The Regulation of Transformers on Three-Phase Systems.

With Load on One Phase Only.

Thesis Class 1912

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A T H E S I S I N

F O U R P A R T S .

PART I.

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P A R T

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E X P L A N A T I O N .

TRANSFORMERS IN CONNECTION WITH POLYPHASE SYSTEMS.

In considering the selection of a thesis subject my attention was directed by the chapter in "Alternating Current Phenomena" by Dr. Charles P. Stinmetz headed "Transformation of Polyphase Systems". Many of the conditions obtained in unbalanced polyphase systems, while generally taken for granted, are not so backed up by published data as to give to the young engineering student any records upon which the statements given are based.

This, together with the fact that the regular College Course as given must of necessity deal only with fundamentals, with but few digressions into the detail of any specific class of phenomena, caused me to select for my thesis the investigation of; first, polyphase currents in general and second, a few specific instances of loading one phase only of a three phase system.

PRELIMINARY TESTS.

In carrying out the desired tests it was very essential that the transformers used should have like characteristics. Six transformers, all of which were of the same capacity, type, and design, were available. If the impedance volts, voltage regulation, etc. of each transformer were not the same there would be an unbalancing of the load and voltage, due to the characteristics of an individual transformer rather than to external conditions. Because it was necessary to know the characteristics of each transformer so as to guard against all errors that might arise in the transformation of polyphase systems, the losses, exciting current, impedance volts, voltage regulation, and voltage ratios of each transformer were determined.

In determining these constants tests were made on each of the six Westinghouse air cooled transformers, Capacity 3K.V.A., Volts primary 220/110, Volts secondary 254/127, Cycles 50. Each transformer is provided with taps so that a one to one ratio can be obtained with each of the following connections: Y-Y, delta-delta, Y-delta, and T.

The following is an average of each set of readings taken:

Copper Loss and Impedance Test.

Serial No.	Load Current	Watts input	Frequancy Cycles per sec.	Impressed Volts	Resistance Primary	Resistance Secondary
278933	13.7	80	50	6.5	.157	.179
278934	13.7	80	50	6.45	.157	.179
278935	13.7	80	50	6.5	.156	.179
278936	13.7	80	50	6.45	.155	.180
278937	13.7	80	50	6.5	.155	.179
278938	13.7	80	50	6.5	.156	.182

Core Loss and Exciting Current Test.

Serial No.	Exciting Current	Watts input	Frequency	Impressed Volts
278933	.458	15.4	50	110.5
278934	.465	15.6	50.5	110.5
278935	.666	15.3	50.5	109.7
278936	.468	15.4	50.5	110.5
278937	.462	15.4	50	109.5
278938	.49	16.1	50	111

Ratio Test and Regulation.

Serial No.	Volts Primary	Volts Secondary	Percent Regulation Calculated.
278933	110	110	1.83
278934	110	110	1.83
278935	110	110	1.82
278936	110	110	1.82
278937	110	110	1.83
278938	110	110	1.84

The percentage regulation of each transformer was calculated by the formula;

% Regulation $= p + \frac{q^2}{200}$ in which p = current times resistance and q = current times the reactance in ohms, each expressed in percent of rated volts.

The characteristics of each transformer, as shown by the results of the tests given above, are very near constant which shows that the transformers are ideal for studying the transformation between polyphase systems. The greatest variation in the percent regulation between any two transformers is 0.02 of one percent. This is well within the limits for accuracy of any test consequently it will not be necessary to make any corrections, whatever, for differences of transformer characteristics.

In determining the copper loss and the impedance, the primary winding of the transformer was connected to an alternator, the secondary winding being short-circuited upon itself, as shown on data sheet. The speed of the alternator was adjusted to give the rated frequency of the transformer. The voltage of the alternator was regulated until full load current (13.7 amperes) flowed through the winding of the transformer.

The current and frequency were kept constant and the following readings taken; watts input, impressed volts, frequency and load current. The resistance of each the primary and secondary winding of the transformers were measured by connecting the leads directly to the binding posts of a dial testing set and the resistance read directly from the dials.

In determining the core losses and the exciting current the primary winding of the transformer was connected to an alternator, the secondary winding being left open. The frequency and voltage of the alternator were adjusted to the rated value of the transformer. The frequency and voltage were kept constant and the following readings taken; exciting current, watts input, frequency, and impressed volts.

The voltage ratio of each transformer was determined by connecting the primary winding to an alternator, of the transformer rated voltage and frequency, and measuring the impressed E.M.F. and the E.M.F. of the secondary winding of the transformer. The primary and secondary voltages were both measured with the same ammeter so as to eliminate the error which might occur if two volt-meters were used.

Problem No. 1.

The purpose of this problem is to determine the unbalancing of the voltage when transforming one three-phase system to another three-phase system when only one phase is loaded, the transformation being by means of static transformers delta-delta connected.

For the study of this problem three transformers were connected as shown on page 1 part 2. The primary and secondary windings were connected so as to give a one to one ratio of transformation. The power was taken from the city distributing system which has an E. M.F. of 2200 volts and is stepped down to 110 volts by transformers connected delta-delta. The load was non-inductive and was by means of a water rheostat. A dynamometer board was connected so that one ammeter could be used to measure the current in each leg of the primary side. All voltages were measured by one voltmeter. This was done so as to eliminate errors that might arrise from using different voltmeters to measure the voltage on the primary and secondary sides of the transformers. A glance at the data sheet, page 1, part 3 will show that the load current divides, one third flowing through transformers B & C and two thirds flowing through transformer A. This takes place becaurs there are two possible paths in which the current may flow (see fig B page 1 part 2).

In one path there are two transformers in series (B & C) and in the other path there is one transformer (A). The path $\overline{BC}$ has twice the reactance as has the path A consequently only one half as much current will flow in $\overline{BC}$ as will flow in A.

The current in each transfermer will be in phase with the load current except for a small current flowing around the delta, due to the tendency of the load to shift the neutral. The perliminary tests show that the transformers have a regulation of 1.82%. The curves on plate C show that the regulation of transformer A in this case is 3.2%. This could not be true if the load current were in phase with the E.M.F. of the transformer. Because of this fact the current in transformer A must lag behind the E.M.F.

Figure B shows that the E.M.F. of transformer B leads the E.M.F. of transformer A by 120 degrees. Therefore the current in B is more that 120 degrees behind the E.M.F. This will cause a drop in voltage of the transformer due to a lagging current flowing through an inductive coil. The E.M.F. of transformer A leads the E.M.F. of transformer C by 120 degrees therefore the current flowing in C will be less than 120 degrees ahead of the E. M.F. of that transformer. This will cause a rise in the voltage of transformer C due to a leading current flowing through an inductive coil.

The curves on plate B show that the voltage across transformer C rises as the load is applied, and that the voltage across transformers B & A falls as the load is applied, but much more rapidly than the regulation of the transformers for a non-inductive load.

The curves on plate A show that transformer A takes approximately two thirds of the load and that transformers B & C take approximately one third of the load. The curves for transformers B & C do not coincide because of the difference in voltages.

The curves on plate C were made from the curves on plates A & B. These curves show that transformer B has a much greater drop in voltage than has the loaded phase for the same K.V.A. of the transformer; but one must not infer that the drop in B will be greater than that in A for a given applied load. The curves on plate B show that the loaded phase has the greatest drop in voltage at any load. "In the delta-delta connection of transformers between three phase systems each phase is transformed by a separate transformer. Therefore the voltage of the system remains balanced even at unbalanced load, within the limits of voltage variation due to the internal self-inductive impendance (or short circuit impendance of the transformers)". Even though a non-inductive load be applied to one phase the power-

Factor in no phase will be unity. The voltage regulation of each phase will be the same as that of each transformer which will depend upon the internal self-inductive impendance of the transformer and the power-factor in that transformer.

When only one phase of the three-phasesis loaded one transformer takes approximately two-thirds of the load and each of the other transformers takes one-third of the load. This will not be the case if the short-circuit impendance of the transformers are not the same. Because of this fact when loading only one phase of the three-phase system it is not necessary to have three transformers of the same size, but unless special reactive coils are in the unloaded transformers it will be necessary that the smaller transformers be large enough to take one-third of the applied load.

If special means were provided to keep the current from flowing in transformers B & C the power-factor in A would be nearer unity and the regulation of each of the three phases would be better than in this case.

The regulation of a three-phase system when only one phase is loaded is not so good as is a single-phase transformation.

PROBLEM NO. 2.

The purpose of this problem is to determine the voltage regulation of transforming one three-phase system to another three-phase system, when the transformers are Y - Y connected and only one phase is loaded.

In this problem three transformers were connected as shown on page 8, part II. The power was taken from the city lines as in Problem No. 1. No ammeters were used on the primary side of the transformers because there is no closed circuit as in the case of a delta connection, consequently the current in each leg of the primary will be equal to the current in the corresponding leg of the secondary. A variable non-inductive load was applied and the voltages on the primary and secondary side of the transformers were measured in the same manner as in Problem No. 1.

The curve on plate A, Page 6, Part II, shows the relation of the load current to the K. V. A. of the loaded phase.

The curves on Plate B show the relation between the load current and the voltage transformation between each of the three phases, and from the neutral to each line.

From the curves showing the voltage transformation from the neutral to each line the regulation of each transformer may be obtained. The transformer from neutral to line No. 1 has a regulation of 100%. This is because no current is allowed to flow in the secondary winding, and this makes it impossible for any current other than the exciting current to flow in the primary winding. The transformer from neutral to line No. 2 has a much greater drop in voltage than the transformer between the neutral and line No. 3. This is due to the fact that the current in each transformer is in phase with the load current and that the E. M. F. of the transformer from 1 - N is approximately 120 degrees out from the E. M. F. of the transformer from 2 - N. Then the power-factor in transformer 1-N will be different from the power-factor in transformer 2-N. From the regulation of the transformers (preliminary test) and their regulation in this case it is evident that the current leads the E. M. F. in transformer 3-N and lags behind the E. M. F. in transformer 2-N.

The regulation of phase 2-3 is better than the regulation from 2-N and is not so good as the regulation from 3-N; but the combined regulation of 3-N and 2-N is much better than the regulation of the phase 2-3, therefore, the neutral has shifted and the angle between 3-N and 2-N is no longer 120 degrees but is something less than that amount.

The curves on plate C show the relation between the load K. V. A. and the regulation between the phases. These curves were plotted from the curves on plates A and B. At full load phase 1-3 has an increase in voltage of 1.5%. The corresponding phase, problem No. 1 (delta-delta connections) has an increase of 0.9%. Phase 1-2 has a drop of 4.1%. The corresponding phase in problem No. 1 has a drop of 2.7%. Phase 2-3 has a drop of 5.1%. The corresponding phase in problem No. 1 has a drop of 4.5%. From this the delta-delta connection is shown to be much better.

In the Y-Y connection we have what is termed the floating neutral and if another test was to be conducted with the same transformers but under different conditions there is no doubt that different results would be obtained.. In this problem, altho the same current flows in transformer A as flows in transformer B, the work done by each transformer is not the same. This is due to the shifting of the neutral which causes a a higher voltage across transformer B than across transformer A. The K. V. A. of transformer B is then greater than the K. V. A. of transformer A and may result in over-heating the transformer, especially if the neutral should shift more than it did in this case.

PROBLEM NO. 3.

The purpose of this problem is to repeat problem No. 2, but using a different source of power.

The tests for this problem were conducted in the same manner as in Problem No. 2. The source of power was a 7.5 K. W. alternator, in which harmonics are known to exist.

The curve on plate A, page 9, part II, shows the relation between the load current and the K. V. A. of the loaded phase.

The curves on Plate B show the relation between the load current and voltage regulation of each of the transformers and between each of the phases. In this problem, because of the harmonics and the size of the system no smooth curves could be obtained, as in Problem No. 2. The loop in curve 1-N, plate B, is caused by the neutral shifting as the load is applied and then, to a limited extent, returning to its natural position as the load is further increased. A glance at the data sheet will show that at a load of 25 ampers the voltage of transformer B (3-N) is more than twice that of transformer A (1-N). This shows that the K. V. A. load on transformer B is more than twice that on transformer A. At this point there is no danger of over heating transformer B because the load is less than the rated K. V. A. load of the transformer; but at 33 amperes the transformer is likely to heat because it has an overload of approximately 30%.

In this problem the neutral was very unstable and was constantly shifting. This, to a limited extent, is due to the current causing a shifting of the field in the alternator which in turn reflects back upon the transformers.

The curves on plate D show very plainly the regulation of transformation between the three phases. The voltage in one of the idle phases rises nearly one per cent and then, instead of going higher as was the case in problem No. 2, it returns to normal again. The voltage drop in this problem is much greater than that in problem No. 2; but here the alternator was not capable of maintaining a voltage as nearly constant as in problem No. 2.

This test shows that the regulation of transformers connected Y-Y depends largely upon the source of power and that the shifting of the neutral depends upon external conditions as well as upon the applied load.

PROBLEM NO. 4.

The purpose of this problem is to load one phase of a three phase system, when the transformers are connected Y-delta, and determine the unbalancing of the voltage.

The curves on plate B, page 15, part II, show the relation between the applied load and the voltage from the neutral to the line. These curves show that there is a shifting of the neutral and that excess voltages are likely to occur, altho there is a delta connection on the secondary side it does not have a great tendency to keep the neutral from floating in space. This is because the voltage in the delta depends almost entirely upon the voltage impressed upon the primary of each transformer (volts from neutral to line). If the neutral on the primary side ten ds to shift, the neutral in the delta shifts accordingly and without offering any great amount of resistance, because the circulating current in the delta will be much less when on the secondary side than when on the primary side. The tendency for the delta to hold the neutral from shifting will then be less in the case of a Y-delta connection than in the case of a delta - Y connection.

The curves on plate C show that the load current divides in the delta, one third flowing through transformers B and C and two thirds flowing through transformers A. In this case the current does not divide according to the reactances of the transformers; but it divides in this way because the primary current of the loaded phase must return over the other two transformers. Because of the high reactances of the unloaded transformers we have nearly 20% drop in voltage on two of the phases and nearly 35% rise in voltage on the other phase. (See curves plate A.)

PROBLEM NO. 5.

The purpose of this problem is to repeat problem No. 4 using the city mains as a source of power rather than the 7.5 K. W. alternator.

The connections for this problem were the same as the connections for the problems No. 4.

The curves on plate A, page 18, part II, show the relation between the load and the voltage regulation of each of the three phases. In this case there is only a 6% rise in the voltage of the idle phase (1-2). In problem No. 4 the corresponding phase has a rise of approximately 30%. This can be accounted for by the fact that the city system is larger than the 7.5 K. W. alternator consequently it will not be affected to such a great extent. The curves on plate B show that the neutral has not shifted so far in this problem as it did in problem No. 4.

In comparing the curves on plate B, problem No. 5 with the curves on plate B, problem No. 4 it is interesting to note that there has not been enough shifting of the neutral to cause a rise in the voltage from neutral to line. This, however, was the case in problem No. 4 and was the cause of the great rise in secondary volts.

The curves on plate C show the ratio of the load current to the current in each of the primary legs and the current in each path of the delta or secondary. The load current divides in the same proportions as it did in problem No. 2, but the total current in the delta is much greater. This is due to the fact that the reactance of the transformers, from which the power was taken, is much less than the reactance of the alternator which was used in problem No. 2. This will allow circulating currents to flow through the transformers under test and the transformers from which the power is taken, i. e. There will be an exchange of currents between the two banks of transformers. Curve I, shows that the current in the loaded phase of the primary side is nearly 30% greater than the load current of the secondary side. This would not be allowable in practice for there would be heating in transformer C.

The shifting of the neutral in a Y-delta connection depends to a very great extent upon the source of power and the size of the system from which the power is taken. There will be no serious trouble from a Y-delta connection if the transformers are connected to such a large system as to have no effect upon the whole system. In problem No. 4 the system was small as compared to the amount of power taken off and the unbalanced load affected the whole system. The delta was not capable of maintaining the balance for the whole system and as a result there was a great rise in voltage on one of the loaded phases.

These tests show that if a small bank of transformers are to be attached to a large distributing system or to any other source of power with a large capacity there will be no serious unbalancing with the transformers Y-delta connected with only one phase loaded.

P roblem N o. 6.

The purpose of this problem is to determine the voltage regulation of a three phase system when the transformers are delta-Y connected and only one phase is loaded.

The connections were made as shown on page 23, part 2, a non-inductive load was applied to one phase and readings taken in the same manner as in the previous problems.

The curves on plate A , page 21, part 2, show the relation of the load to the voltage regulation between the three phases. This is the first problem in which there has been no rise in either of the idle phases. The phase 1-2 has 100% ratio of transformation. This is because there is no closed circuit on the secondary leg of transformer B. It is therefore impossible for a leading current to flow in transformer B and raise the voltage as has been the case in the previous problems. The drop in phase 2-3 is greater than the drop in the transformers. This is due to the shifting of the neutral, but the shifting of the neutral in this case is of a definate amount and corresponds to the voltage drop in the transformers A and C .

The curves on plate B show that there is a shifting of the neutral but only to a limited extent. The change in voltage from the neutral to lines 2 and 3 is due to the impedance of the transformers, although the neutral changes its location with respect to the three corners of the triangle one cannot say it floats as in the Y delta connection. In this problem the delta is on the governing side of the transformers and it regulates the amount of shift according to the load.

When transforming unbalanced three-phased systems with a delta Y connection there will be no phase in which the voltage will rise. The drop in the other two phases will have a definite amount and will depend principally upon the characterestics of the transformers and the power-factor within each transformer.

PROBLEM NO. 7.

The purpose of this problem is to repeat problem no. 3; but instead of using a delta connected source of power a Y connection was used, the neutrals of the Y's being connected.

The connections for this problem were made in a similar manner to the connections in problem no. 3. Instead of loading phase 1-3, phase 1-2 was loaded. The original source of power was a 7.5 K.W. alternator ~~delta~~ Y connected which delivered energy to a bank of transformery delta Y connected which in turn delivered energy to the bank of transformers under test.

The curves on plate A show that the ratio of transformation at no load was not 100%. The transformers are the ones used in the previous tests and have a one to one ratio (as shown in preliminary test) The curve representing the amperes in the neutral, for different percentage of full load K.V.A., shows that 15 amperes is flowing at no-load. This gives a leading current in phase 1-3 and a lagging current in phase 1-2. As a result the voltage across phase 1-3 is raised 2% and the voltage across phase 1-2 is lowered 2%. As the load is applied the flow of current in the neutral becomes less until a minimum of 4 amperes is reached at a load of 63%. As the load is increased beyond this point the current in the neutral increases and finally reaches 11 amperes. This flow of current will heat the transformers and is likely to cause great damage.

The curves on plate B show that there has been a shifting of the neutral in the alternator. Curve 1-3 shows that as the load was applied the voltage across that phase decreased and then increased again. This curve corresponds very closely to the current curve on plate A.

The above problem was repeated but instead of using the 7.5 K.W. delta connected alternator as a source of power a 7.5 K.W. rotary converter was driven by a motor and used as a generator. The connections between the transformers were identical with those of the above problem. The current flowing in the neutral at no load was only 4.5 amperes. At full load the current in the neutral was 0.6 amperes. The ratio of transformation, for phase 1-2 was 89% ; for phase 1-3 was 92.5% .

The above figures show that regulation of transformers, connected in this manner, depends entirely upon the characteristics of the alternator that is used as a source of power.

PROBLEM NO. 8.

The purpose of this problem is to repent problem no. 7; but with no fixed neutrals.

The curves on plate B. show that the inpressed volts vary almost exactly as in problem no. 7.

The curves on plate A show that transformer regulation, or regulation between the phases varies nearly as in problem no. 7.

When only one phase is loaded it makes very little difference, with the voltage transformation between the phases, whether the neutrals are connected, or whether they are left free.

PROBLEM NO. 9.

For this problem the power was taken from the city lines, as in problem no. 1, and then transformed through a bank of transformers (of the same type and design as the transformers under test) connected delta-Y. The transformers under test were connected Y-delta. The neutrals of the Y's were connected.

