Beach & Carper

Efficiency of a Mercury Arc Rectifier for Charging Storage Batteries

Electrical Engineering

B. S.

1909

EFFICIENCY OF A MERCURY ARC RECTIFIER FOR CHARGING STORAGE BATTERIES

BY

BAYARD MACKNET BEACH
JOHN FISHER CARPER

THESIS FOR THE DEGREE OF BACHELOR OF SCIENCE

IN ELECTRICAL ENGINEERING

IN THE

COLLEGE OF ENGINEERING

OF THE

UNIVERSITY OF ILLINOIS

Presented June, 1909

UNIVERSITY OF ILLINOIS

June 1, 1909

THIS IS TO CERTIFY THAT THE THESIS PREPARED UNDER MY SUPERVISION BY

BAYARD MACKNET BEACH and JOHN FISHER CARPER

ENTITLED EFFICIENCY OF A MERCURY ARC RECTIFIER FOR CHARGING STORAGE BATTERIES

IS APPROVED BY ME AS FULFILLING THIS PART OF THE REQUIREMENTS FOR THE

DEGREE OF Bachelor of Science in Electrical Engineering

Ellery B Paine
Instructor in Charge

APPROVED: Morgan Brooks.

HEAD OF DEPARTMENT OF Electrical Engineering

TABLE OF CONTENTS.

THE EFFECIENCY OF THE MERCURY ARC RECTIFIER FOR CHARGING STORAGE BATTERIES.

The almost universal use of alternating current for distribution circuits makes impossible the application of electricity to many devices suitable for use with direct current only, unless a means be provided for rectifying the alternating current. Furthermore, given such a rectifier as will work satisfactorily without the attendance of a skilled operator, and will show good efficiencies over a considerable range of load, lighting and power companies are able to extend and adapt their service to a much wider range of applications than has previously been possible. The added advantage that much power business thus obtained will build up the demand during the hours of light load makes the introduction of such a rectifier a development of great importance to the central station. With the object of satisfying the demand for such a device several forms of rectifier have recently been placed on the market. The type best suited to small installations, and whose cost of maintenance is least, is the mercury arc rectifier.

OBJECT

It is the purpose of the writers to investigate its operation and to demonstrate its advantages over the other forms of alternating current rectifiers, and particularly to discuss its superiority when used for charging storage batteries.

OTHER RECTIFIERS

Alternating current may be converted into direct by several means. Those commonly applied in rectifiers are:

1. By purely mechanical means.
2. By a combination of mechanical and electro-magnetic means.

3. By the ionization of a conducting medium.

Examples of rectifiers operating on these principles are:

1 a. The synchronous rectifier or commutating rectifier.

2 a. The rotary converter.

b. The motor-generator.

3 a. The electrolytic rectifier.

b. The mercury arc rectifier.

The properties, advantages, and disadvantages of these various types are here discussed briefly:

1 a. Synchronous rectifiers may be simple commutating devices which operate by switching at synchronous speed; the rectified circuit is connected first to one side and then the other of the alternating supply; or they may contain reactances which retard the current until a high potential e. m. f. shall have broken down a spark gap, thus avoiding the commutating of the current itself. In either case there must be a motor operating at synchronous speed, and there is continual wear from sparking. Close attendance is required and continual adjustment is necessary to keep the machine in proper order. Up to the present time these devices have not proved practicable.

2 a. The rotary converter is an excellent machine for rectifying alternating current in large quantities, but for several reasons is not applicable to small installations. The direct current voltage derived is dependent directly upon the voltage of the alternating supply, and hence can not be varied when operated on constant pressure circuits. The efficiency of small units is low, and when the machine is run at less than full load the efficiency rapidly falls off - 70% is to be expected at full load, and at quarter-load it will hardly be more than 50%. Skilled attendance is required, and especially is this true at starting.The floor-

space occupied is large in proportion to the capacity, and there is the serious disadvantage of rotating parts.

2 b. The motor-generator set is more satisfactory than the rotary converter, but there are some objectionable features. The direct current voltage may be regulated independently of the supply voltage, but at the expense of a second shunt field with its I^2R loss. The floor-space is large, and there are rotating parts. Hand regulation is necessary to secure voltage variation as for instance in battery charging. Skilled attendance must be provided, and adjustments must frequently be made.

3 a. The electrolytic rectifier depends for its action upon the property of aluminum when immersed in certain electrolytes which permits the flow of current from the aluminum but not toward it. The efficiency is low due to leakage and the high internal drop; as made at present the rectifiers are not reliable, and for this reason constant attendance is required.

3 b. The mercury arc rectifier is both theoretically and commercially practical, and is the best and most easily maintained device for the purpose on the market to-day. There are no moving parts, and very little attention is required. There is very little wear, and the only part requiring renewal is the tube itself, whose replacement cost is not high. The floor-space occupied is not large. The efficiency is high for a small machine, ranging in the neighborhood of 80% from one-quarter to full load. A marked advantage is the feature of self-regulation, which permits the voltage to rise as the current decreases; this characteristic is of value especially when the rectifier is used in charging batteries.

USES OF THE RECTIFIER

Where it is desired to use small motors of variable speed, the

rectifier is employed to furnish direct current, as there are no small variable speed motors using alternating current. Special sets are on the market of small capacity and simple design, made for use with dentists'and jewelers' motors.

