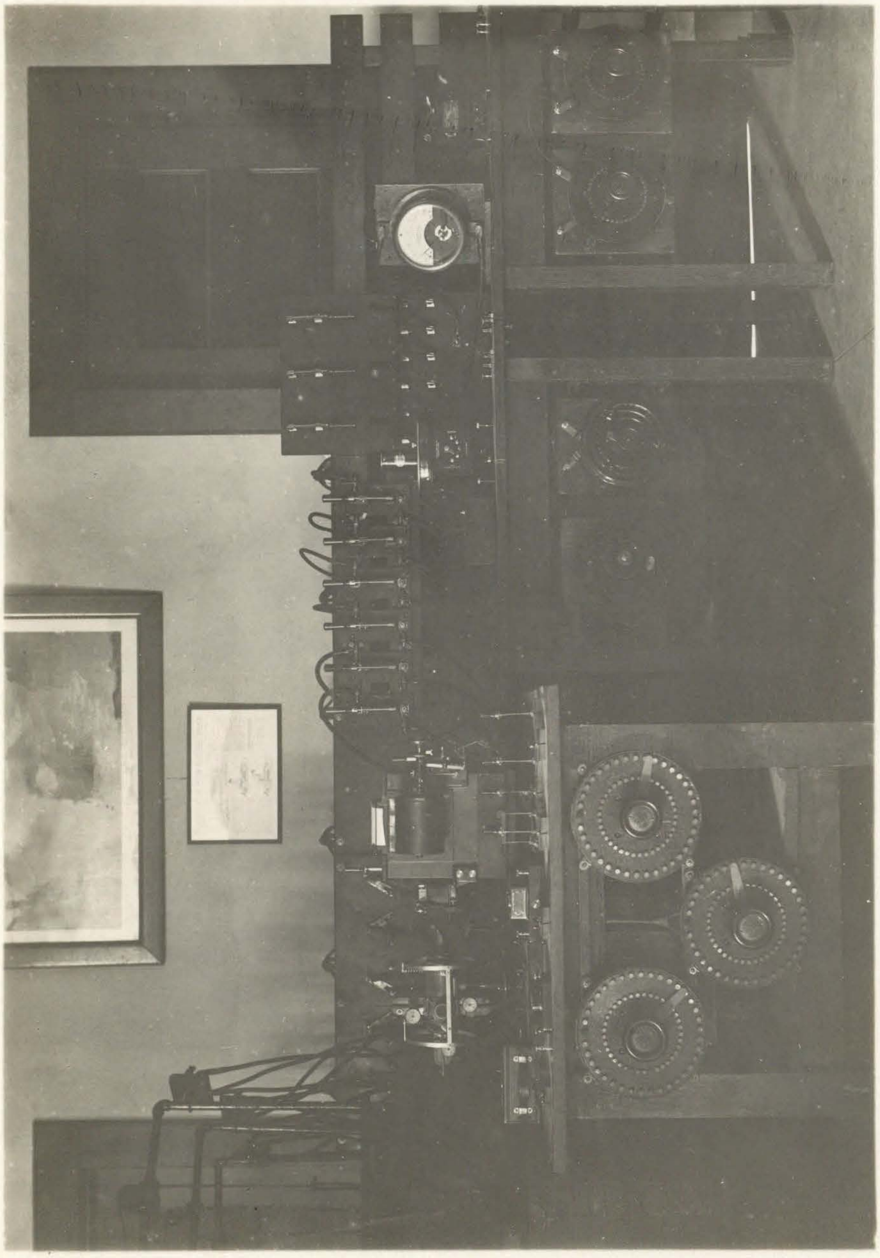
I submit herewith the following pages as my Thesis for graduation with the Degree of Bachelor of Science in Electrical Engineering.

W. L. Newton.



THESIS

INHERENT VOLTAGE RELATIONS IN
Y AND DELTA CONNECTIONS

by

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Class of Nineteen Hundred Fourteen

Department of Electrical Engineering

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THROOP COLLEGE OF TECHNOLOGY

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ACKNOWLEDGMENT

I wish to express my heartiest appreciation to Mr. R. W. Sorensen for his valuable assistance thruout the work, and particularly for the sections on Auto Transformers and Transformer Design, which he supplied in their entirety. The data from which Appendix II was taken was also supplied by him.

INTRODUCTION

In view of the fact that the relative merits of Y and delta systems have not yet been definitely established, the American Institute of Electrical Engineers has set aside the annual Pittsfield meeting for the discussion of the subject, and has requested a number of papers for presentation at that time. The present investigation was undertaken in order to furnish material for a paper to be presented at this meeting, in the hope of bringing out some points upon which little has as yet been published.

The number of articles dealing with the subject, which have appeared, and the multiplicity of conflicting statements to be found, indicate the complexity of the problem, and the impossibility of combining into a single investigation all phases of the subject. It would seem reasonable that any choice between the several systems should be based upon certain features inherent in the method of connections, even though these fundamentals may be modified to a greater or less extent by the various other factors which may exist. The present mode of attack was based on this assumption. It is the purpose therefore, of this investigation to show, if possible, by means of experiments with simple Y and delta connected systems, from which all possible complications are removed, the fundamental relations and relative advantages of the various combinations of connections.

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INHERENT VOLTAGE RELATIONS IN Y AND DELTA CONNECTIONS.

GENERAL.

The simplest polyphase system which could be constructed for the distribution of electric energy would be that of a single three phase line supplied at one end through step up transformers by the generator and at the other end giving out its energy to the connected load thru a bank of step down transformers.

As there can be made with each three phase bank of transformers four combinations of connections, and as the generator and the receiving motor may be connected either Y or delta, itis readily evident that even in a very simple system there may be made a large number of combinations.

The generators as a rule are connected Y because of the better wave form obtained (as seen by a comparison of Figs. 1 and 2), and because of the convenient ground point which is then provided. Experience has practically made standard the delta connection for the low tension windings of both the step up and step down transformers, thus leaving for consideration only the arrangements of the high tension windings of step up or step down transformer banks. These may both be connected Y, as has been very generally done, and the neutral points may be grounded or not grounded, the grounded condition being, however the one in general use. They may both be connected delta or one may be connected delta and the other connected Y, a condition not usual but one which in some cases has been thought desirable. The manner of connecting the load has slight effect upon the rest of the system, and therefore need not be considered in the present investigation.

Having made a selection as to the arrangement to be adopted in any particular system, it is of course obvious that this system must be carried throughout for any points of multiple connection of transformer banks or transmission lines, because of the impossibility of delta Y banks being run in parallel with delta-delta banks.

To determine the inherent relations, a miniature system consisting of a 7.5 Kv. a., revolving field generator with coil terminals brought out so that it could be readily connected Y or delta, and two banks of transformers each consisting of three shell type 3 Kv. a. units, was constructed. All inductive and capacity effects in the transmission line, which was in this case only the necessary leads for connecting together the high tension windings of the step up and step down transformer banks, were entirely eliminated. This must be kept in mind when considering the conclusions drawn from the tests.

All tests were made for constant conditions and the load used was non-inductive. Potentials were measured with a multicellular electrostatic voltmeter, which on closed circuits was carefully checked with a standard portable dynamometer instrument. (See Appendix I)

All connections were carefully insulated from each other and from ground, as also was the frame of the generator, except in such cases as it was well grounded with a copper ground. In all tests the transformer cores and cases were well grounded.

The first group of tests was made on the system connected as in fig. 3, without load, with balanced load, and with load on one phase only, for various conditions of grounding. Some typical results of these tests are shown in Table I. When one phase only is loaded such condition is obtained in one of two ways: by opening a high tension line, or by opening a low tension line on the load end.

