five seconds for this tube to break contact after it has been tilted and when it does so relay MH resets.

Thus within 5 seconds of the main battery voltage attaining 52, 2 counter E.M.F. cells are switched into circuit and the voltage control circuit returned to normal. The contactors controlling the counter E.M.F. cells have two pairs of auxiliary contacts. One pair is connected about ten seconds after the tripping, the other ten seconds after the operation of the contactor. These auxiliary contacts prepare a path for the operation of the next contactor; thus, if the main battery voltage continues to rise and the exchange voltage again reaches 52, the sequence of events will be repeated. This time, however, the trip coils of both the first and second contactors will be energised. As the first one is already tripped, this contactor is not affected, but the second one will trip and insert the second set of cells into the discharge circuit. The arrangements allow of up to four sets of counter E.M.F. cells being introduced into the discharge circuit in this way as the charge of the main battery progresses.

When the pointer of the ampere-hour meter gets back to its zero position at the completion of the charge, its contact AH1 operates relay MS, whose contact MS1 trips the auto starter which, in turn, trips the conductor in the output side of the generator so shutting down the charging unit and disconnecting it from the battery.

The voltage of the main battery will then decrease and in due course the voltage on the exchange will drop to 46. Relay L and then relay ML are then operated and cause the contactor which was last tripped to re-operate and short-circuit the two counter E.M.F. cells which it controls, thus increasing the voltage on the exchange. This operation is repeated until all the contactors are operated and all the counter E.M.F. cells switched out of circuit.

As in the mercury tube scheme, an alarm is given by a contact on the ampere-hour meter if, for any reason, the battery discharges to about 33% of its capacity.

It will be observed that all operating circuits are broken at mercury tube contacts. As the circuits are simple and the apparatus robust, the scheme is expected to give excellent results.

With the scheme applied to 50 volt automatic exchanges, the main battery consists of 25 cells. Although the scheme is essentially a single battery system, the battery will consist of two batteries in parallel. This arrangement will enable battery repairs or replacements of plates to be carried out without inconvenience. The total battery capacity will be sufficient to give one day's reserve and since the battery does discharge to a slight extent, the battery capacity will be about 1.1 times the day's load. The voltage of the counter E.M.F. cells rises to about 2 V. per cell. As there may be eight such cells in circuit, the main battery may be allowed to rise to 68 or, say, 67 for safety, without the voltage on the exchange equipment exceeding 52. A voltage of 67 represents about 2.68 per cell which is attained with a charging rate of about 13 hour rate.

The smaller the charging unit, the greater the discharge of the battery will be and, in order to prevent the battery from discharging more than about 15% under the ultimate conditions, it is necessary to provide a charging unit with an output at 50 V. of approximately the 13 hour rate of the battery. As the voltage of the main battery rises during charge, the current from the charging unit will fall off appreciably so that the finishing rate will be appreciably less than the 13 hour rate and the maximum voltage appreciably less than the limiting value of 68.

This scheme is more economical than the Divided Battery Float scheme up to about 2,000 ampere-hour per day and it is proposed to use it for exchanges up to this size as soon as the trials which are at present being conducted are completed.

It is interesting to note the high power efficiency of these automatically operated single battery schemes. Most of the power to the exchange is served direct from the charging unit, so that battery conversion losses are small, whilst the charging unit is working at full load and high efficiency practically all the time it is in use. In this respect, the scheme is an advance on the full floating scheme in which, due to the output of the machine varying with the exchange load, the efficiency of the charging unit is low for lengthy periods when the exchange load is light. In fact, it is difficult to contemplate any more efficient scheme for serving telephone exchanges.

