THESIS

An Experimental Study of the
Regulation of Alternators.

by

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Class of Nineteen Hundred and Fifteen

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AN EXPERIMENTAL STUDY OF THE REGULATION OF ALTERNATORS.

A careful perusal of the new Standardization Rules of the A. I. E. E. will reveal a no more radical change than in that section devoted to the regulation of alternators. Those who are not familiar with the various articles which have been published on this subject of regulation will no doubt question the reason for changing a rule which has been so long in use, and perhaps will doubt the accuracy of the results obtained by the new method. In considering this subject the writer had a two-fold purpose in view, first, to compare the results obtained by the new method with those obtained by methods which have been advocated in the past, and, second, to discover if possible an easy way of conducting the experimental part of the work which would enable the test to be included in the Junior Laboratory Course.

Previously to this time there have been two general methods in use for obtaining the regulation of an a-c. generator: by a load test, and by means of vectorial calculations from values obtained on open circuit and short circuit tests. The first has been included in the new rules (Rule 295) and stands first in the order or preference. It is, however, applicable only to small machines, for, owing to the difficulty in dissipating the large quantity of energy generated, it is next to impossible to apply it to large units. In the laboratory and factory the test is usually conducted on small machines by driving from a d-c. shunt motor and loading by means of a water resistance. Two errors are inherent in this method of procedure. The first is due to the method of driving and the second to the method of loading. When the a-c. circuit is opened and the load reduced, the d-c. motor will speed up. This causes the alternator voltage to rise to a point above that which it would reach if the speed had remained constant, by a value which is proportional to the difference in speeds. This is quite evident from a consideration of the fundamental generator equation $E = \phi Z n 10^{-8}$. The voltage E and E' generated at the speeds n and n' respectively are in the proportion E: E' = N: N' and their difference is in the proportion E'-E:= n'-n: n. Assuming that the motor has a speed regulation of five per cent the generated voltage E' will be five per cent greater than the voltage E. Now the speed of the motor can be reduced to the speed n by an adjustment of field current but the voltage E' will not be reduced thereby to the voltage E on account of the hysteresis in the iron comprising the magnetic circuit of the alternator. The error introduced by this method of driving will depend upon the speed regulation of the motor and upon the quality and degree of saturation of the iron magnetic path of the alternator. Needless to say this error can be entirely overcome by driving from a constant speed motor; on the other hand the error will be increased if the alternator is driven by an induction motor. A second error is introduced if the power-factor of the load departs even a slight amount from unity. In order to make it plain that even a very slight deviation from unity power-factor introduces a large error it is necessary to demonstrate that the quadrature component of the current has a greater influence on the regulation than the active component. This may be shown by an analysis of the equation for finding the regulation of a transformer. The transformer equation is taken instead of a similar equation which might be developed for an alternator because it is much simpler, no modification being necessary to account for variations due to rotating parts, varying air-gap, etc. This equation is given in section 502 standardization rules as follows: For inductive loads of power-factor m and reactive factor n,

$$\text{Per cent regulation} = mq_r + nq_x + \frac{(mq_x - nq_r)^2}{200}$$

where q_r = per cent resistance drop

and q_x = per cent reactance drop.

For our purpose the last term can be neglected for it is small compared with the other two. Since the reactive drop q_x is several times as great as the resistance drop q_r, a variation in the quantity n will produce a much greater error in the result than a variation in the quantity m. Taking this into consideration and referring to the following table, it is quite evident why a small deviation of the power-factor from unity makes such a difference in the regulation.

Power-Factor (m)	0.995	0.99	0.98	0.90	0.20	0.10
Reactive-Factor (n)	0.10	0.14	0.20	0.435	0.98	0.995

On the other hand a considerable deviation from zero makes practically no difference. This point will be referred to later. It is usual to assume that the current taken by a water-barrel is in phase with the voltage but this is not strictly the case. The water barrel has a slight electrostatic capacity which causes it to draw a leading current. Since a piece of electrical apparatus will have a better regulation on a leading current than on one which is in phase, as a rule the water-barrel-load test of an alternator will give a result which is optimistic.

It may be argued that the error in voltage which is caused by a deviation from rated speed or unity power-factor is quite insignificant. It is true that the absolute value of the error is generally small but it must be remembered that in regulation we are dealing with a difference between two numbers which is small in comparison with the numbers themselves. This being the case the percentage error in the difference due to a slight error in one or both the voltages will be large. Fortunately the two errors just cited are to some extent compensating. The former tends to give a poorer regulation while the latter tends to give a better regulation than the correct value.

I have gone to considerable length to point out some of the difficulties and errors encountered in the experimental determination of regulation by a load test at unity power-factor. We shall now consider some other methods for determining regulation.

These necessitate the running of two curves; namely, the no-load saturation curve and the short-circuit curve, or instead of the latter the synchronous impedance curve. By means of vector quantities which may be obtained from these curves the regulation may be calculated in two different ways. These two methods have received the names e.m.f. (pessimistic) method and m.m.f. (optimistic) method. With the type of alternator in use at the time it was introduced, the pessimistic method gave a very good result; but with the modern machine it gives a regulation usually far in excess of the true value. Hence its name. The m.m.f. method is the one which was adopted by the A. I. E. E. in 1902 and has been recommended by it until the adoption of the 1915 rules. This method while with most modern machines giving results quite close to the true value, is only on approximation.

It was pointed out by B. A. Behrend in a paper published in vol. 21 Transactions of A. I. E. E. that the m.m.f. method neglected the self-inductive effect of the local armature fields. In order to take this effect into account by a test method it becomes necessary to obtain a full-load saturation curve at a power-factor approaching closely to zero. This solution was the one advocated by Mr. Behrend at that time and is the one which has been adopted by the Institute Standardization Committee. It is contained in section 296 of the Standardization Rules as follows: "This consists in computing the regulation from experimental data of the open-circuit saturation curve and the zero power-factor saturation curve. The latter curve, or one approximating very closely to it, can be obtained by running the generator with over excited field on a load of idle-running under-excited synchronous motors. The power-factor under these conditions is very low and the load-saturation curve approximates very closely the zero power-factor saturation curve. From this curve and the open-circuit curve, points for the load saturation curve for any power factor can be obtained by means of vector diagrams." This method sets aside all theories as to the effect of the reactance drop and substitutes in their place experimentally ascertained data from which the regulation at any power-factor can be accurately calculated by means of vectors.

By this method of loading recommended it is possible on small machines to obtain a power-factor of from 20 to 30%. Remembering that it is the reactive-factor which h has the greater effect upon regulation and again referring to the table of power-factors and reactive-factors, one will readily see why a load-saturation curve at a power-factor around 20% is a very close approximation to the zero power-factor curve. I shall later point out a method whereby it is quite possible to obtain a power-factor much lower than is possible by this method of loading.

Having considered thus briefly the four methods of determining regulation let us turn our attention to the experimental side of the question.

The machines available in the laboratory are four in number; two of these are revolving field alternators, the others are synchronous converters. The make, rating, and method of driving these machines can be readily ascertained by reference to the accompanying table.

Name	Rating or Number	Connected	Volts and Cycles	Motor Drive
Central Laboratory Alternator	7.5 Kw	3-phase Y	194 a-c. 60 ~	shunt
" "	7.5 Kw	3-phase Δ	110 a-c. 60 ~	shunt
Westinghouse Converter	7.5 Kw 629991	d-c. armature	125 d-c. 60 ~	shunt
Holtzer-Cabot Synch. Motor	7.5 Kw 130298	Y	110 a-c. 50 ~	shunt
General Electric split-pole Converter	6.75 Kw 695707	d-c. armature	90-125 d-c. 50 ~	induction

The Central Laboratory Alternator has its leads brought out to a terminal board so that it can be connected either Y or delta. This makes it possible to run five series of tests on the four machines available.

The tests run on each machine are as follows:

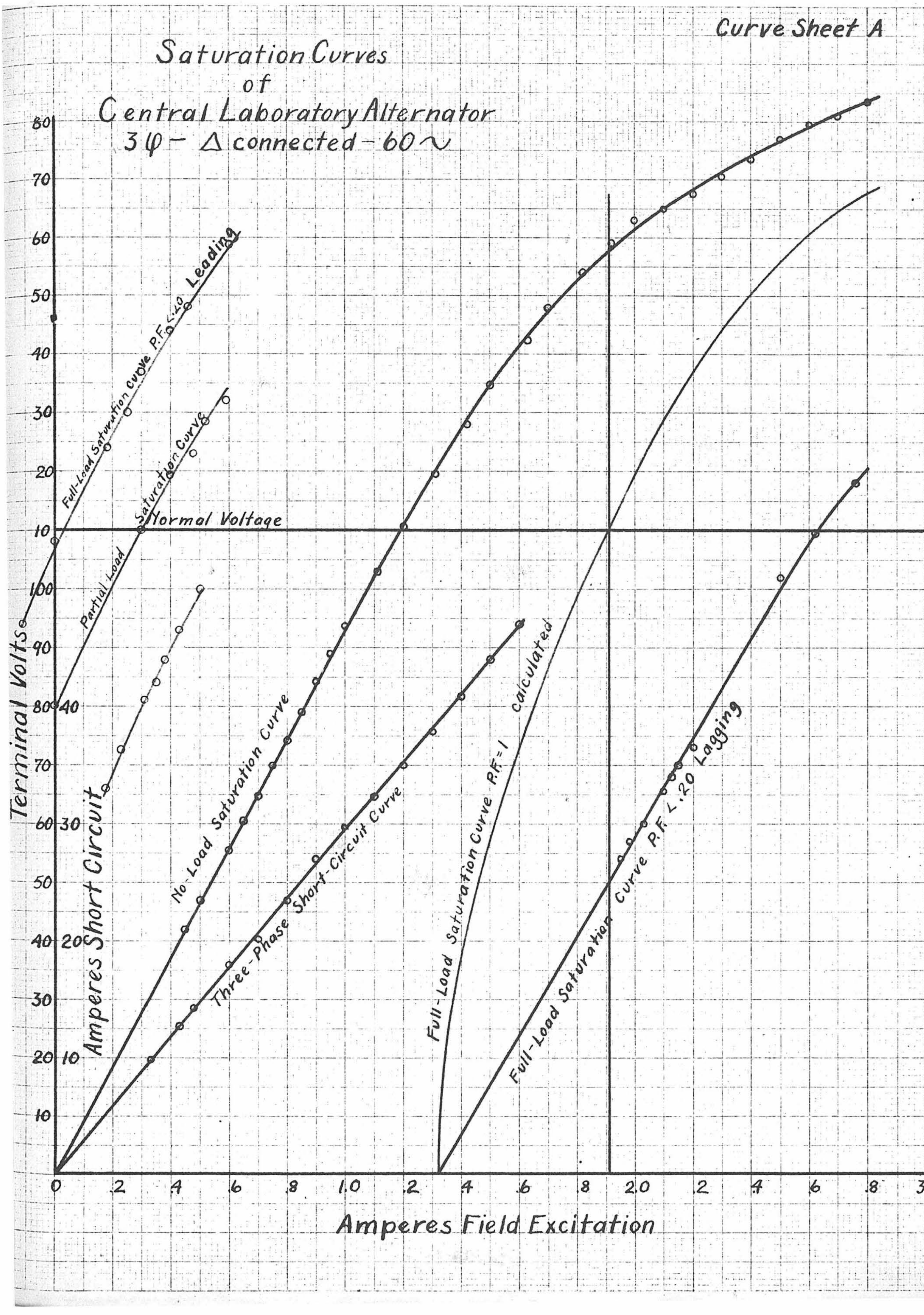
1. Regulation tests by direct loading at unity power-factor.

2. No-load saturation test.

3. Short-circuit test.

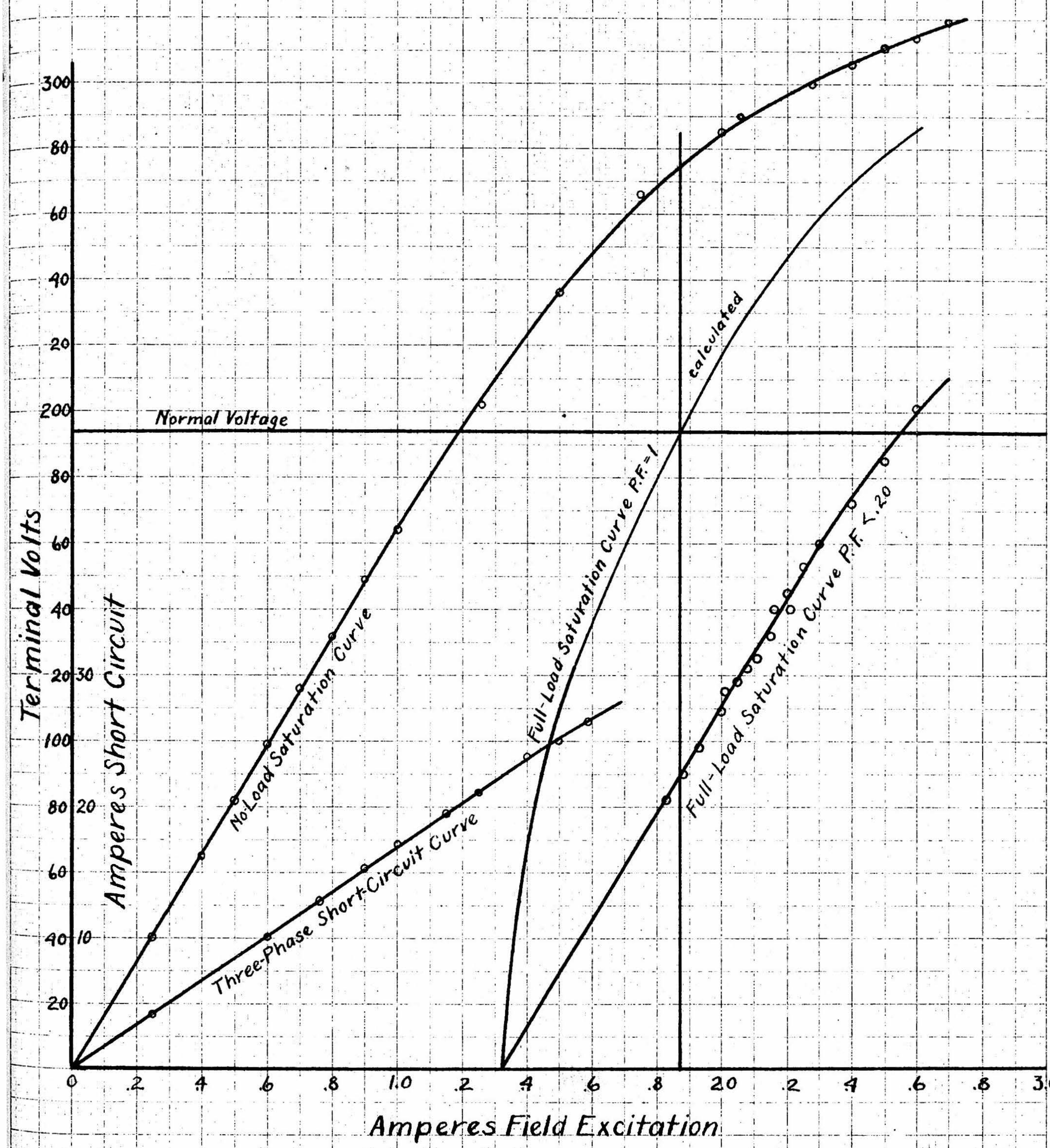
4. Full-load saturation test at power-factor less than 20%.