Fig. 4 shows the no load voltage diagrams of high and low tension lines superimposed upon one another. The step up and step down transformers being identical, the delta represents voltages of generator, primaries of step up transformers and secondaries of step down transformers. Line voltages, secondaries of the step up, and primaries of the step down transformers are shown by the Y. If, as was assumed, the diagram is drawn to scale, it would be supposed that a measurement from any point on the delta to any other point on the Y would give the voltage between corresponding points on primary and secondary of transformers. This, however, was found not to be true in many instances. With no ground point on the system except the transformer cases, the electrostatic strains would be anywhere from 50 to 100% greater than the values obtained by measurements from the diagram. The neutral point of the Y, which should normally be at ground potential, was found to be at some distance above. It was in fact found that no point on the entire system was exactly at ground potential, except of course the transformer cases, and even the frame of the alternator was found to be at a potential above ground greater than normal line voltage. These facts can lead to but one conclusion, namely, that the conditions on all systems cannot be truly represented on one plane.

On this assumption, a great number of readings were taken and it was found that each section of the system might lie in a totally different plane, but that these planes are always approximately parallel.

An end view, then of Fig. 4 would appear as in Fig. 5, in which each line represents the plane on which the respective diagrams would have to be drawn to correctly represent the readings obtained. No definite law seems to govern the relative position of these planes. On one day the distance between them may be twice that obtained on another. However, the primary and secondary planes are always on opposite sides of ground, as shown.

The grounding of the Y neutral brings the transmission line plane to ground potential, but maintains a nearly constant potential between this plane and the generator plane, so that the potnetial between generator plane and ground is doubled, as in Fig. 6. When the generator frame, which heretofore had been well insulated, was thoroughly grounded, all potentials were brought to the same plane and the voltages read corresponded to those measured from the diagram, in Fig. 4.

As load is added to the ungrounded system, the distance between the respective planes decreases, and appears to be some function of the load. When loaded, the difference between them is inappreciable. This is true of unbalanced as well as balanced loads. Conditions, then, are better at load than at no load, or very light load. (See Table I.)

The second group of tests was made with the same transformer arrangement but with the generator connected Y. The tests made under these conditions gave results as in Table II. which are very similar to those of the first group, in that there still remains the tendency for the voltage planes to separate on the ungrounded system, at light load. This condition is probably better, however, than the first, due to the better wave shape obtained with the generator in Y, as can be seen by a comparison of Figs. 1 and 2.

From these data the following conclusions for a Y-connected transmission line may be drawn: The generator should be connected Y. The neutral point should be well grounded at both ends to relieve electrostatic strains. There is, of course, the objection to a grounded neutral, that if a line becomes grounded also, one phase is short circuited. The second point, which fortunately does not often arise in practice, is that all alternator frames, motor frames, and transformer cases should be thoroughly grounded, not only for the above considerations, but also to protect the lives of operators and linemen.

The disadvantages of Y connected transmission line may be summed: Difficulty of obtaining a satisfactory ground on the neutral. Overload or short circuit of one phase by partial or complete grounding of a line. Tendency for the voltage planes to separate at no load with imperfect grounds.

The third group of tests was made with the system connected as in Fig. 7 with the same load conditions as in the previous set of tests. With this arrangement the normal stresses are about the same as with the Y connections, (See Table III) and the unbalancing of load causes no serious variation in voltage relations, but there remains the tendency for the circuits to lie in different planes, which separate decidedly with a removal of the ground connections to the generator frame. In this case, again, the bad wave form of the alternator connected delta is objectional. On the whole this system is not to be recommended, as conditions seem to be particularly unstable, and there is no possibility of obtaining a ground point if occasion demands.

The fourth group of tests was made with the same transformer connections as in group three, but with the generator connected Y, giving the better wave form. This is apparently the ideal condition, as with such an arrangement it is unnecessary to ground this neutral to relieve abnormal electrostatic strains between windings. (See Table IV) All neutral points remain close to ground potential even under unbalanced load. There being no grounded neutral on the system, the danger of a short circuited phase by grounding is entirely obviated,unless two lines should become grounded simultaneously. As far as could be determined, this system has no disadvantages; and is to be recommended by the facts that no ground is required, the wave form is the best obtainable with a given generator, and that there is practically no tendency for abnormal voltages to occur due to separation of the voltage planes.

VOLTAGE DIAGRAMS.

A few voltage diagrams might help to make clear just what happens under various conditions of load. To avoid needless repetition of similar figures, the results obtained in the fourth group of tests are taken as typical diagrams.

Fig. 8 represents conditions under balanced load, in which the Y is the generator diagram, with the neutral at Ng. The delta A1, A2, A3 represents the primaries of the step up bank of transformers, and L1, L2, L3 the secondaries of this bank and the primaries of the step down trans-transformers. The diagram of the secondaries of the step down transformers connected in Y corresponds to A1, A2, A3, and is indicated by W1, W2, W3.

If now one line is opened between step up and step down transformers, conditions result as in Fig. 9, which is lettered to correspond with Fig.8. The heretofore symmetrical figures become considerably distorted. W1, W2, W3 becomes a straight line, and is therefore in series from W2 to W3. The diagrams of the secondaries of the step up bank and of the primaries of the step down bank of transformers are no longer coincident. The former is shown by the triangle L1, L2, L3 and the latter by the straight line L'1, L2, L3. The distance L1-L'1 represents the voltage across the open switch.

An open line between step down transformers and the load gives Fig. 10. The distortion is not so noticeable as in the previous case.

AUTO TRANSFORMERS.

The economic advantage of using auto transformers for changing from one phase to another and for making slight voltage changes when it has not been necessary to keep the two systems insulated from each other, has caused them to be quite extensively used.

Example: A certain large power company had as one source of supply a plant which delivered power to the main distribution center over a 125 mile line at a potential of 50,000 volts. In the new development 60,000 volts was selected as the standard for long distribution feeders, and as the line insulation would not permit the old system to be raised to this voltage, the two projects were tied together by means of three auto transformers, which were connected Y and would carry, on the 50,000 volt taps, 5000 Kv.a. The connections and currents for this bank of auto transformers are shown in Fig.11.

This is the most common arrangement of auto transformers because it is both convenient and economic, and the only one which will be considered, although either the extended delta or the delta connection, as shown in Fig.12 a and b, might have been used to good advantage.

When such an auto transformer is used, it is connected as in Fig. 13. For such an arrangement there may be two conditions, grounded neutral and ungrounded neutral. With grounded neutral the triple frequency e.m.f. which exists from line to ground may become very dangerous, particularly if the line has considerable electrostatic capacity, as would be the case in the assumed problem, because of the intensifying effect of the third harmonic in the charging current. In some tests made the maximum stress was found to approach three times normal potential for the neutral of the auto transformer bank grounded.

With the neutral of the auto transformer bank ungrounded, stresses running up to 50% of line voltage may be measured from ground to neutral, which is of course not a serious matter, as the maximum stress will remain from line to ground and will not be changed from normal value.

Laboratory tests for this connection indicated that the maximum voltage strain from the lower potential lines to ground would be about half the sum of the high voltage and the low voltage, which in this case would be one half 60,000 plus 50,000 volts, or 55,000 volts.

TRANSFORMER DESIGN.

When transformers were made in small sizes only, particularly if they were shell type, there was some advantage in having the windings connected Y for the high tension side of the bank, as this allowed a smaller number of coils and less insulation, because the normal strain was 57.7% that of delta connected transformers. The increase in size of units and the provision for maximum strain where one line becomes grounded has made these economic advantages obsolescent, except in some very special cases of small, high voltage units. Hence, from the point of design and manufacture, there is no advantage for either Y or delta construction.

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APPENDIX I.

