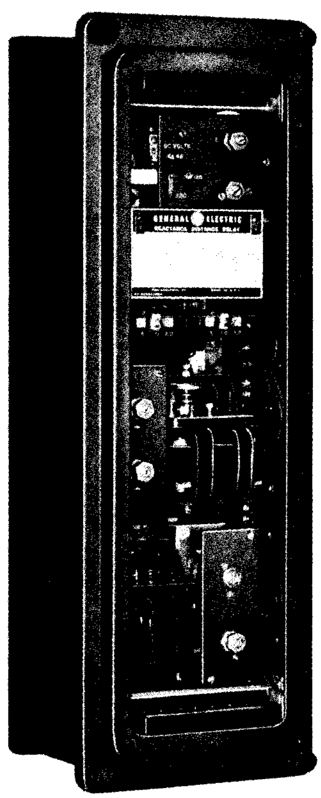
INSTRUCTIONS

GEK-26411B
Supersedes GEK-26411A

DIRECTIONAL GROUND DISTANCE RELAY

TYPE GCXG53



GENERAL ELECTRIC

CONTENTS

DIRECTIONAL GROUND DISTANCE RELAY

TYPE GCXG53

INTRODUCTION

The GCXG53A relay is a three-zone, high speed directional ground distance relay that is intended for step type protection of transmission lines. The first two zones of protection are provided by a reactance (ohm) measuring type unit, while the third zone starting unit is a mho type unit.

These relays are used to provide single phase-to-ground fault protection only. The requirements for each terminal of ground distance protection are three GCXG53A relays, one RPM11D or one SAM14B timing relay, one NAA15E auxiliary relay, and two auxiliary compensating current transformers, one for the ohm unit and one for the mho unit.

APPLICATION

These ground distance relays are intended for use on longer transmission lines. The use of zero sequence current compensation in the mho starting unit makes it possible to reduce the ohmic reach setting of this unit and still provide adequate line protection. This smaller ohmic reach setting reduces the likelihood of the relay interfering with the load carrying ability of the line.

The mho starting units use zero sequence current compensation from the protected line only. Therefore, they will accurately measure the positive sequence impedance to the fault only in the absence of zero sequence mutual impedance to a parallel line. When zero sequence mutual impedance does exist, it introduces an error into the mho starting unit measurement. This is defined under **CALCULATION OF SETTINGS**. The auxiliary compensating current transformer, 0367A0266G-2, is provided for mho unit compensation only. It has one winding for a K' setting using the zero sequence current of the protected line only.

The reactance or ohm unit of the GCXG53A does not have directional characteristics, while the mho starting unit does. For this reason, first and second zone tripping is accomplished through contacts of the ohm unit in series with those of the starting unit. Third zone tripping is initiated by the starting unit alone.

The external connections are illustrated in Figure 6. As noted from the DC connections, each one of the three GCXG starting units is associated with an auxiliary unit in the NAA relay. Thus, when a relay starting unit closes its contacts, it picks up the associated "A" auxiliary in the NAA. The contacts of the A1, A2 and A3 units of the NAA are interlocked so that they permit first and second zone tripping through the ohm unit contacts when only one starting unit is picked up. If more than one starting unit picks up, first and second zone tripping is blocked. Third zone tripping is not limited in this way. However, the zero sequence ground fault detector, IOC, in the NAA relay, will block tripping of all zones for faults that do not involve ground.

Summing up, the scheme provides first and second zone protection for single phase-to-ground faults, plus third zone protection for single phase-to-ground and double phase-to-ground faults.

Operation of the scheme may best be described by assuming a phase-one-to-ground fault. When the fault occurs, the phase one starting unit contacts close. This picks up auxiliary unit A1, which closes its contacts. If this is a first zone fault, the breaker is tripped through the starting unit in series with the IOC contacts, the normally open contacts of A1, the normally closed contacts of A2 and A3, the ohm unit contacts, the normally closed contacts of OX, plus the zone one target (T1) in the RPM relay.

If the fault were in the second zone, instantaneous tripping would not occur because the ohm unit contacts would not be closed. However, after 21G/SU picks up, the TX unit of the RPM is energized, and this in turn energizes the TU (timing unit) of the RPM. When the timing unit times out to second-zone time, the TU-2 contacts close, and energize the OX transfer units. The contacts of the OX units extend the reach of the ohm units by reducing the restraint (see the potential circuits of the GCXG in Figure 6). The ohm unit contacts now close, and the breaker is tripped through the second zone target of the RPM.

For a third zone fault, the operation is the same except that the ohm unit contacts never close, and the breaker is eventually tripped in third zone time through the starting unit contacts.

The potential circuits of the relays require three wye-connected potential transformers, with a secondary voltage of 115 volts, line-to-line (see Figure 6).

The auxiliary compensating current transformer, 0367A0266G-1, is provided for ohm unit compensation. It has two windings, a primary winding for a K' setting using the zero sequence of the protected line; and a secondary winding for the K" setting for the zero sequence mutual compensation of a parallel line. As shown in Figure 6, for both mho starting unit and ohm unit current compensation, the relay coil circuits must be connected across the zero and 100 percent taps of the auxiliary current transformer.

The reactance or ohm unit of the GCXG53A relay measures the positive sequence reactance from the relay location to the fault. When properly compensated by means of the auxiliary compensating transformer, 0367A0266, it does this quite accurately. However, because it is generally not possible to calculate the zero sequence impedance of a line and the zero sequence mutual effects of parallel lines to a high degree of accuracy; and because it is not possible to compensate completely for these effects, it is recommended that the first zone unit be set for a maximum of 80 percent of the protected line length.

Before the GCXG relay is applied on the transmission lines of a power system, it is necessary to determine whether or not the system is "homogeneous." In general terms, a homogeneous system is one composed entirely of overhead transmission lines. In such a system, the positive and zero sequence impedance of the lines are all at about the same angle.

A "non-homogeneous" system includes cable transmission circuits, as well as overhead lines. While the GCXG can be applied on non-homogeneous systems as well as on homogeneous systems, the information in this book only covers the homogeneous system. Application of the GCXG on non-homogeneous systems and resistance grounded systems requires special consideration and should be referred to the local district office of the General Electric Company.

Listed below are several points that must be checked in order to assure proper operation in the application of a GCXG relay on a homogenous system.

1. The starting units must be set with a reach that is long enough to detect single phase-to-ground faults anywhere on the protected line section. Appendix II illustrates how the maximum permissible tap setting (minimum reach setting) of the starting unit may be established.

2. The starting units on the unfaulted phases must not pick up for single phase-to-ground faults in either the tripping or the non-tripping direction. Appendix III illustrates how the minimum safe tap setting (maximum reach setting) of the starting units may be determined.

   Therefore, the starting units must be set somewhere between the limits established by Appendices II and III.

3. For a single phase-to-ground fault, the first zone ohm unit on the faulted phase must not reach beyond the desired setting. Appendix IV illustrates how this may be checked for a variety of system conditions. This includes situations where zero sequence mutual compensation is not employed, or where it is lost when a parallel line breaker is tripped.

4. For a single phase-to-ground fault, the second zone ohm unit on the faulted phase must reach at least to the far bus. Appendix IV illustrates how this may be checked for a variety of system conditions.

5. The overcurrent unit in the associated NAA15E relay must be set with a pickup that is low enough to detect all single phase-to-ground faults for which protection is desired.

6. For best overall results always use the highest basic minimum tap setting that will accomodate the desired reach settings. This applies to both the mho and reactance units.

RELAY AND COMPENSATING AUXILIARY CT SETTINGS

There are six settings that must be made for each GCXG53A relay. These are:

1. Zone 1 ohm unit percent tap setting.
2. Zone 2 ohm unit percent tap setting.
3. Zone 3 mho starting unit percent tap setting.

4. Zone 3 mho starting unit angle of maximum torque.
5. Primary percent tap setting (K') of the auxiliary current transformers, 0367A0266G-1 and 0367A0266G-2, for both the mho and ohm units.
6. Secondary percent tap setting (K") of the auxiliary current transformer, 0367A0266G-1, for the ohm unit only.

If compensation for zero sequence mutual impedance between the protected line and other lines is not required, then setting number six above is not required, and the secondary of the auxiliary current transformer, 0367A0266G-1, is left open circuited.

The various considerations involved in obtaining the desired settings are outlined in Appendices II through IV. Typical calculations for setting the GCXG53A relays are illustrated under **SAMPLE CALCULATIONS FOR SETTINGS.** The following information indicates how the relay is set after the desired settings have been established. The GCXG measures positive phase sequence secondary ohms, so the first step is to convert primary ohms to secondary ohms.

$$\text{Secondary Ohms} = \text{Primary Ohms} \times \frac{\text{CT Ratio}}{\text{PT Ratio}}$$

OHM UNIT SETTING

* $$\text{Percent Tap} = \frac{X_{min}}{X} \times \text{Input Tap} \qquad \text{(Eq. 1)}$$

where:

X_{min} = minimum ohms of the ohm unit as stamped on the nameplate

X = desired reach in secondary reactive ohms

Note that the same equation applies to both first and second zone settings. The input tap is normally set for 100 percent. However, the input tap may be set for any value between 90 and 100 percent to obtain more precise settings. For example, assume that a 0.25 ohm unit requires a reach setting of 2.16 secondary ohms. With a 100 percent input tap setting, and an 11 percent tap setting, the reach will be 2.27 ohms. With the same input, but a 12 percent tap setting, the reach will be 2.08 ohms. However, with a 95 percent input tap setting and an 11 percent tap setting, the reach will be 2.16 ohms.

The input tap setting will affect all three zone settings the same way.

MHO STARTING UNIT SETTING

The mho starting unit maximum torque angle is adjustable from 60 to 75 degrees lag. It is recommended that the 60-degree setting be used whenever possible because it will accomodate more fault resistance than the 75-degree setting. This is of particular importance with ground faults since they tend to include higher fault resistance than phase faults. The 75-degree setting can be used to slightly improve the margin against load or power swings entering the mho starting unit characteristic.

When zero sequence mutual impedance to a parallel line is present, it introduces an error into the measurement of the mho starting unit. The mutual impedance will increase or decrease the apparent impedance seen by the mho unit depending upon the direction of the flow of the zero current in the parallel line. This error quantity is included in equation II-a in Appendix II. Further limitations of the mho unit setting are discussed in Appendix III.

COMPENSATING AUXILIARY CURRENT TRANSFORMER SETTINGS

The K' setting on the primary of both the mho unit and ohm unit auxiliary compensating current transformers is for the ratio of zero sequence current of the protected line to be used.

* $$K' = \frac{X_0' - X_1'}{3X_1'} \times 100 \qquad \text{(Eq. 2)}$$

where:

K' = the primary tap setting in percent

X_0' = zero sequence reactance of the protected line in secondary ohms

X_1' = positive sequence reactance of the protected line in secondary ohms

The K" setting on the secondary of the ohm unit auxiliary compensating current transformer, 0367A0266G-1, is for the ratio of the zero sequence current of the parallel line to be used. This setting is only required when zero sequence mutual impedance between parallel lines must be compensated for in the ohm unit.

* $$K'' = \frac{2X_{om}S_2}{3X_1'S_1} \times \frac{(CTRP)}{(CTR)} \times 100 \qquad \text{(Eq. 3)}$$

where:

K'' = the secondary tap setting in percent

X_{om} = total zero sequence mutual reactance between the protected line and the parallel line in secondary ohms

S_1 = first zone reach setting in per unit of protected line length. Thus, if first zone is set for 75 percent of the line, S_1 would be 0.75.

S_2 = the per unit of total X_{om} which is effective between the relay and the first zone balance point

(CTRP) = CT ratio on the parallel line

(CTR) = CT ratio on the protected line

*Indicates Revision

Note that the compensating auxiliary current transformer has only ten percent stops. It should be set to the nearest tap available.

SAMPLE CALCULATIONS FOR SETTINGS

In order to illustrate the calculations required, assume the portion of a transmission system shown on Figure 12.

Consider the protected line to be Line #1, having the following characteristics:

$Z_1' = 24.0 \underline{/79^o}$ primary ohms

$Z_0' = 72.0 \underline{/75^o}$ primary ohms

$Z_{om} = 14.4 \underline{/75^o}$ primary ohms

CT Ratio = 600/5

PT Ratio = 1200/5

$Z_1' = 2.4 \underline{/79^o} = 0.47 + j2.36$ secondary ohms

$Z_0' = 7.2 \underline{/75^o} = 1.9 + j6.95$ secondary ohms

$Z_{om} = 1.4 \underline{/75^o} = 0.36 + j1.35$ secondary ohms

Consider the relays at breaker "A." The zone 1 unit should be set for a maximum of 80 percent of the reactive component (X_1') of Z_1'.

$$0.8(2.36) = 1.89 \text{ ohms}$$

Use the 1.0 ohm basic minimum tap. The first zone tap setting will be:

$$T = \frac{1.0}{1.89} \times 100 = 53 \text{ percent}$$

* from equation 1

$$K' = \frac{6.95 - 2.36}{3(2.36)} \times 100 = 65 \text{ percent}$$

* from equation 2.

Since K' can be set in ten percent steps, set K' for 60 or 70 percent. The higher setting will cause the relay to reach slightly farther than desired. The lower setting will shorten the reach slightly. For a 70 percent setting, set on taps zero and 70. For a 60 percent setting, set on taps 40 and 100.

$$K'' = \frac{2(1.35)}{3(2.36)(0.8)} \times \frac{400}{600} \times 100 = 31.8 \text{ percent}$$

* from equation 3.

Set K" for 30 percent (taps 10 and 40).

The factor 400/600 appears because the current transformers on the protected line are 600/5, while those on the parallel line are 400/5. The factor 0.8 appears in the denominator because only 80 percent of X_1' exists between the relay and the balance point, while 100 percent of X_{om} is effective. If the two lines were parallel all the way, then the factor 0.8 would appear in both the numerator and the denominator, and would cancel.

Zone 2 should be set beyond the end of the line, say 150 percent of X_1. Thus, the second zone tap setting will be:

$$T = \frac{1.0}{1.5(2.36)} \times 100 = 28 \text{ percent}$$

Zone 3 mho starting unit tap settings are described in Appendices II and III. First consider the maximum permissible tap setting for the mho unit to insure detection of single phase-to-ground fault at the remote bus. The equation for obtaining this value of "T" is given in Appendix II, equation II-1. The following quantities are obtained from a system study for the relays at terminal A with fault F3, Figure 12.

K' = 70 percent or 0.7 per unit

C_0 = 0.17

C = 0.20

I_a' = 13.7 secondary amperes, based on 600/5 CTs

I_0' = 3.89 secondary amperes

θ = 79 degrees

I_0'' = -0.88 secondary amperes, based on the protected line CT ratio. The sign is negative bacause I_0'' flows in the opposite direction in the parallel line from I_0' in the protected line.

K = 2.0 ohm minimum tap

$\emptyset$ = 60 degree maximum torque angle

*Indicates Revision

Substituting the above values and those determined previously into equation II-a of Appendix II, we obtain a maximum permissible tap setting of 62 percent for "T."

It is now necessary to evaluate equations III-a and III-b of Appendix III to determine the minimum permissible tap setting for the mho starting unit based on the conditions of fault F2, Figure 12. From the system study, the following values are obtained:

$C = 0.27$

$C_0 = 0.11$

$Z_1 = 0.875 \underline{/82^o}$ secondary ohms

$Z_0 = 1.05 \underline{/78^o}$ secondary ohms.

First evaluate the term $\left[(3K' + 1)C_0 - C\right]$.

This term is positive and we proceed with evaluation of the equations. The value K_0 is obtained from the curve of Figure III-2 for a 60-degree maximum torque angle and a ratio of 1.2 of Z_0 to Z_1. The results are the following tap settings:

Equation III-a T = 2.7 percent

Equation III-b T = 4.3 percent

Therefore, any zone three tap setting from ten to 64 percent is satisfactory. The zero sequence current compensation considerably reduces the necessary reach of the mho unit, and consequently reduces the likelihood of load impedance entering its characteristic. However, it is still possible for the unit to operate on load if its characteristic is large enough. This condition should be avoided.

Appendix IV describes the effects of uncompensated zero sequence mutual reactance on the reach of the ohm unit. It is not always possible to compensate for mutual induction due to system configurations and operating conditions. This can cause overreach of the measuring units and a lack of coordination with the relays at other terminals. Appendix IV describes the steps necessary to avoid these pitfalls.

RATINGS

The Type GCXG53A relays are available with a rating of 120 volts polarizing circuit, and 70 volts restraint circuit. The current circuit is rated five amperes continuous, with a one second rating of 115 amperes. The relays are available for either 50 or 60 hertz.

