INSTALLATION • OPERATION • MAINTENANCE

INSTRUCTIONS

TYPE KD-10 AND KD-11 COMPENSATOR DISTANCE RELAY

Caution: Before putting protective relays into service, make sure that all moving parts operate freely, inspect the contacts to see that they are clean and operate the relay to check the settings and electrical connections.

APPLICATIONS

The type KD-10 relay (Figure 1), is a polyphase compensator type relay which provides a single zone of phase protection for all three phases. It provides * essentially instantaneous tripping for phase-to-phase faults, two-phase-to-ground faults, and three-phase faults within the reach setting and sensitivity level of of the relay. The relay is interchangeable with KD or KD-4 relays.

The type KD-11 relay (Figure 1), is similar to the KD-10 relay except that its characteristic impedance circle includes the origin. This relay is usually applied as a carrier start relay in directional comparison blocking schemes but it may also be used for time delay tripping in straight distance relaying. Both KD-10 and KD-11 relays have indicating contactor switches rated 0.2/2.0 amperes. The 2.0 ampere tap must be used for directional comparison blocking (KA-4) applications. The 2.0 ampere target is recommended for direct trip applications. The 0.2 ampere target is recommended where a 125 or 250 volt lockout relay (WL) is energized and 2.0 ampere where a 48 volt lockout relay is used.

Refer to I.L. 40-208 for a description of how KD-10 relay are used in directional comparison blocking systems.

For time-distance applications the KD-10 and KD-11 relays are used with the TD-4 or TD-52 or TD-5 d-c transistorized timers. See Figs. 19 and 24 for the external schematics for 3 zone protection, using the TD-4 and TD-52 relays, respectively. For further discussion see "External Connections".

Fault detectors are used to supervise the trip circuit for those applications where the line side potentials are used or loss-of-potential supervision is desired. Otherwise, undesired tripping may occur on line oscillations or loss of potential. The cylinder type KC-2 or KC-4 relay (2-8 amperes) is recommended. The plunger or other magnetic attraction type relays (e.g. a three unit SC relay or a three unit ITH relay) may be used if the fault detector contacts carry trip coil current rather than auxiliary relay (e.g. auxiliary trip unit, timer, etc.) current.

The SC or ITH relay may also be used if a slow dropout contact (e.g. TX contact of TD-5 timer relay) is available to be connected around the fault detector contacts.

CONSTRUCTION

The type KD-10 and KD-11 relays consists of three single air gap transformers (compensators), three tapped autotransformers, two cylinder type operating units, and an ICS indicating contactor switch.

Compensator

The compensator, which is designated T (Fig. 2) is a two-winding air gap transformer, it has one primary current winding. The compensators which are designated T_{AB} and T_{BC} are three winding air gap transformers, they have two primary current windings. Each primary current winding has seven taps which terminate at the tap block (Fig. 3). They are marked:

0.23, 0.307, 0.383, 0.537, 0.690, 0.920, 1.23 — for 0.2 —4.5 ohms relay

* 0.87, 1.16, 1.45, 2.03, 2.9, 4.06, 5.8 for 0.75—21 ohms relay

1.5, 2.0, 2.5, 3.51, 5.0, 7.02, 10.0 for 1.3 — 36.7 ohms relay

All possible contingencies which may arise during installation, operation, or maintenance, and all details and variations of this equipment do not purport to be covered by these instructions. If further information is desired by purchaser regarding his particular installation, operation or maintenance of his equipment, the local Westinghouse Electric Corporation representative should be contacted.

SUPERSEDES I.L. 41-490, dated May 1974
*Denotes change from previous issue.

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Current flowing through the primary coil provides an MMF which produces magnetic lines of flux in the core.

A voltage is induced in the secondary which is proportional to the primary tap and current magnitude. This proportionality is established by the cross sectional area of the laminated steel core, the length of an air gap which is located in the center of the coil, and the tightness of the laminations. All of these factors which influence the secondary voltage proportionality have been precisely set at the factory. The clamps which hold the laminations should not be distrubed by either tightening or loosening the clamp screws.

The secondary winding has a single tap which divides the winding into two sections. One section is connected subtractively in series with the relay terminal voltage. Thus a voltage which is proportional to the phase current is subtracted vectorially from the relay terminal voltage. The second section is connected to a potentiometer and a fixed loading resistor and provides a means of adjusting the phase angle relation between primary current and the induced secondary voltage.

Auto-Transformer

The auto-transformers has three taps on its main winding, S, which are numbered 1, 2 and 3 on the tap block. A tertiary winding M has four taps which may be connected additively or subtractively to inversely modify the S setting by any value from −18 to +18 percent in steps of 3 percent.

The sign of M is negative when the R lead is above the L lead. M is positive when L is in a tap location which is above the tap location of the R lead. The M setting is determined by the sum of per unit values between the R and L lead. The actual per unit values which appear on the tap plate between taps are 0, .03, .09 and .06.

The auto-transformer makes it possible to expand the basic range of "T" ohms by a multiplier of $\frac{S}{1 \pm M}$. Therefore, any relay ohm setting can be made within ±1.5 percent from the desired value by combining the compensator taps T, T_{AB}, and T_{BC} with the auto-transformer taps S and M, S_A and M_A, and S_C and M_C. See tables I, II, and III for compliation of settings available.

Tripping Unit

The device which acts to initiate tripping is a four-pole cylinder unit which is connected open delta and operates as a three-phase induction motor. Contact-closing torque is produced by the unit when the voltage applied to its terminals has a negative-phase sequence. Closing torque for the relay forces the moving contact to the left hand side as viewed from the front of the relay. Contact-opening torque is produced when positive-phase sequence voltages are applied. Hence, the cylinder unit has restraint or operating torque as determined by the phase sequence of the voltages applied to its terminals.

Mechanically, the cylinder unit is composed of three basic components: a die-cast aluminum frame and electromagnet, a moving element assembly, and a molded bridge.

The frame serves as the mounting structure for the magnetic core. The magnetic core which houses the lower pin bearing is secured to the frame by a spring and snap ring. This is an adjustable core which has a .020 inch flat on one side and is held in its adjusted position by the clamping action of two compressed springs. The bearing can be replaced, if necessary, without having to remove the magnetic core from the frame.

The electromagnet has two series-connected coils mounted diametrically opposite one another to excite each set of poles. Locating pins on the electromagnet are used to accurately position the lower pin bearing, which is mounted on the frame, with respect to the upper pin bearing, which is threaded into the bridge. The electromagnet is permanently secured to the frame and cannot be separated from the frame.

The moving element assembly consists of a spiral spring, contact carrying member, and an aluminum cylinder assembled to a molded hub which holds the shaft. The hub to which the moving contact arm is clamped has a wedge-and-cam construction, to provide low-bounce contact action. A casual

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inspection of the assembly might lead one to think that the contact arm bracket does not clamp on the hub as tightly as it should. However, this adjustment is accurately made at the factory and is locked in place with a lock nut and should not be changed.

Optimum contact action is obtained when a specified pressure applied to the face of the moving contact will make the arm slip one-fourth of its total free travel. Free travel is the angle through which the hub will slip from the condition of reset to the point where the clamp projection begins to ride up on the wedge. The free travel can vary between 15° to 20°.

The shaft has removable top and bottom jewel bearings. The shaft rides between the bottom pin bearing and the upper pin bearing which is adjusted to .025 inch from the top of the shaft bearing. The cylinder rotates in an air gap formed by the electromagnet and the magnetic core.

The bridge is secured to the electromagnet and the frame by two mounting screws. In addition to holding the upper pin bearing, the bridge is used for mounting the adjustable stationary contact housing. This stationary contact has .0015 to .0035 inch follow which is set at the factory by means of the adjusting screw. After the adjustment is made the screw is sealed in position with a material which flows around the threads and then solidifies. The stationary contact housing is held in position by a spring type clamp. The spring adjuster is located on the underside of the bridge and is attached to the moving contact arm by a spiral spring. The spring adjuster is also held in place by a spring type clamp.

The main contact of KD-10 and KD-11 relays will close 30 amp at 250V d.c. and the seal-in contact of the indicating contactor switch will carry this current long enough to trip a breaker.

When the contacts close, the electrical connection is made through the stationary contact housing clamp, to the moving contact, through the spiral spring and out to the spring adjuster clamp.

Indicating Contactor Switch Unit (ICS)

The indicating contactor switch is a small d-c operated clapper type device. A magnetic armature, to which leaf-spring mounted contacts are attached, is attracted to the magnetic core upon energization of the switch. When the switch closes, the moving contacts bridge two stationary contacts, completing the trip circuit. Also during this operation two fingers on the armature deflect a spring located on the front of the switch, which allows the operation indicator target to drop. The target is reset from outside of the case by a push rod located at the bottom of the cover.

The front spring, in addition to holding the target, provides restraint for the armature and thus controls the pickup value of the switch.

OPERATION

The KD-10 relay has two major components-compensators and tripping units. In the internal schematic of Fig. 4 the compensators are designated T, T_{AB}, and T_{BC}, the tripping units, Z (3ϕ) & Z $(\phi\phi)$. The phase-to-phase unit, Z $(\phi\phi)$, operates for all combinations of phase-to-phase faults (phase 1-2, 2-3 & 3-1). The 3 phase unit Z (3ϕ) operates for 3 phase faults and for close-in-two-phase-to-ground faults, although most two-phase-to-ground faults are cleared by operation of the phase-to-phase unit. Each of the tripping units and its associated compensator circuit are electrically separate, and will now be considered successively.

Three Phase Unit

A single compensator T has its primary energized with $(I_1 - 3I_0)$ current in Fig. 19. Current I_1 is the phase 1 current; $3I_0$ is the residual current. There are three compensators shown one for each of the three zones. One connection uses an auxiliary current transformer to insert the $-3I_0$ component. The alternate connection supplies the compensator primaries with $(-I_2 - I_3)$. Since $I_1 + I_2 + I_3 = 3I_0$, $(I_1 - 3I_0) = (-I_2 - I_3)$. (Current I_1, I_2 and I_3 are the phase currents). The $3I_0$ current is needed to provide overlap with the $\phi\phi$ unit on 2-phase-to ground faults.

Accordingly, the alternate connection is equivalent to the first arrangement. Note that relay 21—3, a type KD-11, also has a current winding Z. This winding is wound on the tripping unit so that the R-X diagram circle includes the origin, as explained under "Characteristics".

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As shown in Fig. 19 the T compensator secondary is connected to modify the phase 1 voltage. With a fault in the trip direction, the induced voltage in the compensator secondary bucks the phase 1 voltage.

Vector diagrams in Fig. 8 illustrate the operation during 3 phase faults at four locations. The system impedance and the compensator angle are assumed to be at 90° for illustrative purposes only. Prefault voltages are depicted by the large dashed triangle. The smaller dashed traingle in each case is the system voltages at the relay location during the fault. This triangle is modified by the compensator voltage, $-I_1 Z_C$ where Z_C is the compensator mutual impedance. The terminals of the tripping unit are designated: X, Y & Z. Phase 1 tripping unit voltage is:

$$V_X = V_1 - I_1 Z_C \quad (1)$$

Note that $3I_0 = 0$ for 3-phase faults

$$V_1 = 1.5\ V_{10} \quad (2)$$

Phase 2 and phase 3 tripping unit voltages are:

$$V_Y = V_2 \quad (3)$$

$$V_Z = V_3 \quad (4)$$

For a fault at A, beyond the relay operating zone, the compensator voltage, $-I_1 Z_C$, modifies the phase 1 voltage, reducing the voltage triangle of the tripping unit to X-Y-Z. With an X-Y-Z rotation the tripping unit torque is in the restraining direction.

For a fault at B the current is larger than for a fault at A, so that $-I_1 Z_C$ is larger. The point X is in line with points Y & Z. No torque is produced, since the X-Y-Z triangle has a zero area.

For a fault in the operating zone, such as at C, point X is below the YZ line. Now the rotation is
* X, Z, Y, which produces operating torque.

For a fault behind the relay at D, restraining torque is produced. Since the fault is behind the relay the current is of reversed polarity. Compensator voltage, $-I_1 Z_C$, increases the area of the bus voltage triangle, 1-2-3. Tripping unit voltage has an X-Y-Z rotation which produces restraining torque.

A solid 3 phase fault at the relay location, tends to completely collapse the 1-2-3 voltage triangle. The area of the X-Y-Z triangle also tends to be zero under these conditions. A memory circuit in the KD-10 relay provides momentary operating torque under these conditions, for an internal fault. In the KD-11 relay the winding Z in the current circuit, in conjunction with the compensator voltage, produces a current only torque, which maintains operating torque under the condition of zero potential.

The $P_{3A} - R_{3F}$ parallel resistor-capacitor combination in the compensated phase provides correct phase-angle relation between the voltage across the front and back coils of Z (3ϕ) and the current, similar phase shift is produced in left and right hand coils by capacitor C_{3C}. The $P_{3A} - C_{3A}$ combination also provides control of transients in the coils of the cylinder unit.