The connections for the transformers tested were the same as in no. 4.

The curves on plate A show that there is a rise in voltage of over 19% on one of the unloaded phases, and a drop of over 11 volts on the other unloaded phase which is nearly equal to the voltage drop of the loaded phase.

PROBLEM NO. 10.

This problem is the same as problem no. 9 except that the neutrals of the Y's are not connected and are left free to move.

The curves on plate A show that the voltage regulation is not very different from the voltage regulation for problem no. 9. The voltage in one of the idle phases goes a little higher than in problem no. 9, the drop in the other two phases being slightly greater.

The data sheet shows that the volts from neutral to each line is nearly the same in this problem as they were in problem no.9. Therefore it is not necessary to connect the neutrals of Y connections when loading only one phase.

PROBLEM NO. 11.

This problem was carried out to determine the external characteristic curves of the 7.5 K.W. alternator used in problems no. 3,4,7,and 8.

First: The alternator was connected Y and one phase loaded.

The curves on plate A show the regulation between the load-current and the volts across each line. Note the rise in volts at the end of curves 2-3 and 3-N. This rise in volts was nore pronounced in problem no. 3 than in this case; but that is due to the fact that the field current was increased in no. 3 and held constant during this test.

Second: The alternator was connected delta and one phase loaded.

It is interesting to note that the volts across phase 3 first rose slightly and then dropped. This drop is due to the large circulatiig current flowing in the delta. This current is registered on the data sheet under the heading (I_1) The current under the heading (I) represent the load current.

S U M A R Y.

The above tests show that the voltage transformation between two three-phase systems at no load may not be the same under different conditions, that is with different sourses of power. In some cases the voltage of each phase of the three-phase system was transformed according to the ratio of the transformers. In one case there was a slight drop across one phase and a corresponding rise across the other two phases. In one case there was a drop across two phases and an increase across the other phase. In one test, which is not recorded in this thesis, a condition was obtained in which the volts across each on the three phases showed a rise of 1.5%. No case was found in which a drop across all phases could be obtained; but in one problem there was a drop in two phases and no increase in the other phase.

For loading only one phase of a three-phase system the delta-delta connection gives the best results. The Y-Y connections with and without fixed neutrals show approximately the same results. The Y-delta connection both with and without fixed neutrals gives a very great rise in one of the loaded phases and a very great drop in the other two phases. The delta-Y connection stands in second place and gives nearly as good results as the delta-delta.

With but one exception (the delta-Y connection) if a Y connection is used, whether it be in a Y-Y, Y-delta, or a single Y connection such as an alternator, the neutral of the Y should be fixed, or on phase may take nearly all the load and heating will be the result.

P A R T

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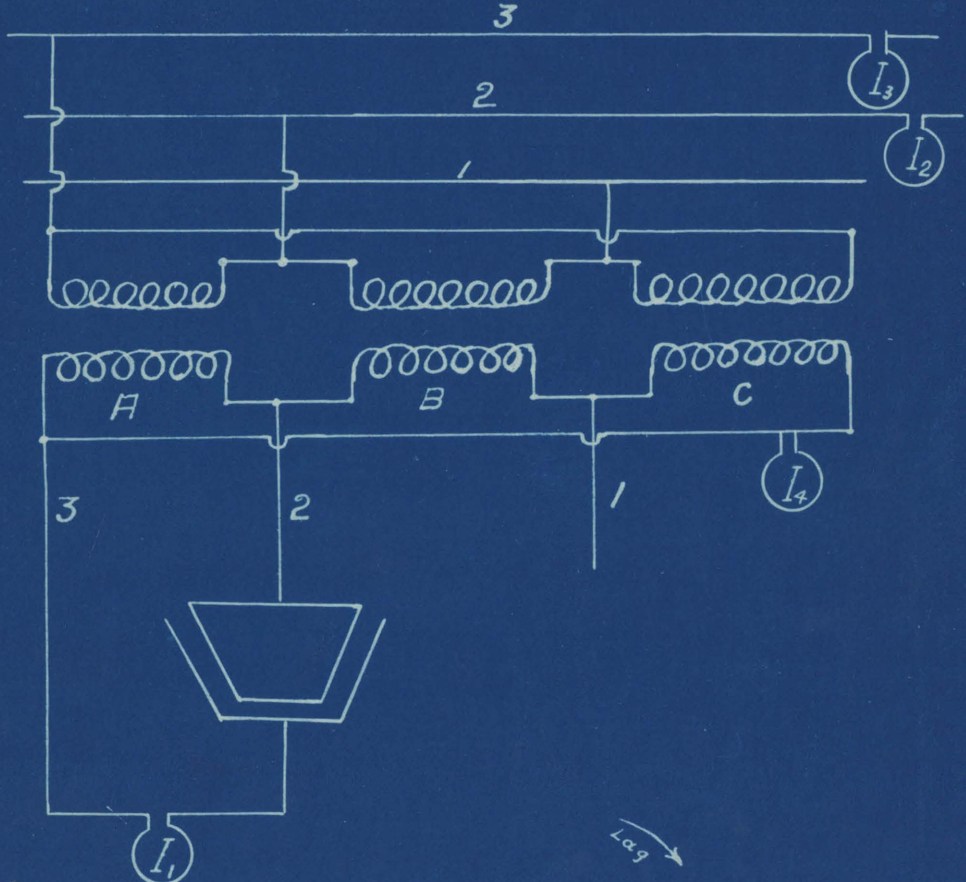
C U R V E S .

Transformer Connections

Fig. A.



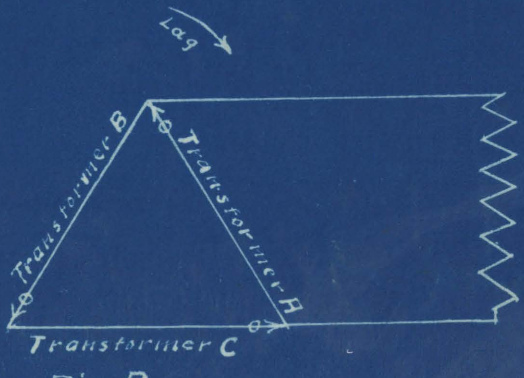
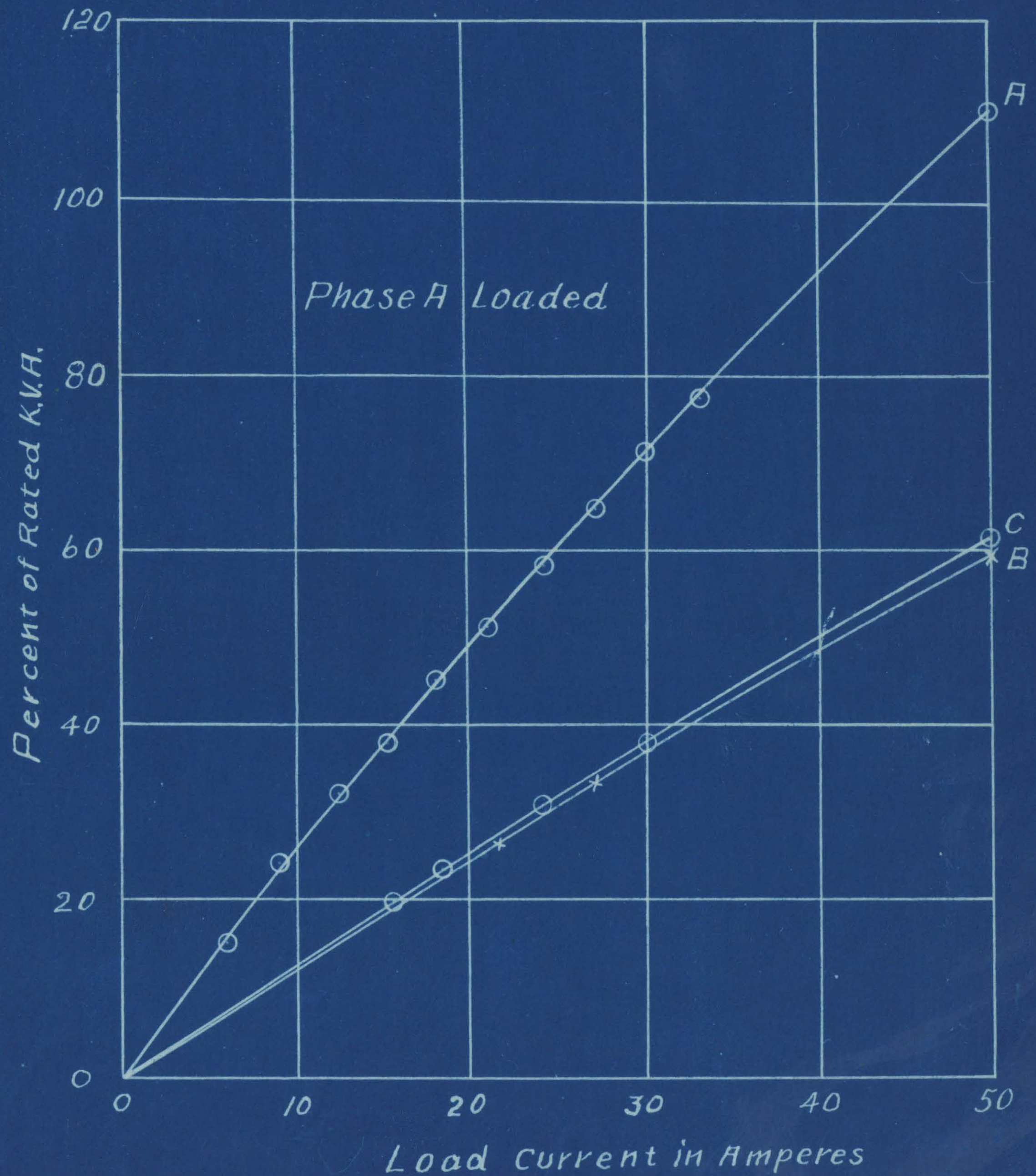


Fig. B.

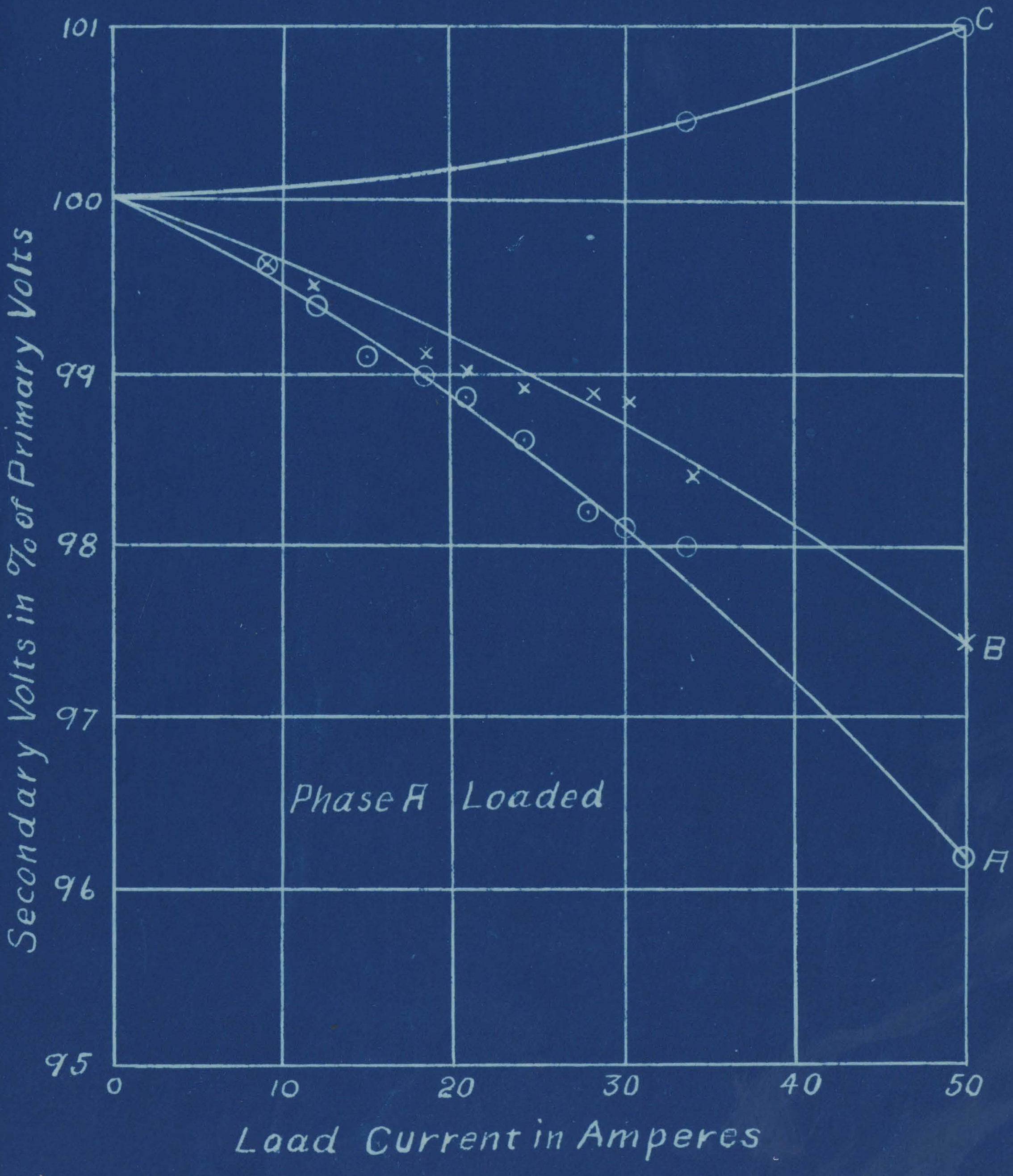
Problem No 1.
Plate A.

Current-Load Curves for
Transformers A, B and C.



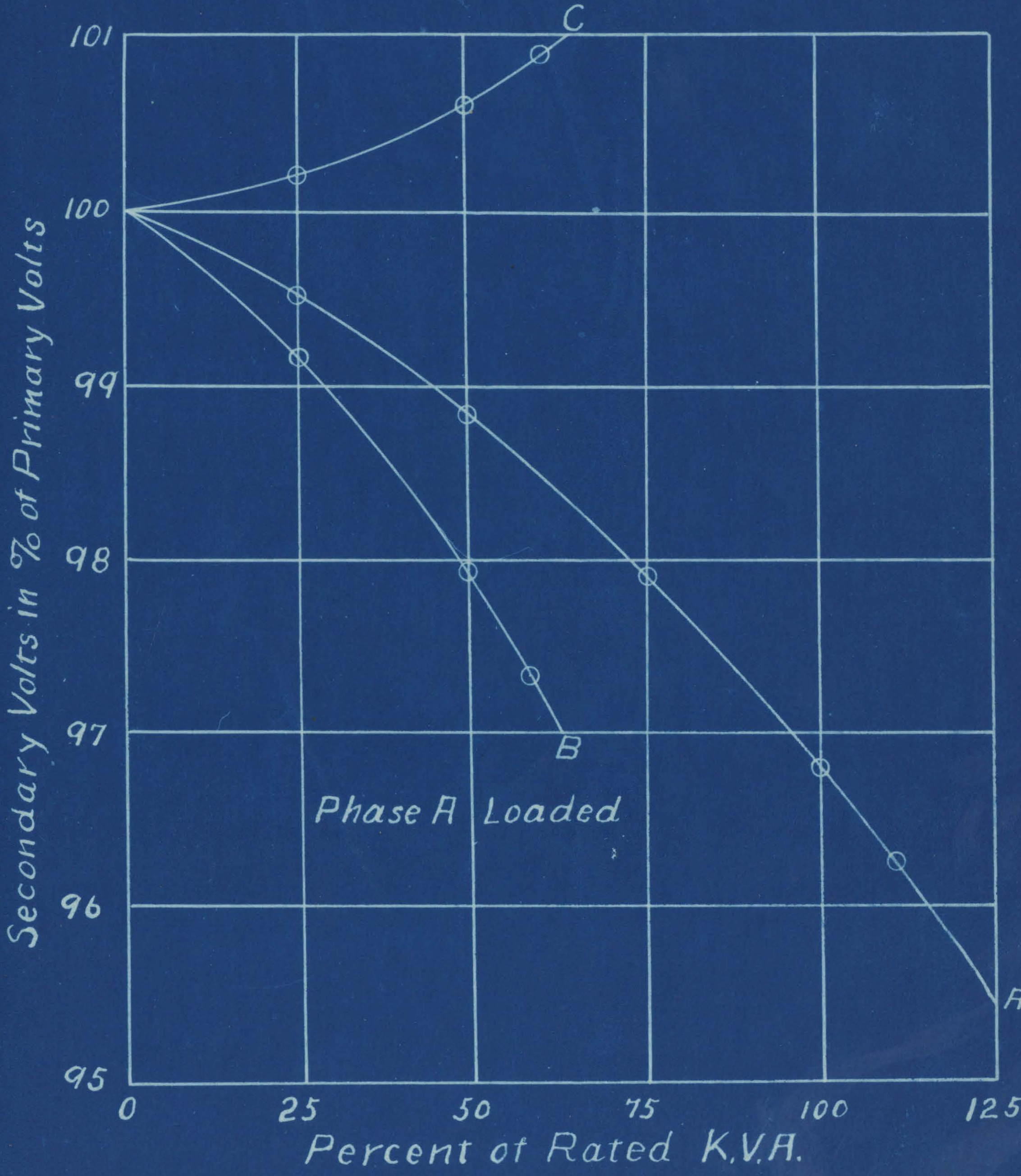
Problem No.1
Plate B.

Current-Volt Curves for Transformers A, B and C.

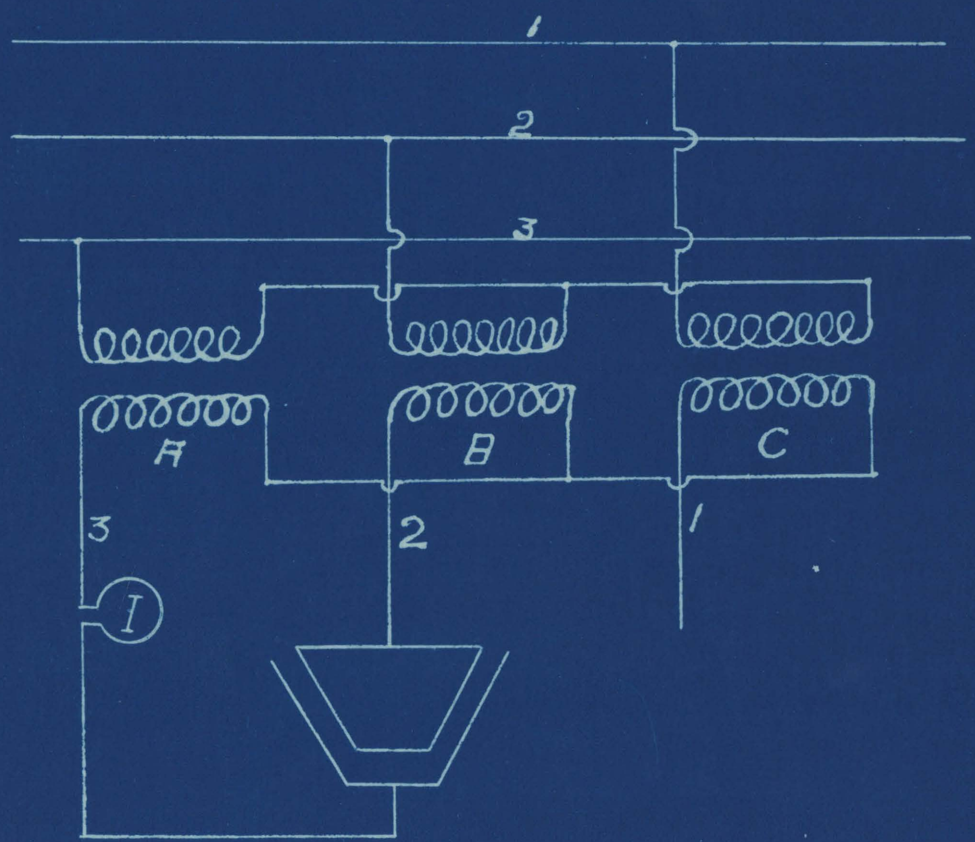


Problem No. 1
Plate C.

