INSTRUCTIONS

GEI-98339E

DIRECTIONAL GROUND DISTANCE RELAY

TYPE GCXG51A11 & UP

GENERAL ELECTRIC

CONTENTS

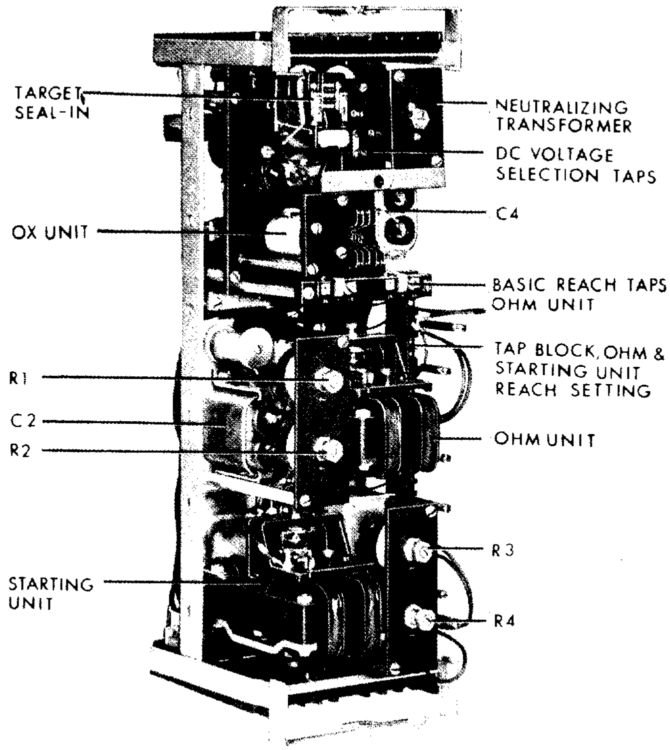


Fig. 1 (8036283) Type GCXG51A Relay Removed From Case. (Front View)

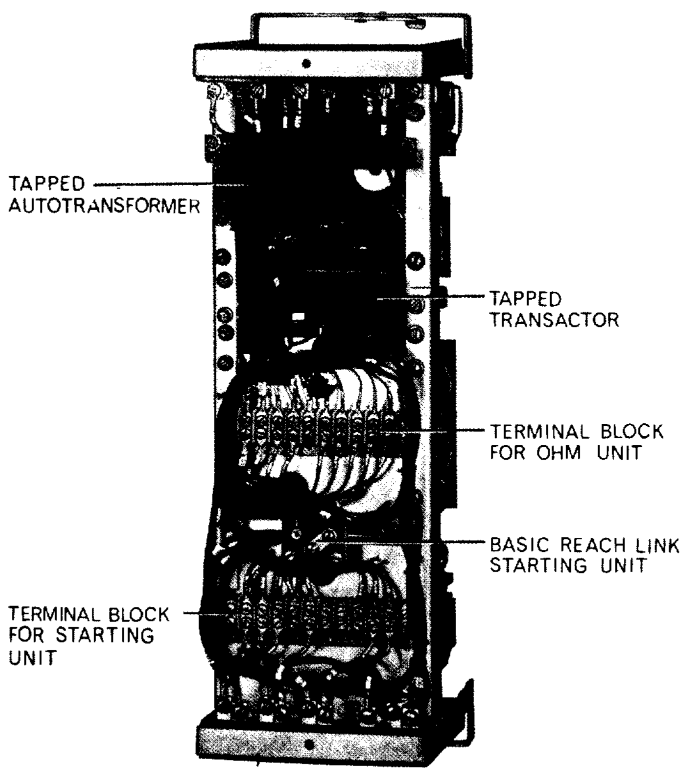


Fig. 2 (8035669) Type GCXG51A Relay Removed From Case. (Rear View)

DIRECTIONAL GROUND DISTANCE RELAY
TYPE GCXG51

INTRODUCTION

The GCXG51A relay is a three-zone high speed directional ground distance relay that is intended for step type protection of transmission and distribution circuits. The first two zones of this relay are provided by a reactance measuring type of unit while the third zone starting unit is of the mho type.

These relays are used to provide single-phase-to-ground fault protection only. For each terminal of straight ground distance protection, three GCXG51A, one RPM11D or SAM14B, and one NAA15E relays are required plus one auxiliary compensating current transformer catalog no. 0367A0266.

APPLICATION

The reactance or ohm unit of the GCXG51A does not have directional characteristics while the mho type 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 to the GCXG51A are illustrated in Figure 3. From the D.C. connections it will be noted that each one of the three GCXG starting units is associated with an auxiliary unit in an 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-1 to ground fault. When the fault occurs, the phase-1 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.

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 3). The ohm unit contacts now close and the breaker is tripped through the second-zone target of the RPM.

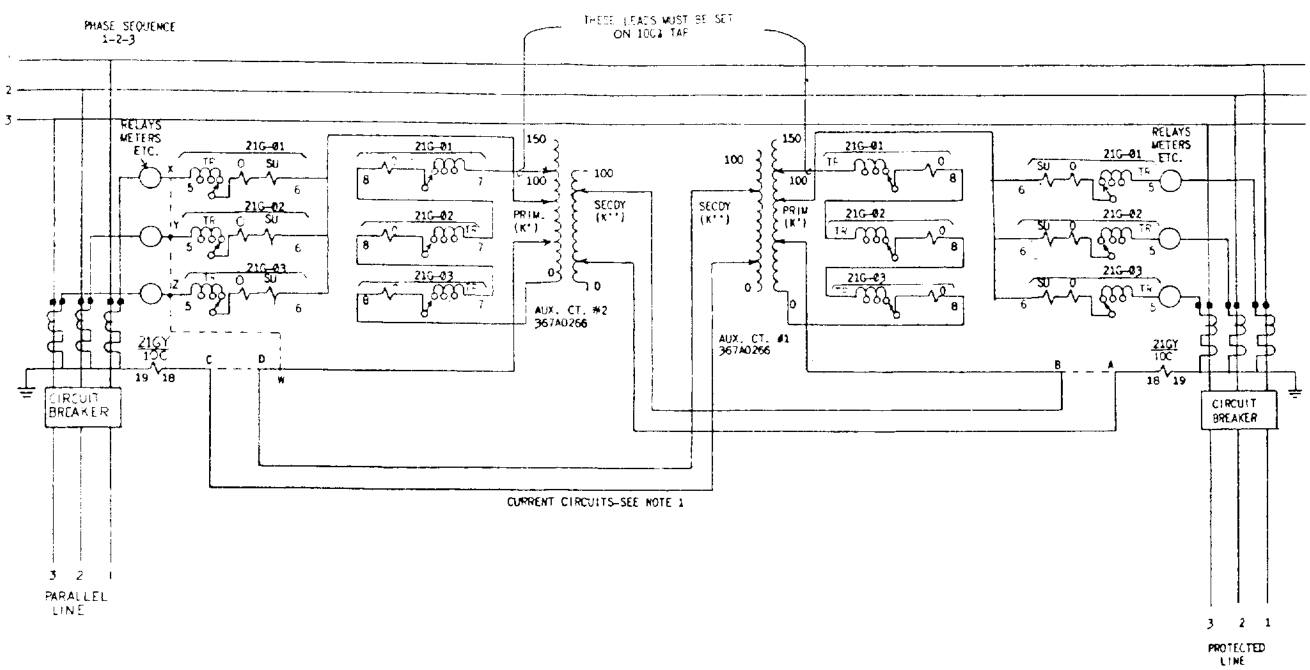
For a third-zone fault the operation is the same except that the ohm unit contacts never close and the breaker is eventually tripped in third-zone time through the starting unit contacts.

It will be noted from Fig. 3 that the potential circuits of the relays require three wye-connected potential transformers with a secondary voltage of 115 volts line-to-line.

The auxiliary compensating transformer 0367A-0266 serves two purposes. First, it compensates for the zero sequence current flowing in the protected line section. Second, it compensates for zero sequence mutual impedance between the protected line and other parallel circuits on the same right of way. While Fig. 3 only illustrates the connections for zero sequence mutual compensation between two parallel circuits, it is possible to provide compensation when the protected line is paralleled by more than one other circuit. For example, Fig. 4 shows how it is possible to compensate the GCXG relays for zero sequence mutual between it and two other lines.

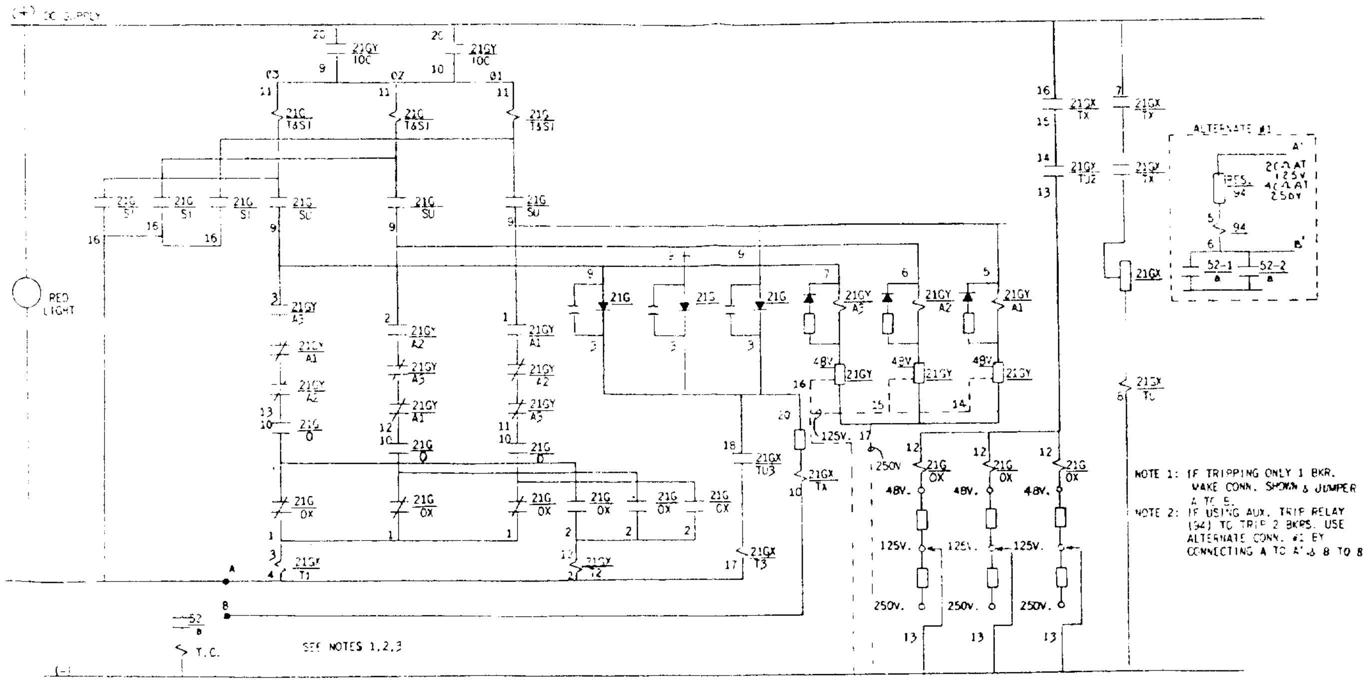
TABULATION OF DEVICES			
TYPE OR DESCRIPTION		INT. CONNS.	OUTLINE
GCXG51A		0195A4924	K-6209276
RPM11D		0178A7092	K-6209272
NAA15E		0195A4943	K-6209272
AUX. CT.		367A0267	367A0267

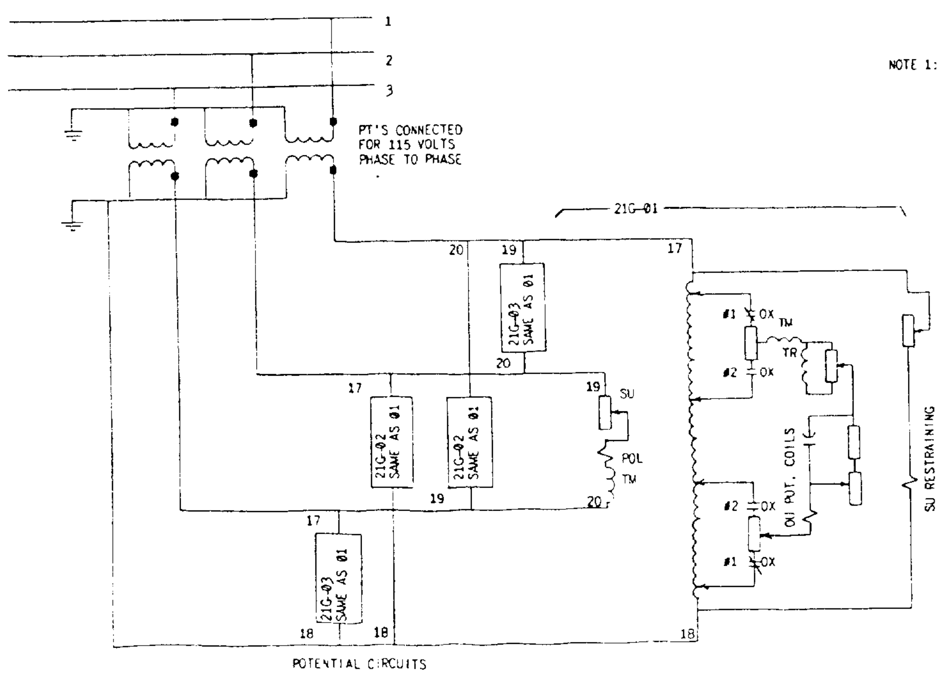
LEGEND			
DEVICE NO.	DEVICE TYPE	INCL. ELEM.	DESCRIPTION
21G	GCXG51A		GROUND DISTANCE RELAY
		SU	DIRECTIONAL STARTING UNIT
		O	REACTANCE TYPE OHM UNIT
		OX	ZONE TRANSFER AUXILIARY FOR O
		T&SI	TARGET AND SEAL-IN
		TR	TRANSACTOR
		TM	MUTUAL TRANSACTOR
21GX	RPM11D		TIMING RELAY
		T1	ZONE 1 TARGET
		T2	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
		IOC	GROUND FAULT DETECTOR
52			POWER CIRCUIT BREAKER
		TC	TRIP COIL
		a	AUXILIARY SWITCH
94	HEA/HAV OR HGA		AUXILIARY TRIPPING RELAY



* Fig.3 (0116B9302 Sh.1 [5] and Sh.2 [3] Typical External Connection Diagram For Three-Step Ground Distance Protection Of A Transmission Line Using Type GCXG51A, NAA15E And RPM11D Relays.

* Revised since last issue





NOTE 1: IF MUTUAL COMPENSATION IS REQUIRED FOR BOTH THE PROTECTED LINE & THE PARALLEL LINE, MAKE THE SOLID CONNECTIONS SHOWN. DO NOT MAKE DASH CONNECTIONS.