Arc lamps, both carbon and flaming, are steadier and more efficient when used on direct current than when fed with alternating, and the very efficient magnetite arc can be used only on direct current. The mercury rectifier may be used in small sizes for supplying the arcs of projectors, moving picture machines, and the like, or it may be used with constant current transformers for feeding a number of arcs in series, as in street or factory lighting. In the latter case a specially designed rectifier is used, and, the efficiency varying with the direct current voltage, when a number of lamps are in series the set shows an efficiency between 95% and 100%.

Units of very small capacity are used for charging ignition and telephone batteries. The efficiency of these sets is very high for such small units.

The most important use of the mercury rectifier is for charging batteries, and particularly vehicle batteries. Here the features of convenience and automatic regulation are most attractive, tho the high efficiency, less floor-space required, reliability, adaptability, and freedom from the necessity of skilled attendance would be sufficient to insure their use in nearly all cases. Even in large garages, where the load would justify the use of a motor-generator set, the arc rectifier is used, because of its higher efficiency, and devices have been perfected by the use of which rectifier sets may be arranged in parellel to carry any load.

DESCRIPTION OF THE RECTIFIER

There are two essential parts to the rectifier,- the tube itself and the reactances. In ordinary commercial operation there are required also an autotransformer, a starting anode connected thru a resistance, circuit-breakers, direct current voltmeter and ammeter, a switch in the supply circuit, a switch for the starting anode, and a holder for the tube which will permit it to be rocked gently to start.

In the single-phase rectifier the tube has two arms or branches, which contain the carbon electrodes, a central vertical column, a hollow at the base containing the pool of mercury, and near the latter a small branch in which is the starting anode.

When designed for use on constant potential the reactances are combined with the autotransformer. This is in two parts: a large set of coils standing on the floor beneath the panel, and fitted with about six taps for coarse voltage adjustment, and a small transformer on the back of the board, fitted with ten taps for finer adjustment.

The starting anode is close beside the mercury cathode, and is very similar to it in construction, but smaller. It is connected thru a resistance mounted on the back of the panel with one of the carbon anodes.

The measuring instruments furnished with the outfit are small, and show slight errors when compared with carefully calibrated instruments, tho this may easily be accounted for by the presence of a strong magnetic field from the reactance. They are accurate enough for all requirements in connection with battery charging, and indeed the voltage of the rectifier varies thru a small range, so that an exact value cannot be obtained.

A double throw single pole switch is connected in the alternating supply circuit, and a double pole circuit-breaker in the load circuit. A small single pole double throw switch in the starting anode circuit is provided with a spring so that it returns to normal position when released, leaving the load in circuit with the carbon anodes. The starting anode is always in the circuit, but as it is connected thru a resistance there would be little current thru it, even if the bulb were so tipped that the mercury connected the cathode with the small anode. A weight is normally attached to the bulb holder in such a manner that the two pools of mercury are kept separate.

The tube holder is of stiff wire covered with cotton, hold- the arms and central column of the bulb firmly, and yet without danger of breaking by expansion. The holder is carried on a rod which pierces the board and terminates in a handwheel, which may be rotated thru a small angle thus breaking the mercury bridge between the starting anode and the cathode.

All the apparatus except the larger transformer is mounted on a slate panel 31" by 16", the floor-space occupied is 24" by16", and the height to the top of the panel is 64".

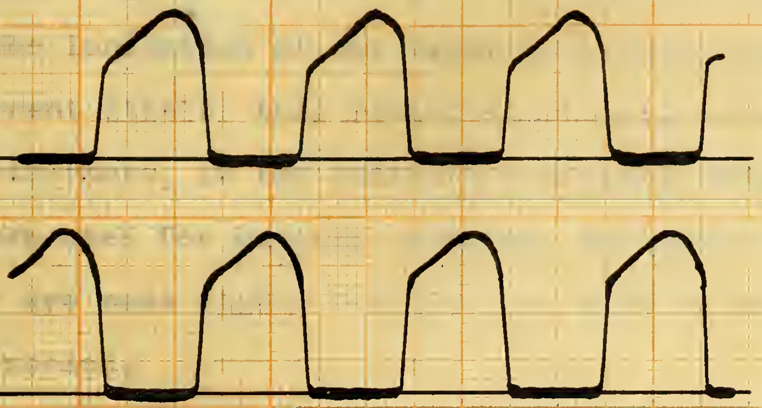
THEORY AND OPERATING CHARACTERISTICS

The working of the rectifier depends upon the fact that ionized mercury vapor is a good conductor of electricity in one direction only. Inert mercury vapor has a high resistance, and a voltage much above any commercially available would be required to cause the current to pass between the electrodes, but when it becomes ionized the drop thru it is comparatively low. When an arc is started in an exhausted tube, with a pool of mercury as the cathode, mercury vapor is given off, and thru this