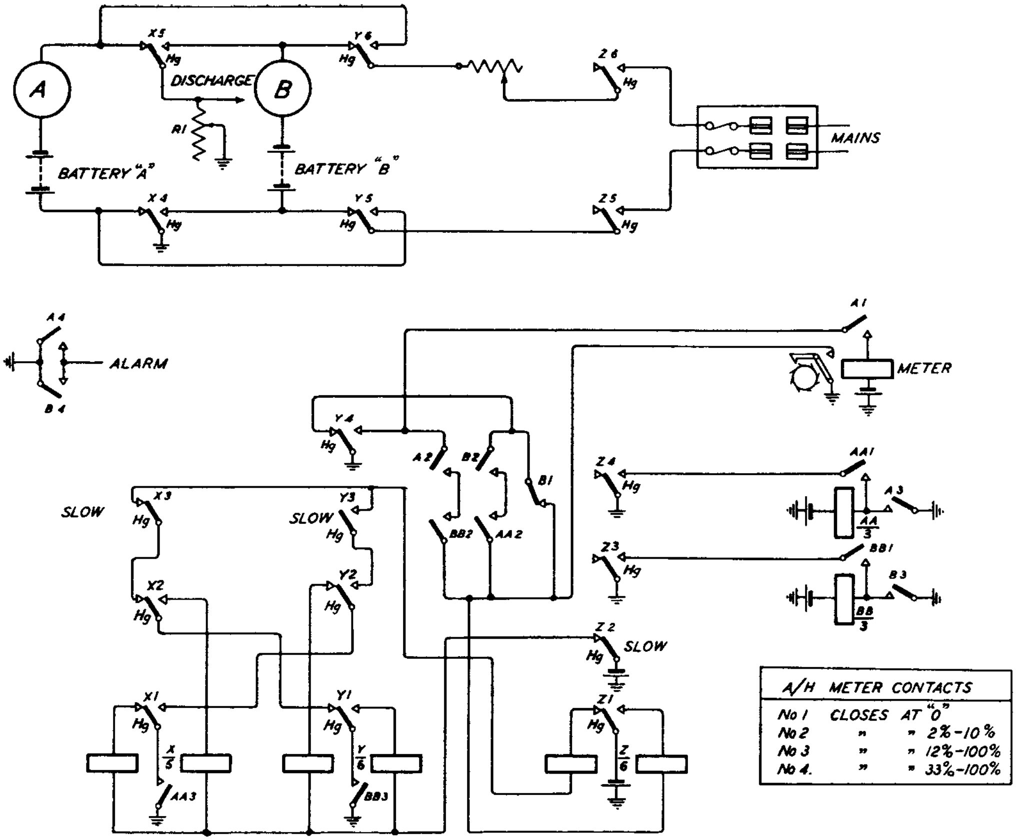
11. Maintenance of Automatically Operating Single Battery Schemes.

The maintenance of these automatically operating single battery power plants is a simple matter. The installations can be left for long periods without attention and it is only necessary to ensure that the battery gets sufficient charge to keep it in good condition. The ampere-hour meter has been made slower in the charge than the discharge direction with this end in view and this is normally sufficient. The condition of the battery will be judged by the specific gravity of the pilot cell taken as opportunity occurs when the installation is visited mainly for other purposes. The specific gravity readings will be plotted in graphical form. The design of the plant is such that the ampere-hour meter pointer will, under ordinary conditions, never be far from zero. The graph will thus be an indication of the specific gravity of the pilot cell when the ampere-hour meter is more or less in its zero position. If, over a period of several weeks, the graph keeps a reasonably constant value, the indication is that the cells are being maintained in a satisfactory condition. If, on the other hand, the graph shows a progressive decrease, the indication is that the charge is inadequate. In such circumstances the pointer of the ampere-hour meter will be re-set by hand to a higher reading so that an extra charge will be given to re-condition the cells. Such attention is likely to be required infrequently. Every three months the specific gravity of all the cells will be read to ascertain whether deterioration is occurring in any cell in the battery.

These occasional specific gravity readings represent the only records required, and it will be appreciated, therefore, that these schemes are a considerable advance on the Charge-Discharge schemes from this point of view.

12. Automatically operating double battery charge discharge scheme for small exchanges with D.C. mains supply.

Several schemes, for small exchanges, based on the use of metal rectifiers, have been described earlier. For small exchanges that are likely to be left for long periods, a static charging unit is most desirable and the metal rectifier is very satisfactory in this respect. As most rural power supplies are developing on an A.C. basis, the metal rectifier will meet most of the cases which arise, but in some areas there are still D.C. supplies and a scheme has been designed to cater for these on a direct charging basis. Under these conditions a double battery system is essential as the power supply must never be connected to a battery serving the exchange owing to the possibility of getting the full mains voltage on the telephone equipment. The arrangement of the circuit is shown in Fig. 13. In series with each



Notes :—
1. Diagram shows Battery " A " on discharge.
" B " fully charged.
2. Mercury contacts X4 and X5 are make before break.

Fig. 13.—Automatically Operating Double Battery Charge-Discharge Scheme for small Exchanges with D.C. Mains Supply.

battery there is an ampere-hour meter having four contacts. These meters, like those used in the single battery schemes, are slower in the charge than in the discharge direction. The contacts are arranged as follows :—

Contact 1 closes when the pointer indicates zero.
,, 2 closes when the pointer indicates between 2 and 10% of the full dial reading.
,, 3 closes when the pointer indicates between 12 and 100% of the full dial reading.
,, 4 closes when the pointer indicates between 30 and 100% of the full dial reading.

There are also three relays which control mercury tube switches and which are operated by contacts on the ampere-hour meters.