IF MUTUAL COMPENSATION IS REQUIRED FOR THE PROTECTED LINE BUT THE PARALLEL LINE IS NOT EQUIPPED WITH GROUND DISTANCE RELAYS THEN AUXILIARY CT #2 AND THE GCXG51A RELAYS ASSOCIATED WITH THE PARALLEL LINE ARE NOT AVAILABLE. IN THIS CASE MAKE THE DASH CONNECTIONS BETWEEN POINTS A & B. MAKE DASH CONNECTIONS BETWEEN POINTS W,X,Y & Z. DO NOT MAKE DASH CONNECTIONS BETWEEN POINTS C & D.

IF PARALLEL LINE DOES NOT EXIST OR MUTUAL COMPENSATION IS NOT REQUIRED, MAKE DASH CONNECTIONS BETWEEN POINTS A & B AND LEAVE THE SECONDARY Y AUXILIARY CT #1 OPEN CIRCUITED.

Fig. 3 (Continued)

The reactance, or ohm, unit of the GCXG 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.

The starting unit of the GCXG relay, because it is uncompensated and because it has only one current coil, is not an accurate distance measuring unit except for 3-phase faults. However, this is not critical because, aside from acting as a directional unit, it provides only third-zone back-up protection.

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 is a system that 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 covers only the case of 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.

In the application of the GCXG relay on a homogeneous system there are several points that must be checked in order to assure proper operation. These points are listed below:

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.

Thus, 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

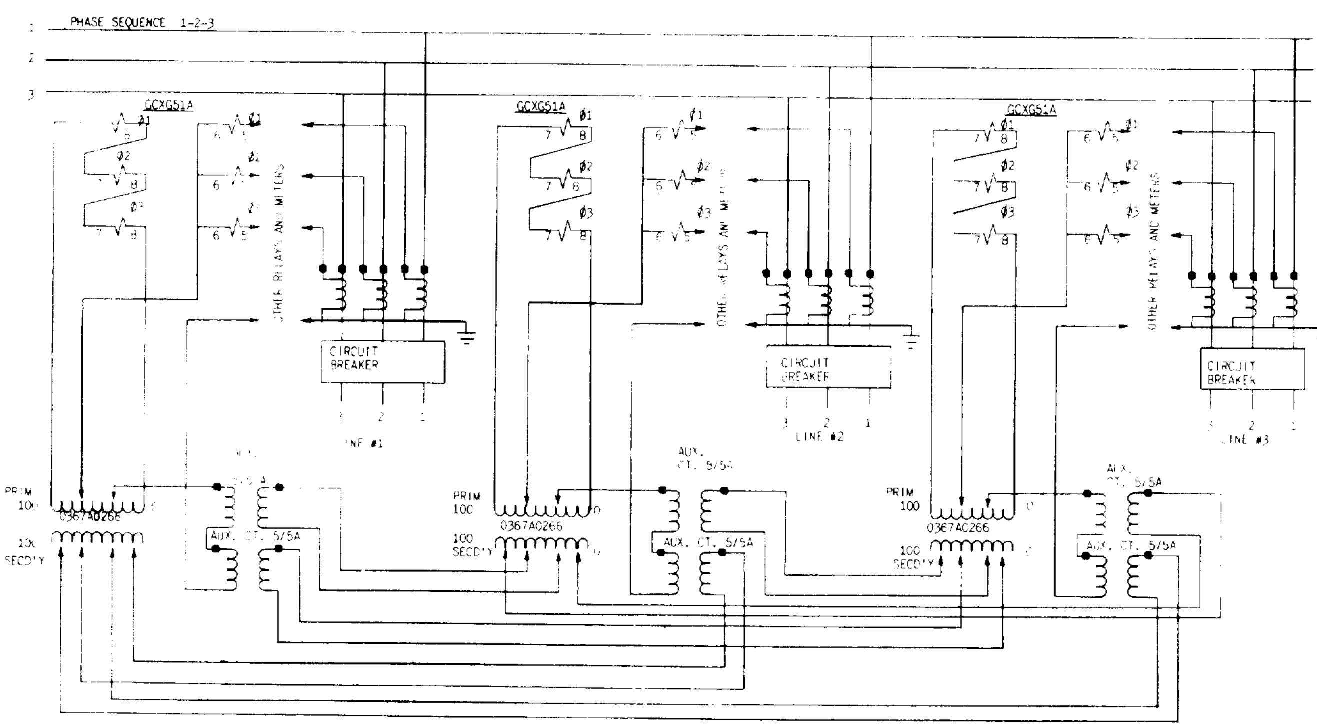


Fig. 4 (0116B6921-0) Current Coil Connections For Zero Sequence Mutual Impedance Compensation When The Type GCXG51A Relay Is Applied On Three Parallel Transmission Lines.

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 pick-up 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 accommodate the desired reach settings. This applies to both the mho and reactance units.

RATINGS

The Type GCXG51A relays covered by these instructions are available with a rating of 120 volts, 60 cycles on the polarizing circuit of the starting unit and 70 volts, 60 cycles on the restraint circuits of the starting unit and ohm unit. The operating circuits are rated 5 amperes continuous, with a 1-second rating of 225 amperes.

* The auxiliary transfer unit (OX) has a multiple D-C voltage rating of 24/48/125 or 48/125/250 depending on the model number. The specific rating is selected by means of a link setting on the front of the relay.

The basic minimum reach settings and adjustment ranges of the ohm and starting units in the short reach, standard reach, and long reach forms of the relay are given in Table I.

It will be noted that for each relay three basic minimum reach settings are listed for the ohm unit and two for the starting 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 starting unit is made by means of a link on a terminal board located at the rear of the starting unit (See Fig. 2).

The reach settings of the ohm and starting units can be adjusted in one percent steps by means of auto-transformer tap leads on the tap block at the right side of the relay. First-zone reach of the ohm unit is determined by the No. 1 leads, second-zone reach by the No. 2 leads, and the reach of the starting unit by the $E2$ leads.

The contacts of the GCXG51 relays will close and carry momentarily 30 amperes DC. 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 0.6/2 ampere target seal-in unit used in the GCXG51 relays has ratings as shown in Table II.

TABLE II

TARGET SEAL-IN UNIT		
	0.6 Amp Tap	2.0 Amp Tap
Minimum Operating	0.6 amps	2.0 amps
Carry Continuously	1.5 amps	3.5 amps
Carry 30 Amps for	0.5 secs.	4 secs.
Carry 10 Amps for	4 secs.	30 secs.
DC Resistance	0.6 ohms	0.13 ohms
60 Cycle Impedance	6 ohms	0.53 ohms

TABLE I

	OHM UNIT		STARTING UNIT		
RELAY	BASIC MIN. REACH ** (Ø-N OHMS)	RANGE (Ø-N OHMS)	BASIC MIN. REACH ** (Ø-N OHMS)	RANGE (Ø-N OHMS)	***ANGLE OF MAX. TORQUE
Short Reach	0.1/0.2/0.4	0.1/4	1/3	1/30	60°
Standard Reach	0.25/0.5/1.0	0.25/10	1/3	1/30	60°
Long Reach	0.5/1.0/2.0	0.5/20	2/6	2/60	60°

***Angle by which the operating current lags the phase-to-neutral restraint voltage.

** 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. For example, the 1-ohm basic reach tap of the starting unit should not be used with restraint tap settings less than 33 percent. If the desired reach setting requires a restraint tap setting less than 33 percent with the 1-ohm basic reach tap, use the 3-ohm tap instead with appropriate restraint setting.

*Indicates revision

OPERATING PRINCIPLES

STARTING UNIT

The starting unit of the Type GCXG51A relays is of the four-pole induction-cylinder construction (see Fig. 19) with schematic connections as shown in Fig. 5. The two side poles, which are energized by the phase-to-phase voltage in quadrature 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 the phase-A starting unit can therefore be expressed by the following equation:

$$\text{Torque} = 0 = KI_a' E_{bc}' \cos(\alpha - 30) - TE_a' E_{bc}' \sin B \qquad (1)$$

where: K = design constant
E_a' = Phase-A-to-neutral voltage at the relay location.
E_{bc}' = Phase B to Phase C voltage ($E_b' - E_c'$) at the relay.
I_a' = Phase A current at the relay location
α = Angle by which I_a' leads E_{bc}'
B = Angle by which E_a' leads E_{bc}' (90^o for balanced 3-phase condition).
T = Restraint tap setting

OHM UNIT

The ohm unit of the GCXG51A relays is also of the four-pole induction-cylinder construction (see Fig. 19) with schematic connections as shown in Fig. 5. 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 ZT is the transfer impedance of the transactor. Torque on the unit results 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:

$$\text{Torque} = 0 = k\, I_a' (I_a' Z_T - E_a') \sin A \qquad (2)$$

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 equation can be reduced to:

$$k I_a' (I_a' Z_T) \sin \emptyset - k\, I_a' (E_a') \sin \theta = 0 \qquad (3)$$

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:

$$k'(I_a')^2 = k\, I_a' E_a' \sin \theta \qquad (4)$$

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

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

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

CHARACTERISTICS

The operating characteristics of the reactance (ohm) and starting units in the GCXG51A relay may be represented on an R-X impedance diagram as shown in Fig. 6. It should be noted that these are steady-state characteristics and are for rather specific fault conditions as described below.

STARTING UNIT

The starting unit has a circular characteristic which passes through the origin of the R-X diagram. The diameter passing through the origin defines the angle of maximum torque of the unit, which occurs when line current (I_a for example) leads the quadrature polarizing voltage (E_{bc} for example) by 30^o. 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^o, which is the condition represented in Fig. 6.

The diameter of the impedance circle would normally be considered as the ohmic reach of the unit, which would be the basic minimum reach (See Table I) with the E^2 tap leads on 100 percent. However, since the starting unit is not compensated it is not an accurate distance measuring unit except on 3-phase faults, or for the special case of single-phase-to-ground faults where the zero-sequence impedance to the fault is equal to the positive sequence impedance to the fault. Instructions are given in Appendices II and III for selecting a reach setting.

The ohmic reach of the starting 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:

$$\text{Ohmic Reach} = \frac{(Z_{min})\,100}{E^2 \text{ Tap Setting } (\%)} \qquad (5)$$

The ohmic reach obtained from equation (5)

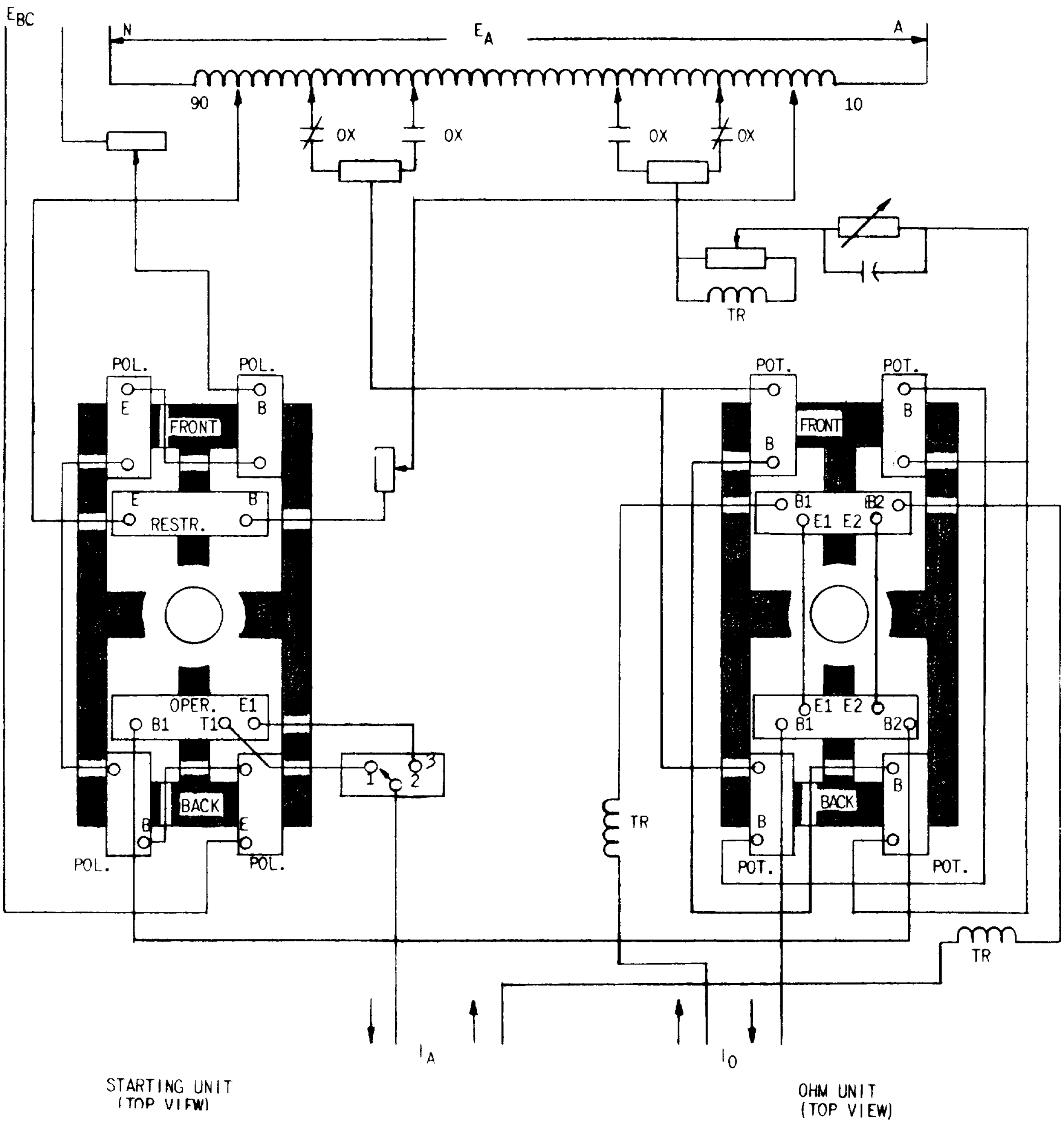


Fig. 5 (0116B6922-0) Schematic Connection Diagram Of Ohm And Starting Units In The Type GCXG51A Relay.