The data obtained from these tests were plotted on coordinate paper and smooth curves drawn through the points thus averaging errors in reading the instruments. From the no-load saturation curves and the short-circuit curves the regulation at unity power-factor for various loads was calculated by both the e.m.f. and m.m.f. methods. These values were plotted for the various machines, and curves drawn through the points in order to average small errors in calculation. The full-load saturation and no-load saturation curves for each machine were plotted on the same sheet and from these two curves the saturation curve at unity power-factor was calculated by means of vector quantities. From this latter curve the regulation at full load and unity power-factor was obtained. The armature



Curve Sheet A
Saturation Curves
of
Central Laboratory Alternator
3φ – Δ connected – 60 ~
Terminal Volts
Amperes Short Circuit
Amperes Field Excitation
Normal Voltage
Full-Load Saturation Curve P.F.<.20 Leading
Partial Load Saturation Curve
No-Load Saturation Curve
Three-Phase Short-Circuit Curve
Full-Load Saturation Curve P.F.=1 calculated
Full-Load Saturation Curve P.F. ∠.20 Lagging
0
.2
.4
.6
.8
1.0
.2
.4
.6
.8
2.0
.2
.4
.6
.8
3.0

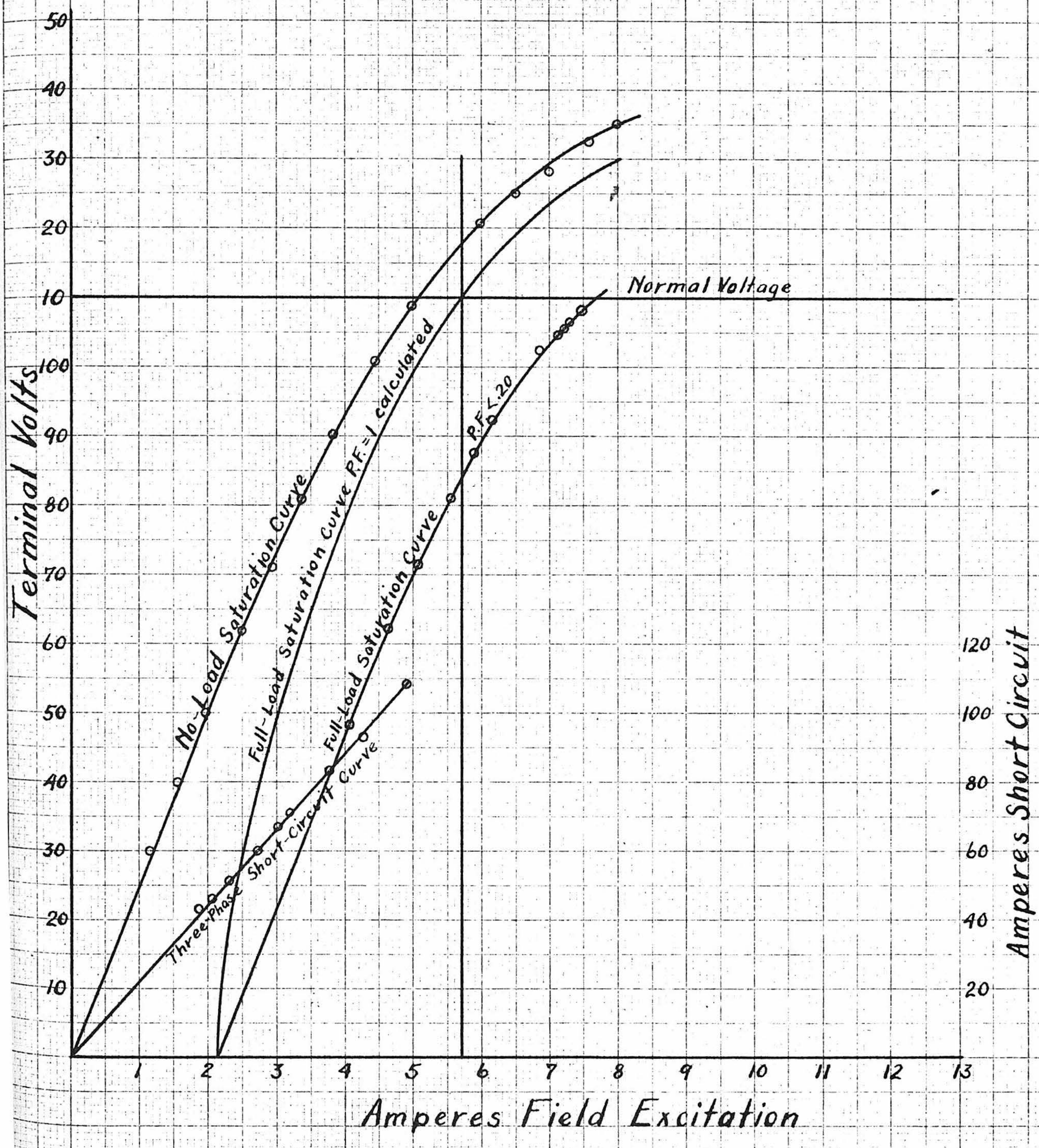
Saturation Curves of Central Laboratory Alternator 3φ - Y connected - 60 ~



Curve Sheet C.

Saturation Curves
of
Holtzer-Cabot A-C. Motor #130298
110 volts 48 amperes 50 cycles

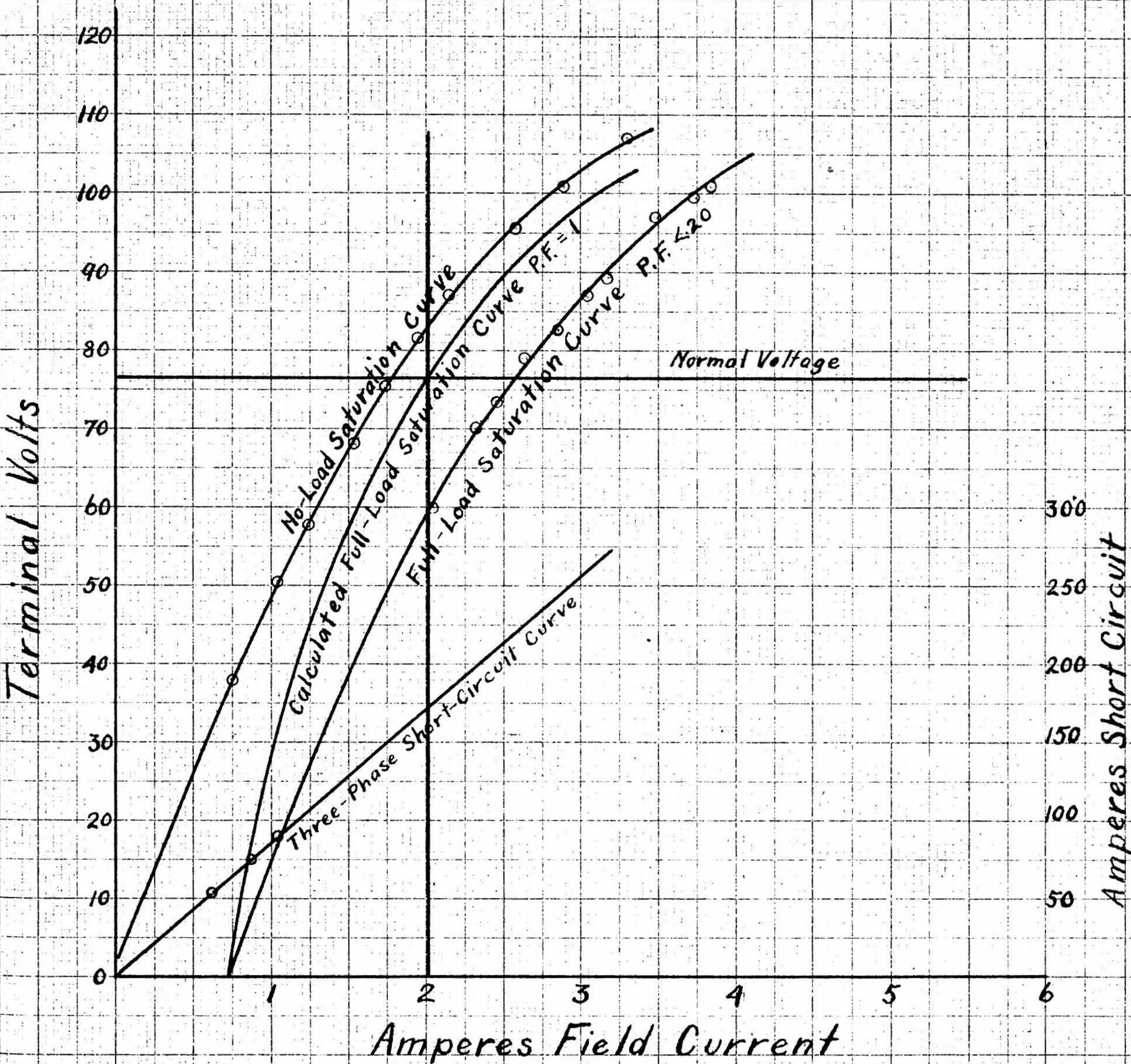
1000 rev. per min. 3 phase



Curve Sheet D

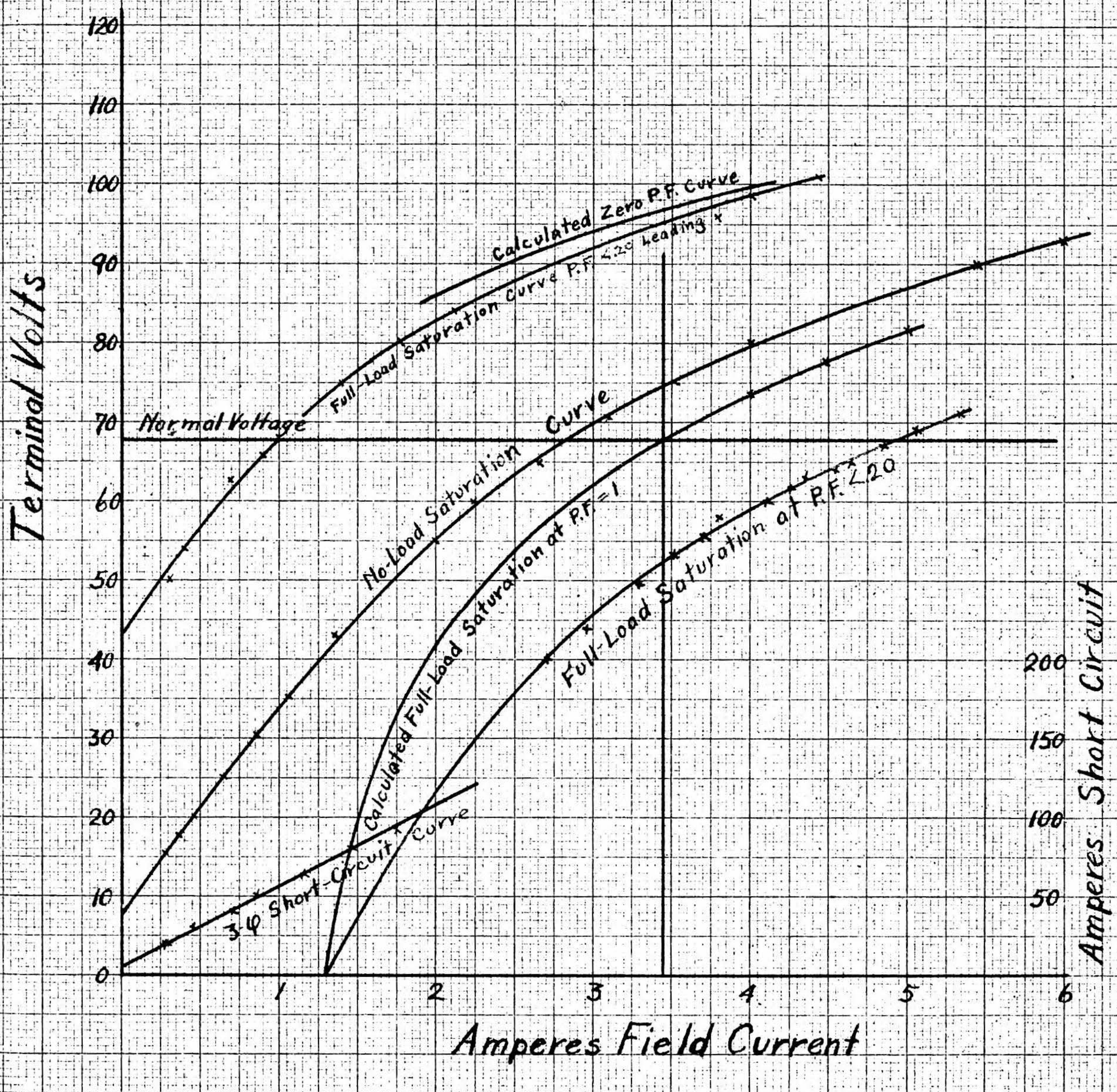
Saturation Curves
of
Westinghouse Rotary Converter # 629991

7.5 Kw. 125 d-c. volts 60 d-c. amperes
60 cycles 1800 rev. per min.
connected three phase



Curve Sheet D'