Regulation Curves for Transformers A, B and C.

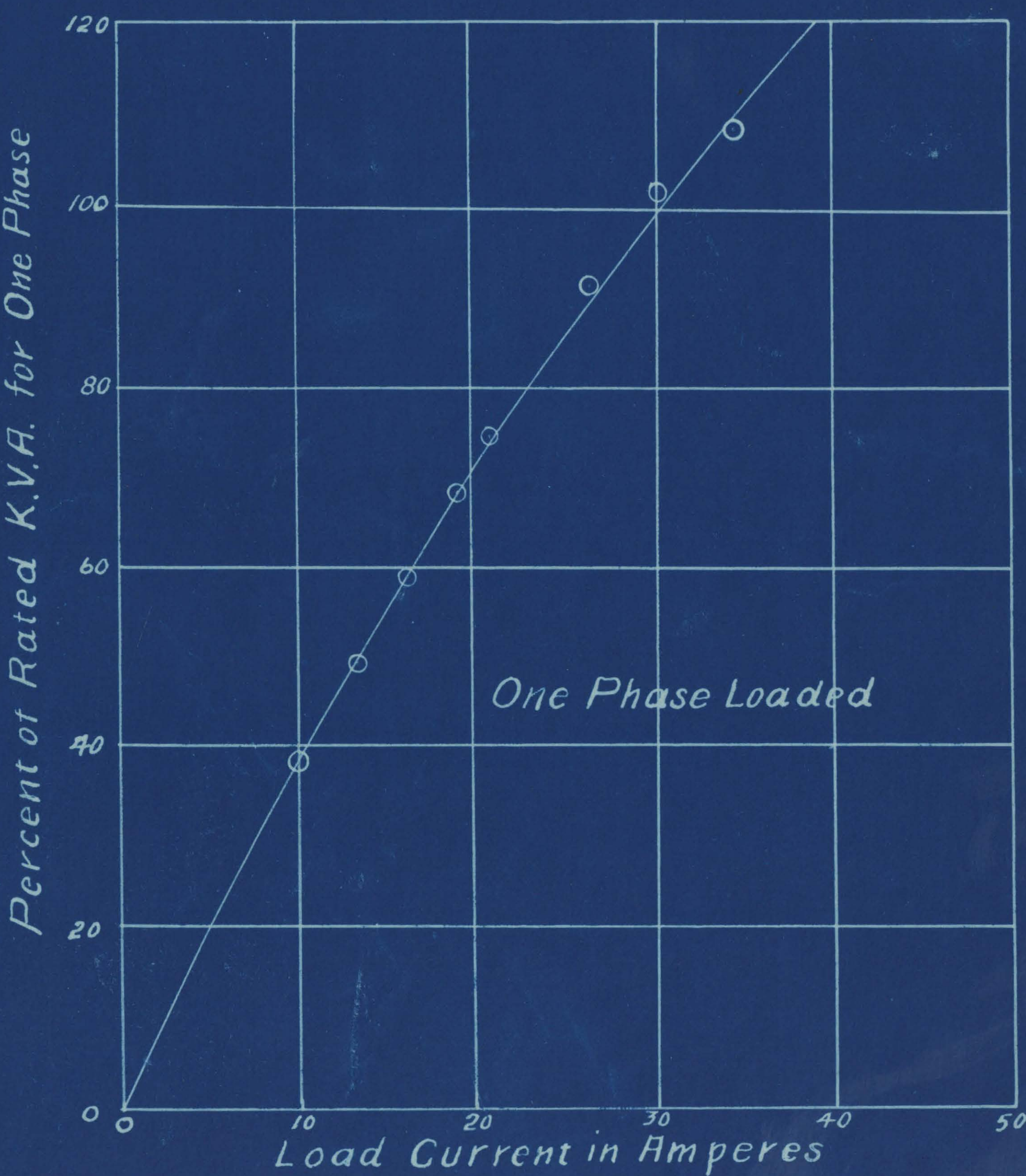


Transformer Connections



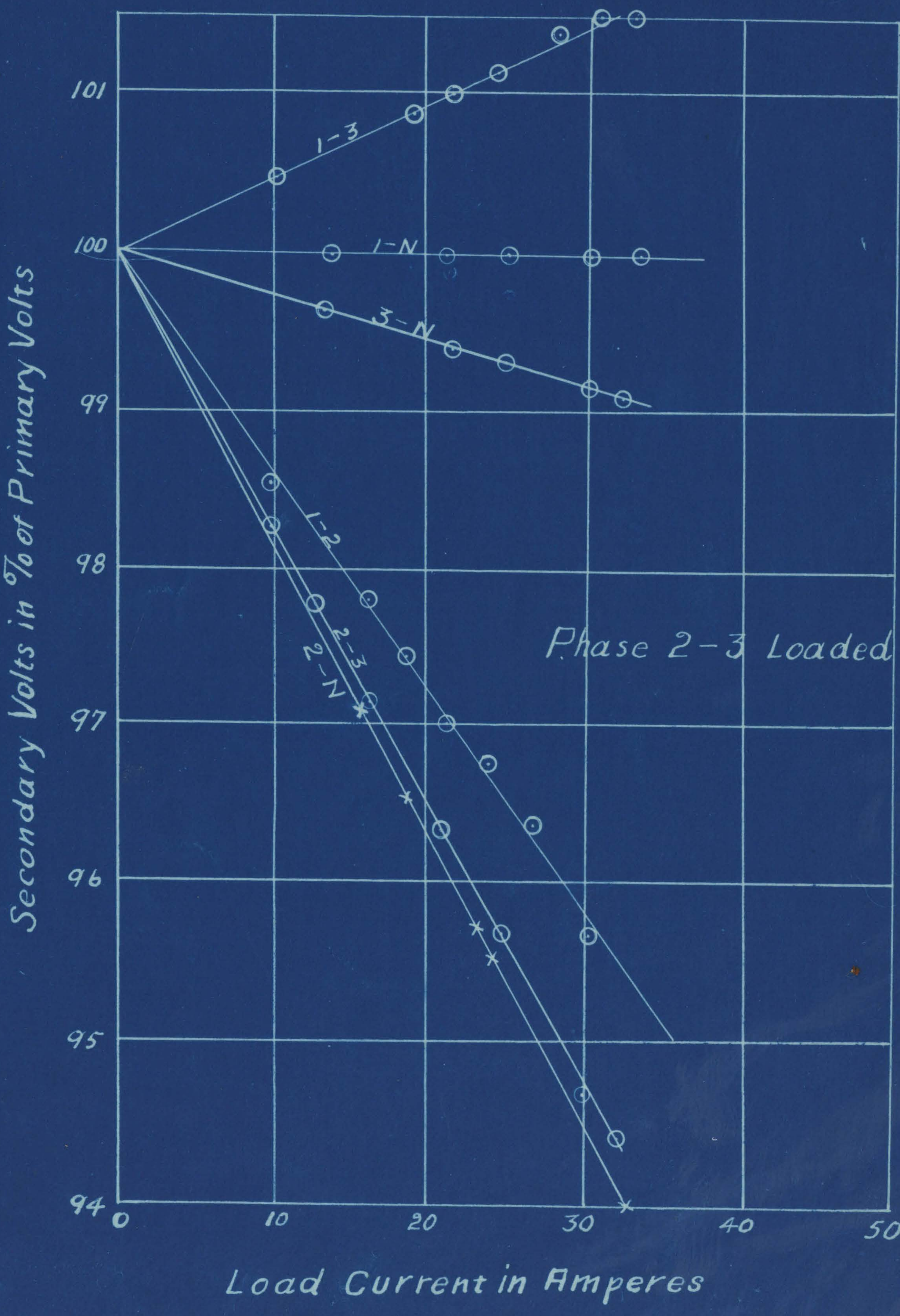
Problem No.2
Plate A

Current-K.V.A. Curves for Transformers A, B and C.

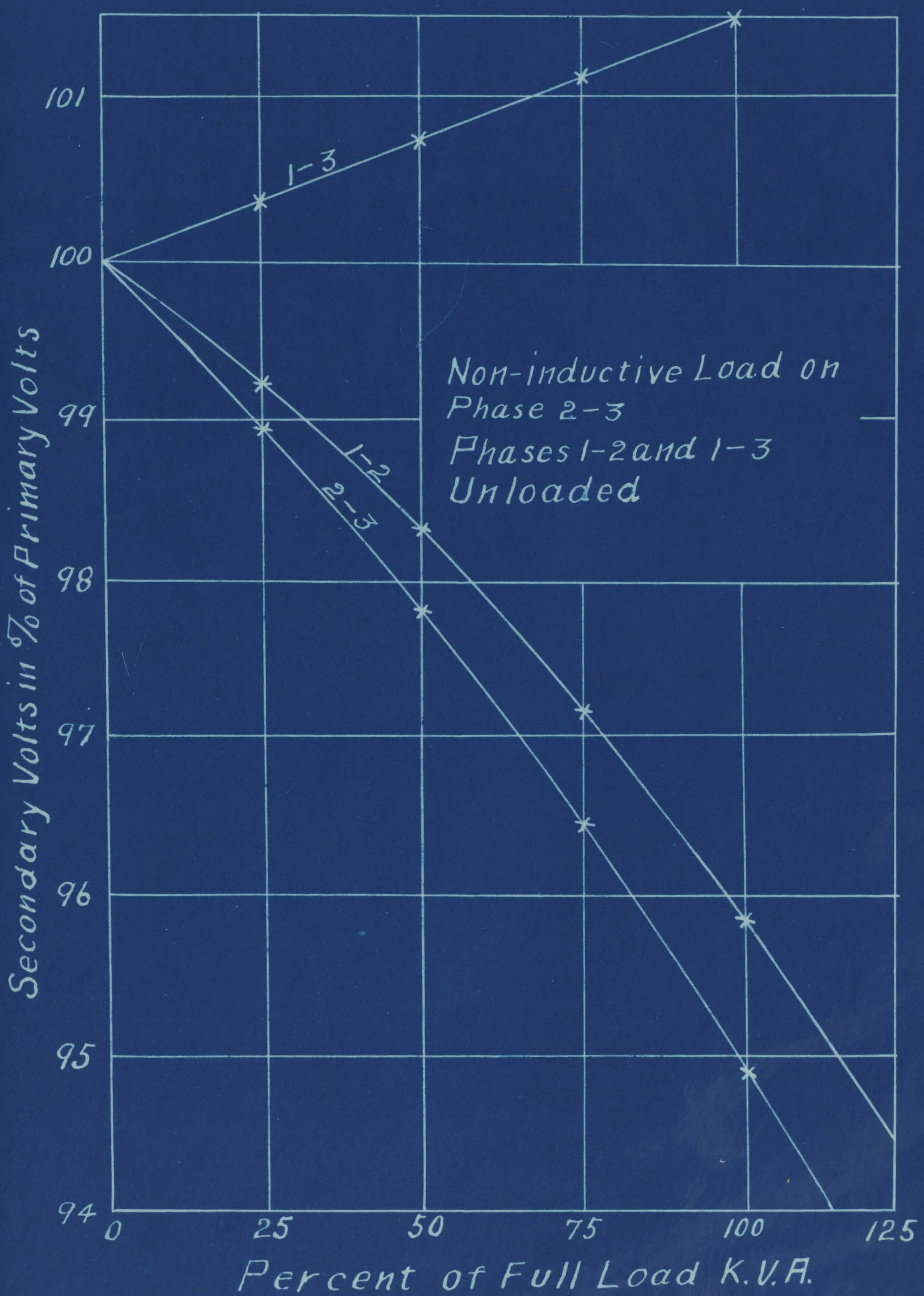


Problem No. 2
Plate B.

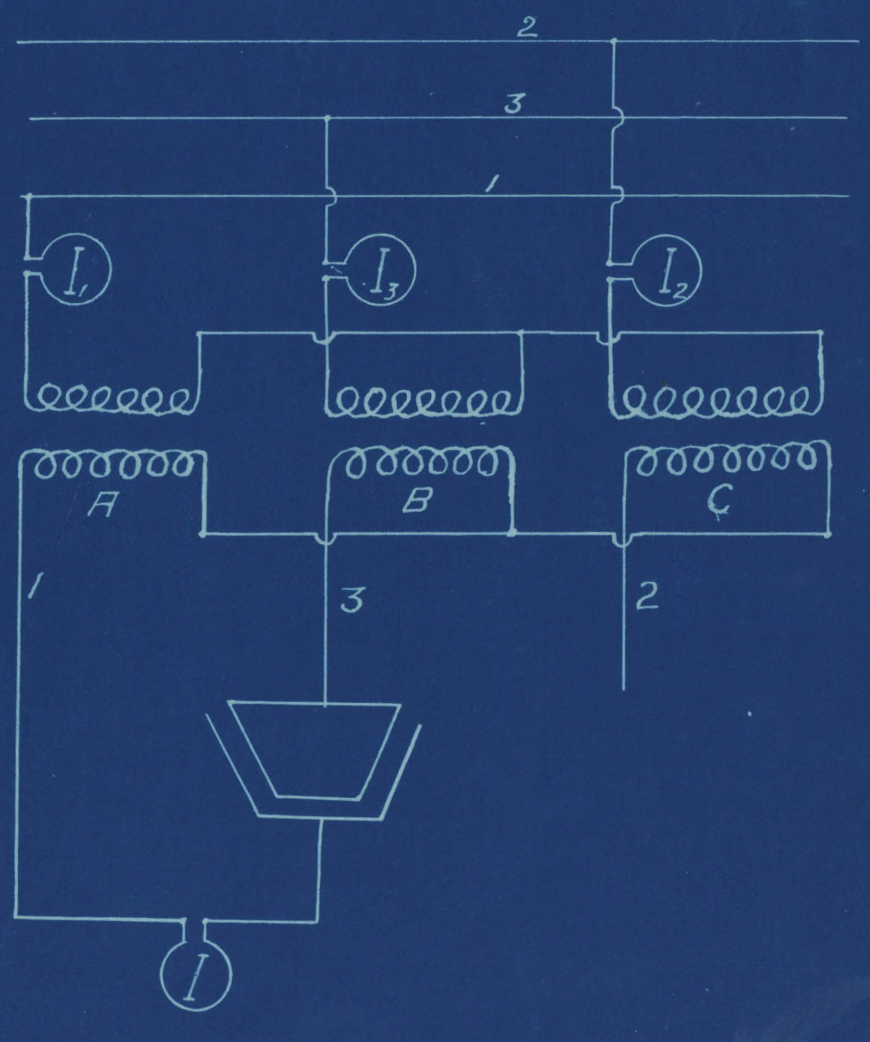
Current-Regulation Curves for Transformers A, B and C.



Regulation Curves for
Phases 1-2, 2-3 and 1-3.

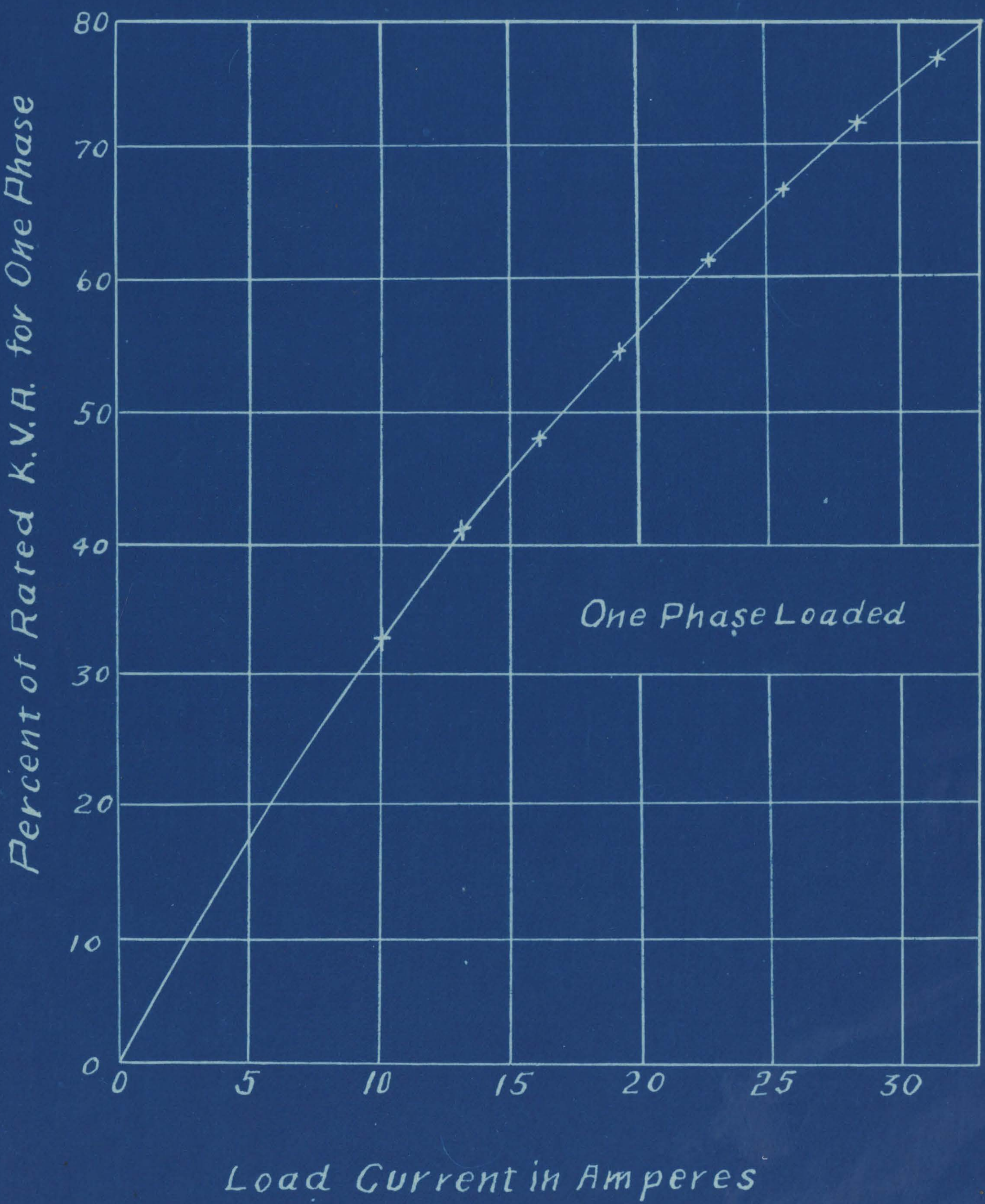


Transformer Connections

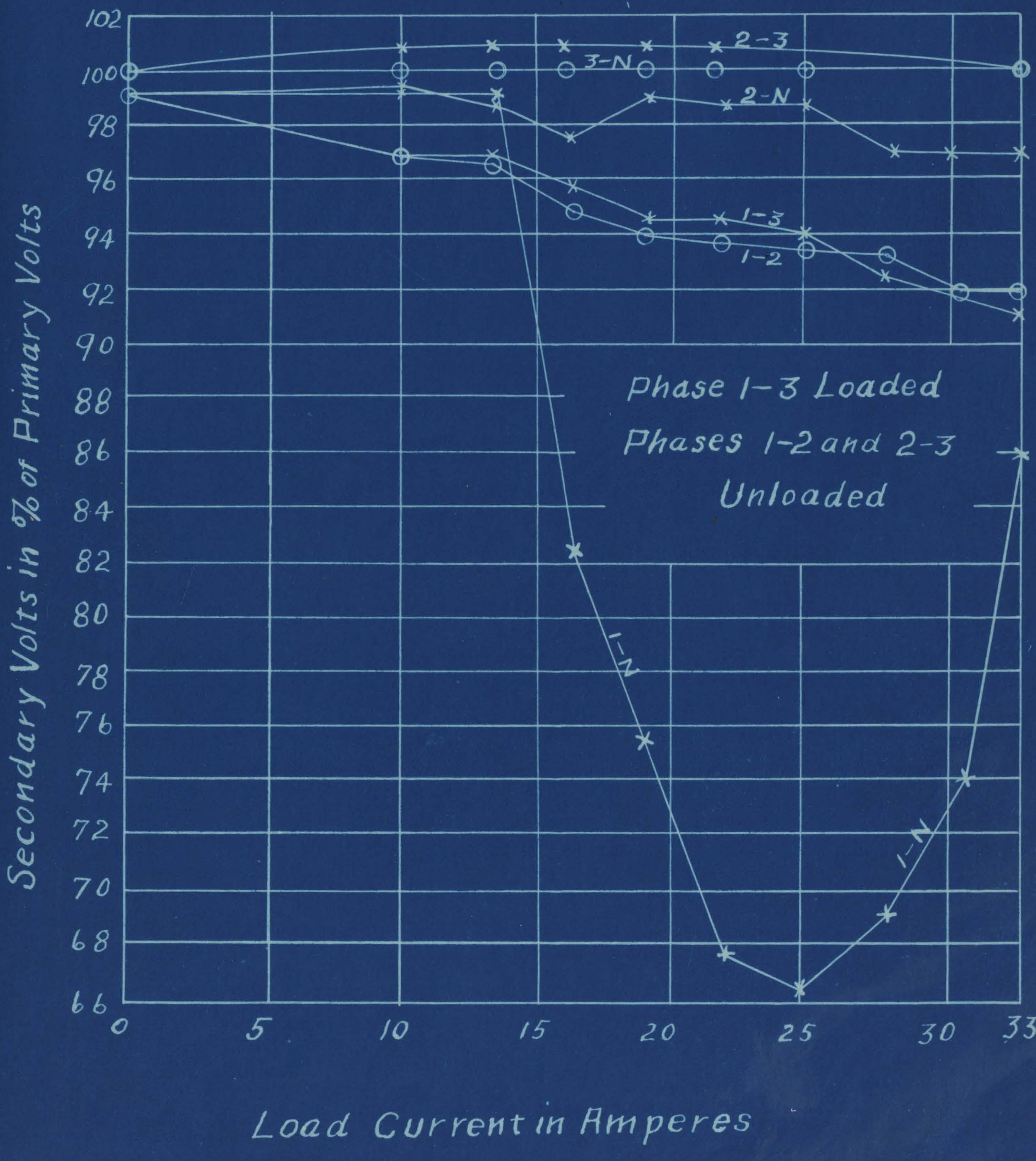


Problem No. 3
Plate A.