The method of working is as follows :—

The batteries are discharged in turn to an amount equivalent to 12% of the dial reading of the ampere-hour meter, after which they are placed on charge. The ampere-hour meters control the charge and discharge as follows :—The battery serving the exchange continues to discharge up to 12% of the dial reading when contact 3 of the ampere-hour meter closes and operates two of the mercury switches, one of which changes over the discharge to the other battery, whilst the other prepares the first battery for charge. After a period of 5 to 10 seconds the third mercury switch operates to complete the charging circuit.

When the load is light such as at night and weekends charging will continue until the ampere-hour meter indicates zero when contact 1 operates one of the mercury switch relays to cut off the charge. Accordingly, the battery is fully charged by the time the other battery is discharged to 12% of the dial reading, when the sequence is repeated.

When the load is comparatively heavy and the discharge rate is greater than the charge rate, the discharging battery discharges to 12% of the dial reading before the ampere-hour meter, in series with the charging battery, reaches zero. Under these conditions contact 2 (which operates between 2 and 10%) controls the termination of the charge. This arrangement reduces the extent to which the batteries are discharged and the number of complete charges. The cells are fully charged again during the next period of light load which is probably the following night.

In the event of a failure of the charge, the battery on discharge will cause contact 4 to complete an alarm circuit when the battery has discharged 30%. The reserve capacity available from the time the alarm is given is thus 70% in one battery and between 80 and 100% in the other.

The circuit operation is as follows :—

The ampere-hour meters are for convenience termed A and B, and their contacts A1 to A4 and B1 to B4. Assume both batteries to be fully charged and battery A to be connected to the exchange. As battery B is fully charged, B1 is at zero and the mains are therefore disconnected from the equipment at Z5 and Z6. As battery A discharges, A2 will in due course close, open again and then later A3 closes. Relay AA operates and its contacts AA3 cause relay X to change over, thus connecting the exchange to battery B through the mercury tubes X4 and X5, which are of the make-before-break type. Relay Y then changes over, the mercury switches Y5 and Y6 preparing a path for the charging of battery A which has just been taken off discharge.

About five seconds after the operation of Y, its slow tube Y3 makes contact, thus changing over relay Z, whose mercury switches Z5 and Z6 connect the mains to the battery A.

Both the ampere-hour meters are now in operation, B in the discharge and A in the charge direction. The subsequent operation of equipment depends on the relative value of the charge and discharge current. Assume first of all, that the load is light, so that the charge takes place more quickly than the discharge. Contact A1 will thus operate before B3. When A1 closes, the counting meter, whose purpose will be mentioned later, registers, relay Z changes over and disconnects the mains at Z5 and Z6, thus stopping the charge. The mercury tube Z2 prepares a path for the operation of relays X and Y. In due course, B3 closes, operates BB, whose contact BB3