Phase-to-Phase Unit

Compensator primaries of T_{AB} and T_{BC} are energized by I_1, I_2 and I_3 as shown in Fig. 19. Compensator secondaries are connected to modify their respective phase voltages (e.g. T_{AB} modifies V_{12}). With a fault in the trip direction, the induced voltages in the compensator secondaries buck the phase-phase voltages.

Vector diagrams in Fig. 9 illustrate the operation during phase 2-3 faults at four locations. The system impedances and the compensator angle are assumed to be at 90°, for illustrative purposes. Prefault voltages are depicted by the large dashed triangles. The smaller light triangle in each case is the system voltages at the relay location during the fault. This triangle is modified by the compensator voltages $-(I_1 - I_2) Z_C$ and $-(I_2 - I_3) Z_C$ where Z_C is the compensator mutual impedance. In this case $I_1 = 0$. The terminals of the tripping unit are designated; X, Y, and Z. Tripping unit voltages for phase 2–3 faults are:

$$V_{XY} = V_{12} - (I_1 - I_2) Z_C \quad (5)$$

$$V_{YZ} = V_{23} - (I_2 - I_3) Z_C \quad (6)$$

For a fault at A, in Fig. 9 beyond the relay operating zone, the compensator voltages change the 1-2-3 voltage sequence to the X-Y-Z sequence. Volt-

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ages of this sequence applied to operating unit produce restraining torque.

For a fault at B, the currents are larger than for a fault at A, so that compensator voltages are larger. Points Y & Z coincide now and the area of the X-Y-Z triangle is zero. No torque is produced.

For a fault in the operating zone, such as at C, the compensator voltages reverse the rotation of tripping unit voltages to X-Z-Y sequence. Voltages of this sequence applied to operating unit produce operating torque.

For a fault behind the relay at D, restraining torque is produced. Since the fault is behind the relay, the current is of reverse polarity and tripping unit voltage has an X-Y-Z rotation. This rotation produces restraining torque.

Note that this unit does not require memory action, since the sound-phase voltage reacts with the compensator voltage to produce a strong restraining or a strong operating torque, depending upon the fault location. This is true even for a complete collapse of the faulted phase-to-phase voltage. The phase-to-phase unit is identical in the KD-10 and KD-11 relays.

Similar vector diagrams apply for a fault between phases 1 and 2 or between phases 3 & 1. Each of the three phase-to-phase fault combinations subjects the cylinder unit to a similar set of conditions.

CHARACTERISTICS

Distance Characteristics-Phase-to-Phase Unit

This unit responds to all phase-to-phase faults and most two-phase-to-ground faults. It does not respond to load current, synchronizing surges, or out-of-step conditions. While a characteristic circle can be plotted for this unit on the R-X diagram as shown in Fig. 10 such a characteristic circle has no significance except in the first quadrant where resistance and reactance values are positive. A small portion of the fourth quadrant, involving positive resistance values and negative reactance values, could have some significance in the event that the transmission line includes a series capacitor. The portion of the circle in the first quadrant is of interest because it describes what the relay will do when arc resistance is involved in the fault. The phase-to-phase unit operating on an actual transmission system is inherently directional and no separate directional unit is required.

An inspection of fig. 10 indicates that the circle of the phase-to-phase unit is dependent on source impedance Z_S. However the circle always goes through the line balance point impedance. The reach at the compensator (and line) angle is constant, regardless of the system source impedance. The broadening out of the characteristic circle with a relatively high source impedance gives the phase-to-phase unit the advantageous characteristic that for short lines, it makes a greater allowance for resistance in the fault. Stated another way, the characteristics approach that of a reactance relay more and more closely as the line being protected becomes shorter and shorter with respect to the source impedance back of the relaying location.

Sensitivity: Phase-to-Phase Unit

A plot of relay reach, in percent of tap block setting, versus relay terminal voltage and current sensitivity is shown in Figure 12. The unit will operate with the correct directional sense for zero voltage phase-to-phase faults. For this condition the fault current must be not less than 0.015 relay amperes with an ohm setting of 5.8 with rated voltage on the unfaulted phase. Pick up current is proportionately higher in S = 2 and S = 3 taps.

The KD-10 relay may be set without regard to possible overreach due to d-c transients. Compensators basically are insensitive to d-c transients which attend faults on high-angle systems. The long time constant of a high angle system provides a minimum rate of change in flux-producing transient current with respect to time, and therefore induces a minimum of uni-directional voltage in the secondary. Asymetrical currents resulting from faults on low-angle systems having a short time constant can induce considerable voltage in the secondary, but for the first half cycle, the transient-derived voltage subtracts from the steady-state value. This transient decays so rapidly that it is insignificant during the second half cycle when it adds to the steady-state value.

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Distance Characteristic – KD-10 3 Phase Unit

The three-phase unit has a characteristic circle which passes through the origin as shown in Figure 11. This circle is independent of source impedance. The three-phase unit is also inherently directional and does not require a separate directional unit.

If a solid-three phase fault occurs right at the relay location, the entire voltage triangle collapses to zero to give a balance point condition, as shown by the relay characteristic in Figure 11 which passes through the origin. However, since the YZ voltage also drops to zero, the relay would be unable to determine whether an internal or external fault existed. To correct this condition, a resonant circuit is added to the 2–3 voltage circuit of the relay which allows the YZ voltage to collapse gradually, thus giving a reference voltage to determine whether the fault is inside the protected line section or behind the relay.

Sensitivity – KD-10 3-Phase Unit

The unit will operate with the correct directional sense for zero voltage three-phase faults when normal voltage exists at the relay terminals prior to the fault. This operation occurs due to memory action as described above. The unit will have zero torque or perhaps a slight opening torque if there is zero voltage at the relay prior to the fault or after the memory action has subsided. For medium and long reach relays with an impedance setting of 5.8 ohms the three-phase unit will directionally operate for fault which produce 2 volts line to line and 1.0 ampere at the relay terminals.

Sensitivity with 2 volts line-to-line for any tap is defined by the following equation:

$$I = \frac{5.8}{T} \text{ amperes} \qquad (7)$$

For short reach relays (.2-4.55 ohms) with an impedance setting of 1.23 ohms the three-phase unit will directionally operate for faults which produce .5 volts line to line and 2.7 ampere at the relay terminals.

Sensitivity with .75 volts line-to-line for any tap is defined by the following equation:

$$I = \frac{3.4}{T} \text{ amperes}$$

The KD-10 relay may be set without regard to possible overreach due to d-c transients.

Distance Characteristic: KD-11, 3 Phase Unit

The three phase unit of the KD-11 relay has a characteristic circle which includes the origin as shown in Figure 13.

A single turn current coil on the cylinder unit provides for current-only torque and is small compared to the many turns of the T Max. setting of the compensator and has very little influence on the overall settings. However, as the compensator setting is reduced, the single turn current coil becomes larger by comparison and has more and more effect on the overall settings.

* For 1.3-37 ohms range the reach and maximum torque angle will vary as follows:

T Nominal	T Actual	% Error	MTA	T Reverse
10	10	0	75°	.13
7.02	7.09	2	76°	.13
5.0	5.10	2	77°	.12
3.51	3.65	4	78°	.12
2.50	2.60	4	80°	.11
2.00	2.08	4	82°	.11
1.50	1.65	10	87°	.11

* For .75-21 ohms range the reach will vary as follows:

T Nominal	T Actual	% Error	MTA	T Reverse
5.8	5.3	0	75°	.13
4.06	4.20	3.5	76•	.13
2.90	3.12	4	78°	.12
2.03	2.15	6	79°	.12
1.45	1.57	8	82°	.12
1.46	1.30	12	85°	.11
.87	1.02	17	90°	.11

When setting KD-11 relays disregard the change in T-value, but include the percentage error into test current values.

Sensitivity: KD-11, 3 Phase Unit

The impedance curve for the KD-11 three-phase unit is shown in Figure 12. This unit will operate to close the left hand contact on current-only for 3 or more amperes relay current with T set for 5.8 or T = 10.0 for 1.3-36 ohm relay and for 7.5 amperes or more with T set for .87.

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General Characteristics

Impedance settings in ohms reach can be made for any value in the range of

.2 – 4.5 – for short reach relays

* .75–21.2 – for medium reach relays

1.27–36.7 – for long reach relays

The maximum torque angle for all phase-to-phase units is set for 75 degrees at the factory, and may be * set for any value from 60 to 63 degrees and from 75 to 78 degrees. A change in maximum torque angle will produce a slight change in reach for any given setting of the relay. Referring to Fig. 2, note that the compensator secondary voltage output V, is largest when V leads the primary current, I, by 90°. This 90° relationship is approached, if the compensator loading resistor (R_{2A}, or R_{2C}) is open circuited. The effect of the loading resistor, when connected, is to produce an internal drop in the compensator, which is out-of-phase with the induced voltage, IT_{AB} or IT_{AC}. Thus the net voltage, V, is phase-shifted to change the compensator maximum torque angle. As a result of this phase shift the magnitude of V is reduced, as shown * in Fig. 2. Other angles may be set by changing fixed series resistors R_{2A} and R_{2C}.

The maximum torque angle of the 3-phase unit of the medium (.73-21.2 ohms) and the long reach (1.27-36.7 ohms) is set for 75 degrees at the factory, and it * may be set for any value from 60 to 63 degrees and from 75 t● 78 degrees. Other angles may set by changing fixed resistor R_3.

The maximum torque angle of the 3-phase unit of the short reach (.2-4.5 ohms) relay is set for 60 degrees at the factory and may be set for any value from 45 to * 48 degrees and from 58 to 63 degrees. By changing R_3 any other angle may be set. The 90-degree setting is approached for all ranges when R_3 resistor is open cir- * cuited. For 3Φ unit or R_{2A} and R_{2C} for phase-to-phase unit.

Tap markings are based upon nominal settings as specified above. If the phase loading potentiometers P_3. P_{2A}, or P_{2C} are adjusted for some other maximum in torque angle the relay reach is different from the nominal as described under settings.

TIME CURVES AND BURDEN DATA

Operating Time

The speed of operation for the KD-10 relay three-phase and phase-to-phase units is shown by the time curves in Figure 14. The curves indicate the time in milliseconds required for the relay to close its contacts for tripping after the inception of a fault at any point on a line within the relay setting.

Figure 15 and Figure 16 show the KD-11 operating time of the phase-to-phase unit and the three-phase unit respectively. These curves show both contact-opening time and contact-closing time for faults within the relay setting.

Current Circuit Rating in Amperes

All rated 10 amp. continuous 1 second 240 amp.
* except for 1-37 ohm range where
for S = 1 T = 10 continuous rating is 6 amp
S = 2 T = 10 continuous rating is 8 amp
S = 3 T = 10 continuous rating is 9 amp
S = 1 T = 7.02 continuous rating is 7 amp

Burden

The burden which the relays impose upon potential and current transformers in each phase is shown by Figure 17 and Figure 18 for the KD-10 and KD-11 relays respectively. The potential burden and burden phase angle are based on 69 volts line-to-neutral applied to the relay terminals.

Trip Circuit Constants

0.2 tap – 6.5 ohms
2 tap – 0.15 ohms

SETTING CALCULATIONS

Relay reach is set on the tap plate shown in Fig. 3. The tap markings are:

T, T_A, T_B and T_C

0.23 – 0.307 – 0.383 – 0.537 – 0.690 – 0.920 – 1.23 (short reach)

* 0.87 – 1.16 – 1.45 – 2.03 – 2.9 – 4.06 – 5.8 (medium reach)

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1.5 — 2.0 — 2.5 — 3.51 — 5.0 —7.02 — 10.0
(long reach)

S, S_A, and S_C
1, 2, 3

M, M_A, M_C
.0, .03, .09, .06

(Values between taps)

Calculations for setting the KD-10 and KD-11 relays are straightforward and apply familiar principles. Assume a desired balance point which is 90 percent of the total length of line. The general formula for setting the ohms reach of the relay is:

$$Z = Zpri \frac{0.9\ R_c}{R_V} \qquad (9)$$

The terms used in this formula and hereafter are defined as follows:

Z = the desired ohmic reach of the relay in secondary ohms.

0.9 = the portion of the total line for which the relay is set.

R_C = current transformer ratio

R_V = potential transformer ratio

Zpri = ohms per phase of the total line section

The relay tap plate setting — Z is set according to the following equation:

$$Z = \frac{ST}{1+M} \qquad (10)$$

T = compensator tap value

S = Auto-transformer primary tap value.

±M = Auto-transformer secondary tap value. (This is a Per Unit value and is determined by the sum of the values between the "L" and the "R" leads. The sign is positive when "L" is above "R" and acts to lower the Z setting. The sign is negative when "R" is above "L" and acts to raise the Z setting.)