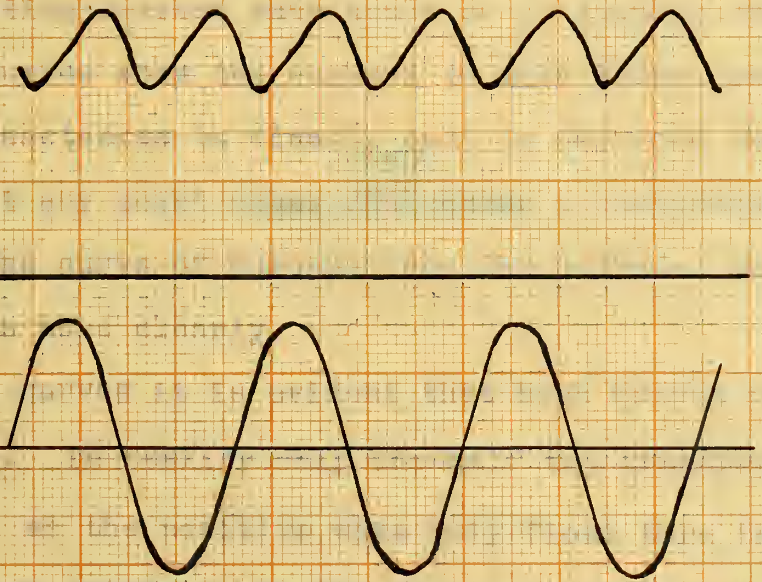
a stream of ions is projected toward the anode. If a positive potential only a few volts above that of the cathode be impressed upon another anode within the region affected by the ionized vapor, current will flow from the anode to the cathode, and the process of ionization will be continued at the cathode as long as the current flows.

The resistance to a flow of current in the opposite direction, however, is very high. Thus if the ionization of the vapor could be maintained in some way and an alternating e.m.f. impressed upon a suitable anode surrounded by the vapor, the positive half-waves would send current toward the cathode, while the negative half-waves would be suppressed by the high "negative anode resistance". If a second anode were connected to the other side of the alternating current supply, the ionization being maintained by some secondary means, each half-wave of current would be used, as first one anode and then the other would discharge to the cathode. The current from the cathode must always be positive, and always flow in the same direction, hence if a storage battery be connected between the cathode and some point in the alternating current circuit which is always at a lower potential, a unidirectional, pulsating current will flow thru it and charge it. This arrangement is applied in the commercial single-phase rectifier, in which case the battery is connected between the cathode and the neutral point of the autotransformer.

Such a rectifier would operate only if some device were provided to maintain the vapor in an ionized condition, such as a direct current of small value kept flowing continuously thru the tube. Another method, and the one used in practice, is to place reactances in the anode circuit. Their effect is to retard the



Anode Currents, Showing Relations of Simultaneous Values in Anodes A and A' of Fig I.



Direct Current Wave Form with Its Accompanying Zero Line Shown in Its Relation to the Impressed E.M.F. it being a Combination of the Anode Current Waves.

current, so that one anode is still discharging current while the other is beginning, hence at no time does the discharge cease entirely, and the ionization of the vapor is maintained by the alternating current itself; this rectifier is said to be "self exciting". Furthermore, in the constant-potential rectifier, which is the form used for battery charging, the coils of the autotransformer are made highly reactive, so that no separate reactances are needed.

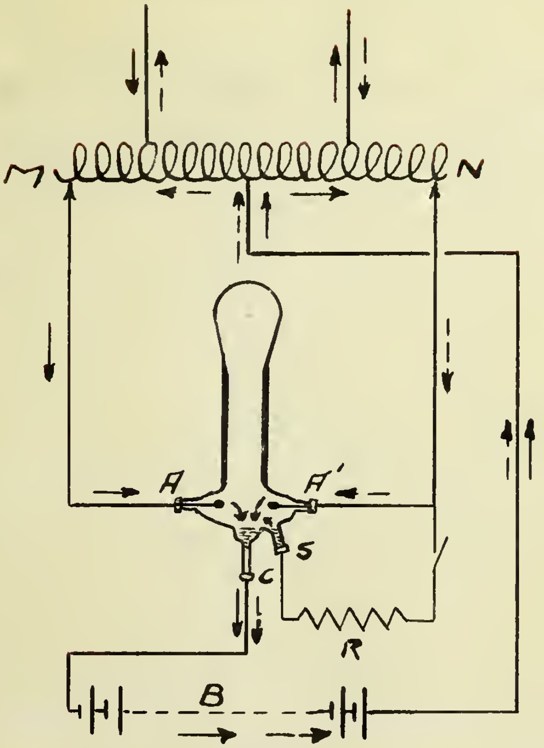
OSCILLOGRAPH CURVES

Tracings of curves taken with the oscillograph are shown on page 8. The lowest curve on the sheet shows the applied e.m.f., and the alternating current wave would be of similar shape. The upper two curves show the current in each anode, and the effect of the reactances is clearly seen in the fact that the two ordinates at any point never fall below a considerable positive value. The curve of current from the cathode, shown next below,shows this more clearly.

From these curves it is evident that both halves of each wave are used. In reality only one-half the transformer is used at a time, as the positive wave only flows thru the coils, the negative loop returning to the center or neutral point instead of thru the other half of the coil. Thus the voltage applied to the arc is only one-half that of the supply, while the current is twice the line current.

Excellent curves were obtained on the oscillograph showing these relations and also the supply current, but before they could be photographed the oscillograph was broken, and for this reason curves were traced from data given in an address ~~given~~ by P. D. Wagoner before the National Electric Light Association,

FIGURE 1.



M-N	Autotransformer and reactance.
A,A'	Anodes.
B.	Direct current load.
C	Cathode.
R	Starting resistance.
S	Starting anode.

at a convention in Denver, Colorado, June 6-11, 1905.