The auxiliary transfer unit (OX) has a multiple DC voltage rating of 48, 125 or 250 volts. The specific rating desired is selected by means of a link setting on the front of the relay.

The basic minimum reach settings and adjustment ranges of the units are shown in Table I.

TABLE I

OHM UNIT		MHO UNIT		
BASIC MINIMUM REACH*** (Ø-N OHMS)	RANGE (Ø-N OHMS)	BASIC MINIMUM REACH*** (Ø-N OHMS)	RANGE (Ø-N OHMS)	**ANGLE OF MAXIMUM TORQUE
0.5 /1.0/2.0	0.5 /20	2/6	2/60	60°
0.25/0.5/1.0	0.25/10	1/3	1/30	60°
0.1 /0.2/0.4	0.1 / 4	1/3	1/30	60°

** Angle by which the operating current lags the phase-to-neutral restraint voltage. The mho unit may also be set for 75-degree lag. The reach at this angle will be three to ten percent greater than that at 60 degrees

*** In selecting the basic minimum reach tap or link setting, always use the highest basic minimum reach compatible with the required reach setting of the unit.

Note that three basic minimum reach settings are listed for the ohm unit, and two for the mho unit. Selection of the desired basic minimum reach of the ohm unit is made by means of two captive tap screws on a tap block at the front of the relay. Selection of the desired basic minimum reach of the mho unit is made by means of a link on a terminal board located at the rear of the mho unit (see Figure 1B).

The reach settings of the ohm and mho units can be adjusted in one percent steps by means of the autotransformer tap leads on the tap block at the right side of the relay. First zone reach of the ohm unit is determined by the #1 leads, second zone reach by the #2 leads, and the reach of the mho unit by the E^2 leads.

The contacts of the GCXG53A relays will close and carry 30 amperes DC momentarily. However, the circuit breaker trip circuit must be opened by an auxiliary switch contact or other suitable means, since the relay contacts have no interrupting rating.

The target seal in the unit used in the GCXG53A relay has ratings as shown in Table II. The units are rated either 0.2/2.0, or 0.6/2.0.

TABLE II

		0.2/2.0 Amp		0.6/2.0 Amp	
		0.2	2.0	0.6	2.0
Carry 30 amperes for	(seconds)	0.05	2.2	0.5	3.5
Carry 10 amperes for	(seconds)	0.45	2.0	5.0	30
Carry continuously	(amperes)	0.37	2.3	1.2	2.6
Minimum operating	(amperes)	0.2	2.0	0.6	2.0
Minimum dropout	(amperes)	0.05	0.5	0.15	0.5
DC resistance	(ohms)	8.3	0.24	0.78	0.18
60 hertz impedance	(ohms)	50	0.65	6.2	0.65
50 hertz impedance	(ohms)	42	0.54	5.1	0.54
DC resistive Interrupting rating	(amperes)	← 2.5 Amp @ 125 volts DC →			

OPERATING PRINCIPLES

MHO UNIT

The mho unit of the Type GCXG53A relays is of four-pole, induction-cylinder construction (see Figure 2), with schematic connections as shown in Figure 3. The two side poles, which are energized by the phase-to-median voltage in phase with the phase-to-neutral voltage of the protected phase, produce the polarizing flux. The flux in the front pole, which is energized by a percentage of the phase-to-neutral voltage of the protected phase, interacts with the polarizing flux to produce restraint torque. The flux in the rear pole, which is energized by the line current of the protected phase, interacts with the polarizing flux to produce operating torque.

The torque at the balance point for phase "A" mho units can be expressed by the following equation:

$$\text{Torque} = 0 = KI_a'E_{am}' \cos(\alpha - \Delta) - TE_a'E_{am}'$$

where:

K = design constant (basic ohmic reach tap)

E_a' = phase A-to-neutral voltage at the relay location

E_{am}' = phase B-to-median voltage at the relay location

I_a' = phase A current at the relay location

α = angle by which I_a' lags E_{am}'

T = restraint tap setting

Δ = Angle of maximum torque (60 degrees or 75 degrees)

OHM UNIT

The ohm unit of the GCXG53A relay is also of four-pole induction-cylinder construction (see Figure 2) with schematic connections as shown in Figure 3. The front and back poles, energized with line current, produce the polarizing flux. The side poles are energized with a voltage equal to the difference between the operating quantity, IZ_T, and the restraint voltage, E, where I is the line current and Z_T is the transfer impedance of the transactor. Torque on the unit resulting from interaction between the net flux in the side, and the polarizing flux in the front and rear poles and at the balance point, can be expressed by the following equation for the phase A relay:

* $$\text{Torque} = 0 = k\, I_a' \,(I_a' Z_T - E_a')\sin A \qquad \text{(Eq. 5)}$$

where:

- k = design constant
- E_a' = phase A-to-neutral voltage at the relay location
- I_a' = line current at the relay location
- Z_T = transfer impedance of the transactor (design constant)
- A = angle between I_a' and $(I_a' Z_T - E_a')$

By means of trigonometric relations, the above equations can be reduced:

* $$kI_a' (I_a' Z_T) \sin \emptyset - kI_a' (E_a') \sin \theta = 0 \qquad \text{(Eq. 6)}$$

where:

- $\emptyset$ = angle between I_a' and $I_a' Z_T$ (i.e., the transactor angle, a design constant)
- θ = angle between E_a' and I_a' (i.e., the angle of fault impedance)

Since Z_T for a particular transactor tap setting is also a design constant, the equation becomes:

* $$k' (I_a')^2 = kI_a' E_a' \sin \theta \qquad \text{(Eq. 7)}$$

$$\frac{k}{k} = K'' = \frac{E_a'}{I_a'} \sin \theta$$

$$K'' = Z \sin \theta = X_F$$

Thus, the unit will operate when the fault reactance, X_F, is less than a constant determined by the transactor characteristic and tap setting.

*Indicates Revision

CHARACTERISTICS

The operating characteristics of the reactance (ohm) and mho units in the GCXG53A relay may be represented on an R-X impedance diagram as shown in Figure 4. It should be noted that these are steady-state characteristics, and are for rather specific fault conditions, as described below.

MHO UNIT

The mho unit has a circular characteristic which passes through the origin and defines the angle of maximum torque of the unit, which occurs when line current (I_a for example) lags the polarizing voltage (E_{am}') by 60 or 75 degrees. Since there is essentially no phase shift in the line-to-neutral voltage for a single phase-to-ground fault, this maximum torque angle (i.e., maximum reach angle) occurs when the line current lags the phase-to-neutral voltage by 60 degrees, which is the condition represented in Figure 4.

The diameter of the impedance circle is the ohmic reach of the unit, which is the basic minimum reach (see Table I) with the E^2 tap leads on 100 percent.

The ohmic reach of the mho unit can be extended by reducing the percentage of the fault voltage applied to the restraint circuit, that is by setting the E^2 tap leads on a lower percentage position on the tap block:

* $$\text{Ohmic Reach} = \frac{(Z_{min})\ 100}{E^2 \text{ Tap Setting } (\%)} \qquad \text{(Eq. 8)}$$

The ohmic reach obtained from equation 8 assumes that line angle and maximum torque angle are equal (60 degrees). The reduced reach at line angles other than 60 degrees can be obtained by multiplying the reach obtained from equation 8 by cos (60-Ø), where Ø is the line angle.

Equation 8 also assumes an input tap setting of 100 percent. In some cases the input tap will be set less than 100 percent to obtain better accuracy on the ohm unit reach (see section on VERNIER ADJUSTMENT FOR LOW TAP SETTINGS). The reach of the mho unit at a lower input tap setting can be obtained by multiplying the reach obtained from equation 8 by:

$$\frac{\text{Input Tap }\%}{100}$$

The primary purpose of the mho unit in the GCXG53A relay is to provide directional discrimination, which is necessary, since the ohm unit is inherently non-directional.

A secondary purpose of the mho unit is to measure fault impedance for the third zone of protection.

*Indicates Revision

OHM UNIT

The ohm unit characteristic, when represented on the R-X diagram (Figure 4), is a straight line parallel with the R-axis. The unit will operate for fault impedances lying below its characteristic and hence is non-directional. During normal conditions, when load is being transmitted over the protected line, the voltage and current supplied to the unit present an impedance which lies close to the R-axis. Since an impedance near the R-axis will lie below the ohm unit characteristic, the ohm unit contact will be closed. This will not cause tripping, however, since the contact of the directional unit will not be closed for this condition (see Figure 4).

As explained in the section on **APPLICATION**, the ohm unit when properly compensated, provides an accurate measurement of the positive sequence reactance from the relay location to the fault. The method of obtaining proper compensation is described in the section, **RELAY AND COMPENSATING AUXILIARY CT SETTINGS**.

The overreach of the ohm unit from transient offset of the fault current is very small, even with highly lagging line impedances, and can be neglected for relay settings within the recommended ranges.

The basic minimum reach of the ohm unit as listed in Table I under **RATINGS** is obtained when the restraint tap leads are on 100 percent. The ohmic reach can be extended by setting the restraint tap leads percentage position on the tap block. The setting of the two tap leads marked #1 determines the reach of the instantaneous or first zone, and the setting of the two tap leads marked #2 determines the reach of the intermediate or second zone. The reach can be expressed as follows:

$$\text{Ohmic Reach} = \frac{(X_{min})\ 100}{\text{Tap Setting (\%)}}$$

where:

X_{min} = basic minimum reach (Table I)

Tap setting = #1 or #2 tap setting

For a numerical example of the determination of the ohm and mho unit settings, refer to the section on **SAMPLE CALCULATIONS FOR SETTINGS**.

At reduced values of fault current, the ohmic reach of the ohm unit will be somewhat lower than its calculated value. Table III lists minimum values of line current for a single phase-to-ground fault which will insure that the reach will be 90 percent or more of the calculated value.

TABLE III

MINIMUM FAULT CURRENT (1Ø-G) FOR REACH OF 90% OR MORE OF CALCULATED VALUE	
BASIC MINIMUM REACH	MINIMUM CURRENT
0.25	3.6
0.5	1.8
1.0	1.2
2.0	0.75

VERNIER ADJUSTMENT FOR LOW TAP SETTINGS

The input leads to the tapped autotransformer are normally set at 100 percent, but with a high secondary line reactance where the #1 tap leads would be set at a low percentage, the input connections may be varied by a vernier method to obtain a closer setting. This is described in detail in the section on **RELAY AND COMPENSATING AUXILIARY CT SETTINGS.**

OHM UNIT TRANSFER AUXILIARY

The ohm unit transfer auxiliary, OX, is a telephone-type relay whose coil and contacts are shown on the internal connection diagram of Figure 5. The unit is mounted near the top of the relay and is used to change the setting of the ohm unit to provide a second step of transmission line protection. Its operation is controlled by the Type RPM or SAM timing relay as shown by the external connection diagram of Figure 6. The normally closed contacts of the transfer auxiliary provide the circuit for instantaneous tripping used for faults in the first step of line protection. If the fault is beyond the first zone of protection, the transfer auxiliary changes the setting of the ohm unit by switching to the #2 taps on the autotransformer, from which a smaller potential is supplied, to the unit potential restraint windings. This extends the ohmic reach of the ohm unit, and enables it to operate for faults in the second zone of transmission line protection.

OPERATING TIME

The operating time characteristics of the ohm and mho units in the GCXG53A relay are determined by a number of factors such as the basic minimum reach setting of the unit, fault current magnitude, and the ratio of fault impedance to the reach of the unit.

Typical time curves for the mho unit are shown in Figure 7 for several ratios of fault impedance to unit reach. These curves are for a single phase-to-ground fault where the fault impedance (Z_{FAULT}) seen by the unit can be calculated as described in Appendix II. Note in the figure that the fault current scale changes with the basic minimum reach setting.

Typical time curves for the ohm unit are shown in Figure 8.

As will be apparent from the typical elementary diagram in Figure 6, the trip chain for a first zone single phase-to-ground fault includes contacts of the instantaneous overcurrent unit and auxiliary unit (A1, A2, or A3) in the associated NAA relay, as well as the unit and ohm unit contacts. Operating time for the instantaneous unit can be obtained from the time curve in the NAA instruction book. The pickup time of the auxiliary unit at rated DC voltage is less than six milliseconds. The operating time of the ohm unit will be greater than the time of the instantaneous unit, or mho unit plus auxiliary unit, for most fault conditions. So, as a general rule, it can be assumed that the ohm time will determine the overall operating time of the Type GCXG53A scheme on single phase-to-ground first zone faults.

BURDENS

CURRENT BURDEN

The burden at five amperes in given in Table IV.

TABLE IV

FREQUENCY	CIRCUIT	TAP USED		OHMS		WATTS	VA	PF
		MHO	OHM	R	X			
60	5-6	3.0	0.4	0.152	0.040	3.80	3.92	0.97
↓	7-8	-	0.4	0.136	0.031	3.40	3.49	0.98
	9-10	3.0	-	0.016	0.009	0.40	0.46	0.87
	5-6	3.0	1.0	0.160	0.060	4.00	4.27	0.94
	7-8	-	1.0	0.144	0.051	3.60	3.82	0.94
	9-10	3.0	-	0.016	0.009	0.40	0.46	0.87
	5-6	6.0	2.0	0.225	0.149	5.62	6.74	0.86
	7-8	-	2.0	0.174	0.114	4.36	5.20	0.84
	9-10	6.0	-	0.052	0.036	1.30	1.58	0.82
50	5-6	3.0	0.4	0.072	0.040	1.8	2.06	0.87
↓	7-8	-	0.4	0.028	0.012	0.70	0.76	0.92
	9-10	3.0	-	0.044	0.028	1.1	1.30	0.84
	5-6	3.0	1.0	0.100	0.080	2.5	3.20	0.78
	7-8	-	1.0	0.060	0.052	1.5	1.98	0.76
	9-10	3.0	-	0.044	0.028	1.1	1.30	0.84

Table IV gives the burden when the maximum basic ohmic reach taps are used. If lower basic ohmic taps are used, the burden will be slightly lower.

POTENTIAL BURDEN

The burden at rated voltage is given in Table V.

TABLE V

RATED		CIRCUIT	OHMS		WATTS	VA	PF
VOLTS	FREQ'Y		R	X			
70	60	OHM POTENTIAL	625	+j175	7.3	7.6	0.96
* 70	60	MHO RESISTANCE	655	+j1037	2.1	4.0	0.52
120	60	MHO POTENTIAL	1058	-j230	13.0	13.3	0.98
70	50	OHM POTENTIAL	540	+j210	7.9	8.5	0.93
70	50	MHO RESISTANCE	427	+j824	2.4	5.2	0.46
120	50	MHO POTENTIAL	1579	-j496	8.3	8.7	0.95

The above burdens are the maximum values and apply when the ohm and mho taps are on 100 percent. If the taps are set at some value less than 100 percent, then the burden of that circuit will be less as given by the following:

* $$Z \text{ (at tap T\%)} = Z \text{ (at tap 100\%)} \times \left(\frac{T\%}{100\%}\right)^2 \quad \text{(Eq. 9)}$$

For ohm potential circuit T = #1 tap of ohm unit

For mho resistance circuit T = E^2 tap of mho unit

The mho potential circuit has no taps and its burden is always that given in Table V.

CONSTRUCTION

The Type GCXG53A relays are assembled in the standard large size, double-end (L2) drawout case having studs at both ends in the rear for external connections. The electrical connections between the relay units and the case studs are made through stationary molded inner and outer blocks, between which nests a removable connecting plug which completes the circuits. The outer blocks attached to the case have the studs for the external connections, and the inner blocks have the terminals for the internal connections.

The relay mechanism is mounted in a steel framework called the cradle and is a complete unit with all leads being terminated at the inner blocks. This cradle is held firmly in the case with a latch at both top and bottom, and by a guide pin at the back of the case. The connecting plug, besides making the electrical connections between the respective blocks of the cradle and case, also locks the latch in place. The cover, which is fastened to the case by thumbscrews, holds the connecting plugs in place.

A separate testing plug can be inserted in place of the connecting plug to test the relay in place on the panel, either from its normal source of current and voltage, or from other sources. Or, the relay unit can be withdrawn for testing and replaced by a spare relay unit which has been tested in the laboratory.

*Indicates Revision

The relay is composed of three major subassembly elements:

1. The bottom element includes the mho unit and associated circuit components. This unit is directional and detects the presence of faults within the zone covered by the relay. It also initiates operation of the zone timer for faults within its reach.

2. The middle element includes the ohm or reactance unit and associated circuit components. This unit provides accurate first or second zone distance measurement.