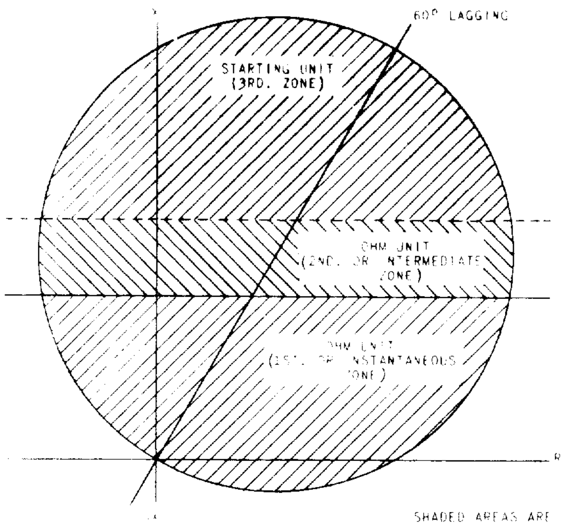


Fig. 6 (0178A9113-0) Characteristics of the Ohm And Starting Unit Of The GCXG51A Relay Represented On An Impedance Diagram.

assumes that line angle and maximum torque angle are equal (60°). The reduced reach at line angles other than 60° can be obtained by multiplying the reach obtained from equation (5) by cos (60-Ø), where Ø is the line angle.

Equation (5) also assumes an input tap setting of 100%. In some cases the input tap will be set less than 100% to obtain better accuracy on the ohm unit reach (See section on "Vernier Adjustment"). The reach of the starting unit at a lower input tap setting can be obtained by multiplying the reach obtained from equation (5) by:

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

The primary purpose of the starting unit in the GCXG51 relay is to provide the directional discrimination which is necessary since the ohm unit is inherently non-directional. The starting unit directional characteristic is such that it will operate correctly for either forward or reverse faults at polarizing voltages down to 4 percent of rated voltage over the current ranges listed in Table III for the various basic minimum reach settings shown.

TABLE III

CURRENT RANGE FOR CORRECT DIRECTIONAL ACTION AT 4 PERCENT OF RATED POLARIZING VOLTAGE

BASIC MIN. REACH	CURRENT RANGE
1 ohm	4.5 - 60A
2	2.3 - 60
3	1.5 - 60
6	.75 - 30

A secondary purpose of the starting unit is to measure fault impedance for the third zone of protection. Since the unit is quadrature polarized, on single-phase-to-ground faults the polarizing voltage for the unit on the faulted phase will be at full value. Hence the reach of the unit, as determined in Appendix II, will be substantially independent of fault current down to the values listed in Table IV for the various basic minimum reach settings.

TABLE IV

BASIC MIN. REACH	MIN. CURRENT
1 ohm	1.5A
2	0.75
3	0.5
6	0.25

OHM UNIT

The ohm unit characteristic when represented on the R-X diagram (Fig. 6) 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. And 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 starting unit will not be closed for this condition (see Fig. 6).

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 a later 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 on a lower percentage position on the tap block. The setting of the two tap leads marked No. 1 determines the reach of the instantaneous or first zone, and the setting of the two tap leads marked No. 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 = No. 1 or No. 2 tap setting

For a numerical example of the determination of the ohm and starting 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 V lists minimum values of line current for a single-phase-to-ground fault which will insure that the reach will be 90% or more of the calculated value.

TABLE V

MINIMUM FAULT CURRENT (1Ø-G) FOR REACH OF 90% OR MORE OF CALCULATED VALUE

RELAY	BASIC MIN. REACH	MIN. CURRENT
Short Reach	0.1 0.2 0.4	5.5A 3.5 2.2
Stand. Reach	0.25 0.5 1.0	2.8 1.8 1.2
Long Reach	0.5 1.0 2.0	1.8 1.2 0.75

Vernier Adjustment For Low Tap Settings

The input leads to the tapped autotransformer are normally set a 100 percent, but with a high secondary line reactance where the No. 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 in the internal connection diagram of Fig. 7. The unit is mounted at 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 Fig. 3. 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 No. 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 starting units in the GCXG51A 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.

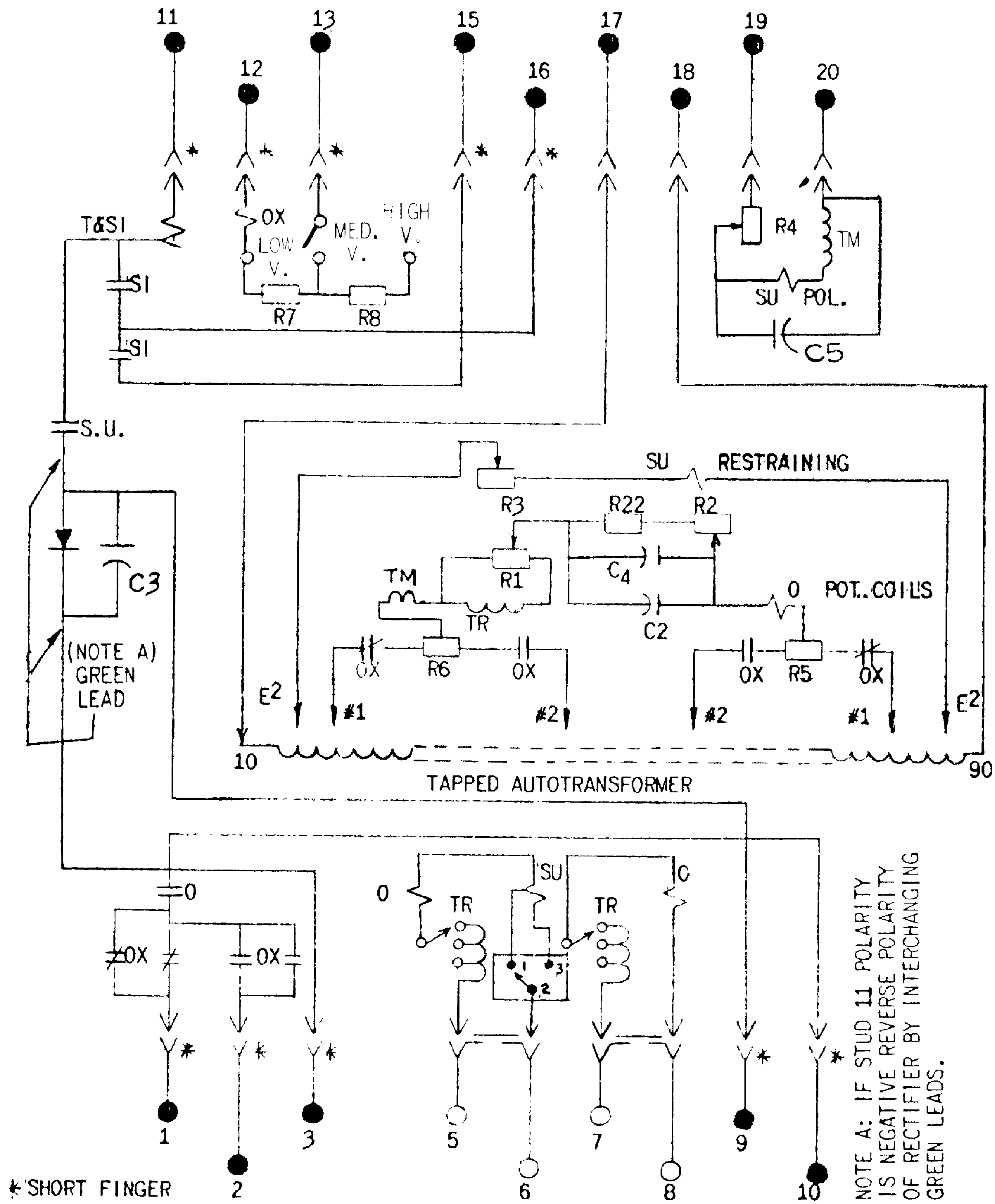
Typical time curves for the starting unit are shown in Fig. 8 for several ratios of fault impedance to unit reach. These curves are for a single-phase-to-ground fault where the fault impedance (Z_{FAULT}) seen by the unit can be calculated as described in Appendix II. Note in the figure that the fault current scale changes with the basic minimum reach setting.

Typical time curves for the ohm unit are shown in Figures 9, 10, and 11 as tabulated below:

Fig. No.	Ohm Unit	Basic Min. Reach Setting
9	0.1/0.2/0.4	0.2
10	0.25/0.5/1.0	0.5
11	0.5/1/2	1.0

In each instance the time curves are for the intermediate basic minimum reach setting of the unit. Operating times for the other basic minimum reach settings can be approximated by multiplying the current scale (abscissa) by a factor inversely proportional to the basic reach taps. For instance in Fig. 10 if operating time for the 0.25 ohm basic minimum reach setting is desired, multiply the current scale by 2.

As will be apparent from the typical elementary diagram in Fig. 3, the trip chain for a first zone single-phase-to-ground fault includes contacts of the instantaneous overcurrent unit and auxiliary unit (A_1, A_2, or A_3) in the associated NAA relay, as well as the starting 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 6 milliseconds. For most fault conditions the operating time of the ohm unit will be greater than the time of the instantaneous unit, or starting unit plus auxiliary unit, so as a general rule it can be assumed that the ohm unit time will determine the overall operating time of the Type GCXG scheme on single-phase-to-ground first-zone faults.



* Fig. 7 (0195A4924-4) Internal Connections of the Type GCXG51A Relay (Front View)

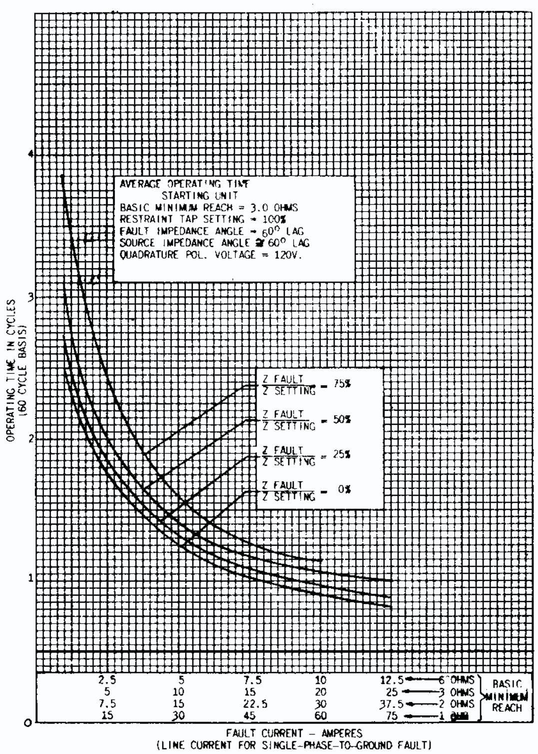


Fig. 8 (0178A9114-0) Operating Time Curves For The Starting Unit In Relay Type GCXG51A.

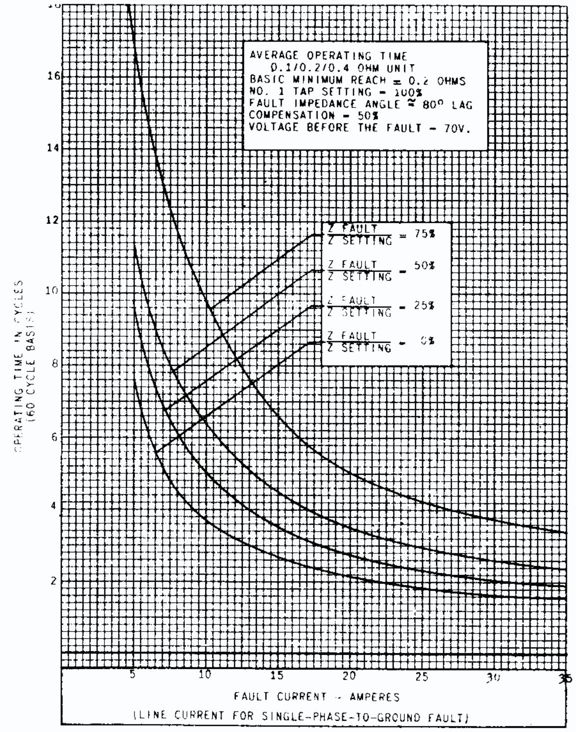


Fig. 9 (0178A9115-0) Operating Time Curves For The Ohm Unit In The Short-reach GCXG51A Relay.

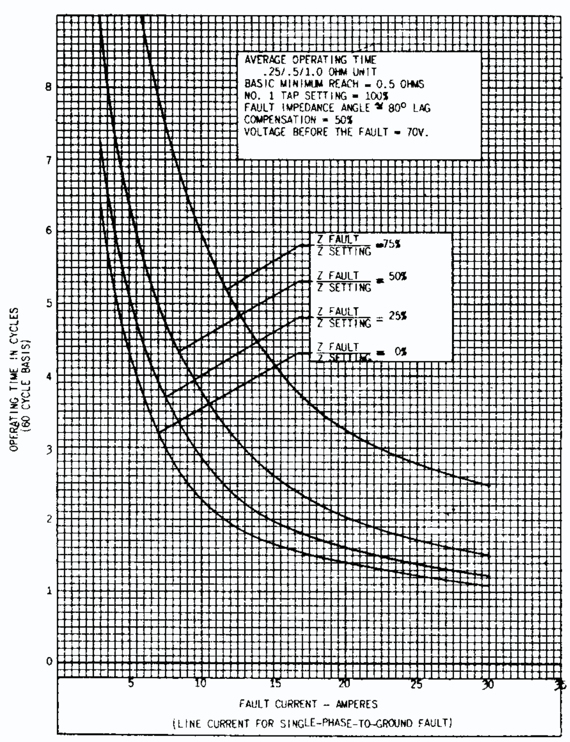


Fig. 10 (0178A9116-0) Operating Time Curves For The Ohm Unit In The Standard Reach GCXG51A Relay.

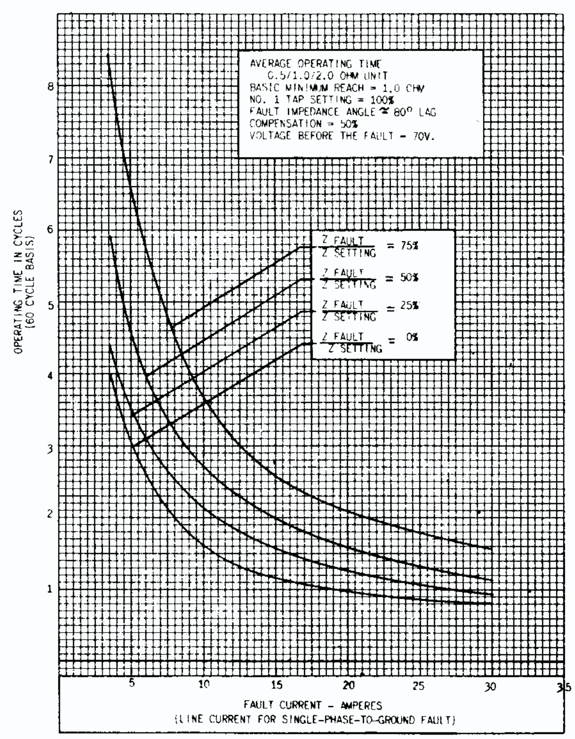


Fig. 11 (0178A9117-0) Operating Time Curves For The Ohm Unit In The Long Reach GCXG51A Relay.