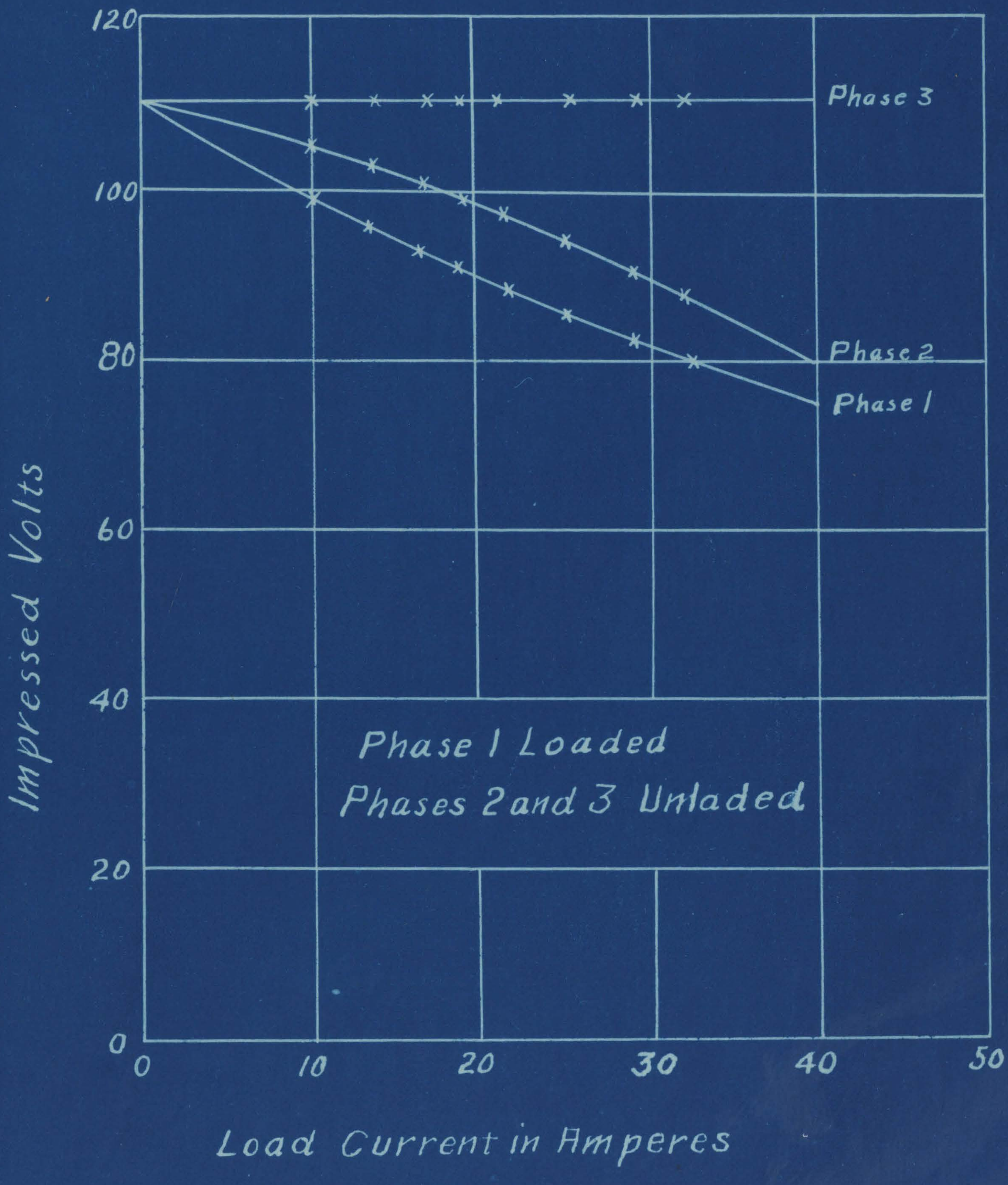
K.V.A.–Load Curve



Current-Volt Curves for Transformers A, B and C.

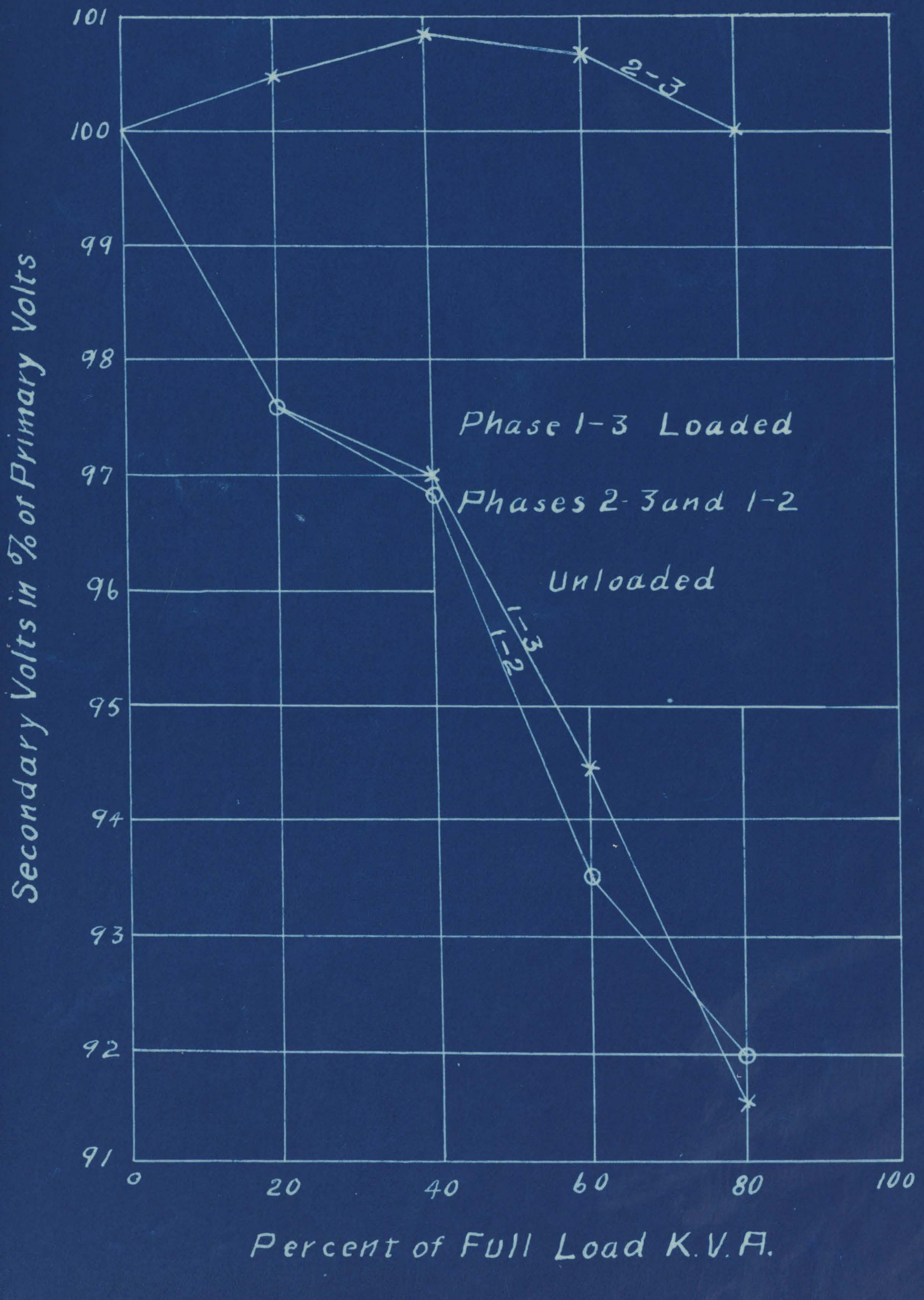


Ampere-Impressed Volt Curves

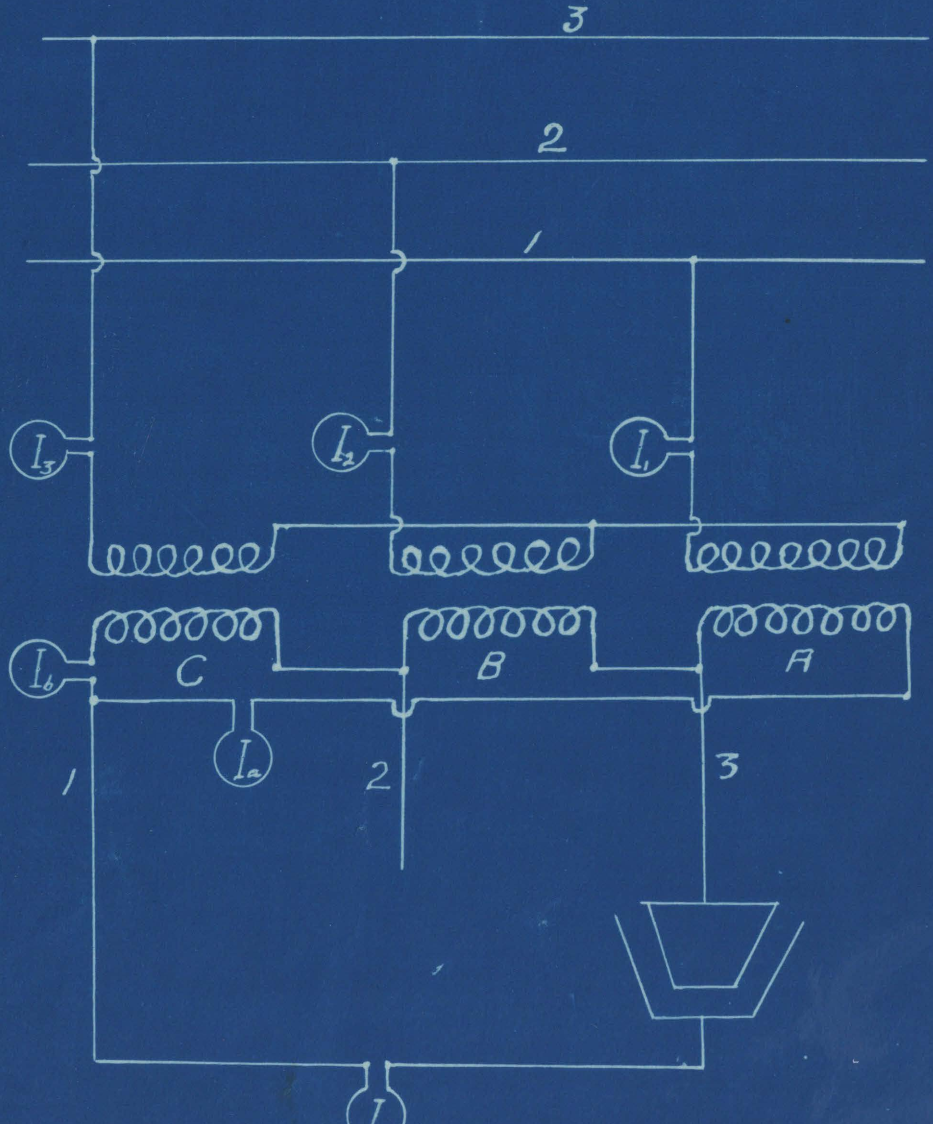


Problem No. 3
Plate D.

Regulation Curves for Transformers A, B and C.

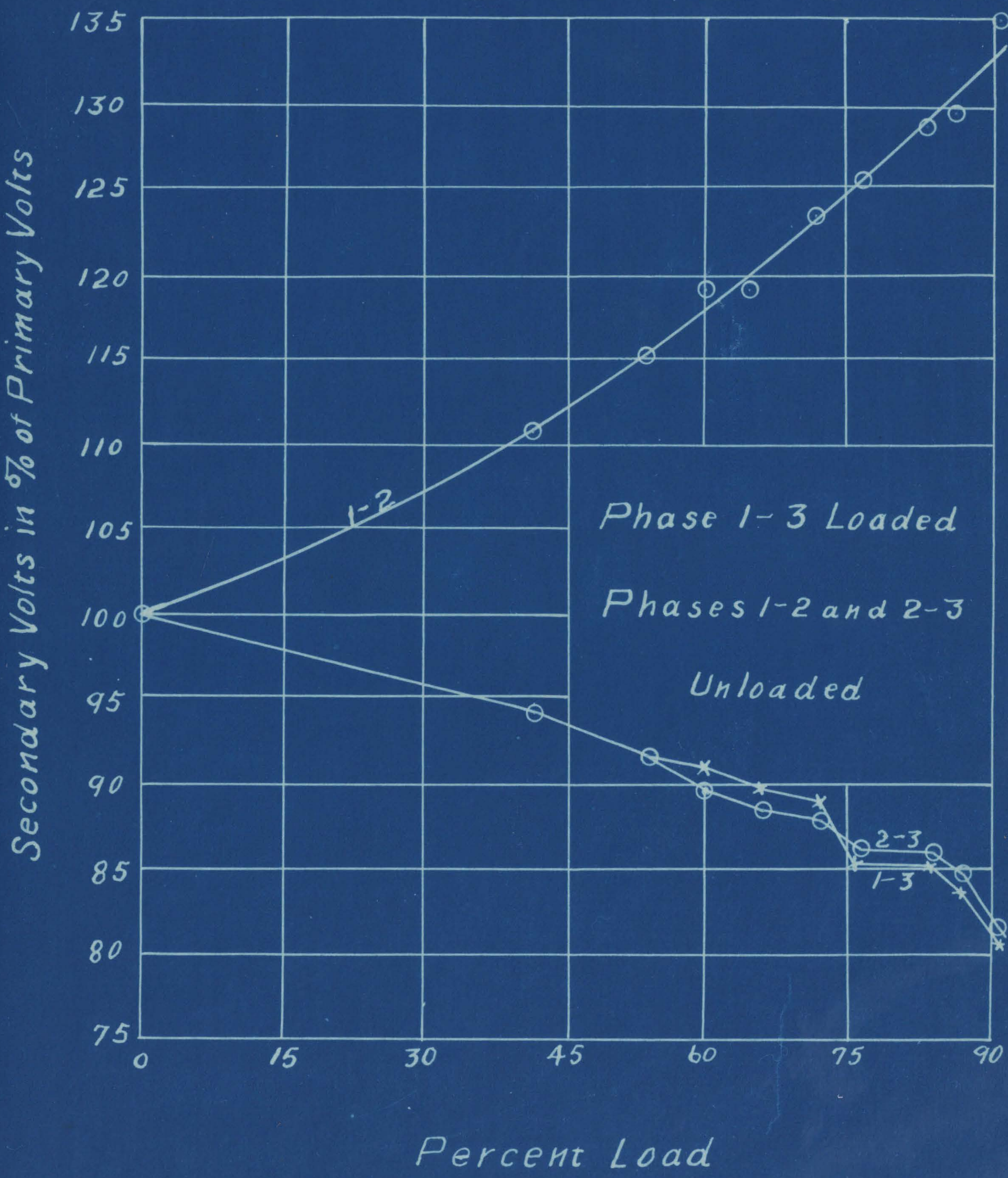


Transformer Connections



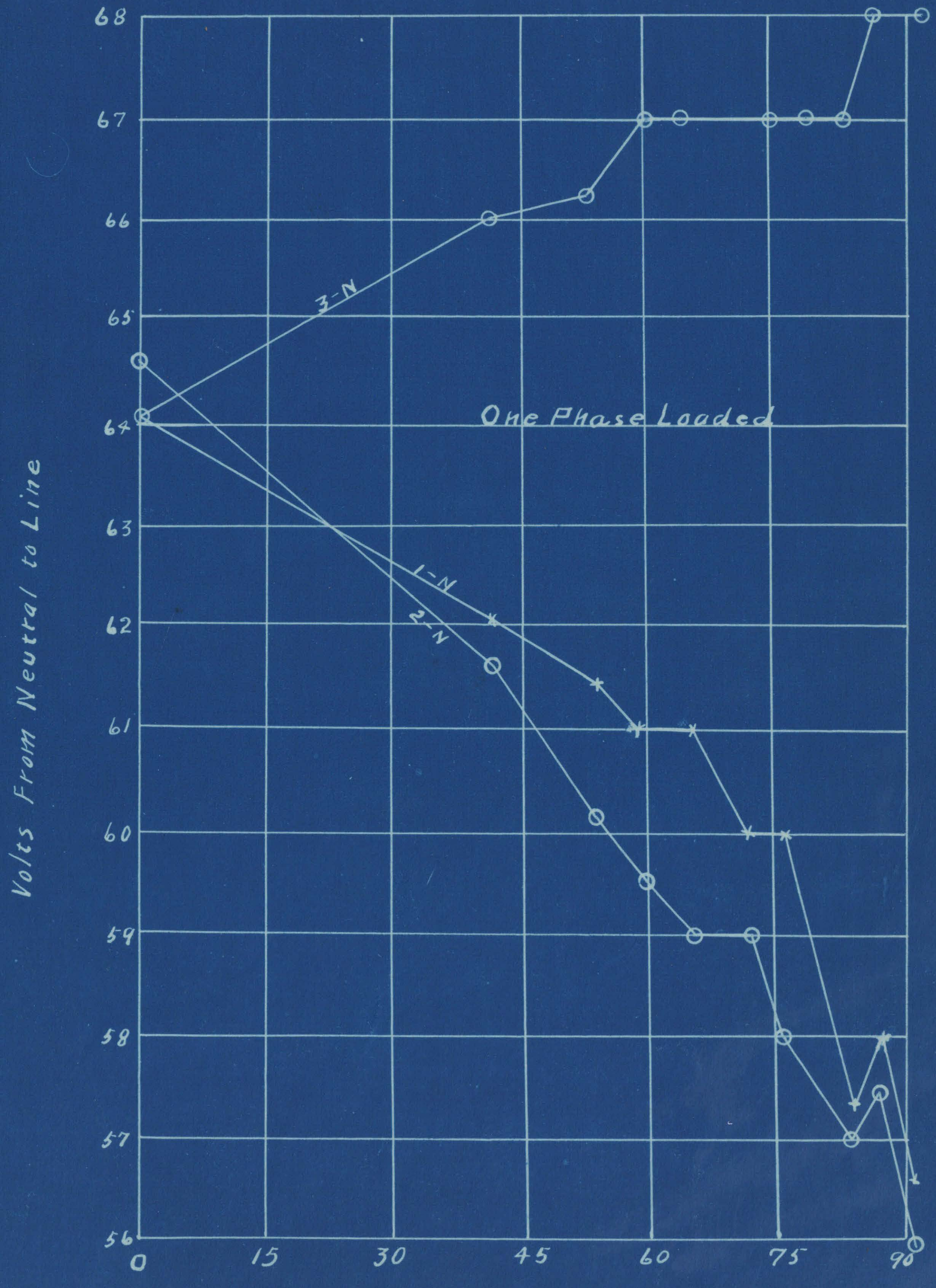
Problem No. 4
Plate A.