3. The top element includes the ohm unit transfer auxiliary, OX, the combination target and seal-in unit, the transactor associated with the ohm unit potential circuit, and the tapped autotransformer which determines the reach of the ohm and mho units. The tap block associated with the autotransformer is mounted along the right side of the relay.

Figure 1A and 1B show the relay removed from its case, with all major components identified. Symbols used to identify circuit components are the same as those which appear on the internal connection diagram in Figure 5.

RECEIVING, HANDLING AND STORAGE

These relays, when not included as part of a control panel will be shipped in cartons designed to protect them against damage. Immediately upon receipt of a relay, examine it for any damage sustained in transit. If injury or damage resulting from rough handling is evident, file a damage claim at once with the transportation company and promptly notify the nearest General Electric Apparatus Sales Office.

Unpack the relay carefully so that none of the parts are damaged, nor any of the adjustments disturbed.

If the relays are not to be installed immediately, they should be stored in their original cartons in a place that is free from moisture, dust and metallic chips. Foreign matter that collects on the outside of the case may find its way inside when the cover is removed, and cause trouble during operation of the relay.

ACCEPTANCE TESTS

Immediately upon receipt of the relay, an inspection and acceptance test should be made to insure that no damage has been sustained in shipment and that the relay calibrations have not been disturbed. If the examination or test indicates that readjustment is necessary, refer to the section on **SERVICING.**

VISUAL INSPECTION

Check the nameplate stamping to insure that the model number and rating of the relay agree with the requisition.

Remove the relay from its case and check that there are no broken or cracked molded parts or other signs of physical damage, and that all screws are tight.

MECHANICAL INSPECTION

1. Check the mechanical adjustments of Table VI.
2. There should be no noticeable friction in the rotating structure of the ohm and mho units.
3. Make sure control springs are not deformed, and spring convolutions do not touch each other.
4. With the relay well leveled, and in its upright position, the ohm and mho unit contacts must be open. The moving contacts of these units should rest against their backstops.
5. The armature and contacts of the seal-in unit should move freely when operated by hand. There should be at least 1/32-inch wipe on the seal-in contacts.
6. Make sure the armature of telephone-type relay (OX) moves freely.
7. Check the location of the contact brushes on the cradle and case blocks against the internal connection diagram for the relay. Make sure that the shorting bars are in their proper location on the case block.

TABLE VI

CHECK POINTS	MHO UNIT	OHM UNIT
Rotating Shaft End Play	0.010-0.015 inch	0.005-0.008 inch
Contact Gap	0.120-0.130 inch	0.035-0.045 inch
Contact Wipe	0.003-0.005 inch	0.003-0.005 inch

ELECTRICAL CHECKS

Before any electrical checks are made on the ohm and mho unit, the relay should be connected as shown in Figure 9 and allowed to warm up for approximately 15 minutes with the potential circuits alone energized at rated voltage, and with the E^2 and #1 tap leads set at 100 percent. The units were warmed up prior to factory adjustment, and if checked when cold, will tend to underreach by three or four percent. Of course, accurately calibrated meters are essential.

MHO UNIT CHECKS

Control Spring

With the relay connected as shown in Figure 9A, disconnect the E^2 taps, and set the basic reach taps on the maximum ohmic reach tap, and the maximum torque links in the 75-degree position. With the voltage at 104 volts, and the current set at 5.0 amperes, set the phase shifter so that current lags voltage by 75 degrees. Now reduce the voltage to five volts and the current to zero. Gradually increase the current until the mho unit contact just closes. The operating point should fall between 0.7 to 1.0 ampere for the six ohm tap. This value will be between 1.4 and 2.0 amperes for the three ohm unit.

Angle of Maximum Torque (75-Degree Position)

The object of this test is to set the rheostat (R4) in the polarizing circuit so that the angle of maximum torque occurs when operating current lags polarizing voltage by 75 degrees.

Connect the relay as shown in Figure 9B. Set the V2 voltage at 70 volts and the polarizing voltage, V1, at 104 volts. The mho links should be set on six. Set E^2 taps at 50 percent, set I for six amperes, and adjust R4 until the angle of maximum torque is 75 degrees lag. For the three ohm unit, set I for 12 amperes.

Angle of Maximum Torque (60-Degree Position)

Place the angle of maximum torque link in the 60-degree position. Set E^2 taps at 50 percent. Connect the relay as shown in Figure 9B. Adjust V1 for 104 volts, and V2 for 70 volts. Set I for seven amperes. R9 is adjusted to obtain an angle of maximum torque of 60 degrees lag. For the three ohm unit, set I for 14 amperes.

Mho Unit Reach

Connect the relay as shown in Figure 9B. Set voltage V1 and V2 per Table VII. Set the phase shifter for the angle of maximum torque (60-degree lag). Increase the operating current unitl the contacts just close. The current should be within the limits given in Table VII.

TABLE VII

BASIC TAP SETTING USED	VOLTAGE V1	VOLTAGE V2	OPERATING CURRENT (AMPS)	E^2 TAP SETTING
1.0	104	25	11.6 - 13.4	50%
2.0	104	25	5.8 - 6.7	50%
3.0	104	70	10.8 - 12.5	50%
4.0	104	70	8.1 - 9.4	50%
6.0	104	70	5.4 - 6.3	50%

The X2 reactor should be adjusted if the mho unit is out of limits to bring it back into limit.

Compensation Winding Check

Repeat tests under MHO UNIT CHECKS, except use studs nine and ten instead of studs five and six.

OHM UNIT CHECKS

Control Spring Adjustment

Using the connections shown in Figure 9B, leave the potential circuit of the relay disconnected and short out studs 17-18. The #1 tap leads should be in the 100 percent position, and the basic reach taps should be as shown in Table VIII. Increase the current gradually until the ohm unit contacts just close. This should occur within the limits shown in Table VIII.

* TABLE VIII

Control Spring Check (Ohm Unit)

RELAY	BASIC MINIMUM REACH SETTING (OHMS)	CLOSING CURRENT (AMPS)
Short reach	0.2	1.1 - 1.6
Standard reach	0.5	0.4 - 0.9
Long reach	1.0	0.2 - 0.5

Ohmic Reach and Angle of Maximum Torque

Since the ohm unit is a reactance measuring device, its angle of maximum torque occurs at 90 degrees, current lagging voltage.

To check the ohmic reach, use the connections shown in Figure 9B, with the #1 tap leads on 100 percent and the basic reach taps in the indicated position. With the voltage set at 70 volts and the current at five amperes, set the phase shifter so that the current lags the voltage by 90 degrees. Now set the current at the value shown in * Table IX for the relay to be checked, and reduce the voltage across studs 17-18 to the point where the ohm unit contacts just close. Table IX shows the theoretical pickup voltage for the indicated basic reach setting of each unit. A variation of plus or minus three percent is permissible. Note that with the test connections of Figure 9B, both the operating winding (5-6), and the compensating winding (7-8), are connected in series and the reach of the unit in the test circuit is twice the nameplate stamping.

*Indicates Revision

*

TABLE IX

Ohmic Reach Check (Ohm Unit)

BASIC MINIMUM TAP USED	RESTRAINT #1 TAP	CURRENT SET AT (AMPS)	OPERATING VOLTAGE (V17-18) I LAGS V BY	
			90 DEGREES	45 DEGREES
0.1 ohm	100%	20	3.88 - 4.12	5.48 - 5.83
0.2	100%	15	5.82 - 6.18	8.23 - 8.74
0.4	100%	15	11.64 - 12.36	16.46 - 17.48
0.25 ohm	100%	15	7.27 - 7.73	10.28 - 10.93
0.50	100%	15	14.55 - 15.5	20.58 - 21.85
1.00	100%	10	19.40 - 20.60	27.16 - 29.20

To check the angle of maximum torque, use the same connections and settings as previously described, except now set the phase shifter so that the current lags the voltage by 45 degrees. Again vary the voltage across studs 17-18 until the point is reached where the contacts just close. The nominal values are listed in Table IX. A variation of plus or minus three percent is permissible.

Other Checks and Tests

In addition to the tests on the ohm and starting units, the following general tests and checks are recommended as a part of the acceptance test routine.

Ohm Unit Transfer Relay (OX):

The ohm unit transfer relay, identified as OX in Figure 5, is provided with a voltage selection link to adapt it for application on 48, 125 or 250 volt DC controls. The unit should be checked for correct operation on each link position. Apply a variable source of DC voltage across stud 12-13, and check that the OX unit picks up at 80 percent or less of nominal tap voltage for each link position.

Target Seal-in Unit:

The target seal-in unit has an operating coil tapped at 0.2 and 2.0, or 0.6 and 2.0 amperes. The relay is shipped from the factory with the tap screw in the lower ampere position. The operating point of the seal-in unit can be checked by connecting from a DC source (positive) to stud 11 of the relay, and from stud 3 through an adjustable resistor and ammeter back to negative. Connect a jumper from stud 15 to stud 3 so that the seal-in contact will also protect the mho unit contact. Then close the mho contact by hand, and increase the DC current until the seal-in unit operates. It should pick up at tap value or slightly lower. Do not attempt to interrupt the DC current by means of the mho unit contact.

If it is necessary to change the tap setting, say from 0.6 to 2.0 amperes, proceed as follows:

Remove the tap screw from the left-hand contact strip and insert it in the 2.0 ampere position of the right-hand contact strip. Then remove the screw from the 0.6

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tap and put it in the vacant position in the left-hand plate. This procedure does not disturb the contact adjustments.

INSTALLATION PROCEDURE

LOCATION

The location should be clean and dry, free from dust, excessive heat and vibration, and well lighted to facilitate inspection and testing.

MOUNTING

The relay should be mounted on a vertical surface. The outline and panel drilling dimensions are shown in Figure 10.

The outline and panel drilling and internal connections diagram for the auxiliary compensating transformers are shown in Figures 11 and 12.

CONNECTIONS

The internal connections for the GCXG53A relay are shown in Figure 5. An elementary diagram of typical external connections is shown in Figure 6.

VISUAL INSPECTION

Remove the relay from its case and check that there are no broken or cracked component parts and that all screws are tight.

MECHANICAL INSPECTION

Recheck the adjustments mentioned under MECHANICAL INSPECTION in the section on **ACCEPTANCE TESTS.**

ELECTRICAL TESTS ON INDUCTION UNIT

The manner in which reach settings are made on the ohm and starting units is briefly discussed in the section titled, **SAMPLE CALCULATIONS FOR SETTINGS**. Examples of the calculation of typical settings are given in that section. The purpose of the electrical tests in this section is to check the ohm and mho unit ohmic pickup settings which have been made for a particular line section.

MHO UNIT

The mho unit is set for the calculated reach and checked by means of the connections shown in Figure 9. With V1 set for ten volts, and V2 set for 70 volts, the current required to just close the contacts may be calculated from the following equation:

* $$I = \frac{V2}{(BMT)\ 100/E^2 \times 2 \cos \theta} \pm 10\% \qquad \text{(Eq. 10)}$$

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where:

V2 = voltage (70 volts)

BMT = basic minimum tap of mho unit

E^2 = restraint tap setting

θ = difference between the angle of maximum torque (either 60 or 70 degrees) and the test being made.

The mho unit angle of maximum torque may be checked by the method as shown in the **ACCEPTANCE TESTS.**

The mho unit compensating winding can be checked in a manner similar to that previously described, except the current is applied to studs 9 and 10 instead of studs 5 and 6.

OHM UNIT

The ohm unit is set for the calculated reach and checked by means of the connections shown in Figure 9. Since the test connections have the operation winding (5-6) and the compensating winding (7-8) connected in series, the resultant reach is twice the nameplate stamping.

The ohm unit angle of maximum torque is checked by the method as shown in the **ACCEPTANCE TESTS.**

OTHER CHECKS AND TESTS

In addition to the calibration checks on the ohm and mho units as described above, it is desirable to make the following general checks and tests at the time of installation.

1. Check that the voltage selection link for the OX transfer unit is in the correct position for the DC voltage to be used (48, 125 or 250 volts, or 48, 110 or 220 volts). Check that the OX unit is picking up at 80 percent of nominal rated voltage as determined by the link position, by applying a variable DC voltage between studs 12 and 13. *

2. Check that the tap screw in the target seal-in unit is in the desired position and the unit is operating at tap value. If it is necessary to change the tap setting, follow the procedure outlined in the section, **ACCEPTANCE TESTS.**

PERIODIC CHECKS AND ROUTINE MAINTENANCE

In view of the vital role of protective relays in the operation of a power system, it is important that a periodic test program be followed. The interval between periodic checks will vary depending upon environment, type of relay and the user's experience with periodic testing. Until the user has accumulated enough experience to select the test interval best suited to his individual requirements, it is suggested that the points listed under **INSTALLATION PROCEDURE** be checked at an interval of from one to two years.

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CONTACT CLEANING

A flexible burnishing tool should be used for cleaning fine silver contacts. This is a flexible strip of metal with an etched-roughened surface, which in effect resembles a superfine file. The polishing action of this file is so delicate that no scratches are left on the contacts, yet it cleans off any corrosion thoroughly and rapidly. The flexibility of the tool insures the cleaning of the actual points of contact. Knives, files, abrasive paper or cloth of any kind should never be used to clean relay contacts.

SERVICING

If the ohm or mho unit calibrations are found to be out of limits during performance of the installation or periodic tests, they should be recalibrated as outlined in the following paragraphs. It is suggested that these calibrations be made in the laboratory. The circuit components listed below, which are normally considered as factory adjustments, are used in recalibrating the units. These parts may be located on Figure 1A and 1B.

R1 - ohm unit reach adjustment
R2 - ohm unit phase angle adjustment
X2 - mho unit reach adjustment
* R4 - mho unit phase angle adjustment - 75° setting
* R9 - mho unit phase angle adjustment - 60° setting

NOTE: Before setting reach or phase angle adjustments on the ohm or mho units, the relay should be allowed to heat up for approximately 15 minutes energized with voltage alone. Also, the relay must be mounted in an upright position so that the units are level.

MHO UNIT

Control Spring Adjustment

The control spring may be adjusted by using the test connections shown in Figure 9A.

1. Open the E^2 taps.

* 2. Set the mho unit links in the six ohm position.

3. Set the angle of maximum torque link in the 60-degree position.

4. Set I for five amperes and V for 104 volts, and the phase angle for 300 degrees (I leading E).

5. Reduce the voltage to five volts and adjust the control spring until the unit just closes between 0.7 and 1.0 ampere. For the three ohm unit, the current will be between 1.4 and 2.0 amperes.

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Angle of Maximum Torque (75 Degrees)

Rheostat R4 is adjusted by using the test connections shown in Figure 9B.

1. Set V2 = 70 volts, and V1 = 104 volts.

* 2. Set the mho links in the 6.0 ohm position.

3. Set the angle of maximum torque link in the 75-degree position.

4. Set the E^2 taps at 50 percent

5. Set I for seven amperes (14 amperes for the three ohm unit).

6. Adjust R4 until the angle of maximum torque is 75 degrees lag.

Angle of Maximum Torque (60 Degrees)

With the same connections as in the 75-degree setting, set the angle of maximum torque link to the 60-degree position and proceed as follows:

1. E^2 taps in 50 percent.

2. V2 = 70 volts, V1 = 104 volts, I = seven amperes (14 amperes for the three ohm unit).

3. Adjust R9 to obtain an angle of maximum torque of 60 degrees lag.

Reach Adjustment

See section titled "**ACCEPTANCE TESTS.**"

OHM UNIT

Control Spring Adjustment

Use the test connections of Figure 9. Leave the potential circuit to the relay disconnected, and short out studs 17-18. The #1 tap leads should be in the 100 percent position, and the basic reach taps in the 0.5 ohm position. Set the operating current at 0.4-0.9 ampere.

Insert the blade of a thin screwdriver into one of the slots in the edge of the spring adjusting ring (see Figure 2) and turn the ring until the contacts just close. If the contacts were closing above the set current, turn the adjusting ring to the right. If they were closing above the set point, turn the adjusting ring to the left.

Neutralizing Transformer Adjustment

Before adjusting the ohm unit, make sure that the mho unit polarizing circuit effect has been neutralized by energizing the mho unit polarizing circuit only at 104 volts (stud 17 to 19 and 20), and measuring the induced voltage across the opened #1 taps. This should be less than 2.0 volts. If not, adjust for a minimum by turning the core of the Tm transformer until a null voltage has been obtained.

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Reach and Angle of Maximum Torque Adjustment

The basic minimum reach of the ohm unit is controlled by rheostat R1, and its angle of maximum torque (90-degree current lagging voltage), may be adjusted by means of rheostat R2. It should be noted, however, that these adjustments are not independent: that is, an adjustment of R2 will have some effect on the reach of the ohm unit, and adjustments of R1 will affect the angle of maximum torque.