Diagram of Connections - A diagram of the connections of the constant potential rectifier is shown on page 10. In this the solid arrows show the path of the current during one half-cycle, while the dotted arrows show its course during the next half-cycle, after the alternating current supply has reversed the direction of its flow.

In this diagram the autotransformer is shown as it would be tapped for 110 volt direct current voltage when the supply voltage is 220, as was the case in most of the tests, and as would be the case in charging batteries. To deliver power at 110 volts the alternating supply would have to be stepped up to about 260 volts to allow for the drop in the arc and other minor losses. The relations stated above, - that the direct current voltage is one-half the supply voltage, and the current twice that in the anode leads, - would not hold in this case of course. The range of the autotransformer is such as to give a maximum direct current voltage of about 120 at full load current of 30 amperes, while the lowest voltage obtainable is about 35.

It must be remembered that in this form of rectifier the reactances are combined with the transformer, the coils being wound to give a high inductance. In some forms there is a separate reactance in each anode lead. In the constant potential set, the one shown, a higher reactance is used than in some other forms, because in charging batteries it is essential that the current curves overlap more to keep the minimum value of the current high. In this case it not only must not fall below a value sufficient to maintain the arc, but it must not allow the battery to exert counter-e.m.f. high enough to overcome the impressed voltage.

Another function of the high reactance in battery charging is to give the set a higher regulation. The bulb itself has zero regulation, while it is known that in charging batteries the best results are secured if a higher voltage and smaller current are used for the last of the charge than at the beginning. This is accomplished with the mercury rectifier thru the regulation drop in the transformer. When the counter-e.m.f. of the battery rises it cuts down the charging current, and would soon extinguish the arc and stop the charge if the impressed voltage did not rise at the same time. On account of the less drop in the transformer and the higher direct current voltage resulting, the battery is given the desired finishing charge at a higher voltage.

DATA

The rectifier was connected thru an ammeter and a wattmeter to 220 volt alternating current supply mains, with a voltmeter across the line, while the direct current circuit was made to include an ammeter and a set of carbon incandescent lamps arranged in banks, with a voltmeter across the terminals. Lamps were used for the load because of their convenience, and the value of the results obtained is not in any way affected by the nature of the load. Connections were made thru the switchboard in the laboratory, and the alternating current was obtained from the 45 kilowatt substation in the laboratory, in order to keep the voltage constant.

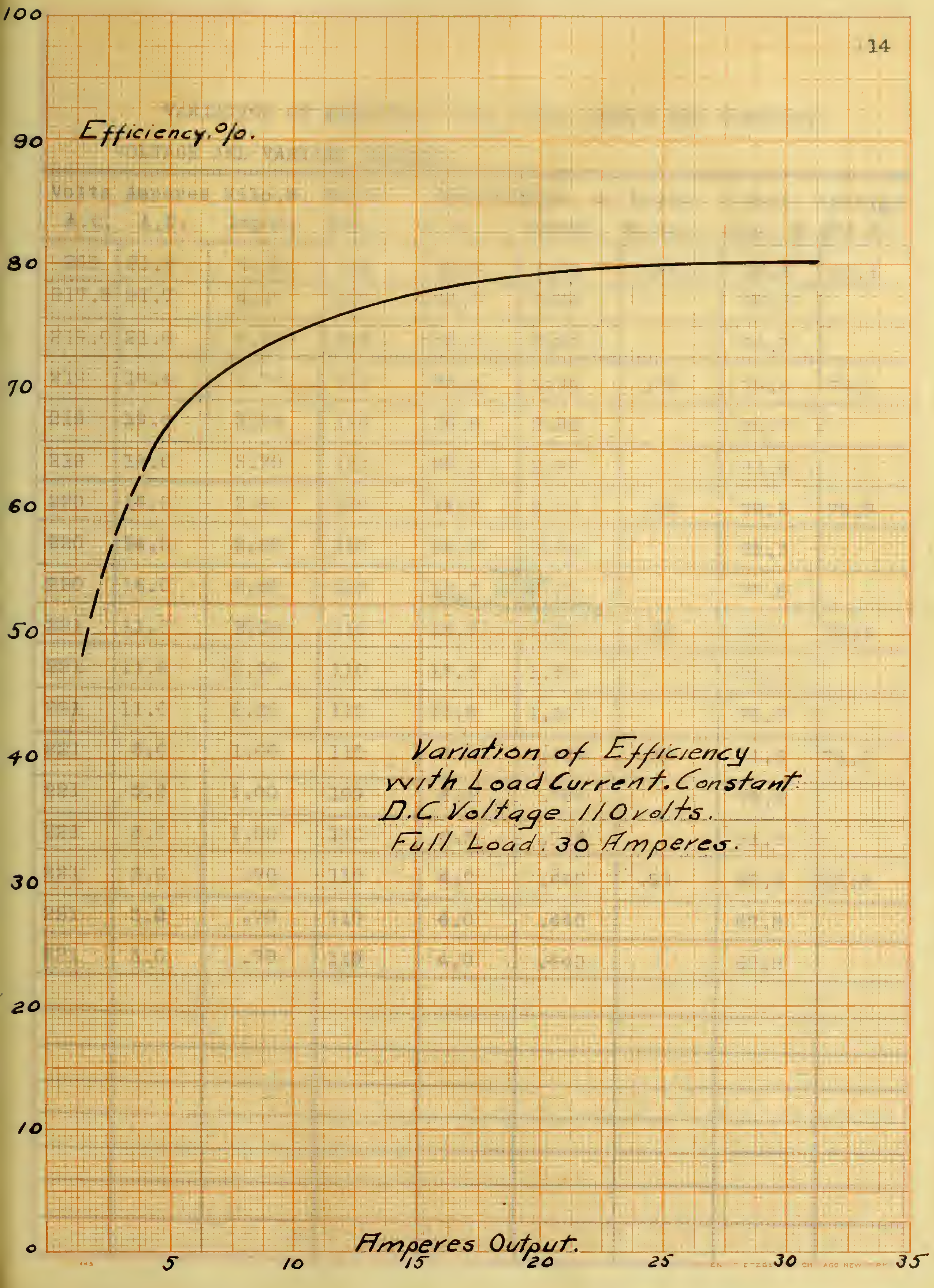
The alternating current instruments used were calibrated before the data was ~~any of it~~ taken, while correction curves were used to give the correct readings of the direct current instruments. Accurate readings representing the real values of current, voltage,