When measuring the electrostatic strain between two points having no electrical connection, as between the primary and secondary windings of a transformer, the ordinary voltmeter is useless, being only an ammeter, and requiring a return circuit for the current it draws, before the instrument will indicate. It was therefore necessary to procure an electrostatic voltmeter for all such readings. Two were found to be available. One had a range from 40 to 160 volts and the other from 500 to 10,000 volts. As the voltages it was desired to measure lay quite frequently between 160 and 500 volts these readings could not be obtained. The low reading instrument was equipped with a multiplier for reading up to 600 volts, but as this was of the resistance type, it could not be used on electrostatic readings. It was then attempted to construct a multiplier with condensers, but with no success. Combinations were tried with the voltmeter and condenser in series; in parallel; and with the voltmeter and condenser in parallel in series with a second condenser, but on trying to check with a standard voltmeter on closed circuits it was found that a definite ratio of multiplication could not be obtained. Although probably the construction and calibration of such a multiplier is possible, it could not be undertaken in the limited time available, and was abandoned.

It was next attempted to reduce the range of the high reading instrument, but this also was found to be impracticable. To overcome this difficulty it was finally necessary to reduce the ratio of transformation sufficienty so that comparatively few of the readings exceeded the upper limit of the low reading voltmeter.

APPENDIX II.

It may be of interest to consider in this connection the actual network diagram of the system of The Pacific Light and Power Corporation, as shown in Fig. 14. The following nomenclature is used:

A- Engine-driven alternator.

TA- Turbine " "

T- Transformers.

AT- Auto-transformers.

The numerals indicate the voltage at various points on the system.

For simplicity, the location of switches has not been shown. Several small generating stations on the system are not shown.

Power house No. 1 contains three (shown as one in diagram) engine driven alternators delivering power at 15,000 volts directly to the bus-bars. The two turbo-generator sets generate at 9000 volts and step up to the bus bar voltage thru auto-transformers. In substation No.1

this is stepped up thru transformers to connect with a 50,000 volt line, and in substation No.2 it connects with a 60,000 volt line thru transformers.

Power house No. 2 (not shown) is a hydro-electric plant. The generator voltage is stepped up with delta-y transformers to 150,000 volts, at which voltage it is delivered to substation No.2, where it is transformed to 60,000 volts as shown. The 50,000 volt line from power house No.3 is connected to this thru auto transformers. Substation No.1 contains a bank of transformers connected Y-delta, with the neutral grounded and the secondary on open circuit. This is merely a dead end for the purpose of obtaining a ground point.

APPENDIX III.

NOTES ON TABLES. Table I is practically a complete record of all the first group of tests made with the generator frame grounded. Table II is not complete, since, as was noted before, the results of the second group of tests were approximately identical to those of the first group. Tables III and IV contain results of only those tests needed for comparison.

It should be noted that the per cent volts from high tension to low tension will vary for every ratio of transformation, so that the figures given will be true only for the ratio employed, namely 1 to 1.154.

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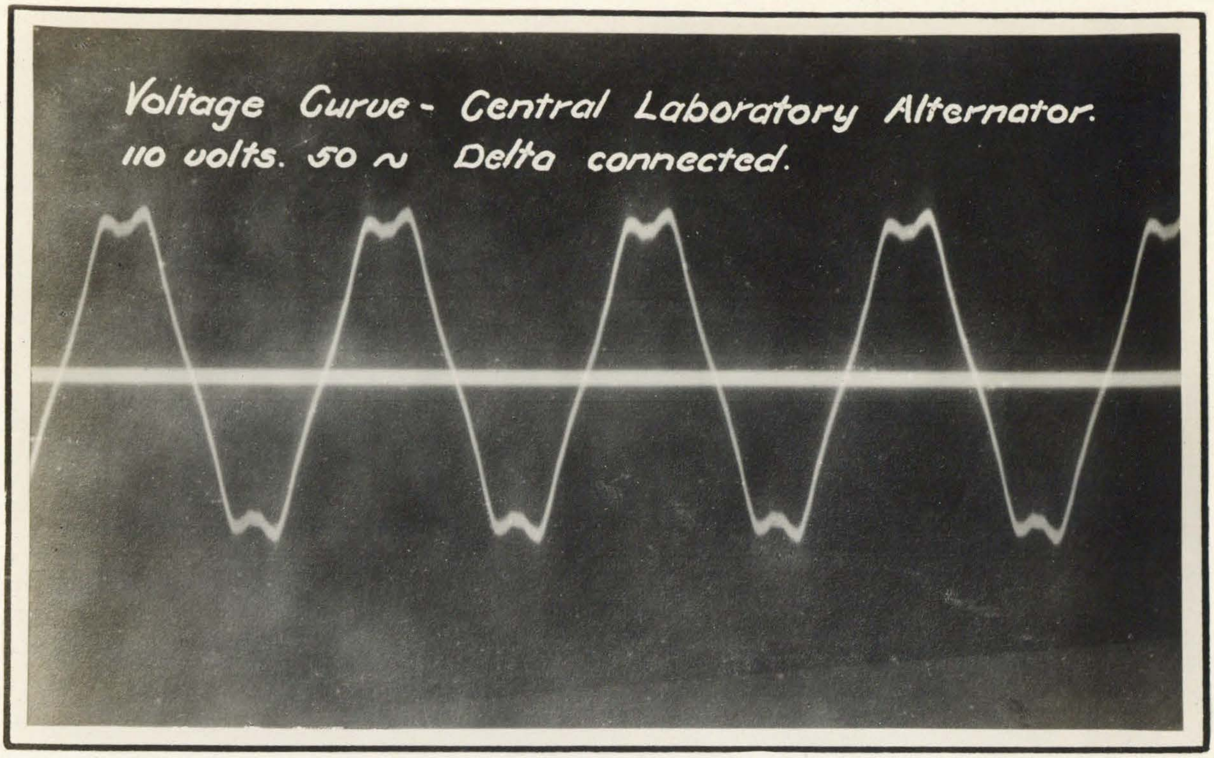

Voltage Curve - Central Laboratory Alternator.
110 volts. 50 ~ Delta connected.

FIG. 1.