To calibrate the ohm unit, place the #1 taps in the 100 percent position, and use the connections shown in Figure 9. Follow the procedure outlined below:

Step 1:

With the current set at five amperes, and voltage at 70 volts, adjust the phase shifter so that the current lags voltage by 90 degrees. Then set the current for the * value shown in Table IX for the basic reach to be checked, and the voltage for the value listed in the column "90-Degrees." For example, for the 1.0 ohm basic minimum reach, the current would be set at ten amperes and the voltage at 20 volts. Adjust R1 rheostat until the ohm unit contacts just close. Now raise the voltage and again lower it slowly until the ohm unit contacts just close. The voltage at the operating point should be within plus or minus one percent of the voltage listed in Table IX in the column "90-Degrees." Readjust R1 until the operating voltage is within a plus or minus one percent limit.

Note that the relay operating circuit should not be left energized with the test current of Table IX for more than a few seconds at a time.

Step 2:

Reset the phase shifter so that current lags voltage by 45 degrees, and with the same current used in Step 1, set the voltage at the value listed in the column "45-Degrees." Then adjust R2 until the contacts just close. Now raise the voltage and reduce it slowly until the contacts just close. The voltage at this operating point should be within plus or minus two percent of the value in Table IX under the "45-Degree" column. Modify the R2 setting until the operating voltage is within this plus or minus two percent limit.

Step 3:

Recheck Step 1. The ohm unit contacts should close within plus or minus three percent of the voltage listed in the "90-degree column." If the ohm unit contacts do not close within these limits, repeat steps 1 and 2 until the unit contacts close within the limits specified.

RENEWAL PARTS

Sufficient quantities of renewal parts should be kept in stock for prompt replacement of any that are worn, broken or damaged.

When ordering renewal parts, address the nearest Sales Office of the General Electric Company. Specify the name of the part wanted, quantity required, and the complete nameplate data for the particular relay. If possible, include the General Electric Company requisition number on which the relay was furnished.

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APPENDIX I

DEFINITIONS OF SYMBOLS

In the following appendices, and throughout other portions of this instruction book, the symbols used for voltages, currents, impedances, etc., are consistent. Note that all of the parameters listed below are secondary quantities based on the CT and PT ratios on the protected line terminal.

A - VOLTAGE

E_a = phase-A-to-neutral voltage

E_b = phase-B-to-neutral voltage

E_c = phase-C-to-neutral voltage

E_{ab} = $(E_a - E_b)$

E_{bc} = $(E_b - E_c)$

E_{ca} = $(E_c - E_a)$

E_0 = zero sequence phase-to-neutral voltage

E_1 = positive sequence phase-to-neutral voltage

E_2 = negative sequence phase-to-neutral voltage

Note that when one of the above symbols is primed, such as E_a', it then represents the voltage at the location of the relay under consideration.

B - CURRENTS

I_a = total phase A current in the fault

I_b = total phase B current in the fault

I_c = total phase C current in the fault

I_0 = total zero sequence current in the fault

I_1 = total positive sequence current in the fault

I_2 = total negative sequence current in the fault

Note that when one of the above symbols is primed, such as I_a' or I_2', it then represents only that portion of the current that flows in the relays under consideration.

I_0'' = zero sequence current flowing in a line that is parallel to the protected line. Considered positive when the current flow in the parallel line is in the same direction as the current flowing in the protected line. While this current flows in the parallel line, the secondary value is based on the CT ratio at the protected line terminal under consideration.

I_0''' = the same as I_0'', except that it is the current flowing in another parallel line.

Note that I_0'' represents the zero sequence mutual currents that will be compensated. I_0''' represents the zero sequence mutual currents that will not be compensated.

C - DISTRIBUTION CONSTANTS

C = positive sequence distribution constant. Assumed equal to the negative sequence distribution constant.

$$C = \frac{I_1'}{I_2} = \frac{I_2'}{I_2}$$

C_0 = zero sequence distribution constant.

$$C_0 = \frac{I_0'}{I_0}$$

D - IMPEDANCE

Z_0 = system zero sequence phase-to-neutral impedance as viewed from the fault.

Z_1 = system positive sequence phase-to-neutral impedance as viewed from the fault.

Z_2 = system negative sequence phase-to-neutral impedance as viewed from the fault. Assume equal to Z_1.

Z_0' = zero sequence phase-to-neutral impedance of the protected line from the relay to the remote terminal, $Z_0' = R_0' + jX_0$.

Z_1' = positive sequence phase-to-neutral impedance of the protected line from the relay to the remote terminal, $Z_1' = R_1' + jX_1$.

Z_2' = negative sequence phase-to-neutral impedance of the protected line from the relay to the remote terminal. Equals Z_1.

Z_{om} = total zero sequence mutual impedance between the protected line and a parallel circuit over the entire length of the protected line, $Z_{om} = R_{om} + jX_{om}$.

E - MISCELLANEOUS

T = relay tap setting in percent.

α, Δ, ϕ, θ, A, B, C, etc. = angles in degrees as defined where used

S_1, S_2 and S_3 = ratio of distances as defined where used

K_0 = X_0'/X_1'

K_m = X_{om}/X_0'

K_S = constant depending on the ratio of Z_0/Z_1

K = basic minimum ohmic tap of the mho starting unit

K' = percent tap setting on primary winding of 0367A0266G-1 or 0367A0266G-2 auxiliary CT

K" = percent tap setting on secondary of 0367A0266G-1 auxiliary CT

CTR = current transformer ratio on protected line terminal

CTRP = current transformer ratio on parallel line terminal for which mutual compensation is being used.

APPENDIX II

MINIMUM PERMISSIBLE REACH SETTING FOR THE MHO STARTING UNIT

The apparent impedance to a single phase-to-ground fault at the far end of the protected line as seen on the faulted phase is:

$$Z_1' + \frac{(Z_0' - Z_1')C_0}{2C + C_0} + \frac{Z_{om}I_0''}{I_a'}$$

where:

Z_1' = positive sequence impedance of the protected line

Z_0' = zero sequence impedance of the protected line

Z_{om} = total zero sequence mutual impedance between protected line and parallel line.

I_0'' = zero sequence current in the parallel line, considered positive when the current flow in the parallel line is in the same direction as the current in the protected line.

I_a' = phase A current in the relay

C = positive sequence distribution constant I_1'/I_1.

C_0 = zero sequence distribution constant I_0'/I_0.

When the zero sequence current compensation is added, the middle term of the above apparent impedance becomes negligible. Thus to insure that the mho starting unit on the faulted phase picks up for a fault at the remote bus, the maximum percent tap setting permissible is:

$$T_{max} = \frac{100(K)\cos(\emptyset - \theta)}{1.25 \quad Z_1' + \left[\frac{Z_{om}I_0''}{I_a' + 3K'I_0'}\right]} \qquad \text{(Eq. II-a)}$$

where:

K = basic minimum ohmic tap

K' = tap setting on compensator CT in per unit

θ = angle of impedance Z_1'

I_0' = zero sequence current in the protected line

ϕ = angle of maximum torque of the relay, 60 or 75 degrees.

If the solution to equation II-a yields a tap value (T) greater than 100 percent, this implies that even the shortest reach setting possible (100 percent tap) will suffice.

The factor 1.25 introduced in equation II-a is a safety factory. In order to extend the reach of the starting unit beyond the far bus, lower tap settings will be required.

If there is no zero sequence mutual impedance, the last term in the denominator of equation II-a becomes zero. If there is mutual impedance existing between the protected line and several other circuits, this last term becomes

$$\frac{1}{I_a' + 3K'I_0'} \sum Z_{om}I_0'' \qquad \text{(Eq. II-b)}$$

Note that in this summation, the direction of the zero sequence current flow (I_0'') in each of the parallel circuits must be considered. All voltage, currents and impedances in the above equations are in terms of secondary quantities based on the CT and PT ratios of the protected line. This applies to I_0'' as well as I_a'. Note that the value of T obtained from equation II-a above is based on an input tap setting of 100 percent. If the input tap setting used is less than 100 percent, then the value of T obtained from equation II-b should be multiplied by the input tap setting to arrive at the final answer.

APPENDIX III

MAXIMUM PERMISSIBLE REACH SETTINGS FOR THE MHO STARTING UNIT

The starting units of the GCXG relays control their operation. The interlocking of the associated NAA contacts is such that tripping is blocked when more than one starting unit picks up. It is possible that a starting unit on a unfaulted phase will pick up, as well as the one on the faulted phase, for a single phase-to-ground fault in the tripping direction under certain system conditions. This would block tripping. Also, under some systems conditions it is possible that one or the other of the starting units associated with the unfaulted phases will pick up during single phase-to-ground faults in the non-tripping direction. This could cause false tripping. Therefore, it is necessary to limit the reach of the mho starting units to prevent them from picking up under either of these conditions.

On most power systems where the GCXG relay is applied, the single phase-to-ground fault in the reverse direction is the limiting case. The minimum permissible tap setting for this condition is given by equation III-a. Evaluate the equation for single phase-to-ground faults on the bus immediately behind the relay, as fault F2 in Figure III-1.

$$T = \frac{(K)\ (K_Q)\ \left[(3K' + 1)C_0\right] - C}{Z_1} \qquad \text{(Eq. III-a)}$$

where:

K_Q = system constant depending upon the ratio of system impedances Z_0/Z_1 as seen from the fault. Use Figure III-2 for 60 degrees, and Figure III-3 for 75 degrees maximum torque.

K' = per unit compensator CT setting

All other terms are defined in Appendix I.

If in making the calculations using equation III-a, the term $\left[(3K' + 1)C_0 - C\right]$ is negative, it is obvious that there will be no limitation imposed on the unit tap setting by the conditions described for equation III-a. However, this does raise the possibility that one of the starting units on the unfaulted phase may also respond to an internal single phase-to-ground fault. Thus, two starting units responding to the fault will block tripping through their A interlocking auxiliaries. The minimum tap setting, T, that can be set on the starting unit to avoid this problem, can be determined by the following equation, evaluated for the internal fault F1, Figure III-1.

$$T = \frac{(K)\ (K_P)\ \left[C - (3K' + 1)\ C_0\right]}{Z_1} \qquad \text{(Eq. III-aa)}$$

where:

K_P = system constant depending upon the ratio of system impedances Z_0/Z_1 as seen from the fault. Use the curves of Figure III-4 for 60-degree and the curves of Figure III-5 for 75-degree maximum torque angle. Substitute the value of K_P obtained directly into equation III-aa.

For these conditions, the term $[C - (3K' + 1)\ C_0]$ will also be negative. Thus, equation III-aa will produce a positive value of T only if the system constant, K_P, is also negative. Comparing the curves of Figure III-4 and III-5, it is obvious that a unit with the 75-degree maximum torque angle has much less exposure to any limitation to its tap setting.

It is possible under some system conditions that the starting unit on the unfaulted phase will pick up during double phase-to-ground faults in the non-tripping direction. Since in the same applications this can result in a false trip, it is necessary to limit the reach setting of the starting units to prevent them from picking up on the reverse double phase-to-ground faults. Equation III-b gives this limit

$$T = \frac{100(K)\ [(3K' + 1)\ C_0 - C]}{3Z_0} \cos(\theta - \emptyset) \qquad \text{(Eq. III-b)}$$

where:

θ = angle of zero sequence impedance, Z_0

$\emptyset$ = maximum torque angle of relay

All other terms as defined above.

Note that the values of C and C_0 are the same for equations III-a and III-b.

After the values of T have been calculated for equations III-a and III-b, the largest of these values should be selected and then some margin, such as ten percent (not ten percentage points), should be added to this setting. This value of tap setting is then the minimum permissible tap setting for the starting units at the terminal under consideration. If either (or both) of the values of T calculated from the equations is negative, that signifies that the particular equation (or equations) offers no limitation on the minimum permissible tap setting.

When evaluating these equations, the first step should be an evaluation of the term $[(3K' + 1)\ C_0 - C]$. If this term is negative for all the system operating conditions for a ground fault at F2, equations III-a and III-b will impose no limitations. Aside from all considerations, the starting units should never be set on a tap lower than ten percent.

All voltages, currents and impedances in the above equations are in terms of secondary quantities based on the CT and PT ratios of the protected line. Note that the value of T obtained from equations III-a and III-b above is based on an input tap setting of 100 percent. If the input tap setting is less than 100 percent, the value of T obtained from the above equations should be multiplied by the input tap setting to arrive at the final answer. The effects of arc resistance have not been included in these calculations.

APPENDIX IV

EFFECTS OF UNCOMPENSATED ZERO SEQUENCE MUTUTAL REACTANCE ON THE REACH OF THE OHM UNIT

When properly compensated, the ohm or reactance unit of the GCXG relay will correctly measure the positive sequence reactance from the relay to a single phase-to-ground fault. However occasions arise where it is not possible or practical to compensate for zero sequence mutual reactance between transmission lines on the same right-of-way. For example, consider a transmission line from Station A to Station B, Figure IV-2. Assume a second transmission line originating at Station A, and running parallel with the first line, on the same right-of-way for a considerable distance, and then branching off to terminate at Station C. It is not possible to compensate the ohm units at either Station B or Station C for the zero sequence mutual coupling between the two lines. This makes it of interest to know how uncompensated zero sequence mutual coupling will affect the reach of the ohm unit. There are several different sets of system conditions that should be considered, and these are discussed one at a time below.

Uncompensated Mutual Due to an Open Circuit Breaker

Consider two similar parallel lines on the same right-of-way as illustrated in Figure IV-1. Assume that the auxiliary compensating current transformer, 0367A0266G-1, is used at all terminals to provide the proper mutual compensation. If a single phase-to-ground fault were to occur at F1, and circuit breaker #3 were to trip on first zone, the current in circuit breaker #3 would instantly go to zero. The protective relays at breaker #1 would lose the zero sequence mutual compensation. However, since the fault current flows down line A and back over line B, there will be a mutual effect which would tend to cause the ohm unit at breaker #1 to overreach. The ohm unit at breaker #4 will still have its compensation, so it will not overreach. For these conditions, it is important that the overreach of the ohm unit at breaker #1 does not result in a lack of coordination with the relays at breaker #4.

The reactance as seen by the ohm unit at breaker #1 for a fault at F1 with breaker #3 open, and no infeed from Station D, is given by the following equation:

$$X_R = X_1 \left[1 + S_3 \frac{2 + K_0 - 2K_mK_0}{2 + K_0} \right] \qquad \text{(Eq. IV-a)}$$

where:

X_1' = positive sequence reactance of the protected line, A

X_0' = zero sequence reactance of the protected line, A

K_0 = X_0'/X_1'

X_{om} = total zero sequence mutual reactance between line A and line B

K_m = X_{om}/X_0'

S_3 = the ratio of the distance from breaker #4 to the fault, to the total length of Line A or Line B.

There are two points to consider. First, the first zone ohm unit at breaker #1 should not reach into the first zone of the relays at breaker #4 for a phase-to-neutral fault on Line B with breaker #3 open. Next, the second zone ohm unit at breaker #1 should not reach into the second zone of the relays at breaker #4 for a phase-to-neutral fault on line B with breaker #3 open.

The most severe condition of overreach will occur for the larger values of K_m and K_0. On actual systems, K_m will have a maximum value of about 0.7, but will generally be about 0.5. K_0 will average about 3.5, but may be as high as 5.5. A check of equation IV-a will show that the reactance seen by the ohm unit at breaker #1 for a fault anywhere on line B will always be greater than the reactance setting of the first zone, which should never exceed 80 percent of the line length. Thus, the first zone unit of the relays at breaker #1 will never reach to the far bus.

The maximum second zone ohm unit reach setting at breaker #1 must be established to insure that it does not reach beyond the first zone unit at breaker #4. Assuming that the first zone units are set for 80 percent of the line length, then the second zone units at breaker #1 should not see faults on line B beyond 50 percent of the distance to breaker #3. For this fault, S_3 = 0.50.

Referring to equation IV-a and assuming K_m = 0.5, and K_0 = 3.5, we get $X_R = 1.18\ X_1'$. Thus, for the conditions assumed, a single phase-to-ground fault on line B half-way from breaker #4 to breaker #3, with breaker #3 open and no infeed from Station D, the second zone ohm unit at breaker #1 will see a reactance which is 118 percent of the protected line length. For these conditions, the reach setting of the second zone ohm unit at breaker #1 should not exceed 118 percent of the positive sequence reactance of the protected line section.