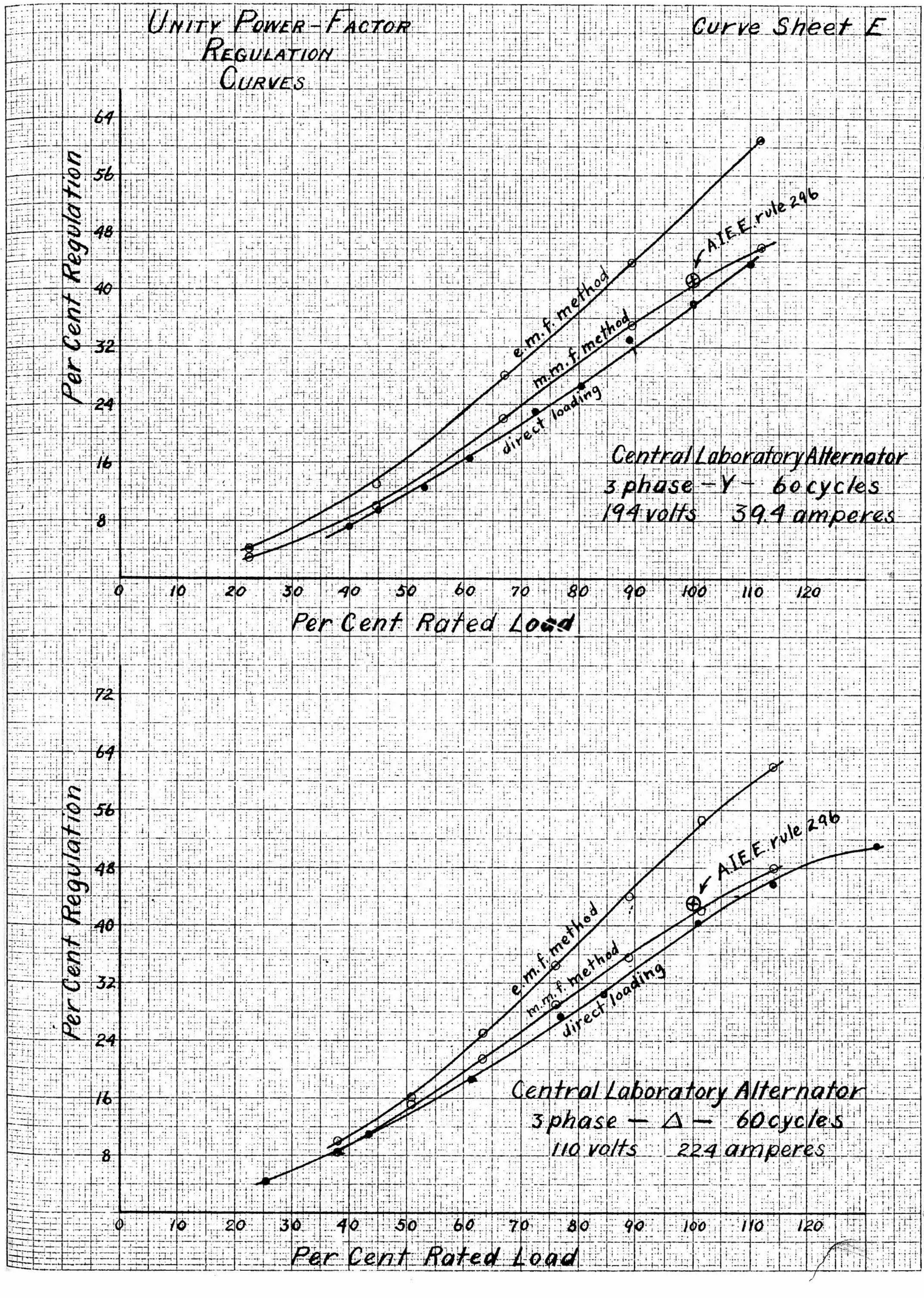
Saturation Curves
of
G. E. Double-Current Generator 695701
Type Y. C. Class 4 - 6 3/4 - 1500
Form P Speed 1500
d-c. amperes 75 d-c. volts 90/125
50 cycles



resistance of each machine was measured at room temperature by means of a portable Wheatstone bridge. The resistance calculated for a temperature of 75° C is the one used in all calculations. Since in obtaining the regulation by the direct method of loading the armature conductors did not attain a temperature of 75° C, this test will be slightly optimistic as compared with the others. The regulation at full load and unity power-factor obtained by means of these various methods are tabulated in the accompanying table.

Manufacturer	Connection	Direct Load	m.m.f.	Rule 296	e.m.f.
Central Laboratory	Y	38	40.7	41.2	52
" "	delta	40	41.7	43.	53
Westinghouse		8.95	8.50	8;70	13.30
Holtzer-Cabot		7.80	7.30	7;30	13.95
General Electric			9.2	10;0	20.6

In the cases of the two machines with low reactance, the Holtzer-Cabot motor and the Westinghouse converter, attention is called to the close agreement of the results obtained by the m.m.f. method and by rule 296. In this connection we may point to section 297 of the standardization in which a method is given for obtaining the zero power-factor saturation curve from the open circuit and short circuit characteristics of the machine in question by reference to tests at zero power-factor on other machines



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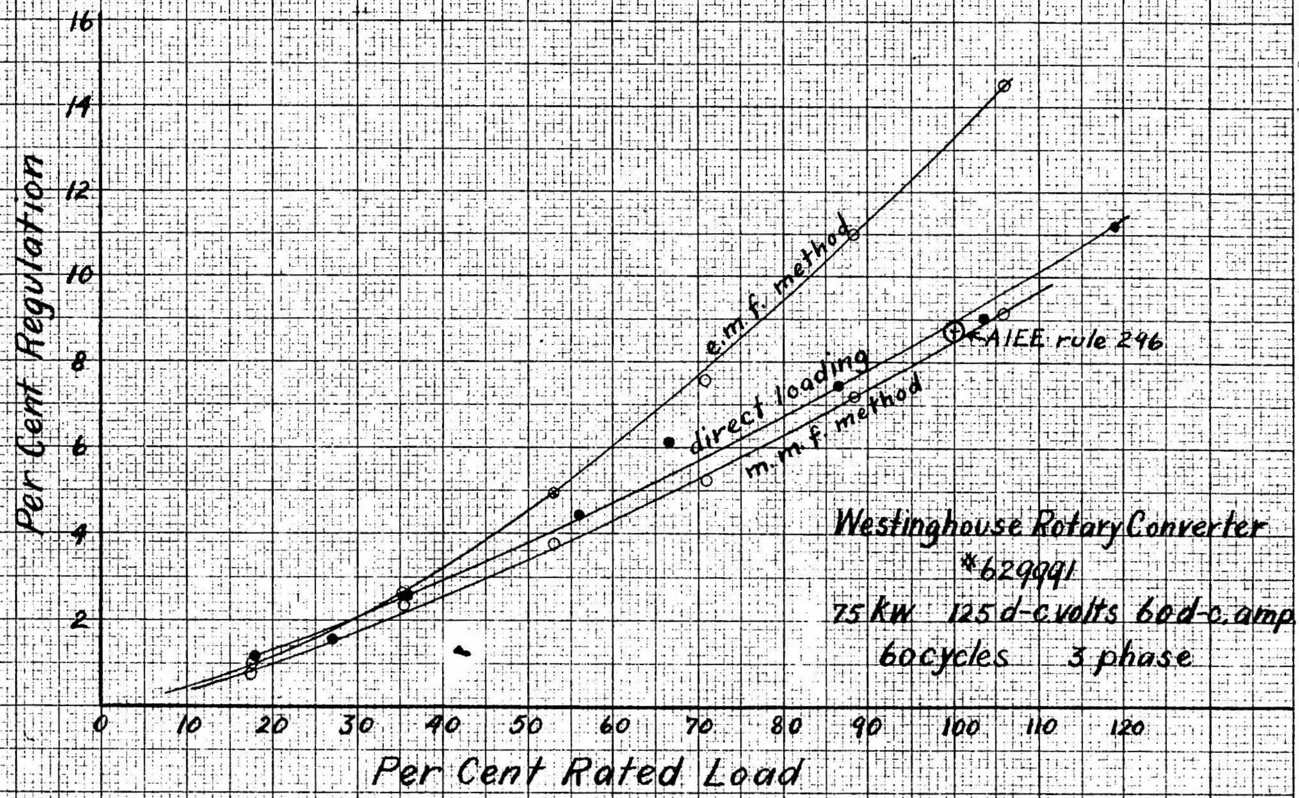
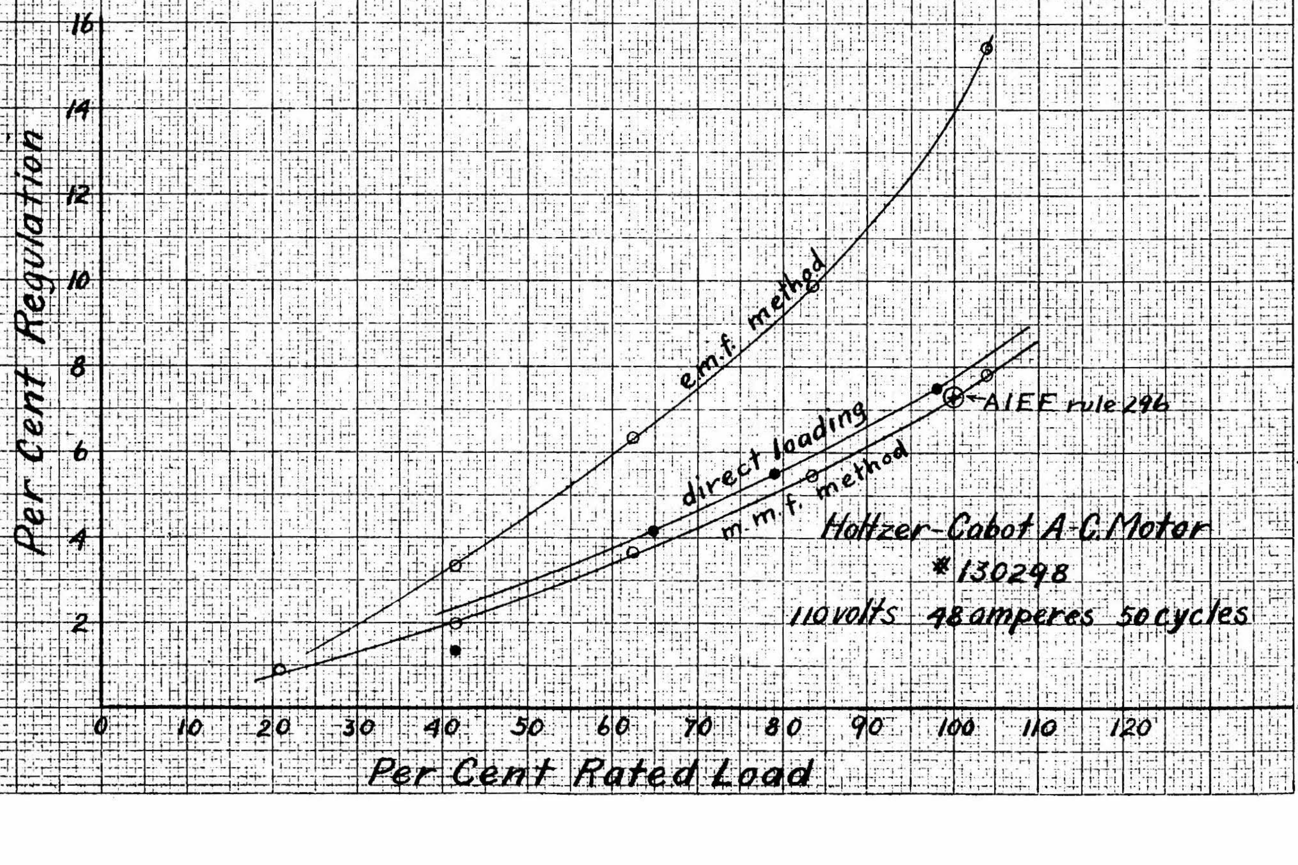
Negative 2.

UNITY POWER-FACTOR REGULATION CURVES

Curve Sheet F





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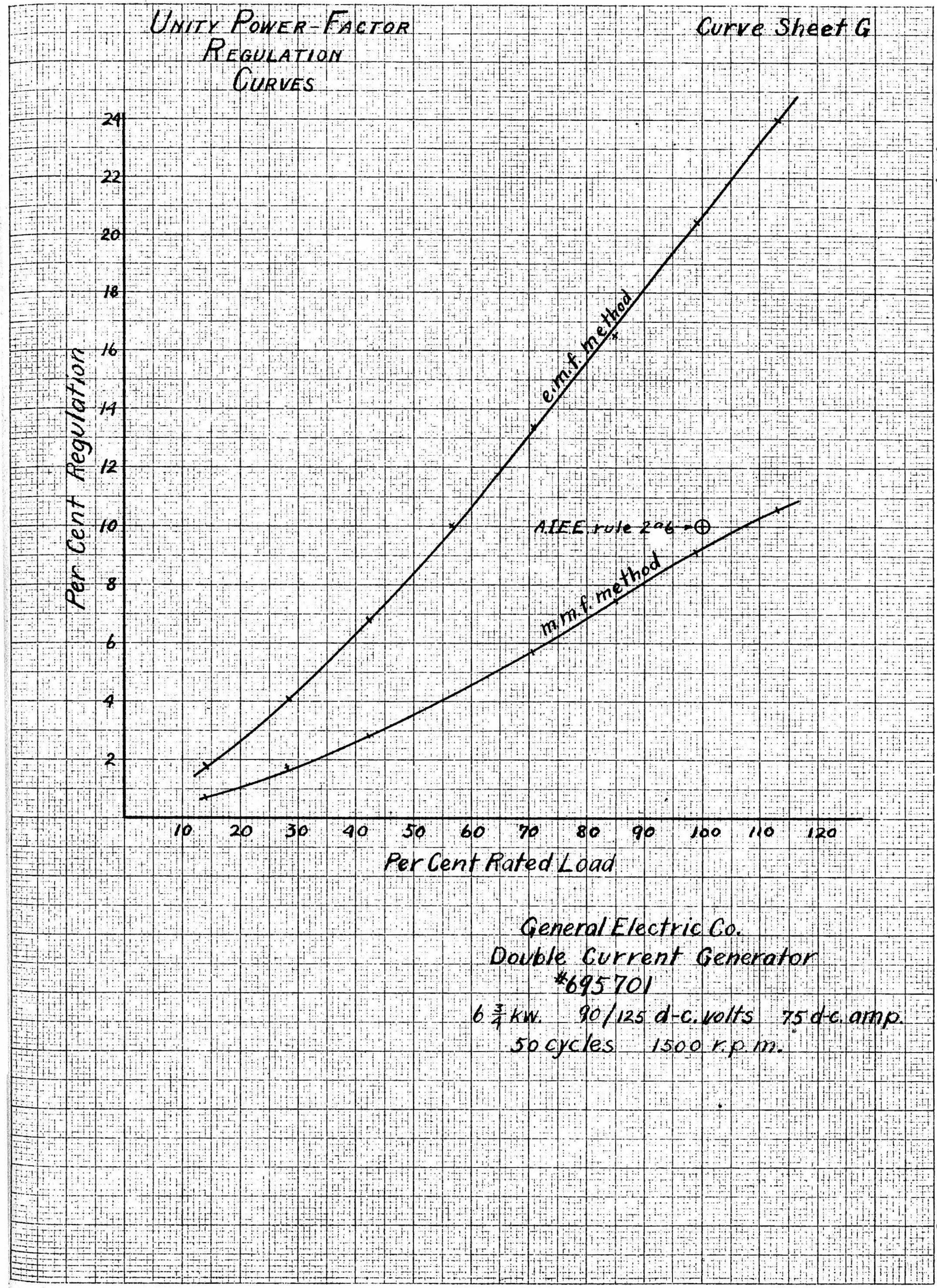


Unity Power-Factor Regulation Curves
Curve Sheet G
Per Cent Regulation
24
22
20
18
16
14
12
10
8
6
4
2
10 20 30 40 50 60 70 80 90 100 110 120
Per Cent Rated Load
e.m.f. method
m.m.f. method
A.I.E.E. rule 296 → ⊕
General Electric Co.
Double Current Generator
#695701
6 3/4 kw. 90/125 d-c. volts 75 d-c. amp.
50 cycles 1500 r.p.m.