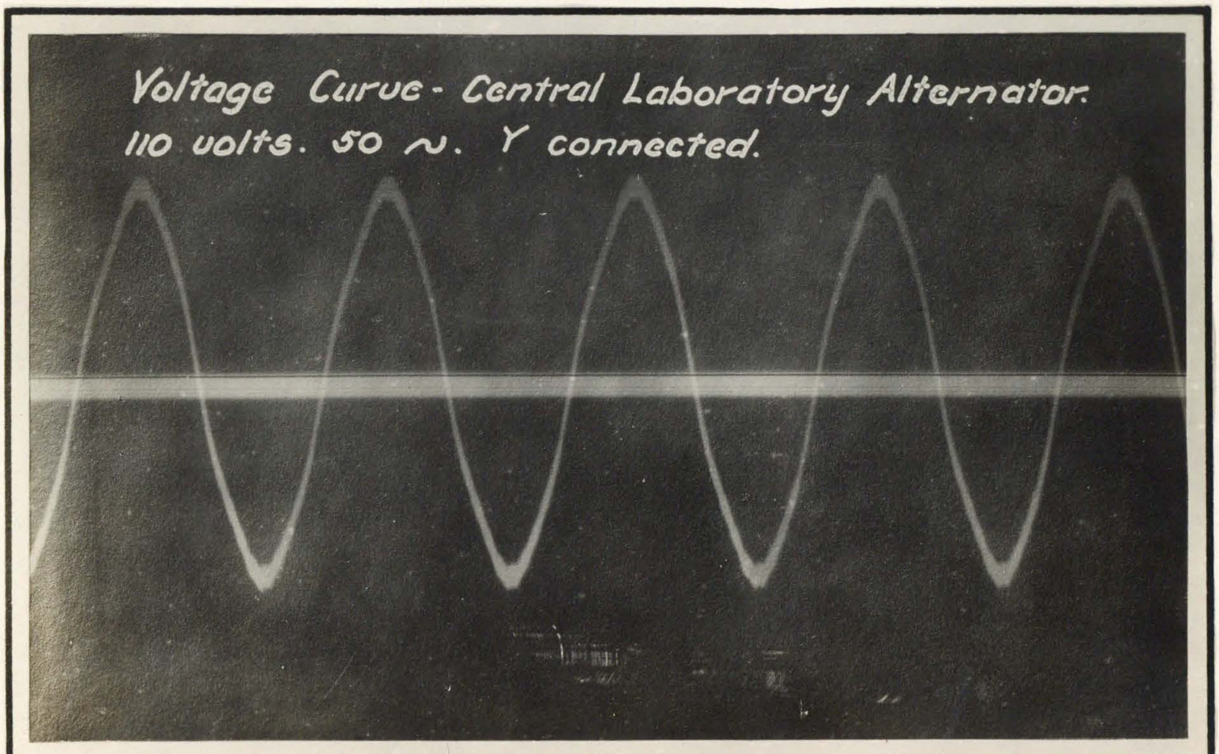

Voltage Curve - Central Laboratory Alternator.
110 volts. 50 ~. Y connected.

FIG. 2.

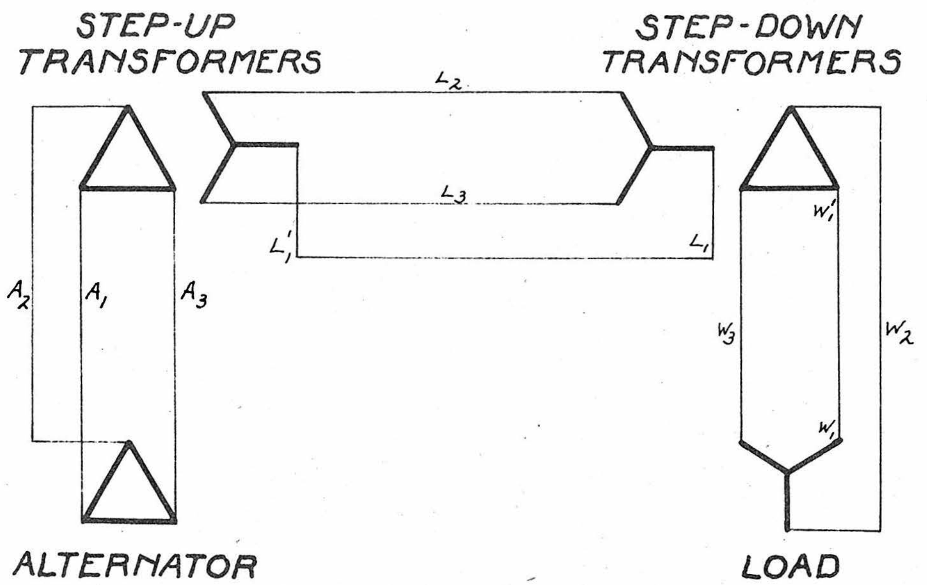

STEP-UP
TRANSFORMERS
STEP-DOWN
TRANSFORMERS
L2
L3
L'1
L1
A2
A1
A3
W'1
W3
W2
W1
ALTERNATOR
LOAD

FIG. 3.

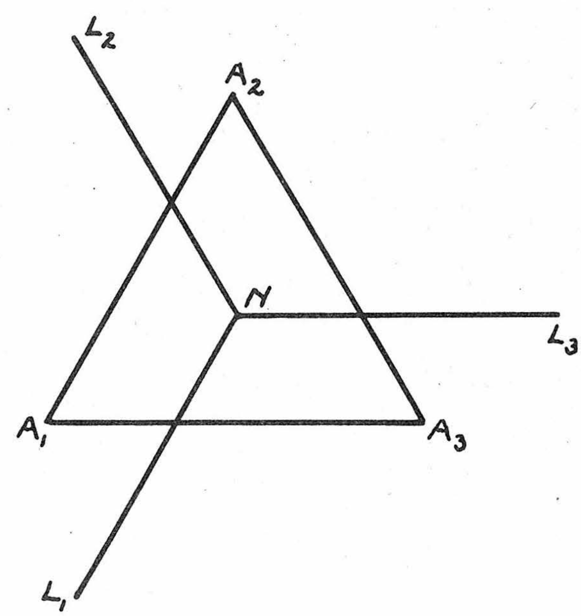
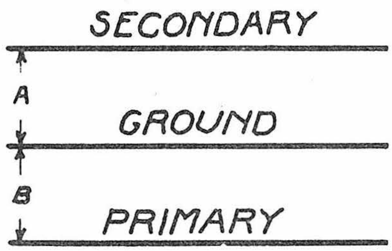
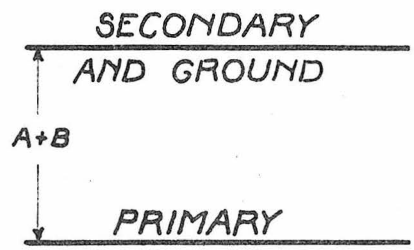

L2
A2
N
L3
A1
A3
L1

FIG. 4.





STEP-UP TRANSFORMERS

FIG. 5.

FIG. 6.

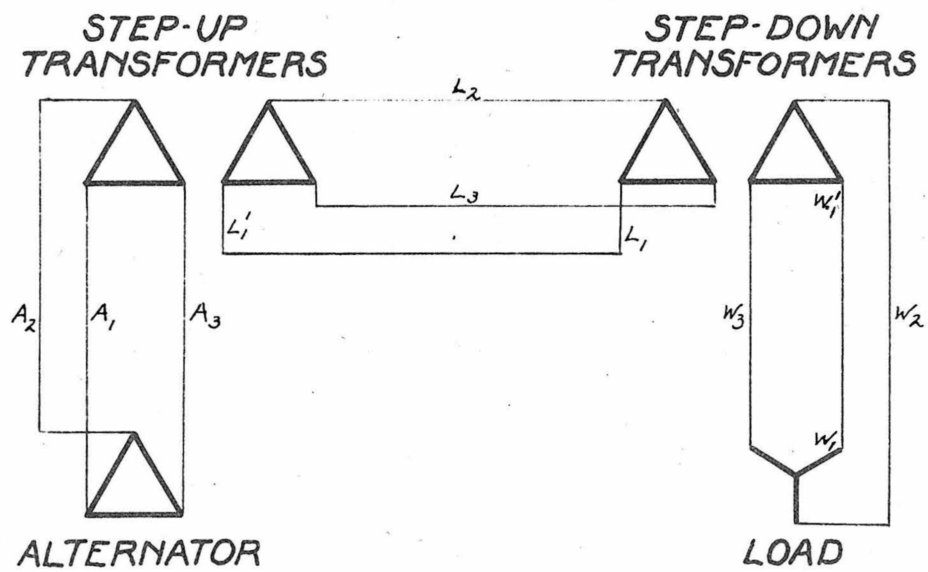


FIG. 7.

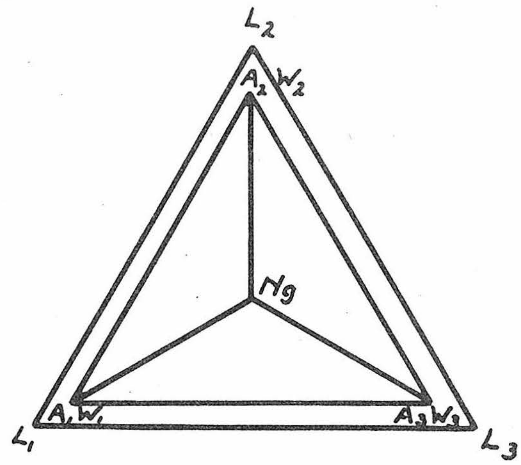


FIG. 8.