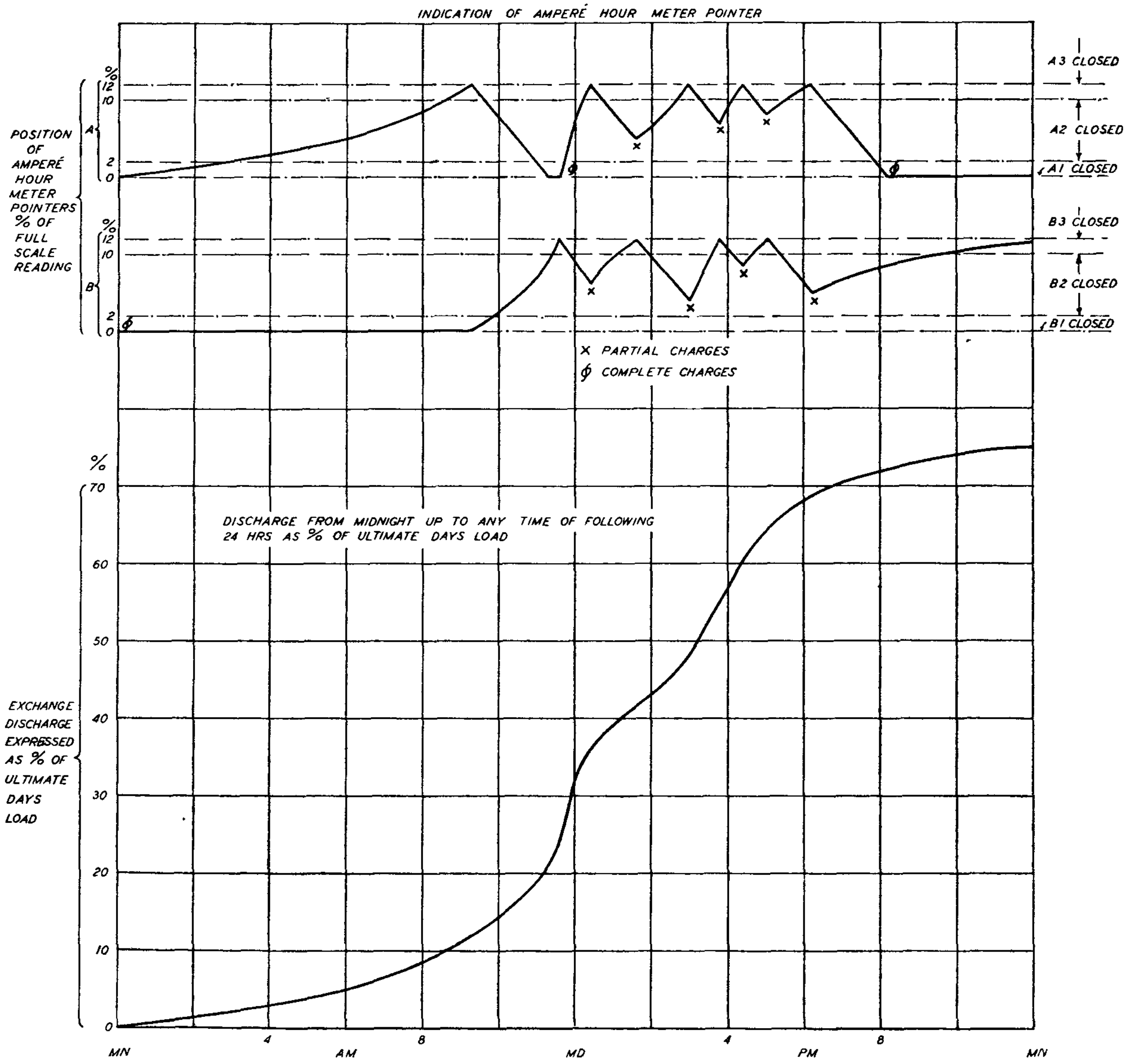


FIG. 14.—GRAPHICAL PERFORMANCE OF AUTOMATICALLY OPERATING DOUBLE BATTERY SCHEME.

changes over relay X, which changes over battery A to serve the exchange. The charge is then connected to battery B as described previously.

Assume that the discharge from A is now at a higher rate than the charge to battery B, as a corollary A3 will close before B1, which previously has controlled the end of the charge. Under these conditions, the battery changes over as soon as contacts A3 and B2 are closed together. Excessive discharge of the batteries is thus eliminated and the number of completed charges limited so that excessive gassing does not occur.

The performance of the circuit is shown graphically in Fig. **14**. It is assumed that the exchange is loaded to three-quarters of its ultimate load. The charging rate is at the 16-hour rate. The capacity of each battery is numerically equal to the ultimate day's load in ampere-hours, and the full dial reading of the ampere-hour meters is numerically equal to the ultimate battery capacity. The two curves, A and B, show how the ampere-hour meters in series with the two batteries operate during a typical 24 hours' working. Starting with both batteries fully charged at midnight, battery A discharges whilst B stands in a fully charged condition with the charge disconnected. By about 9.30 a.m. battery A has discharged to about 12 per cent. of the dial reading of the ampere-hour meter. Battery B is then switched on to the exchange, whilst A is charged until shortly before mid-day, when the ampere-hour meter gets back to zero, and the charge is cut off. Several minutes later, the meter in series with B indicates 12 per cent. of its dial reading. Battery A is then put on discharge, and the charging of B commences. The discharge rate by this time is heavy and battery A discharges to 12 per cent. before B is fully charged. The batteries are, however, changed over as soon as both the A3 and B2 contacts are closed together, that is, when B becomes 12 per cent. discharged. Subsequently, it will be seen that batteries A and B are alternately on charge and discharge until about 8 p.m., when the exchange load is decreasing and when A becomes fully charged and stands in this condition waiting for the ampere-hour meter in series with battery B to reach the 12 per cent. position, which occurs somewhat after midnight.

The number of times the batteries are brought to a fully charged condition is dependent on the charging rate. For instance, if the charging rate is higher than the discharge rate at any time during the day, it is obvious that the time of recharge will be less than the discharge period, and each charge will, therefore, be complete. This is undesirable. The purpose of the meter which operates each time the first contact of the ampere-hour meter A closes, is to register the number of times the battery is completely charged. This number should not exceed 1-2 per day. If, over a period of several days, the number exceeds this value, the charge rate will be reduced. There is, of course, no urgency about such adjustments which will be made from time to time when the installation is visited in connection with other work.

13. Summary.

From what has been described, it will be seen that future arrangements for exchange power plant are likely to be on the following lines :—

(1) Magneto and C.B.S. exchanges at present served by primary cells, and where A.C. supplies can conveniently be obtained, to be served in future by All-Mains units.

(2) Small exchanges such as Unit Automatic Exchanges requiring up to about 100 ampere-hours per day, to be served by the Automatically Operating Single Battery System, using mercury tubes for switching and a metal-rectifier charging unit, where A.C. supplies are available, or by the Automatically Operating Double Battery Charge-Discharge Scheme with direct charging where D.C. supplies are available.