CAUTION The tap plate values refer to standard maximum torque angle adjustment as per table I, II, or III.

In general recalibration of the relay to a torque angle other than the standard value is neither desirable nor required. Where it is necessary, the phase loading potentiometers P_3, P_{2A}, or P_{2C} are adjusted for some other maximum torque angle, the relay reach becomes different from the nominal tap plate settings and tap plate setting should be modified as outlined under Maximum Torque Angle Consideration.

The following procedure should be followed in order to obtain an optimum setting of the relay.

1. Establish Z, as per Equation (9).
2. Now refer to Table I, II, or III, these tables lists optimum relay settings for relay.
   a) Locate a table value for relay reach nearest to the desired value Z (it will always be within 1.5% or less off the desired value).
   b) Read off the Table "S, T" and "M" settings. "M" — column includes additional information for "L" and "R" leads setting for the specified "M" value.
   c) Recheck the obtained S, T, M — settings by using equation (10).

$$Z = \frac{ST}{1+M}$$

For example, assume the desired reach, Z is 7.8 ohms at 75°. (Step 1)

Step (2a) In Table II we find nearest value to 7.8 ohms 7.88 that is $100 \times \frac{7.88}{7.77} = 101$ percent of the desired reach.

Step (2b). From Table I read off:

S = 2

T = 4.06

M = +.03

and "L" — lead should be connected over "R"— lead, with "L" lead connected to "03" — tap and "R" — lead to tap "0".

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ages of this sequence applied to operating unit produce restraining torque.

For a fault at B, the currents are larger than for a fault at A, so that compensator voltages are larger. Points Y & Z coincide now and the area of the X-Y-Z triangle is zero. No torque is produced.

For a fault in the operating zone, such as at C, the compensator voltages reverse the rotation of tripping unit voltages to X-Z-Y sequence. Voltages of this sequence applied to operating unit produce operating torque.

For a fault behind the relay at D, restraining torque is produced. Since the fault is behind the relay, the current is of reverse polarity and tripping unit voltage has an X-Y-Z rotation. This rotation produces restraining torque.

Note that this unit does not require memory action, since the sound-phase voltage reacts with the compensator voltage to produce a strong restraining or a strong operating torque, depending upon the fault location. This is true even for a complete collapse of the faulted phase-to-phase voltage. The phase-to-phase unit is identical in the KD-10 and KD-11 relays.

Similar vector diagrams apply for a fault between phases 1 and 2 or between phases 3 & 1. Each of the three phase-to-phase fault combinations subjects the cylinder unit to a similar set of conditions.

CHARACTERISTICS

Distance Characteristics-Phase-to-Phase Unit

This unit responds to all phase-to-phase faults and most two-phase-to-ground faults. It does not respond to load current, synchronizing surges, or out-of-step conditions. While a characteristic circle can be plotted for this unit on the R-X diagram as shown in Fig. 10 such a characteristic circle has no significance except in the first quadrant where resistance and reactance values are positive. A small portion of the fourth quadrant, involving positive resistance values and negative reactance values, could have some significance in the event that the transmission line includes a series capacitor. The portion of the circle in the first quadrant is of interest because it describes what the relay will do when arc resistance is involved in the fault. The phase-to-phase unit operating on an actual transmission system is inherently directional and no separate directional unit is required.

An inspection of fig. 10 indicates that the circle of the phase-to-phase unit is dependent on source impedance Z_S. However the circle always goes through the line balance point impedance. The reach at the compensator (and line) angle is constant, regardless of the system source impedance. The broadening out of the characteristic circle with a relatively high source impedance gives the phase-to-phase unit the advantageous characteristic that for short lines, it makes a greater allowance for resistance in the fault. Stated another way, the characteristics approach that of a reactance relay more and more closely as the line being protected becomes shorter and shorter with respect to the source impedance back of the relaying location.

Sensitivity: Phase-to-Phase Unit

A plot of relay reach, in percent of tap block setting, versus relay terminal voltage and current sensitivity is shown in Figure 12. The unit will operate with the correct directional sense for zero voltage phase-to-phase faults. For this condition the fault current must be not less than 0.015 relay amperes with an ohm setting of 5.8 with rated voltage on the unfaulted phase. Pick up current is proportionately higher in S = 2 and S = 3 taps.

The KD-10 relay may be set without regard to possible overreach due to d-c transients. Compensators basically are insensitive to d-c transients which attend faults on high-angle systems. The long time constant of a high angle system provides a minimum rate of change in flux-producing transient current with respect to time, and therefore induces a minimum of uni-directional voltage in the secondary. Asymetrical currents resulting from faults on low-angle systems having a short time constant can induce considerable voltage in the secondary, but for the first half cycle, the transient-derived voltage subtracts from the steady-state value. This transient decays so rapidly that it is insignificant during the second half cycle when it adds to the steady-state value.

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Distance Characteristic – KD-10 3 Phase Unit

The three-phase unit has a characteristic circle which passes through the origin as shown in Figure 11. This circle is independent of source impedance. The three-phase unit is also inherently directional and does not require a separate directional unit.

If a solid-three phase fault occurs right at the relay location, the entire voltage triangle collapses to zero to give a balance point condition, as shown by the relay characteristic in Figure 11 which passes through the origin. However, since the YZ voltage also drops to zero, the relay would be unable to determine whether an internal or external fault existed. To correct this condition, a resonant circuit is added to the 2–3 voltage circuit of the relay which allows the YZ voltage to collapse gradually, thus giving a reference voltage to determine whether the fault is inside the protected line section or behind the relay.

Sensitivity – KD-10 3-Phase Unit

The unit will operate with the correct directional sense for zero voltage three-phase faults when normal voltage exists at the relay terminals prior to the fault. This operation occurs due to memory action as described above. The unit will have zero torque or perhaps a slight opening torque if there is zero voltage at the relay prior to the fault or after the memory action has subsided. For medium and long reach relays with an impedance setting of 5.8 ohms the three-phase unit will directionally operate for fault which produce 2 volts line to line and 1.0 ampere at the relay terminals.

Sensitivity with 2 volts line-to-line for any tap is defined by the following equation:

$$I = \frac{5.8}{T} \text{ amperes} \qquad (7)$$

For short reach relays (.2-4.55 ohms) with an impedance setting of 1.23 ohms the three-phase unit will directionally operate for faults which produce .5 volts line to line and 2.7 ampere at the relay terminals.

Sensitivity with .75 volts line-to-line for any tap is defined by the following equation:

$$I = \frac{3.4}{T} \text{ amperes}$$

The KD-10 relay may be set without regard to possible overreach due to d-c transients.

Distance Characteristic: KD-11, 3 Phase Unit

The three phase unit of the KD-11 relay has a characteristic circle which includes the origin as shown in Figure 13.

A single turn current coil on the cylinder unit provides for current-only torque and is small compared to the many turns of the T Max. setting of the compensator and has very little influence on the overall settings. However, as the compensator setting is reduced, the single turn current coil becomes larger by comparison and has more and more effect on the overall settings.

★ For 1.3-37 ohms range the reach and maximum torque angle will vary as follows:

T Nominal	T Actual	% Error	MTA	T Reverse
10	10	0	75°	.13
7.02	7.09	2	76°	.13
5.0	5.10	2	77°	.12
3.51	3.65	4	78°	.12
2.50	2.60	4	80°	.11
2.00	2.08	4	82°	.11
1.50	1.65	10	87°	.11

★ For .75-21 ohms range the reach will vary as follows:

T Nominal	T Actual	% Error	MTA	T Reverse
5.8	5.3	0	75°	.13
4.06	4.20	3.5	76°	.13
2.90	3.12	4	78°	.12
2.03	2.15	6	79°	.12
1.45	1.57	8	82°	.12
1.46	1.30	12	85°	.11
.87	1.02	17	90°	.11

When setting KD-11 relays disregard the change in T-value, but include the percentage error into test current values.

Sensitivity: KD-11, 3 Phase Unit

The impedance curve for the KD-11 three-phase unit is shown in Figure 12. This unit will operate to close the left hand contact on current-only for 3 or more amperes relay current with T set for 5.8 or T = 10.0 for 1.3-36 ohm relay and for 7.5 amperes or more with T set for .87.

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General Characteristics

Impedance settings in ohms reach can be made for any value in the range of

.2 – 4.5 – for short reach relays

* .75–21.2 – for medium reach relays

1.27–36.7 – for long reach relays

The maximum torque angle for all phase-to-phase units is set for 75 degrees at the factory, and may be * set for any value from 60 to 63 degrees and from 75 to 78 degrees. A change in maximum torque angle will produce a slight change in reach for any given setting of the relay. Referring to Fig. 2, note that the compensator secondary voltage output V, is largest when V leads the primary current, I, by 90°. This 90° relationship is approached, if the compensator loading resistor (R_{2A}, or R_{2C}) is open circuited. The effect of the loading resistor, when connected, is to produce an internal drop in the compensator, which is out-of-phase with the induced voltage, IT_{AB} or IT_{AC}. Thus the net voltage, V, is phase-shifted to change the compensator maximum torque angle. As a result of this phase shift the magnitude of V is reduced, as shown * in Fig. 2. Other angles may be set by changing fixed series resistors R_{2A} and R_{2C}.

The maximum torque angle of the 3-phase unit of the medium (.73-21.2 ohms) and the long reach (1.27-36.7 ohms) is set for 75 degrees at the factory, and it * may be set for any value from 60 to 63 degrees and from 75 to 78 degrees. Other angles may set by changing fixed resistor R_3.

The maximum torque angle of the 3-phase unit of the short reach (.2-4.5 ohms) relay is set for 60 degrees at the factory and may be set for any value from 45 to * 48 degrees and from 58 to 63 degrees. By changing R_3 any other angle may be set. The 90-degree setting is approached for all ranges when R_3 resistor is open cir- * cuited. For 3Φ unit or R_{2A} and R_{2C} for phase-to-phase unit.

Tap markings are based upon nominal settings as specified above. If the phase loading potentiometers P_3. P_{2A}, or P_{2C} are adjusted for some other maximum in torque angle the relay reach is different from the nominal as described under settings.

TIME CURVES AND BURDEN DATA

Operating Time

The speed of operation for the KD-10 relay three-phase and phase-to-phase units is shown by the time curves in Figure 14. The curves indicate the time in milliseconds required for the relay to close its contacts for tripping after the inception of a fault at any point on a line within the relay setting.

Figure 15 and Figure 16 show the KD-11 operating time of the phase-to-phase unit and the three-phase unit respectively. These curves show both contact-opening time and contact-closing time for faults within the relay setting.

Current Circuit Rating in Amperes

All rated 10 amp. continuous 1 second 240 amp.
* except for 1-37 ohm range where
for S = 1 T = 10 continuous rating is 6 amp
S = 2 T = 10 continuous rating is 8 amp
S = 3 T = 10 continuous rating is 9 amp
S = 1 T = 7.02 continuous rating is 7 amp

Burden

The burden which the relays impose upon potential and current transformers in each phase is shown by Figure 17 and Figure 18 for the KD-10 and KD-11 relays respectively. The potential burden and burden phase angle are based on 69 volts line-to-neutral applied to the relay terminals.

Trip Circuit Constants

0.2 tap – 6.5 ohms
2 tap – 0.15 ohms

SETTING CALCULATIONS

Relay reach is set on the tap plate shown in Fig. 3. The tap markings are:

T, T_A, T_B and T_C

0.23 – 0.307 – 0.383 – 0.537 – 0.690 – 0.920 – 1.23 (short reach)

* 0.87 – 1.16 – 1.45 – 2.03 – 2.9 – 4.06 – 5.8 (medium reach)

1.5 — 2.0 — 2.5 — 3.51 — 5.0 —7.02 — 10.0 (long reach)

S, S_A, and S_C

1, 2, 3

M, M_A, M_C

.0, .03, .09, .06

(Values between taps)

Calculations for setting the KD-10 and KD-11 relays are straightforward and apply familiar principles. Assume a desired balance point which is 90 percent of the total length of line. The general formula for setting the ohms reach of the relay is:

$$Z = Zpri \frac{0.9\ R_c}{R_v} \qquad (9)$$

The terms used in this formula and hereafter are defined as follows:

Z = the desired ohmic reach of the relay in secondary ohms.

0.9 = the portion of the total line for which the relay is set.

R_C = current transformer ratio

R_V = potential transformer ratio

Zpri = ohms per phase of the total line section

The relay tap plate setting — Z is set according to the following equation:

$$Z = \frac{ST}{1+M} \qquad (10)$$

T = compensator tap value

S = Auto-transformer primary tap value.

±M = Auto-transformer secondary tap value. (This is a Per Unit value and is determined by the sum of the values between the "L" and the "R" leads. The sign is positive when "L" is above "R" and acts to lower the Z setting. The sign is negative when "R" is above "L" and acts to raise the Z setting.)

CAUTION The tap plate values refer to standard maximum torque angle adjustment as per table I, II, or III.

