A METHOD OF RELAY PROTECTION FOR THE POWER NETWORK OF THE OHIO EDISON COMPANY

Thesis for the Degree of M. S.

Orin D. Dausman

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THESIS

A METHOD OF RELAY PROTECTION FOR THE POWER NETWORK OF THE OHIO EDISON COMPANY.

A Thesis Submitted to

The Faculty of

MICHIGAN STATE COLLEGE.

By

Orin D. Dausman

Candidate for the Degree

of

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THESIS

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I.

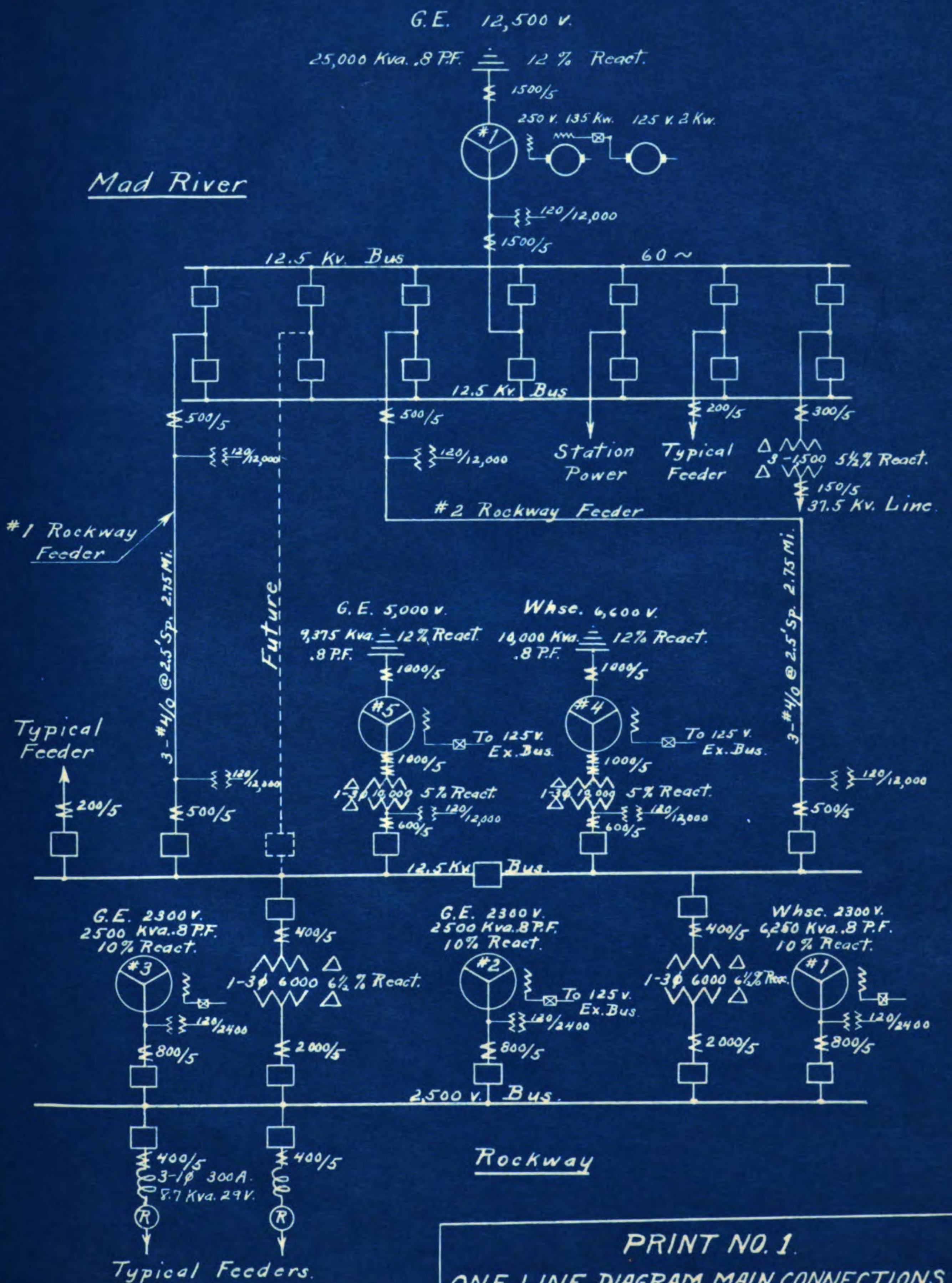
INTRODUCTION.

Statement of Problem.

The purpose of this investigation is to design, as a typical problem in Protective Engineering, a satisfactory system of relay protection for the power network of the Ohio Edison Company. The Ohio Edison Company, located at Springfield, Ohio, is one of the electrical operating companies controlled by the Commonwealth Power Corporation of Jackson, Michigan. The general information concerning the power system, and the data necessary for the design of the protective system were supplied by the Commonwealth Power Corporation.

The power system, as shown on the accompanying prints, consists of two generating stations, Mad River station and Rockway station, with feeders leading from each, a 37.5 kilovolt line from the Mad River station, and two 12.5 kilovolt connecting circuits between the two. The Rockway station is in operation at the present time, while the Mad River plant is under construction.

On print No. 1, page 2, may be found the ratings and transient reactance values of the various units of the power system, and the locations of oil circuit breakers, instrument transformers, etc. as provided by the Commonwealth Power Corporation.



PRINT NO. 1

ONE LINE DIAGRAM MAIN CONNECTIONS

MAD RIVER & ROCKWAY STATIONS

SHOWING SYSTEM REACTANCES

Acknowledgments.

At this time, the writer wishes to express his indebtedness to the Electrical Engineering Department of the Commonwealth Power Corporation, not only for submitting the data for the problem, but also for the valuable suggestions and for the use of their calculating table in the solution of the problem, and to Prof. L. S. Foltz and Prof. A. Naeter of the Department of Electrical Engineering at M. S. C. for their advice and instruction throughout.

II.

SOLUTION OF THE PROBLEM.

General Method of Procedure.

The first step in the solution of the problem was to determine the short-circuit currents throughout the system in case of a fault at any one of the various points of the system. These values of short-circuit current were first determined by the analytical method, and then, later, by means of the calculating table. In determining the current values by the analytical method, the system reactances were reduced to the ohmic basis, while the percent reactances at a definite kv.a. base were used for the calculating table work. These two methods of expressing the reactances were used in order that a better check on the analytical solution might be obtained when the calculating table was used. After the system reactances had been evaluated, the equivalent reactances for determining the short-circuit currents were obtained by a method of simplifying the circuit diagrams, step by step, as may be seen under the actual analytical solution. (See pages 10 to 21.)

The analytical method of solution was roughly checked experimentally. An equivalent system, using common laboratory type resistance boxes, was set up. With a definite voltage applied on the system, the current was measured in various parts of the system. The result of this experimental determination of short-circuit current may be found on pages 22 -25. The values of the short-circuit current obtained by experiment checked very closely with those obtained by the analytical method.

The determination of the short-circuit currents by means of the calculating table was carried on in conjunction with Mr. C. W. Methfessel at the Jackson office of the Commonwealth Power Corporation. The results of these determinations are found on pages 26-31. It may be noticed that these short-circuit currents do not check very well with those obtained by the analytical method. This is not because of errors in either method of solution, but rather because more accurate reactance values were obtained for some of the units, two of the Rockway teneraters (G_1 & G_5) were removed from service, and larger transformers were installed between the 12.5 and the 2.5 kilovolt busses of the Rockway station between the time that the original data was obtained and the time that the calculating table was used. These revised values of reactance are the ones shown on print No. 1, and the ones actually used in determining the final relay settings.

Since, in order to determine the proper relay settings, it is necessary to know the values of the short-circuit currents under minimum operating conditions as well as the maximum conditions, the minimum short-circuit current values were next obtained. These may be found on pages 32-34.

After the short-circuit currents were determined, the method of protection to be used at the different points in the system were determined. This was accomplished by making a study of the various possible schemes of protection for the types of apparatus used in this power system, and by selecting the most satisfactory scheme. The comparative advantages and disadvantages of the schemes considered, along with the selected schemes, may be found on pages 35-45. The

general method of protection for the entire system is shown on Print No. 2, page 7.

Following the detemination of the proper type of relay protection, all that remained was to determine the relay settings and to draw the diagrams. The necessary settings to give proper selectivity under all short-circuit conditions are given on pages 46 and 47. The time settings were determined from the curves given on page 113 of the ''Relay Handbook'' (1926 edition), published by the N.E.L.A. These are average curves for Westinghouse, type CO, overcurrent, inverse and definite minimum time relay elements. The settings were determined to accomplish the following results:

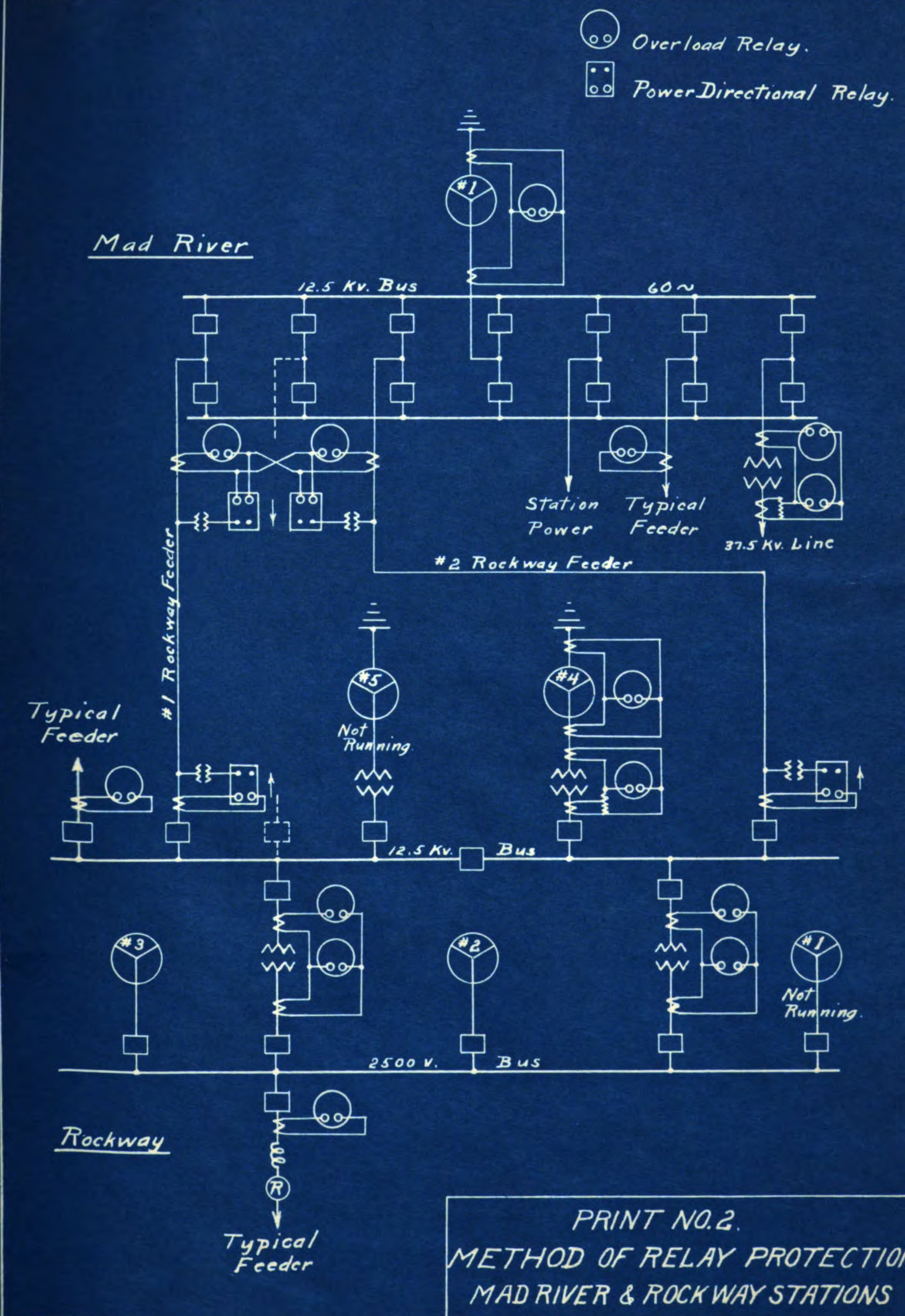
a. Give proper selective action under maximum, minimum, and other short-circuit conditions.

b. Clear maximum short circuit in less than 2.0 seconds.

c. Clear trouble under minimum short-circuit conditions.

d. Carry maximum full load.

e. Clear all trouble with least amount of disturbance.



PRINT NO. 2.
METHOD OF RELAY PROTECTION
MAD RIVER & ROCKWAY STATIONS

Short Circuit Calculations.

(Analytical Method).

Circuit Reactance Reduced to 12.5 kv. Basis.

Mad River

G_1 25,000 kv.a. 12.5 kv. 13% react. on rating.

Full load current = $\dfrac{25{,}000 \times 1{,}000}{12.5 \times 1{,}000 \times 53}$ = 1,155 amperes.

Voltage to neutral $\dfrac{12{,}500}{\sqrt{3}}$ = 7,225 volts.

Generator react. = 13% = $\dfrac{.13 \times \text{voltage}}{\text{current}}$

$$= \frac{.13 \times 12{,}500 \times 12.5 \times 1{,}000 \times \sqrt{3}}{\sqrt{3} \times 25{,}000 \times 1{,}000} = .8125 \text{ ohm.}$$

Transformer on 37.5 kv. line.

3 - 1,500 kv.a. 12.5 to 37.5 kv. 5% react. on rating.

Trans. react. = 5% = $\dfrac{.05 \times \text{voltage to neutrals}}{\text{full load current (at 12.5 kv.)}}$

$$= \frac{.05 \times 12{,}500 \times 12.5 \times 1{,}000 \times \sqrt{3}}{\sqrt{3} \times 3 \times 1{,}500 \times 1{,}000} = 1.736 \text{ ohms.}$$

Rockway Feeders.