Regulation Curves for Phases 1-2, 1-3 and 2-3



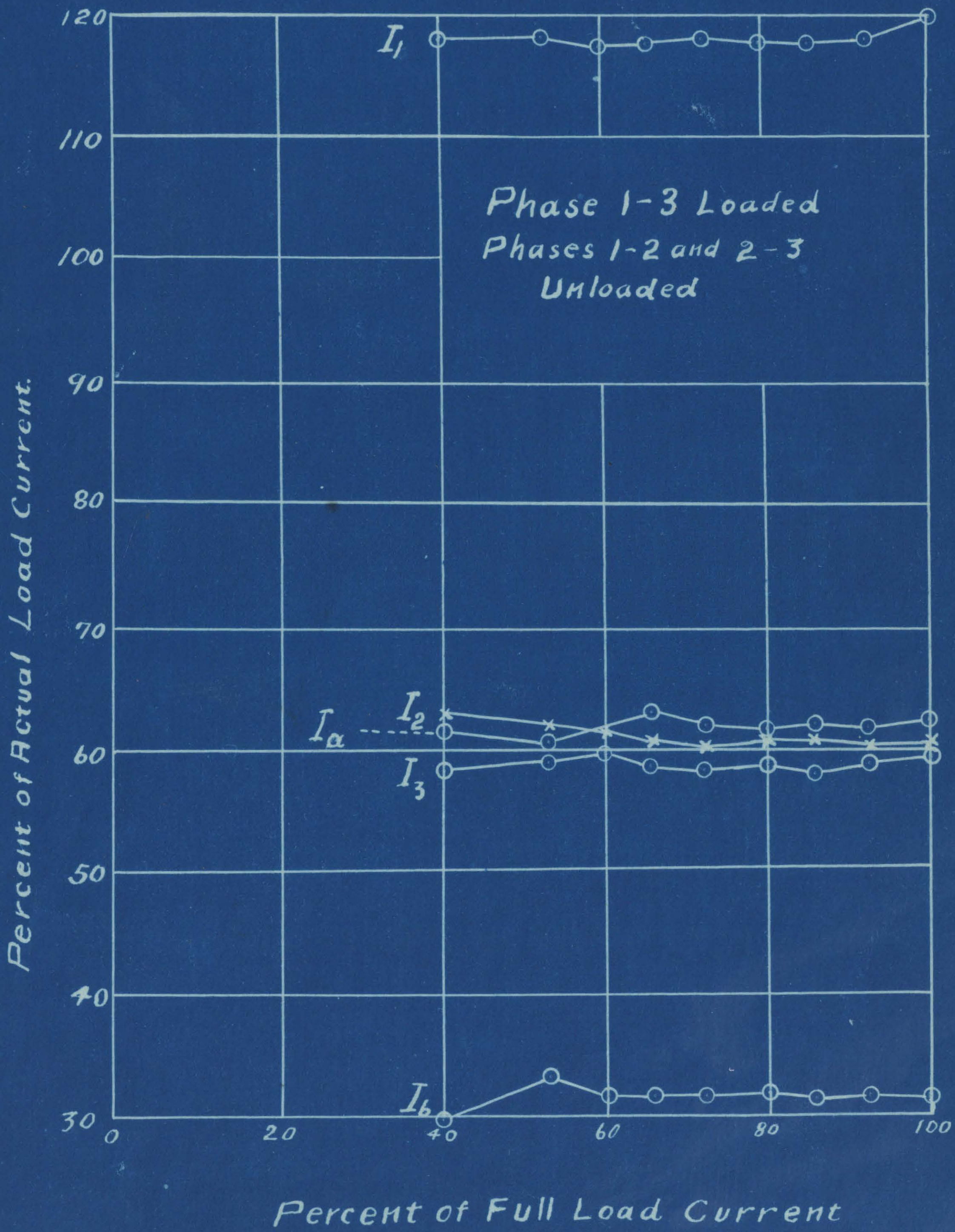
Problem No. 4
Plate B.

Volt-Load Curves for Primary Side



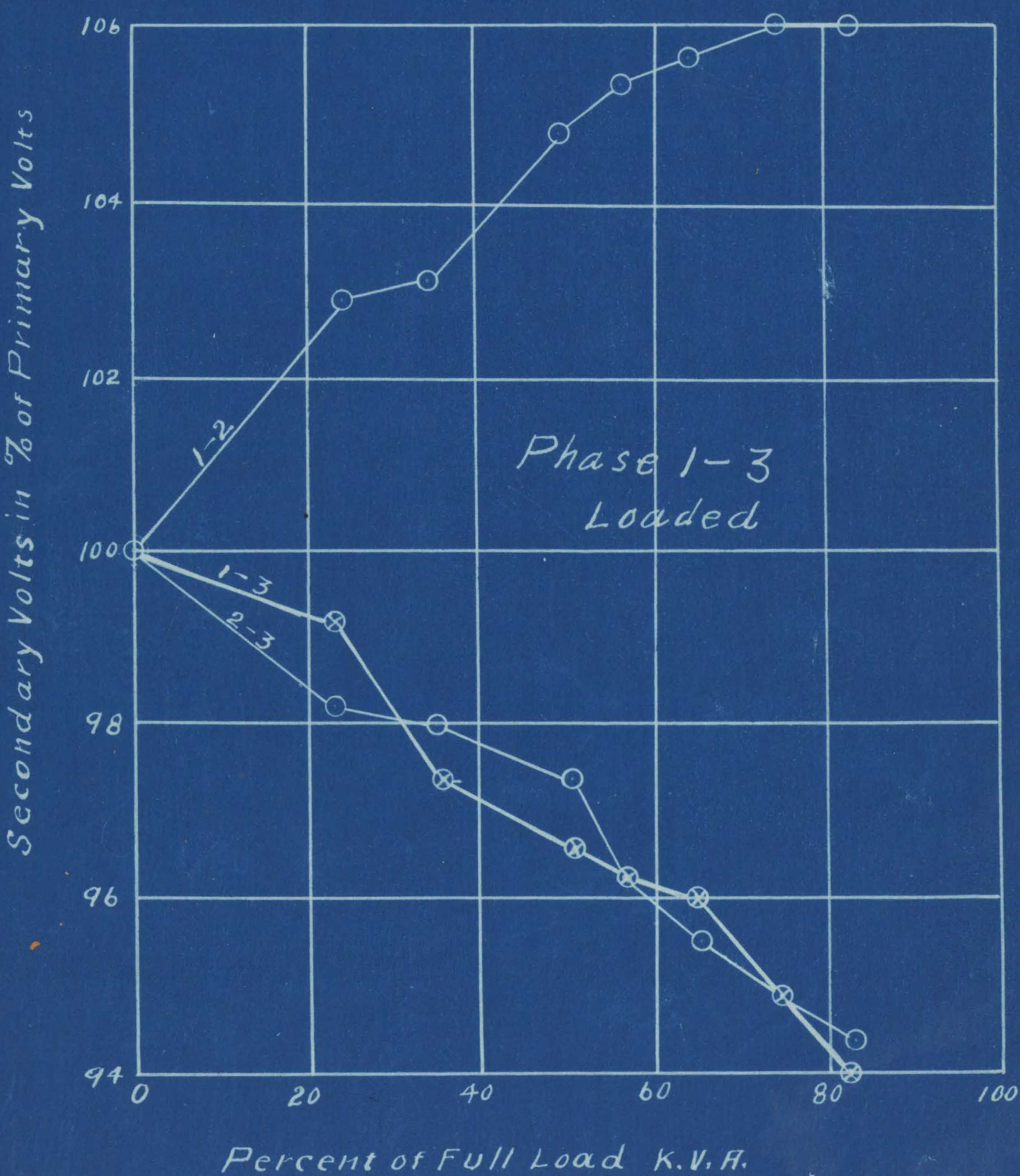
Problem No. 4
Plate C.

Current Curves for
Primary and Secondary
of Transformers A, B and C



Problem No. 5
Plate A.

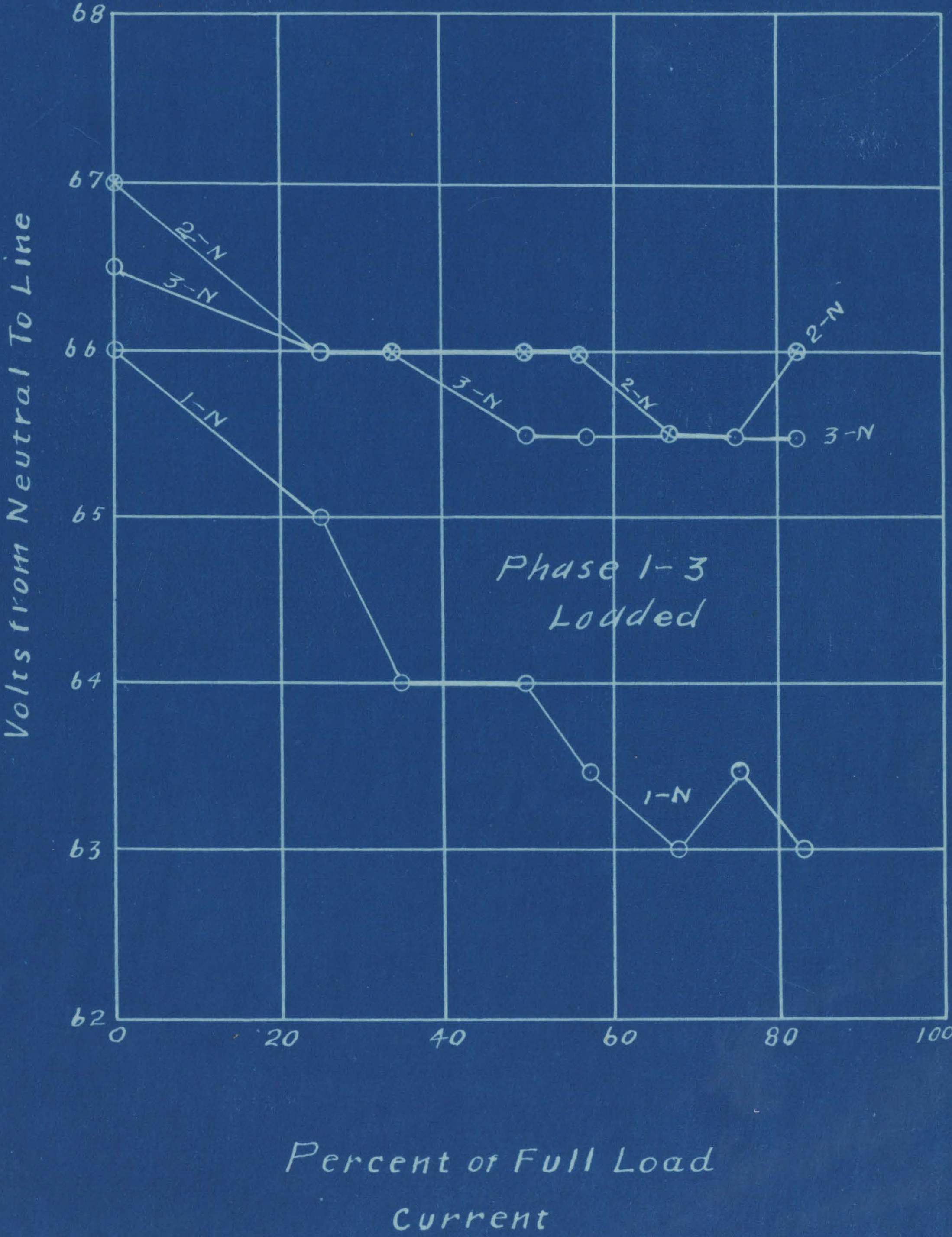
Regulation Curves for Phases 1-2, 1-3 and 2-3



Problem No. 5
Plate B

Volt - Load Current Curves

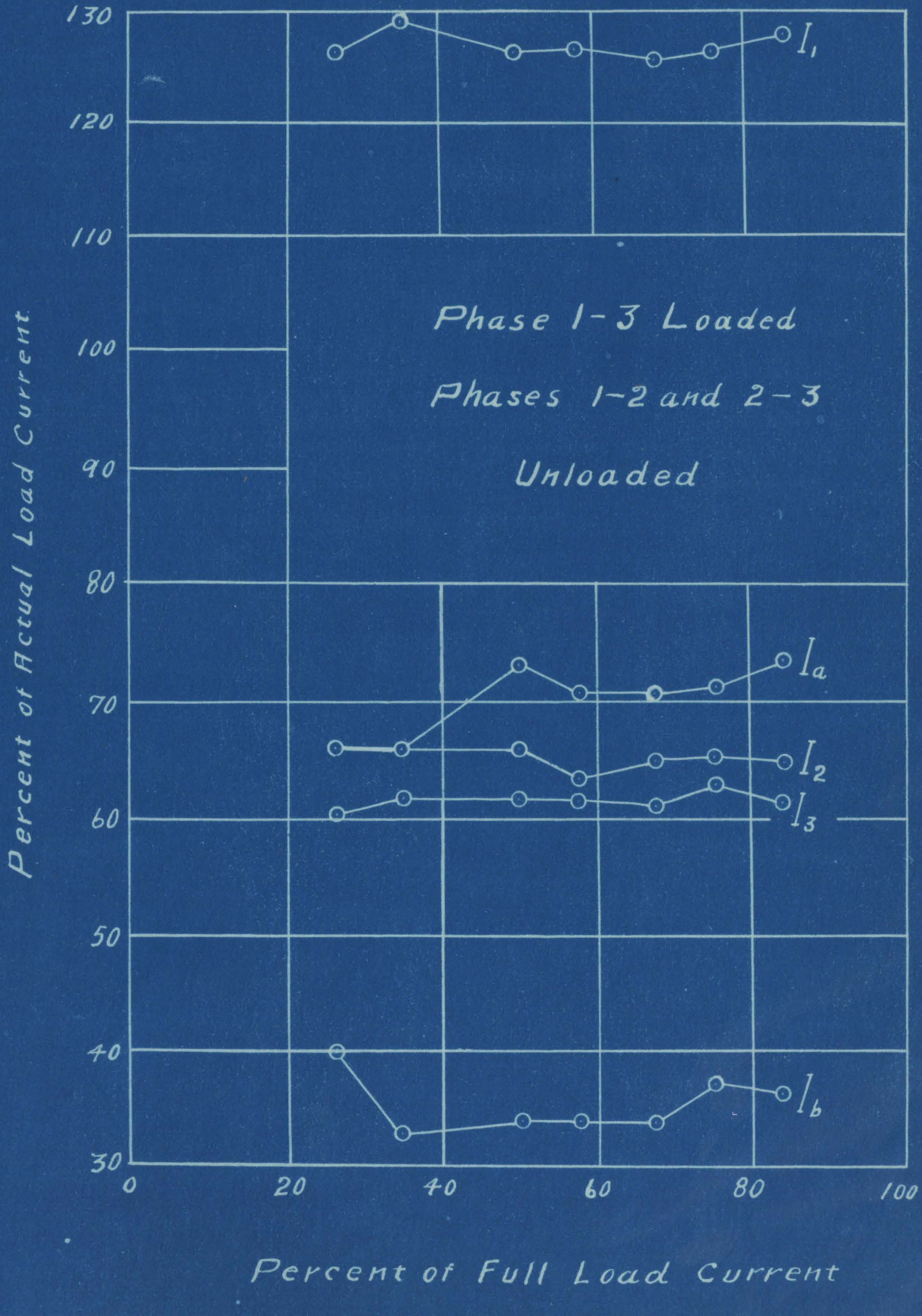
From Neutral to Line



Problem No. 5

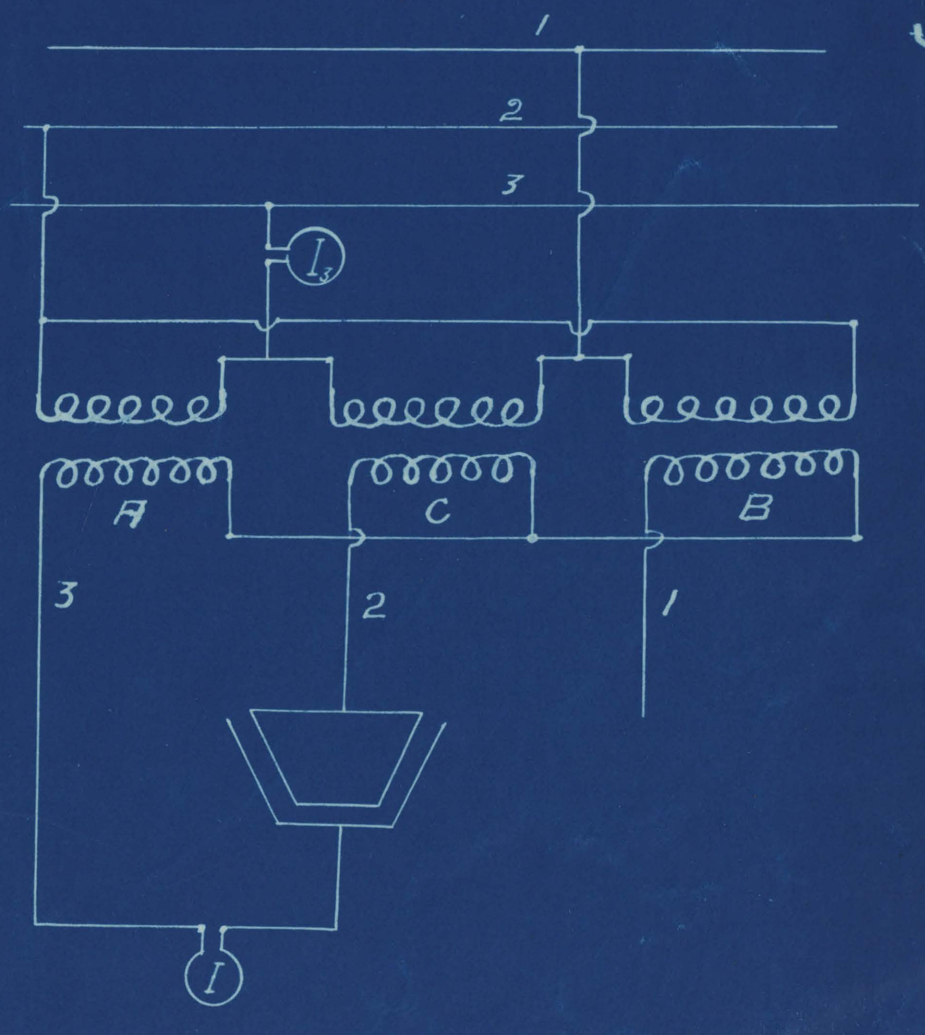
Plate C.