Note that system constants (K_0 and K_m) which are different from those assumed will lead to a different safe maximum reach setting. Also, any dependable infeed from Station D will permit a longer second zone reach setting at breaker #1. Equation IV-b below gives the reactance as seen by the ohm unit at breaker #1 for single phase-to-ground faults on line B with breaker #3 open and infeed from Station D.

$$X_R = X_R' \left[1 + \frac{S_3}{2C + K_0 C_0}\left(K_0 + 2 - [C_0 + 1]\ K_m K_0\right)\right] \qquad \text{(Eq. IV-b)}$$

where:

C = positive sequence distribution constant I_1'/I_1

C_0 = zero sequence distribution constant I_0'/I_0

Equation IV-b applies to the configuration of Figure IV-1, except that infeed is present at Station D. Since we do not wish the second ohm units at breaker #1 to reach beyond a point half-way from breaker #4 to breaker #3, assume a fault at the midpoint of line B. For this fault, $S_3 = 0.5$. As in the previous example, assume $K_m = 0.5$ and $K_0 = 3.5$. Assume that the infeed from Station D is rather weak, so that $C_0 = 0.7$ and $C = 0.8$.

Substituting these values in equation IV-b, we get:

$$X_R = 1.31\ X_1'$$

Thus, to the relay at breaker #1, this fault will appear to be at a point 31 percent of the distance from breaker #4 to breaker #3. If it is desired to limit the reach of breaker #1 second zone unit to a point midway on line B, it is necessary to limit the set reach of the unit to 131 percent of the protected line length.

Uncompensated Mutual Due to Partial Parallel Circuits

When it is not possible to compensate for zero sequence mutual reactance between two parallel circuits because they do not terminate at the same stations, it is of interest to know how this lack of compensation affects the reach of the ohm units. Consider the system illustrated in Figure IV-2.

Line A is the protected line under consideration and the relays associated with breaker #1 are being studied. Line B is a parallel circuit with one end terminating at Station A and the other end terminating at Station B, or some other remote station. Since both breakers #1 and #4 terminate at Station A, compensation for the zero sequence mutual reactance between lines A and B is possible for the relays at breakers #1 and #4. This is assumed in the following analysis.

Line C does not terminate at Station A. It may or may not terminate at Station B. Zero sequence mutual exists between lines A and C, but the relays at breaker #1 cannot be compensated for this. While zero sequence mutual will exist between lines B and C, the magnitude is not required for these calculations once the fault currents have been obtained.

There are two situations to be investigated. The first is the reactance seen by the relays for a fault at the set reach of the relay. It is important that the effects of the uncompensated mutual between lines A and C do not cause the first zone ohm unit to overreach the setting (F_1). Next, it is important to insure that the effect of the uncompensated mutual does not result in a pull back in the reach of the second zone unit so that it fails to see a fault at the far end of the line (F_2).

Note that the effects of the uncompensated mutual will cause both first and second zones to overreach or underreach. It cannot cause one to overreach and the other to underreach. The direction of the current flows (I_0' and I_0''') as assumed in Figure IV-2, will cause both zones to underreach. If I_0'' flows in the opposite direction, this will cause both zones to overreach.

For a fault at the first zone set balance point (F_1), equation IV-c gives the reactance as seen by the relay:

$$X_R = X_1' \left[S_1 + \frac{\frac{1}{X_1'} \sum S_3 X_{0M}' I_0'''}{I_a' + 0.03K'I_0' + 0.015 \sum K'' I_0''} \right] \qquad \text{(Eq. IV-c)}$$

where:

X_1' = positive sequence reactance of the protected line

X_0' = zero sequence reactance of the protected line

X_{om}' = total mutual reactance between line A and line C

K' = compensating auxiliary CT primary setting

K'' = compensating auxiliary CT secondary setting

S_1 = ratio of the distance from breaker #1 to the fault, to the length of line A.

S_3 = per unit of the total X_{om}' that is invovled in the fault

I_a' = phase A current in the protected line at the relay location

I_0' = zero sequence current in the protected line at the relay location

I_0'' = zero sequence current in the parallel line which can be compensated (line B). Taken as positive when flowing in the same direction as I_0'

I_0''' = zero sequence current in the parallel line which cannot be compensated (line C). Taken as positive when flowing in the same direction as I_0'

The summation in the numerator of equation IV-c applies in the event that there is more than one circuit similar to line C for which compensation cannot be or is not applied. The summation in the denominator applies when there is more than one circuit similar to line B for which compensation is applied.

As an example in the use of equation IV-c, assume the system illustrated in Figure IV-2. Assume that neither line B nor line C terminates at Station B. Check the ohm unit for a fault at the set reach of the first zone ohm unit. Let this be a fault at F_1 in Figure IV-2, 80 percent of the distance to breaker #2. Now assume the following system constants, fault currents and compensator CT settings.

K' = 80
K'' = 10
I_a' = 50 secondary amperes
I_0' = 15 secondary amperes
I_0'' = 5 secondary amperes
I_0''' = 4.16 secondary amperes
X_{om}' = 0.6 X_1'
S_1 = 0.8

} Based on CT Ratio of Breaker #1

Since the entire mutual of line C will be involved in this fault, $S_3 = 1.0$.

Substituting these values in equation IV-c and noting that the negative sign associated with I_0''' indicates that I_0''' is actually flowing in a direction opposite to that assumed in Figure IV-2, we obtain:

$$X_R = 0.771\ X_1'$$

Thus, the first zone unit will see a reactance which is 96 percent of the actual positive sequence reactance to the fault. Or, stated in other words, the first zone unit will overreach about four percent for the condition assumed.

For an end zone fault at F_2, equation IV-c may be used again, except that now the currents will be slightly different. Also, the S constants will change. For example, for a fault at F_2:

$$S_1 = 1.0$$

$$S_3 = 1.0$$

For the conditions assumed, the second zone unit will see a reacance that is slightly smaller than the actual reactance to the fault. However, since the second zone is set to reach beyond the far bus, this slight overreach is of no practical importance. On the other hand, if the current I_0''' had been assumed in the opposite direction, a slight underreach would result. In this case it would be necessary to insure that the setting of the second zone would be sufficiently long so that it sees a fault at the remote bus despite the small underreach.

Note that equation IV-c is quite general and may be applied to almost any system configuration for a fault in the protected line section. For example, if there were no zero sequence mutual compensation between the relays at breakers #1 and #4, then the last term in the denominator of equation IV-c is zero. Also, the summation in the numerator would then include the effects of line B and I_0''. If line B did not exist at all, the the last term in the denominator goes to zero, and there is no I_0'' term to consider in the numerator.

All voltages, currents and impedances in the above equations are in terms of secondary quantities based on the CT and PT ratios employed on the protected line. This includes I_0''' and I_0'', as well as I_0'.

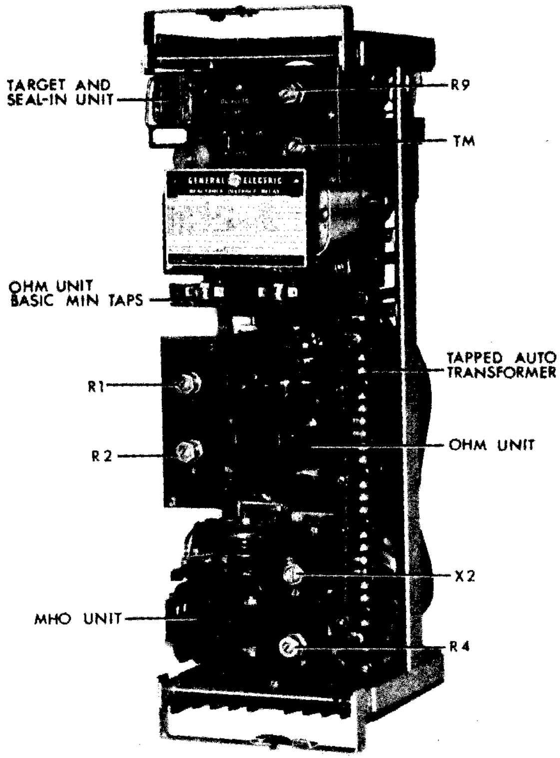


Figure 1A (8038374-0) Type GCXG53A Relay Removed from Case, Approximately 3/4 Front View

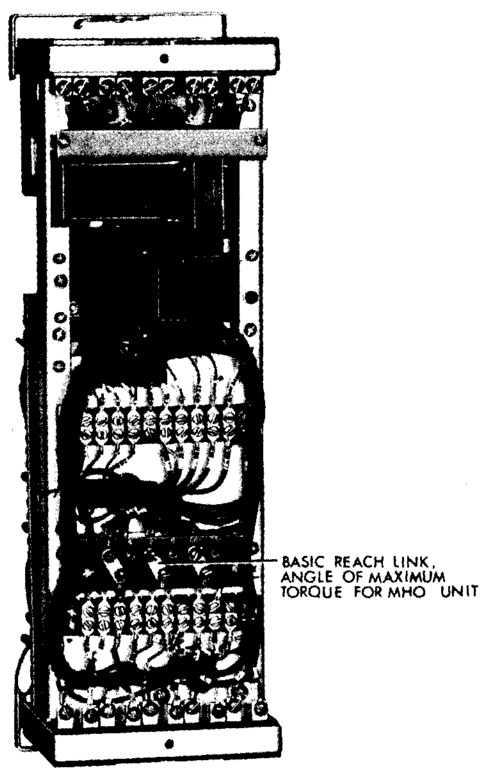


Figure 1B (8038370-0) Type GCXG53A Relay Removed from Case, Rear View

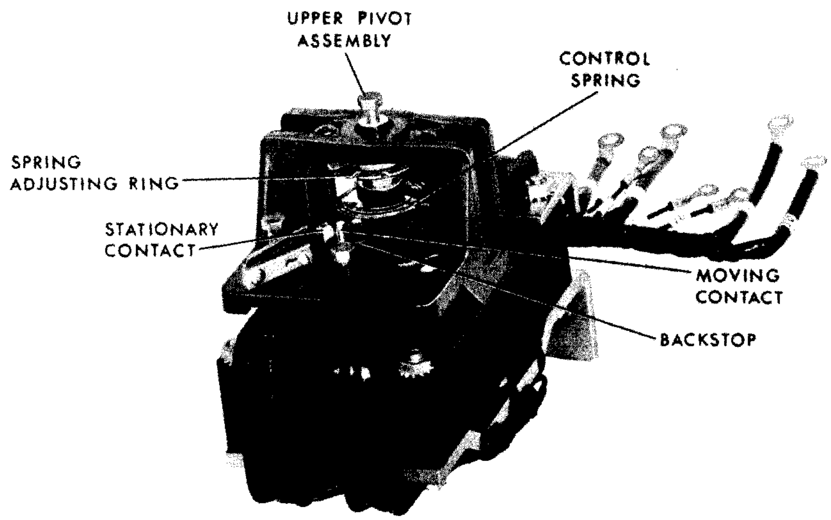


Figure 2 (8034958-0) Four Pole Induction Cylinder Unit
Used in the GCXG53A Relay

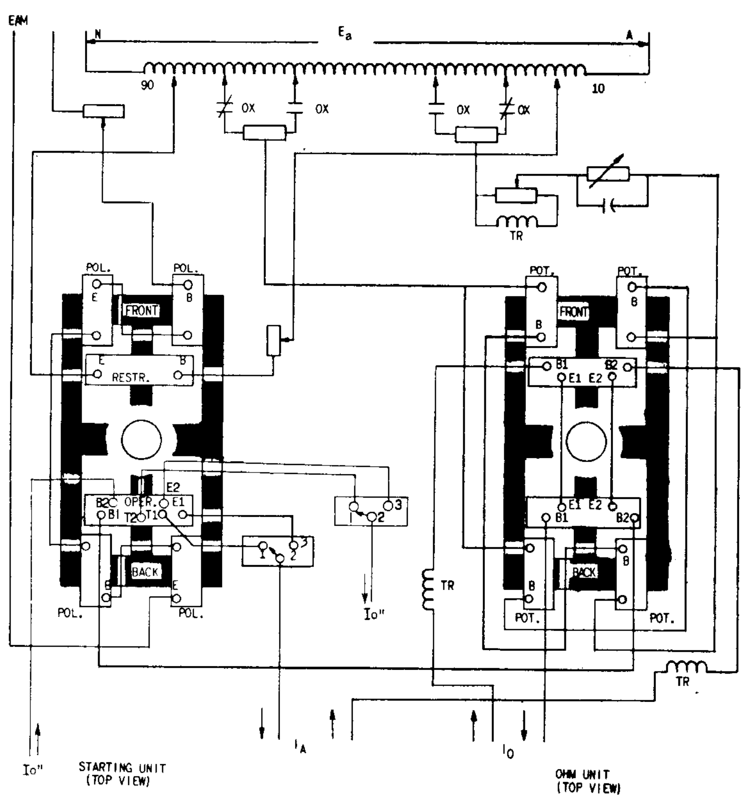


Figure 3 (0183B2310-0) Schematic Diagram of the Ohm and Starting Units
in the GCXG53A Relay

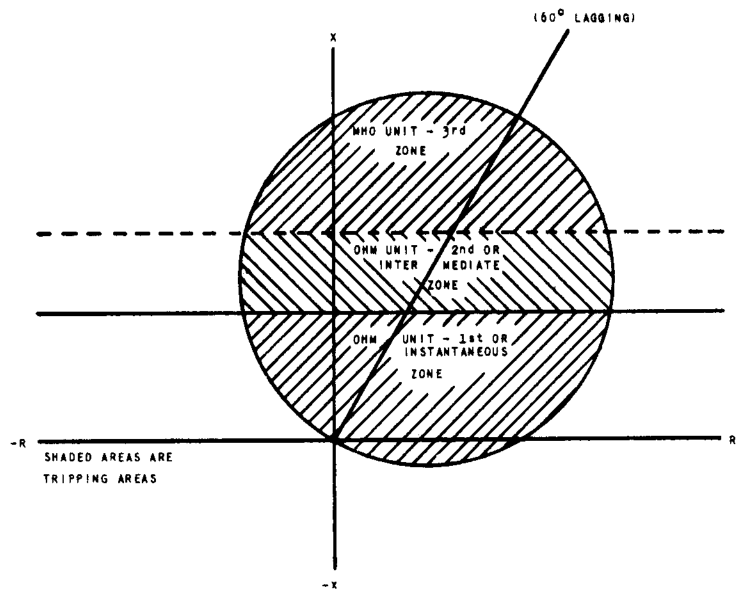


Figure 4 (K-6305889-4) Characteristics of the Ohm and Starting Units on an Impedance Diagram for the GCXG53A Relay

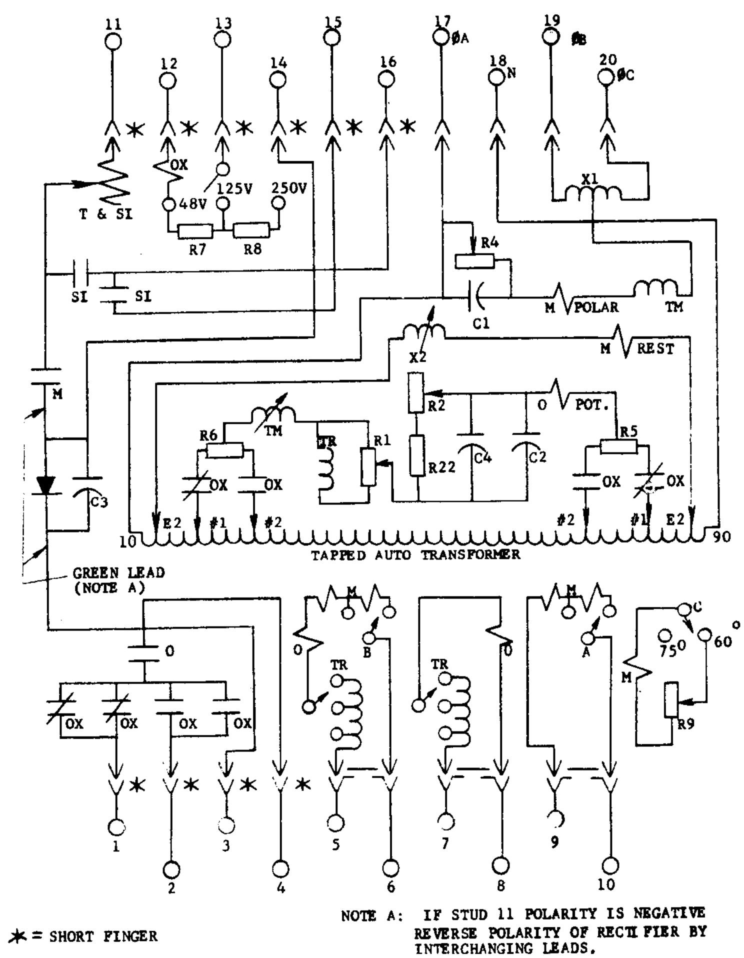
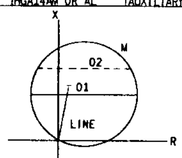