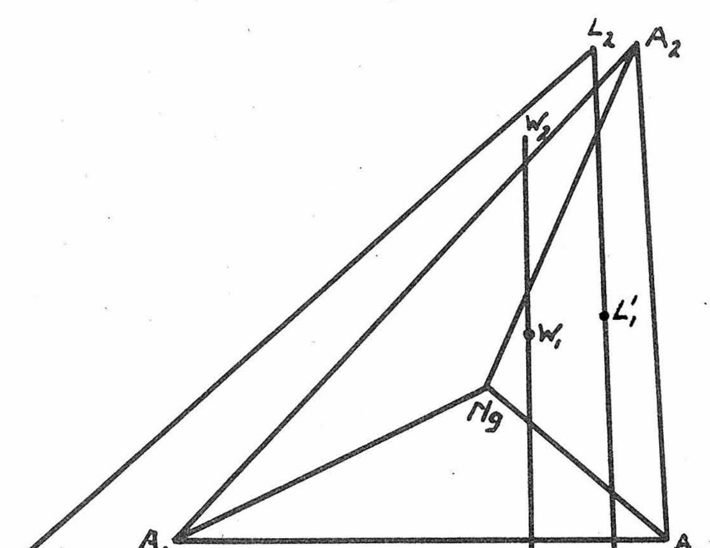


FIG. 9.

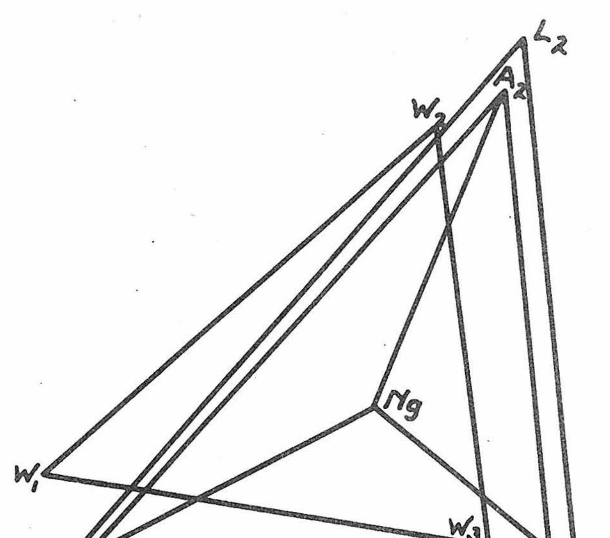
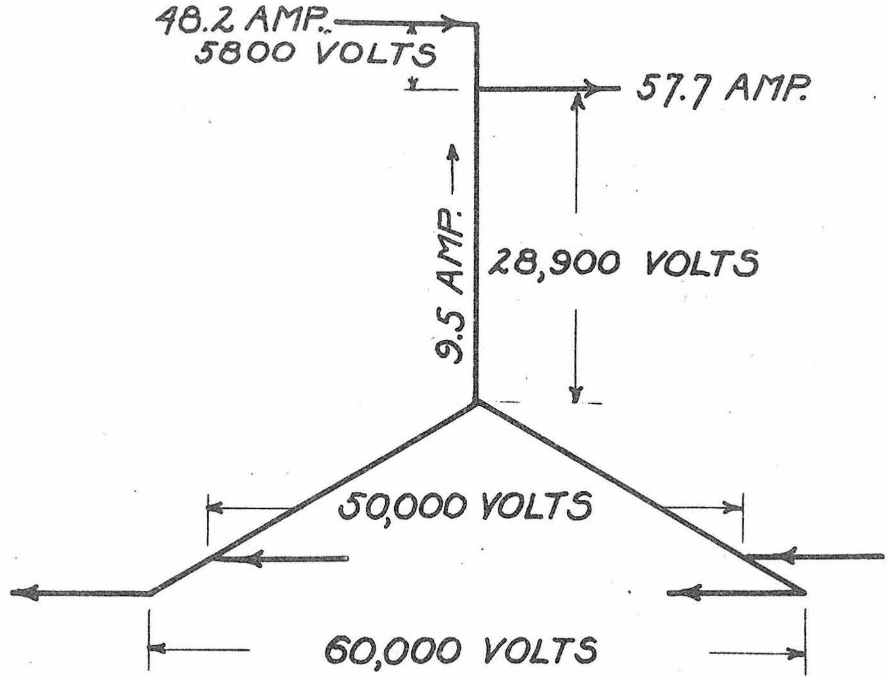
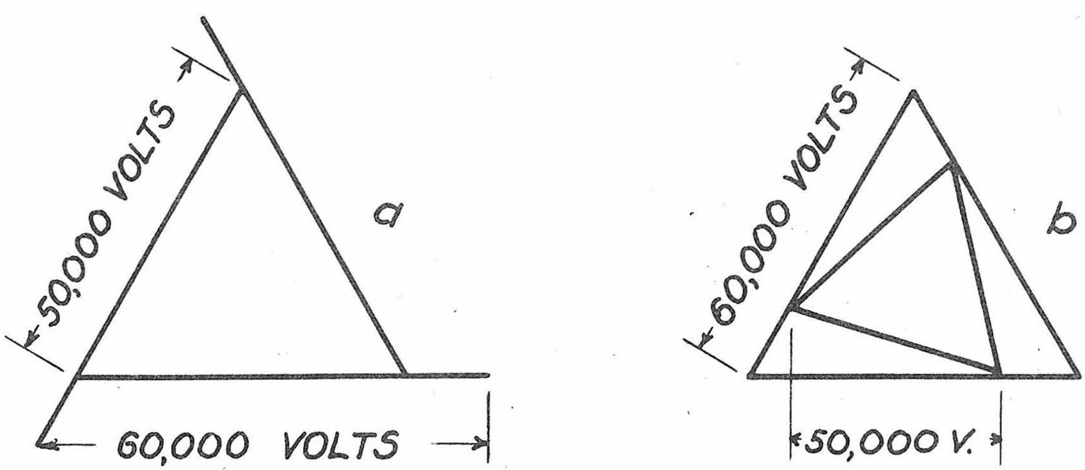


FIG. 10.



48.2 AMP.
5800 VOLTS
57.7 AMP.
9.5 AMP.
28,900 VOLTS
50,000 VOLTS
60,000 VOLTS

FIG. 11.



50,000 VOLTS
a
60,000 VOLTS
60,000 VOLTS
b
50,000 V.

FIG. 12.

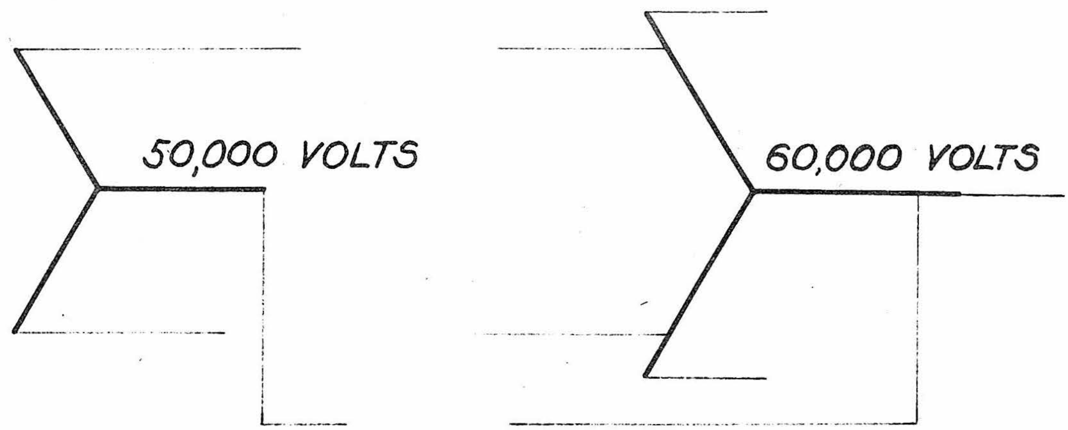

50,000 VOLTS
60,000 VOLTS

FIG. 13.