Current-Load Curves



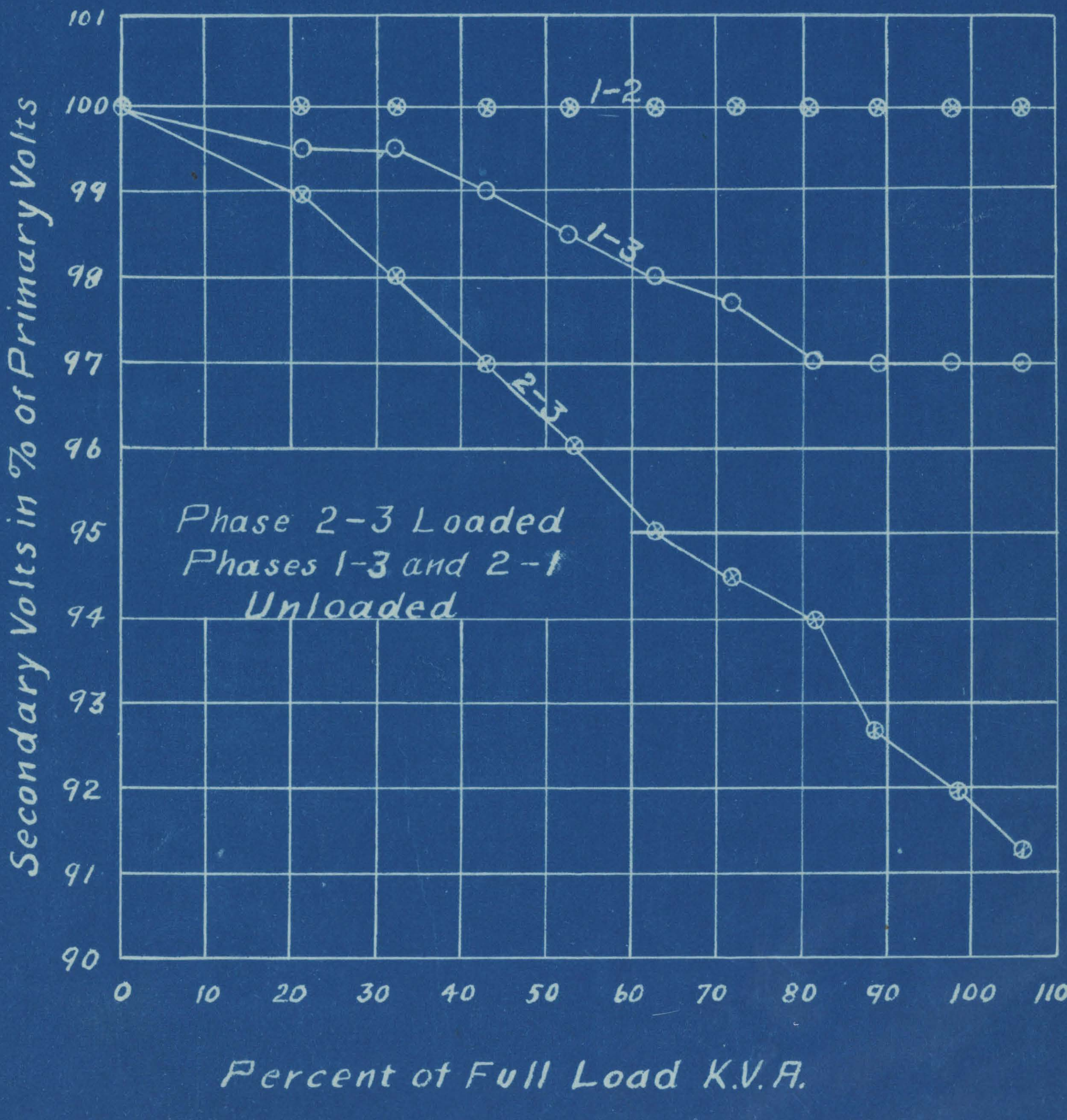
Problem No. 6

Transformer Connections



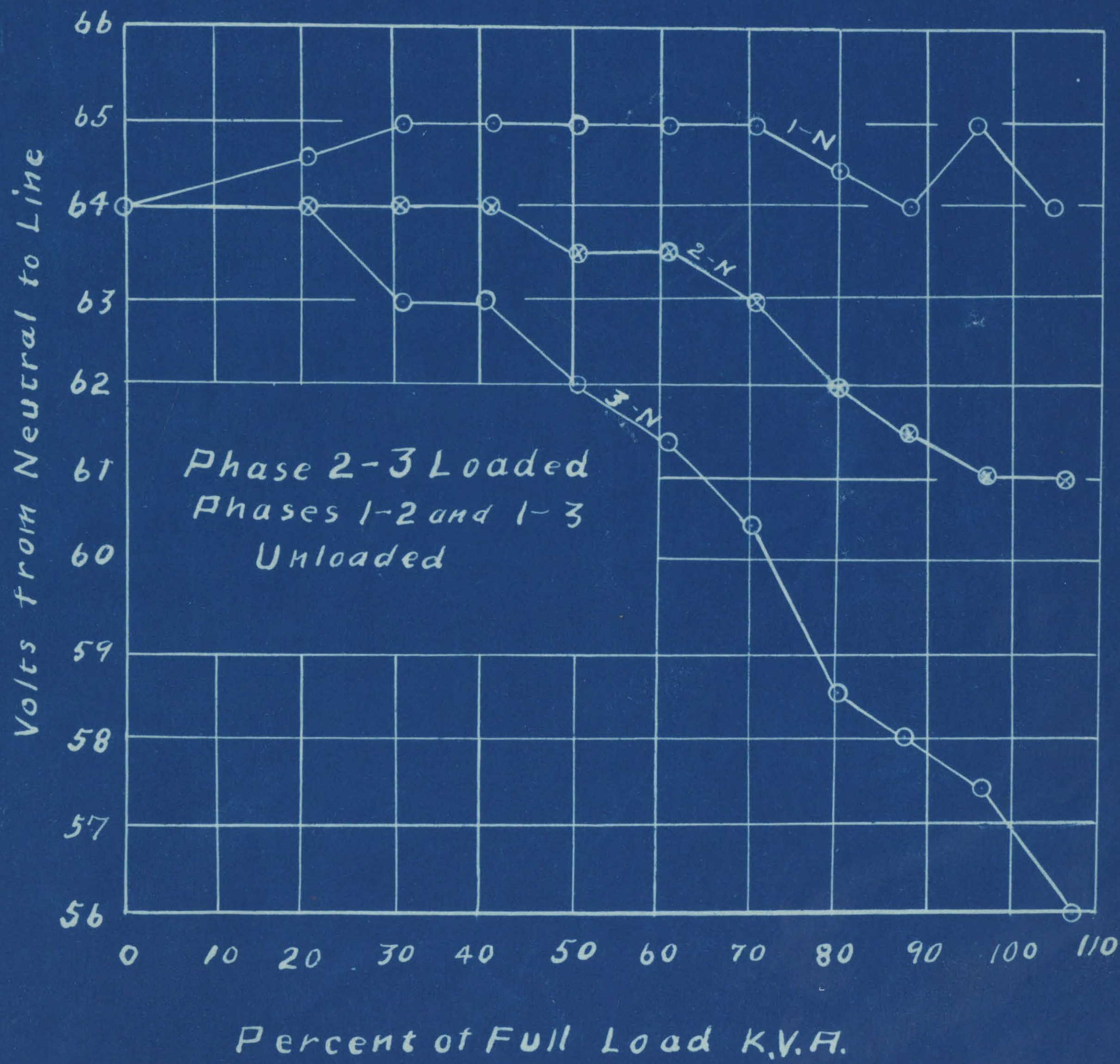
Problem No. 6
Plate A.

Regulation Curves
for
Phases 1-2, 1-3 and 2-3



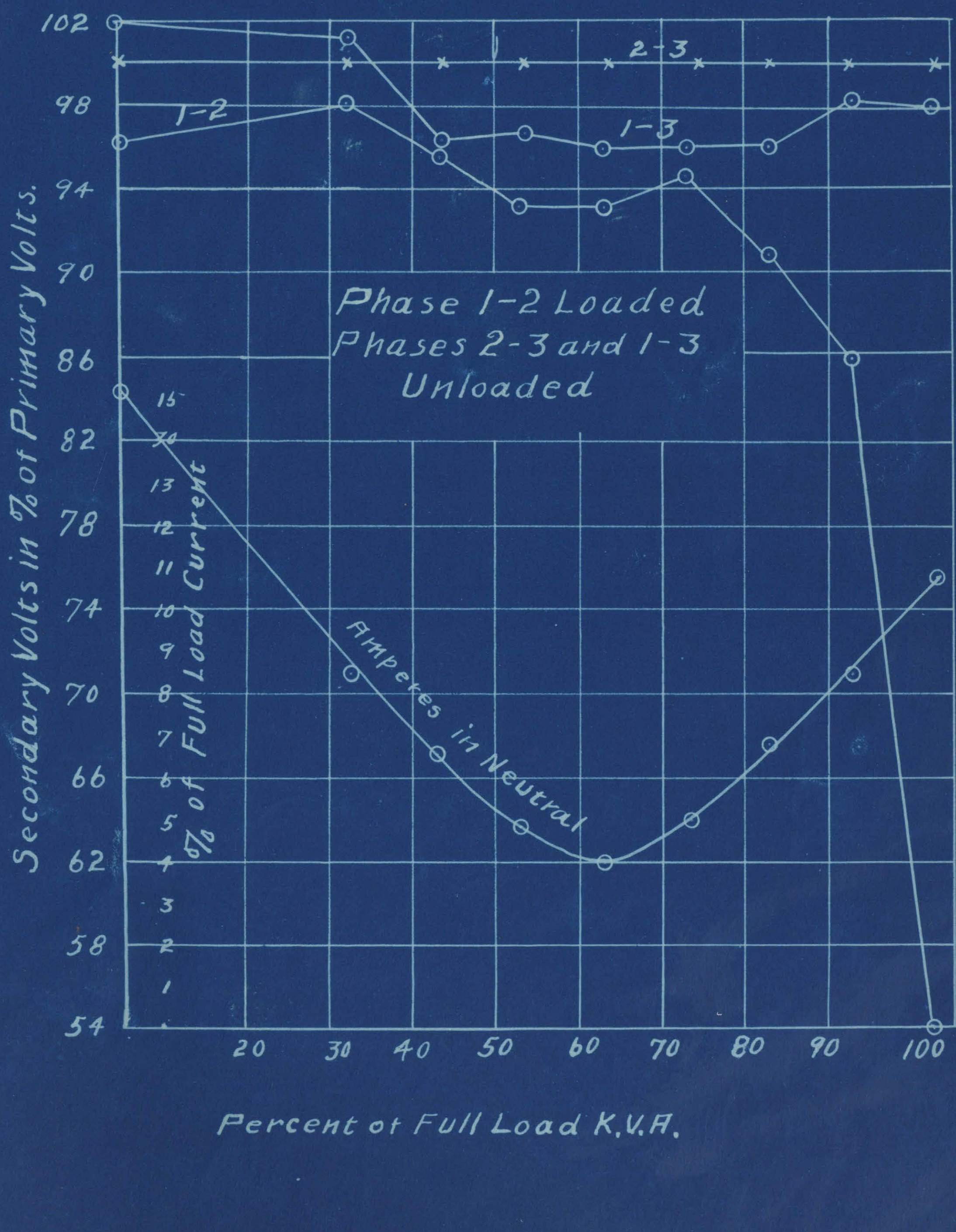
Problem No. 6
Plate B

Load-Volt Curves for Phases
1, 2 and 3



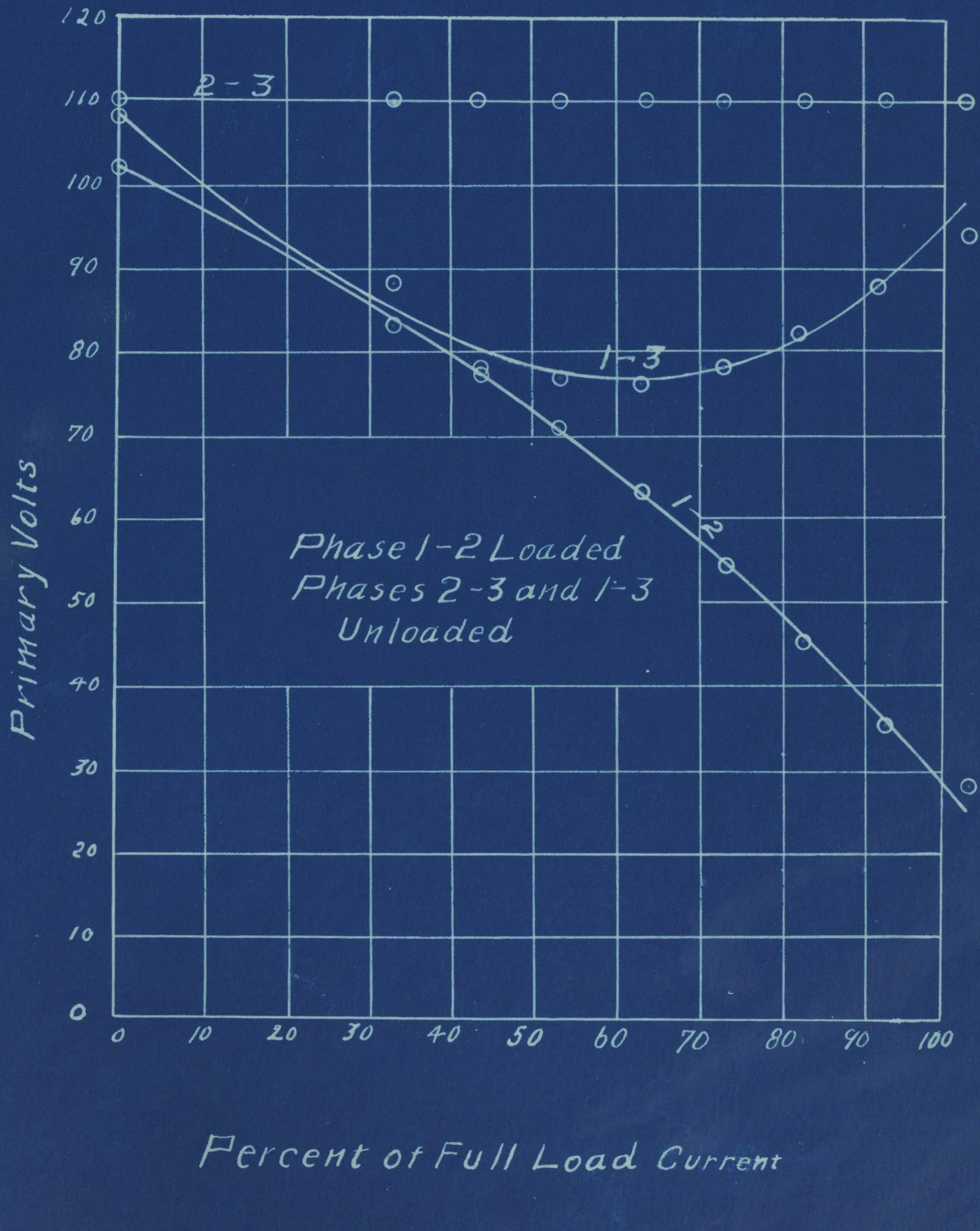
Problem No. 7
Plate A.

Regulation Curves for Phases 1-2, 1-3 and 2-3



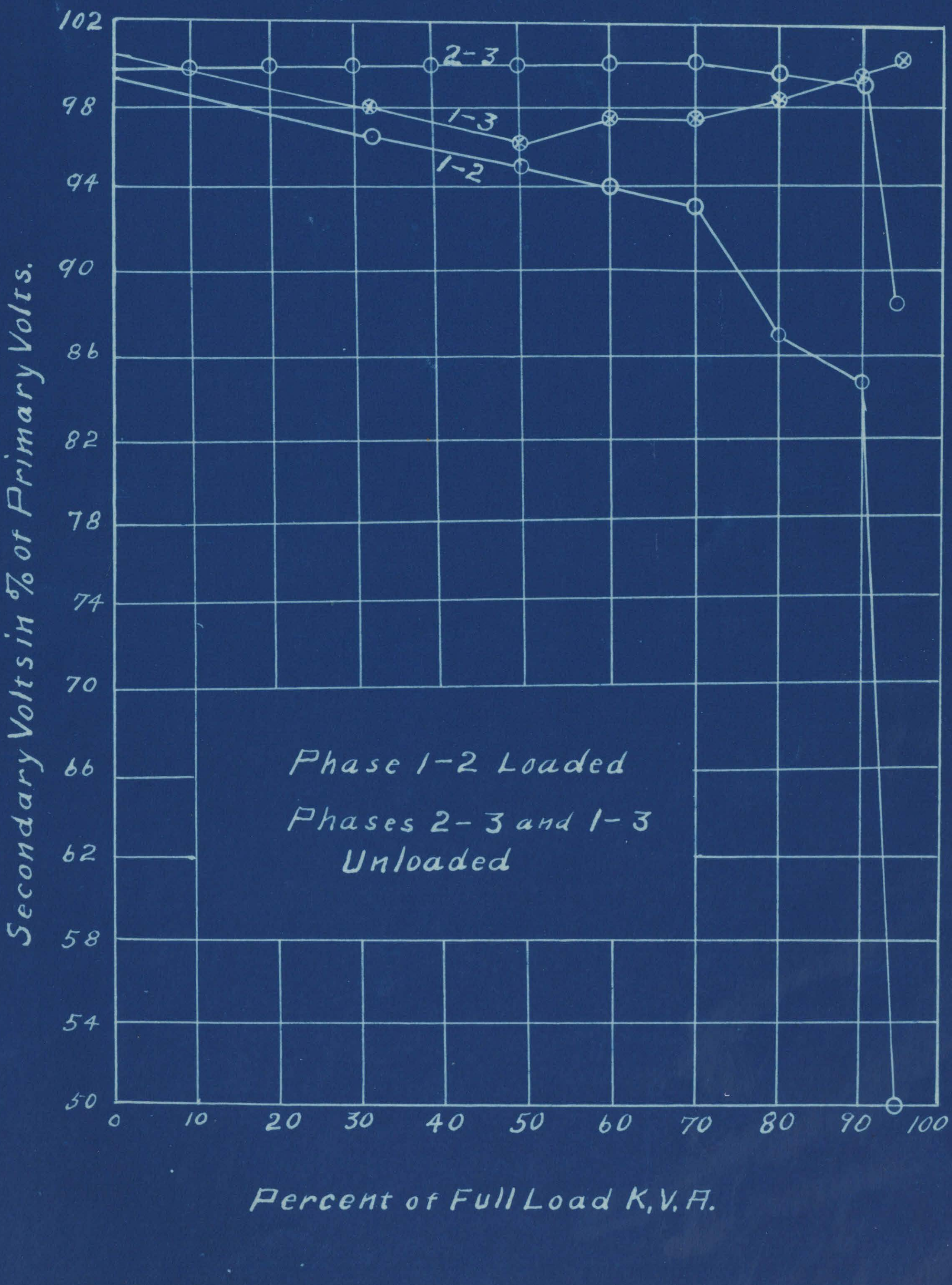
Problem No. 7
Plate B.

Load - Impressed Volts Curves.