Negative 2.

of similar magnetic circuit. This is done by shifting the open-circuit saturation curve to the right by an amount equal to the number of ampere turns necessary to send rated current through the armature at short circuit. In high speed machines having low reactance and a low degree of saturation in the magnetic circuit the zero power-factor curve will be quite close to this curve. This is the theory upon which the m.m.f. method is based and in the case of the two alternators just cited the experimental results are in agreement with this theory. With machines having high reactance, high saturations and high magnetic leakage, the zero power-factor curve will fall below this curve. This is evidenced by the case of the Central Laboratory Alternator in which the regulation as calculated by rule 296 is considerably greater than that obtained by the m.m.f. method.

In running the tests on the various machines some difficulty was at first encountered in obtaining the zero power-factor saturation curve. In the case of the machines first experimented on, the Westinghouse converter was used as a load. It was synchronized from the d-c.side, after which the d-c. circuit was opened. With a very much under-excited field on the motor it was difficult to obtain a power-factor of less than 30%. Trouble was also encountered in keeping the machines in step. Several expedients were tried to lower the power-factor. The first was to supply energy to the converter from the d-c. side. This method was unsatisfactory because a change in the converter field not only changed the torque but also the a-c. voltage. A load of idle-running induction motors was next tried. This method of loading was successful in that a low power-factor was procured, but the number of induction motors necessary to obtain full ampere load was an undesirable feature. The synchronous converter was again resorted to for a load but instead of attempting to supply energy from the d-c.side of the converter it was driven by a shunt motor. By a careful adjustment of the shunt motor field it was made to supply the energy losses in the converter, thus reducing the power-factor to a value very nearly zero.

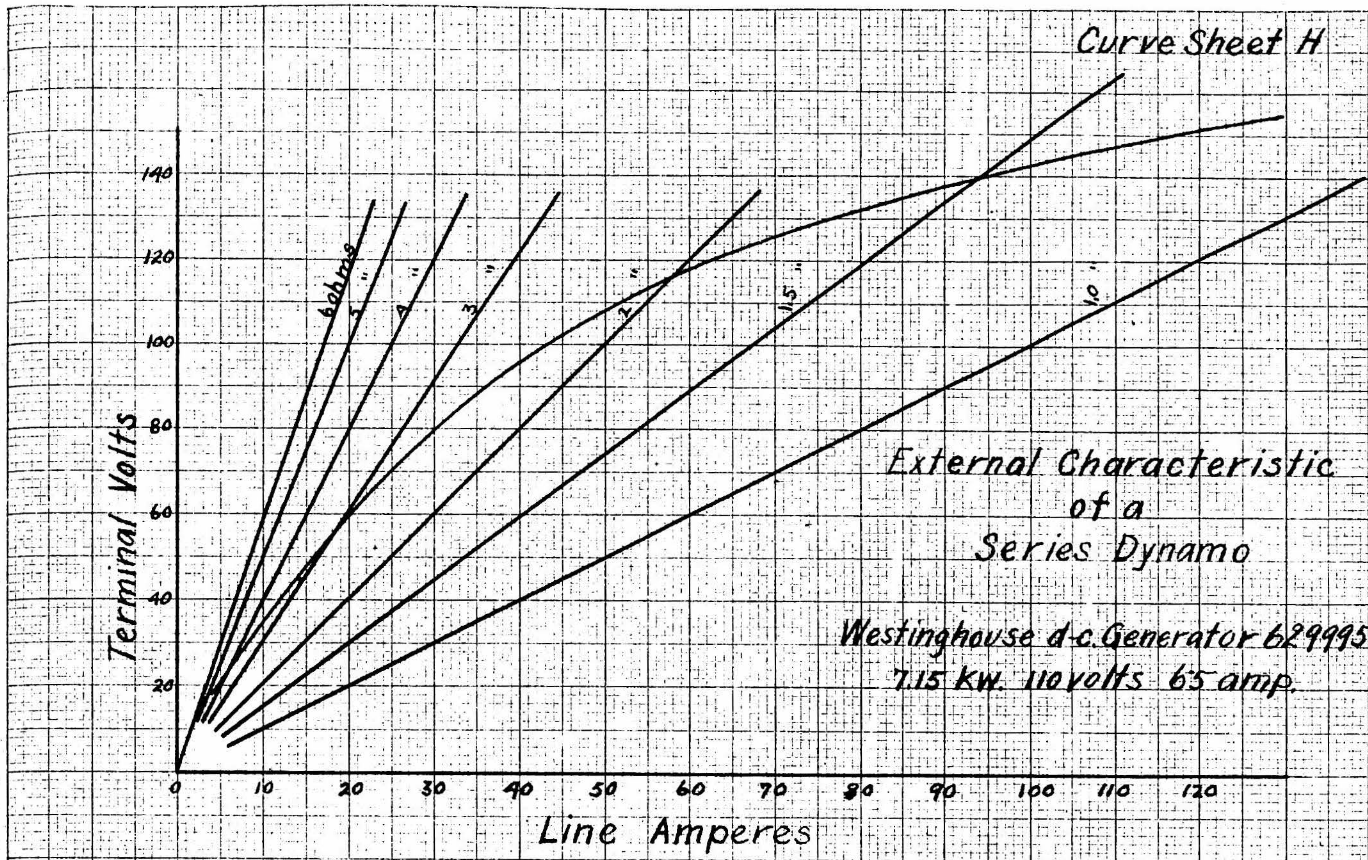
The published papers do not apply the vector solution outlined in section 296 to the solution of the regulation of an alternator drawing a leading current. In order to check this method a test was run on the G. E. Double Current Generator to obtain the saturation curve at zero power-factor leading. The results thus obtained are compared with the calculated results in the following table and the curves obtained by these two methods are shown on curve sheet D.

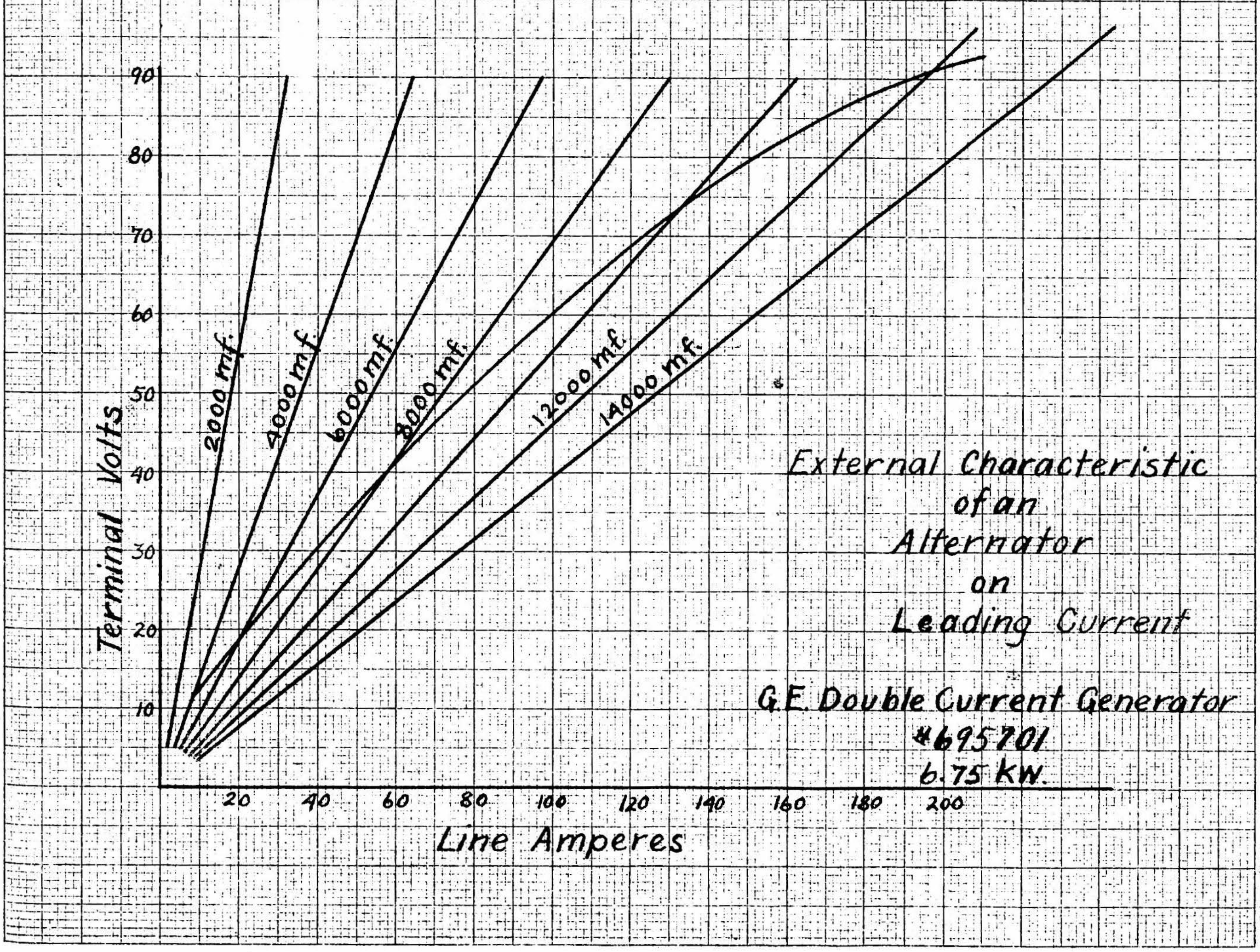
FIELD CURRENT	VOLTAGE DROP		REGULATION	
	by exp.	by calc.	by exp.	by calc.
2	27.8	31.6	33.5	36.4
2.5	24.6	27.2	28.0	30.0
3.45	20.6	21.9	21.6	22.7
4.	19.0	20.1	19.3	20.2

The curve obtained by experiment falls a little below the calculated curve, thus making the regulation obtained from the experimental determination at leading power-factor of zero a little less than that calculated from the saturation curve at a lagging power-factor of zero. However, no very definite conclusions can be drawn for this condition until tests have been made on more machines.

This consideration of regulation on a high condensive load has led to a study of some of the conditions at first encountered in the operation of the Big Creek Transmission Line of the Pacific Light and Power Corporation. Power is supplied to this line at 150 Kilovolts from two generating stations. One of the stations contains two 17500 Kva. Westinghouse alternators; the other two General Electric alternators of the same rating. The line is 241 miles long and has a capacity of 3.413 micrafarads, an inductance of 528 millihenrys and a resistance of 36.1 ohms. With a voltage of 150,000 at the generator end the charging current is 98.38 amperes. The complex expression of this current is .6584 + 98.38 j. As is seen by this expression the reactive component is very large. In consequence the voltage of the generator supplying this current will be boosted very high. In practise this is the case. With one generator charging the line it is necessary to excite the field in a reverse direction in order to keep the voltage within safe limits. With one General Electric alternator charging the line and with no exciting current in the field windings and with the line open circuited at the receiver end, the voltage at the generator rises to a value of 7,000; with one Westinghouse alternator the voltage rises to a value of 9,000 volts at the generator which corresponds to 205,000 volts between lines. The normal generator voltage is 6600. The writer is indebted to Mr. Woodbury's paper entitled "150,000-Volt Transmission System," published in the Sept. 1914 Proceedings of the A. I. E. E. for these values.

The operation of an alternator supplying charging current to a long transmission line is similar in many respects to the regular operation of a series generator. On curve sheet H are plotted the external characteristic curve of a 7.5 Kw. series generator, and the voltage-current curves corresponding to a total resistance of 1,1.5,2,3,4,5, and 6 ohms respectively. These curves show that, while with a line resistance of 3 ohms the voltage builds up to a value of 60, with 4 ohms resistance the limiting voltage is 17. In other words the





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curves show that there is a certain critical line resistance above which the generator voltage will not build up, but that if this resistance is decreased the voltage will build up and, if it were not for the saturation of the iron, it would continue to build up indefinitely.

The same method of reasoning may be applied to an alternator operating without field excitation and supplying charging current to a long transmission line. On curve sheet H is also shown a characteristic curve of an 6.75 Kw, alternator operating without any direct current excitation, and the voltage-current characteristics of a number of circuits having capacities of 2,000 mf., 4,000 mf., etc. respectively. The curve shown is that of the General Electric Double Current Generator #695,701 and was obtained by approximation after a careful study of the four characteristic curves of this machine already procured. The conditions pictured in this figure are in all respects analogous to those previously set forth for the series generator and the conclusions drawn are the same for both cases.

Referring to these curves we may now explain some of the conditions encountered on the Big Creek Line. It is found that with half the length of line connected, the voltage will not build up without field excitation. From the curves on curve sheet H we see that with a line capacity of 12,000 mf., the voltage will attain a value of 90 while with half this capacity the pressure rise stops at a value of 20 volts and in order to build it up higher some field excitation will be necessary. Then, again, with two alternators charging the line the voltage does not rise to the excessive value which it reaches when one alternator charges the line. This is for the reason that, since the line current flows through the two machines in parallel, the flux which is formed by this current is divided between the two machines, and consequently the voltage will not rise to a value as high as it did with but one machine charging the line.