In general recalibration of the relay to a torque angle other than the standard value is neither desirable nor required. Where it is necessary, the phase loading potentiometers P_3, P_{2A}, or P_{2C} are adjusted for some other maximum torque angle, the relay reach becomes different from the nominal tap plate settings and tap plate setting should be modified as outlined under Maximum Torque Angle Consideration.

The following procedure should be followed in order to obtain an optimum setting of the relay.

1. Establish Z, as per Equation (9).
2. Now refer to Table I, II, or III, these tables lists optimum relay settings for relay.
   a) Locate a table value for relay reach nearest to the desired value Z (it will always be within 1.5% or less off the desired value).
   b) Read off the Table "S, T" and "M" settings. "M" — column includes additional information for "L" and "R" leads setting for the specified "M" value.
   c) Recheck the obtained S, T, M — settings by using equation (10).

$$Z = \frac{ST}{1+M}$$

For example, assume the desired reach, Z is 7.8 ohms at 75°. (Step 1)

Step (2a) In Table II we find nearest value to 7.8 ohms 7.88 that is $100 \times \frac{7.88}{7.77} = 101$ percent of the desired reach.

Step (2b). From Table I read off:

S = 2

T = 4.06

M = +.03

and "L" — lead should be connected over "R"— lead, with "L" lead connected to "03" — tap and "R" — lead to tap "0".

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$$Z = \frac{0.5 \sin 60°}{\sin 45°} = .612 \text{ ohms}$$

Referring to Table I use closest setting

For phase-to-phase unit

$T_A, T_B, T_B, T_C = .537$

$M_A, M_C = -.06$

$S_A, S_C = 1$

For 3-phase unit closest setting

$T = .690$

$M = +.12$

$S = 1$

5. If for some reasons an exact correction is required to match up the line impedance Z_L at an angle α, and relay has been recalibrated from nominal maximum torque to a new maximum torque angle $\beta \neq \alpha$, then relay setting Z – should be equal to

$$Z = \frac{Z \text{ Line} \sin \theta_m}{\sin \beta \cos (\beta - \alpha)} \qquad (13)$$

For Example:

Relay with original $\theta_m = 75°$ has been recalibrated to $\beta = 60°$ and to be applied to 5 ohm-line with line angle $\alpha = 50°$

The relay setting –Z relay – should be according to Eq. (13)

$$Z \text{ relay} = \frac{5 \sin 75°}{\sin 60°. \cos (60° - 50°)} = 5.65 \text{ ohms.}$$

or referring to Table II relay actual setting should be $S = 1$

$T = 5.8$

$M = +.03$

SETTING THE RELAY

The KD-10 and KD-11 relays require settings for each of the three compensators (T, T_{AB}, and T_{BC}), each of the auto-transformers primaries (S, S_A, and S_C) and secondaries (M, M_A, and M_C). All of these settings are made with taps on the tap plate which is located between the operating units and relay de-energized. Fig. 3 shows the tap plate.

Compensator (T, T_{AB} and T_{BC})

Each set of compensator taps terminate in inserts which are grouped on a socket and form approximately three quarters of a circle around a center insert which is the common connection for all of the taps. Electrical connections between common insert and tap inserts are made with a link that is held in place with two connector screws, one in the common and one in the tap. There are two T_B settings to be made since phase B current is passed through two compensators. A compensator tap setting is made by loosening the connector screw in the center. Remove the connector screw in the tap end of the link, swing the link around until it is in position over the insert for the desired tap setting, replace the connector screw to bind the link to this insert, and retighten the connector screw in the center. Since the link and connector screws carry operating current, be sure that the screws are turned to bind snugly.

Auto-Transformer Primary (S, S_A, and S_C)

Primary tap connections are made through a single lead for each transformer. The lead comes out of the tap plate through a small hole located just below or above the taps and is held in place on the tap by a connector screw. (Figure 3).

An "S" setting is made by removing the connector screw, placing the connector in position over the insert of the desired setting replacing and tightening the connector screw. The connector should never make electrical contact with more than one tap at a time.

Auto-Transformer Secondary (M, M_A, and M_C)

Secondary tap connections are made through two leads identified as L and R for each transformer. These leads come out of the tap plate each through a small hole, one on each side of the vertical row of "M" tap inserts. The lead connectors are held in place on the proper tap by connector screws.

Values for which an "M" setting can be made are from –.18 to +.18 in steps of .03. The value of a setting is the sum of the numbers that are crossed when going from the R lead position to the L lead position. The sign of the "M" value is determined by which lead is in the higher position on the tap

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plate. The sign is positive (+) if the L lead is higher and negative (−) if the R lead is higher.

An "M" setting may be made in the following manner. Remove the connector screws so that the L and R leads are free. Determine from the Tables I to III the desired "M" value. Neither lead connector should make electrical contact with more than one tap at a time.

Line Angle Adjustment

Maximum torque angle adjustment, if required, is accomplished by adjusting the compensator loading resistors P3, P_{2A}, and P_{2C}. Refer to Repair Calibration for procedure.

Indicating Contactor Switch (ICS)

Connect the lead located in front of the tap block to the desired setting by means of the connecting screw. When the relay energizes a 125- or 250- volt d-c type WL relay switch, or equivalent, use the 0.2 ampere tap; for 48-volt d-c applications set the unit in a tap 2 and use a type WL relay with a S#304C209G01 coil, or equivalent. The relay is shipped set for 2.0 tap.

INSTALLATION

The relays should be mounted on switchboard panels or their equivalent in a location free from dirt, moisture, excessive vibration and heat. Mount the relay vertically by means of the mounting stud for the type FT projection case or by means of the four mounting holes on the flange for the semi-flush type FT case. Either the stud or the mounting screws may be utilized for grounding the relay. The electrical connections may be made directly to the terminals by means of screws for steel panel mounting or to the terminal stud furnished with the relay for thick panel mounting. The terminal stud may be easily removed or inserted by locking two nuts on the stud and then turning the proper nut with a wrench.

For detail information on the FT case refer to I.L. 41-076. The relay contacts should stay open with panel de-energized.

EXTERNAL CONNECTIONS

Fig. 19 shows the connections for 3 zone protection utilizing the TD-4 timer. Fig. 24 is similar to Fig. 19 except that the TD-52 timer is used instead of the TD-4 (Fig. 20 does show the use of the 5/5 auxiliary current transformer so that the CT neutral may be formed elsewhere; however, this connection is equally applicable whether the TD-4 or TD-52 timer is employed).

A-C connections for additional applications are shown in Figs. 20, 21, 22 and 23. Three of these, Figs. 20, 21, and 22 apply when the transmission line is terminated in a power transformer, and when low side voltage and current are used to energize the relays. In calculating the reach setting, the bank impedance must be added to the line impedance.

For the case of a wye-delta bank (Figs. 22 and 21) the voltages and currents are phase-shifted by 30°; however, this fact should be ignored, as the KD-10 and KD-11 relays are not affected by this phase shift.

Fig. 23 shows a KD-10 and TD-5 relay connected for generator back-up protection.

SWITCHBOARD TESTING WITH KD-10 AND KD-11 RELAYS

Immediately prior to placing the relay in service, the external wiring can be checked by manipulating the current and voltage applied to the relay. If such a check is desired, refer to Appendix I for the procedure.

RECEIVING ACCEPTANCE

KD-10 and KD-11 relays have a very small number of moving parts and mechanical devices which might become inoperative. Acceptance tests in general consist of:

1. A visual inspection to make sure there are no loose connections, broken resistors, or broken resistor wires.
2. An electrical test to make certain that the relay measures the balance point impedance accurately.

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Distance Unit-Electrical Tests

Check electrical response of the relay using test connections shown in Figure 26. Figure 27 features the same connections except shows use of additional switches that facilitate fast switchover from "phase-to-phase" – fault mode to "three phase" – fault mode. Test connections, referred to in test, are the same on both drawings. Accuracy of the test results will depend to large degree on the accuracy of the instrumentation used. In general, it is advisable to restrict instrument readings to the last 20 percent of the scale. For most accurate phase angle readings use phase shifter scale. This method requires calibration of the scale using accurate wattmeter (at 90° – 0 watts and at 0° – maximum watts), or an accurate phase angle meter.

Make sure that correct lead-lag reference is established. Once phase shifter is calibrated remove wattmeter from the circuit. Make all phase angle reading from phase shifter scale. This method eliminates the need for switching the current ranges in phase angle meter when used and results in superior accuracy. Always observe contact condition before current is applied. Closed contacts indicate reverse voltage sequence applied. Special attention should be paid to the phase-to-phase fault mode.

All testing is done outside the case. All current
* readings include for convenience, ±6 percent tolerance. This tolerance includes ±2.5 percent factory tolerance and ±3.5 percent allowance for total instrumentation error.

All phase angle settings are fault current lagging the $V_{PH1\text{-}PH2}$ – voltage.
The impedance measured by the 3-phase unit in

test 1 (Fig. 26) is $Z_R = \dfrac{V_{L-L}}{1.73\ I_L}$ (14)

where V_{L-L} is the phase-to-phase voltage and I_L is the test current; similarily, in tests 5, 6 & 7 of Fig.

26 the phase-to-phase unit measures $Z_R = \dfrac{V_{L\text{-}L}}{2I_L}$ (15)

With phase shifter set at maximum torque angle (θ_m).

$$I \text{ test (3 phase)} = \frac{V_{L\text{-}L}}{1.73 Z_R} \qquad (16)$$

$$I \text{ test } (\phi - \phi) = \frac{V_{LL}}{2\ Z_R} \qquad (17)$$

When testing 3 phase unit, phase shifter settings are always set for 30° higher than nominal maximum torque angle to account for test set-up where all angle measurements are made with reference to phase-to-phase and not phase-to-neutral quantities. 3ϕ-unit maximum torque angle is always referred to phase-to-neutral.

At any other angle α, relay reach is

$$Z = Z_\theta \cos(\theta_M - \alpha) \qquad (18)$$

where Z_θ – relay reach at maximum torque angle – θ_m.

Test current – $I\alpha$ – is calculated as

$$I\alpha = \frac{I\,\theta M}{\cos(\theta_m - a)} \qquad (19)$$

$I\theta_m$ – test current at θ_m.

This equation (19) should be used to predict test current when plotting impedance circle response of the relay.

Relay Settings – Set relay as follows:

Relay Range	.2-4.5	.75-20	1.3-36
T, T_A, T_B, T_B, T_C	1.23	5.8	10.0
M, M_A, M_C	+.15	+.15	+.15
S, S_A, S_C	1.0	1.0	1.0

If the relay is tested with other settings than specified in acceptance test use voltage levels specified here, except double the voltage specified for S = 2 settings and triple for S = 3 settings.

When testing KD-11 relays with other settings than specified here, refer to correction factors listed under Distance Characteristics: KD-11 3-Phase Unit.

Use equations (16) and (17) to estimate test current, and allow ±5 percent tolerance as explained above.

Three Phase Unit (Lower Unit)

A. Use test connections #1 of Fig. 26 and set $V_{1F2F} = V_{1F3F} = 30$ volts.

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The current required to close contacts of the bottom unit should be:

	.2-4.5	.75-20	1.3-36
* Trip current amp	15.3-17.6	3.3-3.68	1.90-2.16
Δ Phase Shifter set at	90°	105°	105°
Nominal maximum torque angle θ_m	60°	75°	75°

ΔIf maximum torque angle θ_m has been changed

to a new angle β, the new $I_t = \frac{I_t \sin \theta_m}{\sin \beta}$ (20)

and test the relay at the new β – angle.

Phase-To-Phase Unit (Top Unit) =

A. Use test connection #5 set V_{F1F2} = 30 volts = V_{fault}
Note that to set this voltage set voltage $V_{1-1F} = V_{2-2F}$, first.

Make sure that, $V_{1-1F} = V_{2-2F} = \frac{V_{in} - V_{fault}}{2}$ (22)

Example: V_{in} = 120

V_{fault} = 30

then $V_{1-1F} = V_{2-2F} = \frac{120-30}{2}$ = 45 volts, trim up one of these voltages to set V_{FAULT} at exact value.

The current required to close contacts of the top unit should be:

Range	.2-4.5	.75-20	1.3-36
Δ Trip Current (I_t) amperes	13.3-14.7	2.85-3.15	1.63-1.80
Phase Shifter set current lagging V_{1F-2F}	75°	75°	75°

ΔIf maximum torque angle, θ_M, has been changed to a new angle, use equation (20) for trip current limits.

B. Repeat the test using test connections #6 and #7.

Maximum Torque Angle Test

If maximum torque angle test performance is desired follow instructions under CALIBRATION allowing ±5° tolerance. Observe the same voltage and current limits correction as mentioned above when relay is set for other settings than specified here. The test currents should be modified by following multiplier

$\frac{1.07}{Z}$ for .2-4.5 ohm range

$\frac{5.03}{Z}$ for .75-20 ohm range

$\frac{8.7}{Z}$ for 1.3-36 ohm range

Indicating Contactor Switch (ICS)

Close the main relay contacts and pass sufficient d-c current through the trip circuit to close the contacts of the ICS. The current should not be greater than the particular ICS tap setting being used for the 0.2-2.0 ampere ICS. The operation target should drop freely.