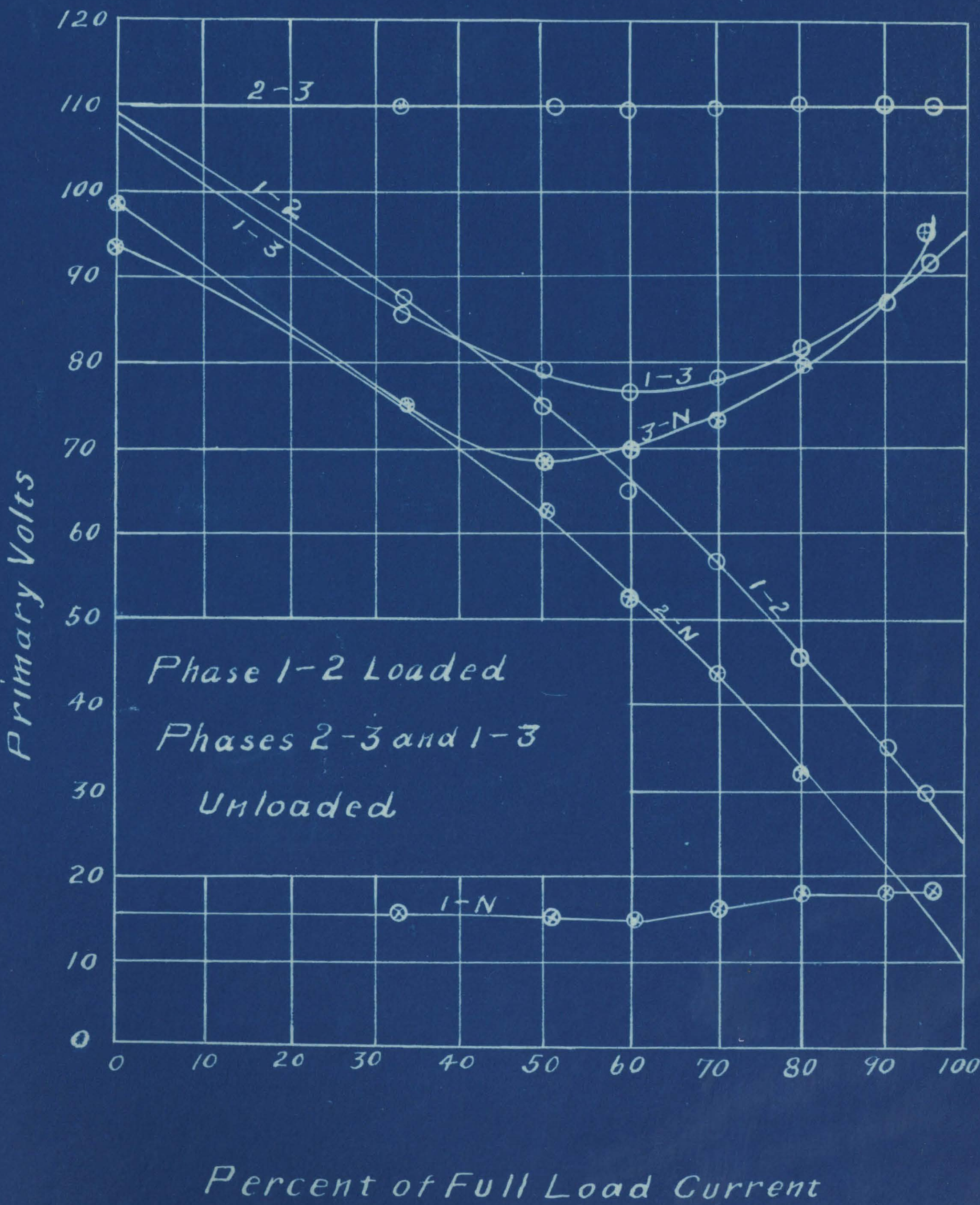
Problem No. 8
Plate A.

Regulation Curves for Phases 1-2, 1-3 and 2-3



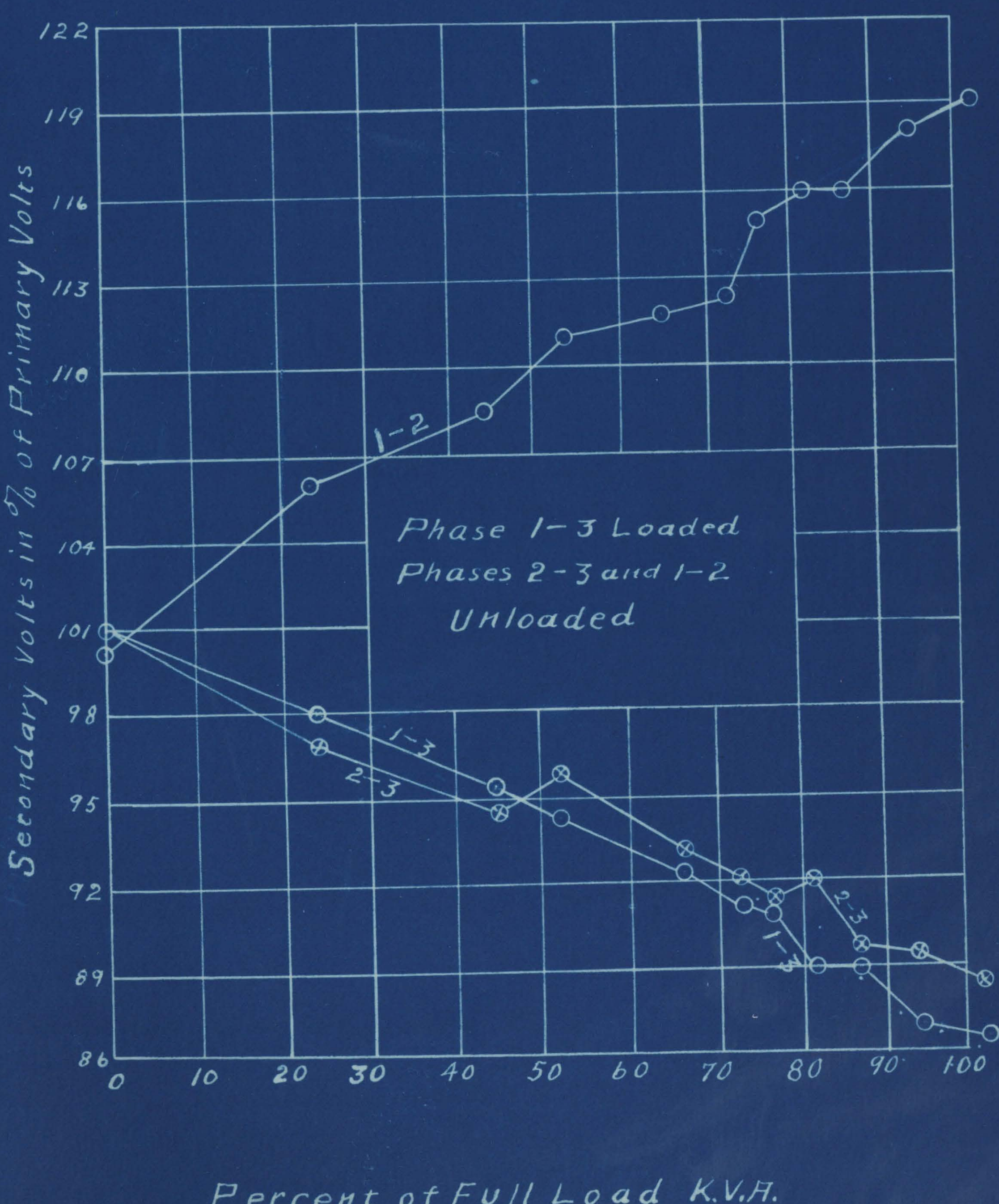
Problem No. 8
Plate B.

Load – Impressed Volt Curves



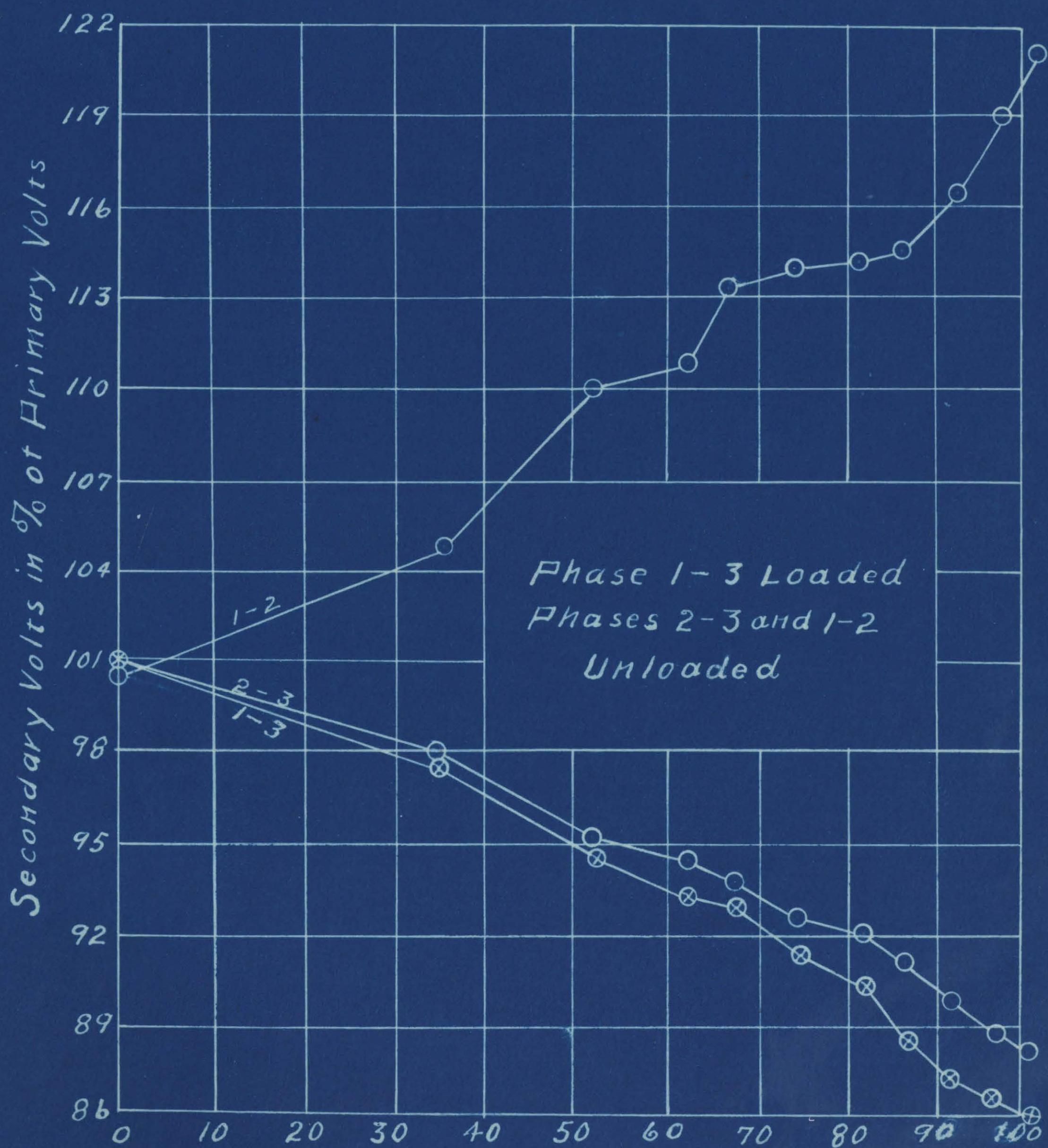
Problem No. 9
Plate A.

Regulation Curves
for
Phases 1-2, 1-3 and 2-3



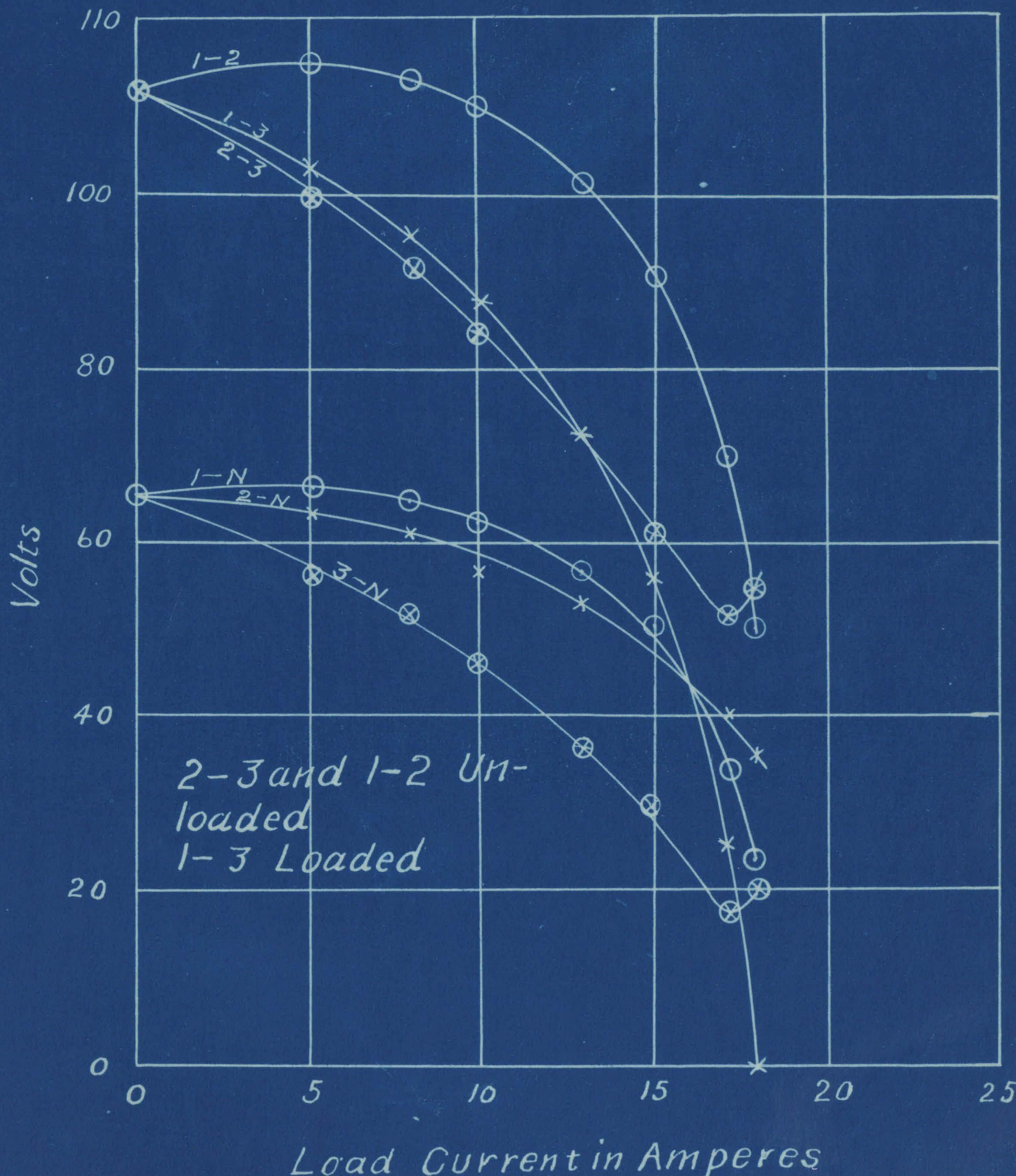
Problem No. 10
Plate A.

Regulation Curves
for
Phases 1-2, 1-3 and 2-3



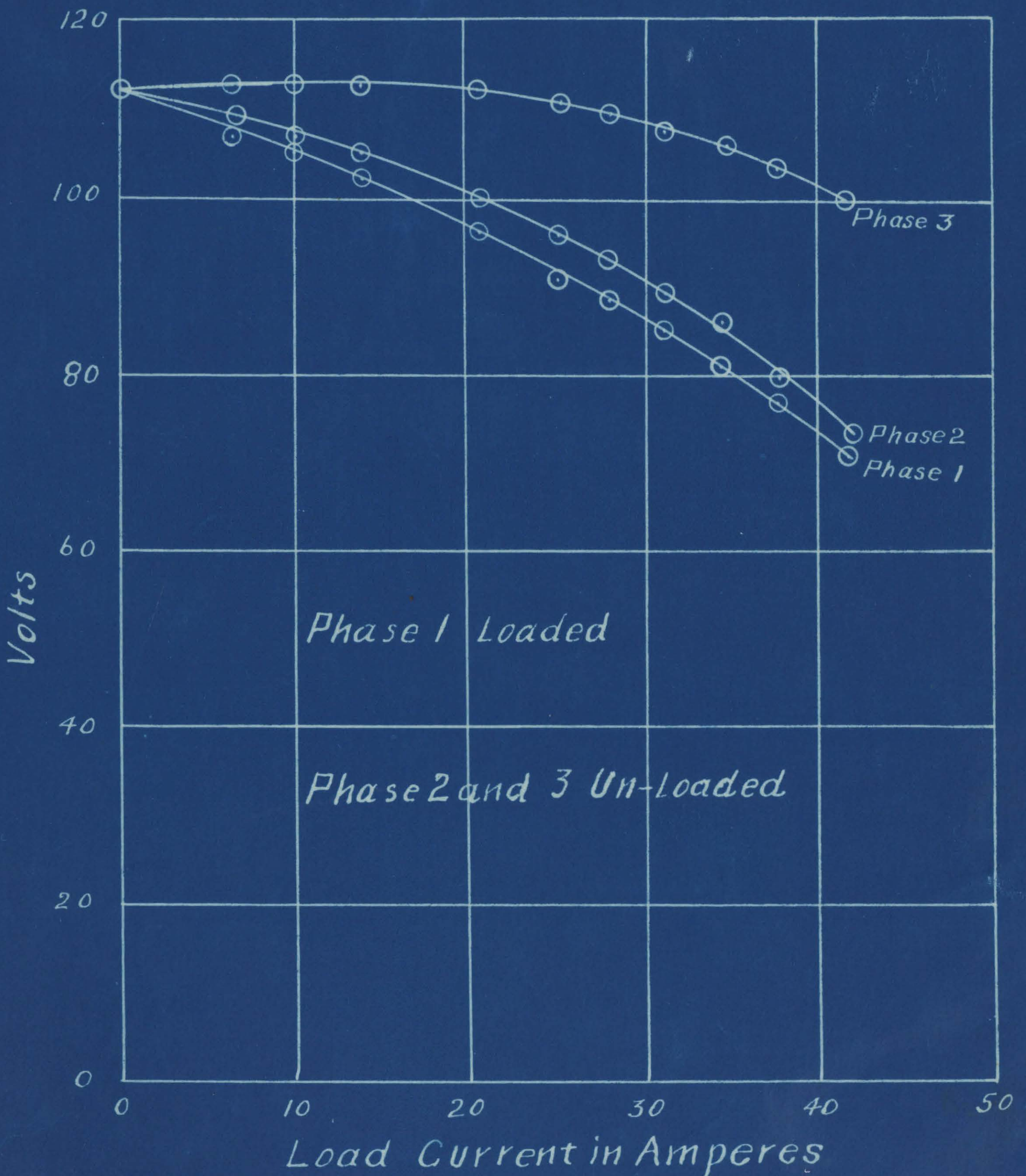
Percent of Full Load K.V.A.

Current-Volt Curves for Central Loboratory Alternator Star Connected.



Problem No. 11
Plate B.

Current-Volt Curves for Central Laboratory Alternator Delta Connected



P A R T

- 3 -

D A T A .

Problem No.1.

DATA SHEET.

Current				Volts primary			Volts secondary		
I_1	I_2	I_3	I_4	1-2	1-3	2-3	1-2	1-3	2-3
0	0	0	0	114	113	117	114	113	117
6	7.2	6	2	113.5	112	115.5	113.5	112	115.5
9	10.8	9	2.9	113.5	112	114.5	113	112	114
12	13.5	11.2	3.9	112.5	111	113.5	112	111	112.5
15	16.5	14.5	4.8	112.5	111	113	111.5	111	112
18	19.7	17.2	5.7	112.5	111	112	111.5	111	111
21	22.6	20.6	6.7	112	111	111.5	111	111	110
24	25.8	23.5	7.7	112	111	111	110.5	111	109.5
27	29	26.5	8.8	111.5	110.5	110	110	111	108
30	32	30	9.8	111	110	109	110	110.5	107
33	35	33	10.8	111	110	108	109	110.5	106
		50		110	109	104	107	110	100

Frequency held constant at 50 cycles per second. Serial number of transformer A, B and C; 278933, 278934 and 278935 respectively.