BURDENS

The current burden at 5 amperes imposed on one CT for a single-phase-to-ground fault is listed in Table VI.

TABLE VI
Current Burdens

Amps	Cy	Watts	V-A
5	60	6.5	7

The data is for the standard reach relay set on its maximum basic reach tap. The burden for its lower basic reach taps or for the short reach relay will be slightly lower. The current burden for the long reach relay will be slightly higher.

Complete potential burden data with the no. 1 taps of the ohm unit (O.U.) and E^2 taps of the starting unit (S.U.) on 100 percent, and with input taps on 100 percent are given in Table VII.

The burdens listed in Table VII are maximum values. The burdens imposed by the ohm unit potential circuit and starting unit restraint circuit will decrease as the tap setting is reduced and can be calculated from the following formulae:

Ohm Unit:

$$VA = (a + jb)\left[\frac{\text{No. 1 Tap Setting (\%)}}{\text{Input Tap Setting (\%)}}\right]^2 \qquad (6)$$

Starting Unit:

$$VA = (c + jd)\left[\frac{E^2 \text{ Tap Setting (\%)}}{\text{Input Tap Setting (\%)}}\right]^2 \qquad (7)$$

The terms (a + jb) and (c + jd) in the above equations represent the burdens of the ohm and starting unit restraint circuits expressed as Watts + j Vars at 70 volts. The total burden imposed on each potential transformer by a terminal installation of three GCXG51A relays can be determined by adding the values of Watts +j Vars obtained from the above equations to the Watts +j Vars of the starting unit polarizing circuit (e + jf), converting the resulting sum to volt-amperes. The values of these terms for 60 cycle relays are given in Table VIII.

TABLE VIII

Circuit	Terms	Watts +j Vars
OU Potential	a + jb	7.3 +j2
SU Restraint	c + jd	2.7 +j4
SU Polarizing	e + jf	15.7 +j21.5

The input tap setting in the above formulae is normally 100 percent. In some cases, however, the input tap may be set at some point between 90 and 100 percent (see "Vernier Adjustment for Low Tap Settings" in the CHARACTERISTICS section).

RELAY AND COMPENSATING AUXILIARY CT SETTINGS

There are four and possibly five settings that must be made for each GCXG51A relay. These are:

1. Zone 1 ohm unit percent tap setting.
2. Zone 2 ohm unit percent tap setting.
3. Zone 3 starting unit percent tap setting.
4. Primary of 0367A0266 auxiliary curent transformer percent tap setting (K').
5. Secondary of 0367A0266 auxiliary current transformer percent tap setting (K").

If compensation for zero sequence mutual impedance between the protected line and other lines is not required, then setting number 5 above is not required and the secondary of the auxiliary current transformer 0367A0266 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 GCXG51A 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.

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

TABLE VII
Maximum Potential Burdens

Circuit	Freq.	Volts	Impedance	Watts	VA
O.U. Pot'l.	60	70	625 +j 175	7.3	7.6
S.U. Restr.	60	70	570 +j 840	2.7	4.8
S.U. Polar.	60	120	325 +j 450	15.7	26.5

OHM UNIT SETTING

$$\text{Percent Tap} = \frac{X_{min}}{X} \times \text{Input Tap} \qquad (8)$$

where:

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

X = desired reach in secondary reactive ohms

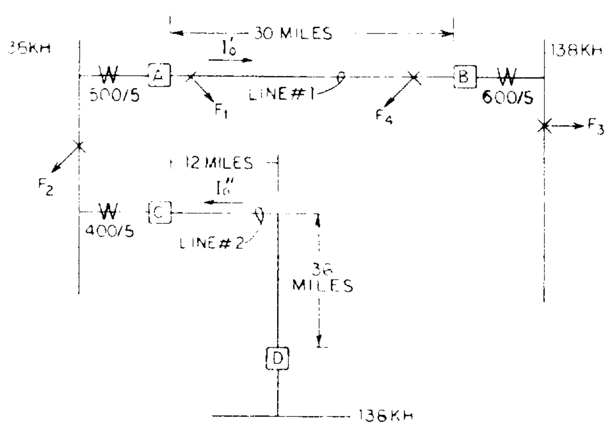
Note that the same equation applies to both first and second zone settings. The input tap is normally set for 100 percent. However, the input tap may be set for any value between 90 and 100 percent to obtain more precise settings. For example, assume that a 0.25 ohm unit requires a reach setting of 2.16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

It should be recognized that the input tap setting will affect all three zone settings the same way.

COMPENSATING AUXILIARY CT SETTING

The compensating CT has two settings. One setting is on the primary side and is called K'. The other is on the secondary side and is called K". The latter setting is only required when zero sequence mutual impedance between parallel lines must be compensated for. The former setting is always required.

$$K' = \frac{X_0' - X_1'}{3X_1'} \times 100 \qquad (9)$$



* Fig.12 (0165A7622 [2]) Portion Of A Transmission Line.

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.

$$K'' = \frac{2X_{om}S_2}{3X_1'S_1} \times \frac{(CTRP)}{(CTR)} \times 100 \qquad (10)$$

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

Note that the compensating auxiliary CT has only 10 percent steps. It should be set to the nearest tap available.

STARTING UNIT SETTING

The proper setting for the starting unit is discussed in Appendices II and III.

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:

$Z_1' = 24.0 \angle 79^\circ$ primary ohms

$Z_0' = 72.0 \angle 75^\circ$ primary ohms

$Z_{om} = 14.4 \angle 75^\circ$ primary ohms

CT Ratio = 600/5

PT Ratio = 1200/1

$Z_1' = 2.4 \angle 79^\circ = 0.47 + j\,2.36$ secondary ohms

$Z_0' = 7.2 \angle 75^\circ = 1.9 + j\,6.95$ secondary ohms

$Z_{om} = 1.4 \angle 75^\circ = 0.36 + j\,1.35$ secondary ohms

* Revised since last issue

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:

$$T = \frac{1.0}{1.89} \times 100 = 53 \text{ percent} \quad \text{From Eq. (8)}$$

$$K' = \frac{6.95 - 2.36}{3(2.36)} \times 100 = 65 \text{ percent} \quad \text{From Eq. (9)}$$

Since K' can be set in 10 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 70 percent setting set on taps 0 and 70. For 60 percent setting set on taps 40 and 100.

$$K'' = 2\frac{1.35}{3(2.36)(0.8)} \times \frac{400}{600} \times 100 = 31.8\ (\%) \quad \text{From Eq. (10)}$$

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

The factor 400/600 appears because the CT's 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:

$$T = \frac{1.0}{1.5(2.36)} \times 100 = 28 \text{ percent} \quad \text{From Eq. (8)}$$

Having set zones 1 and 2, it is now necessary to consider zone 3. Appendix III of this book provides the information that is necessary to determine the minimum permissible tap setting (maximum permissible reach setting). Consider first a single phase-to-ground fault at F_1 in Figure 12. For this fault assume that a system study yields the following system constants:

$C = 0.73$

$C_o = 0.89$

$Z_1 = 0.875 \angle 82^\circ$ secondary ohms

$Z_o = 1.05 \angle 78^\circ$ secondary ohms

Now, for a fault at F_2 in Figure 12 the following system constants apply from the previous assumptions.

$C = 0.27$

$C_o = 0.11$

$Z_1 = 0.875 \angle 82^\circ$ secondary ohms

$Z_o = 1.05 \angle 78^\circ$ secondary ohms

Assuming the 3.0 ohm basic minimum tap setting and evaluating equations III-a, III-b, III-c, III-d and III-e of Appendix III the minimum permissible values of T are tabulated below (Table IX).

As explained in Appendix III, the identical results obtained for single-phase-to-ground faults at F_1 and F_2 are not coincidental but should be expected.

TABLE IX

QUANTITY	FAULT AT F_1	FAULT AT F_2
Z_1	$0.875 \angle 82^\circ$	$0.875 \angle 82^\circ$
Z_o	$1.05 \angle 78^\circ$	$1.05 \angle 78^\circ$
Z_o/Z_1	1.2	1.2
C_o	0.89	0.11
C	0.73	0.27
K_s	100	100
A	123 degrees	123 degrees
θ	82 degrees	82 degrees
T(Equation III-a)	-10.5 percent	--
T(Equation III-b)	-17.9 percent	--
T(Equation III-c)	--	-10.5 percent
T(Equation III-d)	--	-17.9 percent
T(Equation III-e)	--	-14.5 percent

Since all the values of T in the above table are negative, these equations impose no restrictions on the third zone tap setting. Thus, the third zone may be set as low as 10 percent as noted in Appendix III.

Now it is necessary to determine the maximum tap setting for third zone to insure detection of a single phase-to-ground fault at the remote bus. The method for obtaining this value of T is given in Appendix II, equation II-b. From a system study the following quantities are obtained for the relays at Terminal "A" with the fault at F_3.

$C_0 = 0.17$

$C = 0.20$

$I_a' = 13.7$ secondary amperes based on 600/5 CT's

$\theta = 79$ degrees

$I_0'' = -0.88$ secondary amperes based on the protected line CT ratio of 600/5. Note the negative sign because I_0'' flows in the opposite direction in line #2 from that in which I_0 flows in line #1.

Substituting these values into equation II-b of Appendix II and recalling the values of:

$Z_{om} = 1.4$ secondary ohms

$Z_0' = 7.2$ secondary ohms

$Z_1' = 2.4$ secondary ohms

K = 300 for the 3.0 ohm basic minimum tap of the starting unit.

we obtain for T a maximum permissible setting of 61 percent. Thus, the third zone unit may be set anywhere between 10 and 61 percent. However, it should be noted that the third zone starting unit will be sensitive to load current and will measure effective load impedance in the same accurate manner in which it measures three-phase fault impedance. For this reason the tap setting should not be made so low that load impedance is inside the relay characteristic unless the zero sequence fault detector is used.

Now consider the relays at Terminal "B". Since there is mutual impedance between Line #1 and Line #2, that cannot be compensated for at Terminal "B", the secondary of the 0367A0266 auxiliary current transformer will be left open circuited. For this condition the reach of the ohm unit of the GCXG51A at Terminal "B" will be somewhat in error. In order to evaluate this, equation IV-c of Appendix IV will give the reactance seen by the ohm unit at Terminal "B" for single phase-to-ground fault at F_2 in Figure 12. Since there is no mutual compensation at Terminal "B", the last term in the denominator of equation IV-c is zero.

The primary setting of the compensating auxiliary CT (K') at Terminal "B" will be the same as that setting for Terminal "A".

K' = 70 percent

From the system configuration and the location of the fault we have:

$X_1' = 2.36$ secondary ohms

$X_{om}' = 1.35$ secondary ohms

$S_1 = 1.0$

$S_3 = 1.0$

From a board study of the system:

$I_a' = 15.4$ sec. amps. based on 600/5 CT's

$I_0' = 2.7$ sec. amps. based on 600/5 CT's

$I_0''' = 1.6$ sec. amps. based on 600/5 CT's

Substituting these values into equation IV-c of Appendix IV, the reactance seen by the relay is 2.47 secondary ohms. Since the actual positive sequence reactance from the relay to the fault is 2.36 secondary ohms, the ohm unit underreaches by about 4.6 percent as a result of the lack of mutual compensation. Because the uncompensated mutual causes underreaching in this case, the first zone may be set at 80 percent of the line length. The second zone must be set for at least 104.6 percent of the line length. Actually the second zone should be set for 125-150 percent of the protected line length.

Having set Zones 1 and 2, it is now necessary to consider Zone 3. Appendix III of this book provides the information that is necessary to determine the minimum permissible tap setting (maximum permissible reach setting). Consider first a single phase-to-ground fault at F_3 in Figure 12. For this fault assume that a system study yields the following system constants.

$C = 0.20$

$C_0 = 0.17$

$Z_1 = 0.72 \angle 82^\circ$ secondary ohms

$Z_0 = 1.33 \angle 78^\circ$ secondary ohms

Now for a fault at F_4 in Figure 12 the following constants apply from the previous assumptions.

$C = 0.80$

$C_0 = 0.83$

$Z_1 = 0.72 \angle 82^\circ$ secondary ohms

$Z_0 = 1.33 \angle 78^\circ$ secondary ohms

Assuming the 3 ohm basic minimum tap on the relay and evaluating equations III-a, III-b, III-c, III-d and III-e of Appendix III the minimum permissible values of T are tabulated below:

Quantity	Fault at F4	Fault at F_3
Z_1	0.72 $\angle 82^o$	0.72 $\angle 82^o$
Z_0	1.33 $\angle 78^o$	1.33 $\angle 78^o$
Z_0/Z_1	1.85	1.85
C_0	0.83	0.17
C	0.80	0.20
K_s	70	70
A	130 degrees	130 degrees
θ	82 degrees	82 degrees
T(Equation III-a)	-1.4 percent	--
T(Equation III-b)	-2.8 percent	--
T(Equation III-c)	--	-1.4 percent
T(Equation III-d)	--	-2.8 percent
T(Equation III-e)	--	-2.1 percent

Since all the values of T in the above table are negative, these equations impose no restrictions on the third zone tap setting. Thus, the third zone may be set as low as the minimum value of 10 percent as noted in Appendix III.

Now it is necessary to determine the maximum tap setting for third zone to insure detection of a single phase-to-ground fault at the remote bus. The method for obtaining this value of T is given in Appendix II, equation II-b. From a system study the following quantities are obtained for the relays at Terminal "B" with the fault at F_2.

$C_0 = 0.11$

$C = 0.27$

$I_a' = 15.4$ sec. amps. based on 600/5 CT's

$\theta = 79$ degrees

$I_0'' = 1.55$ sec. amps. based on the protected line CT ration of 600/5.

Substituting these values into equation II-b of Appendix II and recalling the values of:

$Z_{om} = 1.4$ secondary ohms

$Z_1' = 2.4$ secondary ohms

$Z_0' = 7.2$ secondary ohms

$K = 300$ for the 3.0 ohm basic minimum tap on the starting unit

we obtain for T a maximum permissible setting of 67.5 percent. Thus, the third zone unit may be set anywhere between 10 and 67 percent. However, it should be noted that the third zone unit will be sensitive to load current and will measure effective load impedance in the same accurate manner in which it measures three-phase fault impedance. For this reason the tap setting should not be made so low that load impedance is inside the relay characteristic unless the zero sequence fault detector is used.

CONSTRUCTION

The Type GCXG51 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 the steel framework called the cradle and is a complete unit with all leads being terminated at the inner block. 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 drawn 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 own source of current and voltage, or from other sources. Or the relay can be drawn out and replaced by another which has been tested in the laboratory.

The relay is composed of three major subassembly elements:

1. The bottom element includes the starting 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 starting units. The tap block associated with the autotransformer is mounted along the right side of the relay.