(3) Medium sized exchanges beyond the size indicated in category (2) and requiring up to about 2,000 ampere-hours per day, to be served by an Automatically Operating Single Battery Scheme, using contactors for switching and either A.C. or D.C. driven motor-generator sets or rectifiers as the charging device.

(4) Large exchanges beyond the size indicated in category (3) to be served by the Divided Battery Float System.

It is confidently expected that these schemes will prove to have considerable advantages over the existing practice.

The new schemes will first be applied to new exchanges, but provided the anticipated advantages are substantiated in service, it may prove advantageous to modify some of the existing plants.

EXTRACTS FROM THE NOTES OF THE DISCUSSION.

MR. F. P. DUMJOHN :

In connection with the divided battery float scheme and the standby capacity which it is proposed to have in the battery, Mr. Jones realises that the battery should be floated at 2.15V per cell in order to ensure that its full capacity is available when required. He is going to float it, however, at 2.01 to 2.07V per cell, and I am at a little bit of a loss to understand how the battery is going to be in a fully charged condition when taken out of service at the end of the first week. It would appear that such floating voltages between 2.01 and 2.07 will not ensure that the load is supplied wholly by the machine and that the battery will supply part of the load, therefore the drain will not be replaced. Further, the cell can be fully discharged and its voltage will still read 2.01. One has evidence of this in the case of the discharge of a cell at the 60 hour rate when it will have lost some 70% of its capacity, but its voltage still reads 2.01.

Another point in this connection—what reserve is being allowed in the battery for emergency? In the paper it is proposed to provide a capacity of 45% of the day's load and a typical case is given of the 4 busy hours taking 44% of the day's load. The capacity obtainable from a battery is dependent on the rate of its discharge and in the event of failure of supply or of the motor generator set, the battery would be drained at something like the 3 or 4 hour rate. At the 4 hour rate according to B.S. Specification a battery will give 80% only of its capacity, also as we must not allow the voltage of the cells to go below 1.88, it seems that there will be only 2 hours reserve in the battery that can be relied upon.

COL. F. REID :

The divided battery float scheme seems to combine all the advantages and economies of the floating battery scheme with simplicity, particularly the elimination of the counter E.M.F. cells, which I think is a very important point. I think it is on the right lines and I have only one misgiving—what will be the life of the secondary cells kept floating for weekly periods between the voltage limits of 2.01 and 2.07? I think we should have had some more evidence that under these conditions a long life will be secured. The very large secondary cell batteries we have been using in the past have given a good deal of trouble and the divided battery float scheme which reduces the size of the batteries should in this respect meet with approval.

MR. P. B. FROST :

The life of the batteries is a big factor affecting the costs of the float scheme. The life of the positive plates of batteries under the present charge-discharge conditions, I think I am right in saying, still varies beween 2½ and 9 years. These figures it must be remembered apply under conditions when all the harmful irregularities of battery maintenance, which have in the past led to such a short life, can best be prevented by careful maintenance instructions and close supervision. Now, the Post Office has at least 25 years' experience of the ordinary charge-discharge scheme and still we get these extreme variations in life. I see that the author expects to get an increase in life of some 50% when batteries are floated. I should like to ask whether we have any practical experience upon which to base that claim. It is so important that if a 50% increase in life could be obtained by any scheme I think that on the basis of cost you could justify its introduction. Batteries are very expensive both to install and to maintain and their life is really the fundamental factor.

I cannot allow to pass without comment the machine efficiency figures shown in Fig. 5. They are altogether too high even for test conditions and would never be obtained in daily use. The small machine is assumed to have an efficiency of 38% at 13% of its rated full load output and of 76% at 60% of its rated output. The larger machine has 60% efficiency at 32% of its rated output.

In view of the recent breakdowns, evidently inseparable from the use of transmission lines, it seems rather a bad moment to choose to become more dependent on the continuity of supply mains and less on batteries. I should have thought it was a moment to consider whether the standby plant is really adequate to deal with the breakdowns which have extended not over a few towns but over vast areas. Had the breakdowns lasted very long it is possible that the exchange load could not have been catered for by the standby plant provided at present. I see that in the divided battery scheme it is proposed to provide a capacity to cater for 12 busy hours which represents, according to the author, 90% of the capacity required for the 24 hours load. I submit that it is rather unwise in order to save 10% of the battery capacity to forego the advantages of 12 hours extra standby capacity.