No. 1 and No. 2 are similar, each consisting of 3 - No. 4/0 at 2.5' spacing, 2.75 miles long.

Reactance/mile of each conductor = .620 ohm.

React. of each feeder = 2.75 x .620 = 1.705 ohms/wire.

Rockway Station.

G_1 2,300 V. 6,250 kv.a. 12% react. on rating.

Reactance = $\dfrac{.12 \times \text{voltage to neutral}}{\text{full load current}}$

$$= \frac{.12 \times 2{,}300 \times 2.3 \times 1{,}000 \times \sqrt{3}}{\sqrt{3} \times 6{,}250 \times 1{,}000} = .1016 \text{ on 2,300 V.}$$

Reactance at 12.5 kv. = $.1016 \times \left(\frac{12.5}{2.3}\right)^2$ = 3.0 ohms.

G_2-G_3 2,300 V. 2,500 kv.a. 12% reactance on rating.

Reactance = $\frac{.12 \times 2{,}300 \times 2.3 \times 1{,}000 \times \sqrt{3}}{\sqrt{3} \times 2{,}500 \times 1{,}000}$ = .254 at 2300 V.

Reactance at 12.5 kv. = $.254 \times \left(\frac{12.5}{2.3}\right)^2$ = 7.50 ohms.

G_4 6600 V. 10,000 kv.a. 8% react. on rating.

Reactance at 6,600 V. = $\frac{.08 \times \text{voltage to neutral}}{\text{full load current}}$

$= \frac{.08 \times 6{,}600 \times 6.6 \times 1{,}000 \times \sqrt{3}}{\sqrt{3} \times 10{,}000 \times 1{,}000}$ = .3485 ohm.

Reactance at 12.5 kv. = $.3485 \times \left(\frac{12.5}{6.6}\right)^2$ = 1.250 ohms.

G_5 5,000 V. 9,375 kv.a. 8% react. on rating.

Reactance at 5,000 V. = $\frac{.08 \times 5{,}000 \times 5 \times 1{,}000 \times \sqrt{3}}{\sqrt{3} \times 9{,}375 \times 1{,}000}$ = .2134 ohm.

Reactance at 12.5 kv. = $.2134 \times \left(\frac{12.5}{5}\right)^2$ = 1.334 ohms.

Transformers to G_4 & G_5.

12.5 kv., 10,000 kv.a. 5% react. on rating.

Reactance = $\frac{.05 \times 12{,}500 \times 12.5 \times 1{,}000 \times \sqrt{3}}{\sqrt{3} \times 10{,}000 \times 1{,}000}$ = .782 ohm.

Transformers between 2.5 & 12.5 kv. Busses.

3 - 1,000 kv.a. 6-1/2% react. on rating.

Reactance = $\frac{.065 \times 12{,}500 \times 12.5 \times 1{,}000 \times \sqrt{3}}{\sqrt{3} \times 3{,}000 \times 1{,}000}$ = 3.39 ohms.

3 - 2,000 kv.a. 6-1/2% react. on rating.

Reactance = 50% of 1,000 kv.a. size = .5 x 3.39 = 1.695 ohms.

Reactors in 2,500 V. feeders.

$X = \frac{E}{I} = \frac{29}{300}$ = .0967 ohm at 2,500 V.

Reactance at 12.5 kv. = $.0967 \times \left(\frac{12.5}{2.5}\right)^2$ = 2.4175 ohms.

Determination of Short-Circuit Current in Case of a Fault on the 37.5 Kv. Line from the Mad River Station.

(All Switches Closed)

The complete simplified diagram of the Ohio Edison System, showing the circuit reactances reduced to the 12.5 kv. (Ohmic) basis, is shown in Fig. 1 on the following page. The succeeding figures show the method of simplification of this diagram in order to obtain the resulting single equivalent reactance for the system.

Fig. 2 is a more simple diagram of the system, showing only those circuits along which power may flow in case of a fault at ''X'', and the equivalent reactances for the different portions of these circuits.

Fig. 3 represents Fig. 2 converted into a simple network. In Fig. 4, the parallel paths of Fig. 3 have been replaced by their equivalent circuits. The method of combining these reactances is the simple method used in combining parallel resistances in D.C. circuits, since the powerfactor is being neglected in these computations. The equivalent reactances of the generators are also shown in Fig. 4.

Fig. 5 is a reproduction of Fig. 4 with the generators replaced by their equivalent reactances and connected at the common point ''O''. The successive figures from Fig. 5 to 10 show the steps in the simplification of the network to the final equivalent reactance of 2.275 ohms.

Short-Circuit Current, $I_{sc} = \frac{12,500}{\sqrt{3} \times 2.275} = \underline{3,165 \text{ amperes.}}$

Current delivered by Mad River generator,

$$I_{G_1'} = \frac{X}{X_{G_1'}} \times I_{sc} = \frac{.539}{.8125} \times 3,165 = \underline{2,100 \text{ amperes}}$$

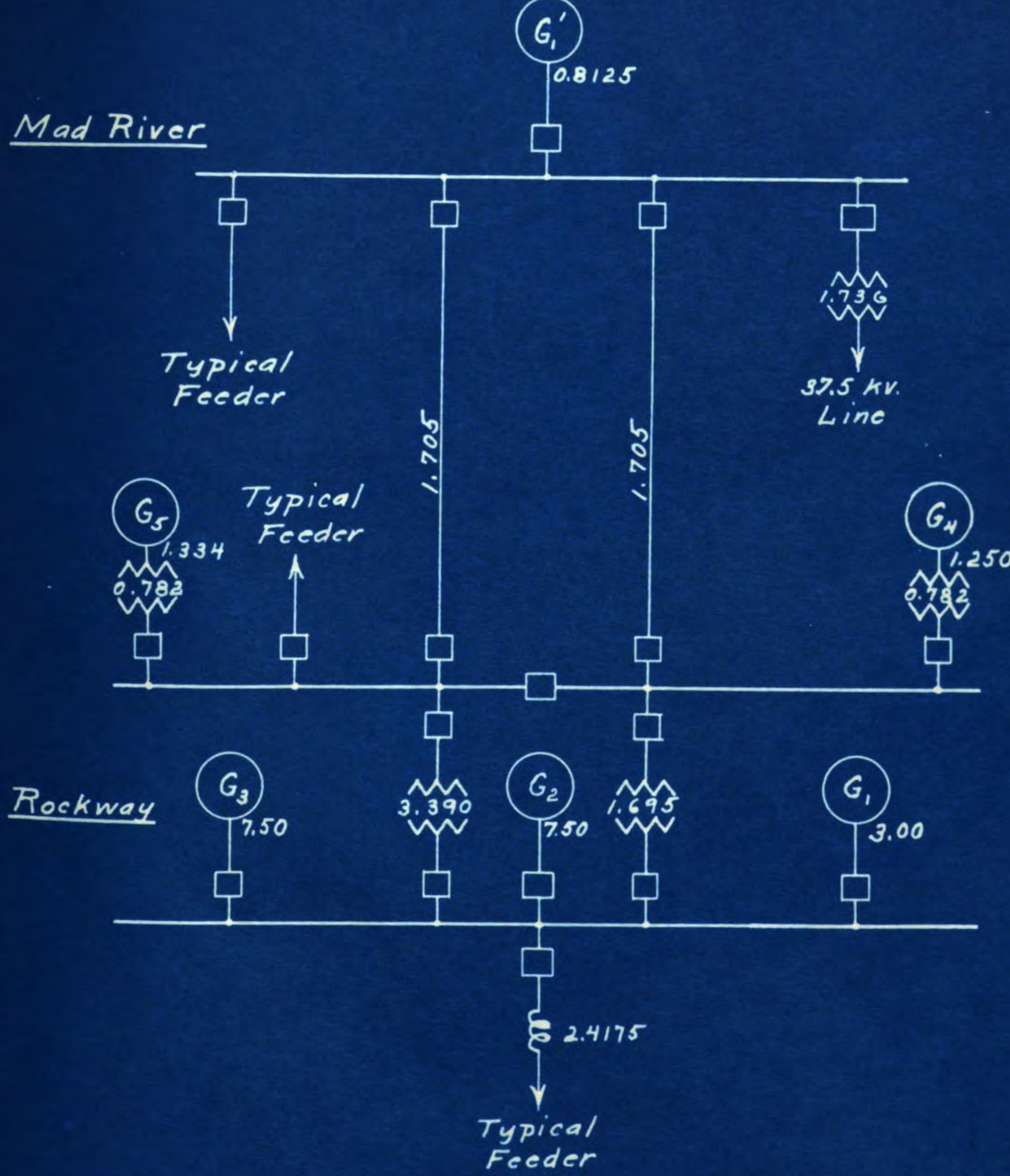

G1'
0.8125
Mad River
Typical Feeder
1.705
1.705
1.736
37.5 kv. Line
G5
1.334
0.782
Typical Feeder
G4
1.250
0.782
Rockway
G3
7.50
3.390
G2
7.50
1.695
G1
3.00
2.4175
Typical Feeder

Fig. 1.

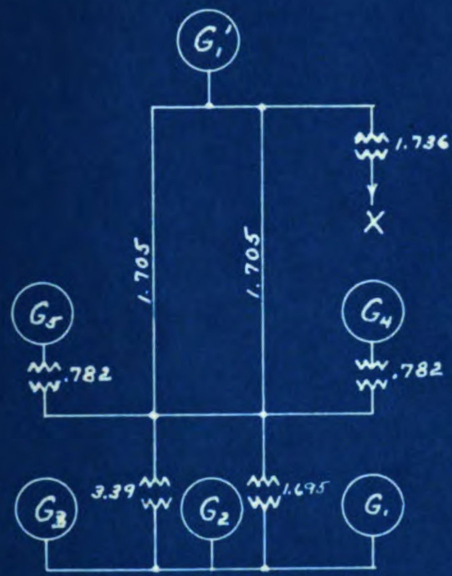


Fig. 2.

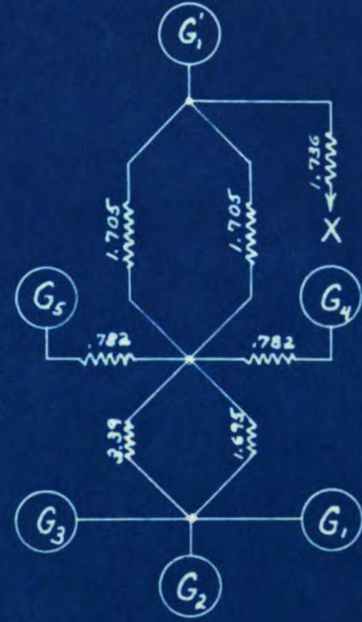


Fig. 3.

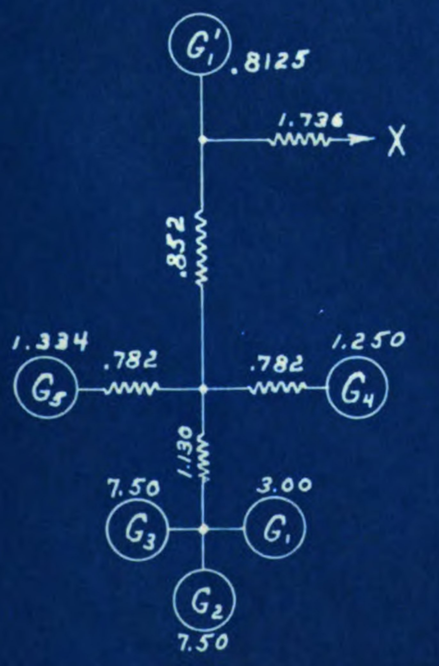


Fig. 4.

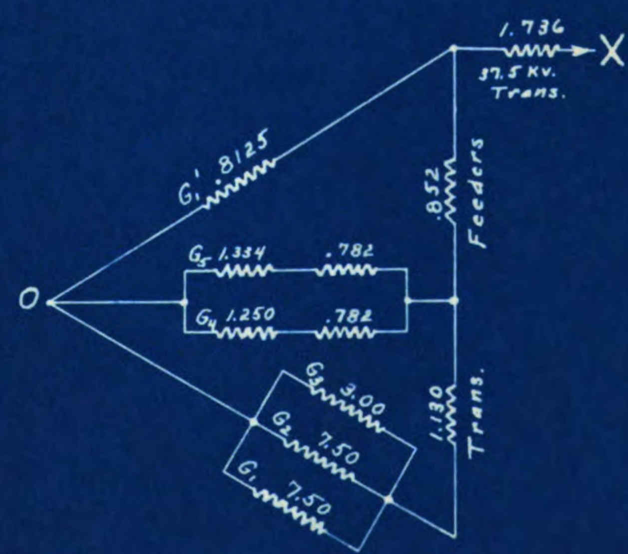


Fig. 5.

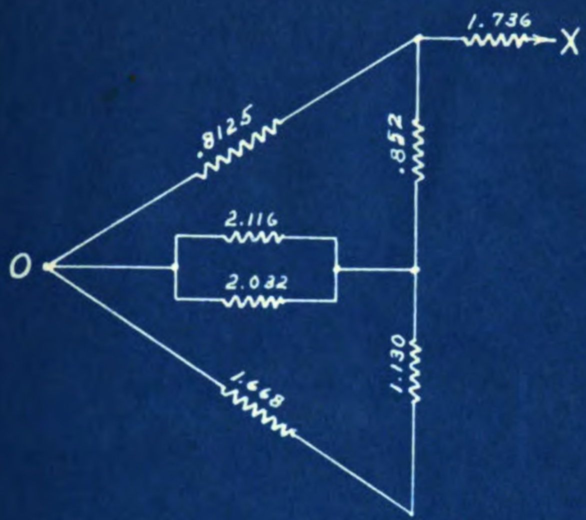


Fig. 6.