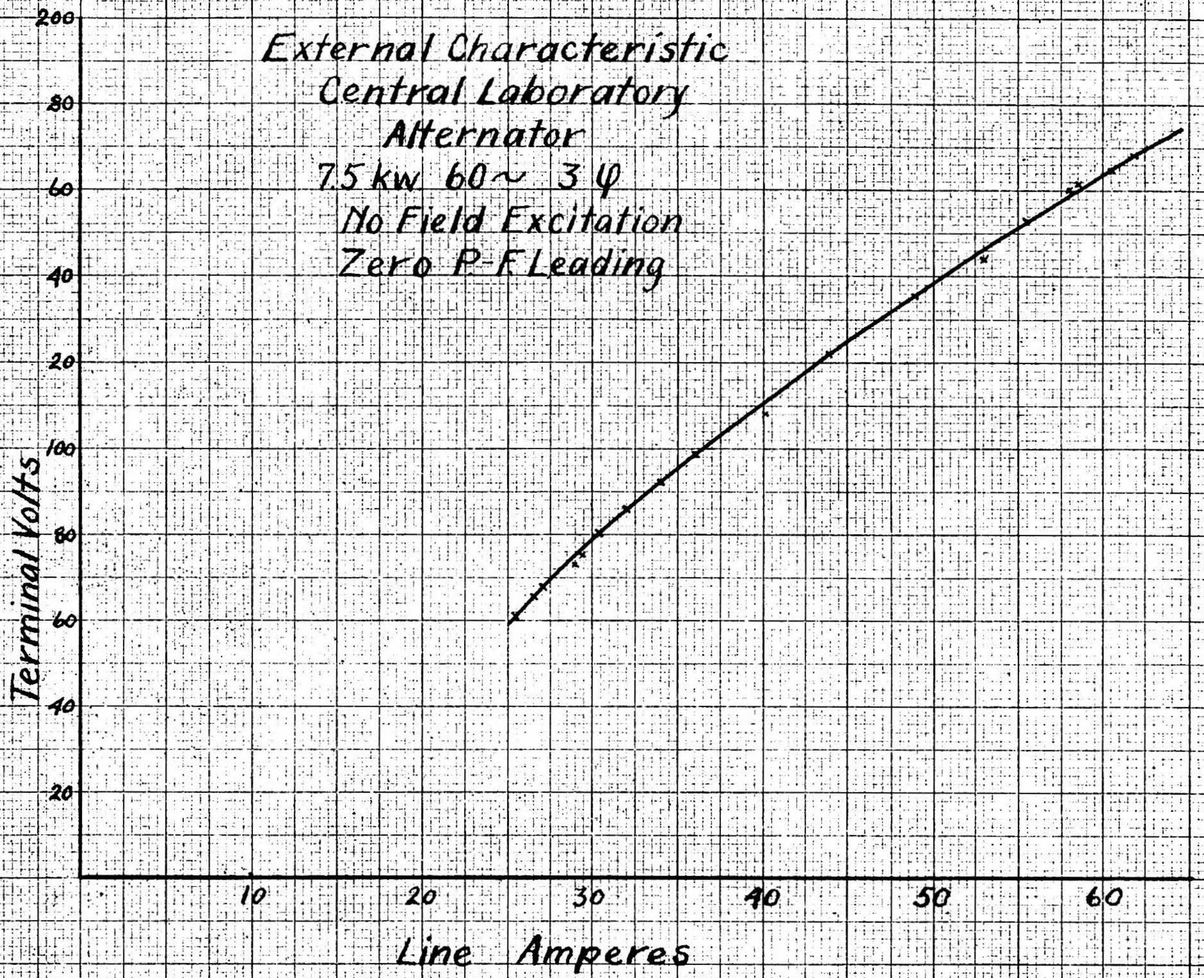
What has gone before shows that the External Characteristic is of great importance in the case of alternators built to supply energy to be transmitted through long lines with considerable electrostatic capacity. A careful consideration of this working characteristic by the manufacturer would prevent an occurence like the one encountered in the Big Creek development in which, in spite of guarantees, a voltage of 9,000 is reached when the alternators of one manufacturer charge the line unless a provision is made for reversing the excitation.

An attempt was made in the laboratory to make a further study of the External Characteristic. This curve was obtained for the Central Laboratory Alternator. The

Holtzer-Cabot motor running with strongly over-excited field supplied the load. No field excitation was used on the alternator. Under these conditions the excitation is supplied entirely by the motor. This condition approximates closely the one obtained when a generator supplies charging current to a transmission line. The field of the Holtzer-Cabot motor was varied, and readings taken of generator voltage and line current. Curve sheet I shows the results. A saturation point has not been reached at the highest point on the curve but it was impossible to carry the current any higher for fear of overheating.

It has been the desire of the writer to make a test on the generators at Big Creek, but this has not been done as yet. However, through the courtesy of Professor Sorensen the short-circuit and open-circuit characteristics of both the Westinghouse and General Electric alternators have been procured and from these approximations of the external characteristic curves without field excitation for the alternators of both manufacturers have been made. This was done by assuming that for a leading power-factor of zero the load saturation curve corresponding to any given current is formed by shifting the no-load saturation curve to the left by an amount equal to the number of ampere turns necessary to send

Curve Sheet I



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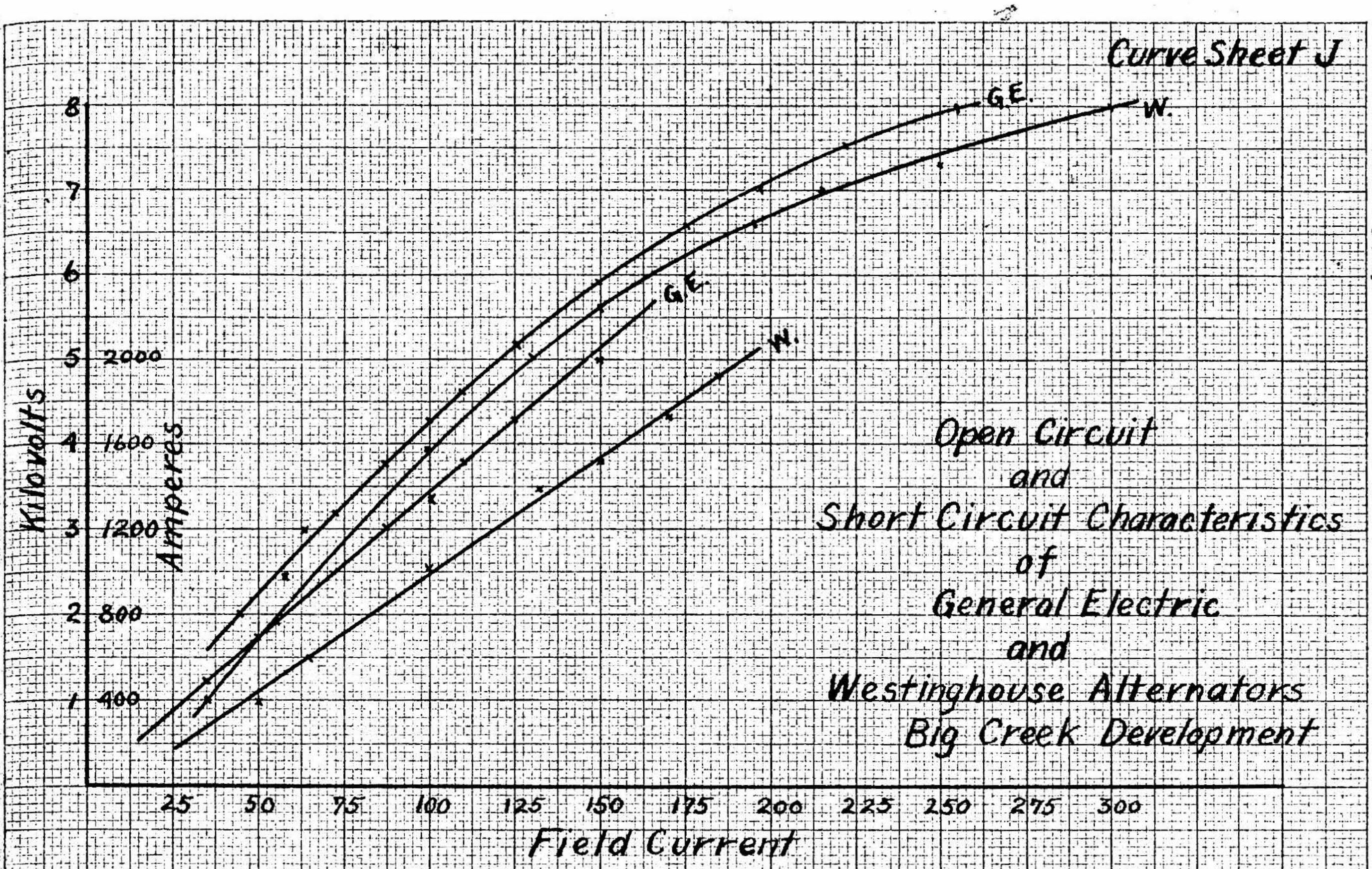
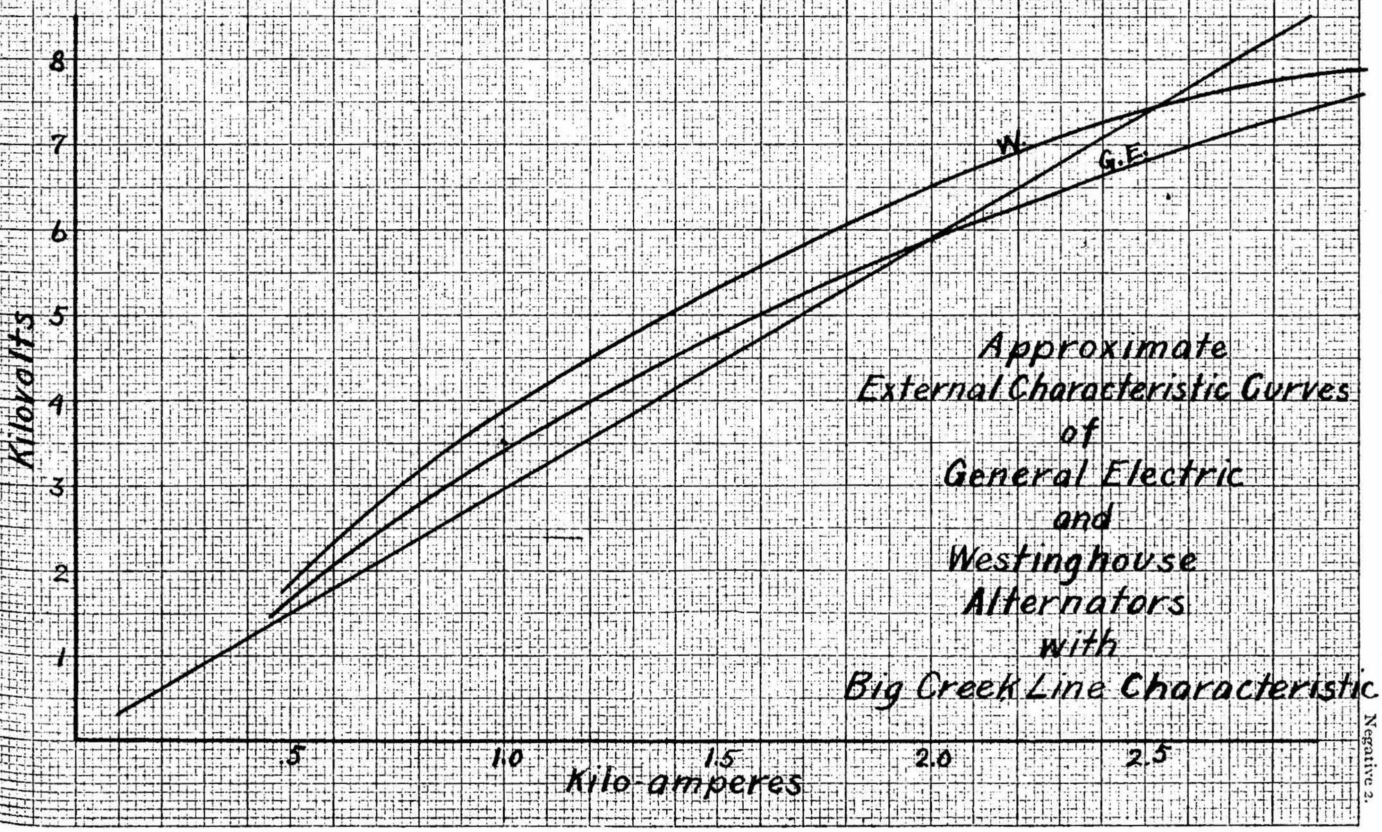
rated current through the armature at short circuit. A number of currents were taken and the saturation curves at zero power-factor corresponding to these currents were laid off. The values of voltage where these curves crossed the vertical axis were plotted as ordinates against the corresponding line currents as abscissas and curves drawn through these points. These curves together with the Big Creek Line Characteristic are to be found on Curve sheet J. While these curves neglect the boosting effect of the transformers and the magnetic leakage in the alternators themselves, they show with a fair degree of accuracy the comparative values of the limiting voltages which the machines will generate when connected to the Big Creek line. The boosting effect of the transformers and the magnetic leakage, however, will cause the voltage to rise much higher than the values shown by these curves.

By a careful consideration of the method just outlined it will be quite evident that the load saturation curve of that machine having the higher reactance will be shifted further to the left than the saturation curve of the other machine, and in consequence the voltage which corresponds to zero field excitation will be higher in this machine than in the other. It is for this reason that, for line currents within the range of values plotted on curve sheet J. the voltages of the Westinghouse alternator are higher than the voltages of

Curve Sheet J





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the General Electric alternator. It will be noticed, however, that the Westinghouse alternator is reaching a saturation point more rapidly than the General Electric Alternator and, had the transmission line been a little longer, conditions might have been reversed; that is, the voltage might have risen higher with the General Electric alternator charging the line than with the Westinghouse alternator charging it. After saturation is once reached, however, a considerable increase in the length of line will cause the voltage to rise only a trifle higher.

In conclusion, the rise in voltage inherent in the two alternators under consideration when separately charging the Big Creek Line might have been entirely prevented by designing them with lower reactance, or the rise in voltage might have been arrested at a lower value either by designing with lower reactance or by designing the magnetic circuit to have a higher saturation.