The contact gap should be approximately 0.047" between the bridging moving contact and the adjustable stationary contacts. The bridging moving contact should touch both stationary contacts simultaneously.

If the electrical response is outside the limits a more complete series of test outlined in the section titled "Calibration" may be performed to determine which component is faulty or out of calibration.

ROUTINE MAINTENANCE

The relays should be inspected periodically, at such time intervals as may be dictated by experience, to insure that the relays have retained their calibration and are in proper operating condition.

All contacts should be cleaned periodically. A contact burnisher #182A836H01 is recommended for this purpose. The use of abrasive material for clean-

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ing contacts is not recommended because of the danger of embedding small particles on the face of the soft silver and thus impairing the contact.

Distance Units

CAUTION: Before making "hi-pot" tests, jumper all contacts together to avoid destroying arc-suppressor capacitors.

For effective and quick maintenance it is advisable to repeat the acceptance test with the field settings and then using K-DAT test set (I.L. 41-493.1) to record K-DAR-test set dial readings, so in the future all field tests can be made with the K-DAR test box just by referring to the previous dial readings without using more elaborate test set up of fig. 26. When testing with S = 2, - double test voltage. When testing with S = 3, triple the test voltage. Note that KD-11 reach and maximum torque angle are increased with the lower T-settings (see Distance Characteristics KD-11).

Indicator Contactor Switch (ICS)

Close the main relay contacts and pass sufficient d-c current through the trip circuit to close the contacts of the ICS. The current should not be greater than the particular ICS tap setting being used for the 0.2-2.0 amperes ICS. The operation indicator target should drop freely.

REPAIR CALIBRATION

Use the following procedure for calibrating the relay if the relay has been taken apart for repairs or the adjustments disturbed.

Connect the relay for testing as shown in Figure 26. Figure 27 shows a four-pole-double-throw switch in the test circuit that selects a phase-to-phase or a three-phase fault voltage condition, that will be applied to the relay voltage terminals. The rotary switch switches the fault voltage to various terminals and thereby simulates any phase combination of phase-to-phase fault without the tester having to change connections or readjust the phase shifter and variable auto-transformers.

For best results in checking calibration, the relay should be allowed to warm up for approximately one hour at rated voltage in a case. However, a cold relay will check to within two percent of the warm relay. Calibrate relay outside the case.

Initial Spring Setting

Set the moving contact spring adjuster so that the contact floats freely in the gap. Make sure that there is no friction which prevents free movement of the cylinder and contact arm.

Shaft Clearance

The upper pin bearing should be screwed down until there is approximately .025 inch (one complete turn of the screw) between it and the top of the shaft bearing. The upper pin bearing should then be securely locked in position with the lock nut. The lower bearing position is fixed and cannot be adjusted.

Autotransformer Check

Auto-transformers may be checked for turns ratio and polarity by using the No. 1 test connections of Fig. 26, and the procedure outline below.

Set S, S_A, and S_C on tap number 3. Set the "R" leads of M, M_A, M_C all on 0.0 and disconnect all the "L" leads. Adjust the voltages V_{1F2F} and V_{2F3F} for 90 volts. Measure the voltage from terminals 8 to the #1 tap of S and S_A. It should be 30 volts. From B to the #2 tap of S and S_A should be 60 volts. The voltage should read 30 volts from 8 to S_C = 1 and 60 volts from 8 to S_C = 2.

Set S, S_A and S_C on 1 and adjust V_{1F2F} and V_{2F3F} for 100 volts. Measure the voltage drop from terminal 8 to each of the M and the M_A taps. This voltage should be equal to 100 (1 + the sum of values between R and the tap being measured). Example: 100 (1 + .03 + .09) = 112 volts.

Check the taps of M_C in the same manner. Transformers that have an output different from nominal by more than 1.0 volts probably have been damaged and should be replaced.

Distance Unit Calibration

1. Make the following relay settings

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Relay Range	.2-4:5	.75-20	1.3-3.6
T, T_A, T_B, T_B, T_C	1.23	5.8	10.0
M, M_A, M_C	+15	+15	+15
S, S_A, S_C	1.0	1.0	1.0

2. Read Acceptance Test—Distance Unit Electrical Test — to become familiar with testing connections, instrumentation, and measurements. Use Fig. 26 or 27 for test connections.

Three Phase Unit (lower unit) Core & P_{3A} Adjustment

* 1. Set P_{3A} and P_3 potentiometers for maximum resistance (clockwise).

Restraint spring set as above per Initial Spring Adjustment.

The relay should be preheated for at least one hour in the case with closed cover to compensate for effects of self-heating.

A. Connect relay terminals 8 and 9 together, apply rated a-c voltage between terminals 7 and 8. Adjust core by turning it slightly until the contact arm floats or restrains very slightly.

B. KD-10 only. Connect relay terminals 7 and 8 together and apply rated a-c voltage between 7 and 9 and adjust core until the contact arm just floats or restrains very slightly. If this is not possible rotate core 90° and adjust. Recheck part A to see if contact is floating or restraining. If not, repeat parts A and B.

* C. Connect relay for Test #7, set V_{F1F2}=4-5volts omit conn. from 1F to relay terminal 9, short relay terminals 7 and 9. Set phase shifter so that voltage leads current by 75°. Adjust P_{3A} so that 3ϕ unit trips at 3.10 – 3.30 amperes for .2-4.35 range

0.55-0.60 amperes for .7-21.0 range

0.30-0.35 amperes for 1.3-36 range

Remove current. The three phase-unit should stay open. If P_{3A} does not have proper range to make proper adjustment use R_{3F} – resistor to bring P_{3A} within adjustable range.

This calibration point is temperature sensitive and will change with time but relay should stay open when terminals 7 and 9 are shorted and rated voltage applied to terminals 7 and 8, with no current applied.

This test assures proper response of 3 phase unit for CA faults.

D. For KD-10 Only

* This check is done to prevent contact closing on current-only. (The KD-11 relay is purposely biased to produce current-only contact-closing torque and will open its right hand contact at a current value of 3 amperes or less when T is on maximum tap.)

Check it as follows:

1. Short circuit relay terminals 7, 8 and 9 together.
2. Pass 5 amperes in the current circuit in terminal 18 out terminal 19 and increase the current to 30 amperes in convenient steps.
3. Relay contacts should stay open. If contacts close, turn core further 90 degrees and repeat part A, B and C.

MAXIMUM TORQUE ANGLE ADJUSTMENTS

1. Use test connection #1.
2. Adjust voltages V_{1F-2F} and V_{1F-3F}, and current as per table below.
3. Adjust P3 to obtain maximum torque angle using procedure described.

	Relay Range	.2-45	.75-20	1.3-36
	V_{1F-2F} = V_{1F} V_{3F}	15	30	30
△	I_T Test Current	13	7	4
	Adjust P3 for max. torque angle, θ_m (Nominal)	60°	75°	75°

Rotate the phase shifter to find the angles, $\theta 1$ and $\theta 2$, at which the bottom unit contacts just close. The maximum torque angle θ_m for the three-phase unit then is $\left(\frac{\theta_1 + \theta_2}{2} - 30\right)$degrees. Do not

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allow more than ±2 degrees error in this adjustment.

The 30° degree correction is made to account for the fact that test set up angle measurements are made with reference to phase-to-phase voltage instead of line-to-neutral voltages. The 3 phase unit maximum torque angle is always referred to as phase to neutral.

Λ—Test current for other than nominal torque angle setting should be

$$I_\theta = \frac{I_T \sin \theta_m}{\sin \beta} \qquad (12)$$

Where β = new maximum torque angle

Example, For $\theta_m = 75°$, I test = 7 amp.

if $\beta = 60°$

$$\text{new I test} = \frac{7 \times \sin 75°}{\sin 60°} = 7.8 \text{ amps.}$$

Increasing P_3 Value increases maximum torque angle, and, conversely, decreasing the P_3 value results in smaller angle.

For lower maximum torque angle adjustment below 70 degrees, for medium and long ranges, and for short range for settings below 55 degrees move red lead on fixed phase shifting resistor R3, to the opposite terminal.

Contact Adjustment

KD-10 relay: With moving-contact arm against right-hand backstop, screw the stationary contact in until it just touches the moving contact. (Check for contact by using an indicator lamp.) Then back the left-hand contact out two-thirds (2/3) of one turn to give 0.020-inch gap between contacts.

KD-11 relay: With moving-contact arm against right-hand side of bridge, screw the right-hand contact in to just touch the moving contact and then continue for one more complete turn. Adjust left-hand contact as described above, except back off one (1) turn to give approximately 0.31 inch gap.

Spring Restraint

Reconnect for a three-phase fault, Test No. 1. and set the phase shifter so that the current lags voltage by the

90° for .2-4.5 range
105° for .75-20 and
1.3-36 ranges

Adjust the spring so that the current required to close the left hand contact is as follows:

Relay Range	0.2 -4.5	.75-20	1.3-36
$V_{1F-2F} = V_{1F-3F}$	2.5	10	10
I trip KD-10	1.55-1.65	1.22-1.28	.710-.750
KD-11	—	1.22-1.30	.710-.765

De-energizing the relay spring should open the contacts. Friction in the movement, relay level, electrostatic attraction may contribute to difficulties in adjusting this point. To avoid these difficulties it is recommended to level the relay properly, at this point omit light indicating circuit, and look for smooth contact action. Friction in bearings or dirt in cylinder will cause improper action.

Impedance Check

A. Use test connections #1 and set $V_{1F2F} = V_{1F3F}$ = 30 volts. The current required to close contacts of the bottom unit should be:

	Relay Range	.2- 4.5	.75-20	1.3 -36
Δ	Trip Current	15.3-17.0	3.4-3.65	1.90-2.10
φ	Phase Shifter set at	90°	105°	105°
	The Nominal M-T-Angle	60°	75°	75°

φPhase shifter settings are always set for 30° higher than nominal maximum torque angle to account for phase difference between phase-to-phase and phase-to-neutral quantities. 3φ unit maximum torque angle is always referred to phase-to-neutral since it receives only one single phase current.

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ΔTo determine the limits for current when θ is not equal to nominal maximum torque angle specified, multiply the nominal values tabulated above by the ratio $\frac{\sin \theta_m}{\sin \theta}$, where

θ_m = original maximum torque angle

θ = recalibrated maximum torque angle.

I Phase-to-Phase Unit

(Top Unit)

Core and Reactor (X_{lac}) Adjustments

Set restraint spring as above per Initial Spring Setting and P_{2A}, P_{2C} for maximum resistance (clockwise).

A. Connect terminals 7 & 8 together and apply rated a-c voltage between terminals 8-9. Adjust core until contact arm floats in the middle of the gap. Use a screwdriver with insulated blade to avoid accidental contact with tap plate inserts.

* B. Use test connection #5 Set V_{F1F2} = 2 volts = V_{fault}. Note that to set this voltage you have to set voltages $V_{1F-1F} = V_{2-2F}$ first where

$$V_{1-1F} = V_{2-2F} = \frac{V_{in} - V_{fault}}{2}$$

if V_{in} = 120 volts

V_{fault} = 2 volts

$V_{1-1F} = V_{2-2F} = \frac{120-2}{2} = 59$ volts. Now trim up either voltage to get V_{fault} = 2 volts.

The current required to close contacts of the top unit should be

Range	.2–4.5	.75–20	1.3–36
Trip Current Amperes	0.9–1.10	0.202–0.227	.115–.135
Phase Shifter Set at current lag	75°	75°	75°

With no current relay contacts should stay open. If relay contacts are closed recheck voltage settings, incorrect voltage setting may result in negative sequence voltage phasing.

Set phase shifter for maximum torque angle. Check pickup current. It should be within the limits specified above if not rotate core slightly until pickup current falls within specified range. Connect relay for 2-3 fault (Test No. 6) and recheck pickup. It should be within limits specified. For best trip calibration results adjust core so that trip current for Test No. 5 and No. 6 are equal.

Connect relay for Test No. 7. Check trip current Use X_{Lac} adjustable reactor to bring relay response within the specified limits. Moving red lead from front terminal to rear terminal or from rear terminal to front terminal of the reactor will reverse contact action of the unit. Screwing in or out the adjustable core should bring unit response within the limits. There are three possible connections for reactor coils; series (loose coil termination leads connected together), parallel (each loose lead connected to the fixed terminals of the other coil), single front coil (omit loose lead of the rear coil from the circuit, bury it in insulation tubing). The reactor connections, should not require any changes unless some of the components of the phase to phase unit circuitry have been exchanged. Tighten up the locking nut when finished.