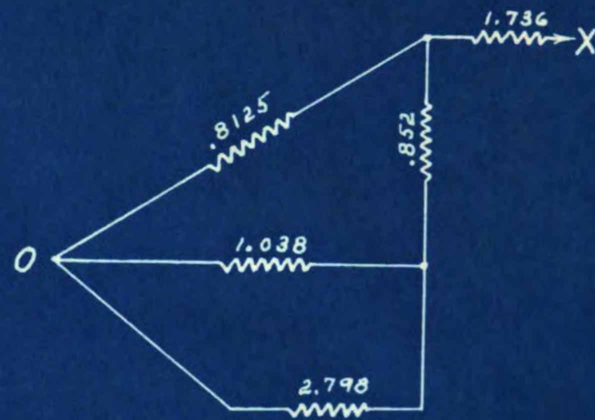


Fig. 7.

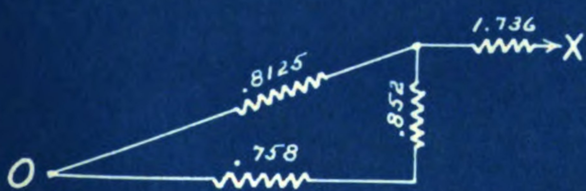


Fig. 8.

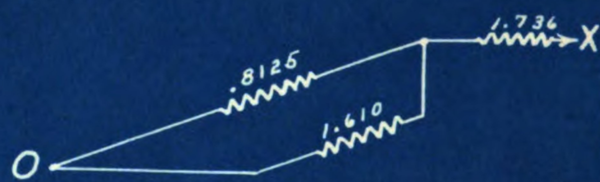


Fig. 9.

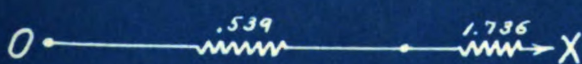


Fig. 10.

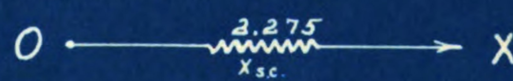


Fig. 11.

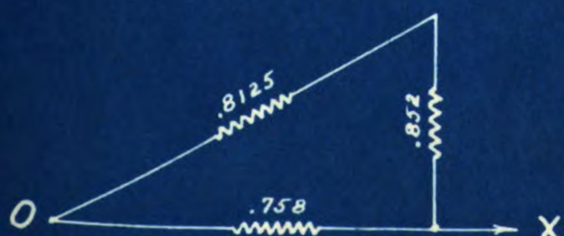


Fig. 12.

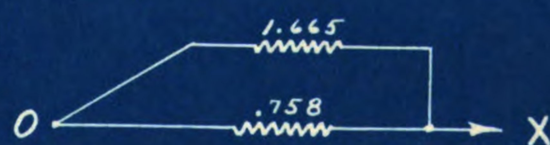


Fig. 13.

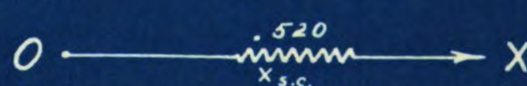


Fig. 14.

Current delivered by Rockway Station,

$$I_{Rockway} = \frac{X}{X_{Rockway}} \times I_{sc} = \frac{.539}{1.610} \times 3,165 = \underline{1,065 \text{ amperes}}$$

Current delivered by each Rockway Feeder,

$$I_{Rock\text{-}Feeder} = I_{Rockway} \div 2 = 1065 \div 2 = \underline{532.5 \text{ amperes}}$$

All the above currents are found on the 12,500 volt basis.

The actual current in the transmission line is

$$I_{sc \text{ at } 37.5 \text{ kv.}} = \frac{12,500}{37,500} \times 3,165 = \underline{1,055 \text{ amperes}}$$

Determination of Short-Circuit Current in Case of a Fault at the Mad River Bus or Any Circuit Directly Connected to the Bus.

(All switches closed.) (All based on 12.5 kv.)

The total reactance in this case is the total reactance as found in this case is the total reactance as found in the case for the 37.5 kv. line minus the reactance of the 37.5 kv. transformers. Referring back to Fig. 10,

X_{sc} = .539 ohms.

Short-Circuit Current,

$$I_{sc} = \frac{12,500}{\sqrt{3} \times .539} = \underline{13,380 \text{ amperes.}}$$

Current delivered by Mad River Generator,

$$I_{G_1'} = \frac{X_{sc}}{X_{G_1'}} \times I_{sc} = \frac{.539}{.8125} \times 13,380 = \underline{8,880.}$$

Current delivered by Rockway Station,

$$I_{Rockway} = \frac{X_{sc}}{X_{Rockway}} \times I_{sc} = \frac{.539}{1.610} \times 13,380 = \underline{4,500}$$

Current delivered by each Rockway Feeder,

$$I_{Rockway\ Feeder} = I_{Rockway} \div 2 = 4500/2 = \underline{2,250}$$

Current delivered to 12,5 kv. Bus by G_4 & G_5,

$$I_{G_4+G_5} = \frac{X \text{ Rockway Station}}{X \text{ 12.5 kv.}} \times I_{Rockway} = \frac{.758}{1.038} \times 4,500 = \underline{3,295}.$$

Current delivered to 12,5 kv. Bus from 2.5 kv. bus,

$$I_{2.5\ kv.} = \frac{X \text{ Rockway St.}}{X \text{ 2.5 kv.}} \times I \text{ Rockway} = \frac{.758}{2.798} \times 4,500 = \underline{1,205.}$$

Based on 12.5 kv.

$$I_{G4} = \frac{X \text{ 12.5 kv.}}{X_{G4} + \text{trans}} \times I_{G4\ \&\ G5\ \&\ \text{trans.}} = \frac{1.038}{2.032} \times 3,295 = \underline{1,665}$$

$$I_{G5} = \frac{X \text{ 12.5 kv.}}{X_{G5} + \text{trans}} \times I_{G4\ \&\ G5\ \&\ \text{trans.}} = \frac{1.038}{2.116} \times 3,295 = \underline{1,630}$$

$$I_{2000\ kva.\ trans.} = \frac{X \text{ trans.}}{X_{2000\ kva.\ trans.}} \times I_{2.5\ kv.} = \frac{1.130}{1.695} \times 1,205 = \underline{803}$$

$$I_{1000 kva.} = \frac{X \text{ trans.}}{X_{1000\ kva.\ trans.}} \times I_{2.5\ kv.} = \frac{1.130}{3,39} \times 1,205 = \underline{402}$$

Determination of Short-Circuit Current in Case of a Fault on the 12.5 kv. Bus at Rockway Stations.

(All Switches Closed.) (All Based on 12,500 V.)

By referring back to figure 2 to 8 and comparing figure 8 with figure 12, it will be seen that figure 12 represents the system with a fault on the 12.5 kv. bus at "X".

The final equivalent short-circuit reactance is .520 ohms as represented by Fig. 14.

Short-Circuit Current,

$$I_{sc} = \frac{12,500}{\sqrt{3} \times .520} = \underline{13,850 \text{ amperes.}}$$

Current delivered by Mad River Generator,

$$I_{G'_1} = \frac{X_{sc}}{X \text{ To Mad River}} \times I_{sc} = \frac{.520}{1.665} \times 13,850 = \underline{4,325}.$$

Current delivered by each Rockway Feeder,

$$I_{\text{Rockway Feeder}} = I_{G'_1} \div 2 = 4,325/2 = 2,162.$$

Current delivered by Rockway Station,

$$I_{\text{Rockway}} = \frac{X_{sc}}{X \text{ Rockway}} \times I_{sc} = \frac{.520}{.758} \times 13,850 = \underline{9,520.}$$

Current delivered to Bus by G_4 & G_5,

$$I_{G4 + G5} = \frac{X \text{ Rockway}}{X_{G4 + G5 \text{ trans.}}} \times I_{\text{Rockway}} = \frac{.758}{1.038} \times 9,520 = \underline{6,930.}$$

Current delivered from 2.5 kv. Bus.

$$I_{2.5 \text{ kv.}} = \frac{X_{\text{Rockway}}}{X_{2.5 \text{ kv.} + \text{ trans.}}} \times I_{\text{Rockway}} = \frac{.758}{2.788} \times 9,520 = \underline{2,590}.$$

$$I_{G4} = \frac{X_{G4 + G5 \text{ \& trans.}}}{X_{G4 \text{ \& trans.}}} \times I_{G4 + G5} = \frac{1.038}{2.032} \times 6,930 = \underline{3,530}.$$

$$I_{G5} = \frac{X_{G4+G5 \text{ \& trans.}}}{X_{G5 \text{ \& trans.}}} \times I_{G4 + G5} = \frac{1.038}{2.116} \times 6,930 = \underline{3,400.}$$

$$I_{\substack{2000\ kva. \\ trans.}} = \frac{X\ trans.}{X_{2000\ kva}} \times I_{2.5\ kv.} = \frac{1.130}{1.695} \times 2,590 = \underline{1,727.}$$

$$I_{\substack{1000\ kva. \\ trans.}} = \frac{X\ trans.}{X_{1000\ kva.}} \times I_{2.5\ kv.} = \frac{1.130}{3.39} \times 2,590 = \underline{863.}$$

$$I_{G_1} = \frac{X_{G_1+G_2+G_3}}{X_{G_1}} \times I_{2.5\ kv.} = \frac{1.668}{3.00} \times 2,590 = \underline{1,440.}$$

$$I_{G_2} = \frac{X_{G_1+G_2+G_3}}{X_{G_2}} \times I_{2.5\ kv.} = \frac{1.668}{7.50} \times 2,590 = \underline{575.}$$

$$I_{G_3} = \underline{X_{G_1+G_2+G_3}} \times I_{2.5\ kv.} = \frac{1.668}{7.50} \times 2,590 = \underline{575.}$$

Determination of Short-Circuit Current in Case of a Fault on the 2,500 V. Bus at Rockway Station.

(All Switches Closed.) (All based on 12,500 V.)

By referring to Figs. 2 to 6 and comparing with No. 15, it will be seen that Fig. 15 represents the system with a fault on the 2,500 V. bus. Figs. 15 to 19 show the simplification of the system until the short circuit reactance of .858 ohms is obtained.

Short-Circuit Current,

$$I_{sc} = \frac{12,500}{\sqrt{3} \times .858} = \underline{8,400 \text{ amperes.}}$$

Current delivered by G_1, G_2, G_3,

$$I_{2,500\ V} = \frac{X_{sc}}{X_{2500\ V}} \times I_{sc} = \frac{.858}{1.668} \times 8,400 = \underline{4,320}.$$

Current to fault from 12.5 kv. Bus,

$$I_{12.5\ kv.} = \frac{X_{sc}}{X_{12.5\ kv.}} \times I_{sc} = \frac{.858}{1.768} \times 8,400 = \underline{4,080}.$$

$$I_{G_1} = \frac{X_{2500\ V}}{X_{G_1}} \times I_{2500\ V.} = \frac{1.668}{3.00} \times 4,320 = \underline{2,400}.$$

$$I_{G_2} = \frac{X_{2500\ V}}{X_{G_2}} \times I_{2500\ V.} = \frac{1.668}{7.50} \times 4,320 = \underline{960.}$$

$$I_{G_3} = \frac{X_{2500\ V}}{X_{G_3}} \times I_{2500\ V.} = \frac{1.668}{7.50} \times 4,320 = \underline{960.}$$

Current flowing between 12.5 kv. & 2500 V. Busses.

$$I_{\substack{2000\ kva. \\ trans.}} = \frac{X\ trans.}{X_{\substack{2000\ kva. \\ trans.}}} \times I_{12.5\ kv.} = \frac{1.130}{1.695} \times 4,080 = \underline{2,720.}$$

$$I_{\substack{1000\ kva. \\ trans.}} = \frac{X\ trans.}{X_{\substack{1000\ kva. \\ trans.}}} \times I_{12.5\ kv.} = \frac{1.130}{3.39} \times 4,080 = \underline{1,360.}$$

Current supplied to 12.5 kv. Bus by G_5 & G_4.

$$I_{G_5+G_4} = \frac{X_{12.5\ kv.}\ trans.}{X_{\substack{G_5+G_4\ \& \\ trans.}}} \times I_{12.5\ kv.} = \frac{.638}{1.038} \times 4,080 = \underline{2,515.}$$

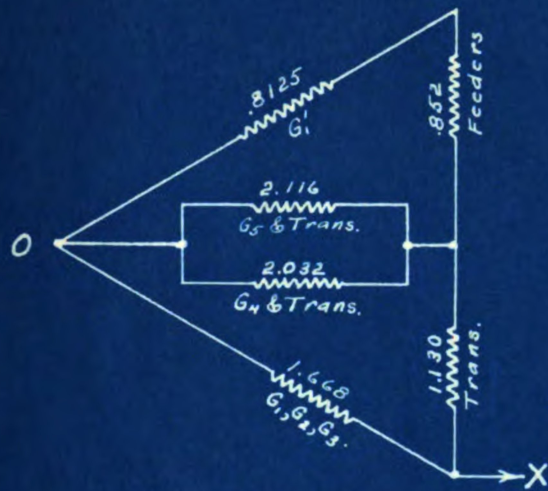


Fig. 15.

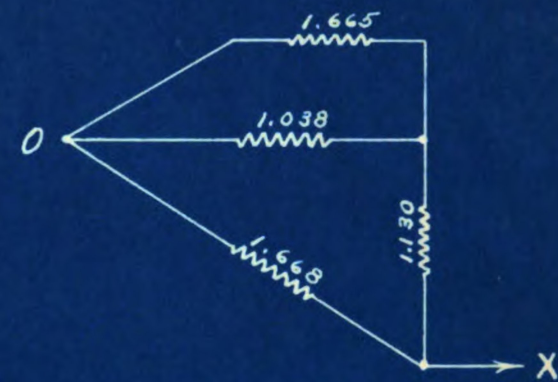


Fig. 16.

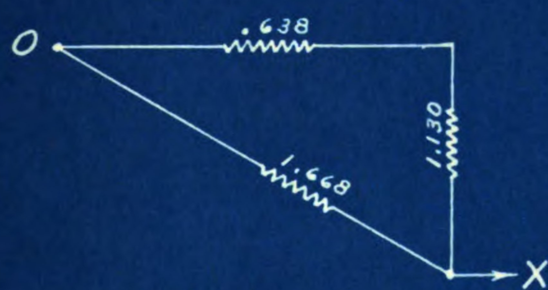


Fig. 17.