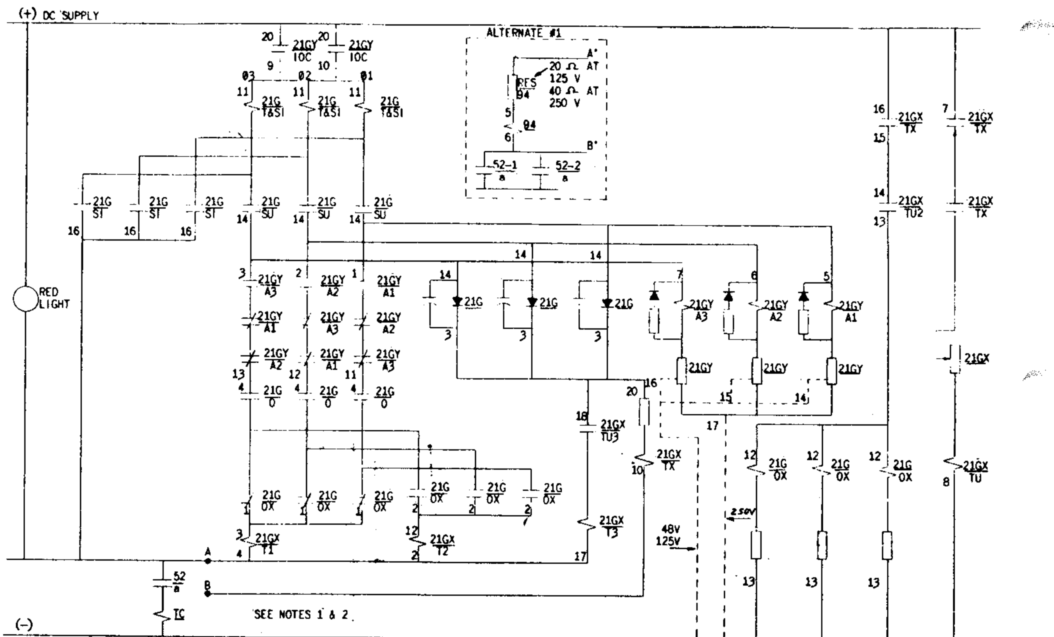
Figure 5 (0207A7825-1) Internal Connections Diagram for the GCXG53A Relay (Front View)

TABULATION OF DEVICES		
TYPE OR DESCRIPTION	INT. CONNS.	OUTLINE
GCXG53A	0207A7825	K-6209276
RPM11D	0178A7092	K-6209272
NAA15E	0178A8168	K-6209272
AUX.CT. 367A0266 G-1	0367A0267	0367A0267
AUX.CT. 367A0266 G-2	0207A5465	0207A5465

LEGEND			
DEVICE NO.	DEVICE TYPE	INCL. ELEM.	DESCRIPTION
21G	GCXG53A		GROUND DISTANCE RELAY
		SU	DIRECTIONAL STARTING UNIT
		O	REACTANCE TYPE OHM UNIT
		OX	ZONE TRANSFER AUX. FOR O
		T&SI	TARGET & SEAL-IN
		TR	TRANSACTOR
		TM	MUTUAL TRANSACTOR
21GX	RPM11D		TIMING RELAY
		T1	ZONE 1 TARGET
		T2	ZONE 2 TARGET
		T3	ZONE 3 TARGET
		TU	TIMING ELEMENT
		TU-2	ZONE 2 TIMING CONTACT
		TU-3	ZONE 3 TIMING CONTACT
		TX	AUXILIARY TO TU
21GY	NAA15E		AUXILIARY TO 21G
		A1	PHASE 1 AUXILIARY
		A2	PHASE 2 AUXILIARY
		A3	PHASE 3 AUXILIARY
		10C	GROUND FAULT DETECTOR
52			POWER CIRCUIT BREAKER
		TC	TRIP COIL
		a	AUXILIARY SWITCH
94	HGA14AM OR AL		AUXILIARY TRIPPING RELAY



RELAY CHARACTERISTICS



NOTE 1: IF TRIPPING ONLY ONE BKR. MAKE CONN. SHOWN & JUMPER A TO B.
NOTE 2: IF USING AUX. TRIP RELAY (94) TO TRIP 2 BKRS. USE ALTERNATE #1 BY CONNECTING A TO A' AND B TO B'.

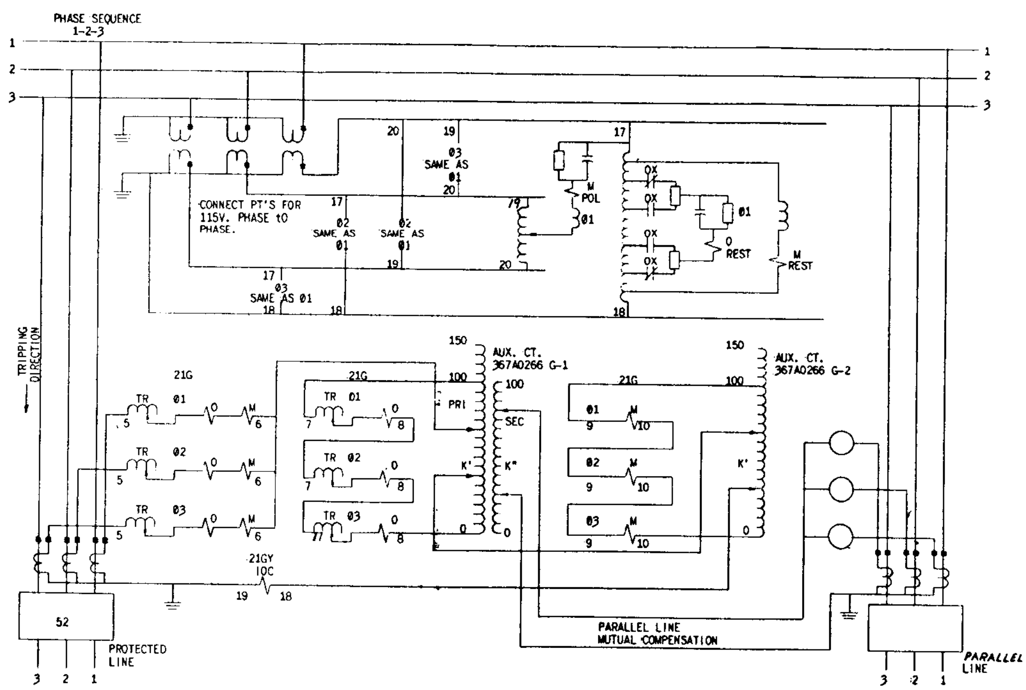


Figure 6 (0116B9419-0) Elementary Diagram for Three-Step Ground Distance Protection using the GCXG53A, NAA15E and the RPM11D Relays

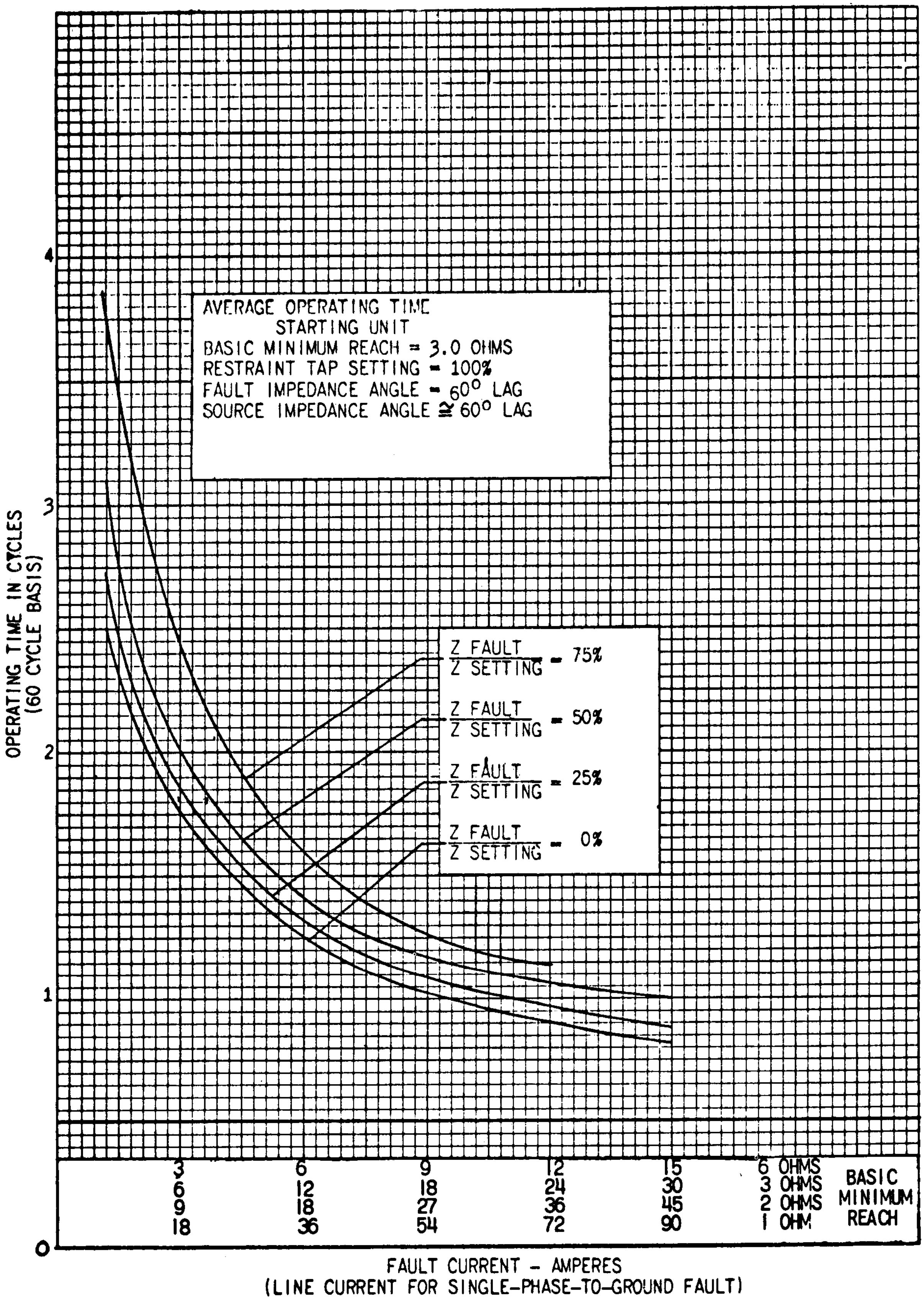


Figure 7(0227A2682-0) Operating Time Curve for the Starting Unit in the GCXG53A Relay

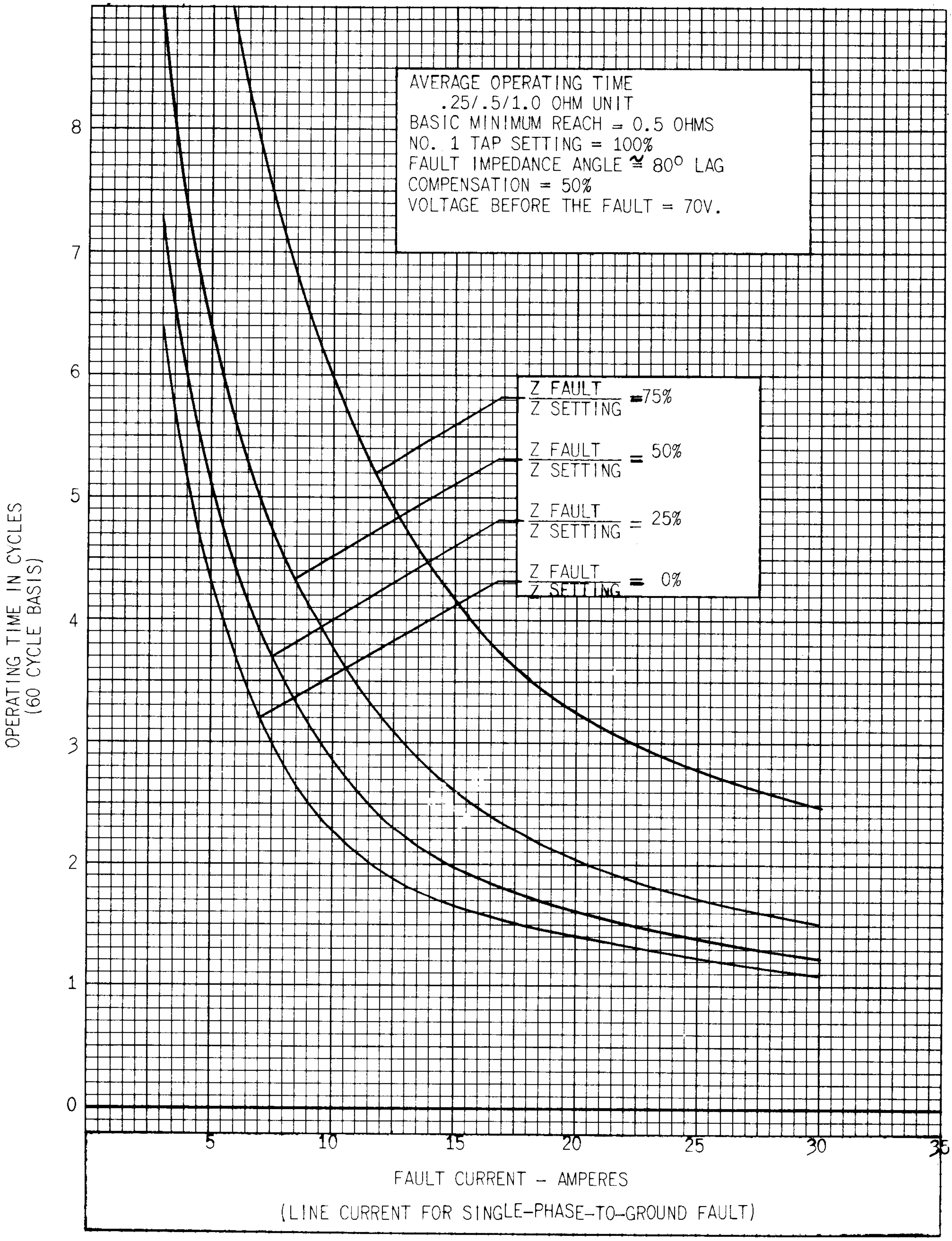


Figure 8 (0178A9116-0) Average Operating Time Curves for the GCXG53A Ohm Unit

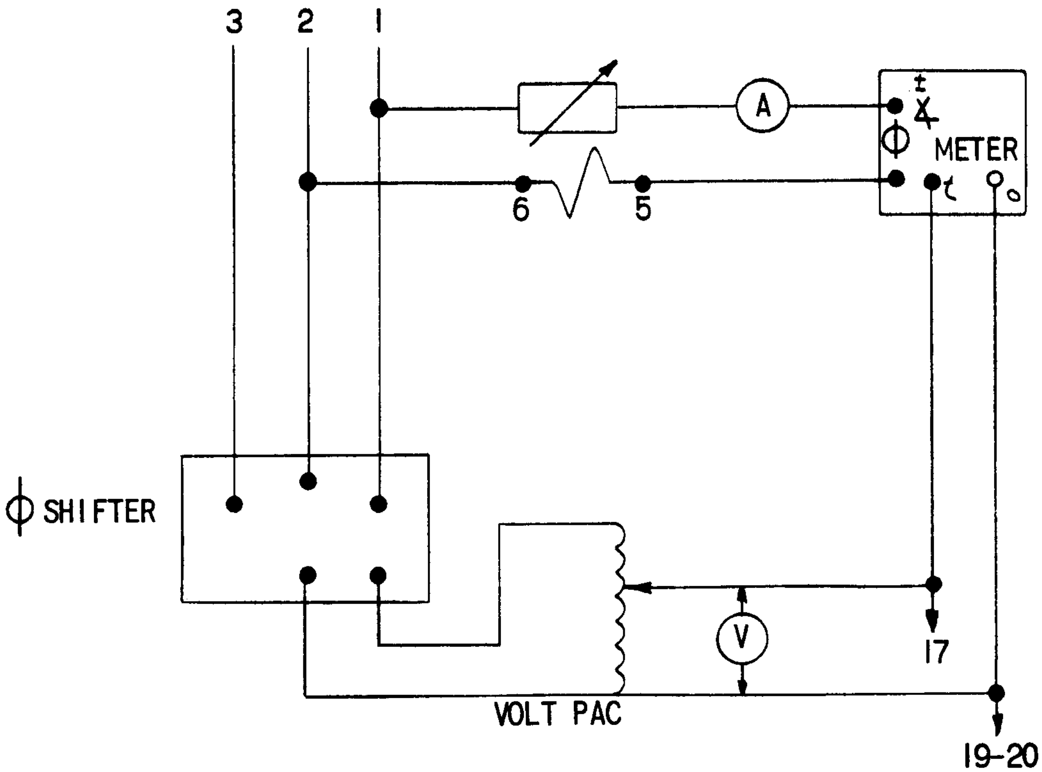


Figure 9A (0227A2568-0) Test Connections for the Directional and Control Spring Adjustments in the GCXG53A Relay