MR. J. INNES :

I had the opportunity of visiting the United States along with three other engineers last year. During our visit we made enquiry regarding the life of batteries under full float conditions. The period quoted was 14 years as compared with 6 to 8 years for batteries on full charge and discharge cycles, and in one case where pasted plates were in use, the batteries were still in good condition after 12 years' service. There has been a further development in America in the paralleling of batteries and some comment by Mr. Jones on this practice would be welcome. In the most recent jobs the American Companies are using a totally enclosed glass cell of 1000 ampere-hours capacity and three sets are used in parallel if 3000 ampere-hour capacity is required. One battery company parallel each cell, but others only parallel the complete battery. As the cells are sealed, the batteries are placed next to the power plant. It would be interesting to have the author's views on this arrangement and on the possibility of adopting a standard size of cell.

Mr. P. J. Ridd :

Mr. Jones has my wholehearted support. I have in fact advocated the direct service from generators and the reduction in the size of batteries at various intervals during the last 25 years. The economics of the question will be affected in some areas by the reduced tariff rate per unit for night charging. In London for example very favourable terms have been secured for night loads at some of the exchanges, and it was partly on that account that the question of floating was not pressed more than it was. Economies in day to day maintenance will no doubt result from the use of the smaller batteries and reduced discharges. I am perfectly certain that in the exchanges in London with which I was concerned for many years the lives of the comparatively lightly loaded batteries at the single battery exchanges exceeded those of the double battery exchanges.

One effect of the reduction in capacity will be a welcome reduction of the depth of the plates. In connection with the examination and removal of plates, the increased depth with the recent 10,000 Ah batteries was a nuisance.

The point is not mentioned in the paper that with the charge-discharge scheme, the nine hour rate would as a rule cover the busy hour discharge. With the smaller battery, the busy hour rate will certainly much exceed the nine hour rate; it will be more like the four hour rate. I am not quite sure whether Mr. Jones proposes to make arrangements for switching the two batteries in parallel to meet the peak load. I am principally interested in the arrangements made for the large exchanges as it is at those exchanges at which the main savings are to be obtained—but it struck me that the arrangements for the smaller ones are rather elaborate. There must be a number of private exchanges working in London to-day on batteries charged over power leads, with series resistances adjusted to maintain the necessary charge rate, and my experience is that they give very little trouble. Many years ago there were public exchanges, the batteries of which were charged from other exchanges over the junctions during the idle time of the junctions and they gave very little trouble indeed.

Mr. H. J. Gregory (*communicated*) :

No particulars are given of the type of generator proposed for the divided battery scheme, but it is assumed that telephone type machines are intended. It may be mentioned that an ordinary commercial machine can be used for floating without causing noise on the exchange battery provided it is shunted with an electrolytic condenser. The result of a test made on one of the generators at Clerkenwell exchange shows the effect of the condenser shunt. The machine was charging the battery at 300 amps. *via* a choke coil and comparative noise measurements were made at the machine terminals.

Capacity shunt.	*Relative Noise PD.*
0 μF.	28 mV.
1240	20
2005	10
3890	7.5

A 20 amp. fuse was put in series with an electrolytic condenser. The generator had interpoles and the windings of these being in series with the armature add to the internal impedance of the machine and thus make the condenser shunt more effective.

A method of measuring the impedance of a choke coil and the degree of noise generated by a machine has been developed by the Research Section. It will be appreciated that if a floating generator is not to put noise on an exchange battery the noise PD of the generator must not be too high and the choke coil must have an adequate impedance. The worst condition is at full load because :

(1) The noise or ripple generated increases with the load on the machine.

(2) The heavy direct current tends to saturate the iron core of the choke coil and thus reduces its inductance.

The method is illustrated by Fig. **15**. If the test is to be made on an existing power plant in the telephone exchange a current transformer of special construction is inserted in the main charging lead. If the test is made at a contractor's works the circuit conditions are the same except that a water resistance would be used as the load. The current transformer consists of a copper bar or tube which will carry the maximum current required and round it is fixed a secondary winding wound on insulating material, *e.g.*, wood. The current transformer is calibrated by passing a measured current of known frequency through the bar and measuring the E.M.F. induced in the secondary winding.

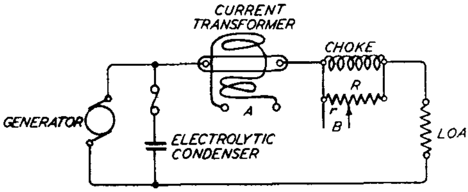


Fig. **15**.

If I amps. = primary current
w = frequency radians per second
V = E.M.F. induced in the secondary

The mutual inductance of the current transformer

$$= M = \frac{V}{wI} \text{ henry}$$

As the current transformer is air cored this mutual inductance will be constant for all practical purposes at all loads at telephonic frequencies.

To measure the impedance of the choke coil the load is adjusted to a definite value and the potentiometer across the choke is adjusted until the reading of the amplifier rectifier is the same whether placed across the secondary terminals A of the current transformer or across the potentiometer terminals B. The ripple of the generator current is thus used as the testing alternating current.