power, and the direct current voltage and current were hard to obtain, because the flickering of the arc made it difficult to decide on a fair average reading of the needles. For this reason three readings at each state of the circuit were taken, and the results averaged. All instruments were read as nearly as possible at the same time, and in most cases the three readings of each set agree rather well.

The instruments were set on a table about twenty-five feet away from the rectifier itself, on account of the stray field surrounding the reactances. It is likely that there was some considerable loss in the leads to and from the instrument table, and this no doubt influenced the results somewhat. But while exactly this source of loss would probably not be met in practice, there are doutless small losses of the same or greater importance in every installation.

A set of readings was taken covering the conditions of varying voltage and constant full load current - 30 amperes. A second set was taken to show the efficiency at varying loads, with the voltage kept constant at 110 volts. Preliminary data was taken to indicate the drop across the arc itself, but before final values were taken with calibrated instruments the vacuum of the tube was destroyed, and a new tube substituted in its place does not show the same characteristics.

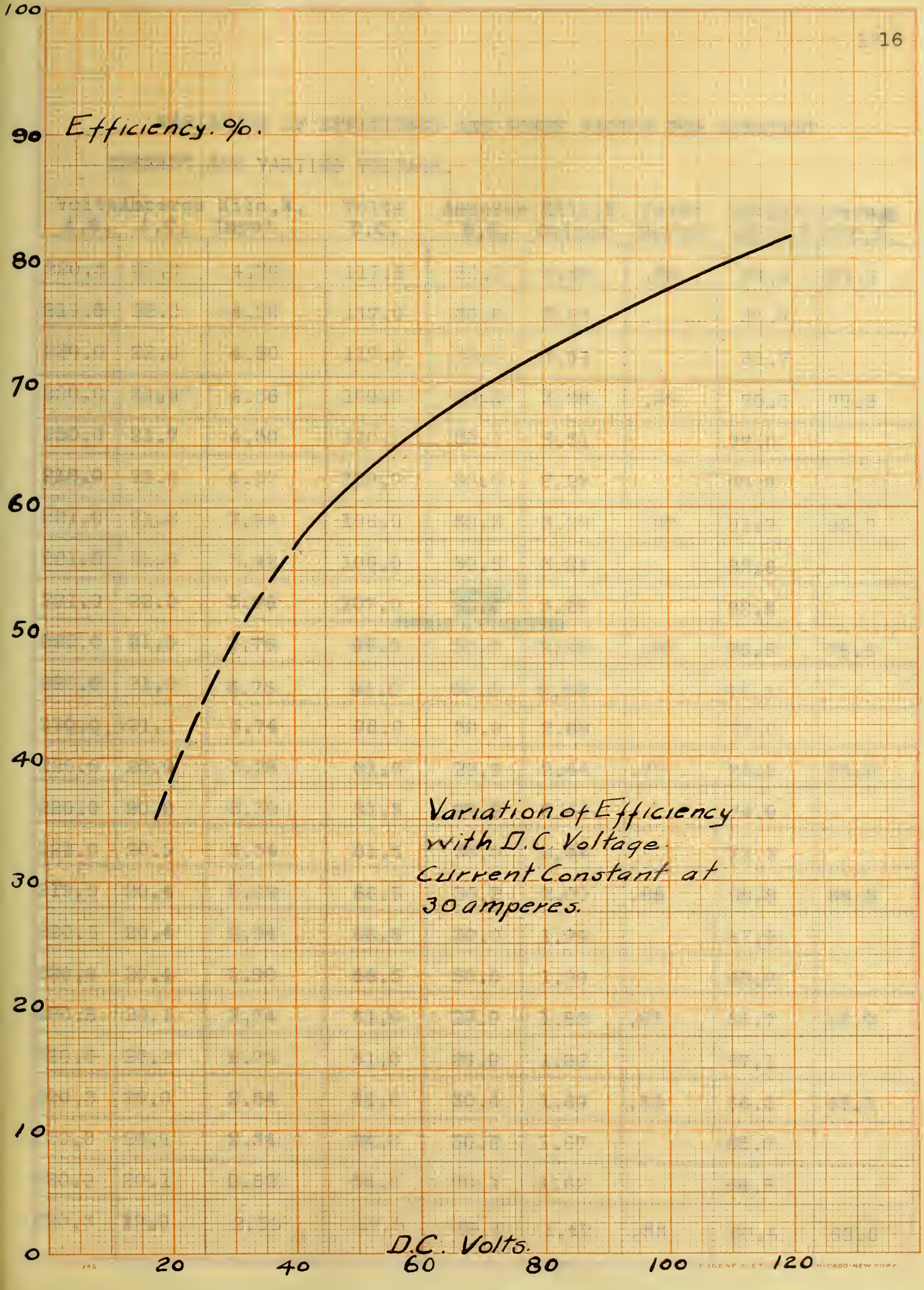
A similar set of data was taken on a motor generator set in actual use for charging the batteries of an electric automobile, in which case only the voltages and currents actually called for in charging were used. Finally, for the purpose of comparing the rectifier and the motor generator set, the same readings were taken on the rectifier.