Figs. 1 and 2 show the relay removed from its drawout 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 Fig. 7.

RECEIVING, HANDLING AND STORAGE

These relays, when not included as a 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.

Reasonable care should be exercised in unpacking the relay in order that none of the parts are injured or 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 collected on the outside of the case may find its way inside when the cover is removed and cause trouble in the 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. It is recommended that the mechanical adjustments in Table X be checked.

2. There should be no noticeable friction in the rotating structure of the ohm and starting units.

3. Make sure control springs are not deformed and spring convolutions do not touch each other.

4. With the relay well leveled in its upright position the ohm unit and starting unit contacts must be open. The moving contact of the ohm and starting 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 lease 1/32" wipe on the seal-in contacts.

6. Make sure the armature of telephone-type relay (OX) is moving 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 X

CHECK POINTS	STARTING UNIT	OHM UNIT
Rotating Shaft End Play	.010-.015 inch	.010-.015 inch
Contact Gap	.120-.130 inch	.035-.045 inch
Contact Wipe	.003-.005 inch	.003-.005 inch

ELECTRICAL CHECKS

Before any electrical checks are made on the ohm and starting units the relay should be connected as shown in Fig. 13 and allowed to warm up for approximately 15 minutes with the potential circuits alone energized at rated voltage (i.e. 120 volts across studs 19-20 and 70 volts across studs 17-18) and with the E^2 and No. 1 tap leads set at 100%. The units were warmed up prior to factory adjustment and if rechecked when cold will tend to underreach by 3 or 4 percent. Accurately calibrated meters are, of course, essential.

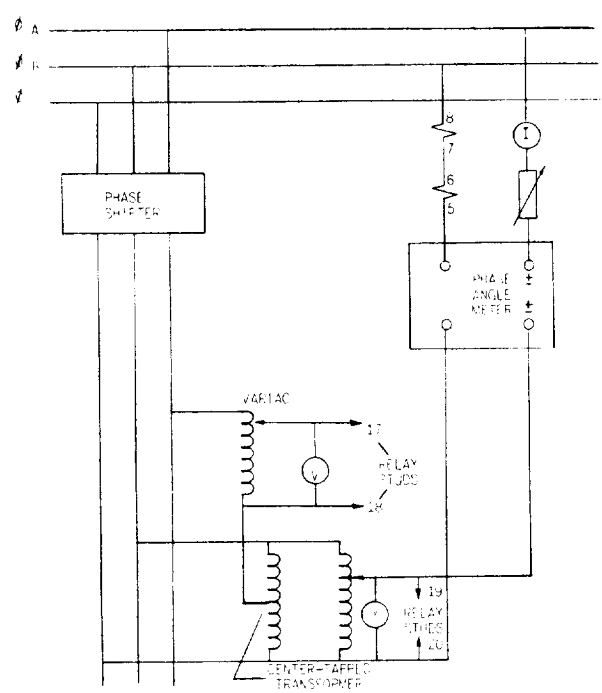


Fig. 13 (0178A9118-0) Test Circuit For The Starting Unit Of The Type GCXG51A Relay, Using A Phase Shifter

It is desirable to check the factory settings and calibrations by means of the tests described in the following sections. It is assumed that these electrical acceptance tests will be made in the laboratory so the test diagrams in the section on ACCEPTANCE TESTS have been prepared on this basis. The ohm and starting units were carefully adjusted at the factory and it is not advisable to disturb their settings unless the following checks indicate conclusively that the settings have been disturbed. If readjustments are necessary refer to the section on SERVICING for the recommended procedure.

Before proceding with the electrical checks on the ohm and starting units be sure that the relay is level in its upright position.

STARTING UNIT CHECKS

a. Control Spring

With the relay connected as shown in Fig. 13 disconnect and short out the restraint circuit (studs 17-18). With the polarizing voltage (19-20) at 120 volts and the current set at 5 amperes, set the phase shifter so that current leads voltage by 30°. Now reduce the voltage to 5 volts and the current to zero. Gradually increase the current until the starting unit contact just closes. This operating point should fall within the limits shown in Table XI. Be sure that the link at the rear of the starting unit is set for basic minimum reach listed in the table.

TABLE XI

Control Spring Check (SU)

Relay	Basic Min. Reach	Closing Current
Short Reach	3 ohms	1.4-1.8 amps
Std. Reach	3	1.4-1.8
Long Reach	6	0.7-0.9

b. Ohmic Reach

With the relay still connected as shown in Fig. 13 remove the jumper from studs 17-18 and reconnect the restraint circuit as shown. With the E^2 taps still in the 100% position, polarizing voltage (19-20) set at 120 volts, and current leading polarizing voltage by 30°, set the restraint voltage (17-18) at the value listed in Table XII for the relay to be checked. Increase the current until the starting unit contacts just close. This should occur within the limits shown in Table XII.

TABLE XII

Ohmic Reach Check (SU)

Relay	Basic Min. Reach	V17-18 Set At	Pickup Amps
Short or Std. Reach	3 ohms	60V.	19.4 - 20.6
	1	20	19.4 - 20.6
Long Reach	6	60	9.7 - 10.3
	2	20	9.7 - 10.3

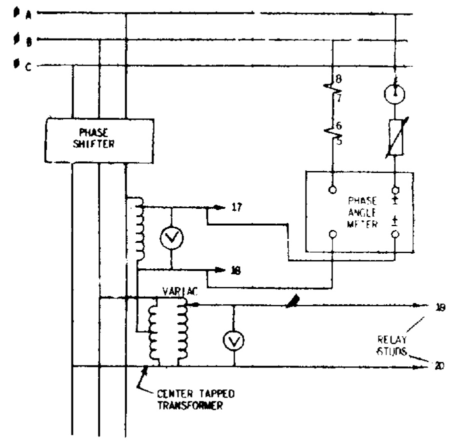


Fig. 14 (0178A9119-3) Test Circuit For The Ohm Unit Of The Type GCXG51A Relay. Using A Phase Shifter.

c. Angle of Maximum Torque Check

The preceding check of ohmic reach was made at the angle of maximum torque of the unit, that is operating current leads polarizing voltage by 30°. If the operating currents fall within specified limits, the angle of maximum torque is probably correct. The angle of maximum torque can be checked if desired by means of the same test circuit of Fig. 13. With the E^2 taps still on 100%, with the restraint voltage at the value shown in Table XIII, and with the polarizing voltage at 120V, check pickup with the current displaced by 30° from the nominal maximum torque position, first in the lead and then in the lag direction.

TABLE XIII

Maximum Torque Angle Check (SU)

Relay	Basic Min. Reach	V17-18 Set At	Test Angles (I leads V_p)	Pickup Amps
Short or Std. Reach	3 ohms	60V	60° & 0°	22-24A
Long Reach	6	60V	60° & 0°	11-12

OHM UNIT CHECKS

a. Control Spring Adjustment

Using the connections shown in Fig. 14, leave the potential circuit of the relay disconnected and short out studs 17-18. The No. 1 tap leads should be in the 100% position and the basic reach taps should be in the middle position. Increase the current gradually until the ohm unit contacts just close. This should occur within the limits shown in Table XIV.

TABLE XIV

Control Spring Check (OU)

Relay	Basic Min. Reach Setting	Closing Current
Short Reach	0.2 ohm	1.1 - 1.6A
Std. Reach	0.5	0.4 - 0.9
Long Reach	1.0	0.2 - 0.5

b. Ohmic Reach and Angle of Maximum Torque

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

* 1. To check the ohmic reach use the connections shown in Figure 14 with the No.1 tap leads on 100% and the basic reach taps in the intermediate position. With the voltage across studs 19-20 set for 120 volts and the voltage across studs 17-18 set at 70 volts and the current at 5 amperes, set the phase shifter so that the current lags the voltage by 90°. Now set the current at the value shown in Table XV for the relay to be checked and reduce the voltage across studs 17-18 until the point is found where the ohm unit contacts just close. Table XV shows the theoretical pickup voltage for the intermediate basic reach setting of each unit. A variation of ± 3% is permissible. Note that with the test connections of Figure 14 both the operating winding (5-6) and the compensating winding (7-8) are connected in series with the result that the reach of the unit in the test circuit is twice the nameplate stamping.

TABLE XV

Ohmic Reach Check (OU)

Relay	Basic Min. Reach Setting	No. 1 Tap	Current Set At	Operating Points (V17-18) I lags V by: 90°	30°
Short Reach	0.2 ohms	100%	15A	6V	12V
Std. Reach	0.5	100%	15A	15V	30V
Long Reach	1.0	100%	10A	20V	40V

2. To check the angle of maximum torque use the same connections and settings as in (1) above except now set the phase shifter so that current lags voltage by 30°. Again vary the voltage across studs 17-18 until the point is found where the contacts just close. The nominal values are listed in Table XV for the three forms of the relay in the column headed 30°. A variation of ±3% is permissible.

Note that the relays are normally shipped from the factory with the basic minimum reach adjustment taps in the intermediate setting, that is 0.2 ohms for the short reach form, 0.5 ohms for the standard reach, or 1.0 ohms for the long reach. If the units are set in either of the remaining two basic minimum reach taps (see Table I) the reach of the units will be within ±4% of the tap plate marking.

Other Checks and Tests

In addition to the tests on the ohm and starting units, it is recommended that the following general tests and checks be made as a part of the ACCEPTANCE TEST routine.

a. Ohm-Unit Transfer Relay (OX)

The ohm-unit transfer relay, identified as OX in Fig. 7, is provided with a voltage selection link to adapt it for application on 48, 125, or 250 volt DC control. The unit should be checked for correct operation on each link position. Apply a variable source of D-C voltage across studs 12-13 and check that the OX unit picks up at 80 percent or less of the nominal tap voltage for each link position.

b. Target Seal-in Unit

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

If it is necessary to change the tap setting, say from 0.6 to 2.0 amps, proceed as follows: Remove the tap screw from the left-hand contact strip and insert it in the 2.0 amp position of the right hand contact strip. Then remove the screw from the 0.6 amp tap and put it in the vacant position in the left hand plate. If this procedure is followed the contact adjustments will not be disturbed.

INSTALLATION PROCEDURE

LOCATION

The location of the relay should be clean and dry, free from dust, excessive heat and vibration, and should be 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 Fig. 20.

The outline panel drilling and internal connections for the auxiliary compensating transformer are shown in Fig. 21.

CONNECTIONS

The internal connections of the GCXG51A relay are shown in Fig. 7. An elementary diagram of typical external connections is shown in Fig. 3.

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 seven adjustments mentioned under Mechanical Inspection in the section of ACCEPTANCE TEST.

* Revised since last issue

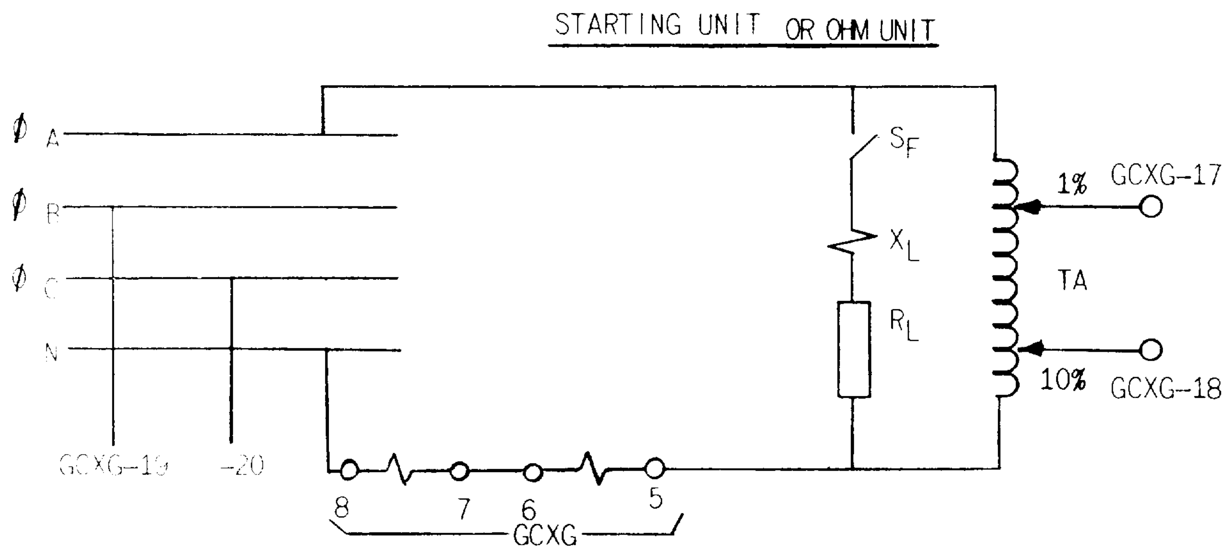


Fig. 15 (0178A9120-1) Schematic Diagrams Of Test Circuits For Field Testing The Type GCXG51A Relay.

Electrical Check Tests On Induction Units

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. It is the purpose of the electrical tests in this section to check the ohm and starting unit ohmic pickup settings which have been made for a particular line section.

To eliminate errors which may result from instrument inaccuracies the test circuits shown in schematic form in Fig. 15a for the ohm unit or Fig. 15b for the starting unit are recommended. In these figures $R_S + jX_S$ (when used) is the source impedance, S_F is the fault switch, and $R_L + jX_L$ is the impedance of the line section for which the relay is being tested. The autotransformer T_A which is across the fault switch and line impedance is tapped in 10 percent and 1 percent steps so that the line impedance $R_L + jX_L$ may be made to appear to the relay very nearly as the actual line on which the relay is to be used. This is necessary since it is not feasible to provide the portable test reactor X_L and the test resistor with enough taps so that the combination may be made to match any line.

For convenience in field testing, the fault switch and tapped autotransformer of Fig. 15 have been arranged in a portable test box, Cat. No. 102L201, which is particularly adapted for testing directional and distance relays. The box is provided

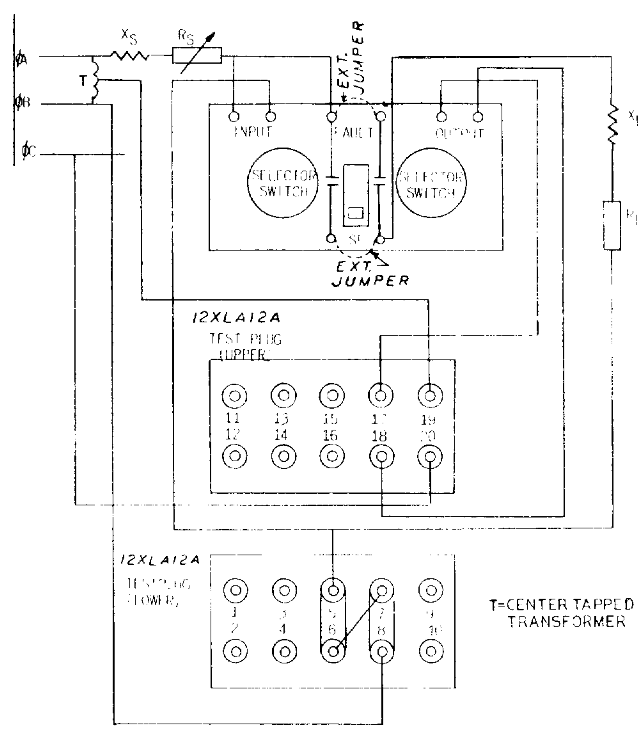


*Fig. 16 (0178A9121-4) Connections for Field Testing the Ohm Unit of the Type GCXG51A Relay Using the Type XLA Test Plugs.