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Soren H. Mortensen

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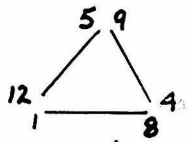
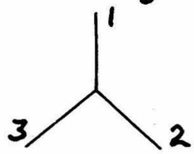
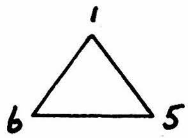
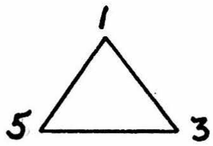
Standardization of the A. I. E. E.

Machine	Connected	Terminal	Resistance	Temp.	Res. at 75°C per phase
Central Laboratory Alternator		1-8	.164	24 C	
		4-9	.164	24 C	
		5-12	.165	24 C	.197
Holtzer Cabot Synch. Motor		1-2	.059		
		1-3	.059	24 C	.0354
		2-3	.059		
Westing-house Rotary Converter		1-5	.058		
		1-6	.058	24 C	.104
		5-6	.058		
General Electric Split-pole Converter		1-3	.049		
		1-5	.049		
		3-5	.049	22 C	.088

7.5 Kw. Central Laboratory Generator

3 phase--delta connected--60 cycles

No-Load Saturation Curve

If	E	f
.45	42	60
.50	47	"
.55	51	"
.60	55.5	"
.65	60.5	"
.70	64.7	"
.75	70.	"
.80	74.2	"
.85	79.1	"
.90	84.2	"
.95	89.	"
1.00	93.8	"
1.11	103.	"
1.20	110.5	"
1.31	119.5	"
1.42	128.	"

7.5 Kw. Central Laboratory Generator

3 phase--delta connected--60 cycles

No-Load Saturation Curve

If	E	f
1.50	134.8	60
1.63	142.2	"
1.70	148	"
1.82	154	"
1.92	159	"
2.00	163	"
2.10	164.5	"
2.20	167.5	"
2.30	170.5	"
2.40	173.5	"
2.50	177	"
2.60	179.5	"
2.70	181	"
2.80	183.5	"

7.5 Kw. Central Laboratory Alternator

3 phase--delta connected--60 cycles

Three-Phase Short Circuit Current

I_f	I_a	E	f
.33	9.80	30.0	60
.43	12.85	40.0	"
.48	14.20	45.0	"
.60	17.90	56.3	"
.70	20.1	65.5	"
.80	23.5	75.5	"
.90	27.0	85.0	"
1.0	29.7	94.0	"
1.1	32.3	102.0	"
1.2	35.0	110.5	"
1.3	37.8	118	"
1.4	40.8	127	"
1.5	44.0	136	"
1.6	47.0	141	"

Central Laboratory Alternator

3 phase--delta connected--60 cycles

Full-Load Saturation Curve at Zero Power-Factor

P.F.	E.	I.	I_f	f
19	54	39.4	1.95	60
15	53.5	"	1.94	"
20	60.	"	2.03	"
21	65.5	"	2.10	"
0	57	"	1.98	"
22	70	"	2.15	"
17	68	"	2.13	"
25	73	"	2.20	"
22	109.5	"	2.62	"
22	118	"	2.76	"
23	102	"	2.50	"

Full-Load Saturation Curve at Zero Power-Factor Leading

110 volts--------7.5 Kw

E	I	I_f	f
159	39.4	.6	60
108	39.4	0	59.5
137	39.4	.3	60
124	"	.18	59.5
144	"	.4	60
120	"	.11	"
130	"	.25	"
148	"	.46	"
94	"	-.11	"

Central Laboratory Alternator

3 phase--delta connected--60 cycles

110 volts------7.5 Kw.

Fractional-Load Saturation Curves

E	I	I_f	f
132	30	.59	60
128.5	"	.52	"
123	"	.48	"
119.5	"	.40	"
110	"	.30	"
80	"	0	"
100	20	.5	60
93	"	.43	"
81	"	.31	"
88	"	.38	"
66	"	.18	"
84	"	.35	"
72.5	"	.23	"
65	"	.17	"
56.5	"	.12	"

Central Laboratory Alternator

7.5 Kw--110 volt--60 cycles

3 phase --delta connected

Regulation:- Direct Method

f	I_f	I	% full load			$E'-E_0$	$\frac{E_1-E_0}{E_0} \times 100$
60	1.19	0.0	0.00	110			
"	1.28	10.0	25.4	111	116	5	4.5
"	1.34	17.1	43.5	109	121	12	11.0
"	1.42	24.2	61.5	108	128	20	18.5
"	1.57	30.3	77.0	110	140	30	27.3
"	1.62	33.2	84.4	109	142	33	30.3
"	1.77	40.0	101.0	109	153	44	40.4
"	1.90	45.3	114.0	109	159	50	45.8
"	2.10	51.8	132	110	166	56	51.0

External Characteristic Curve

Running as a generator taking leading current with no field excitation. This curve is similar to the External Characteristic of a Series Dynamo.

P. F.	f	I	E
22	60	62	168
"	"	60.5	165
"	"	58.5	161
"	"	58	160
""	"	57.5	158
"	"	55.5	153
"	"	53	144

Central Laboratory Alternator

7.5 Kw--110 volt--60 cycles

3 phases--delta connected

External Characteristic Curve

P. F.	f	I	E
22	60	49	135
22	"	44	122
22	"	34	92
22	"	40	108
22	"	36	99
22	"	32	86
23	"	30.5	80
23	"	29.5	75
23	"	29	73
24	"	28	70.5
24	"	27	68
24	"	26.5	66
24	"	25.5	61
24		25.3	59

7.5 Kw. Central Laboratory Alternator.

3 phases--Y connected--60 cycles

No-Load Saturation Curve

E	I_f	f
40	.25	60
65	.40	"
82	.50	"
99	.60	"

7.5 Kw Central Laboratory Alternator

3 phase --Y connected--60 cycles

NO-Load Saturation Curve

E	I_f	f
116	.70	60
132	.80	"
149	.90	"
164	1.00	"
202	1.26	"
236	1.50	"
266	1.75	"
285	2.0	"
290	2.06	"
300	2.28	"
306	2.40	"
311	2.50	"
314	2.60	"
319	2.70	"

Three-Phase Short-Circuit Current

I_f	I_a	E	f
.25	4.2	40	60
.50	8.6	82	"
.60	10.1	98	"
.76	12.85	122	"
.90	15.3	148	"
1.00	17.2	165	"

7.5 Kw. Central Laboratory Alternator

3 phase --Y connected--60 cycles

Three-Phase Short Circuit Current

I_f	I_a	E	f
1.15	19.5	185	60
1.25	21.1	201	"
1.40	23.8	220	"
1.50	25.0	234	"
1.59	26.5	246	"

7.5 Kw.--60 cycles--191 volts

3 phase--Y connected

Regulation:- Direct Method

f	I_f	I	% full load	E_0	E'	$E'-E_0$	$\frac{E'-E_0}{E_0} \times 100$
60	1.20	0.0	0.0	192			
"	1.25	9.0	39.8	192	206	14	7.3
"	1.30	10.1	44.8	191	209	18	9.4
"	1.35	12.1	53.3	191	215	24	12.5
"	1.40	13.8	60.7	192	224	32	16.7
"	1.50	16.4	72.5	191	235	44	23.0
"	1.55	18.3	80.5	"	242	51	26.6
"	1.61	20.3	89.3	"	254	63	33.0
"	1.71	22.6	100	"	264	73	38.2
"	1.82	24.9	110	"	274	83	43.5

7.5 Kw. Central Laboratory Alternator

3 phase--Y connected-60 cycles--22.4 amperes

Full-Load Saturation Curve at Zero Power-Factor Lagging

P. F.	E	I	f	I_f
18	160	22.4	60	2.3
19	153	"	"	2.25
21	145	"	"	2.2
22	135	"	"	2.1
17.5	172	"	"	2.4
17	183	"	"	2.5
16	200	"	"	2.6
22	140	"	"	2.16
20	150	"	"	2.24
18	171	"	"	2.39
17	185	"	"	2.5
16	201	"	"	2.6
18	118	"	"	2.05
17	122	"	"	2.08
15	125	"	"	2.11
12.5	132	"	"	2.15
9	140	"	"	2.21
16	115	"	"	2.01
17	109	"	"	2.00

The following points obtained with a load of induction motors running light.

7.5 Kw Central Laboratory Alternator

3 phase--Y connected--60 cycles--22.4 amperes

Full-Load Saturation Curve at Zero Power-Factor Lagging

P. F.	E	I	f	I_f
19	108	22.4	60	1.99
25	98	"	"	1.93
30	90	"	"	1.88
32	82	"	"	1.83
54	63	"	"	1.68
47	69	"	"	1.73
38	76	"	"	1.79

Holtzer-Cabot A-C. Motor

Type C P Size 20 HP 10

110 volts--48 amperes--50 cycles

1000 R. P. M.--3 phase--No. 130,298

No-Load Saturation Curve

E	I_f	f
30	1.17	50
40	1.57	"
46	1.80	"
50	1.99	"
54	2.18	"
62	2.49	"
65.5	2.68	"
71	2.96	"
76	3.15	"

Holtzer-Cabot A-C. Motor

Type O P Size 20 HP 10

110 volts--48 amperes--50 cycles

1000 R. P. M.--3 phase--No. 130,298

No-Load Saturation Curve

E	If	f
81	3.38	50
86	3.64	"
90	3.84	"
95.5	4.15	"
101	4.44	"
105	4.72	"
109	5.02	"
117.5	5.61	"
120.5	5.89	"
125	6.5	"
128.	7.0	"
132.5	7.6	"
135	8.01	"
137	8.46	"

Holtzer-Cabot A. C. Motor

Type O P Size 20 HP10

110 volts--48 amperes--50 cycles

1000 R. P. M.--3 phase --No. 130,298

I_f		I_a		$\frac{E}{3}$	f
1.07				30	50
1.57				40	"
1.91	43	43	43	50	"
2.11	46	46	46	54.5	"
2.31	51	51	51	60	"
2.71	60	60	60	68	"
3.01	66.5	67	66.5	76	"
3.20	71	71	71	80	"
3.76	83	83	83	92	"
4.26	93	93	93	100	"
4.90	108	108	108	110	"

Full-Load Saturation Curve at Zero Power-Factor

P. F.	E.	I	I_f	f
10	48	48	4.07	50
22	62	"	4.64	"
15	71.5	"	5.07	"
19	81	"	5.54	"
18	87.5	"	5.90	"
0	91.7	"	6.08	"
22	92.2	"	6.15	"

Holtzer-Cabot A. C. Motor

Type C P Size 20 HP10

110 volts--48 amperes--50 cycles

100 R. P. M.--3 phase--N. 130,298

P. F.	E.	I	I_f	f
0	102.5	48	6.86	50
0	104.5	"	7.12	"
0	105.5	"	7.22	"
0	106.5	"	7.29	"
0	108	"	7.49	"

Regulation:- Direct Method

f	I_f	I	% full load	E_0	E_1	$E_1 - E_0$	$\frac{E_1 - E_0}{E_0} \times 100$
50	5.0	20	41.7	110	111.5	1.5	1.36
"	5.3	31.3	65.2	"	114.7	[illegible]	4.19
"	5.4	38	79.2	"	115.5	5.5	5.01
"	5.6	47	98.0	"	117.5	7.5	6.82

No-Load Saturation Curve

Westinghouse Rotary Converter No. 629991

7.5 Kw. 125 d-c. volts 60 d-c. amperes.

60 cycles 1800 R. P. M.

E	I_f	f
30	.57	60
37	.74	60
43.5	.87	"
48	1.01	"
50.5	1.04	"
54	1.14	"
57.5	1.24	"
68.2	1.54	"
75.5	1.74	"
81.5	1.95	"
87	2.16	"
95.5	2.57	"
101	2.89	"
107	3.30	"

Three-Phase Short-Circuit Current

I_f	I_a	E	f
.62	53.5	30	60
.84	72	40	60
1.04	90	50	60

Westinghouse Rotary Converter No 629991

7.5 Kw   125 d-c. volts   60 d-c. amp.

60 cycles   1800 R. P. M.

Full-Load Saturation Curve at Zero Power-Factor

P. F.	E	I	I_f	f
		56.5		
0	73.5	56.5	2.44	60
0	79	"	2.64	"
0	82.5	"	2.84	"
0	87	"	3.04	"
20	89.5	"	3.18	"
0	97	"	3.49	"
20	99.5	55.7	3.74	"
00	101	56.8	3.84	"
0	105	56.5	4.19	"

Regulation:- Direct Method

f	I_f	I	% full load	E_o	E_1	E_1-E_o	$\frac{E_1-E_o}{E_o} \times 100$
60	11.7	10.0	18.0	76.6	77.5	.9	1.18
"	1.7	15.0	27.0	"	77.8	1.2	1.57
"	1.72	20.0	36.1	"	78.6	2.0	2.61
"	1.80	31.1	56.3	"	80.0	3.4	4.44
"	1.89	37	66.7	"	81.3	4.7	6.14
"	1.90	48	86.6	"	82.3	5.7	7.45
"	1.95	57.5	103.6	"	83.5	6.9	9.02
"	2.00	66	119	"	85.2	8.6	11.20

General Electric Double Current Generator #695701

Type Y C   Class 4--6$\frac{3}{4}$--1500

Form P   Speed 1500

Continuous Current Amperes 75 Volts 90/125

Alternating Current Cycles 50

No-Load Saturation Curve

E	I_f	f
15.5	0.27	51
17.5	0.37	"
20	0.46	"
25	1.66	"
30.5	0.86	"
35.5	1.06	"
43	1.36	"
55	1.99	"
60	2.28	"
65	2.66	"
70.5	3.11	"
75	3.53	"
80	4.01	"
90	5.46	"
93	5.99	"

General Electric Double Current Generator #695701

Type Y C Class 4--6--1500

Form P Speed 1500

Continuous Current Amperes 75 Volts 90/125

Alternating Current cycles 50

Three-Phase Short Circuit Curve

E	I_f	f	I_1	I_2	I_3
15	.28	50.5	22	22	20
21	.46				29
25.5	.70				41
30	.86	50.5	52.5	51	50
37	1.14				62.5
45	1.46	50.5	80.5	80	79
50.5	1.74				91

Full-Load Saturation Curve at Zero Power-Factor Lagging

P. F.	E	I	I_f	f
27	64.7	70.7	4.66	50
10	67	"	4.86	50
05	69	"	5.06	50.5
10	71	"	5.34	50
10	63	"	4.36	50.5
10	53.5	"	3.51	50.5
20	55.5	"	3.71	50.5
15	57	"	3.81	50.5
12	60	"	4.09	50.5