Variation of Efficiency with Load Current. Constant D.C Voltage 110 volts. Full Load. 30 Amperes.

VARIATION OF EFFICIENCY AND POWER FACTOR FOR CONSTANT VOLTAGE AND VARYING CURRENT.

Volts A.C.	Amperes A.C.	Kilo.W. Input.	Volts D.C.	Amperes D.C.	Kilo. W. Output.	POWER Factor.	Effici- ency, %.	Average Eff.%.
219	21.8	4.10	110	30.8	3.39	.86	82.6	80.4
217.5	21.7	4.10	108	30.0	3.24		79.3	
219.0	21.8	4.10	108	30.0	3.24		79.3	
219	19.4	3.70	111	26.5	2.94	.86	79.5	79.7
219	19.6	3.74	110	26.8	2.94		78.7	
219	19.6	3.70	111	27.0	2.99		81.0	
220	14.0	2.60	110	18.7	2.06	.84	79.3	78.7
220	14.0	2.60	110	18.7	2.06		79.3	
220	14.0	2.60	110	18.3	2.01		77.5	
221	11.0	2.00	110	13.8	1.52	.89	76.0	75.5
221	11.0	2.20	110	13.8	1.52		75.3	
221	11.0	2.20	110	13.8	1.52		75.3	
221	5.0	1.00	110	6.5	.715	.90	71.5	71.3
221	5.0	1.00	109	6.5	.709		70.9	
221	5.0	1.00	110	6.5	.715		71.5	
221	3.0	.70	110	4.0	.440	.91	62.8	62.8
221	3.0	.70	110	4.0	.440		62.8	
221	3.0	.70	110	4.0	.440		62.8	



Variation of Efficiency with D.C. Voltage. Current Constant at 30 amperes.

VARIATION OF EFFICIENCY AND POWER FACTOR FOR CONSTANT CURRENT AND VARYING VOLTAGE.

Volts A.C.	Amperes A.C.	Kilo.W. Input	Volts D.C.	Amperes D.C.	Kilo.W. Output	Power Factor	Efficiency, %.	Average Eff. %.
220.5	22.0	4.30	117.5	30.0	3.52	.88	81.9	81.8
219.5	22.0	4.20	117.0	30.0	3.51		81.7	
220.0	22.0	4.30	117.0	30.0	3.51		81.7	
220.0	21.80	4.36	109.0	30.1	3.28	.88	75.3	77.3
220.0	21.7	4.30	110.0	30.1	3.31		77.0	
218.0	21.4	4.10	109.0	30.0	3.27		79.8	
221.0	21.6	3.94	106.0	30.3	3.22	.87	81.7	82.3
221.0	21.5	3.92	106.0	30.5	3.24		82.6	
221.0	22.0	3.96	107.0	30.6	3.28		82.8	
220.0	21.0	3.76	96.0	30.0	2.88	.82	76.6	76.6
220.0	21.0	3.78	96.0	30.0	2.88		76.3	
220.0	21.1	3.74	96.0	30.0	2.88		77.0	
220.0	20.9	3.28	81.5	29.9	2.44	.72	74.5	73.9
220.0	20.8	3.30	81.5	29.9	2.44		74.0	
221.0	20.9	3.34	81.5	30.0	2.44		73.3	
219.0	20.4	2.92	66.5	30.2	2.00	.66	68.8	68.5
220.5	20.4	2.94	66.5	30.0	1.99		67.9	
220.8	20.4	2.90	66.5	30.0	1.99		68.8	
220.8	20.1	2.74	61.0	29.9	1.82	.63	66.7	66.9
220.5	20.2	2.72	61.0	29.9	1.82		67.1	
220.3	20.0	2.54	54.0	30.4	1.69	.58	66.5	65.3
220.0	20.1	2.54	54.0	30.2	1.67		65.8	
220.0	20.1	2.52	54.0	30.1	1.62		64.8	
220.3	19.9	2.36	47.0	39.3	1.42	.56	60.4	60.6

VARIATION OF EFFICIENCY AND POWER FACTOR FOR CONSTANT CURRENT AND VARYING VOLTAGE.