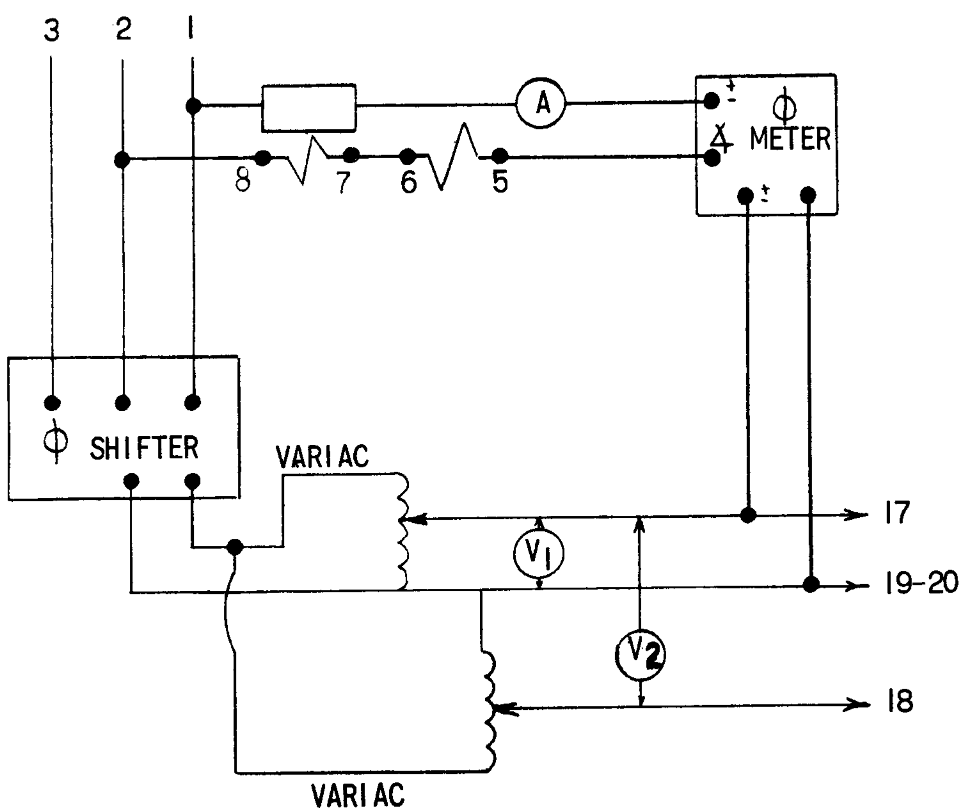


Figure 9B (0227A2569-0) Test Connections for the Angle of Maximum Torque and Reach Adjustments in the GCXG53A Relay

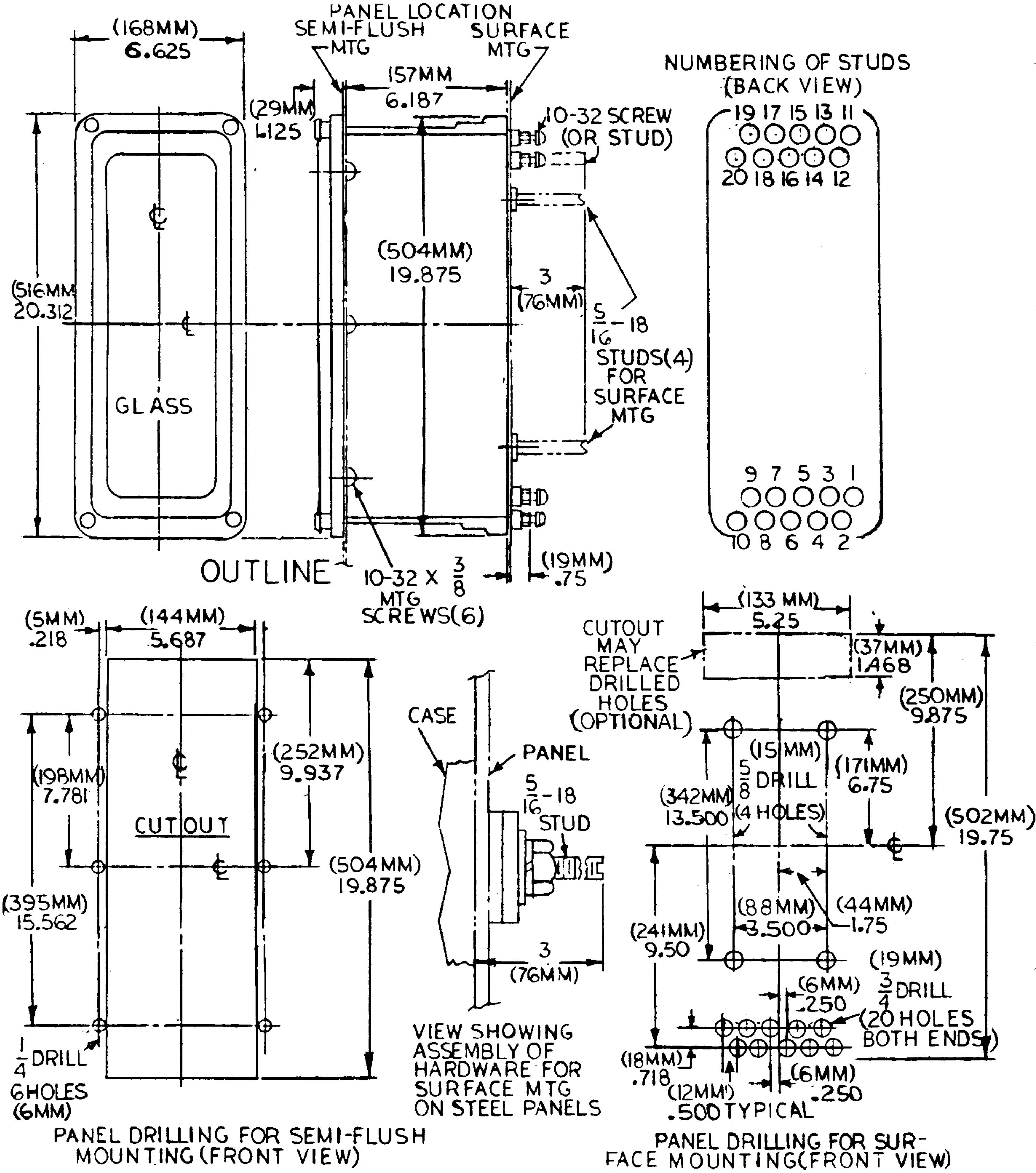


Figure 10 (K-6209276-3) Outline and Panel Drilling Dimensions
for the GCXG53A Relay

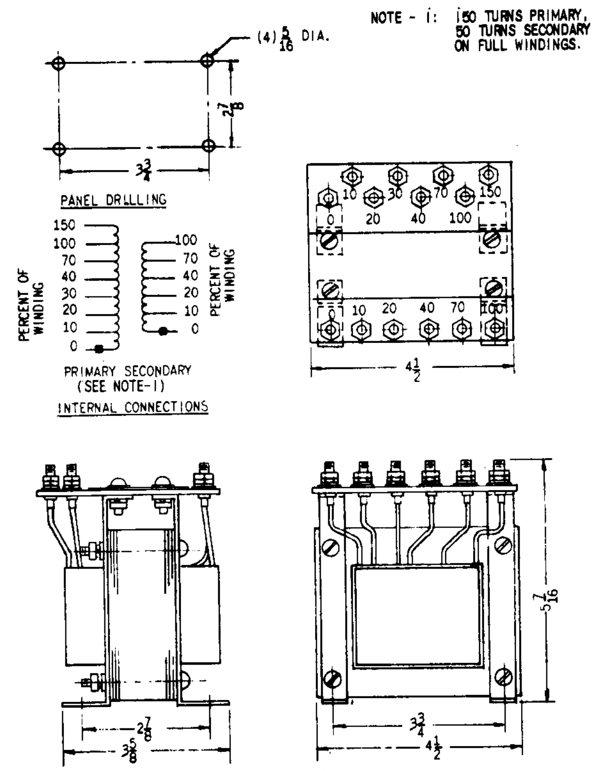


Figure 11 (0367A0267-2) Outline and Panel Drilling Dimensions of the Auxiliary Transformer used with the GCXG53A Relay

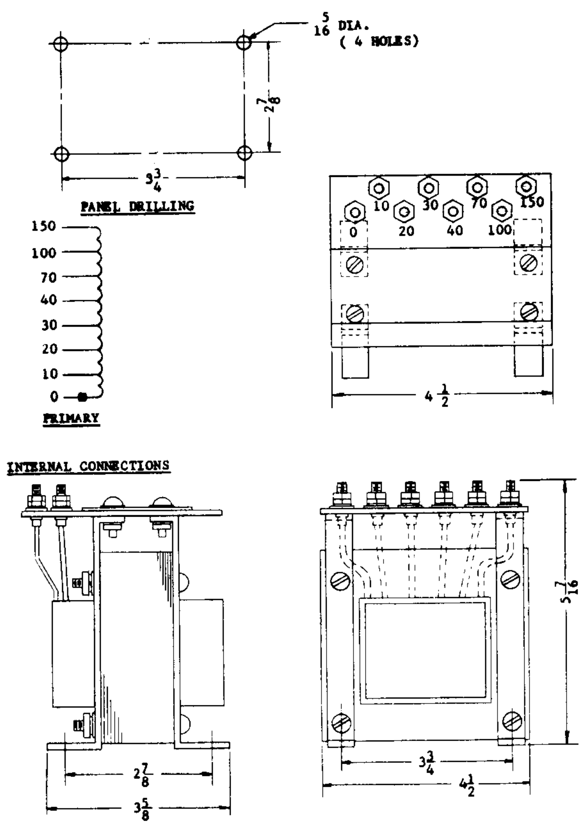


Figure 12 (0207A5465-0) Outline and Panel Drilling Dimensions of the Auxiliary Transformer used with the GCXG53A Relay