General Electric Double Current Generator #695701

Type Y C Class 4-- 6¾--1500

Form P Speed 1500

Continuous Current Amperes 75 Volts 90/125

Alternating Current Cycles 50

Full-Load Saturation Curve at Zero Power-Factor Lagging

P. F.	E	I	I_f	f
15	61.7	70.7	4.26	50.5
32	39	"	2.71	50.5
05	49.5	"	3.29	51
15	40	"	2.71	51
15	44	"	2.96	50.5

Full-Load Saturation Curve at Zero Power-Factor Leading

Leading

P. F.	E	I	I_f	f
10	74.5	70.7	1.44	50
10	71	"	1.29	"
10	67.5	"	1.06	"
10	66	"	0.90	"
10	62.5	"	0.70	"
0	58.5	"	0.62	"
0	56.7	"	0.51	"
0	54	"	0.40	"
0	50	"	0.32	"

General Electric Double Current Generator #695701

Type Y C   Class 4--6$\frac{3}{4}$--1500

Form P   Speed 1500

Continuous Current Amperes 75 Volts 90/125

Alternating Current Cycles 50

Full-Load Saturation Curve at Zero Power-Factor Leading

leading

P.F	E	I	I_f	f
10	80	70.7	1.78	50
10	81.5	"	1.94	"
5	84	"	2.12	"
10	96.3	"	3.60	"
10	98.5	"	4.00	"
10	101	"	4.45	"

Central Laboratory Alternator

7.5 Kw   110 volts   39.4 amperes

60 cycles   3- phase   delta connected

Calculation of Regulation at Unity Power-Factor

e.m.f. method

I	XI	RI	E+RI	$\overline{XI}^2$	$\overline{E+RI}^2$	E'^2	E'	E' E	% reg	% load
15	47	1.70	111.5	2209	12430	14640	121.0	11.0	10.	38.1
20	63	2.27	112.5	3690	12630	16320	127.9	17.9	16.25	50.8
25	78	2.84	113.0	6200	12770	18970	137.8	27.8	25.22	63.5
30	95	3.41	113.5	9025	12900	21925	148.0	38.0	34.60	76.2
35	110	3.98	114.0	12100	13000	25100	158.5	48.5	44.1	89.0
40	124	4.55	114.5	15625	13150	28775	170.0	60.0	54.5	101.6
45	137	5.12	115	18800	13225	32025	179	69	62.7	114

Central Laboratory Alternator

7.5 Kw 110 volts 39.4 amperes

60 cycles 3-phase delta connected

Calculation of Regulation at Unity Power-Factor

m.m.f. method

I	i_r	i_x	i_r^2	i_x^2	i_z^2	i_z	E'	E'-E	% reg	% load
15	121	.50	1.46	.250	1.71	1.31	119.5	9.5	8.65	38.1
20	122	.68	1.49	.462	1.95	1.40	126.6	16.5	15	50.8
25	123	.84	1.51	.706	2.22	1.49	133.5	23.5	21.4	63.5
30	124	1.02	1.54	1.04	2.58	1.61	142	32	29.1	76.2
35	124	1.19	1.54	1.42	2.96	1.72	149	39	35.5	89.0
40	125	1.37	1.56	1.88	3.44	1.86	156.7	46.7	42.5	101.6
45	126	1.54	1.59	2.37	3.96	1.99	162.8	52.8	48.1	114

Calculated Regulation at Unity Power-Factor

194 volts 22.4 amperes Y connected

m.m.f. method

I	ir	ix	i_r^2	i_x^2	i_z^2	i_z	E'	E'-E	% reg	% load
5	.28	1.21	.078	1.46	1.54	1.24	200	6	3.1	22.4
10	.58	1.22	.326	1.49	1.83	1.35	215	21	10.8	44.8
15	.88	1.24	.773	1.54	2.31	1.52	238	44	22.7	67.2
20	1.18	1.26	1.39	1.58	2.97	1.72	262	68	35	89.5
25	1.50	1.27	2.25	1.61	3.86	1.97	283	89	45.8	112

Calculated Regulation at Unity Power-Factor

Central Laboratory Alternator

7.5 Kw. 194 volts 22.4 amperes

60 cycles 3-phase Y connected

e.m.f. method

I	XI	RI	E+RI	$\overline{XI}^2$	$\overline{E+RI}^2$	E_1^2	E_1	E_1 E	%reg	% load
0			194							
5	45	1.71	196	2025	38416	40441	202.1	8.1	4.17	22.4
10	96	3.42	197.5	9216	39000	48216	219.6	25.6	13.20	44.8
15	146	5.13	201.	21316	40400	61716	248.4	54.4	28.00	67.2
20	191	6.34	202.5	36481	41000	77481	278.4	84.4	43.50	89.5
25	236	8.55	204.5	55696	41800	97496	312.2	118.2	61.00	112

Holtzer-Cabot a-c. Motor 130298

110 volts 48 amperes 50 cycles 3-phase

Calculation of Regulation at Unity Power-Factor

e.m.f. method

I	XI	RI	E+RI	$\overline{XI}^2$	$\overline{E+RI}^2$	E_1^2	E_1	E_1-E	%reg.	%load
10	11	.6	110.6	121	12200	12300	111	1	.91	20.8
20	22.5	1.2	111.2	506	12400	12900	113.7	3.7	3.36	41.7
30	35	1.8	111.8	1220	12500	13700	117.0	7.0	6.36	62.6
40	45.5	2.5	112.5	2060	12600	14600	120.9	10.9	9.90	83.5
50	58	3.1	113.1	3360	12800	16100	127.0	17.0	15.45	104

Calculation of Regulation at Unity Power-Factor

Holtzer-Cabot a-c. Motor 130298

110 volts 48 amperes. 50 cycles 3-phase

m.m.f. method

I	i_r	i_x	i_r^2	i_x^2	i_z^2	i_z	E'	$E'-E$	% reg.	% load
10	5.1	.45	26.0	.2	26.2	5.13	111	1.0	.91	20.8
20	5.15	.90	26.5	.8	27.3	5.23	112.2	2.2	2.00	41.7
30	5.20	1.40	26.9	2.0	28.9	5.38	114	4.0	3.64	62.6
40	5.25	1.80	27.5	3.2	30.7	5.55	116	6.0	5.45	83.5
50	5.30	2.30	28.0	5.3	33.3	5.78	118.5	8.5	7.82	104

Westinghouse Rotary Converter 629991

7.5 Kw. 125 d-c. volts 60 d-c. amperes

60 cycles 3 phase

a-c. volts 76.6 a-c. amperes 56.5

e.m.f. method

I	XI	RI	$E+RI$	$\overline{XI}^2$	$\overline{E+RI}^2$	E'^2	E'	$E'-E$	% reg.	% load
10	6	.6	77.2	36	5950	5986	77.4	.8	1.04	1717
20	12	1.2	77.8	144	6050	6194	78.6	2.0	2.62	35.4
30	18	1.8	78.4	323	6140	6460	80.4	3.8	4.96	53.1
40	24	2.4	79.0	573	6230	6800	82.4	5.8	7.58	70.9
50	30.5	3.0	79.6	930	6320	7250	85.1	8.5	11.1	88.6
60	35.5	3.6	80.2	1260	6420	7680	87.7	11.1	14.5	106

Calculation of Regulation at Unity Power-Factor

Westinghouse Rotary Converter 629991

7.5 Kw. 125 d-c. volts 60 d-c. amperes

60 cycles 3-phase

a-c. volts 76.6 a-c amperes 56.5

m.m.f. method

I	i_r	i_x	i_r^2	i_x^2	i_z^2	i_z	E'	E'-E	% reg.	% load
10	1.80	.12	3.23	.01	3.24	1.80	77.2	.6	.78	17.7
20	1.83	.24	3.34	.06	3.40	1.85	78.4	1.8	2.35	35.4
30	1.85	.36	3.41	.13	3.54	1.88	79.5	2.9	3.78	53.1
40	1.87	.47	3.49	.22	3.71	1.93	80.6	4.0	5.22	70.9
50	1.89	.59	3.56	.35	3.91	1.98	82.1	5.5	7.18	88.6
60	1.91	.70	3.64	.49	4.13	2.04	83.8	7.2	9.14	106.

Calculation of Regulation at Unity Power-Factor

General Electric Double Current Generator #695701

67.8 volts 70.7 amperes.

50 cycles 3-phase

e.m.f. method

I_0	XI	RI	E+RI	$\overline{XI}^2$	$\overline{E+RI}^2$	E'^2	E'	E'-E	% reg.	% load
10	10	.50	68.3	100	4660	4760	69	1.2	1.77	14.13
20	16	1.00	68.8	256	4730	4986	70.6	2.8	4.13	28.26
30	21	1.49	69.29	441	4790	5231	72.4	4.6	6.78	42.40
40	26.5	1.99	69.79	700	4860	5560	74.6	6.8	10.0	56.50
50	31	2.48	70.28	960	4940	5900	76.9	9.1	13.4	70.70
60	35	2.98	70.88	1220	5010	6230	79.0	11.2	16.5	84.80
70	40	3.48	71.28	1600	5080	6680	81.7	13.9	20.5	99.00
80	44	3.97	71.77	1930	5150	7080	84.1	16.3	24	113.0

Calculation of Regulation at Unity Power-Factor

General Electric Double Current Generator #695701

67.8 volts 70.7 amperes

50 cycles 3-phase

m.m.f. method

I	i_r	i_x	i_r^2	i_x^2	i_z^2	i_z	E'	$E'-E$	% reg.	% load
10	2.87	.10	8.21	.01	8.22	2.87	68.3	.5	.74	14.13
20	2.90	.30	8.40	.09	8.49	2.92	69	1.2	1.77	28.26
30	2.95	.44	8.60	.24	8.84	2.98	69.7	1.9	2.80	42.40
40	2.99	.68	8.91	.46	9.37	3.06	70.4	2.6	3.84	56.60
50	3.04	.88	9.21	.77	9.98	3.16	71.7	3.9	5.75	70.70
60	3.09	1.07	9.53	1.14	10.67	3.27	72.9	5.1	7.52	84.80
70	3.13	1.25	9.78	1.58	11.36	3.37	74	6.2	9.15	99.00
80	3.17	1.45	10.00	2.10	12.10	3.48	75	7.2	10.60	113.00

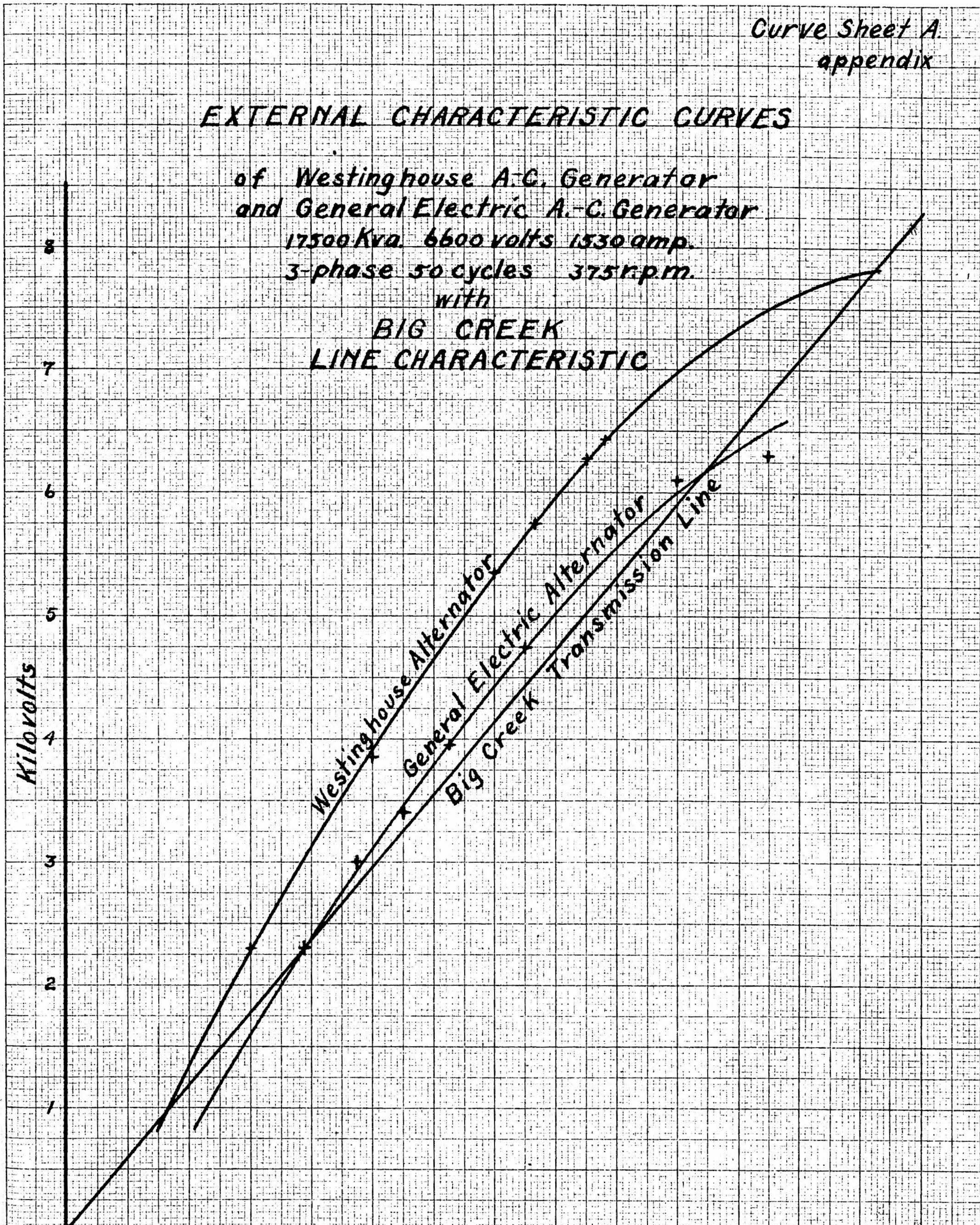
APPENDIX

Since writing the above thesis a test has been made on the alternators at Big Creek and in order to make the thesis more complete the results of this test will now be added.