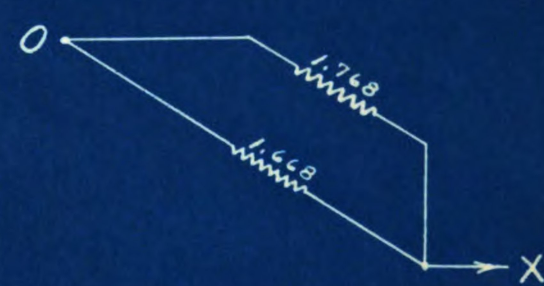


Fig. 18.

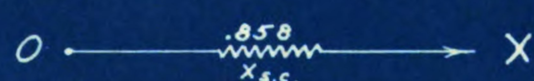


Fig. 19.

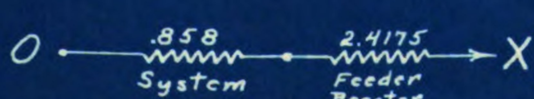


Fig. 20.

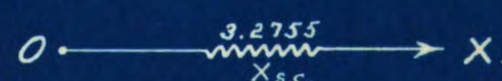


Fig. 21.

$$I_{G_4} = \frac{X_{G4+G5 \text{ trans.}}}{X_{G4 \text{ \& trans.}}} \times I_{G_4+G_5} = \frac{1.038}{2.032} \times 2,515 = \underline{1,290.}$$

$$I_{G_5} = \frac{X_{G4+G5 \text{ \& trans.}}}{X_{G5 \text{ \& trans.}}} \times I_{G_4+G_5} = \frac{1.025}{2.116} \times 2,515 = \underline{1,225.}$$

Current supplied from Mad River Station,

$$I_{G_1} = \frac{X_{\text{12.5 kv.-trans.}}}{X_{\text{Mad River \& Rockway Feeders}}} \times I_{12.5 \text{ kv.}} = \frac{.638}{1.665} \times 4,080 = 1,565.$$

Current delivered by each Rockway Feeder,

$$I_{\text{Rockway Feeder}} = I_{G_1} \div 2 = 1,565 \div 2 = \underline{782.5}$$

Determination of Short-Circuit Current in Case of a

Fault on a 2,500 V. Reactance Protected Feeder.

(All Switches Closed.) (All based on 12,500 V.)

The short-circuit reactance for the 2,500 V. feeder is equal to the short-circuit reactance for the 2500 V. bus plus the reactance of the current limiting reactance, as illustrated by figures 20 and 21.

$$I_{sc} = \frac{12{,}500}{\sqrt{3} \times 3.2755} = \underline{2{,}200 \text{ amperes.}}$$

This value is 26.2% of the short-circuit value on the 2500 V. bus. Therefore, all the other values will be 26.2% of their corresponding bus short-circuit values.

Current delivered by G_1, G_2, & G_3 = 26.2% of 4,320 = 1,132.

Current to fault from 12.5 kv. bus = 26.2% of 4,080 = 1,070.

I_{G_1}	= 26.2% of	2,400 =	629.
I_{G2}	= 26.2% of	960 =	251.
I_{G_3}	= 26.2% of	960 =	251.
$I_{2000 \text{ kva. trans.}}$	= 26.2% of	2,720 =	731.
$I_{1000 \text{ kva. trans.}}$	= 26.2% of	1,360 =	356.
$I_{G_4 + G_5}$	= 26.2% of	2,515 =	659.
I_{G4}	= 26.2% of	1,290 =	338.
I_{G5}	= 26.2% of	1,225 =	321.
$I_{G'_1}$	= 26.2% of	1,565 =	410.

Current delivered by each Rockway Feeder

= 26.2% of 782.5 = 205.

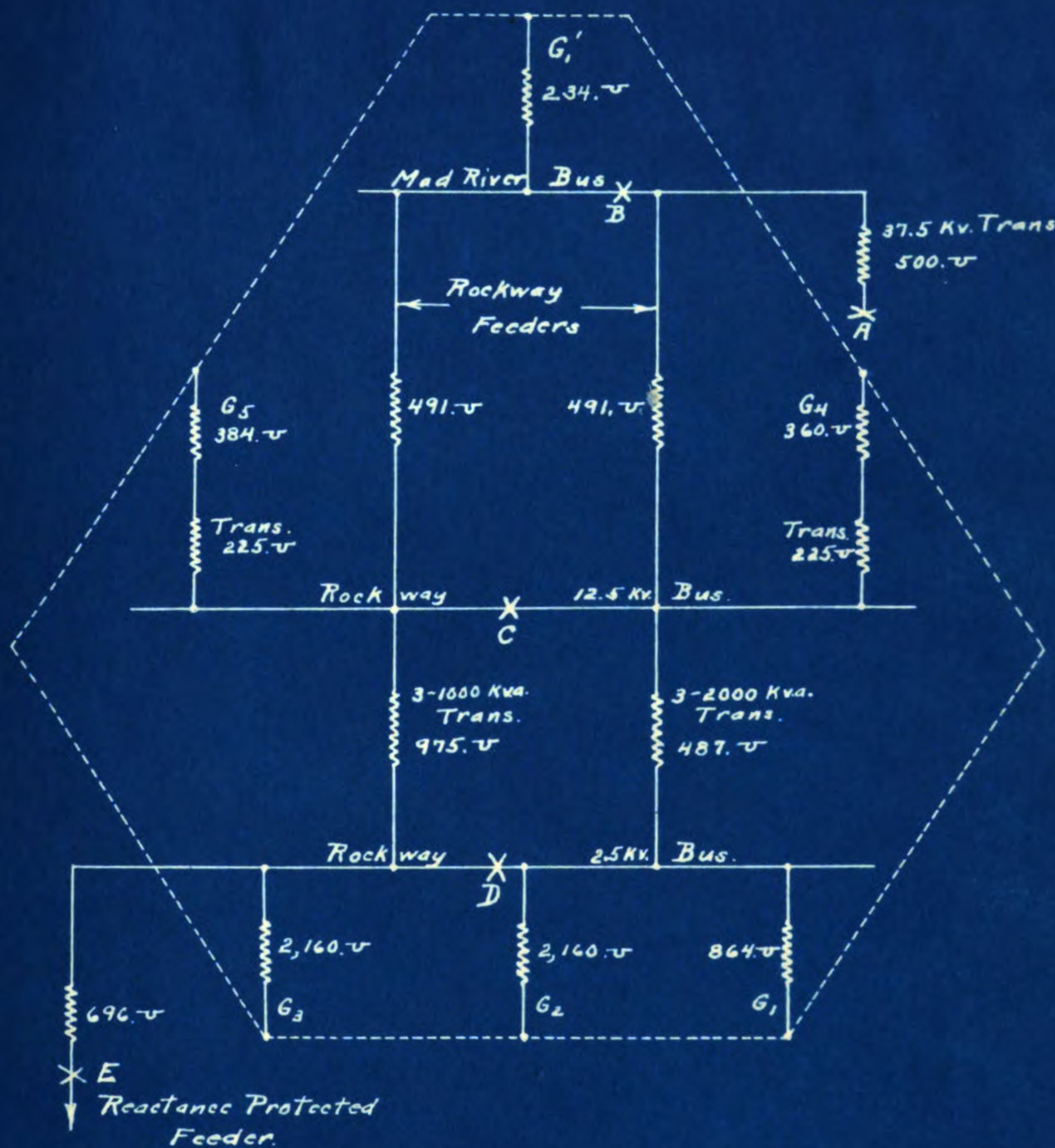


Fig. 22. Equivalent Circuit Diagram for Experimental Determination of Short-Circuit Currents.

System Reactances

For Experimental Determination of Short-Circuit Currents.

Unit.	Kva. Capacity	% React. at Rating	% React. at 45,000 kva.
G'_1	25,000	13%	23.4%
G_1	6,250	12%	86.4%
G_2	2,500	12%	21.6%
G_3	2,500	12%	21.6%
G_4	10,000	8%	36.0%
G_5	9,375	8%	38.4%
Trans. G_4	10,000	5%	22.5%
Trans. G_5	10,000	5%	22.5%
Trans. 37.5 kv.	4,500	5%	50.0%
Trans. 12.5-2.5 1000	3,000	6-1/2%	97.5%
Trans. 12.5-2.5 2000	6,000	6-1/2%	48.7%
Rockway Feeder		1.705 ohms at 12.5 kv.	49.1%
Reactance Protected Feeder		2.4175 ohms at 12.5 kv.	69.6%

Values of resistance used in the experiment and indicated on the diagrams, Fig. 22, are equal to 10 x % reactance based on 45,000 kv.a. as shown above.

E = volts applied between Generators and Fault at A, B, C, etc.

I = milliamperes in circuits as recorded.

Location of Fault	Circuit Considered.	E.	$I_{D.C.}$	S.C. Current $I_{D.C.}$ x 164
A	A	12.65	19.0	3,120
	G'_1	12.65	12.5	2,050
	Rockway Feeders	12.65	6.5	1,068

Location of Fault	Circuit Considered.	E	$I_{D.C.}$	S.C. Current $I_{D.C.}$ x 164
B	B	12.65	78.0	12,800
	G'_1	12.65	52.0	8,540
	Rockway Feeders	12.65	26.	4,270
	G_4	12.65	10.	1,640
	G_5	12.65	9.	1,475
	3-2000 kva. trans.	12.65	4.5	738
	3-1000 " "	12.65	2.25	369
C	C	12.6	80.25	13,150 (x 164.5)
	Rockway Feeders	12.6	24.25	4,025
	G_4	12.6	21.0	3,450
	G_5	12.6	20.0	3,290
	3-2000 trans.	12.6	10.0	1,645
	3-1000 trans.	12.6	5.0	822
	G_1	12.6	8.25	1,355
	G_2	12.6	3.25	535
	G_3	12.6	3.25	535
D	D	12.6	49.0	8,060
	G_1	12.6	14.0	2,310
	G_2	12.6	6.0	986
	G_3	12.6	6.0	986
	3-1000 trans.	12.6	8.0	1,315
	3-2000 trans.	12.6	16.0	2,630
	G_4	12.6	7.5	1,232
	G_5	12.6	7.0	1,151
	Rockway Feeders	12.6	9.5	1.562

Location of Fault	Circuit Considered.	E	$I_{D.C.}$	S.C. Current $I_{D.C.}$ x 164.5
E	E	12.6	15.0	2,465

Determination of multiplier for converting D.C. milliamperes as read in the experimental equivalent system to short-circuit current.

At the base of 45,000 kv.a. and 12.5 kv. the full load current will be

$$\frac{45,000 \times 1,000}{12,500 \times \sqrt{3}} = 2,075 \text{ amp.}$$

Since 100% system reactance is represented by 1,000 ohms in the experimental circuit, the constant of the set-up at 12,65 volts corresponding to 100% reactance is

$$I = \frac{12.65}{1,000} = .01265 \text{ amp., or } 12.65 \text{ milliamperes,}$$

$$\therefore \text{ One milliampere represents } \frac{2,075}{12.65} = 164 \text{ amp.}$$

and likewise when E = 12.6, one M.A. represents $\frac{2,075}{12.6} = 164.5$ amp.

Short Circuit Calculations by Means of the Calculating Table.

System Reactances for Short-Circuit Calculations.

Unit.	Kva. Capacity	% React. at Rating	% React. at 100,000 Kva.
G'_1	25,000	12	48
G_1 (not running)	6,250	10	160
G_2	2,500	10	400
G_3	2,500	10	400
G_4	10,000	12	120
G_5 (not running)	9,375	12	125
Trans. G_4	10,000	5	50
Trans. G_5	10,000	5	50
Trans. 37.5 kv.	4,500	5-1/2	122
Trans. 12.5-2.5 kv. each	6,000	6.5	108
Rockway Feeder	1.705 ohms at 12.5 kv.		100
React. Protected Feeder	1,300	2.01	155

Sheet No. 1.

COMMONWEALTH POWER CORPORATION OF MICHIGAN

Electrical Engineering Department
Jackson, Michigan.

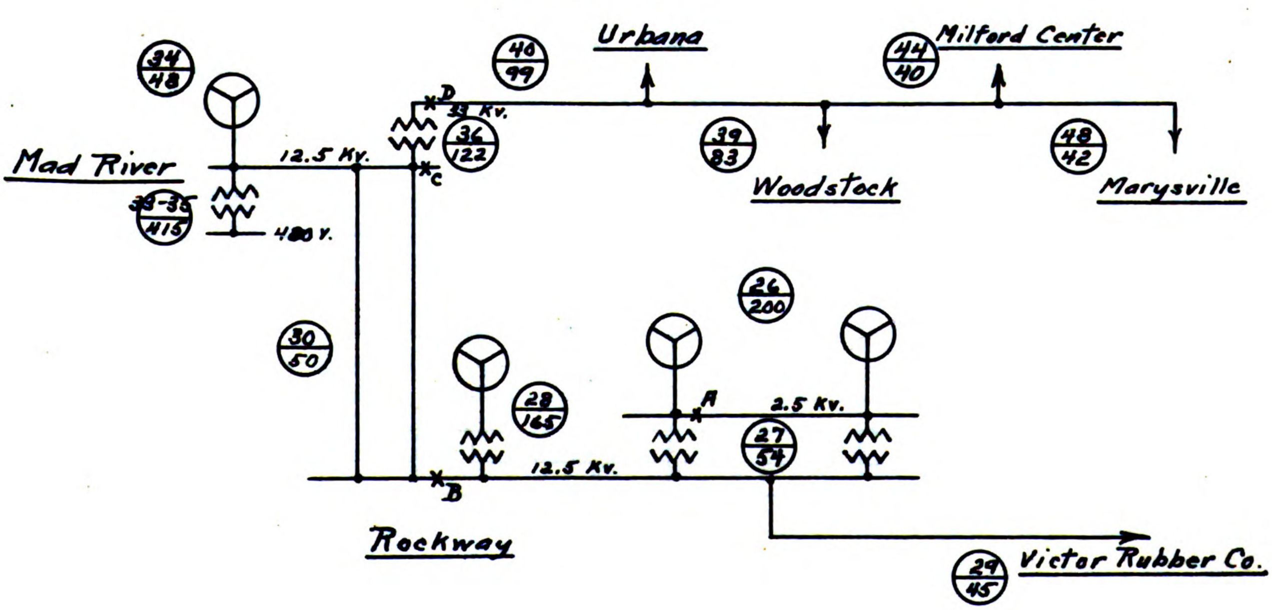
SHORT CIRCUIT CALCULATION

OPERATING CO. *Ohio Edison Co.* WO ______ S.C.Calc.No. *36.*
STATION *System* Cycles *60* Made by *C.W.M.-A.D.D.* Date *1-25-27.*
BASIS OF CALCULATION References ______
( ) Present ( ) Ultimate (✓) *1927* KVA Base *100,000*
PURPOSE OF CALCULATION
(✓) OCB Application ( ) Bus Stresses (✓) Relay Settings ______
( ) Reactor " ( ) P.T. Resistors ( ) Trouble Report ______
( ) ______
RECOMMENDATIONS

SUMMARY OF CALCULATIONS
KVAs DUE TO SHORT CIRCUITS AT VARIOUS POINTS

Circuit	S.C.at *A*	S.C.at *B*	S.C.at *C*	S.C.at *D.*	S.C.at	S.C.at	S.C.at
T	*135,000*	*200,000*	*273,000*	*61,000*			
26	*50,000*						
27	*86,000*	*41,000*	*29,000*	*5,000*			
28	*34,000*	*60,000*	*41,000*	*8,000*			
30	*51,000*	*100,000*	*68,000*	*14,000*			
34			*205,000*	*48,000*			

ONE LINE DIAGRAM



Sheet No. 2.