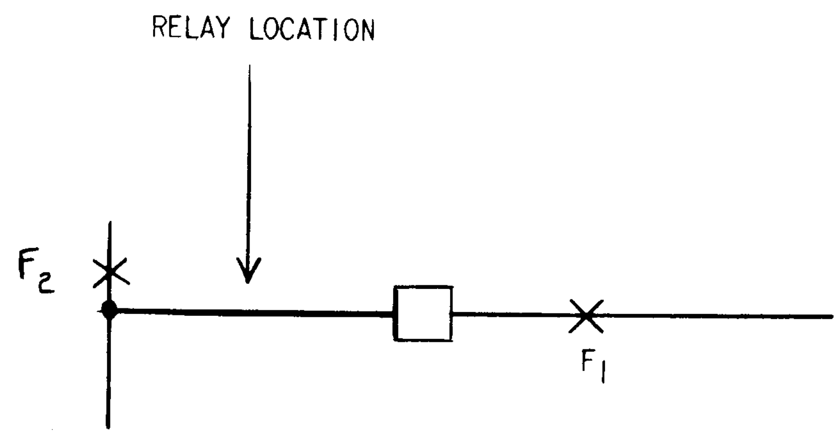


Figure III-1 (0165A7623-1) Typical Transmission Line with Fault

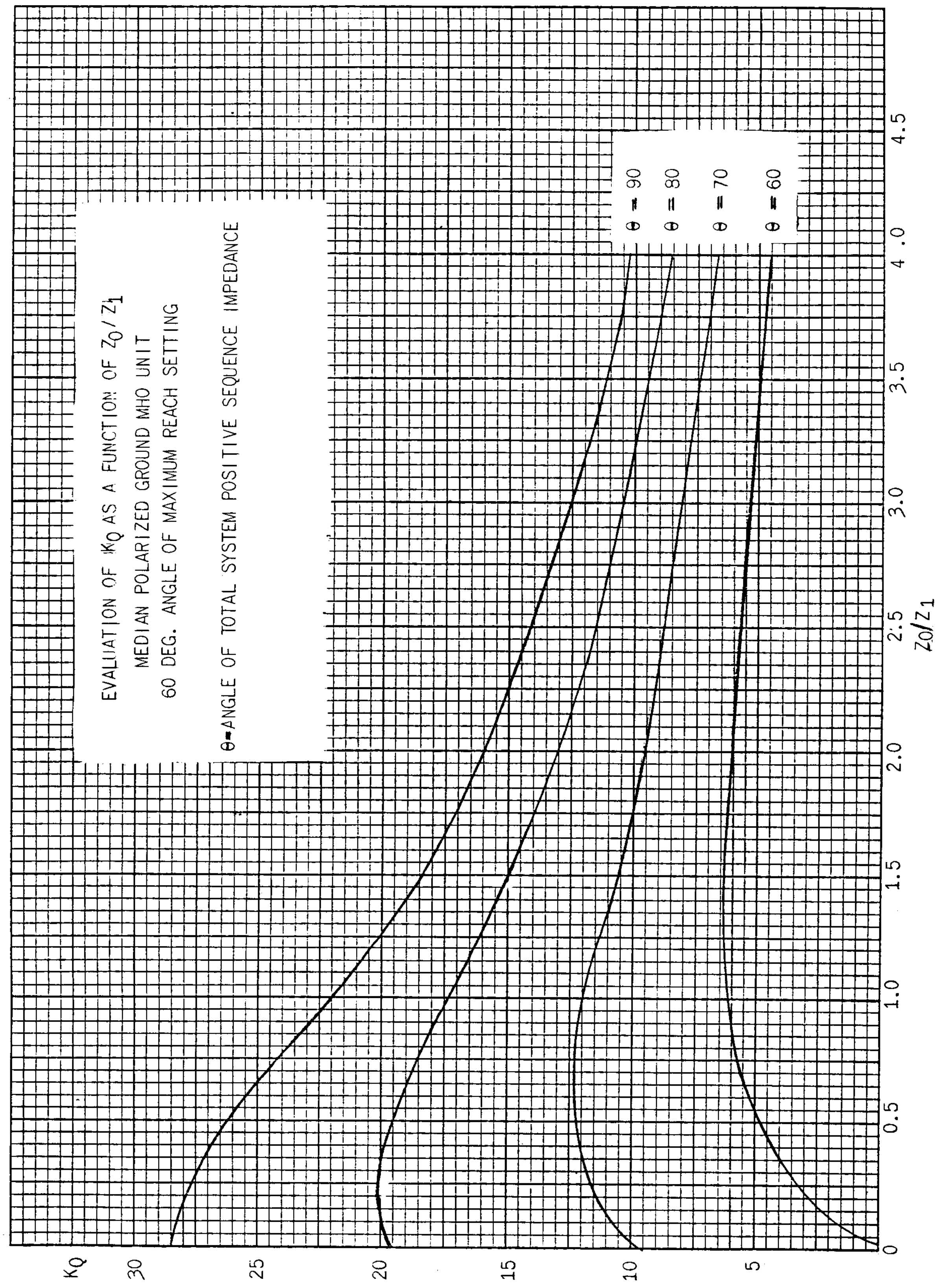


Figure III-2 (0226A6904-2) Evaluation of K_Q 60-Degree Angle of Maximum Torque

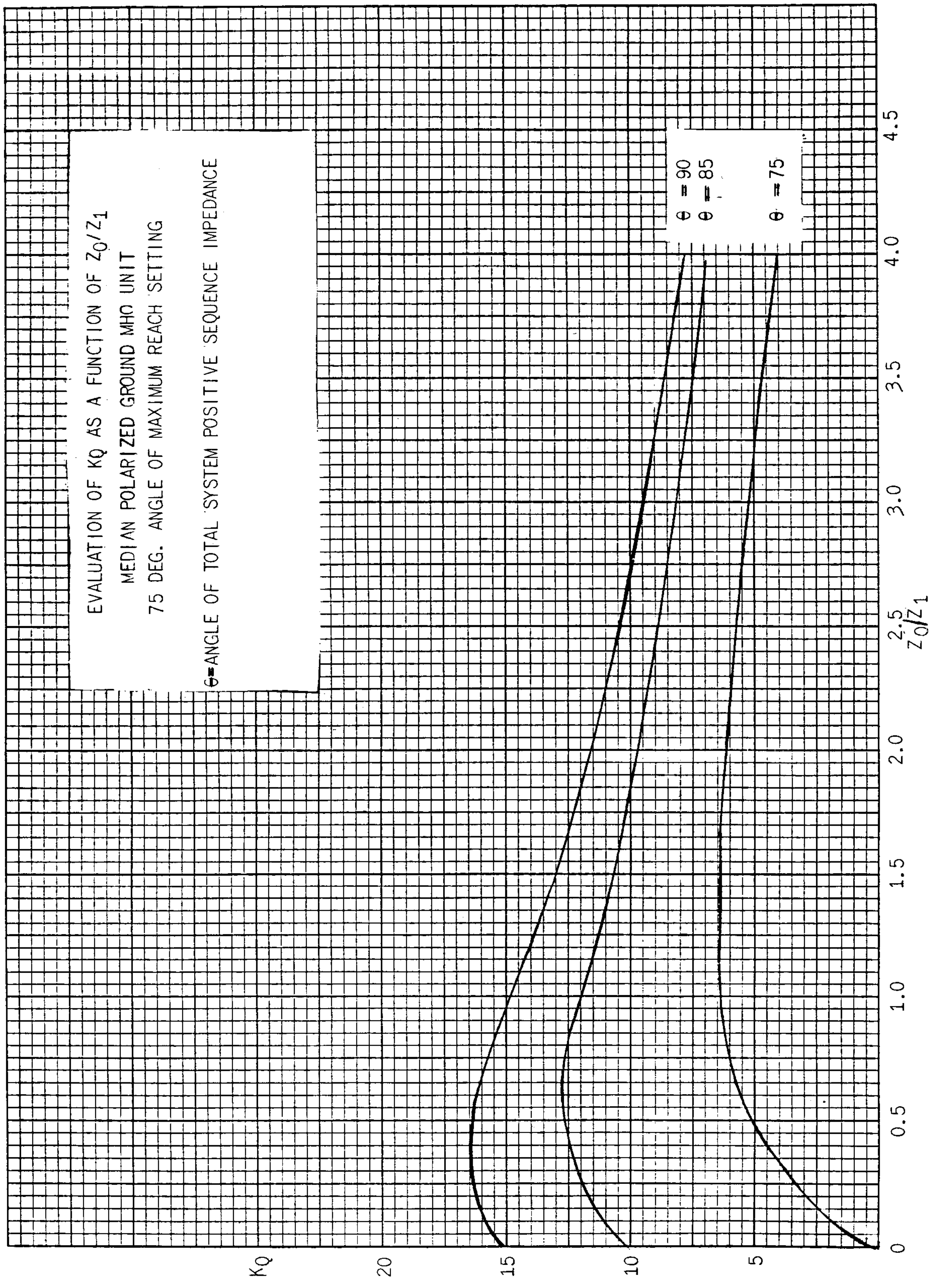


Figure III-3 (0226A6905-2) Evaluation of K_Q 75-Degree Angle of Maximum Torque

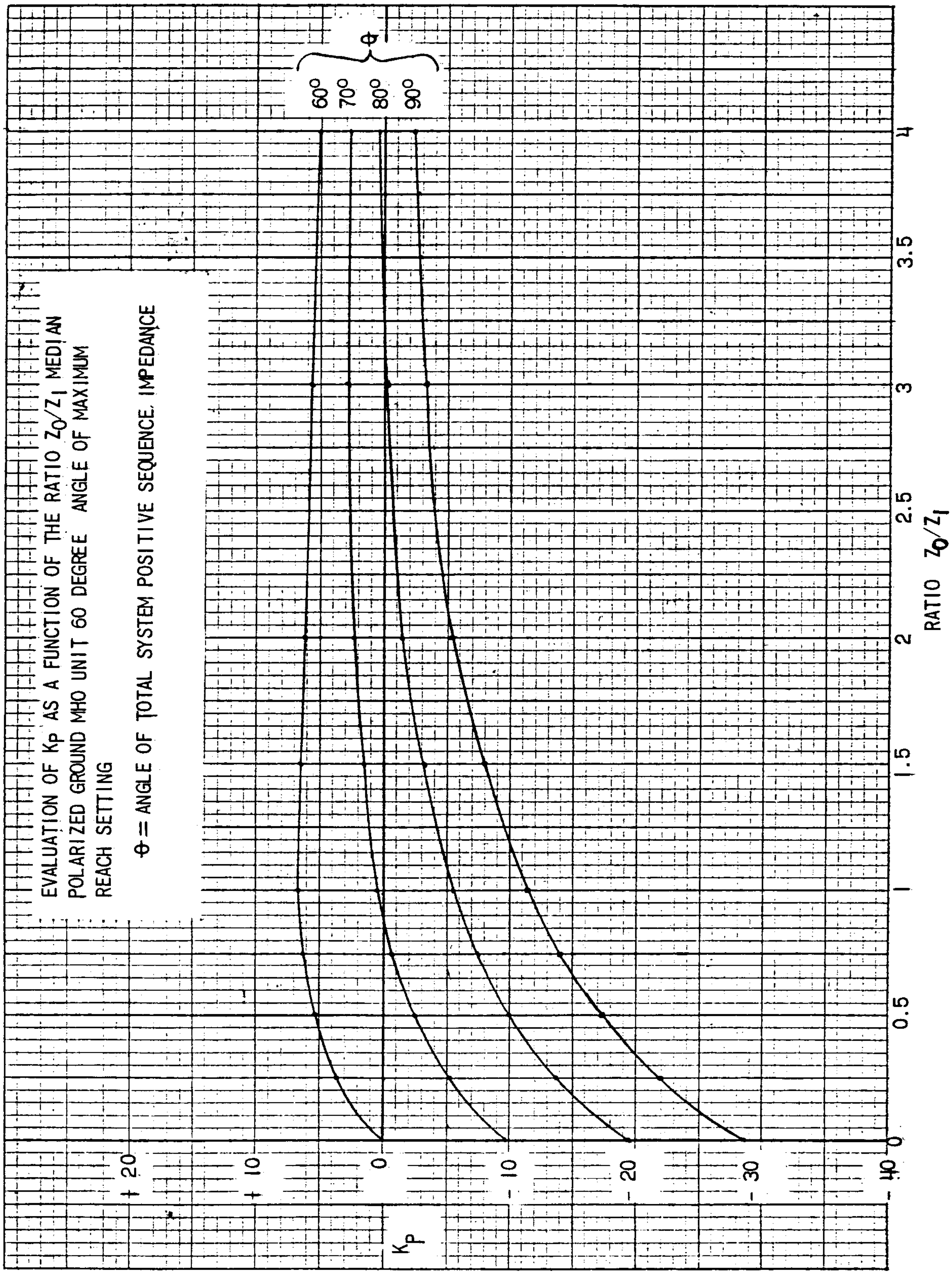


Figure III-4 (0227A7182-1) Evaluation of Kp 60-Degree Angle of Maximum Torque

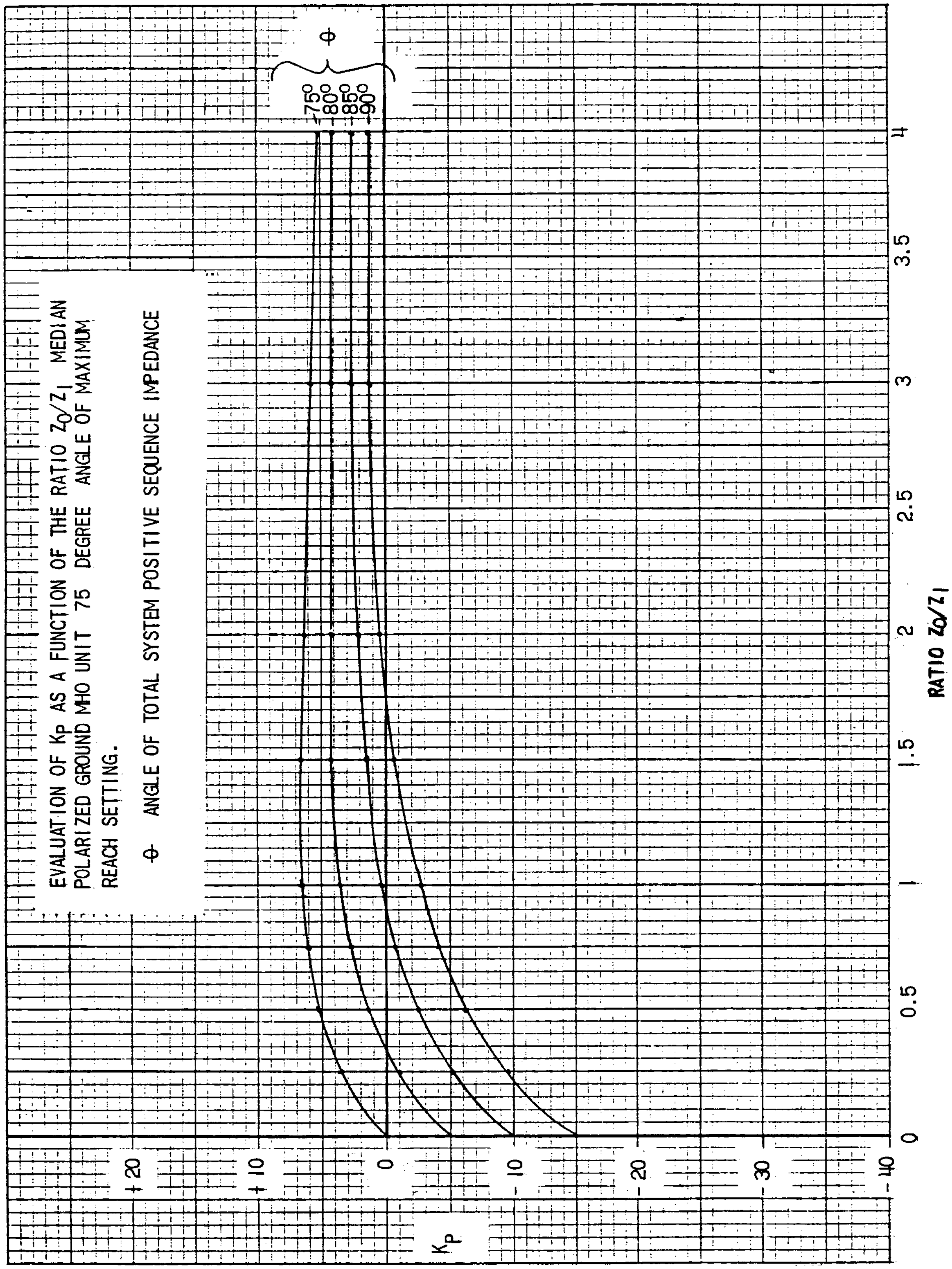


Figure III-5 (0227A7183-1) Evaluation of Kp 75-Degree Angle of Maximum Torque

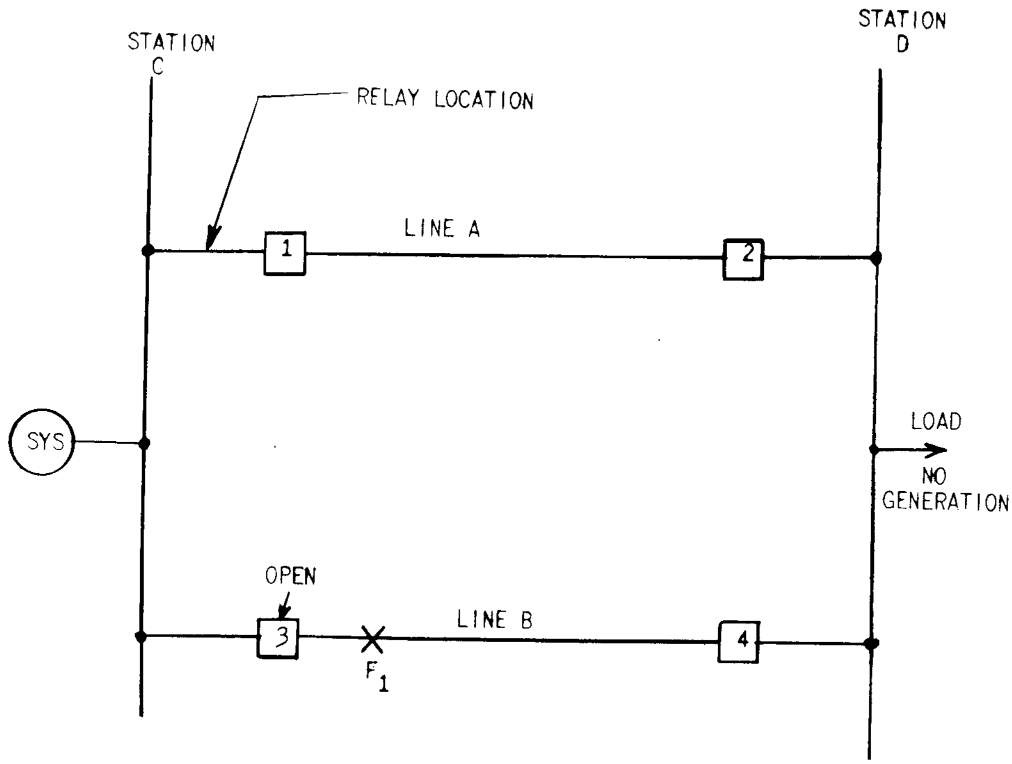


Figure IV-1 (0165A7621-0) Parallel Transmission Lines with Ground Fault

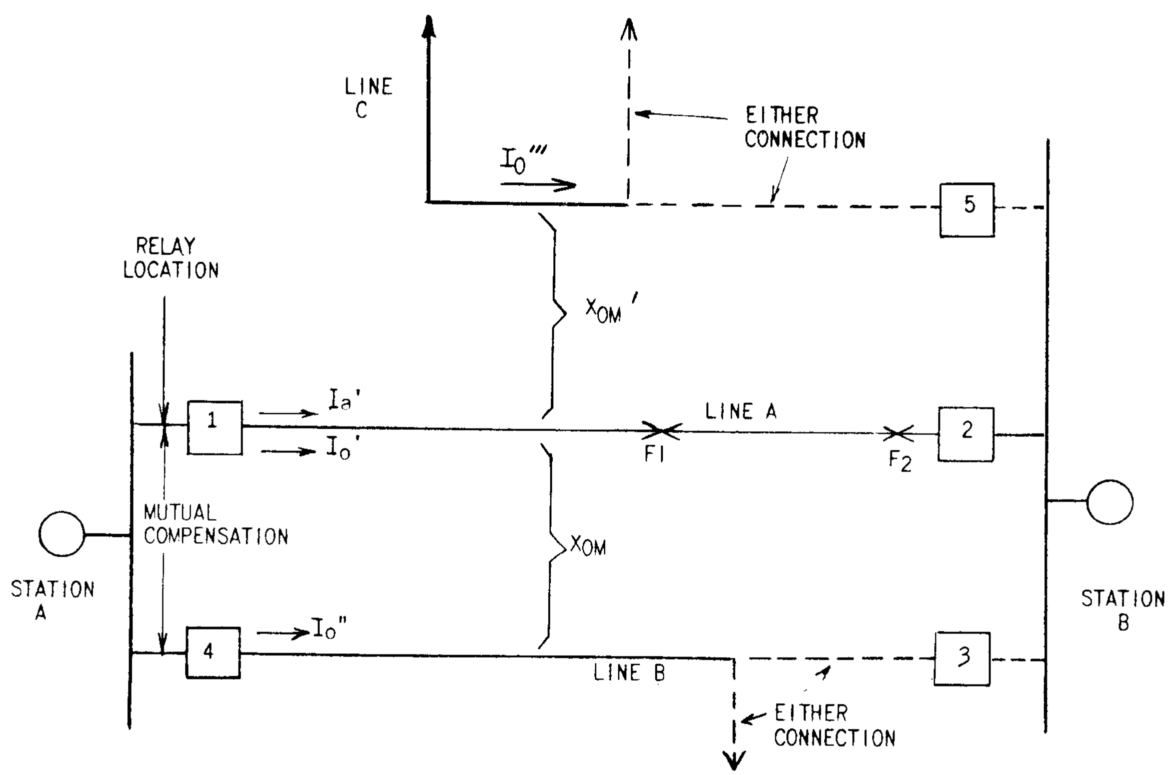


Figure IV-2 (0165A7620-1) Transmission Line System with Lines Terminating at Remote Stations

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