 *Indicates revision

with terminals to which the relay current and potential circuits as well as the line and source impedances may be readily connected. For a complete description of the test box the user is referred to GEI-38977.

a. Testing the Ohm Unit

To check the calibration of the ohm unit it is suggested that the portable test box, Cat. No. 102L201, portable test reactor, Cat. No. 6054975 and test resistor Cat. No. 6158546 be arranged with Type XLA test plugs as shown in Fig. 16. These connections of the test box and associated equipment are similar to the schematic connections in Fig. 15a except that the Type XLA test plug connections are now included.

In the circuit of Fig. 16 it will be noted that the test current is passed through both the operating circuit (5-6) and the compensating circuit (7-8) of the ohm unit. This is equivalent to 100% compensation and causes the reach of the unit to be twice the line-to-neutral positive-phase-sequence ohms it normally measures. Making the reach test in this manner provides a check of both operating and compensating circuits of the unit, but it must be remembered that the apparent reach of the unit will be twice normal for the taps in use.

For any particular ohm unit tap setting the value of test reactor ohms (X_L) to select will be the portable test reactor tap nearest above twice the uncompensated (or positive sequence) reactance setting as determined by the basic reach tap and No. 1 (or No. 2) tap settings.

* When testing the ohm unit it is necessary to keep R_S ohms as low as possible in order to get the correct balance point. R_S should only be used to make fine adjustments of the current. X_S should be chosen to limit the current to 14 to 16 amperes.

The unit characteristic should first be checked near the 90° point by using the test reactor X_L alone, with R_L at zero. The percent tap setting of the test box autotransformer, which should cause the ohm unit to just close its contacts, is given by equation (11).

$$\%Tap = \frac{2\,(X_{OU})}{X_L} \qquad (11)$$

To illustrate the above assume that a standard-reach relay is being tested and that the ohm unit range selection taps have been set for a basic minimum reach of 1.0 ohm. Further assume that the No. 1 taps are set at 53 percent providing a zone-1 reach of 1.89 ohms. These values were used in the section SAMPLE CALCULATIONS OF SETTINGS.

$$2X_{OU} = 2(1.89) = 3.78 \text{ Ohms}$$

Therefore, it will be necessary to use the 6 ohm test reactor tap for X_L since this is the nearest tap above twice the unit reach. Assume now that the calibration curve for the particular test reactor in use has been checked and that the reactance of the 6 ohm tap at the 15 ampere current level to be used in the test is actually 6.25 ohms. The percent

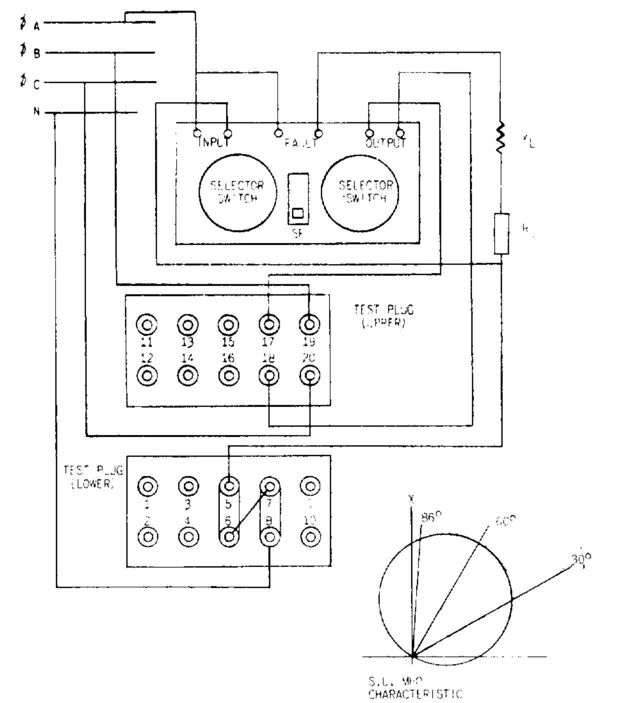


Fig. 17 (0178A9122-1) Connections For Field Testing The Starting Unit Of The Type GCXG51A Relay Using Type XLA Test Plugs And a 3-Phase, 4 Wire Source.

tap of the test box autotransformer at which the ohm unit contact will just close can then be calculated as follows from equation (11):

$$\%Tap = \frac{3.78}{6.25}(100) = 60.5\%$$

The ohm unit should, therefore, theoretically close its contact with the test box autotransformer taps set at 60 percent and remain open with the taps at 61 percent. A range of 59 to 62 percent is acceptable.

The phase angle of the ohm unit reactance characteristic can be readily checked by adding resistance R_L in series with the line reactance X_L in the test circuit Fig. 16. This resistance R_L should be non-inductive and about 3 to 4 times as large as the line reactance X_L. The source impedance should also be readjusted so that when the pickup point is checked the fault current will be approximately the same as in the previous test with reactance alone. When the fault switch is closed the ohm unit should close its contacts at the same test box percent tap setting as in the previous test.

A check of the ohm unit second zone setting may be made in the same manner, except that the transfer relay OX must be picked up by applying rated DC voltage between studs 12 and 13 (be sure the DC voltage selection link position agrees with the voltage to be used). It may also be necessary to use a different test reactor tap setting.

*Indicates revision

Note that in the preceding tests the use of the test box may result in a momentary closure of the ohm unit contact as the knob is switched from one tap to the next, since all voltage is removed from the unit at the instant of switching. This should not be construed as indicating transient overreach of the unit. Only the steady-state output of the test box should be used in determining the balance point.

b. Testing The Starting Unit

To check the calibration of the starting unit it is suggested that the test box, test reactor, and test resistor be arranged with Type XLA test plugs as shown in Fig. 17. These connections are similar to the schematic connections of Fig. 15b except that the XLA test plug connections are now included. As noted in the section on CHARACTERISTICS the starting unit provides an accurate distance measurement on ground faults only for the special case where the zero sequence impedance is equal to the positive sequence impedance to the fault. The tests outlined below check the line-to-neutral ohms that the unit would measure under these conditions.

After the starting unit has been set for the desired reach, select a value of test impedance at 60°, that is $R_L + jX_L\ /60°$, which exceeds the reach setting of the unit by the smallest amount possible. Then using the test circuit of Fig. 17 (note that current limiting impedance X_S and R_S is omitted), turn the test box fault switch S_F to the "ON" position and adjust the selector switches to obtain a balance point. The percent tap setting of the test box autotransformer, which should cause the starting unit to just close its contacts, is given by equation (12).

$$\%\text{Tap} = \frac{Z_{SU}\cos(60 - \theta)}{Z_L}\ (100) \qquad (12)$$

where: Z_{SU} = Ohmic reach of the starting unit (See Equation 5 in CHARACTERISTICS section).

Z_L = Test impedance in ohms

θ = Angle of test impedance

The portable test reactor (Cat. No. 6054975) and test resistor (Cat. No. 6158546) are normally sold as a set identified by a calibration curve number shown on the nameplate. The test resistor taps have been set at the factory in conjunction with taps on the associated rest reactor to provide a range of impedances at 60° and 30° angles. If one of the 60° impedance values thus obtained is used the angle θ in the above equation will be 60°. If a resistor-reactor tap combination other than those covered by the calibration sheet is used, or if the test reactor is used with some other non-inductive resistance to approximate the 60° impedance, then the actual value of θ should be used in equation 12. The angles of the test reactor at the various nominal tap settings are given in Table XVI.

TABLE XVI

TEST REACTOR TAP	ANGLE
24	88°
12	87°
6	86°
3	85°
2	83°
1	81°
0.5	78°

As an illustration of the above assume that the 3 ohm basic minimum reach link setting is to be used and that it has been decided to set the E^2 tap on 45 percent. This setting falls within the limits of 10 and 67 percent determined in the example in the section SAMPLE CALCULATIONS OF SETTINGS. Ohmic reach of the starting unit at its 60° angle of maximum torque will then be 6.68 ohms, as determined from equation 5 in the CHARACTERISTICS section.

Using a typical combination of test reactor and test resistor, the 60° impedance closest above this reach setting is 14.4 ohms. The percent tap of the test box autotransformer at which the starting unit contacts will just close can then be calculated as follows from equation (12):

$$\%\text{Tap} = \frac{6.68\cos(60° - 60°)}{14.4}\ (100) = 46.3\%$$

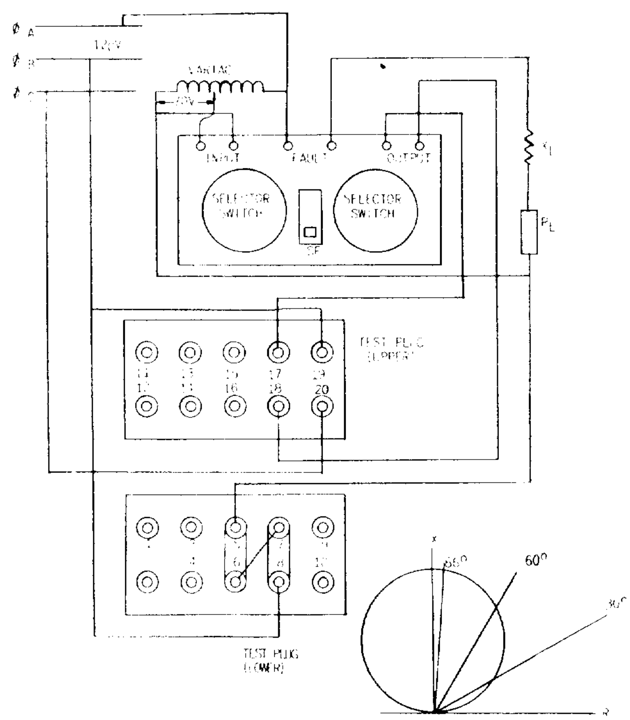


Fig. 18 (0178A9123-1) Connections For Field Testing The Starting Unit Of The Type GCXG51A Relay, Using The Type XLA Test Plug And A 3-Phase, 3-Wire Source.

The starting unit should therefore theoretically close its contacts at 46 percent and remain open at 47 percent. A range of 44 to 49 percent in the balance point (±5% of the nominal) is satisfactory tolerance for the starting unit.

If the ohmic reach of the starting unit checks correctly according to the above procedure, the angle of maximum torque is probably correct also. The angle can be verified if desired by checking two other points on the mho characteristic of the starting unit. It is suggested that the check be made for a fault impedance angle near 90° by using the test reactor alone, and for a fault impedance of 30° by using the appropriate resistor-reactor combination.

Assume that the nominal 12 ohm reactor tap is used with $R_L = 0$, and that the actual reactance value of this tap is 11.9 ohms. Since the angle of this tap (Table XVI) is 87°, the impedance is:

$$Z_L = \frac{X_L}{\cos 3^\circ} = \frac{11.9}{.993} = 11.95 \text{ ohms}$$

It is obvious from the above that the reactance and impedance can be assumed to be the same for this reactor tap. Actually the difference need only be taken into account on the 3, 2, 1 and 0.5 ohm taps.

The test box autotransformer tap required for the contacts to just close can be determined from equation (12) as follows:

$$\%\,\text{Tap} = \frac{6.68 \cos (60 - 87)}{11.9} (100) = 50\%$$

A range of 47 to 53 percent in the balance point indicates acceptable tolerance for the starting unit angle. A similar approach can then be taken using a 30° combination of reactor-resistor taps.

If a four-wire test source is not available, the starting unit mho characteristic can be checked using a three-phase, three-wire test source and the test circuit of Fig. 18. Following the same procedure outlined above for the four-wire test circuit the only difference in results is a 30° shift in the mho characteristic. With these connections maximum reach occurs at 90°, with 86.6% reach at 60°, and 50% reach at 30°. A starting unit which produces the mho characteristic shown in Fig. 18 for the three-wire connections will produce the mho characteristic shown in Fig. 17 when supplied with normal polarizing, restraining and operating quantities.

c. Other Checks and Tests

In addition to the calibration checks on the ohm and starting 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 250V). 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 (either 0.6 or 2A) and that the unit is operating at tap value. If it is necessary to change the tap setting, follow the procedure outlined in the section on 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. It is recognized that 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.

CONTACT CLEANING

For cleaning fine silver contacts, a flexible burnishing tool should be used. This consists of a flexible strip of metal with an etched-roughened surface resembling in effect a superfine file. The polishing action is so delicate that no scratches are left, yet it will clean off any corrosion thoroughly and rapidly. Its flexibility insures the cleaning of the actual points of contact. Do not use knives, files, abrasive paper or cloth of any kind to clean relay contacts.

SERVICING

If it is found during the installation or periodic tests that the ohm or starting unit calibrations are out of limits, 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 from Fig. 1 and 2.

R_1 - Ohm unit reach adjustment.

R_2 - Ohm unit phase angle adjustment.

R_3 - Starting unit reach adjustment.

R_4 - Starting unit phase angle adjustment.

NOTE: Before making pickup or phase angle adjustments on the ohm or starting units, the unit should be allowed to heat up for approximately 15 minutes energized with voltage alone. Also it is important that the relay be mounted in upright position so that the units are level.

STARTING UNIT

a. Control Spring Adjustment

Using the test connections shown in Fig. 13 disconnect and short out the restraint circuit (studs 17-18). With the polarizing voltage (19-20) set at 120 volts and the current at 5 amperes, set the phase shifter so that current leads voltage by 30°. Now reduce the polarizing voltage to 5 volts and set the current at the value shown in Table XVII for the relay to be tested. Also be sure that the link at the rear of the starting unit is set for the basic minimum reach shown in the Table.

TABLE XVII

Control Spring Setting (SU)

Relay	Basic Min. Reach	Set Current At
Short Reach	3 ohms	1.6A
Std. Reach	3	1.6
Long Reach	6	0.8

Insert the blade of a thin screwdriver into one of the slots in the edge of the spring adjusting ring (see Fig. 19) and turn the ring until the contacts just close. If the contacts were closing below the set current in Table XVII turn the adjusting ring to the right. If they were closing above the set point, turn the adjusting ring to the left.

b. Ohmic Reach Adjustment

The basic minimum reach of the starting unit can be adjusted by means of rheostat R_3 which is identified in Fig. 1. Increasing R_3 by turning the screw driver adjustment in a counterclockwise direction increases the reach of the unit.