Maximum Torque Angle Adjustment

1. Use the No. 2 test switch position and lead connections. This connection is for checking and adjusting the maximum torque angle of the T_{AB} compensator.

Set voltages and currents as per Table below.

RELAY RANGE	.24-4.5	.75-20	1.3-36
$V_{1F2F} = V_{1F3F}$ (volts)	10	50	50
Δ I_{test} (amp)	12	10.0	6.0

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Loosen the locking nut on P_{2A} and P_{2C}. Adjust P_{2A} for 75 degrees current lagging the voltage. Rotate the phase shifter to find two angles θ_1 and θ_2, at which the top unit contacts just close. The maximum torque angle θ for the phase to phase unit then is $(\frac{\theta_1 + \theta_2}{2} - 30)$ degrees. Do not allow more than ±2 degrees error in this adjustment. Tighten the locking nut.

△ I_{test} – for other than nominal maximum torque angle, current should be $I_\theta = \frac{I_T \sin \theta_m}{\sin \beta}$ (12)

Where θ_m = original maximum torque

β = recalibrated maximum torque angle

Example: For $\theta_m = I_{test}$ = 10 amps

For new $\beta = 60^\circ$

$$\text{new } I_{test} = \frac{10 \times \sin 75^\circ}{\sin 60} = 11.1 \text{ amps}$$

Increasing P_{2A}-value rotation in clockwise direction increases maximum torque angle, and conversely, decreasing the P_{2A} – value results in smaller angles.

For lower maximum torque angle than 70-degrees, move red lead on fixed phase shifting resistor R_{2A}, to the opposite terminal. Lock P_{2A}.

2. Use the No. 4 test connection and repeat the procedure above for adjustment of the T_{BC}– compensator. This adjustment is made with P_{2C}-potentiometer.

Spring Restraint

1. Use test No. 1 connections except reverse the voltage phase sequence by interchanging the Brush connections so that Brush 1 is connected to 3F and Brush 2 is connected to 1F.

2. Adjust the voltage V_{1F2F} and V_{2F3F} for 3.5 volts each with Brush No. 2 and Brush No. 1 respectively. Position the moving-contact spring adjuster so that the contact just floats and then return the circuit connections to normal with Brush 1 to 1F and Brush 2 to 3F. De-energize relay. Spring should reset the contacts.

Contact Adjustment

The procedure for contact adjustment for the phase-to-phase unit is identical to that described for three-phase unit.

Impedance Check

Using the connections for Test Nos. 5, 6, and 7, set the phase shifter so that the current lags voltage by θ_m. The current required to trip the phase-to-phase unit should be within the limits specified for each of the voltages. Note that for the phase-to-phase unit the impedance measured by the relay is $Z_R = \frac{V_{L-L}}{2I_L}$ where V_{L-L} is phase-to-phase fault voltage and I_L is phase current.

The current required to close contacts of the top unit should be:

RELAY RANGE	.2-4.5	.75-20	1.3-3.6
$V_{fault} = V_{1F-2F}$ (volts)	30	30	30
△ Trip Current (amps)	13.3-14.7	2.85-3.15	1.63-1.80
Phase Shifter Set at current lagging V_{1F-2F} (θ_m)	75°	75°	75°

For test voltages to be of correct sequence and values, use equations $V_{1\text{-}1F} = V_{2\text{-}2F} = \frac{V_{in} - V_{fault}}{2}$.

ΔFor current limits when θ_M– maximum torque angle is not 75°- multiply the values above by $\frac{\sin 75}{\sin \beta}$ where β – new maximum torque angle for which the relay was recalibrated.

Indicating Contactor Switch (ICS)

Close the main relay contacts and pass-sufficient d-c current through the trip circuit to close the contacts of the ICS. The current should not be greater than the particular ICS tap setting being used for the 0.2-2.0 ampere ICS. The operation indicator target should drop freely.

The contact gap should be approximately 0.047" for the 0.2/2.0 ampere unit between the bridging

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moving contact and the adjustable stationary contacts. The bridging moving contact should touch both stationary contacts simultaneously.

III. Compensator Check

Accuracy of the mutual impedance Z_C of the compensators is set within very close tolerances at the factory and should not change under normal conditions. The mutual impedance of the compensators can be checked with accurate instruments by the procedure outlined below.

A. Set T, T_A, T_B, T_B and T_C on the 1.23 tap for .2 -4:50 range
   5.80 tap for .75-21.0 range
   10.0 tap for 1.3-36 range

B. Disconnect the "L" leads of sections M, M_A, and M_C and the red-marked leads of R_3, R_{2A}, and R_{2C} (with resistor loading removed $\theta = 90°$).

C. Connect terminals 12 to 14, 15 to 17, 16 to 18 and pass 10 amperes a.c. current in terminal 19 and out of terminal 13.

D. Measure the compensator voltage V_C with a high resistance voltmeter (5,000 ohm/volt) as tabulated below. Refer to Figure 1 for the location of R_3, R_{2A}, and R_{2C}.

MEASURE V_C BETWEEN		
* Lead	and Fixed End of	Voltmeter Reading
"L" of M	R3	$V_C = 1.5\, I\, T\, (\frac{\sin\theta}{\sin 75°})^{\Delta}$
"L" of M_A	R_{2A}	$V_C = 2\, I\, T\, (\frac{\sin\theta}{\sin 75°})$
"L" of M_C	R_{2C}	

* Δ Use sin 60° for .2-4.5 range

For example: For .75-21 ohm range T = 5.8 relay 3 phase compensator will read V_C = 90.1 volts and for phase-to-phase compensators where T-5.8 the voltages are:

V_C = 120 volts (phase A)

V_C = 120 volts (phase C)

Accuracy of the measurement will depend on the instrumentation used. Factory adjusted compensator is within ±0.5% on maximum tap and ±1% on all other taps. A realistic tolerance should be allowed for accuracy of the primary current measurement, and the accuracy of the voltmeter to be used to arrive at what is a "good" compensator. No voltage reading may be caused by open potentiometer or compensator.

Additional measurements using compensator can be made to check compensator tap sequence, and to check on condition of all (except terminals 8-9-circuit of the 3 phase unit) relay circuits.

With relay energized with 120 v.a.c. and all S-settings set = 1, and M = +15 check voltage drops starting at the minimum tap and each successive tap —T. Voltage readings will start at millivolt level, and increase with successive tap values. Erratic voltage reading will indicate open tap. These type of readings could be taken at any relay setting except when compairing two relays, or readings from the same relay at different times it should be clear that relay settings for which measurements are taken should be identical. The table below gives * typical readings for settings specified above. Use this table as guide only.

.2 – 4.35 OHMS RANGE	
T_A, T_B, T_B, T_C	T
.003 — .006	.008 — .016
.008 — .011	.018 — .031
.017 — .021	.044 — .063
.026 — .031	.066 — .088
.040 — .047	.100 — .138
.060 — .068	.145 — .210
.75 – 20 OHMS	
T_A, T_B, T_B, T_C	T
.015 — .026	.033 — .050
.032 — .054	.072 — .092
.072 — .110	.145 — .190
.125 — .190	.260 — .190
.200 — .290	.400 — .340
.295 — .470	.645 — .800
1.3 – 36 OHMS	
T_A, T_B, T_B, T_C	T
.038 — .052	.055 — .070
.080 — .100	.105 — .150
.150 — .200	.220 — .300
.290 — .340	.390 — .540
.450 — .535	.600 — .850
.700 — .860	.950 — 1.30

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APPENDIX I

SWITCHBOARD TESTING WITH KD-10 AND KD-11 RELAYS

External connections may be checked at the relay provided there is sufficient load current flow at a known power factor angle. Relay current should be at least $\frac{7}{T}$ amperes (1.2 amps when T = 5.8). This check is appropriate prior to commissioning the relay or when trouble shooting.

Potential Circuit Check

Close the three relay potential switches numbered 7, 8, and 9, (Figure 19). The connection for the proper phase sequence will be indicated by a strong contact-opening torque. Closing torque will indicate reverse-phase sequence.

Current Verification

To verify the proper current connections use the following procedure:

1. Read watts, vars and amperes. The current should be at least $\frac{7}{T}$ amperes.
2. Plot watts and vars on the diagram in Fig. 29. Draw a line at the load angle determined by this plot. Designate this line as I_{REF}. See Fig. 30 for example.
3. Set T = 5.8, S = 1 for maximum sensitivity. (Lower or higher taps may be used, provided current exceeds 7/T).
4. Perform the 9 switching combinations in Table IV, recording the relay contact position for each combination. (Actually only 6 combinations are needed to verify the currents, so that any group of three need not be used. This is important where the load angle falls too close to the zero torque line. If the indicated power-factor angle is within 3° of the test limit for any group of three tests, these should be ignored.)
5. Verify the currents using the procedure illustrated in Table IV. Here the "correct contact position" is determined by observing whether the I_{REF} line in Fig. 26 intersects the solid or dashed part of circle. (For example, test 1b shows a solid circle indicating that the contacts should close.) Next compare the actual contact positions to the correct ones.
6. If the contact positions are proper, the current connections are correct and the test is complete, otherwise proceed to identify the currents using the following procedure.

Current Identification

If the verification check discloses incorrect current connections, the following procedure may be used to determine what is wrong. However, if one set of three switching combinations places the relay too close to the zero-torque line, use conventional techniques, instead, since identification requires all 9 switching combinations.

1. Plot aI_{REF} and a^2I_{REF} at 120° angles from I_{REF}. See Fig. 30 for example. These currents are related to the phase currents as shown in the following table:

Phase Receiving Current	I_{REF}	$a^2 I_{REF}$	$a\ I_{REF}$
1	I_{PH1}	I_{PH2}	I_{PH3}
2	I_{PH2}	I_{PH3}	I_{PH1}
3	I_{PH3}	I_{PH1}	I_{PH2}

2. Prepare a table similar to Table V using Fig. 30. For example, for test 1b the contacts were open. Such a result would occur if I_{REF} of the wrong polarity is actually flowing in the phase 1 circuits of the relay. This conclusion is drawn by noting that I_{REF} in Fig. 30 intersects the solid part of the test 1b circle. This says that if $+I_{REF}$ is flowing the contacts would close. Since the contacts actually open, then $-I_{REF}$ could be flowing. Similarly, for test 1b, $-a^2 I_{REF}$ could be flowing, since the a^2I_{REF} line also intersects the solid part of the test 1b circle By the process of elimination for each set of 3 tests, the actual current is identified. For example, in Table V, phase 1 receives $-I_{PH1}$, whereas $+I_{PH1}$ should be flowing. In phase 2, $+I_{PH3}$ is flowing as shown in Fig. 31. To extract this bit of information from Table V, use the above table relating the phase currents to I_{REF}, a^2I_{REF} and aI_{REF}.

   Note in Table V that $a^2 I_{REF}$ is flowing in the phase 2 circuits of the relay. The above table shows for this set of 3 tests that $a^2I_{REF} = I_{PH3}$.
3. Correct the external connections and then verify the currents.

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TABLE IV
SWITCHING FOR CURRENT VERIFICATION AND IDENTIFICATION

SWITCHING COMBINATION	POSITION OF SWITCHES NUMBERED:								UNIT WHICH SHOULD BE OBSERVED	PHASE RECEIVING CURRENT
	VOLTAGE SWITCH				CURRENT SWITCH (BLANK INDICATES OPEN SWITCH)					
	V_1	V_2	V_3		I_1	I_2	I_3	I_1		
	7	8	9		12, 13	14, 15	16, 17	18, 19 (3ϕ)		
1	Open & jump sw. jaw to 9	Closed	Closed	a			Closed		ϕ-ϕ & †	3
				b	‡ Closed			Closed	ϕ-ϕ & 3ϕ	1
2	Closed	Open & jump sw. jaw to 7	Closed	a	Closed			Closed	ϕ-ϕ & 3ϕ	1
				b		Closed			ϕ-ϕ & †	2
3	Closed	Closed	Open & jump sw. jaw to 8	a		Closed			ϕ-ϕ & †	2
				b			Closed		ϕ-ϕ & †	3
4	Closed	Closed	Open & jump sw. jaw to 7		‡ Closed			Closed	ϕ-ϕ & 3ϕ	1
5	Open & jump sw. jaw to 8	Closed	Closed			Closed			ϕ-ϕ & †	2
6	Closed	Open & jump sw. jaw to 9	Closed				Closed		ϕ-ϕ & †	3

† Block 3ϕ Unit Open

‡. If Current is Over 5 Amps.