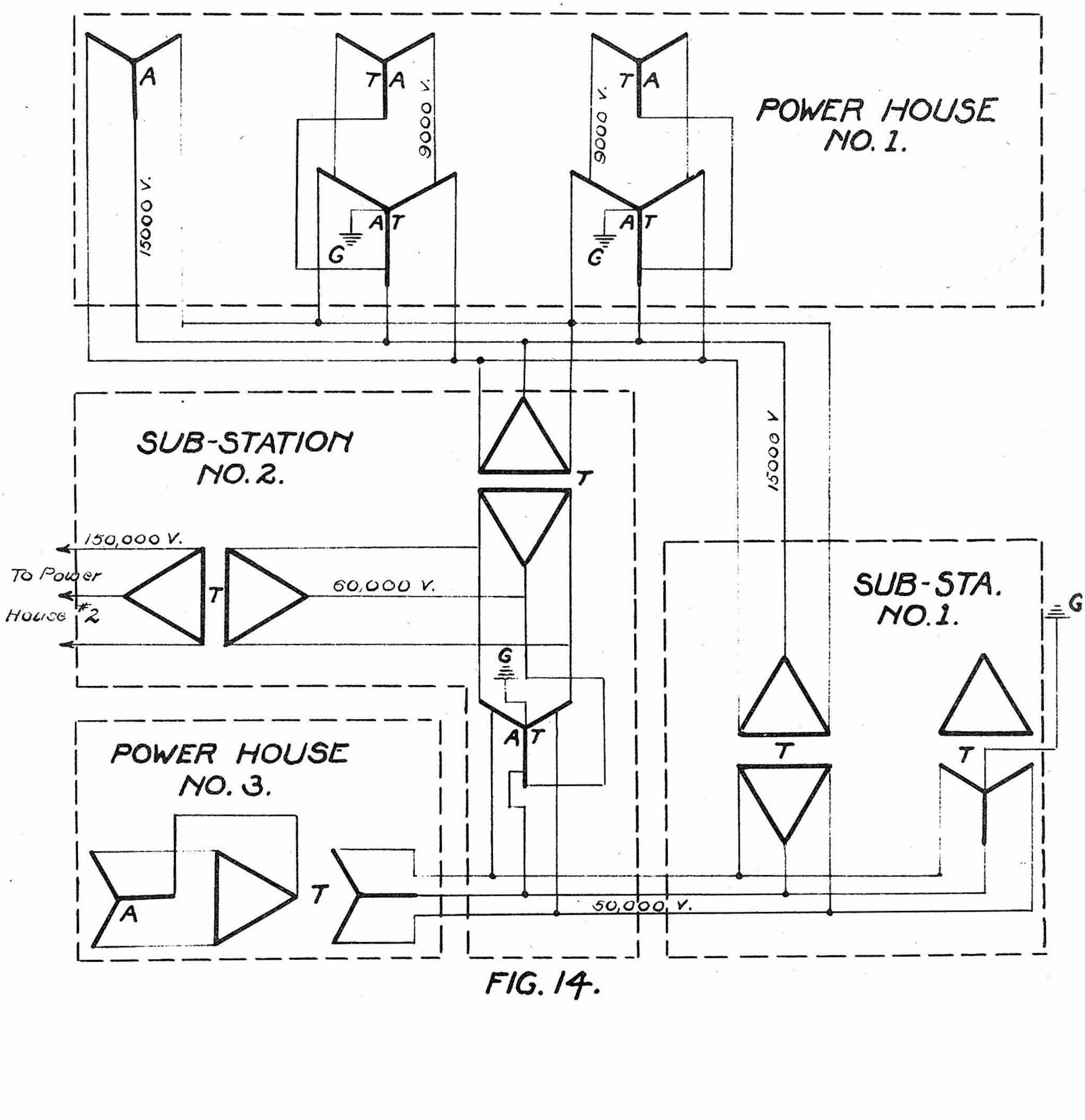

POWER HOUSE NO. 1.
A
T A
9000 V.
15000 V.
G
A T
SUB-STATION NO. 2.
T
150,000 V.
To Power House #2
60,000 V.
G
A T
SUB-STA. NO. 1.
15000 V
G
POWER HOUSE NO. 3.
50,000 V.

FIG. 14.

TABLE I[†]

LOAD.	GR'D. POINT.	OPEN POINT.	MAXIMUM PER CENT VOLTS. H.T. TO GR'D. % H.T.	L.T. TO GR'D. % L.T.	H.T. TO L.T. % H.T.	H.T. TO L.T. % L.T.	N TO GR'D. % H.T.
0	NONE	NONE	57.7	57.7	82.0	163.0	0
0	NEUTRAL	"	"	"	"	"	"
BALANCED.	NONE	"	"	"	"	"	"
"	NEUTRAL	"	"	"	"	"	"
1 PHASE.	NONE	ONE H.T. LINE	51.0	69.5	90.0	180.0	18.2
"	NEUTRAL	"	73.0	167.0	138.0	276.0	0
"	NONE	ONE LOAD LEAD	74.5	70.0	100.0	200.0	4
"	NEUTRAL	"	62.4	71.5	104.0	209.0	0
BALANCED.	ONE H.T. LINE	NONE	100.0	65.0	—	—	—
	N & 1 " "	"	91.2	57.7	—	—	0

TABLE II

* 0	NONE	NONE	57.7	61.0	85	167.0	0
BALANCED	"	"	"	"	"	"	"

† READINGS WITH UNGROUNDED GENERATOR FRAME ARE OMITTED, AS THIS CONDITION SO RARELY EXISTS IN PRACTICE. (EXCEPT,* IN WHICH IT WAS NOT GROUNDED.)

TABLE III

LOAD.	GR'D. POINT	OPEN POINT.	MAXIMUM PER CENT VOLTS. H.T. TO GR'D. % H.T.	L.T. TO GR'D. % L.T.	H.T. TO L.T. % H.T.	H.T. TO L.T. % L.T.	N TO GR'D. % H.T.
O	NONE	NONE	58.3	57.7	91.2	105.0	—
BALANCED	"	"	"	59.0	"	"	—
1 PHASE	"	ONE H.T. LINE	60.1	69.1	104.0	120.0	—
"	"	ONE LOAD LEAD	65.0	67.2	109.0	126.0	—
O	ONE H.T. LINE.	NONE	100.0	64.5	135.0	156.0	—

TABLE IV

* O	GEN. N. (N_g)	NONE	58.7	57.7	94.4	109.0	0
"	NONE	"	58.2	"	"	"	3.
BALANCED	GEN. N.	"	57.7	60.0	"	"	0
1 PHASE	"	ONE H.T. LINE	71.7	90.0	167.0	192.0	4.
"	"	ONE LOAD LEAD	81.2	84.0	142.0	164.0	"
O	1 H.T. LINE & N_g	NONE	100.0	58.0	145.0	167.0	"
"	ONE H.T. LINE	"	"	63.7	148.0	168.0	"
BALANCED	1 H.T. LINE & N_g	"	"	58.0	145.0	167.0	"

* GEN. FR. NOT GR'D.

ADDENDA.

ORIGINAL DATA.

The following pages contain the results of the original tests, and form the basis for the statements made, and conclusions drawn, in the first (GENERAL) and second (VOLTAGE DIAGRAMS) sections of this investigation.