If r is the tap on the potentiometer of resistance R, the inductance of the choke coil will be $\frac{M \cdot R}{r}$ henry. The choke coil will, of course, have an effective resistance to noise currents much greater than its D.C. resistance so that the measurement really refers to the impedance, $\frac{w_1 \cdot M \cdot R}{r}$ ohms where w_1 is the frequency of the testing current. As the ripple is of by no means a single frequency, however, it is preferable to retain the result in henrys, bearing in mind that the effective resistance is included. The results obtained by this method on a choke coil at City Exchange are given in Fig. **16**. Although this choke has a straight core and open magnetic circuit it will be seen that it became saturated under full load.

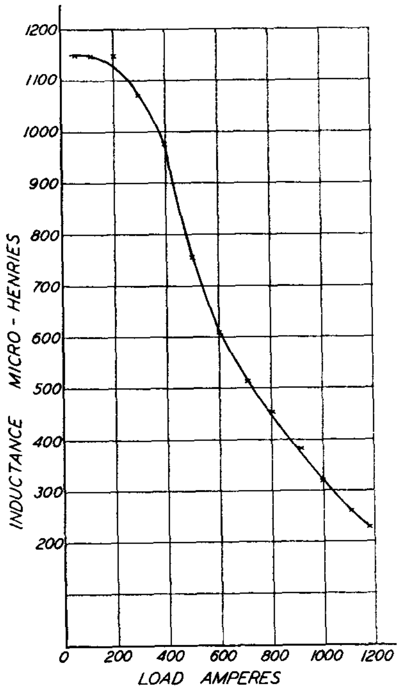


Fig. **16**.

The noise PD of the generator is measured by placing a standard noise meter across the terminals. The amplifier rectifier referred to above is a part of this noise meter.

Mr. A. Armitage (*communicated*) :

I should like to know the length of time the tests have been in operation in the various schemes.

The first thing that interests me is the use and reliability of the ampere-hour meters, these instruments do not take into account the *rate* of charge or discharge—a battery may require approximately twice the ampere-hours for charging at half normal rate and will only give a smaller total output if discharged at a high rate.

With regard to the automatic operation of the charging motor generators, I was unable to gather if they were shunt or compound wound generators; if the former type I should like to know how the correct voltage is maintained having regard to the increase in resistance of the shunt field winding due to temperature rise with time. I have found that the field volts have had to be increased by 12% to 15% during a full load run of 7 to 8 hours to maintain constant output voltage of a generator.

Author's Reply :

Mr. Dumjohn has emphasised a point which was clearly stated in the paper, that some discharge will take place from the batteries worked on the Divided Battery principle during the weekly periods when the batteries are floated at between 2.01 and 2.07 volts per cell. He rather infers that the battery voltage normally will be of the order of 2.01, whereas it will be more nearly 2.04. At this voltage it is not anticipated that any large proportion of the battery capacity will be discharged in one week. An installation working on this prinicple is in use at Leicester; here 30 cell batteries are floated at 61 volts and no change in specific gravity of the cells is perceptible during the weekly periods of floating.

On the question of reserve capacity it should be realised that this scheme will be installed at large exchanges where engineering attendance will be available during the day time and the reserve capacity is that of both batteries, not of one only. The intention is to parallel the batteries under emergency conditions and the switching is arranged accordingly. The total capacity of the two batteries will be 0.9D and, allowing for 10% loss of capacity in one battery during a floating period, at least 0.85D will be available. It has been demonstrated that this capacity will suffice for practically the twelve busiest hours of the day under ultimate conditions. The question of voltage is not a vital consideration. The battery voltage would certainly decrease rapidly assuming the batteries were fairly well discharged when the peak load occurred, but for such a condition to occur the batteries must have been discharged by the light current drain occurring during the previous night, so that the emergency condition must have commenced some considerable time, certainly more than twelve hours earlier. Again, assuming the emergency condition to commence about the time of peak load, by the time the batteries are discharged the load will be relatively light, so that a full discharge can be obtained without undue drop of voltage. Mr. Dumjohn's figure of only two hours' reserve under emergency conditions is, therefore, greatly underrated.

Col. Reid and Mr. Frost have some misgivings about the battery life under Divided Battery float conditions. We have no experience of life under the exact conditions which will apply, but from studies of the behaviour of cells under various conditions we are justified in expecting appreciably longer life than under charge-discharge conditions. Certain eminent battery authorities with whom this scheme has been discussed, have expressed the opinion that cells will last even longer with the Divided Battery Float Scheme than under ordinary trickle charge conditions. In the U.S.A. under floating conditions the life of the plates usually exceeds 14 years. It is not improbable that we shall obtain some similar results, though a more conservative figure has been used as a basis for financial comparisons in connection with the Divided Battery Float Scheme.