Volts A.C.	Amperes A.C.	Kilo,W. Output	Volts D.C.	Amperes D.C.	Kilo.W. Input	Power Factor	Effici- ency,%.	Averag Eff.%.
220.0	19.9	2.34	47.0	30.2	1.42		60.7	
220.0	19.9	2.34	47.0	30.3	1.42		60.9	
220.0	19.6	2.18	41.5	30.3	1.25	.53	57.6	57.1
220.0	19.6	2.20	41.3	30.1	1.24		56.5	
220.0	19.6	2.20	41.5	30.4	1.26		57.3	
221.0	14.3	1.92	38.5	30.1	1.15	.60	60.2	59.4
220.0	14.0	1.86	38.0	29.6	1.12		59.4	
220.0	14.0	1.88	37.5	29.6	1.11		58.6	

COMPARISON OF EFFICIENCY OF MERCURY RECTIFIER AND MOTOR GENERATOR SET.

FOR VOLTAGES AND CURRENTS USED IN CHARGING BATTERIES.

RECTIFIER.

Volts A.C.	Amperes A.C.	Kilo.W. Input	Volts D.C.	Amperes D.C.	Kilo.W. Output	Power Factor	Effici- ency,%.	Average Eff,%.
219,0	7.30	1.33	86.0	11.0	.946	.871	71.0	70.3
220.7	5.62	1.08	84.0	9.0	.756	.878	69.5	
220.8	6.22	1.21	85.0	10.0	.850	.882	70.3	
219.5	6.25	1.20	85.0	10.0	.850	.881	70.4	

MOTOR- GENERATOR.

*	*	2.100	84.0	10.0	.840	*	40.0	40.81
		1.93	85.0	9.0	.765		39.6	
		2.50	86.0	12.5	1.073		42.9	
		1.90	86.0	9.0	.774		40.75	
		2.55	110.0	10.0	1.100		43.12	43.2
		2.54	110.0	10.0	1.100		43.28	

*Readings of Power were obtained with an integrating wattmeter, volts and amperes not being measured, so power factor could not be calculated.

CURVES

From the average readings curves were plotted between load current and efficiency, and between direct current voltage and efficiency. From these it may clearly be seen how well the efficiency holds up down to low loads. The upper half of the voltage-efficiency curve is practically a straight line, showing the intimate relation between the efficiency and the voltage.

LOSSES AND EFFICIENCY

In the rectifier set proper there are two sources of loss - the reactive drop in the transformer, and the drop across the arc itself. The loss in the transformer is in the nature of a reactive drop, which is naturally a function of the load. It is this loss which causes the rise of direct current voltage with the falling off of the current. It is not large enough to be very serious. The transformer drop is less at the higher voltages, because for these voltages the taps are so set that the current goes thru the transformer without passing thru as much copper as when the direct current voltage is lower and the ratio of transformation more widely divergent from unity.

The most important and the most interesting loss in the set is the drop in the arc. This is practically constant, and in the neighborhood of 15 volts. Preliminary tests indicated a drop of about 14 volts, but the tube was broken before exact readings were taken. This drop is peculiar in that it is practically constant at all loads and voltages, which property is derived from the fact that the contact resistance of the electrodes and the vapor is in inverse proportion to the current flowing, so that the product IR is constant. It is because of this constant drop that the efficiency of the constant current rectifier is so high for the

higher voltages, since the drop is a much smaller part of the total applied voltage. In this connection it is worthy of note that if the rectifier is used for higher voltages than those within the range of these tests, such as for charging cells of more than sixty cells, the efficiency of the set would be found gratifyingly high.

In the tests on which this thesis is based, there is probably an unusually high I^2R loss on account of the long conductors used. This would affect the efficiencies at the higher voltages especially, but the difference would not be serious, and it is likely that in practice there would be other small losses to off-set this, such as poor contacts.

The most pleasing feature about the efficiency tests is the excellent efficiency at low loads. Very few pieces of electrical apparatus, and none performing the same service, can show as good efficiencies at one-quarter and one-sixth load as the mercury rectifier.

POWER FACTOR

The power factor varies from 53 to 91, but the lower values are for lower voltages than would often be used in practice. These low values are not the fault of the rectifier, but of the transformer, and a set with coils especially designed for these lower voltages would operate at the same high power factor that this set shows on the higher voltages. It is stated by a storage battery manufacturer* that the power factor is independent of the size of battery charged.

---

*"Mercury Arc Rectifiers", by P. D. Wagoner.

EFFECT ON BATTERIES

It is stated by a storage battery manufacturer* that the battery engineers consider the slightly pulsating current from the rectifier not only not harmful, but actually of benefit to the battery, as the gassing is less, and the charge more thoro than is the case with ordinary direct current.

EXAMPLE OF BATTERY CHARGE

On page19 is given a set of data taken on a motor generator set in almost daily use for charging the cells of an electric automobile, the voltages and currents being those found best for the battery, and readings from the mercury rectifier for the same values. The battery consisted of 42 cells, and the voltages and currents prescribed by the manufacturer were 86 and 102 volts, and 22 and 9 amperes at start and finish, respectively. But the owner had found from long experience that the charge lasted better if at a slower rate, and had given instructions that the current was to be kept constant at 10, and the voltage at start and finish were to be 86 and 110 respectively. Readings were taken therefore at the values, and the same conditions applied to the rectifier. Below is given a comparison of the cost of one charge by each method, the price of power being assumed at eight cents, the lowest that can be obtained locally.