The letters correspond to those of Figs. 3 and 7. The figures opposite each pair of letters indicates the voltage between the two points represented by the letters, under the given conditions.

For the sake of brevity, and ease of reference, the following outline has been followed:

A-Group I- Delta-delta Y-Y delta.

1. No load.
   - (a) Neutral not grounded. Gen. frame grounded.
   - (b) " " " Gen. frame not grounded.
   - (c) Neutral grounded. Gen. frame grounded.
   - (d) " " Gen. frame not grounded.
2. Balanced non-inductive load.
   - (a), (b), (c), and (d) as above.
3. One phase loaded.
   - (1) Switch open in L1.
     - (a), (b), (c), and (d) as above.

(2) Switch open in W1.

(a), (b), (c), and (d) as above.

4. Balanced load. Hógh resistance ground on L1.

(a), (b), (c), and (d) as above.

B-Group II- Y-delta Y-Y delta.

1. No load.

(a) No ground point. (Except transformer cases.)

(b) Both gen. and line neutrals grounded.

2. Balanced non-inductive load.

(a) and (b) as above.

C-Group III- Delta-delta delta-delta delta.

1. No load.

(a) Generator frame grounded.

(b) Generator frame not grounded.

2. Balanced non-inductive load.

(a) and (b) as above.

3. One phase loaded.

(1) Switch open in L1.

(a) and (b).

(2) Switch open in W1.

(a) and (b).

4. No load. Ground on L1.

(a) and (b).

D-Group IV- Y-delta delta-delta delta.

1. No load.

(a) Gen. frame and gen. neutral grounded.

(b) No ground point. (Except transformer cases.)

2. Balanced non-inductive load.

(a) and (b).

3. One phase loaded.

(1) Switch open in L1.

(a) and (b).

(2) Switch open in W1.

(a) and (b).

4. No load. Ground on L1.

(a) as above.

(b) Generator frame only grounded.

5. Balanced load. Ground on L1.

(a) and (b) as in 4 above.

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The preceding outline indicates nearly all the combinations which could be made on the system used for test purposes. A number of the tests listed above were not made as frequently a few readings would suffice to show that conditions were the same as in some preceding test, and time was not taken to continue that particular test. The reason for omitting any part is noted under its proper heading.

The upper limit of the electrostatic voltmeter used was 160 volts, and readings given as "160 plus" are off the scale. Their exact value may be determined, if necessary, by constructing a diagram to scale, and measuring the required voltage, having due regard for the separation of the planes, if any exists.

The original data follow:

A-Group I.	1				2			
	(a)	(b)	(c)	(d)	(a)	(b)	(c)	(d)
A1A2	110	110	110	110	110	110	110	110
A1A3	110	110	110	110	110	110	110	110
A2A3	110	110	110	110	110	110	110	110
L1N	127	127	127.5	127	124	125	125	125
L2N	127	127	127.8	127	124	125	124	125
L3N	127	127	127.7	127	124	126	125	125
L1L2	220	220	222	222	216	218.5	218	218
L1L3	220	220	222	222	216	220	218	220
L1L3	220	220	222	222	216	219	219.5	220
W1W2	110	110	110	110	106	107	106	107
W1W3	110	110	110	110	106	107	106	108
W2W3	110	110	110	110	106	107	106	107
A1G	64	127	64.7	118	~~4~~58	88	61.5	75
A2G	63.5	127	67	120	63	92	64.5	81
A3G	63	126	66.5	123.2	63	91	64.5	78
L1G	125.1	133	127.5	127.5	120	124	124	125
L2G	125.2	133.7	127.8	126.5	119.5	124	124	125
L3G	121	133	127.7	125	126	130	124	124.6
NG	0	20	0	0	0	15	0	0
W1G	61	65	61.5	59	45	52	49	62.5
W2G	62	66	62.5	60	57	61	62	60

A-(Cont.)	1				2			
	(a)	(b)	(c)	(d)	(a)	(b)	(c)	(d)
W3G	57	61	0	55	72	76	75	75
A1L1	82	85.5	79	115.5	71	87	76.5	89
A1L2	137.5	142	139	160pl.	52.5	142.5	137.5	146
A1L3	160pl.	160pl.	160pl.	160pl.	160pl.	160pl.	160pl.	160pl.
A2L1	160pl.	160pl.	160pl.	160pl.	160pl.	160pl.	160pl.	160pl.
A1W1	0	45	0	86.5	0	66	5	48
A1W2	102	110	100.5	134	110	129	110	118.5
A1W3	100	108	98	132	118	134.5	117	124.5
A2W1	107	104	102	136.5	103	123	102.5	115
AfG	0	155	0	134	0	80	0	80

The following readings are for A-1-(a) only. No further readings were taken for any of the others above.

A1N	63.5	A2N	63.5	A3N	63	W1N	63
W2N	58	W3N	56	W1G	63	W2G	59
W3G	56	L1W1	72	L2W2	70	L3W3	78
A1W1	0	A2W2	0	A3W3	0	A3W2	103.5
A3W1	107	A3W3	100				

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A-3.	(1)				(2)			
	(a)	(b)	(c)	(d)	(a)	(b)	(c)	(d)
A1A2	131	134	134	130	135	137	137	136
A2A3	134	136	137	132	119.5	120.5	120	120
A1A3	110	116	116	108	115	117	116	116
L1N	73	76	75	80	156	158	158	156

A-3.	(1)				(2)			
	(a)	(b)	(c)	(d)	(a)	(b)	(c)	(d)
L2N	152	137	155.5	151	134	136	136	136
L3N	123.5	130	130	120	131	133	133	132
L1L2	117	122	120	118	261	264	264	262
L1L3	113	120.5	122	110	255	259	256	259
L2L3	232	244.2	244	231	215	220.7	219	238
W1W2	0	0	0	0	50	60	60	60
W1W3	102	103	104	96	55	55	55	55
W2W3	102	104	103	99	115	117	116	114.5
A1G	68.5	96.1	66	88	71.5	103	71	77.5
A2G	76.5	100	184	101	77	106.5	78.5	83.5
A3G	69	96	71	91.8	64	97.5	64.5	71
L1G	40	48.2	77	75	160pl.	160pl.	160pl.	156
L2G	122.8	137	160pl.	153	134	137.2	137	136
L3G	113.2	125	133	125	124	135.5	134	132
NG	30	44.5	0	0	5	30	0	0
W1G	40	42	55	57.5	15	15	15	15
W2G	40	43	54	53	66	69	67.2	66
W3G	59.5	65	65	61	51.5	52.5	50	51
A1L1	102	112	135	146.4	95.6	103	95	99.5
A1L2	143	151	160pl.	160pl.	160pl.	160pl.	160pl.	160pl.
A1L3	160pl.	160pl.	160pl.	160pl.	160pl.	160pl.	160pl.	160pl.
A2L1	30	57	25	71	160pl.	160pl.	160pl.	160pl.
A1W1	81	101	96	109.5	91.5	117	88	91.5
A1W2	81	100	96	110	116	129.5	114.8	117

A-3	(1)				(2)			
	(a)	(b)	(c)	(d)	(a)	(b)	(c)	(d)
A1W3	111	125.3	121	130	94	109.5	90	96
A2W1	49	66.4	30	66.5	57.5	82.5	64	74
AfG	0	82	0	83	0	113	0	
L'1N	152	154	154	150				
L'1L2	160pl.	281	282	276				
L'1L3	160pl.	239	240	232				
L'1G	160pl.	160pl.	156	152				
A1L'1	124.5	131	102	114.7				
A2L'1	160pl.	160pl.	160pl.	160pl.				
L'1L1	225	227	229	223				
W'1W2					136.5	137	138	135.5
W'1W3					113	114	114	112
W'1G					83	86	88	87.3
A1W'1					5	54	20	35
A2W'1					160pl.	148	144.5	145.5
W'1W1					111	109.5	110	110