As regards Mr. Frost's comments on the efficiency curves shown in Fig. 5, I can only say that the figures were obtained from actual tests on machines of average size on full, half and quarter loads. Full load efficiencies of over 80% are frequently obtained with modern machines, but it will be seen from the curves that a much more conservative figure has been allowed for. Mr. Frost raises an interesting point, as to whether the time is opportune to reduce the margin of capacity in view of widespread breakdowns in the electricity supplies which have occurred recently. This seems to be a reasonable question. It must be realised, however, that the new basis of provision allows of a twelve hours margin under the worst conditions, that is towards the end of the battery life and even then, if the breakdown occurs at the worst time of the day, usually about 9 a.m. A breakdown at other times will find a much greater margin available. Whilst there is certainly no evidence that the number of power supply failures is diminishing, fortunately there does not seem to be any appreciable increase as evidenced by the table shown early in the paper. The duration of failures is usually of the order of one to two hours, and under these circumstances the margin now being arranged should prove adequate. The charge-discharge scheme could not be worked with a less margin than twenty-four hours' reserve as it was not practicable to charge more than once per day. It was, in fact, worked with the smallest batteries it was practicable to provide. The float scheme enables battery capacity to be based on reserve capacity, which was not possible with the charge-discharge scheme. On this basis the reserve now proposed appears to be quite adequate. As a matter of interest, a less margin is allowed by most other administrations.

An interesting reference has been made by Mr. Innes to the use in large exchanges in U.S.A. of parallel batteries of cells in glass boxes. Mr. Innes mentioned the possibility of three sets being used in parallel, but I understand that as the exchanges grow more sets are added until ultimately 6 or 8 sets may be working in parallel. The pros and cons of the matter require detailed study, which is difficult in this country because the particular type of cells used in America is not manufactured here. There is one difficulty with the parallel arrangement, however, which is likely to have a big bearing on the success, or otherwise, of the scheme. It is the fact that cells of different ages require different values of trickle charge to keep them in condition. As a rule the older the cell the greater the amount of charge it requires. With the parallel arrangement each battery is at the same voltage and an attempt is sometimes made to adjust the charging rates in the various batteries by working them with different acid density, but this is rather a hit-or-miss method. If this scheme is not successful, the only other alternative is to ensure that the oldest cells get sufficient charge, and this means that the new ones get too much.

Mr. Ridd makes a useful point in connection with the effect of the reduced size of batteries on the size of the plates it will be necessary to use in future. There has been no alternative at large exchanges of recent years but to use very large plates, in many cases of 300 and 430 ampere-hour capacity each. These plates have a large area, and it is an accepted fact that the larger the plate the more liable to buckle it is likely to be. The introduction of float working will enable the maximum plate size to be kept down to 200 ampere-hours, which is another reason why a longer life may be anticipated for large exchange batteries in future.

Mr. Ridd referred to certain simple schemes by which batteries were charged over junctions. These were doubtless for feeding apparatus which could be worked over a wide range of voltage. The present-day automatic systems, however, require a much more constant voltage than the systems to which Mr. Ridd doubtless refers, and it is this requirement which necessitates the apparently elaborate arrangements which he mentions.

Mr. Gregory's communication is a useful addition to the information given in the paper, in which I purposely omitted for the sake of clarity, details of the actual plant such as generators, chokes, voltage regulators, etc. It should be stated, however, that as a result of Mr. Gregory's co-operation it has been possible to lay down a specification for the floating machines and choke coils which will ensure a satisfactory degree of silence on the exchange. The principle involves the specification of the maximum allowable noise disturbance across the generator measured in mV at 800 cycles and the inductance of the choke coil in mH when carrying full load current. The method of measuring the inductance of the choke will be that described by Mr. Gregory.

With regard to Mr. Armitage's enquiry, I think it will be clear that we have not yet had much experience with the Divided Battery Float Scheme. As previously mentioned, however, the system is working satisfactorily at the Leicester Exchange, and in view of the results at this installation and the experience of other administrations with similar schemes, there is every reason to expect that the success anticipated for the Divided Battery Float Scheme will be realised.

The principle of the two automatically operating battery schemes using ampere-hour meters and contact voltmeters is established by several experimental installations, some of which have been in use for 2½ years. The condition of the cells after this time is excellent.

As regards the use of ampere-hour meters, these instruments are being used solely for the purpose of starting and stopping the charge. The instrument is slower in the charge than in the discharge direction to allow for the necessary amount of over-charge. Absolute accuracy of the instrument is not important as it does not matter whether the charging unit is connected when the battery is 5 or 10 per cent. discharged. The percentage overcharge is designed to be adequate, but if it is not sufficient in any individual case, an extra charge can be given by manual resetting of the pointer when a suitable opportunity presents itself.

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