COMMONWEALTH POWER CORPORATION OF MICHIGAN

Electrical Engineering Department
Jackson, Michigan.

SHORT CIRCUIT CALCULATION

OPERATING CO. Ohio Edison Co. WO ________ S.C.Calc. No. 36.
STATION 1927 System Cycles 60 Made by ADD.-CWM. Date 1-25-27
KVA_s Constant = KVA base x 100 = 10^7

S.C. at Rockway 2.5 Kv.				S.C. at Mad River 33 Kv				S.C. at Mad River 480 v				S.C. at			
Cir-cuit	Meter readg	Calculated KVA_s	Calculated I_s	Cir-cuit	Meter readg	Calculated KVA_s	Calculated I_s	Cir-cuit	Meter readg	Calculated KVA_s	Calculated I_s	Cir-cuit	Meter readg	Calculated KVA_s	Calculated I_s
		26/27				36/40				33-35/-					
T	.0135	125,000	21,200	T	.0061	61,000	2,810	T	.0022	22,000					
26	.0050		11,500	34	.0048		2,220	34	.0018	18,000					
27	.0086		3,970	30	.0014		646	30	.0004	4,000					
28	.0034		1,570	28	.0008		369								
30	.0051		2360	27	.0005		231								
	Rockway 12.5 Kv.				Urbana 33 Kv.				System with one Rockway Feeder Open						
		27/28				39/40			(Rhea. No.30 Increased to 100%)						
T	.020	200,000	9,230	T	.0004	4,000									
27	.0041		1,890						Rockway 2.5 Kv.				Mad River 12.5 Kv.		
28	.006		2,770							26/27				34/36	
30	.010		4,620					T	.0125	125,000	28,800	T	.0252	252,000	11,600
					Woodstock 33 Kv.			26	.005		11,500	34	.0202		9,330
						39/44		27	.0075		3,460	30	.005		2,310
				T	.0003	3,000		28	.0037		1,710				
	Victor Rubber 12.5							30	.0038		1,750				
		29/-													
T	.0069	69,000	3,180										Mad River 33 Kv.		
					Milford Center 33 Kv.									36/40	
						44/48			Rockway 12.5 Kv.			T	.0061	61,000	
				T	.00027	2,700				27/28		34	.005	50,000	
	Mad River 12.5 Kv.							T	.0163	163,000	7,520	30	.001	10,000	
		34/36						27	.004		1,850				
T	.0273	273,000	12,600					28	.0059		2,720				
30	.0068		3,140		Marysville 33 Kv.			30	.0065		3,000				
34	.0205		9,460			48/-									
28	.0041		1890	T	.00025	2,500									
27	.0029		1,840												

The Short Circuit Calculating Table

Above—Left: A calculating system set-up using both 120 circuit tables at the Westinghouse works, East Pittsburgh.

Above—Right: Rear view of 72-circuit calculating table.

Below—A "close-up" showing resistor unit rheostats, ammeter, jacks, cords and ammeter lugs.

Short circuit current data is essential—for the solution of such problems as the selection of oil circuit breakers; the selection of relays and determination of their settings; the calculation of mechanical stresses in structural elements of apparatus subject to short circuits; and the determination of the size of current limiting reactors.

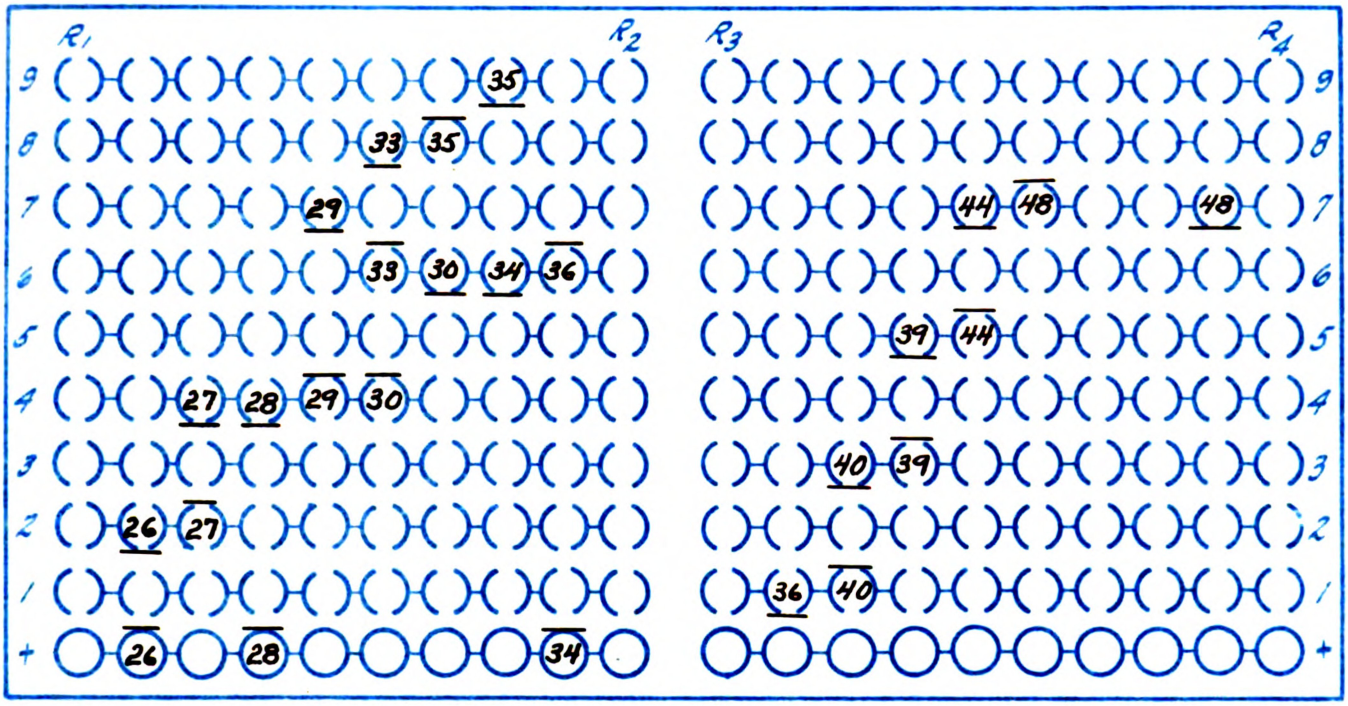
An easy method for quickly obtaining comprehensive short circuit data is by the use of d-c. calculating table. Two forms of the apparatus are built, one employing fixed resistances, and the other using variable resistances. The latter form has proved extremely flexible, being applicable to any system or any part of a system network.

The d-c. calculating table consists essentially of a number of variable resistors with associated telephone cords, plugs and jacks so arranged as to afford an easy means of making a system miniature "set-up". Resistor units are used to represent reactance values of generators, transformers and transmission lines.

A system is set up in miniature on the calculating table by tying together a number of variable resistor circuits adjusted proportional to the actual equivalent reactance ohms of the various parts of the system. A known direct-current voltage is impressed between a positive bus, to which one end of each resistance representing synchronous machines is tied, and some desired point of fault. A reading of milli-amperes for total current as well as for branch current will give values proportional to the instantaneous symmetrical current for that particular point of fault. The negative lead of the circuit is so arranged that it can be inserted at any point on the system, thereby giving a means for throwing a short circuit at any point desired. Readings are easily obtained for all the branches as well as readings of total short circuit current.

Westinghouse Picture News Service.
Westinghouse Electric & Manufacturing Co. East Pittsburgh, Pa. Number 2754

SECTION No 2



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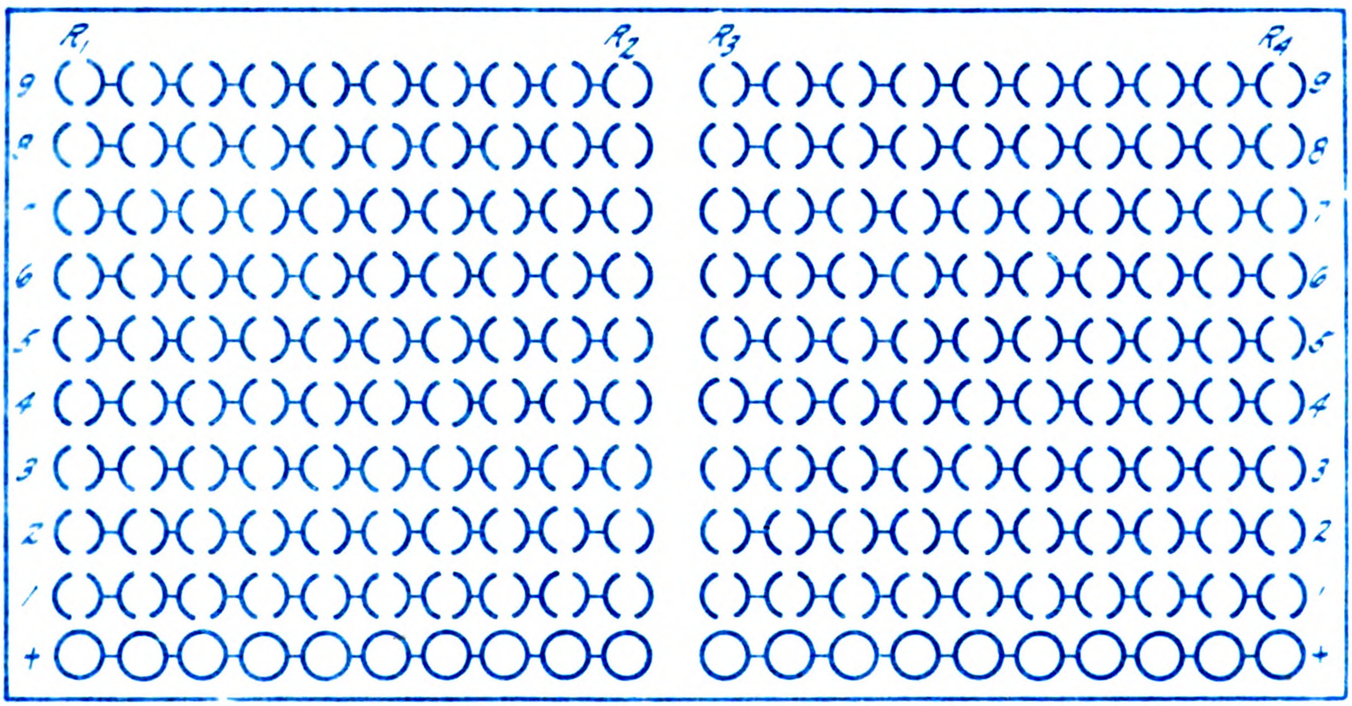


NOTES

The lower horizontal row of each section is connected to the + generator bus.

One side of jacks R_1, R_2, R_3 and R_4 of each of the upper nine rows of each section is respectively connected to one side of the jacks of the same number in the corresponding row of the other sections.

COMMONWEALTH POWER CORPORATION
ENGINEERING DEPARTMENT JACKSON, MICHIGAN

SCHEME OF CONNECTIONS USED ON CALCULATING TABLE

OPERATING CO. Ohio Edison Co.
STATION. System
BY C.W.N. O.R.D. INSP'D.
DATE 1-25-27 DATE
W.O. NO. .... S.C. CALC. NO. 36

RHEOSTAT SETTINGS USED ON CALCULATING TABLE

OPERATING CO. Ohio Edison Co. W. O. No. ____ S.C. Calc. No. 36
STATION System Made by. C.W.M. Date 1-25-27.

SECTION #1			SECTION #2			#3	SECTION #4			SECTION #5		
8	16	24	32	40 / 99	48 / 42	FUTURE SECTION	80	88	96	104	112	120
7	15	23	31	39 / 83	47		79	87	95	103	111	119
6	14	22	30 / 50	38	46		78	86	94	102	110	118
5	13	21	29 / 95	37	45		77	85	93	101	109	117
4	12	20	28 / 165	36 / 122	44 / 40		76	84	92	100	108	116
3	11	19	27 / 54	35 / 204	43		75	83	91	99	107	115
2	10	18	26 / 200	34 / 48	42		74	82	90	98	106	114
1	9	17	25	33 / 210	41		73	81	89	97	105	113

COMMONWEALTH POWER CORPORATION OF MICHIGAN ENGINEERING DEPT. JACKSON, MICHIGAN.

TITLE RHEOSTAT SETTINGS USED ON CALCULATING TABLE.