Using the connections shown in Fig. 13 remove the jumper from studs 17-18 and reconnect the restraint circuit as shown. With the E^2 taps on 100%, polarizing voltage (19-20) set at 120 volts, and current leading polarizing voltage by 30°, set the restraint voltage at the value listed in Table XVIII for the relay in test. Adjust R_3 so that the starting unit picks up within the current limits shown in Table XVIII.

TABLE XVIII

Ohmic Reach Setting (SU)

Relay	Basic Min. Reach	V_{17-18} Set At	Pickup Amps
Short Reach	3 ohms	60V	19.8-20.2
Std. Reach	3	60V	19.8-20.2
Long Reach	6	60V	9.9-10.1

c. Angle of Maximum Torque

The procedure used in setting the angle of maximum torque of the starting unit is to adjust the rheostat R_4 so that the pickup amperes, with a

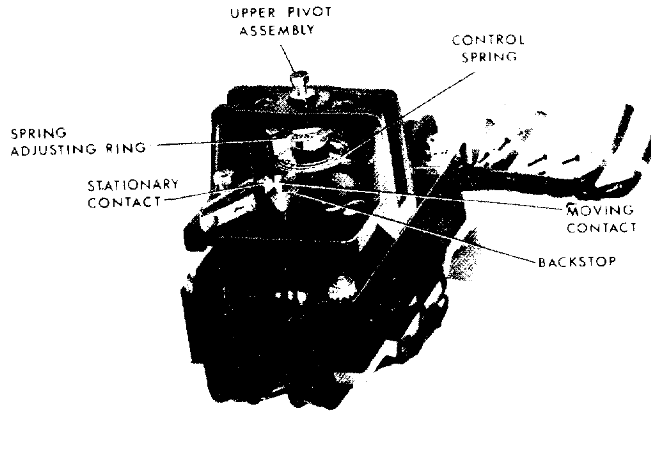


Fig. 19 (8034958) Four-Pole Induction Cylinder Unit Typical Of The Ohm Unit And Starting Unit In The Type GCXG51A Relay.

specified restraint voltage on studs 17-18 will be the same at angles leading and lagging the nominal maximum torque angle by 30°. The test angles, set restraint voltages, and the pickup amperes are shown in Table XIII. The test connections shown in Fig. 13 should be used with the polarizing voltage at 120V, the E^2 tap leads on 100%, and the basic minimum reach set as shown in Table XIII.

With the restraint voltage (V_{17-18}) set at 60 volts, record the pickup current with the current first in phase with the polarizing voltage, and then leading the polarizing voltage by 60°. Then adjust R_4 until the pickup current at these two test angles (0° and 60°) is the same within ±4%. Now the reach of the unit at its nominal angle of maximum torque should be checked and readjusted if necessary as described in paragraph (b) and Table XVIII. Then recheck the pickup currents at 0° and 60°. Pickup should fall within the limits shown in Table XIII. Touch up R_4 if necessary, and continue this "cross adjustment" of reach and angle of maximum torque until both are within limits.

* d. Clutch Setting

The clutch of the starting unit should slip when a force of 45-65 grams is applied to the moving contact. The cup assembly must be held securely with a special wrench (0246A7916, 1/2 inch wrench, 1/32 inch thick) placed between the front coils and contact lead. The clutch pressure is varied by loosening or tightening the self-locking nut (3/8 inch) at the top of the cup shaft.

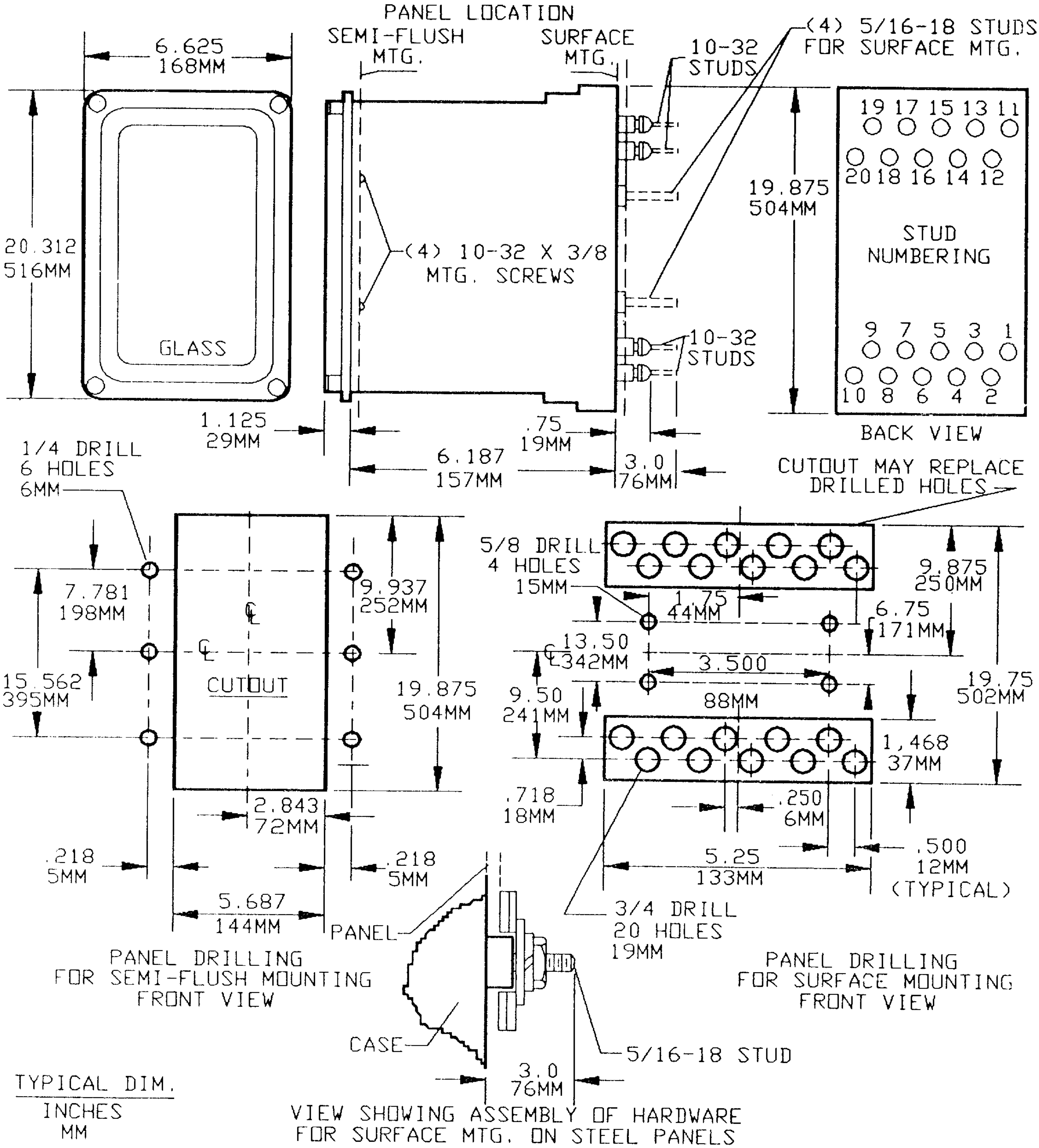
TABLE XIX

OHM UNIT

a. Control Spring Adjustment

Using the test connections of Fig. 14 leave the potential circuit to the relay disconnected and short out studs 17-18. With the No. 1 tap leads in the 100% position and the basic reach taps in the middle position of their range, set the operating current at the value shown in Table XIX.

* Revised since last issue



* Fig. 20 (6209276 [4]) Outline and Panel Drilling Dimensions for the Type GCXG51A Relay

*Indicates revision

TABLE XIX

Control Spring Setting (OU)

Relay	Basic Min. Reach Setting	Set Current At
Short Reach	0.2 ohms	1.35A
Std. Reach	0.5	0.65
Long Reach	1.0	0.35

Instert the blade of a thin screw driver into one of the slots in the edge of the spring adjusting ring (see Fig. 19) and turn the ring until the contacts just close. If the contacts were closing below the set current in Table XIX turn the adjusting ring to the right. If they were closing above the set point, turn the adjusting ring to the left.

b. Before adjusting the ohm unit make sure that the starting unit polarizing circuit effect has been neutralized. This is done by energizing the starting unit polarizing circuit only at rated voltage and measuring the induced voltage at studs 17-18. This should be less than 0.4 volt. If it is not, adjust for a minimum by turning the core of the Tm transformer until a null voltage has been obtained.

c. Reach and Angle of Maximum Torque Adjustment

The basic minimum reach of the ohm unit is controlled by rheostat R_1, and its angle of maximum torque (90° current lagging voltage) may be adjusted by means of rheostat R_2. It should be noted, however that these adjustments are not independent; that is an adjustment of R_2 will have some effect on the reach of the ohm unit, and adjustments of R_1 will affect the angle of maximum torque.

To calibrate the ohm unit place the No. 1 taps in the 100% position and use the connections shown in Fig. 14. Follow the procedure outlined below:

Step 1:

With current set at 5 amps and voltage at 70V adjust the phase shifter so that the current lags voltage by 90°. Then set the current for the value shown in Table XV for the basic reach to be checked and the voltage for the value listed in the column headed "90°". For example, for the 0.2 ohm basic minimum reach, the current would be set at 15 amps and the voltage at 6V. Adjust R_1 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 ±1% of the voltage listed in Table XV in the column headed "90°". Readjust R_1 until the operating voltage is within the ±1% limit.

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

Step 2:

Reset the phase shifter so that current lags voltage by 30°, and with the same current used in Step 1 set the voltage at the value listed in column headed "30°". Then adjust R_2 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 ±1% of the value in Table XV under the "30°" column. Modify the R_2 setting until the operating voltage is within this ±1% limit.

Step 3:

Recheck Step 1. The ohm unit contacts should close within ±2% of the voltage listed in the "90°" 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.

d. Reduce the current to that listed in Table V. The reach should not reduce more than 10%. If it is more, readjust the core of Tm so that it is only a 10% drop and repeat step c.

* d. Clutch Setting

Short the potential circuit (studs 17-18). With the basic ohm tap in the middle position, apply current to the current circuit and check the level at which the clutch slips.

Middle Tap of ohm unit	Clutch Action
1.0	Clutch slips between 18 and 25A
0.5	Clutch slips between 34 and 44A
0.2	Clutch slips above 60A

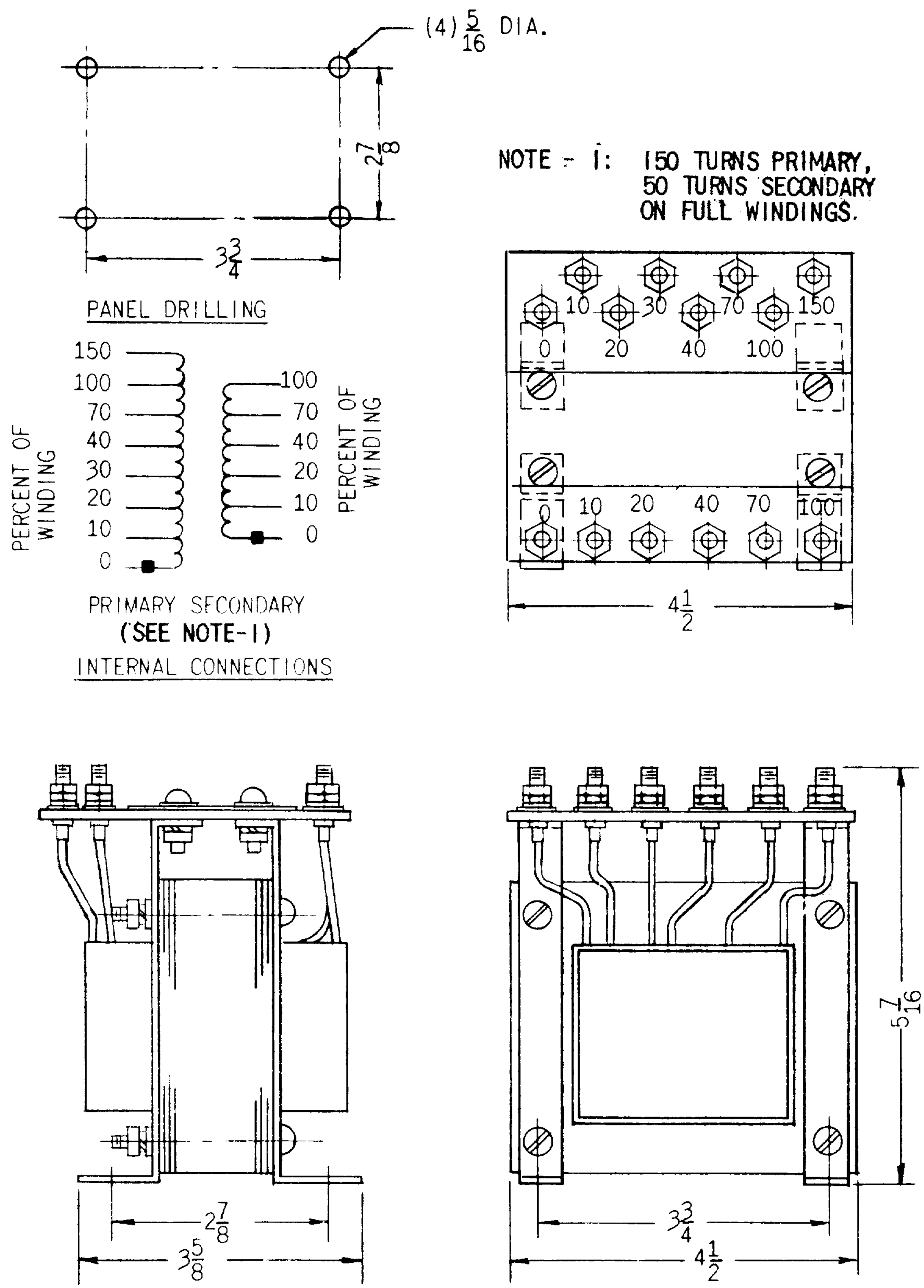
Adjust the clutch slipping value by loosening or tightening the self-locking nut at the top of the cup shaft.

RENEWAL PARTS

It is recommended that sufficient quantities of renewal parts be carried in stock to enable the 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 quantity required, name of part wanted, and give complete nameplate data. If possible, give the General Electric requisition number on which the relay was furnished.

 * Revised since last issue



* Fig 21. (00367A0267 [2]) Outline, Panel Drilling Dimensions And Internal Connections For Auxiliary Transformer Cat. No. 0367A0266.