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TABLE V

VERIFICATION EXAMPLE USING ASSUMED LOADING OF FIG. 30

PHASE TO BE VERIFIED	SWITCHING COMBINATION	CORRECT CONTACT POSITION	ACTUAL CONTACT POSITION	
			IF WIRING IS CORRECT	EXAMPLE WITH INCORRECT WIRING
1	1b	C	C	O
	2a	C	C	O
	4	O	O	C
2	2b	C	C	C
	3a	C	C	O
	5	O	O	C
3	3b	C	C	O
	1a	C	C	O
	6	O	O	O

TABLE VI

IDENTIFICATION EXAMPLE USING ASSUMED LOADING OF FIG. 30

I_{REF} PHASE RECEIVING CURRENT	SWITCHING COMBINATION	EXAMPLE OF CONTACT POSITION	CURRENT & POLARITY WHICH CAN PRODUCE OBSERVED CONTACT POSITION		
			$I_{REF.}$	$a^2 I_{REF.}$	$a I_{REF.}$
1	1b	O	–	–	+
	2a	O	– †	+	+
	4	C	–	+	–
2	3b	C	+	+	–
	3a	O	–	+ †	+
	5	C	–	+	–
3	3b	O	–	–	+
	1a	O	–	+	+ †
	6	9	+	–	+

† See Fig. 31 for actual connections.

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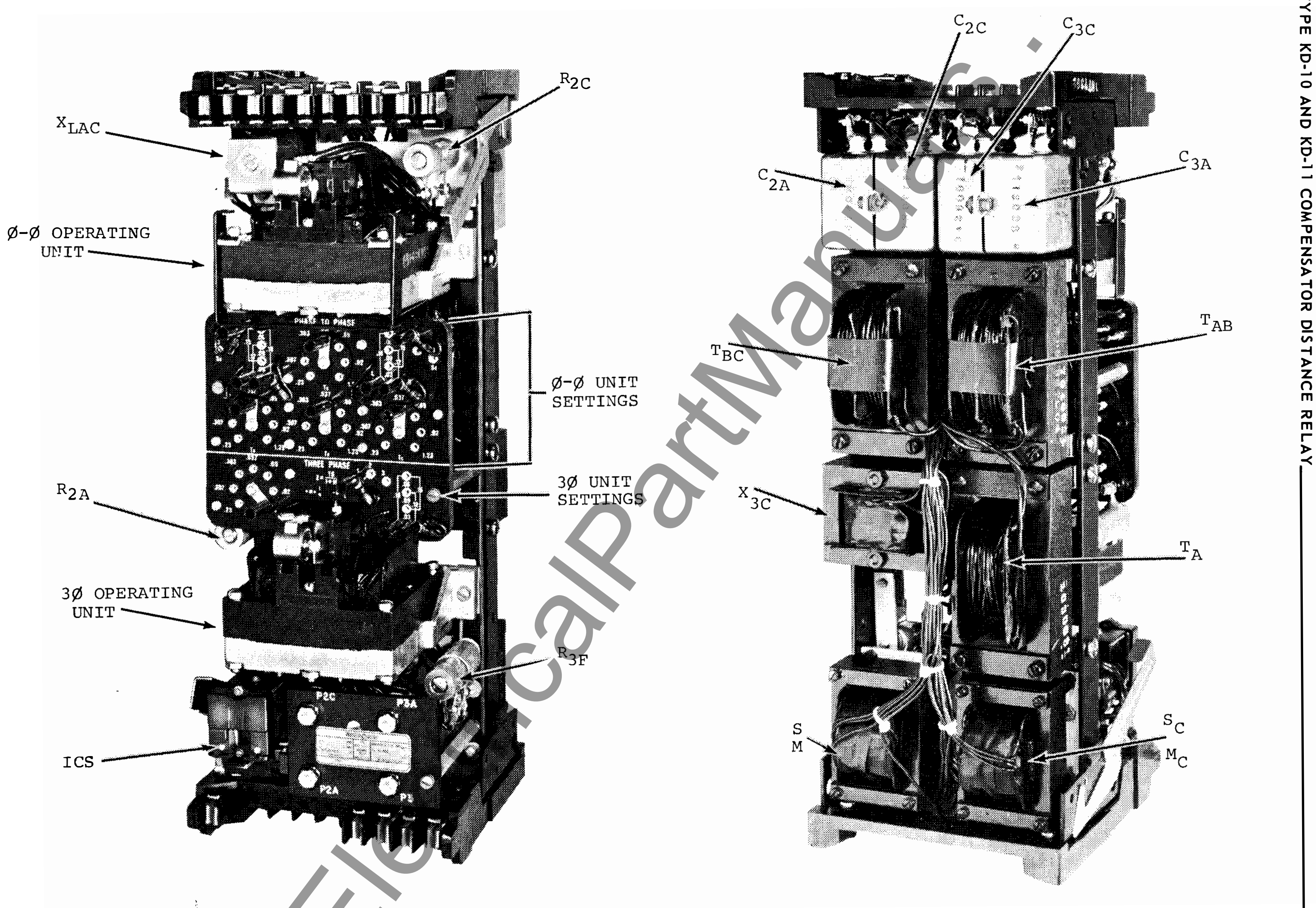

Fig. 1 Type KD-10 Relay Chassis – Front and Back

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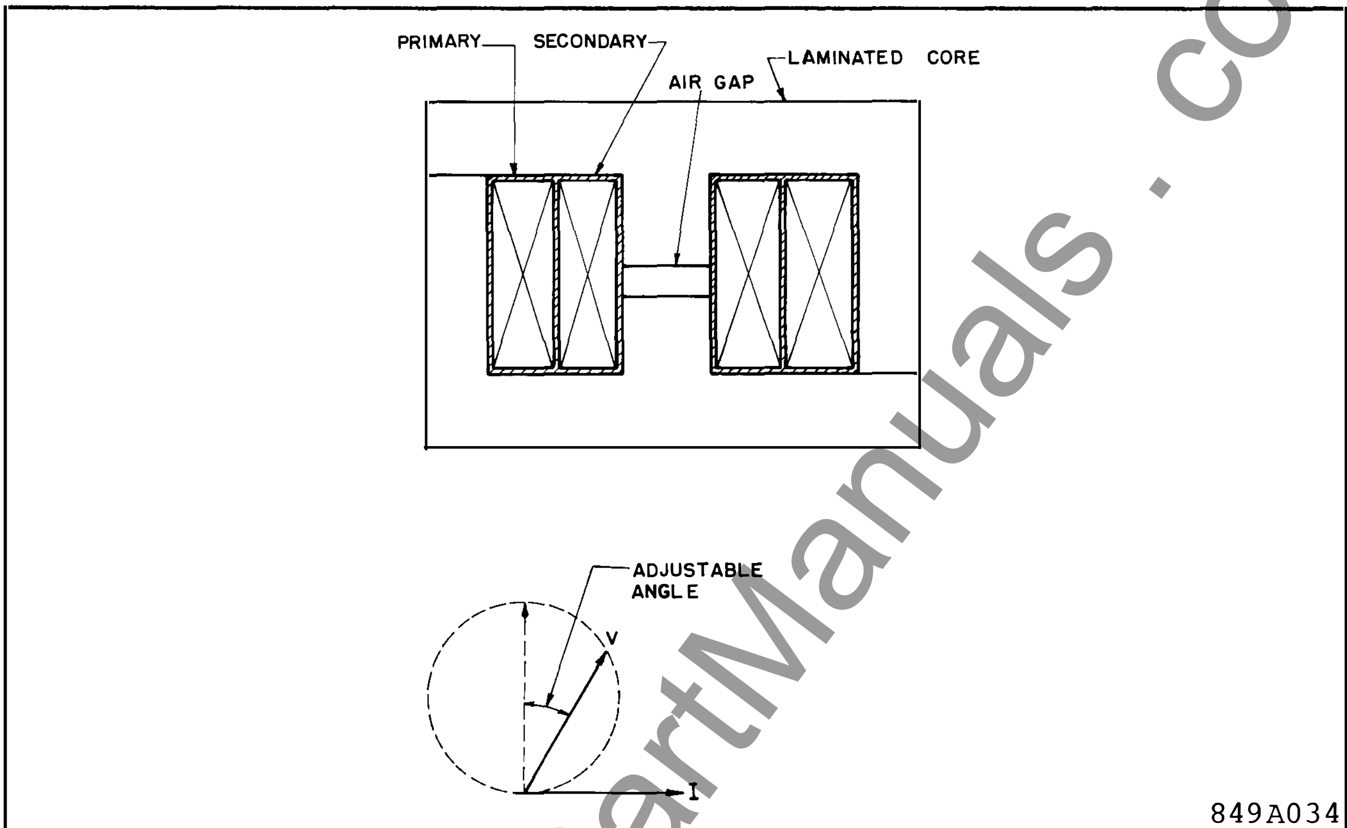