Date 6/23/26 | Tab EX-4 | Approved | Dwg No T.S A21506

Minimum Short-Circuit Calculations.

The conditions for minimum short-circuit values are assumed with only G_2 and G_4 at the Rockway station in operation. The resulting current values are determined as follows.

Fault on the 37.5 kv. Line from Mad River.

The sequence of figures from Fig. 23 to Fig. 26, on the following page, shows the reduction of the system to a single equivalent reactance of 296% on a basis of 100,000 kv.a.

% Reactance = 296 on 100,000 kv.a. basis.

Short-Circuit kv.a. at fault $= \dfrac{100,000}{2.96} = 33,800$

Short-Circuit Current at fault $= \dfrac{33,800}{\sqrt{3} \times 12.5} = \underline{1,560 \text{ amps.}}$

Current in each Rockway Feeder = <u>780 amps.</u>

Current delivered by $G_4 = \dfrac{454}{624} \times 1560 = \underline{1,135 \text{ amps.}}$

Current delivered by $G_2 = \dfrac{170}{624} \times 1560 = \underline{425 \text{ amps.}}$ at 12.5 kv.

Fault on Mad River Bus.

% Reactance = 296 - 122 = 174 (See Fig. 23 & 25.)

Short-Circuit kv.a. at fault $= \dfrac{100,000}{1.74} = 57,400$ kv.a.

Short-Circuit Current at fault $= \dfrac{57,400}{\sqrt{3} \times 12.5} = \underline{2,650 \text{ amps.}}$

Current in each Rockway Feeder = <u>1,325 amps.</u>

Current delivered by $G_4 = \dfrac{454}{624} \times 2,650 = \underline{1,930 \text{ amps.}}$

Current delivered by $G_2 = \dfrac{170}{624} \times 2,650 = \underline{720 \text{ amps.}}$ at 12.5 kv.

Fig. 23.

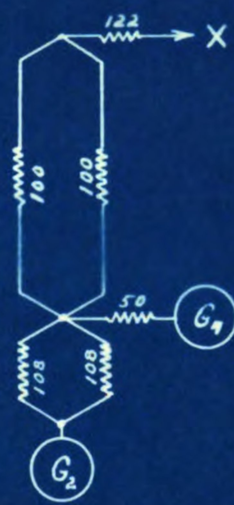


Fig. 24.

Fig. 25.

Fig. 26.

Fig. 27.

Fig. 28.

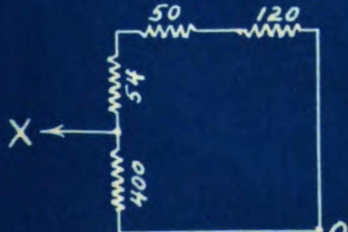


Fig. 29.

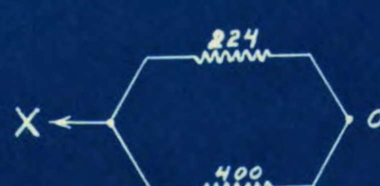


Fig. 30.

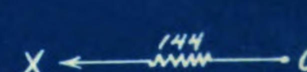


Fig. 31.

Fault on Rockway 12.5 kv. Bus.

% Reactance = 296 - 172 = 124 (See Fig. 24, 26 & 27).

Short-Circuit Kv.a. at fault = $\frac{100,000}{1.24}$ = 80,600 kv.a.

Short-Circuit Current at fault = $\frac{80,600}{\sqrt{3} \times 12.5}$ = 3,720 amps.

Current delivered by G_4 = $\frac{454}{624}$ x 3,720 = 2,710 amps.

Current delivered by G_2 = $\frac{170}{624}$ x 3,720 = 1,010 amps. at 12.5 kv.

Current thru each 12.5-2.5 kv. Trans. = 505 amps. at 12.5 kv.

Fault on 2.5 kv. Rockway Bus.

Fig. 29 is obtained from Fig. 25 and reduces to Fig. 31, which gives a reactance of 144% based on 100,000 kv.a.

Short-Circuit kv.a. at fault = $\frac{100,000}{1.44}$ = 69, 400 kv.a.

Short-Circuit Current at fault = $\frac{69,000}{\sqrt{3} \times 12.5}$ = 3,200 amps. at (12.5 kv.

Current delivered by G_2 = $\frac{224}{624}$ x 3,200 = 1,150 amps. at 12.5 kv.

Current delivered by G_4 = $\frac{400}{624}$ x 3,200 = 2,050 amps.

Current thru each 12.5-2.5 kv. Trans. = 1,025 amps.

Selection of Methods of Protection for the Different Parts of the System.

Types of apparatus to be Protected.

1. Generators.
2. Transformers.
3. Rockway Circuits.
4. Typical Feeders.

I. Generators.

A. Possible Schemes for Protection.

1. Simple Differential Scheme.
2. Self-Balanced Schemes.
3. Power-Directional Schemes.

B. Advantages and Disadvantages of Different Schemes.

1. Simple Differential Scheme.

Advantages.

Simplicity.
Ease of Application.
Sensitive settings permitted, resulting in quick action.
No special apparatus required.

Disadvantages.

Current transformers must have identical characteristics, if sensitive settings are required.

Protects Against

Phase-to-phase short circuits.
Grounds (If neutral is grounded solidly on through a low resistance.)

Does Not Protect Against

High resistance grounds.
Open circuits.
Short-circuited turns.
Faults in leads from generator to bus.

2. Self-Balanced Scheme.

Advantages.

Eliminates the normal unbalance due to two current transformers having dissimilar

Disadvantages.

Carrying two leads (having a large potential difference) through the same characteristics. This makes possible a very low relay setting so that the generator can be disconnected for low fault current, with small resulting damage.

transformer opening.

Difficulties in machine construction and installation.

Special current transformers are required.

Protects Against

Faults actually inside the machine, as with the simple differential scheme.

Does Not Protect Against

Faults not detected by the simple differential scheme.

Faults in leads from generator to bus.

3. Power-Directional Scheme.

Advantages

Comparatively simple and not very expensive.

Disadvantages

Cannot be given a sensitive setting, on account of circulating and other transient currents.

Requires the use of potential transformers.

Protects Against

Severe phase-to-phase short-circuits.

Severe ground faults (under some conditions.)

Does Not Protect Against

Short-circuited turns.

Open circuits.

Any fault until it is serious.

C. Selected Protective Schemes for Generators.

It is recommended that the Simple Differential Scheme be used for the protection of the Mad River Generator and of the 10,000 kv.a. generator (G_4) on the 12.5 kv. Rockway Bus.

This scheme has all the advantages listed above for all of the three schemes which might be applied to these generators. The neutrals are solidly grounded. Therefore, there will be no necessity for extra-sensitive relay settings and slight dissimilarity of instrument transformer characteristics will not be troublesome. Since the leads are all brought out in both of these machines, the adaptation of this scheme will be of relatively low cost.

It is recommended that no protection be provided for the 2,500 kv.a. generators (G_2 and G_3) on the 2500 volt Rockway Bus. The leads are not brought out on both sides in the manner necessary for differential protection, and the advantages offered by any type of overcurrent or power-directional protection are not sufficient to warrant the installation of the necessary equipment.

II. Transformers.

A. Possible Schemes for Protection.

1. Overcurrent.

2. Current Differential.

3. Power Differential.

4. Directional Overcurrent.

B. Advantages and Disadvantages of Different Schemes.

1. Overcurrent.

Advantages	Disadvantages
Simplicity.	Is not selective; operates on faults outside the transformer.

Protects Against	Not Suitable For
Short-circuits and grounds taking excessive currents whether in the transformer or in the secondary distribution system.	Protecting against open circuit. Protecting against an incipient or other fault taking a small current. Protecting transformers connected in parallel.

2. Current-Differential Scheme.

Advantages	Disadvantages
There is no interruption in case of a through short circuit; thus the fault is confined to the smallest possible area. An internal fault gives a large differential current, so	Exact balance of normal currents is required, and calls for additional apparatus and rather complicated connections. Not very sensitive to grounds on ungrounded

that a sturdily-built relay can produce a strong, sensitive action.

The relay is simple, inexpensive, and not liable to get out of order.

There are no voltage connections requiring voltage transformers.

systems and systems with high resistance between ground and neutral.

Protects Against	Does Not Protect Against
Phase-to-phase short circuits, short-circuited turns, and low resistance grounds.	Open circuit. High resistance ground.

3. Power-Differential Scheme.

Advantages	Disadvantages
Same as for the current-differential scheme.	More complicated, more expensive, more difficult of adjustment than current-differential scheme. Requires voltage connections.

4. Directional-Overcurrent Scheme.

Advantages	Disadvantages
Accurate current balancing is unnecessary. Application and adjustment are simple.	Does not discriminate between line and transformer faults, unless an added step is introduced in the definite-minimum time setting. Requires potential transformers. Requires high current settings on account of possible transient conditions.

Protects Against	Does Not Protect Against
Phase-to-phase short circuits. Low-resistance grounds.	Open circuits. High resistance grounds. Short-circuited turns, except serious short-circuits. Applicable only where there is a source of back feed to the transformer.

C. Selected Protective Schemes for Transformers.

1. For Transformer on 37.5 kv. line.

It is recommended that a combination of the current-differential and the overcurrent schemes be used at this location.

A comparison of the advantages and disadvantages of the schemes outlined above shows that the current-differential scheme gives the most complete protection without excessively high cost. Satisfactory operation may be expected even though bushing type transformers must be balanced against standard type current transformers, since it will not be necessary to make sensitive relay settings.

The overcurrent scheme of protection sould be added in order to give protection to the system in case of a fault on the transmission line, rather than for the protection of the transformer itself.

2. 6,000 kv.a. Transformers between 12.5 kv. & 2,500 V. Rockway Busses.

Same as above. (For same reasons).

3. 10,000 kv.a. Transformer between 10,000 kv.a. Generator and 12.5 kv. Rockway Bus.

It is recommended that the current differential scheme be used to protect this transformer. The advantages of this scheme for this unit are the same as those listed for (1) & (2) above.

NOTE: The application of the current differential schemes as recommended above will give a uniform system of protection for the generators and transformers. This will be of great advantage in test and maintenance work after the system is put in operation. It should also be observed that the necessary current transformers for this type of protection are already in place throughout the system.

III. Rockway Circuits.

A. Possible Schemes for Protection.

1. Schemes Commonly Applied to Parallel Feeders.

   a. Overcurrent Protection with Directional Selectivity.

   b. Overcurrent Inverse Time Protection.

   c. Current Differential Protection by Current Balancing.

   d. Current Differential Protection using Selective-Differential-Current Relays.

   e. Current Differential Protection with Directional Selectivity.

2. Schemes Applicable to Loop Systems or Networks.

   a. Overcurrent Time and Directional Scheme.

   b. Pilot Wire Schemes.

B. Advantages and Disadvantages of Different Schemes.

1. Schemes Commonly Applied to Parallel Feeders between Generating Stations and Substations.

   a. Overcurrent Protection with Directional Selectivity.

   (Overcurrent relays at source, directional at receiver.)

Advantages	Disadvantages
Simple and reliable method of protecting any number of parallel feeders.	Requires voltage transformer connections.
Not affected by removal of part of the feeders from service.	Requires time operation of overcurrent relays.
When only one feeder remains in service it has overcurrent protection.	Requires overcurrent elements in conjunction with directional elements if normal flow of power is to be allowed in reverse direction.

Protects Against	Does Not Protect Against
Short-circuits on lines and buses, except bus at generating station. Low resistance grounds, on systems with neutrals grounded solidly or through low resistance.	High resistance grounds. Single grounds on systems not solidly grounded.

b. Overcurrent-Inverse Time Protection.

Applicable only where there are always at least three parallel feeders in service and all are of about equal impedance.

c. Current-Differential Protection by Current Balancing.

Advantages	Disadvantages
It is extremely simple. Easy to apply. Employs standard inexpensive apparatus. Eliminates use of voltage connections. Does not require fine adjustment of relay. Is not affected by through short circuits. Operation at generating end can be made practically instantaneous.	Does not discriminate between good and faulty lines that are paired together. Not applicable except in pairs.

Protects Against	Does Not Protect Against
Line short-circuits.	Bus short-circuits.

d. Current-Differential Protection using Selective-Differential-Current Relays.

Advantages	Disadvantages
No potential transformers are required. Protection is practically instantaneous.	Protection depends on the correct functioning of three relays with their contacts in series if protection of the remaining feeders is to be continued.

Protects Against	Does Not Protect Against
Currents in faulty line exceeding those in good line. Overcurrent in the last line in service, if relays are suitably arranged & set.	Currents in faulty line equal to or less than currents in good line. Bus short-circuits.

e. Current-Differential Protection, with Directional Selectivity. (Cross-Connected Power Directional Scheme.)

Advantages	Disadvantages
Always selects the faulty line. Practically instantaneous in operation. It can be set to operate on currents smaller than the full-load current of each feeder. It may be applied to any system, no matter how complex, if the feeders are run parallel between the switching points.	Will not clear the trouble when the buses or all the feeders are involved. There may be trouble in cutting feeders in and out of service under heavy loads. The wiring is complex. It is necessary to provide a means for changing the C.T. connections when the circuit breaker operates if the remaining feeders are to be protected.

2. <u>Schemes Applicable to Loop Systems or Networks.</u>

a. Overcurrent Time and Directional Schemes.

(Inverse definite-minimum time overcurrent and directional relays are put on the loop where it enters and leaves each station and are made operative on power flow in the direction from the station bus.)

Advantages	Disadvantages
Least expensive of all satisfactory schemes. Simple to install, check and maintain. Applicable to ground protection with little or no additional equipment. Equally satisfactory for protecting short and long sections of the loop.	Not instantaneous. Operates only on overcurrent values of fault current.

Applicable To	Not Applicable
Loops having four stations or less.	By itself to loops having more than four stations.