* Revised since last issue

APPENDIX I

DEFINITIONS OF SYMBOLS

In the following appendicies, 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. Taken as 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 for. I'''_0 represents the zero sequence mutual currents that will not be compensated for.

C - Distribution Constants

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

$$C = \frac{I'_1}{I_1} = \frac{I'_2}{I_2}$$

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. Assumed 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. $Z_{om} = R_{om} + j X_{om}$

Z'_{om} = Same as Z_{om} except for another parallel line. $Z'_{om} = R'_{om} + j X'_{om}$

Note, that Z_{om} represents the zero sequence mutual impedance for which compensation will be provided. Z'_{om} represents zero sequence mutual impedance for which there will be no compensation.

Miscellaneous

T = Relay tap setting in percent.

α,A,B,θ & ϕ = Angles in degrees as defined where used.

S_1, S_2, & S_3 = Ratio of distances as defined where used.

$K_o = X_o'/X_1'$

$K_m = X_{om}/X_o'$

K_s = Constant depending on the ratio of Z_o/Z_1.

K = Design constant of starting unit and it depends on the basic tap setting.

= 100 for the 1 ohm basic minimum tap setting of the starting unit.

= 300 for the 3 ohm basic minimum tap setting of the starting unit.

K' = Percent tap setting on primary winding of 367A0266 auxiliary CT.

K" = Percent tap setting on secondary of 367A-0266 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 STARTING UNIT

The starting unit will measure distance accurately on three-phase faults. However, on single-phase-to-ground faults its reach is generally foreshortened. The operating equation for the phase A starting unit is given below. For the phase B and phase C units, similar equations apply except that different potentials and currents are applied.

$$T E_a' E_{bc}' \sin B = K I_a' E_{bc}' \cos(\alpha - 30) \qquad \text{II-a}$$

where:

T = Tap setting in percent.

K = Design Constant
100 for the 1.0 ohm basic minimum tap.
* 200 for the 2.0 ohm basic minimum tap.

E_a' = Phase A-to-neutral voltage applied to the relay.

E_{bc}' = Phase B-to-C voltage applied to the relay

I_a' = Phase A current in the relay.

B = Angle by which E_a' leads E_{bc}'.

α = Angle by which I_a' leads the voltage E_{bc}'.

The relay will operate to close its contacts when the operating torque (righthand side of equation II-a) exceeds the restraint torque (left-hand side of the equation). For balanced 3-phase faults E_a' will lead E_{bc}' by 90 degrees and Sin B will equal * 1.0. The angle α becomes 90-θ, where θ is the angle by which I_a' lags E_a'; this is the impedance angle of the protected line. For this type of fault, the reach of the starting unit in secondary-phase-to-neutral positive-sequence ohms for any line impedance angle as a function of tap setting is given by:

$$Z = \frac{K}{T} \cos(60 - \theta)$$

Conversely, the tap setting in percent required to reach a given secondary ohms at a given angle is

$$T = \frac{K}{Z} \cos(60 - \theta)$$

For single-phase-to-ground faults the reach of the starting unit is pulled back. The effective impedance as seen by the starting unit on the faulted phase for a fault at the far end of the line becomes:

$$Z_1' + \frac{(Z_o' - Z_1')\, C_o}{2C + C_o} + \frac{Z_{om} I_o''}{I_a'}$$

where:

Z_1' = Positive sequence impedance of the protected line.

Z_o' = Zero sequence impedance of the protected line.

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

I_o'' = Zero sequence current in the parallel line, taken as 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_o = Zero sequence distribution constant I_o'/I_o.

To insure that the starting unit on the faulted phase picks up for a fault at the remote bus, the maximum percent tap setting permissible is:

$$T = \frac{K \cos(60^o - \theta)}{1.25 \left[Z_1' + \frac{(Z_o' Z_1')\, C_o}{2C + C_o} + \frac{Z_{om} I_o''}{I_a'} \right]} \qquad \text{II-b}$$

*Indicates revision

If the solution to equation II-b 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-b is a safety factor. 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-b becomes zero. If there is mutual impedance existing between the protected line and several other circuits, this last term becomes

$$\frac{1}{I_a'} \sum Z_{om} I_0''$$

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 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. This applies to I_0'' as well as I_a'.

Note that the value of T obtained from equation II-b 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 SETTING FOR THE STARTING UNIT

The starting units of the GCXG51A relays control the operation of these relays. The interlocking of the associated NAA contacts is such that tripping is blocked when more than one starting unit picks up. Under certain system conditions, for a single phase-to-ground fault in the tripping direction, it is possible that a starting unit on an unfaulted phase will pick up as well as the one on the faulted phase. This would block tripping. In order to avoid such occurrences, it is necessary to limit the reach setting of the starting units as given in equations III-a and III-b below.

$$T = \frac{K_s(C-C_0)}{Z_1} \text{Cos}\,(150-A-\theta) \qquad \text{III-a}$$

$$T = \frac{K_s(C-C_0)}{Z_1} \text{Cos}\,(A-\theta-30) \qquad \text{III-b}$$

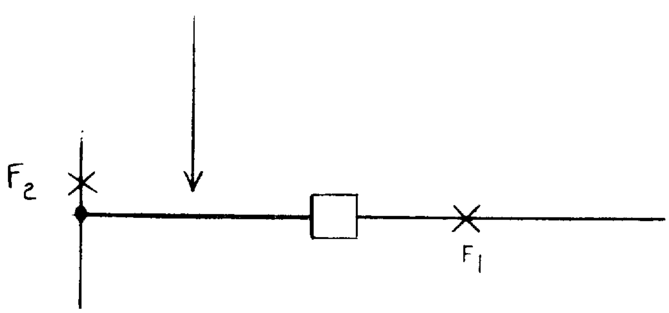


Fig. III-1 (0165A7623-1) Typical Transmission Line With Fault.

The system constants in the above equations should be evaluated for a single-phase-to-ground fault in the tripping direction at the relay terminals. This fault location is designated as F_1 in Figure III-1.

T = Minimum permissible tap setting in percent

C = Positive sequence distribution constant I_1'/I_1.

C_0 = Zero sequence distribution constant I_0'/I_0.

Z_1 = System positive sequence impedance as viewed from the fault.

Z_0 = System zero sequence impedance as viewed from the fault.

θ = The angle of the system positive sequence impedance Z_1.

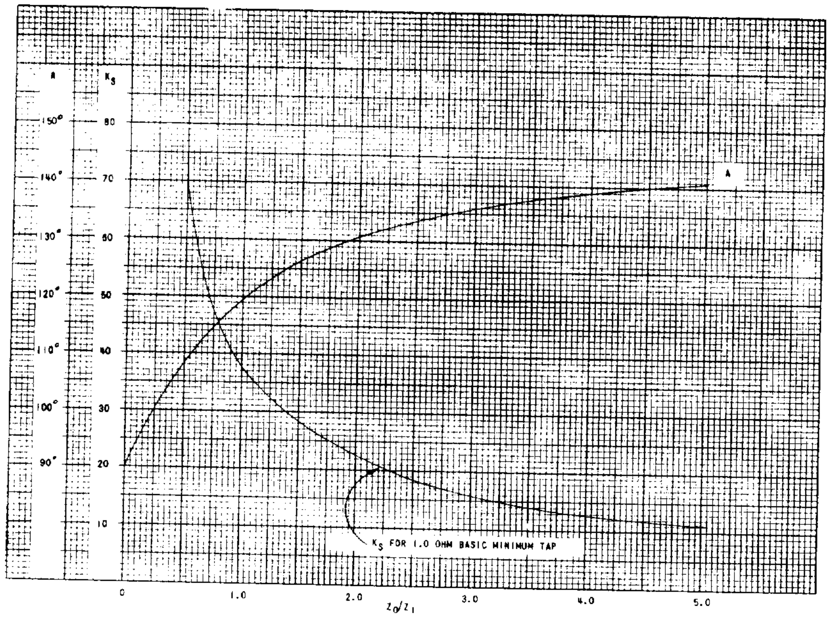
K_s = Constant depending on the ratio of Z_0/Z_1. See curves on Fig. III-2.

A = Angle depending on the ratio of Z_0/Z_1. See curves on Fig. III-2.

Under some system conditions it is possible during single-phase-to-ground faults in the non-tripping direction that one or the other of the starting units associated with the unfaulted phases will pick up. Since 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 reverse faults. Equations III-c and III-d give this limit.

$$T = \frac{K_s(C_0-C)}{Z_1} \text{Cos}\,(150-A-\theta) \qquad \text{III-c}$$

$$T = \frac{K_s(C_0-C)}{Z_1} \text{Cos}\,(A-\theta-30) \qquad \text{III-d}$$



* Fig. III-2 (0178A9124-1) Evaluation of K_S and A as A Function of Z_0/Z_1.

The system constants in these equations should be evaluated for a single-phase-to-ground fault in the nontripping direction at the relay terminals. This fault location is designated as F_2 in Figure III-1.

Note that the value of C_0 for a fault at F_1 is 1.0 minus the value of C_0 for a fault at F_2. The same applies to the value of C. Because of this (C_0-C) in equation III-c is identically equal to $(C-C_0)$ in equation III-a. The same applies to equation III-d and III-b. Thus, equations III-a and III-c will yield identical results. Equations III-b and III-d will also yield identical results. For this reason it is only necessary to check equations III-a and III-b or III-c and III-d. Under the section of sample calculations all four equations were evaluated to illustrate this point.

Under some system conditions it is possible, during double-phase-to-ground faults in the nontripping direction, that the starting unit on the unfaulted phase will pick up. Since in some 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 reverse double-phase-to-ground faults. Equation III-e gives this limit.

$$T = \frac{K(C_0-C)}{3Z_0} \cos(\theta - 60) \qquad \text{III-e}$$

where:

K = Design constant
100 for 1.0 basic minimum tap
*200 for 2.0 basic minimum tap

θ = The angle of the system zero sequence impedance Z_0.

All other terms are defined above.

Note that C_0 and C in equation III-e have the same values as they have in equations III-c and III-d.

After the values of T have been calculated for equations III-c, III-d and III-e above, the largest of the three values should be selected and then some margin such as 10% (not 10 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 all) of the values of T calculated from the three equations is negative, that signifies that the particular equation (or equations) offers no limitation on the minimum permissible tap setting.

Aside from all of the above, the starting units should never be set on a tap that is lower that 10 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, III-b, III-c, III-d and III-e above is based on an input tap setting of 100 percent. If the input tap setting is less than 100 percent, then 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.

*Indicates revision

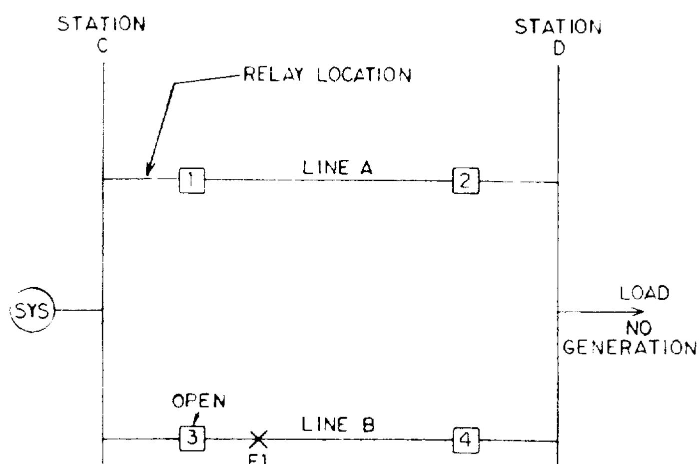
APPENDIX IV

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

The ohm or reactance unit of the GCXG51A relay, when properly compensated, will measure correctly the positive sequence reactance from the relay to a single-phase-to-ground fault. However, occasions arise where it is not possible or not 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. 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 of the GCXG51A relays at either Station B or C for the zero sequence mutual coupling between the two lines. For this sort of reason it is 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.

A. 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.



* Fig. IV-1 (0165A[illegible] [1]) Parallel Transmission Lines [illegible] Fault.

Assume that the auxiliary compensating CT 367A0266 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 co-ordination 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.

$$X_R = X_1' \left[1 + S_3 \frac{2 + K_o - 2K_m K_o}{2 + K_o} \right] \qquad \text{IV-a}$$

where:

X_1' = Positive sequence reactance of the protected line, A.

X_o' = Zero sequence reactance of the protected line, A.

$K_o = X_o'/X_1'$

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

$K_m = X_{om}/X_o'$

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_o. On actual systems, K_m will have a maximum value of about 0.7 but will generally be about 0.5. K_o 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 $K_o = 3.5$, we get $X_R = 1.18X_1$. 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_o 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.

$$X_R = X_1' \left[1 + \frac{S_3}{2C + K_o C_o}\left(K_o + 2 - [C_o + 1] K_m K_o\right)\right] \quad \text{IV-b}$$

where:

C = Positive sequence distribution constant I_1'/I_1

C_o = Zero sequence distribution constant I_o'/I_o

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 zone 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 $K_o = 3.5$. Assume that the infeed from Station D is rather weak so that $C_o = 0.7$ and $C = 0.8$.

Substituting these values in equation IV-b we get:

$$X_R = 1.31\, X_1'$$

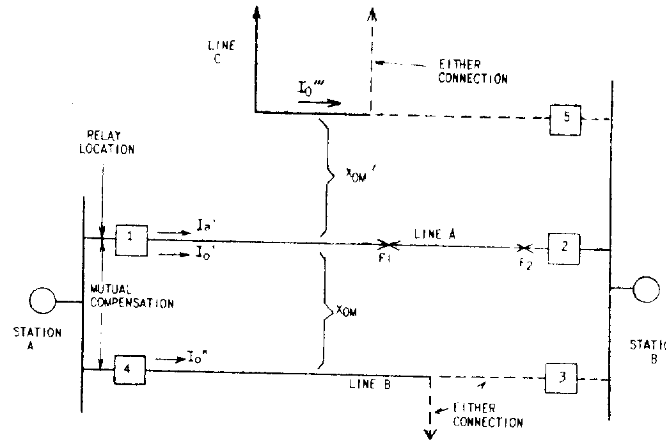


Fig. IV-2 (0165A7620-1) Transmission System With Lines Terminating At Remote Stations.

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 the 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.

B. 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. In the following analysis this is assumed.

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. First, 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 Fig. 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.

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

where:

X_1' = Positive sequence reactance of the protected line.

X_0' = Zero sequence reactance of the protected line.

X_{0m}' = 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_{0m}' that is involved 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 Fig. IV-2. Assume that neither line B nor line C terminate 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 Fig. IV-2, 80 percent of the distance to breaker #2. Assume now 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
(Based on CT Ratio of Breaker #1)

$X_{0m}' = 0.6\, X_1'$

$S_1 = 0.8$

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 Fig. 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 4 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 reactance 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, then 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'.

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