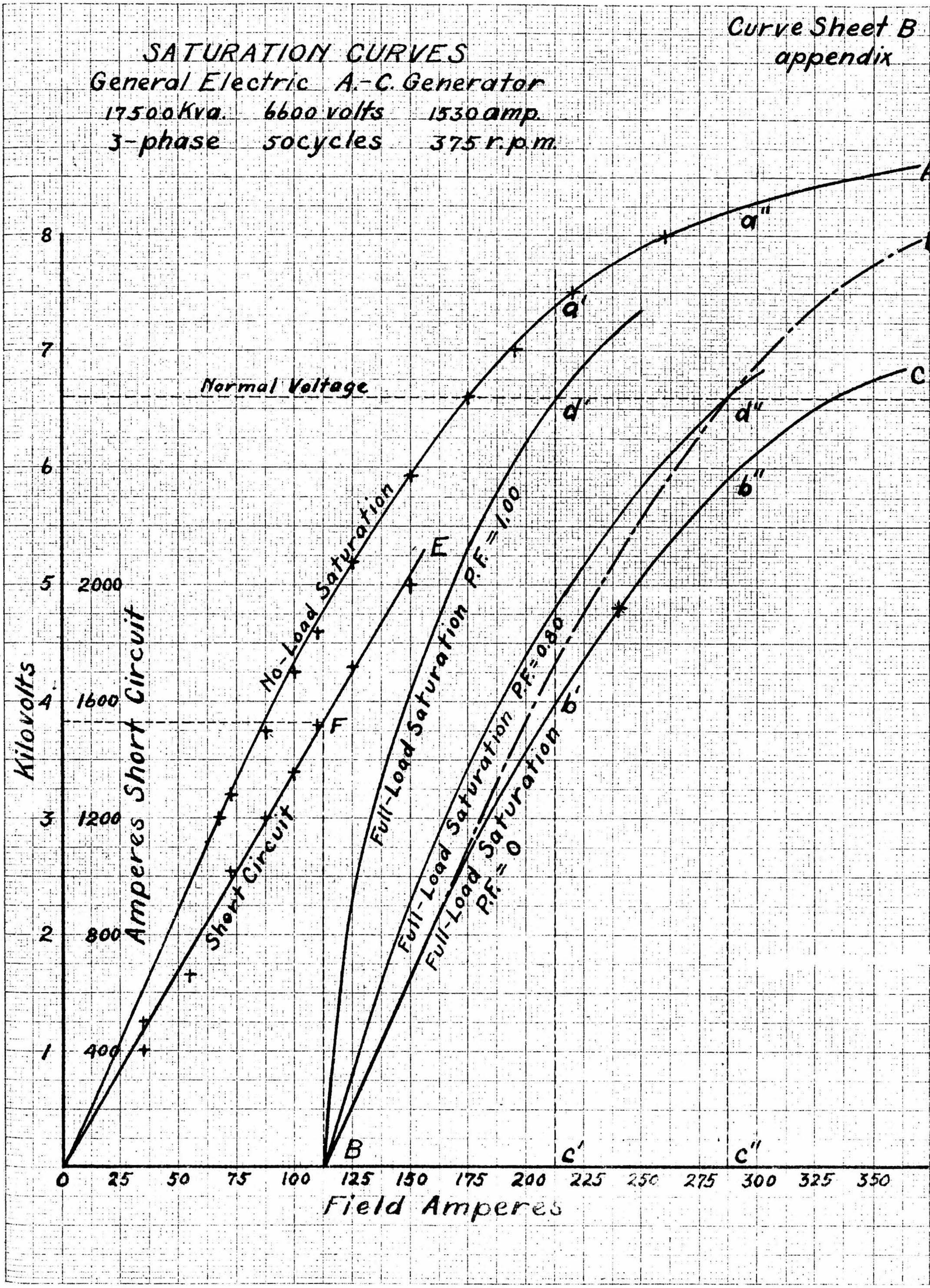
The following tests were run on the alternators at Power House No. 1 and Power House No. 2 of the Big Creek development.

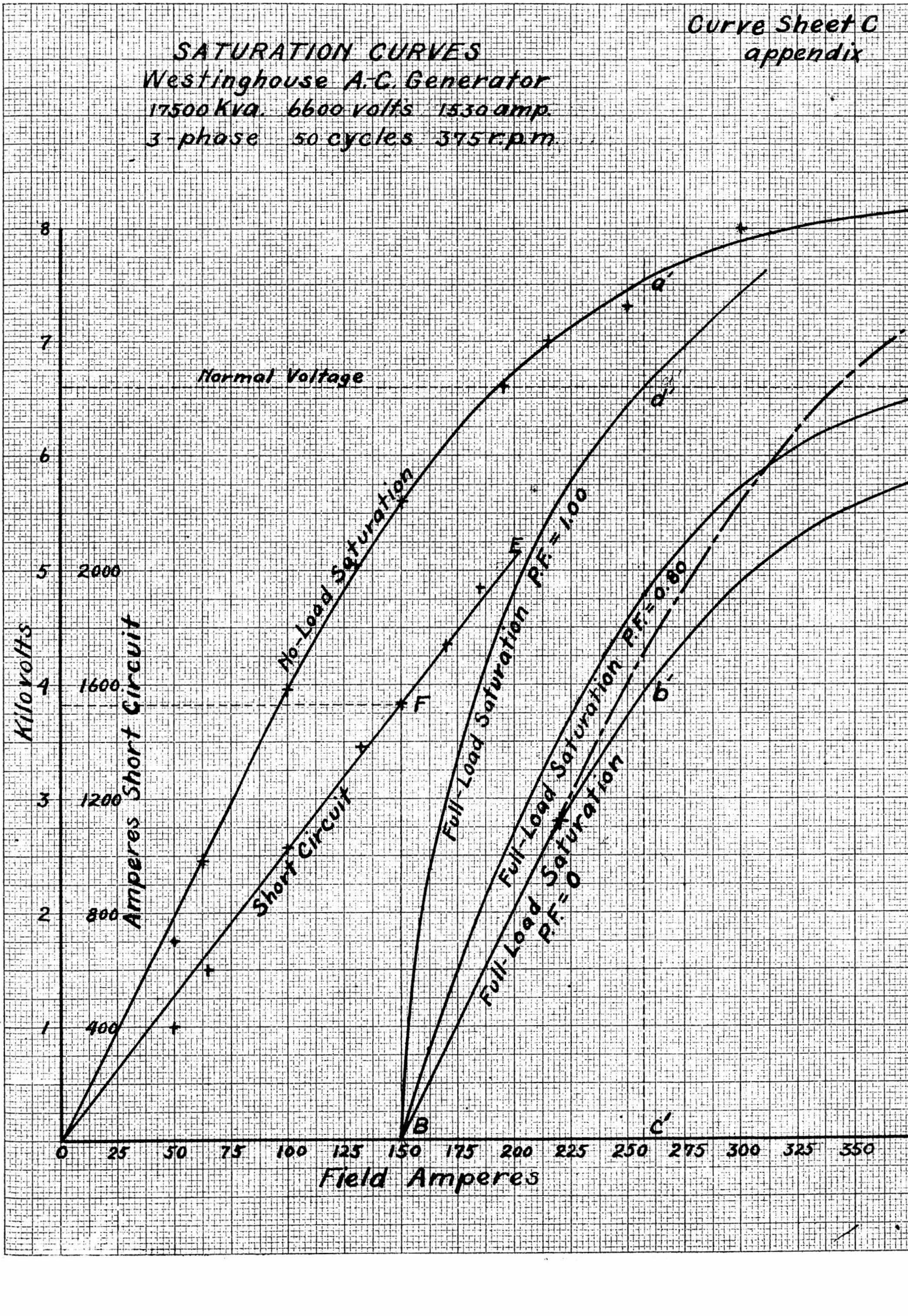
Running one alternator with no field current, but supplying excitation by means of the other alternator operating as a synchronous motor with over-excited field, readings were taken of armature current and terminal voltage. These quantities were made to vary by controlling the field current of the alternator which was operating as a synchronous motor or condenser. The results of these tests have been plotted on Curve Sheet A.

An attempt was made to run the Zero Power Factor Saturation Curves of the alternator at both power houses. To do this one machine should be operated as a generator and the other as a motor with under-excited field. By this method of loading the alternator under test a power factor of approximately zero can be obtained. Readings are taken of exciting current and voltage. A series of readings may be obtained by varying the field of the motor or synchronous reactor. Due to the fact, however, that the stations are each equipped with but one exciter buss, it was impossible to obtain the necessary high excitation of the alternator and at the same time a low excitation of the synchronous reactor. Points were obtained, however, by running the motor without excitation. By this means one point was obtained for the G. E. alternator and two



Curve Sheet A.
appendix
EXTERNAL CHARACTERISTIC CURVES
of Westinghouse A-C. Generator
and General Electric A.-C. Generator
17500 Kva. 6600 volts 1530 amp.
3-phase 50 cycles 375 r.p.m.
with
BIG CREEK
LINE CHARACTERISTIC
Kilovolts
Kilo-amperes
0.0
0.5
1.0
1.5
2.0
2.5
1
2
3
4
5
6
7
8
Westinghouse Alternator
General Electric Alternator
Big Creek Transmission Line


Curve Sheet B
appendix
SATURATION CURVES
General Electric A.-C. Generator
17500 Kva. 6600 volts 1530 amp.
3-phase 50 cycles 375 r.p.m.
Normal Voltage
No-Load Saturation
Short Circuit
Full-Load Saturation P.F. = 1.00
Full-Load Saturation P.F. = 0.80
Full-Load Saturation P.F. = 0
A
a"
a'
D
C
d'
d"
b"
b'
E
F
B
c'
c"
Kilovolts
Amperes Short Circuit
Field Amperes
0
1
2
3
4
5
6
7
8
400
800
1200
1600
2000
25
50
75
100
125
150
175
200
225
250
275
300
325
350



Curve Sheet C
appendix
SATURATION CURVES
Westinghouse A-C. Generator
17500 Kva. 6600 volts 1530 amp.
3-phase 50 cycles 375 r.p.m.
Normal Voltage
No-Load Saturation
Short Circuit
Full-Load Saturation P.F. = 1.00
Full-Load Saturation P.F. = 0.80
Full-Load Saturation P.F. = 0
Kilovolts
Amperes Short Circuit
Field Amperes
A
B
C
D
E
F
a'
d'
b'
c'
0
25
50
75
100
125
150
175
200
225
250
275
300
325
350
1
2
3
4
5
6
7
8
400
800
1200
1600
2000

for the Westinghouse alternator. In the case of the Westinghouse alternator one point was obtained with the motor operating as an induction motor and the other as a synchronous machine. The points thus obtained were sufficient to give a fairly accurate location of the zero power factor curve. These curves and the No-Load Saturation and Short Circuit Curves are plotted on Curve Sheets B and C. The method of Article 296 of the Standardization Rules was used to calculate the regulation. The results are shown in the accompanying table.

Make of Alternator	Regulation at Unity Power Factor	At 0.80 Power Factor, lagging
Westinghouse	14.4 %	24.2 %
General Electric	12.1 %	24.2 %

No great degree of accuracy can be claimed for the value of regulation of the Westinghouse machine at 80% power factor since not enough points in the upper portion of the no-load saturation curve have been obtained to locate it with precision.

On Curve Sheet A, the External Characteristic Curves with No Field excitation for both the G. E. and Westinghouse alternators have been plotted alohg with the current-voltage relation of the Big Creek Transmission Line. It was impossible to run the curve of the Westinghouse machine to a point where it intersects the Transmission Line Characteristic, because to do so would necessitate over-exciting the synchronous condenser to a very high degree. However, this test shows conclusively that the Westinghouse machine will build up the voltage of the line on charging to a much higher degree than the G. E. machine. It is also possible from these results to determine a length of line upon which the Westinghouse generator would operate without exceeding rated voltage when charging.

It will be interesting to compare the results obtained from test and plotted on curve sheet A of the appendix with corresponding values found by approximation and plotted on Curve Sheet J of the thesis.

Line Voltage Kilovolts	Armature Currents Kilo-amperes			
	Westinghouse		General Electric	
	Test results	Approx.	Test results	Approx.
2.	0.54	0.53	0.70	0.58
3.	0.77	0.75	0.97	0.87
4.	1.02	1.04	1.26	1.20
5.	1.30	1.38	1.60	1.60
6.	1.62	1.78	2.00	2.06
7.	2.02	2.25	----	2.60

By means of the accompanying table these values may readily be compared. The accuracy with which the test values were approximated demonstrates beyond a doubt the applicability of Section No. 297 of the Standardization Rules to the approximation of the current-voltage relation of alternators supplying long transmission lines.

General Electric A. C. Generator No. 559520

A.T.B. - 16 - 17,500 M. - 395 - 14000 Kw.

P.F. 0.8 Volts 6600 Amperes 1530.

No-Load Saturation

E.	Field I
1000	35
3000	68
3200	73
3750	88
4250	100
4600	110
5200	125
5925	150
6600	175
7000	195
7500	220
8000	260

Three-Phase Short Circuit

Arm. I.	Field I.
500	35
760	56
1015	73
1200	88
1350	100
1520	110
1720	125
2000	150

Westinghouse A. C. Generator No. 1100596

17500 Kv.-A.	6600 volts	1530 amp.
3-phase	50 cycles	375 r.p.m.

No-Load Saturation

E.	Field I
1750	50
2450	63
3950	100
5050	130
5600	150
6600	195
7000	215
7300	250
8000	300

Three-Phase Short Circuit

Arm. I.	Field I.
400	50
600	65
1030	100
1380	132
1530	150
1735	170
1935	185

Westinghouse A. C. Generator

17500 Kv.-A.	6600 volts	1530 amp.
3-phase	50 cycles	375 r.p.m.

External Characteristic with No Field Excitation.

Arm. I.	E.	Leading P.F.
600	2300	.05
1000	3850	.05
1400	5350	.05
1530	5750	.05
1700	6275	.05
1760	6425	.05

Full-Load Saturation at Zero P.F. lagging.

Arm. I.	E.	Field I.	P.F. lagging
1550	2800	220	.20
1500	5800	380	.00

General Electric A.C. Generator

A.T.B. - 16 - 17500 M. - 375 - 14000 Kw.

Volts 6600, amperes 1530, - 375 r.p.m.

External Characteristic with No Field Excitation.

Arm. I	E.	P.F.
775	2300	0 leading
950	3000	0 "
1100	3400	0 "
1250	3950	0 "
1500	4750	0 "
2000	6100	0 "
2300	6300	0 "

Full-Load Saturation at Zero P.F. lagging.

Arm. I.	E.	Field I.	P.F. lagging
1530	4800	240	.075