Loops having any number of stations, if used in conjunction with another scheme.

b. Pilot Wire Schemes. (General)

Advantages	Disadvantages
Not affected by through faults.	Cost of pilot wire.
Operating on fault currents that are small compared with load currents.	Cost of current transformers having the required characteristics.
Operating almost instantaneously, and not interferring with successive time settings employed in other parts of the system.	Difficulty of providing current transformers of similar characteristics at all currents.
Discriminating especially well on short lines.	Possibility of an undetected break in the pilot wire.
Not requiring additional equipment for protection against ground currents.	Possibility of false operation due to voltage in pilot wires induced by short-circuit current in neighboring circuit.
Not requiring short-circuit calculations to determine the current that will flow.	
Simple construction.	
Not requiring potential connections.	

C. <u>Selected Protective Scheme for Rockway Circuits.</u>

It is recommended that the scheme of overcurrent protection with directional selectivity be used at the Rockway end and that the cross-connected power directional in conjunction with plain overload be used at the Mad River and of the Rockway circuits.

Examination of the advantages and disadvantages of the different protective schemes listed above shows that the cross-connected power directional scheme, the overcurrent time and directional scheme, and the pilot wire scheme are all that discriminate between the good and the faulty circuit unless the current in the faulty circuit is appreciably greater than the current in the good circuit. The pilot wire scheme is expensive to install, and at the same time no excess current protection is provided, in case of a bus short or other fault outside the actual circuits protected, without the addition of the common overcurrent protection.

A consideration of the problem shows that it is possible to provide adequate protection as long as the Mad River generator is in operation by installing over current-power directional relays at the Rockway end and excess current relays at the Mad River end of the circuits. If the Mad River generator is not in operation, this scheme still gives over current protection, but it will not give discrimination in case of a fault on one of the feeders.

An installation using overcurrent-power directional relays at both ends, as in the loop protective scheme, will give discrimination when the Mad River generator is not running as well as when it is running, provided the time settings of all the relays are properly changed each time the generator is put on or taken off the bus. Obviously, it would not be desirable to use this method in order to obtain discrimination.

The cross connected power directional system of protection gives adequate protection and discrimination in case of a phase to phase short circuit on either feeder. However, in order to leave the remaining circuit protected, in case one circuit has been removed due to a fault or for any other reason, and in order to make the scheme extendable when another feeder is added some time in the future, it is necessary to use a complicated system of wiring. Difficulties will also be encountered when trying to remove one circuit from service, or replace a circuit in service during periods of heavy load unless the protective system is rendered inactive during the switching period.

By using the recommended scheme of protection, which is a combination of the loop protective scheme and the cross-connected power directional shheme, it is possible to obtain good discrimination in case of a fault on either feeder, whether or not the Mad River generator is running. The use of the overcurrent relays at the Mad River end of the circuits provides for protection against sustained through short-circuits and bus faults at Rockway. At the same time they furnish more positive ground fault protection than can be depended upon when the directional elements are used. The connections for the recommended system are more simple than if the cross connected system were used throughout. There will be no difficulty in putting the second feeder in parallel with the first even when heavily loaded, provided the Rockway end is closed before the Mad River end is closed. Likewise, there will be no danger of destroying the continuity of service when removing one of the feeders provided the Mad River end is opened first. The wiring of the recommended system is less complicated than that of the cross-connected system and may also be more easily extended when a third feeder is installed.

IV. Typical Feeders.

It is recommended that overcurrent, inverse-time relays be used on all the feeder circuits. It is further recommended that induction type relays, rather than plunger type relays, be used because of their greater accuracy, more permanent adjustments, and greater reliability, and because they place less burden on the current transformers. In all cases, in order to provide adequate protection from ground faults, three relays instead of only two should be used.

Form 380—9-25-26—1m—De May's

SHEET NO. 1

COMMONWEALTH POWER CORPORATION

OF MICHIGAN

ELECTRICAL ENGINEERING DEPARTMENT

RELAY DATA

OPERATING CO. Ohio Edison Company.

STATION System

Cycles 60

Minimum Short Circuit

Special

References

W. O.

R. S.

Made by O.D.D.

Date 1927

Insp.

Date

Insp.

Date

App.

Date

ELECTRICAL ENGINEER

App.

Date

OPERATING ELECTRICAL ENGINEER

SETTINGS MADE

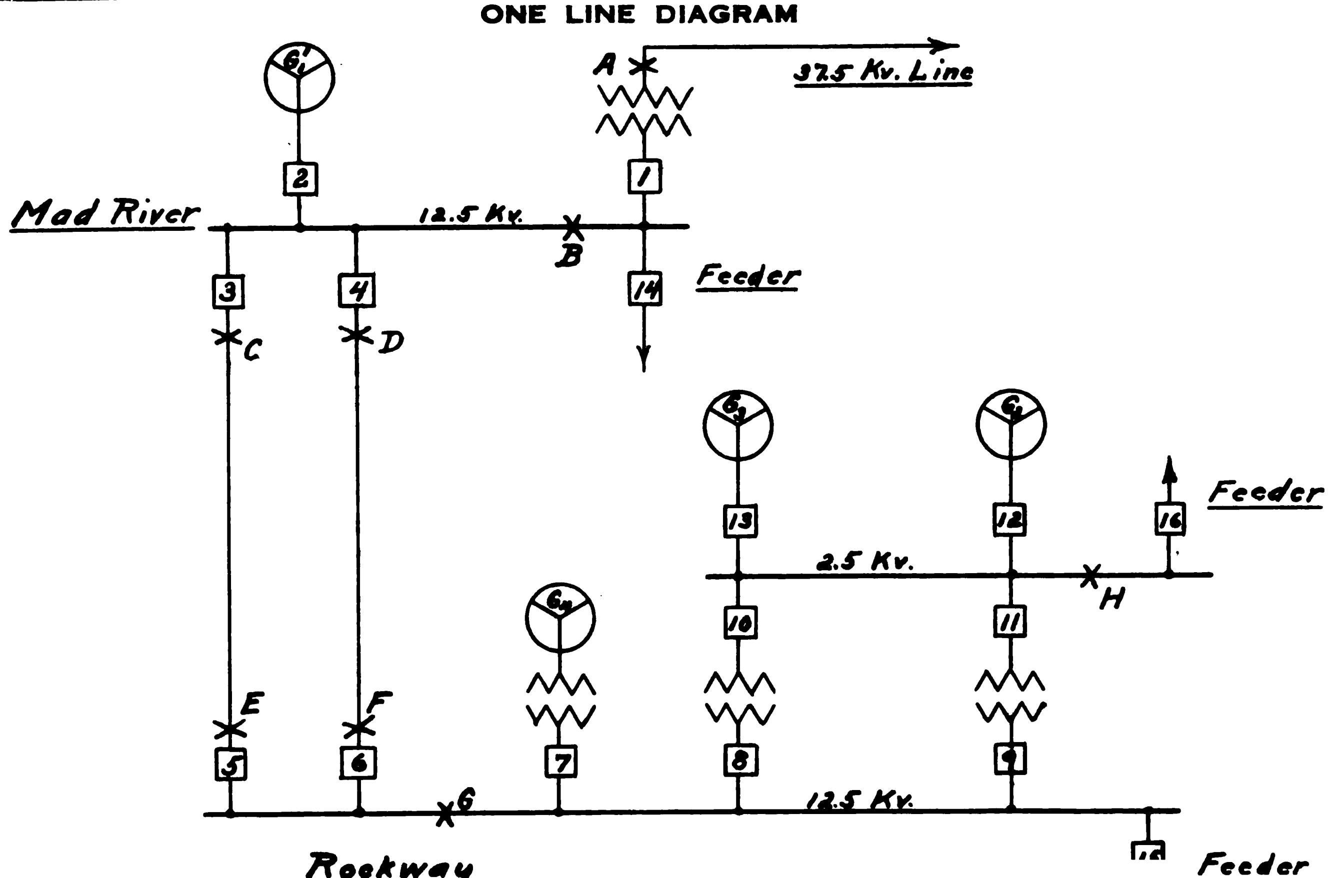
By

Date

SUMMARY OF SETTINGS

O.C.B. No.	Min. S.C. Sec.	Approx. F.L. Sec.	RELAY Type	RELAY Pickup Current	RELAY Time Setting	O.C.B. No.	Min. S.C. Sec.	Approx. F.L. Sec.	RELAY Type	RELAY Pickup Current	RELAY Time Setting
1	26	3.5	CO O.L.	10	L. - 2						
			CO Diff.	4	L. - 1						
2		3.8	CO Diff.	1	L. - 1	(Low Energy)					
3	13.2	5	CO O.L.	10	L. - 5						
			CR Cross	4	L. - 1						
4	13.2	5	CO O.L.	10	L. - 5						
			CR Cross	4	L. - 1						
5	13.2	5	CR	8	L. - 3						
6	13.2	5	CR	8	L. - 3						
7	Trans.		CO Diff.	4	L. - 1						
	Gen.		CO Diff.	1	L. - 1	(Low Energy)					
8-10	12.8	3.5	CO O.L.	7	L. - 4						
			CO Diff.	4	L. - 1						
9-11	12.8	3.5	CO O.L.	7	L. - 4						
			CO Diff.	4	L. - 1						
Feeders		?	CO O.L.	?	L. - 1						

ONE LINE DIAGRAM



Sheet No. 2 47

COMMONWEALTH POWER CORPORATION
OF MICHIGAN
ELECTRICAL ENGINEERING DEPARTMENT
RELAY DATA

OPERATING CO. Ohio Edison Company   W.O.   R.S.
STATION System   Cycles 60   Made by C.   Date 1937

S. C. At	O. C. B. No.	O. C. B. Type	Relay Type	Primary Short Circ. Amps.	C. T. Ratio	Secondary Short Circ. Amps.	Relay Pickup Current	Times Pickup	Relay Time Setting	Time Delay Seconds	O.C.B. Tripped
A	1		CO, 11	2,810	300/5	46.8	10	4.7	2	0.4	1
	3-4		CO	323	500/5	3.2	10	---	5	---	
	5-6		CR	220	500/5	2.2	8	---	3	---	
B	3-4		CO	1,570	500/5	15.7	10	1.57	5	2.5	
	5-6		CR	1,570	500/5	15.7	8	1.96	3	1.1	5-6
	8-9		CO	670	400/5	8.4	7	1.20	4	0.[illegible]	
C	3		CO	11,030	500/5	110.	10	11	5	1.0	
	3		CR Cross	11,030	500/5	62.8	4	15.7	1	0.[illegible]	(1) [illegible]
	4		CO	1,570	500/5	15.7	10	1.57	5	[illegible]	
	5-6		CR	1,570	500/5	15.7	8	1.96	3	1.1	(2) [illegible]
	8-9	(Same as B)								[illegible]	
D	4		CO	11,030	500/5	110	10	11	5	1.0	
	4		CR Cross	11,030	500/5	62.8	4	15.7	1	0.2	(1) [illegible]
	3		CO	1,570	500/5	15.7	10	1.57	5	[illegible]	
	5-6		CR	1,570	500/5	15.7	8	1.96	3	1.1	(2) [illegible]
	8-9	(Same as B & C)								[illegible]	
G	5-6		CR	2,310	500/5	23.1	8	2.9	3	---	
	3-4		CO	2,310	500/5	23.1	10	2.31	5	1.5	(1) 3-[illegible]
	8-9		CO	930	400/5	11.6	7	1.66	4	1.8	(2) 7-[illegible]
E	5		CR	6,920	500/5	69.2	8	8.65	3	0.6	(1) [illegible]
	6		CR	2,310	500/5	23.1	8	2.9	3	---	
	3-4		CO	2,310	500/5	23.1	10	2.31	5	1.5	
	3	(After No. 5	CR Cross	2,310	500/5	19.8	4	4.95	1	[illegible]*	(2) [illegible]
	4	opens)	CR Cross	1,570	500/5	19.8	4	4.95	1	---	
	8-9	(Same as G)								1.8	
F	6		CR	6,920	500/5	69.2	8	8.65	3	0.6	(1) [illegible]
	5		CR	2,310	500/5	23.1	8	2.9	3	---	
	3-4		CO	2,310	500/5	23.1	10	2.31	5	1.5	
	4	(After No. 6	CR Cross	2,310	500/5	19.8	4	4.95	1	[illegible]	(2) [illegible]
	3	opens)	CR Cross	1,570	500/5	19.8	4	4.95	1	---	
	8-9	(Same as G)									
H	8-9		CO	1,965	400/5	24.6	7	3.52	4	0.9	8-9
	5-6		CR	1,180	500/5	11.8	8	1.47	3	---	
	3-4		CO	1,180	500/5	11.8	10	1.18	5	7.5	

*After 5 opens.