	A-4		B-1	C-1		C-2	
	(c)	(d)	(a)	(a)	(b)	(a)	(b)
A1A2	90	88	110	110	110	110	110
A1A3	104.5	104	110	110	110	110	110
A2A3	90	88.5	110	110	110	110	110
L1N	98	96	~~63.5~~ 123				
L2N	102	100	~~63.5~~ 123				

	A-4		B-1	C-1		C-2	
	(c)	(d)	(a)	(a)	(b)	(a)	(b)
L3N	117	117.5	123				
L1L2	162	158	220	126.5	126.7	125	125
L1L3	191.5	191	220	126.8	126.7	125	125
L2L3	196	195	220	126.5	126.7	125	125
W1W2	82	84	109.8	109.8	110	106	106
W1W3	100	100.5	109.8	109.9	110	106	106
W2W3	86	85.5	109.8	109.8	110	106	106
A1G	55.5	67	67	60.5	91.4	61.5	
A2G	49	61	67	63	93.5	64	
A3G	59	72	67	63.1	93.4	65	
L1G	94.5	96		66.5	69.5	67	
L2G	101	102		73	75	72.5	
L3G	116	119.3		74	75.5	74	
NG	0	0	0				
AfG	0	94	131	0	87		
W1G	77	57		58.5		59	
W2G	68	43.5		65		59.8	
W3G	72	50		58		58.9	
A1L1	51	59	77	10	45	10	
A2L1	142	134	160pl.	113	125.6	114	
A3L1	130		138	112.6	126.5	113	
A2L2	84		77	10	45	10	
A1W1	55	25		0	52	5	
A1W2	92.2	85		105	119.5	113	

	A-4		B-1	C-1		C-2
	(c)	(d)	(a)	(a)	(b)	(a)
A1W3	102	97		101	118	101.8
A2W1	100	87		100.5	118	104.3
AfNg			101.5			
NNg			0			
L1,L2,L3,-N			126			
A1L2			138	116	129	115.5
A3L3			77	10	45	10
L1W1			72		10	
A1,A2,A3,-Ng			63.5			
GNg			30			
L2W1			138		112	113.4
A1L3				116.8	129	115
A2L3				115.5	125.5	116
A3L2				114.5	127	113
A2W2				0		5
A2W3				98.8	115	107
A3W1				105	120	108
A3W2				107.5	120.5	104
L1W2				112.3	112.5	109.8
L1W3					108	105.5
L2W3					108	110.3
L3W1					118	116.5
L3W2					118	112

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Only one set tests was made under B (Group II) as the results are practically identical to those of Group I, as determined by a number of readings taken at random.

A-4 (a) and (b) are the same as A-1 (a) and (b).

	C-3		C-4	D-1		D-2
	(1)	(2)				
	(a)	(a)	(a)	(a)	(b)	(a)
A1A2	138	133.5	110	110	110	110
A1A3	118	114.3	110	110	110	110
A2A3	120	117.4	110	110	110	110
L1L2	67.5	153	126.5	127	127	124
L1L3	67.5	129	126.5	127	127	124
L2L3	136.6	132	126.5	127	127	124
W1W2	59	56	110	110	110	106.5
W1W3	58	56	110	110	110	106.5
W2W3	117	112.2	110	110	110	106.5
A1G	76	70	51	64	63.5	66
A2G	76	74	70	64	~~73.5~~ 63.5	66
A3G	64	62.8	71	64	63.5	66
L1G	~~78.5~~ 20	~~0~~ 78.5	~~68~~ 0	68	68	68
L2G	76.4	82.5	126.5	73	73	71.5
L3G	69	72	126.5	74.5	74	73
W1G	0	25	10	58	58	59.5
W2G	57.5	65	88	64	63	59.5
W3G	56	54.5	88	61.5	61.5	59
A1L1	100.5	5	51	5		

	C-3		C-4	D-1		D-2
	(1)	(2)				
	(a)	(a)	(a)	(a)	(b)	(a)
A1L2	131	138.2	172	120		120
A1L3	110	118	160pl.	120		
A3L1	57.5	117.5	71	114		
A3L2	123	120.7	133			
A3L3	10	10	65	117		
A2L1	65.5	137	70	114		
A2L2	5	10	65	5		
A2L3	129	120.3	132	118		
A1Ng				63.5	63.5	66
A2Ng				63.5	63.5	66
A3Ng				63.5	63.5	66
NgG				0	5	0
A1W1	86	94.5	30			
A1W2	109.6	117	129			
A1W3	91	96.8	128			
A2W1	71	60	81			
A2W2	20	10	30			
A2W3	120.5	111	106			
A3W1	56.5	56.5	83			
A3W2	106	109	109			
A3W3	20	10	30			
L1W2	55		88			
L1W3	61.5		88			

	C-3		C-4
	(1)	(2)	
	(a)	(a)	(a)
L'1L2	160pl.		
L'1L3	138		
L'1G	102		
A1L'1	20		
A2L'1	158		
A3L'1	137		
L'1W2	133		
L'1W3	112		
L'1L1	130		
W'1W2		134	
W'1W3		111.8	
W'1G		77.6	
W'1W1		109.5	

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The subdivisions (b) under C-3 and 4 are similar to corresponding ones under A. D-2 (b) is similar to D-1 (b)

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	D-3		D-4		D-5
	(1)	(2)			
	(a)	(a)	(a)	(b)	(a)
A1A2	183	169	110	110	110
A1A3	134	123	110	110	110
A2A3	132	126.5	110	110	110
A1Ng	96	87.5	64	64	65.5
A2Ng	99	92.5	64	64	65.5
A3Ng	67.5	64	64	64	65.5
L1L2	70	193	126.2	126	
L1L3	79	139.5	126.3	126	
L2L3	150	142	126.5	126	
W1W2	61	60.5	109.8	110	105
W1W3	64	60.5	109.9	110	105
W2W3	125.5	121	110	110	105
A1G	95.5	87.5	64	52.5	67
A2G	99	92.5	63.5	68.5	67
A3G	68	64	64	70	67
NgG	3	0	0	0	0
L1G	38	97			0
L2G	91	103			124
L3G	68	69			124
W1G	10	32	20	20	10
W2G	66	79	88.5	89	87
W3G	59	52.2	87	87	77
A1L1	129	10			

	D-3		D-4		D-5
	(1)	(2)			
	(a)	(a)	(a)	(b)	(a)
A1L2	160pl.	160pl.			
A1L3	121				
A2L1	72	160pl.			
A2L2	5	10			
A2L3	151				
A3L1	65	131			
A3L2	133	136			
A3L3	20	10			
A1W1	107.5	117			
A1W2	141.8	150			
A1W3	97	104			
A2W1	83	565			
A2W2	39	20			
A2W3	143	122			
A3W1		65			
A3W2		118			
L1W3		113			
L'1L1	160pl.				
A1L'1	40				
L'1G	130				
W'1G	92.5				
W'1W2	160pl.				

	D-3		D-4		D-5
	(1)	(2)			
	(a)	(a)	(a)	(b)	(a)
W'1W3		120.5			
W'1W1		131			
W'1A3		129			
W2Ng			88	80	84
W1Ng			20	30	20
L1Ng			0	10	10
L2Ng			126	115	124
L3Ng			126	114	124
L2W1			136	135	138
L1W1			20	20	
L3W1			137	136	
L1W2			88	88	
L2W2			35	40	
L3W2			118	120	
L2W3			115	115	

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The subdivisions (b) under D-3 and D-5 correspond almost exactly to subdivisions (a).

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In the above data N denotes the line neutral; Ng the generator neutral, when connected Y; and G denotes ground.

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