Problem No. 2.

DATA SHEET.

Volts Primary.

1-2	1-3	2-3	1-N	2-N	3-N
110	110	110	68	68.5	68
109	110	109	69.5	68	69
109.5	110	110	69.5	68	69
110	111	108.5	69.5	67	68
110	111.5	108	69.5	67	68
110	111.5	107	69.5	66	67
110	110.5	106	69.5	66	66.5
109	110	106	69.5	65.5	66
109	110	106	69.5	65	66

Volts Secondary.

						Load Current
110	110	110	68	68.5	68.5	0
108	110.5	107.5	68	66	67.5	10
108.5	112	107.5	69.5	66	68.5	14
107.5	112.5	106	69.5	65	68	18
107	112.5	104.5	69.5	64	67	22
106	112.5	102.5	69.5	63	67	26
105	112	101.5	69.5	62.5	66	28
105	112	100.5	69.5	61.5	66	30
104	112	99	69.5	61	65	33

The above test repeated.

Volts primary.

114	114	115	70.5	71	71.5
113.5	113.5	113	70.5	70	70.5
113	113.5	112	70.5	69	70
112.5	113.5	111	70.5	69	69.5
112.5	113	110	70.5	68.5	68.5
112.5	112.5	110	70.5	68	68
111.5	112	108.5	70.5	68	68
112	113	108	71	67.5	67.5
112	112.5	107	71	67	67

Volts secondary.

114	114	115	70.5	71	71.5	0
112	114.5	111	70.5	69	70.5	10
111	114.5	109.5	70.5	68	69.5	13
110	114	108	70.5	67	69	16
109.5	114	107	70.5	66.5	68.5	19
109	114	106	70.5	66	68	21
108	113.5	104	70.5	65	67.5	27
108	114.5	102	70.5	64	67	30
107	114	101	70.5	63	66.5	33

Problem No. 3.

DATA SHEET.

Primary

Current			Volts						
I_1	I_3	I_2	1-2	1-3	2-3	1-N	2-N	3-N	Load current.
0	0	0	110	110	110	15	95	10	0
11.8	10.8	0	105	99	110	15	87	85	10
15.0	14.3	0	102.5	95	110	15	85	81.5	13
17.8	17	0	100	92	110	17	82	77	16
20.6	20	0	99	91	110	20	79	74	19
23.2	23	0	97	88	110	25	76	71	22
26.2	25.8	0	95	85	110	30	73	67	25
29.3	29	0	92	82	110	32	70	65	28
32.2	32	0	89	80	110	34	65	64	31
35.0	34.5	0	88	80	110	35	63	63	33

Secondary

Volts						
1-2	1-3	2-3	1-N	2-N	3-N	Load current
109	109	110	14	95	100	0
101.5	96	110	14	86.5	95	10
99	92	110	14	84	81	13
95	88	110	14	80	77	16
93	86	110	15	78	74	19
91	84	110	17	75	71	22
89	80	110	20	72	67	25
86	76	110	22	68	64	28
82	75	110	25	63	62	31
81	73	110	30	62	63	33

Problem No. 4.

DATA SHEET.

Primary side.

Amperes V.			Volts						I field of generator	Load current amperes
I_1	I_2	I_3	1-2	1-3	3-2	1-N	2-N	3-N		
0	0	0	110	110	110	64	64.5	64	1.5	0
14.2	7.9	7.2	103	111	110	62	61.5	66	1.52	12
19	10	9.5	100	111.5	110	61.4	60.2	66.2	1.55	16
21.1	11.2	10.8	97	111	110	61	59.5	67	1.57	18
23.5	12.2	11.9	97	111	110	61	59	67	1.6	20
26	13.2	13	95	111	110	60	59	67	1.6	22
28.2	14.6	14.2	93.5	111.5	110	60	58	67	1.61	24
30.5	15.9	15.2	91.5	111	110	57.5	57	67	1.62	26
33.2	17	16.7	91.5	111	110	58	57.5	68	1.65	28
36	18.2	18.1	88	111	110	57	56	68	1.65	30
28.3	14.8	14.2	94	111	110	58.6	57	67	1.6	24
23	12.2	11.9	97	111	110	60	59	67	1.59	20
17.5	94	9.1	101.2	111.5	110	61	60.5	66.5	1.54	15
0	0	0	110	110	110	64	64	64	1.5	0

Secondary side.

I_a	I_b	1-2	1-3	2-3	Load current
0	0	110	110	110	0
7.5	2.5	114	104	103	12
9.8	5.5	115.5	112.5	101	16
10.2	5.8	116	101	100	18
12.7	6.5	116	100	98	20
13.7	7.2	118	99	97	22
14.8	7.7	118	96	96	24
16.2	8.2	119	96	95	26
17.5	9	118.5	93.5	93.5	28
19	9.5	118	90	91	30
14.8	7.8	117	95	95	24
12.3	6.8	117	95.5	99	20
9.2	5.4	115	102	101	15
0	0	110.5	110	110.5	0

Frequency = constant = 50 cycles per sec.

Problem No.5.

DATA.

Primary side

Volts

1-2	2-3	1-3	1-N	2-N	3-N	I_1	I_2	I_3
114	114.5	113.5	66	67	66.5	0	0	0
111	114	111	65	66	66	9.5	5	4.5
110.5	113.5	111	64	66	66	13.5	7	6.5
110	114	111	64	65.5	66	19	9.9	9.2
110	114.5	110.5	63.5	65.5	66	22	11.2	10.8
109.5	114	109.5	63	65.5	65.5	25.5	13.2	12.5
110	114.5	110	63.5	65.5	65.5	29	15	14.5
109	115	110.5	63	65.5	66	31.8	16	15.5

Secondary side.

Volts.			Load current		
1-2	2-3	1-3		I_a	I_b
114	114.5	113.5	0	0	0
114	112	110	7.5	5	3
114	111	108	10.5	7	3.5
115	111	107	15	11	5
116	110	106	17.5	12.5	6
115.5	109	105	20.5	14.5	7
116	109	104	23	16.5	8.5
115.5	108.5	103	25	18.5	9

Problem No. 6.

DATA.

PRIMARY

Volts			Current
1-2	1-3	2-3	I_3
110	110.5	111.5	0
111	111	111	7
111.5	111	111	10
112.5	110.5	111	13.3
112	110	110.5	16.5
112	110	110	20.5
112.5	110	110	23.7
111	108	108.5	27.7
111	107.5	107	31
112	107.5	107	35
111	106	106	39

SECONDARY.

Load current	1-2	1-3	2-3	1-N	2-N	3-N
0	110	110.5	111.5	64	64	65
6	111	110	109.5	64.5	64.5	64
9	111.5	110	108.5	65	64	63
12	112	109.5	107.5	65	64	63
15	112	108	106	65	63.5	62
18	111.5	107.5	104.5	65	63.5	61.5
21	112.5	107	104	65	63	60.5
24	111	105	102	64.5	62	58.5
27	111	104	99.5	64	61.5	58
30	112	104.5	98.5	65	61	57.5
33	111	103.5	96.5	64.5	61	56

Problem No. 7.

D A T A .

PRIMARY.

Load current	I_1	I_2	I_3	I_n	1-2	1-3	2-3	1-N	2-N	3-N
0	5.6	2.7	0	4.6	108	102	110	60	65	62
10	13	10	0	2.5	86	83	110	44	61	60
13	15	13	0	1.9	77.5	78	110	38	59	59
16	17.7	16	0	1.4	70.5	77	110	33	57	60
19	20	19	0	1.2	63	76	110	30	55	60
22	22	22	0	1.5	54	78	110	25	52	62
25	24.5	25	0	2	45	82	110	18	49	64
28	26.6	28.2	0	2.6	35	87.5	110	18	46	66
31	29	31.5	0	3.2	28	94	110	25	44	70

SECONDARY.

Load current	1-2	1-3	2-3	1-N	2-N	3-N
0	104	98	110	56	65	62
10	84	80	110	40	61	60
13	74	75	110	34	58	59
16	66	74	110	28	56	60
19	59	73.5	110	18	54	60
22	50	75	110	15	52	62
25	41	80	110	15	48	64
28	30	86	110	15	46	66
31	15	92	110	20	42	69

Problem No. 8.

D A T A.

PRIMARY.

Load current	I_1	I_2	I_3	1-2	1-3	2-3	1-N	2-N	3-N
0	0	0	0	108.5	107.5	110	16	93.5	99
10	11	10	0	88	86	110	17	75	75
15	16	15.5	0	75	79	110	18	62	69.5
18	19	18.5	0	65	77	110	19	53	70
21	21.8	21.6	0	57	78	110	21	44.5	73
24	24.5	24.2	0	46	81	110	22	32	80
27	27.5	27.5	0	35	87	110	22	22	89
28.6	29	28.5	0	30	91	110	23	17	95

SECONDARY.

Load current	1-2	1-3	2-3	1-N	2-N	3-N
0	107.5	108	110	15	93.5	99
10	85	104	110	15	75	76
15	71	76	110	15	61	69
18	61	75	110	16	51	70
21	53	76	110	17	43	73
24	40	80	109.5	17	31	80
27	30	86	109	17	17	88.5
28.6	15	91	108.5	17	17	95

Problem No. 9.

D A T A.

PRIMARY.

Load current	I_1	I_2	I_3	I_n	1-2	1-3	2-3	1-N	2-N	3-N
0	0	0	0	0	110	110	108	64	63	63.5
7	11	6.2	5.8	0	105	108.5	108.5	62	62	63
13	16.8	9	7.8	0	102	107	108	61	60	62.5
16	20.2	10.8	10	0	100	105	107	60	60	63
18	22	11.8	11	0	100	106	108	58.5	61	63.5
20	23.5	11.2	11.8	0	99.5	105.5	107.5	60	60	63
22	26	13.4	13	0	98	105	107	58	59	62
24	28.8	14.8	14	0	94.5	102	105	57	58	61.5
26	30.5	15.8	15.2	0	94.5	102.5	105	55	58	62
28	33.5	17	16.7	0	94	101	105	57	58	62
30	36.5	19.	18	0	95	103	107	57	58	63.5
32	39	20	19.5	0	94	102	108	57	59	63

SECONDARY.

Load current	1-2	1-3	2-3	I_b	I_a
0	110	115.5	109	0	0
7	111	106	105	2	5.8
13	111	102	102	4	8.8
16	111	99.5	102	5.5	10.8
18	110	96	101	6.2	11.8
20	111	98	100	6.7	12.5
22	110	95	98	7.2	13.8
24	109	92	95	7.7	15
26	110	92	97	8.3	17
28	109	90	94	9	17.6
30	112	90	96	9.8	19.6
32	112	89	96	10.3	20.6

Problem No. 10.

D A T A .

PRIMARY.

Load current	1-2	1-3	2-3	1-N	2-N	3-N	I_1	I_2	I_3
32	92	101	108	56	58	63	39	20	19.2
30	96	106	111	56	60	66	36.2	18.5	18
28	97	105	100	57	60	65	33.5	17	17
26	98	105	110	58.5	61	64	31	16	15.4
24	100	106	110	59	61	64	28.5	15	14.2
22	100	106	110	60	61.5	64	26	13.2	12.8
20	100	106.5	110	60	61	64.5	23.8	12.5	12
18	102	107	110.5	61	62	64.5	21.8	11.5	11
15	103	108	110	61.5	62	64.5	18	10	9
10	107	109	110	63	63	64.5	12	6.8	6.2
0	112	112	111	65	65	65	0	0	0

Secondary.

Load current	1-2	1-3	2-3	I_a	I_b
32	111	87	95	20.7	10.2
30	114	90	98	19	9.8
28	113	90	99	17.8	9.2
26	113	94	100	16.3	8.6
24	114	96	101	15.2	8.2
22	113	97	102	13.7	7.5
20	113.5	99	103	12.6	7.1
18	113	100	104	11.5	6.5
15	113	102	105	9.5	5.8
10	112	106	108	6.5	4
4	112.5	113	112.5	0	0

Problem No. 11

D A T A S H E E T.

Volt regulation test on Central Laboratory Alternator with non-inductive load applied to phase 1-3. Phases 2-3 and 1-2 unloaded.

Part A.

Alternator connected delta ammeters to measure load current and current in phase 2-3.

Load current	Current in idle phases	Volts across phase. 1-2	1-3	2-3
0	5	112	112	112
6.5	6	109.5	108	113
9.8	7	108	105	113
14	8.2	105.5	102	113
20.8	10.6	100	96	112
25.5	12	96	91	110.5
28	12.7	93	88.5	110
31	13.4	89	85	108
34	14.2	86	81.5	106.5
38	15	80	77	104
42	15.6	73	71	100

Part B. Alternator connected star.

Load current	Volts			Volts		
	1-2	1-3	2-3	1-N	2-N	3-N
0	112	112	112	65.5	65.5	65.5
5	114.5	104	99.5	66	63	58
8	112.5	95	99	65	61	52
11	110	87	83	62	58	46
13	110.5	72	71	57	53	36
15	91	56	61	50	48	30
17.5	70	25	51	34	40	17
17.8	50	0	55	22	36	20

P A R T

- 4 -

C A L C U L A T I O N S .

Problem No.1.

CALCULATIONS.

Load Current	% of load A	% of load B	% of load C	Secondary volts in % of primary volts A	B	C
0	0	0	0	100	100	100
6	15.4	7.6	7.5	100	100	100
9	22.8	11.3	11.2	99.6	99.6	100
12	33.2	15.0	14.9	99.4	99.5	100
15	37.4	18.4	18.3	99.1	99.2	100
18	44.4	22.3	22.2	99.	99.1	100
21	51.3	26.0	26.1	98.8	99	100
24	58.3	29.4	29.7	998.6	98.9	100
27	64.8	33.0	33.3	98.2	98.8	100.5
30	71.4	36.7	36.9	98.1	98.8	100.5
33	77.8	40.4	40.5	98	98.4	100.5
50	111.	59.1	60.8	96.2	97.4	101

Problem No. 2.

Load Current	Secondary volts in % of primary volts 1-N	2-N	3-N	1-2	1-3	2-3	Percent of rated K.V.A. for one phase of banks.
0	100	100	100	100	100	100	0
10	100	98.6	100	98.5	100.5	98.2	37
13	100	98.5	99.6	98.	100.8	97.8	41.3
16	100	97.1	99.3	97.8	101	97.2	57.5
19	100	97	99.3	97.5	101.1	97	67.8
21	100	97	99.3	97	101.4	96.4	74.3
27	100	95.5	99.2	96.8	101.5	95.8	98.8
30	100	94.8	99.2	96.5	101.5	94.7	102
33	100	94	99.2	95.5	101.5	94.4	107.5

Problem No. 3.

CALCULATIONS.

Load Current	% of rated K.V.A for one phase	Secondary volts in % of primary volts 1-2	1-3	2-3	1-N	2-N	3-N
0	0	99.2	99.2	100	99.2	100	100
10	35.2	97	97	100.9	99.2	99.4	100
13	39.8	96.5	96.7	100.9	99.2	99	100
16	47.0	95	95.5	100.9	82.5	97.8	100
19	54.4	94	94.5	100.9	75.5	99	100
22	61.6	93.8	94.5	100.9	67.4	98.7	100
25	66.8	93.7	94	100.9	66.5	98.5	100
28	71.0	93.5	92.5	100	69	97.2	100
31	77.4	92	93.7	100	74	97	100
33	80.0	92	91.5	100	86	97	100

Problem No. 4.

Load Current	Secondary volts in % of primary volts 1-2	1-3	2-3	% of rated K.V.A. if only one phase is loaded.
0	100	100	100	0
12	101	94	94	41.5
16	115.5	92	92	54.5
18	119.5	91	90	60.4
20	119.5	90	89	66.6
22	124	89	88.1	72.7
24	126.4	85.5	87.1	76.8
26	129	85	86.4	83
28	129.5	84	85	87.4
30	135	81	82.8	91

Rated K.V.A. taken as 27.2 amps at 110 volts or 3,000 K.V.A.

Currents in % of full load current.

I_1	I_2	I_3	I_a	I_b	I_{load}
118.4	65	60	62.5	30	40
118.9	62.2	59.4	61.4	34.2	53.4
117.5	62.2	60	57	32.2	60
117.5	60.5	59.6	64	32.5	66.6
118	6o.1	59.1	62.4	32.6	73.2
117.5	61	59.4	61.9	32.4	80
118	60.9	59.5	62.5	32.9	93.2
120	60.5	60	63.4	31.6	100

Problem No.5.

CALCULATIONS.

Load Current	% of rated K. V. A.	Secondary volts in % of primary volts 1-2	2-3	1-3
0	0	100	100	100
7.5	36.3	102.8	98.2	99.2
10.5	37.8	103.1	98	97.5
15	53.5	104.7	97.5	96.5
17.5	62.3	105.5	96.2	96.2
20.5	71.8	105.7	95.5	96
23	80	106	95	95
25	86	106	94.5	94

Load Current	% of full load current	% of load current I_1	I_2	I_3	I_a	I_b
7.5	25	126.5	66.6	60.2	66.6	40
10.5	35	128.5	66.5	61.8	66.5	33.3
15	50	126	66.2	61.4	73.5	34.6
17.5	58.4	126	64	61.6	71.5	34.2
20.5	68.5	125	65	61	71	34
23	76.8	126	65.2	63	71.6	37
25	83.5	127	64	62	74	36

Problem No. 6.

Load Current	% rated K.V.A	Secondary volts in % of primary volts 1-2	1-3	2-3
0	0	100	100	100
6	21.6	100	99.5	99
9	32.5	100	99.5	98
12	43	100	99	97
15	53	100	98.5	96
18	62.6	100	98	95
21	72.7	100	97.6	94.5
24	81.6	100	97	94
27	89.4	100	97	92.6
30	98.6	100	97	92
33	106	100	97	91.3

Problem No. 7.

CALCULATIONS.

% full load current	Secondary volts in % of primary volts 1-2	1-3	2-3	Load current.
0	96.2	102	100	0
33.3	98	101.5	100	10
43.5	95.5	96.1	100	13
53.2	93.5	96.2	100	16
63.2	93.8	96	100	19
73.2	92.5	96	100	22
83.5	91.2	97.6	100	25
93.5	86	98.2	100	28
103.2	54	98	100	31

Amperes in neutral in % of full load current	% full load current	Load current.
15.3	0	0
8.3	33.3	10
6.3	43.5	13
4.7	53.2	16
4	63.2	19
5	73.2	22
6.7	83.5	25
8.7	93.5	28
10.7	103.2	31

Problem No. 8.

% full load current	Secondary volts in % of primary volts 1-2	1-3	2-3	Load current
0	99.6	100.5	100	0
33.3	96.5	98	100	10
50	95	96	100	15
60	94	97.5	100	18
70	93	97.5	100	21
80	87	99.5	99.6	24
90	85.5	99	99.2	27
95	50	100	88.7	28.6

Problem No. 9.

CALCULATIONS.

%K.V.A.	Secondary volts in % of primary volts 1-2	1-3	2-3	Load current
0	100	101	101	0
24.6	106	98	97	7
44.2	108.7	95.5	94.6	13
54.3	111	94.2	95.5	16
60.5	110	90.5	93.5	18
66.5	111.5	92.7	93	20
72	112.2	90.8	92	22
76	115	90.2	90.5	24
82.5	116	89	92.5	26
87	116	89	89.5	28
95	118	87.4	89.7	30
102	119	87	88.6	32

Problem NO. 10.

% of K.V.A.	Secondary volts in % of primary volts 1-2	1-3	2-3	Load current
110.1	121	86	88	32
98	119	85	88.2	30
93.2	117	85.6	90	28
87	114	88.5	91	26
80.8	114	90.5	92	24
74.6	113	91.5	92.7	22
68.7	113.5	93	93.5	20
62.4	111	93.2	94.4	18
52.5	110	94.5	95.2	15
36	105	97.4	98	10
0	100.4	101	101	0