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SHEET No. 3

COMMONWEALTH POWER CORPORATION

OF MICHIGAN

ELECTRICAL ENGINEERING DEPARTMENT

RELAY DATA

OPERATING CO. Ohio Edison Company

W. O. ____ R. S. ____

STATION System Cycles 60

Made by O.D.D. Date 1927

S. C. At	O. C. B. No.	O. C. B. Type	Relay Type	Primary Short Circ. Amps.	C. T. Ratio	Secondary Short Circ. Amps.	Relay Pickup Current	Times Pickup	Relay Time Setting	Time Delay Seconds	O.C.B. Tripped
		Minimum S.C. Conditions. Mad River Generator not running. Only G_2 & G_4 operating.									
			Selectivity of Relays in Rockway Circuits.								
C	3-4		CO	1,325	500/5	13.25	10	1.32+	5	5.0	[illegible]
	5-6		CR	1,325	500/5	13.25	8	1.68	3	1.4	(2) 5
	3		CR	1,325	500/5	13.25	4	3.31	1	0.2	(1) 3
	4		CR	1,325	500/5	13.25	4	3.31	1	---	
	8-9		CO	360	400/5	4.5	7	----	4	---	
D	3-4		CO	1,325	500/5	13.25	10	1.32+	5	5.0	
	5-6		CR	1,325	500/5	13.25	8	1.68	3	1.4	(2) 6
	4		CR	1,325	500/5	13.25	4	3.31	1	0.2	(1) 4
	3		CR	1,325	500/5	13.25	4	3.31	1	---	
	8-9		CO	360	400/5	4.5	7	----	4	---	
E	5		CR	3,720	500/5	37.2	8	4.65	3	0.65	(1) 5
	3-4-6			0						---	
	3	) (	CR Cross	1,425	500/5	14.25	4	3.75	1	0.2	(2) 3
	4	)After No.(	CR Cross	1,425	500/5	14.25	4	3.75	1	---	
	6	)5 opens (	CR	1,425	500/5	14.25	8	1.78	3	1.2	
	3-4	) (	CO	1,425	500/5	14.25	10	1.45	5	3.5	

COMMONWEALTH POWER CORPORATION
OF MICHIGAN
ELECTRICAL ENGINEERING DEPARTMENT

RELAY DATA

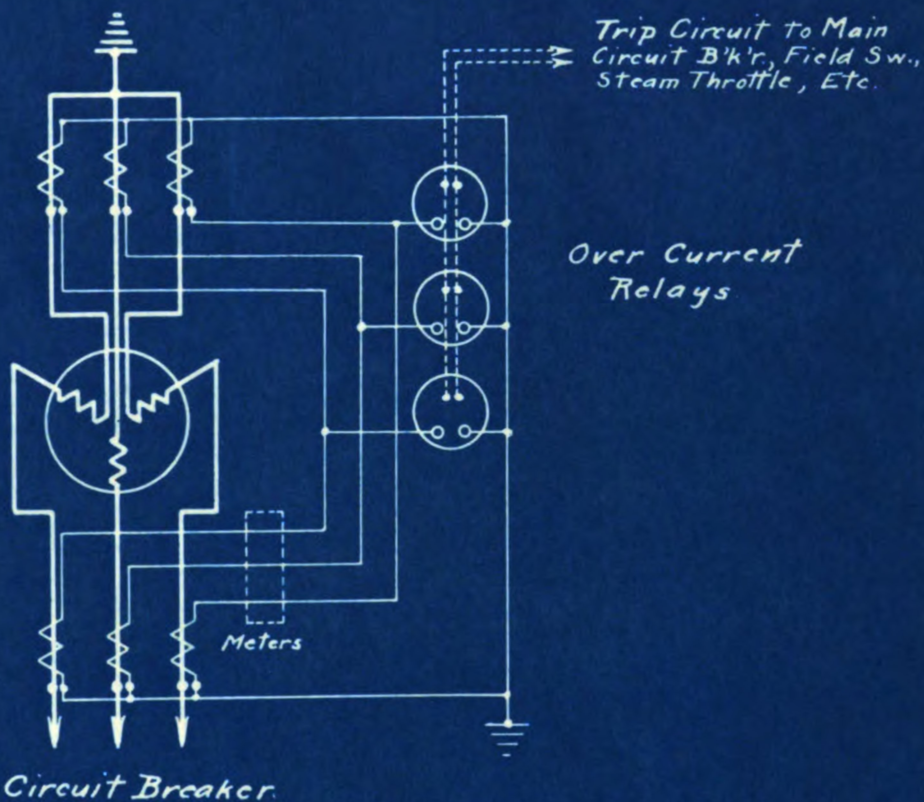
OPERATING CO. Ohio Edison Company   W.O.   R.S.

STATION System   Cycles 60   Made by O.L.   Date 1927

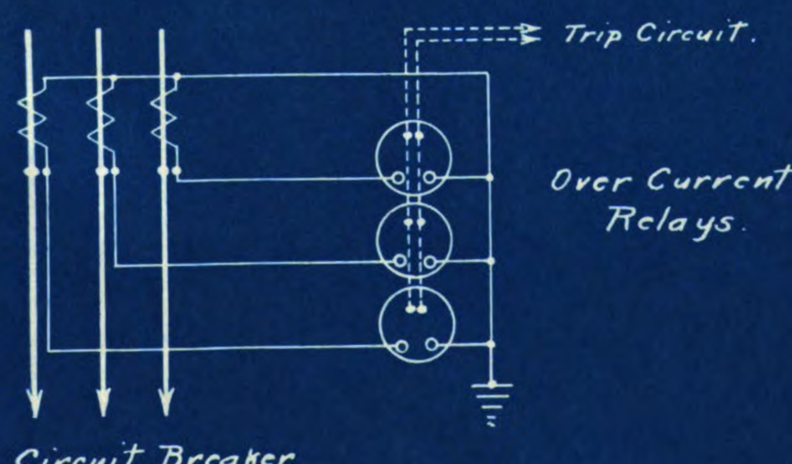
S.C. At	O.C.B. No.	O.C.B. Type	Relay Type	Primary Short Circ. Amps.	C.T. Ratio	Secondary Short Circ. Amps.	Relay Pick-up Current	Times Pickup	Relay Time Setting	Time Delay Seconds	O.C.B. Tripped
			Minimum S.C. Conditions. Sal River Generator not running. Only G3 & G4 operating.								
			Selectivity of relays in loop circuits.								
C	3-4		CO	1,225	500/5	12.25	10	1.22	5	5.0	
	5-6		CR	1,325	500/5	13.25	8	1.63	3	1.4	(2) 5
	3		CR	1,325	500/5	13.25	4	3.31	1	0.5	(1) 3
	4		CR	1,325	500/5	13.25	4	3.31	1	---	
	8-9		CO	360	100/5	4.5	7	----	4	---	
D	3-4		CO	1,325	500/5	13.25	10	1.324	5	5.0	
	5-6		CR	1,325	500/5	13.25	8	1.63	3	1.4	(1) 6
	4		CR	1,325	500/5	13.25	4	3.31	1	0.3	(1)
	3		CR	1,325	500/5	13.25	4	3.31	1	---	
	8-9		CO	360	400/5	4.5	7	----	4	---	
E	5		CR	3,720	500/5	37.2	8	4.65	2	0.67	(1) 3
	3-4-6			0						---	
	3	( )	CR Cross	1,425	500/5	14.25	4	3.56	1	0.5	(2) 3
	4	(After No.)	CR Cross	1,425	500/5	14.25	4	3.56	1	---	
	6	(5 opens)	CR	1,425	500/5	14.25	8	1.78	3	1.0	
	3-4	( )	CO	1,425	500/5	14.25	10	1.43	5	2.5	

Relay Connections.

Mad River Generator & Rockway Generator #4.

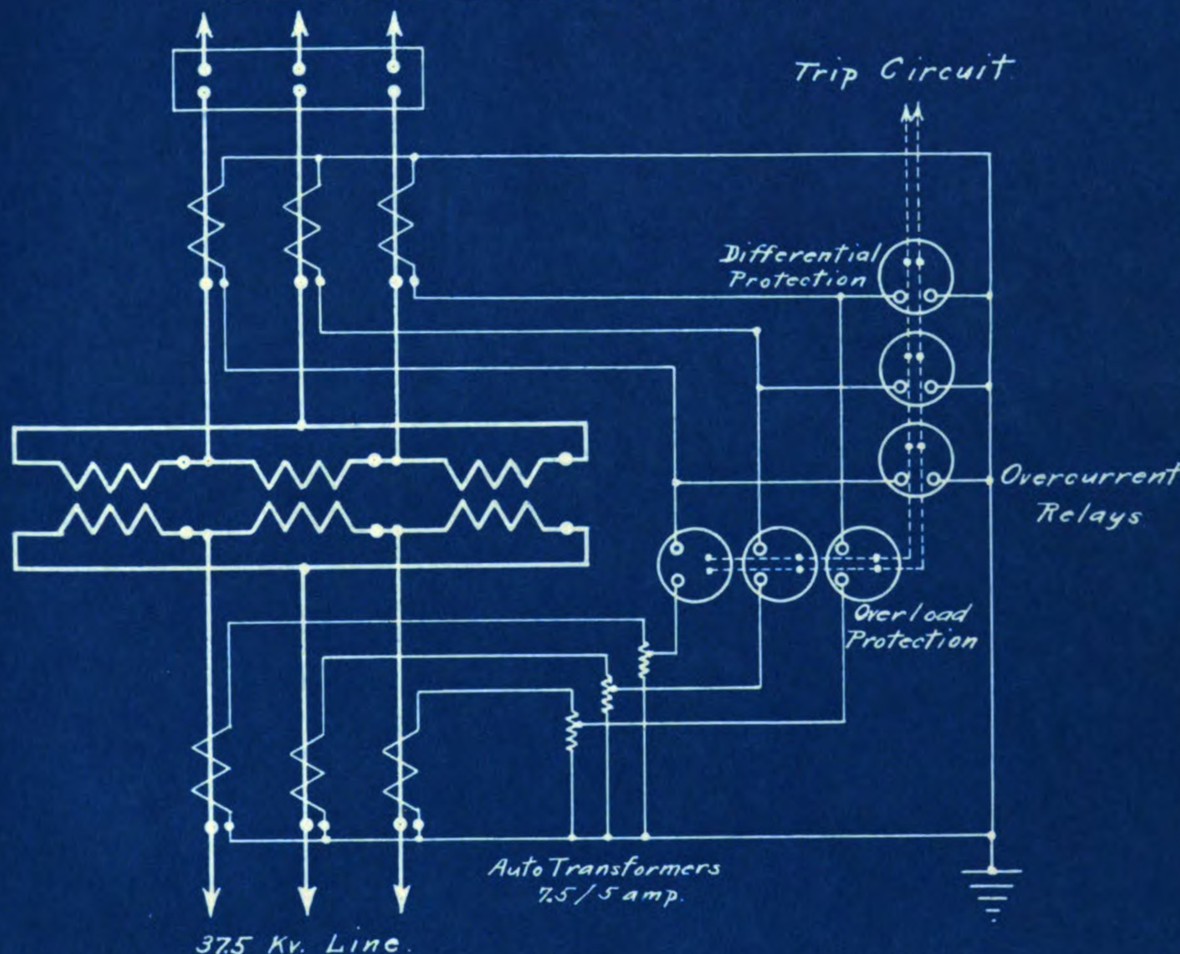


Typical Feeder



Relay Connections.

12.5 - 37.5 Kv. Transformer.



12.5 - 2.5 Kv. Transformers.

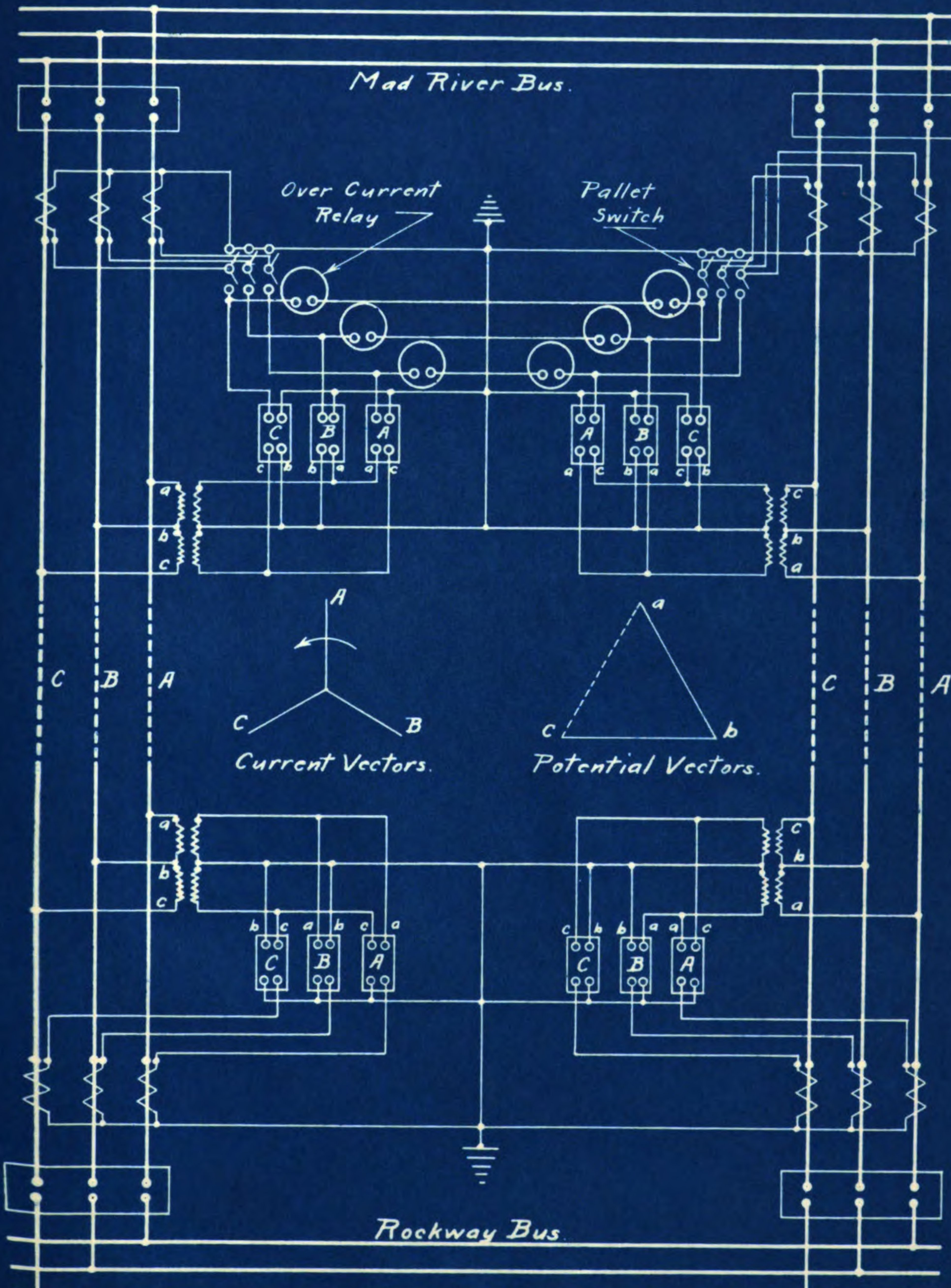
The connection diagram is the same as the above diagram, except that no autotransformers are used. The trip circuit runs to circuit breakers on both sides of the transformers.

Transformer with G_4.

The connection diagram is the same as the above diagram, except that no overload protection is provided. The autotransformers are 4.4/5 ampere rating.

Relay Connections.

Rockway Circuits.



III

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