From this comparison it appears that the saving is considerable when the rectifier is used. The life of the bulb is now placed at 1000 hours by the manufacturers, but assuming only that it is 800 hours, one bulb will last thru one hundred regular chargings. At this rate, with the saving per charge $0.59 as

---

* "Mercury Arc Rectifiers", by P. D. Wagoner.

shown below, the total saving is $59.00 in the life of the bulb, or practically three times what it cost.

Cost per charge -

Motor generator -

7 hours @ 2.1 k.w. = 14.7 k.w.H
1 " @ 2.55 " = 2.55 "
Total = 17.25 k.w.H
Cost per charge at 8¢ per k.w.H = $1.38

Mercury rectifier -

7 hours @ 1.21 k.w. = 8.47 k.w.H
1 " @ 1.47 " = 1.47 "
Total = 9.94 k.w.H
Cost per charge @ 8¢ per k.w.H = .79
Saving per charge = $0.59

CAPACITIES AND LIMITATIONS

Commercial rectifier sets are made in capacities ranging from five to thirty amperes. The limit of thirty amperes is not exceeded because it is not commercially possible to make bulbs of larger capacity whose life is long enough to justify their extra expense. The limit is determined by the heating of the bulb and the leading-in wires. Bulbs of larger size have been run successfully when immersed in oil, but for commercial installations this is not convenient, and no attempt is made to make the larger sizes. When it is desired to use more than thirty amperes of direct current, two or more tubes are connected in parellel, and the operating characteristics are approximately the same as for a single bulb.

The voltages may be almost anything met in practice. Most

of the demand is for sets to operate on 110 or 220 volt circuits, and the outfits manufactured for these voltages may be arranged to work satisfactorily with an output voltage of anywhere from 16 to 120 volts. Special sets may be designed for any given supply voltage, but the efficiency is slightly less owing to greater transformer drop. The limit of the voltage applied to the anodes is set by the value at which the e.m.f. is high enough to flash across from one anode to the other. Bulbs are used with voltages as high as 4000 in series arc lighting; in this case the anodes are enclosed in glass tubes open at the lower end on the side away from the other anode. These high voltage bulbs show a very high efficiency, but are expensive to manufacture, and there is little demand for them except in connection with constant current transformers for series arc lighting.

Commercial sets are designed for 60 cycles per second frequency, but may be used on any frequency from 25 to 140. A proper design of reactances would enable the bulbs to be used on other frequencies, but the efficiency is not noticeably higher at higher frequencies, and there is no demand for them.

CONCLUSION

The purchaser requires two advantages in choosing between the mercury rectifier and an equivalent device; - these are greater economy, and greater convenience. Both of these are found to lie with the rectifier.

The first cost of the rectifier is less than that of a motor generator set, - and the motor generator set is the nearest rival of the rectifier. The set on which these tests were made cost $195.00 while the motor generator set with which the

comparison was made cost about $300.00. This means a saving of about $14.00 a year, if the rate of interest and depreciation be taken at 14%. The operating expense is less not only on account of the power saved, but because there is less expense for maintainence and repairs, and the charges for attendance are less. If the battery be charged once each week, which is probably not a high figure, one bulb will last two years, and the saving per year will be in the neighborhood of $20.00, with a total expense for power of about $40, in the example of comparison. The life of the bulb is placed by the makers at 1000 hours, while single tubes have been known to burn for over 4500 hours. The bulb in use in the exchange of the Home Telephone Company in Champaign is known to have been used for over 2400 hours.

The convenience of the rectifier is a point strongly in its favor. An automatic starting device is now applied to charging panels where the current is subject to interruption, and as the regulation automatically raises the voltage as the counter-e.m.f. of the battery rises, no attention need be paid the set from the time it is started till the charging period is completed. Its cleanliness and noislessness are attractive features where the set is used in private garages.

On account of its great economy, convenience, and flexibility the mercury arc rectifier has not only displaced to a large extent the other devices formerly used for the same purpose, but it has made possible many applications not previously practicable.

LIST OF REFERENCES.

The following were found of great assistance in the preparation of this thesis:

1. Transient Phenomena, - C. P. Steinmetz. McGraw, 1909.
2. Modern Engineering Practice, - American School of Correspondence, 1906. Vol. 4, Pages 461-74.

3. Constant Current Mercury Arc Rectifier, - C. P. Steinmetz. American Institute of Electrical Engineers, Transactions. June 19 1905.
4. Cooper Hewitt Static Converter, Electrical World and Engineer. January 17, 1903.
5. Mercury Arc Rectifier, - W. T. Small. Purdue Engineering Review, Purdue University, 1908.
6. Mercury Arc Rectifiers, - The Electric Journal, May, 1909.
7. Mercury Rectifier Battery Charging Outfits, - P. D. Wagoner. Address Delivered Before The National Electrical Light Association, Denver, June 6-11, 1905.
8. Mercury Arc Rectifiers for Charging Storage Batteries, - A. Fred Collins, Scientific American, February 17, 1906.
9. Mercury Vapor Converters, - P. H. Thomas. Electric Journal, July, 1905.

10. Bulletin of the Electric Storage Battery Company, 1905.
11. Bulletin of the General Electric Company, 1908.
12. Bulletin of the Westinghouse Electric and Manufacturing Company, #1148, January, 1909.