Fig. 2 Compensator Construction

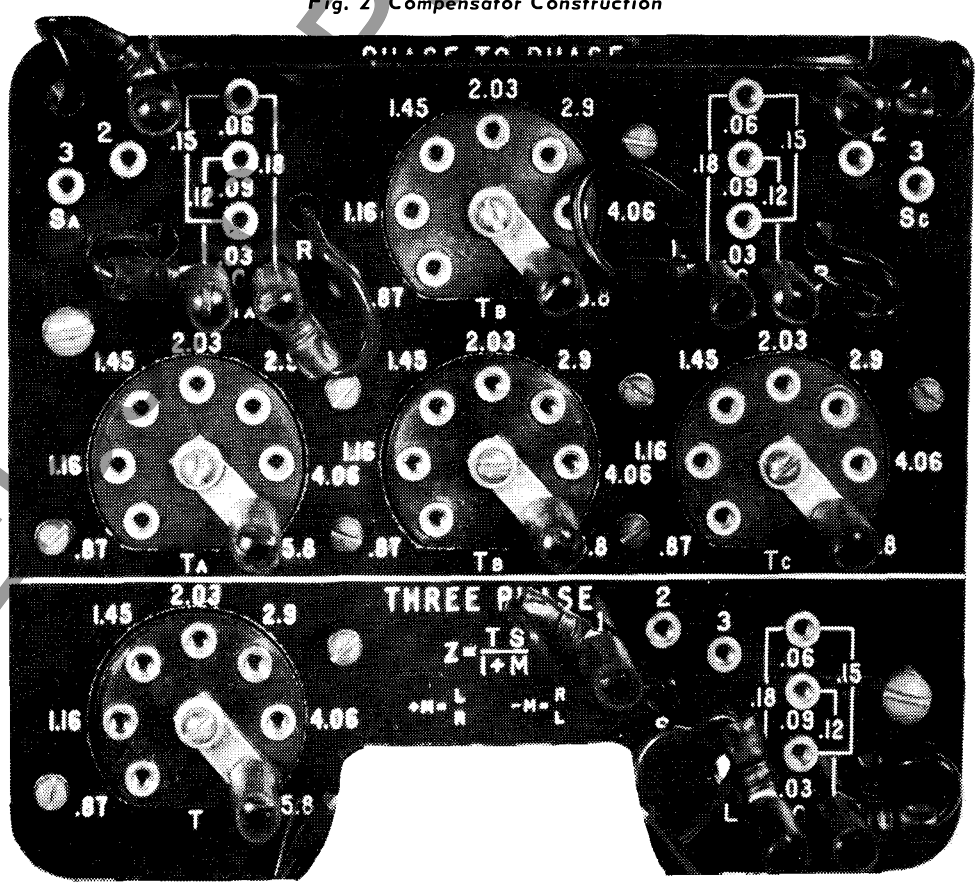

Fig. 3 Typical Tap Plate

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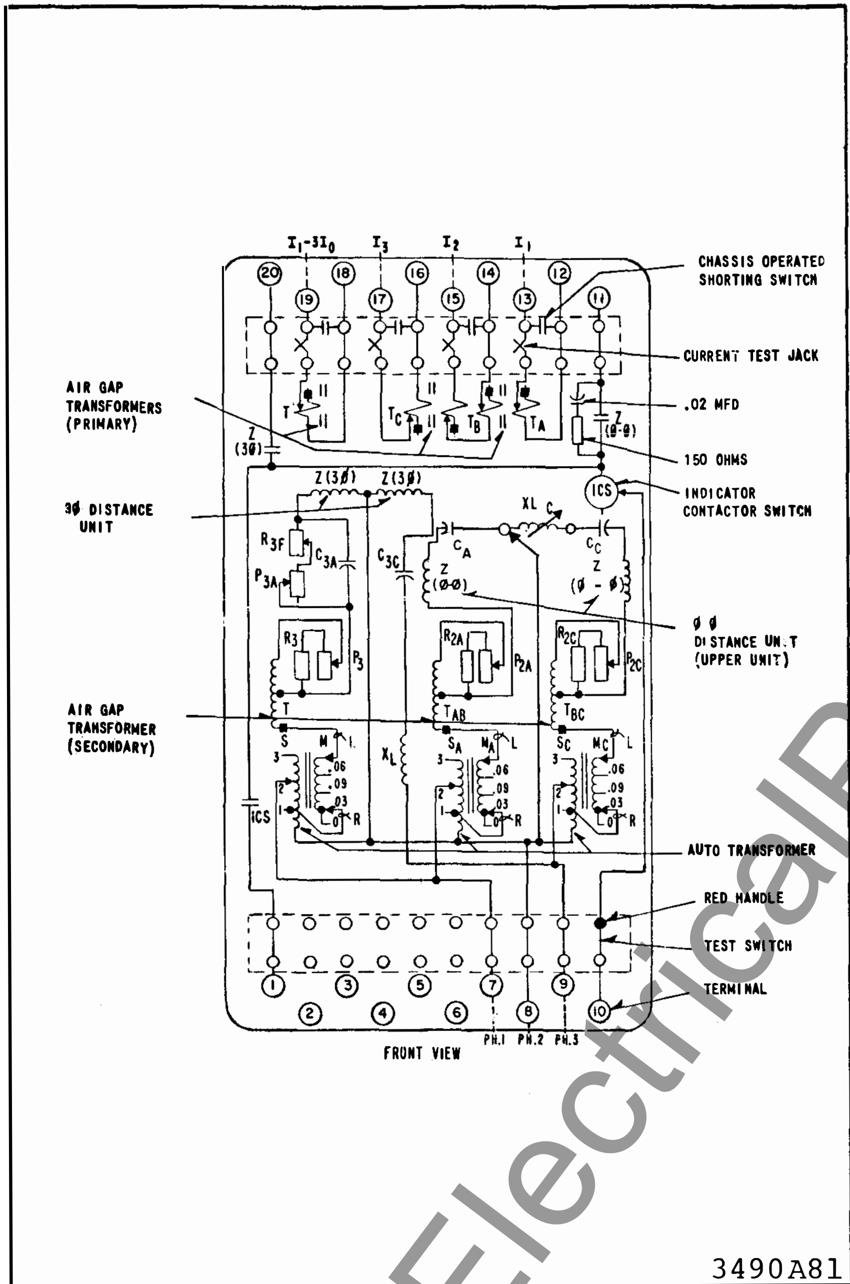
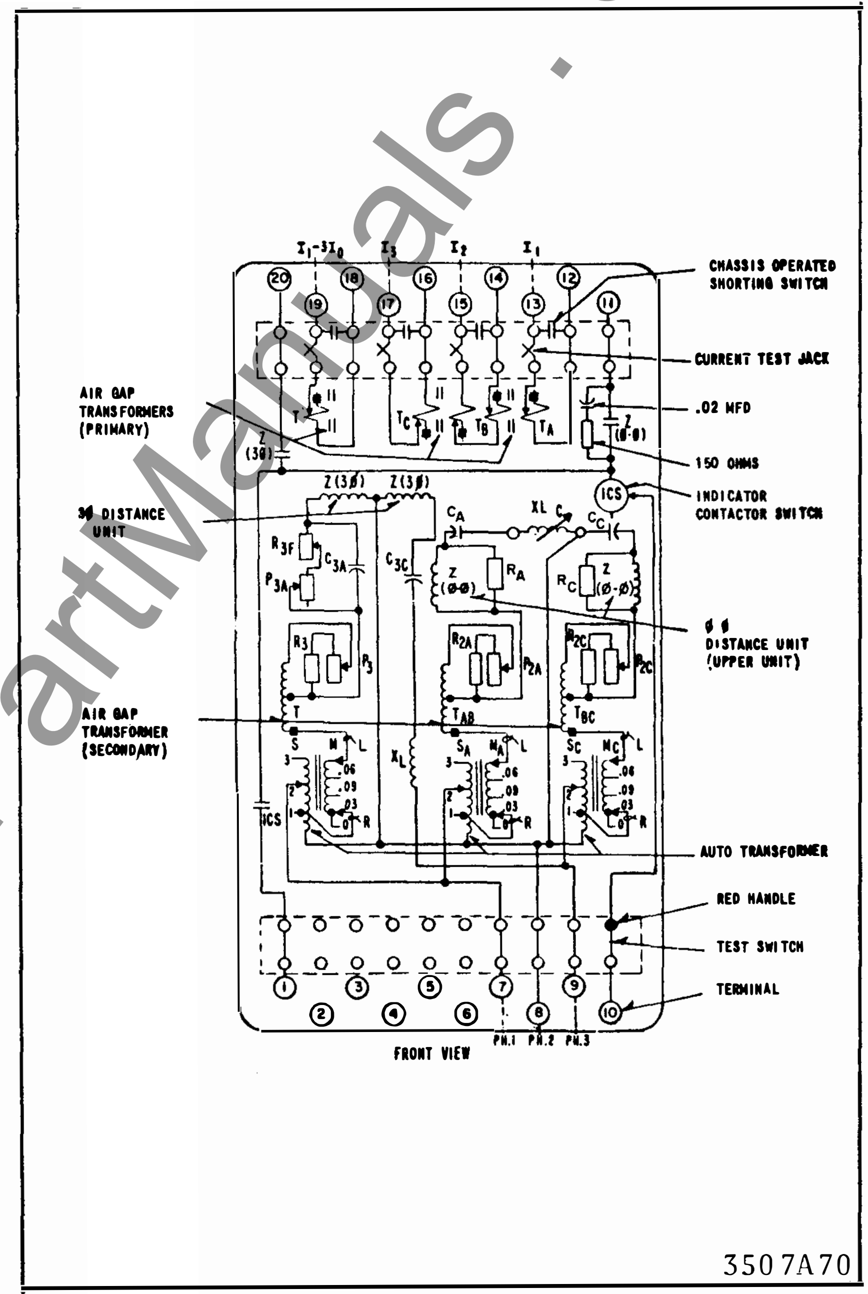


Fig. 4 Internal Schematic of KD-10 Relay (.25-4.5 ohm range)



* *Fig. 5 Internal Schematic of KD-10 Relay (.75-21.0 ohm range)*

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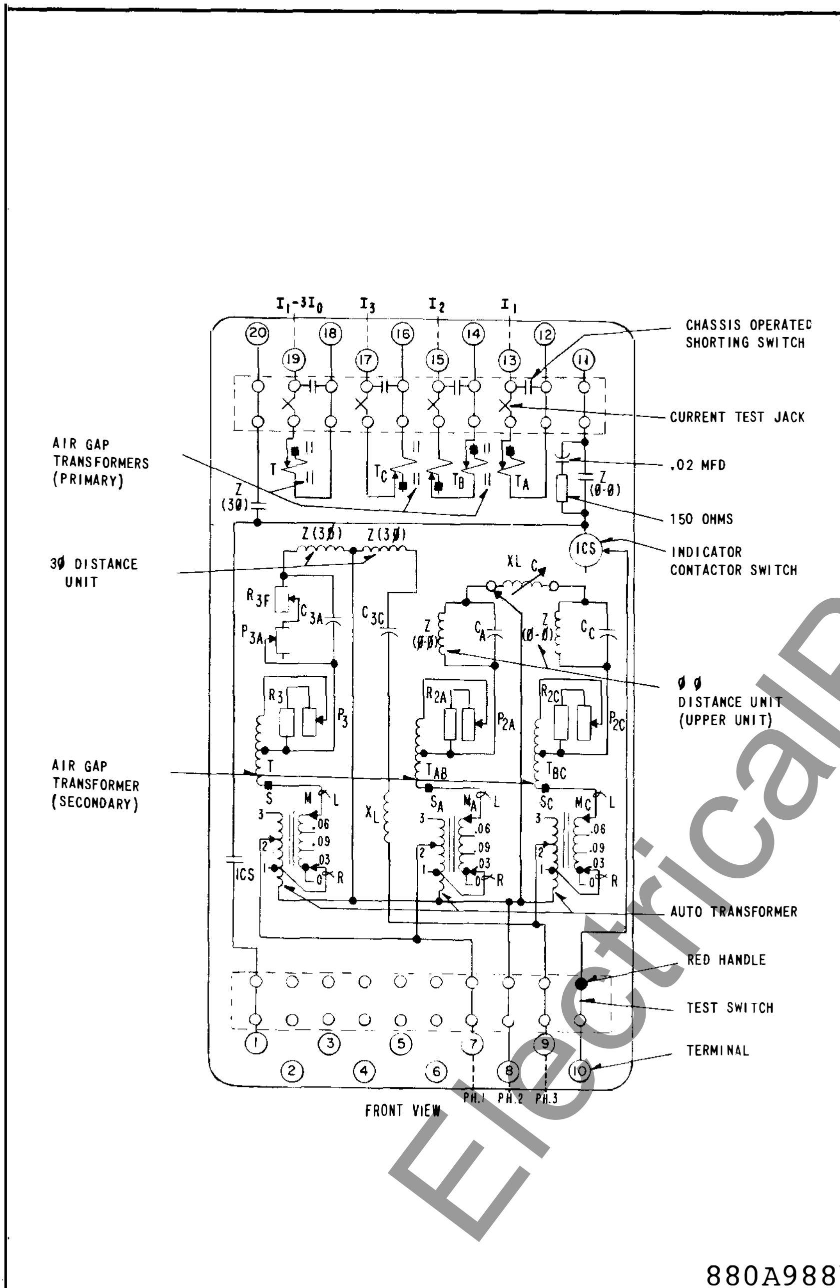

Fig. 6 Internal Schematic of KD-10 relay (1.3-36.0 ohm range)

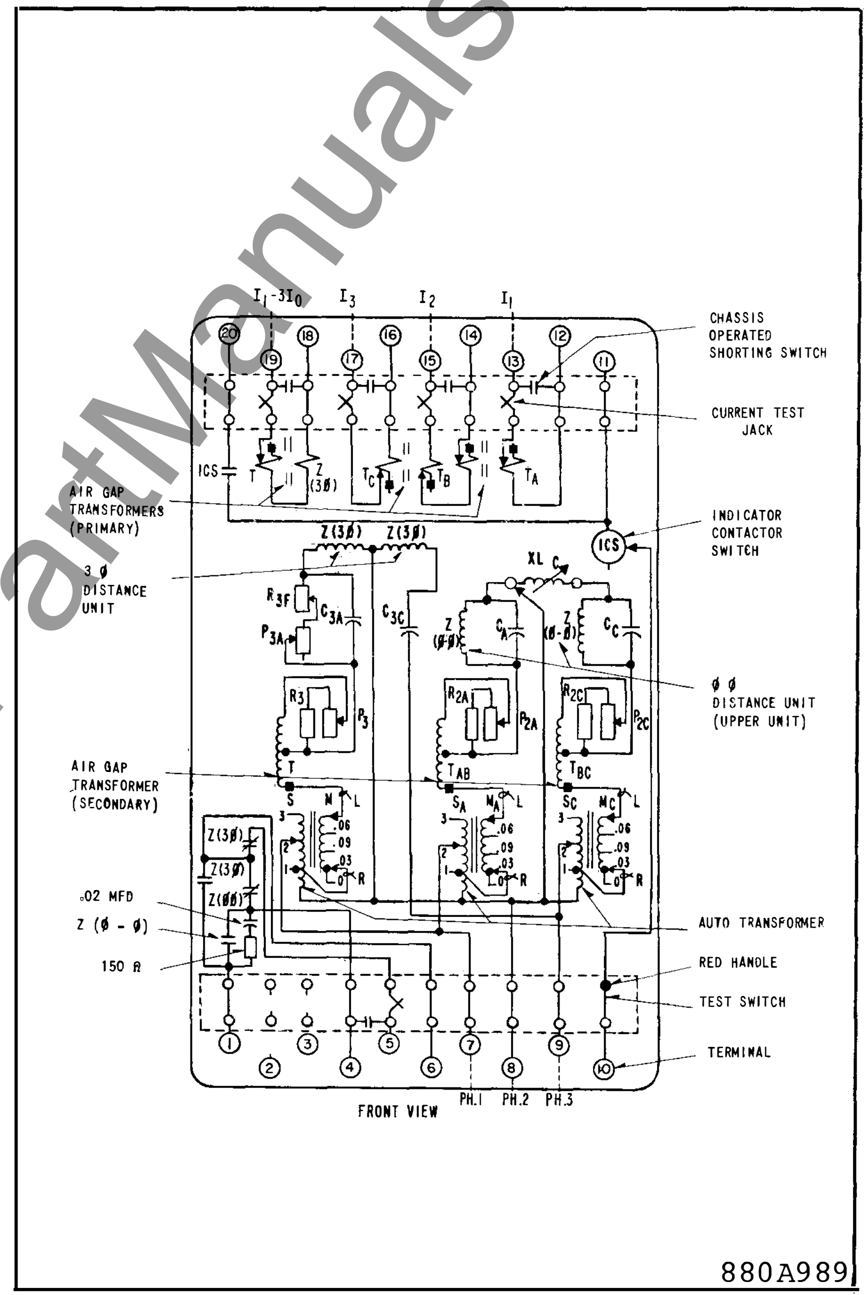

Fig. 7 Internal Schematic of KD-11 Relay (1.3-36.0 ohm range)

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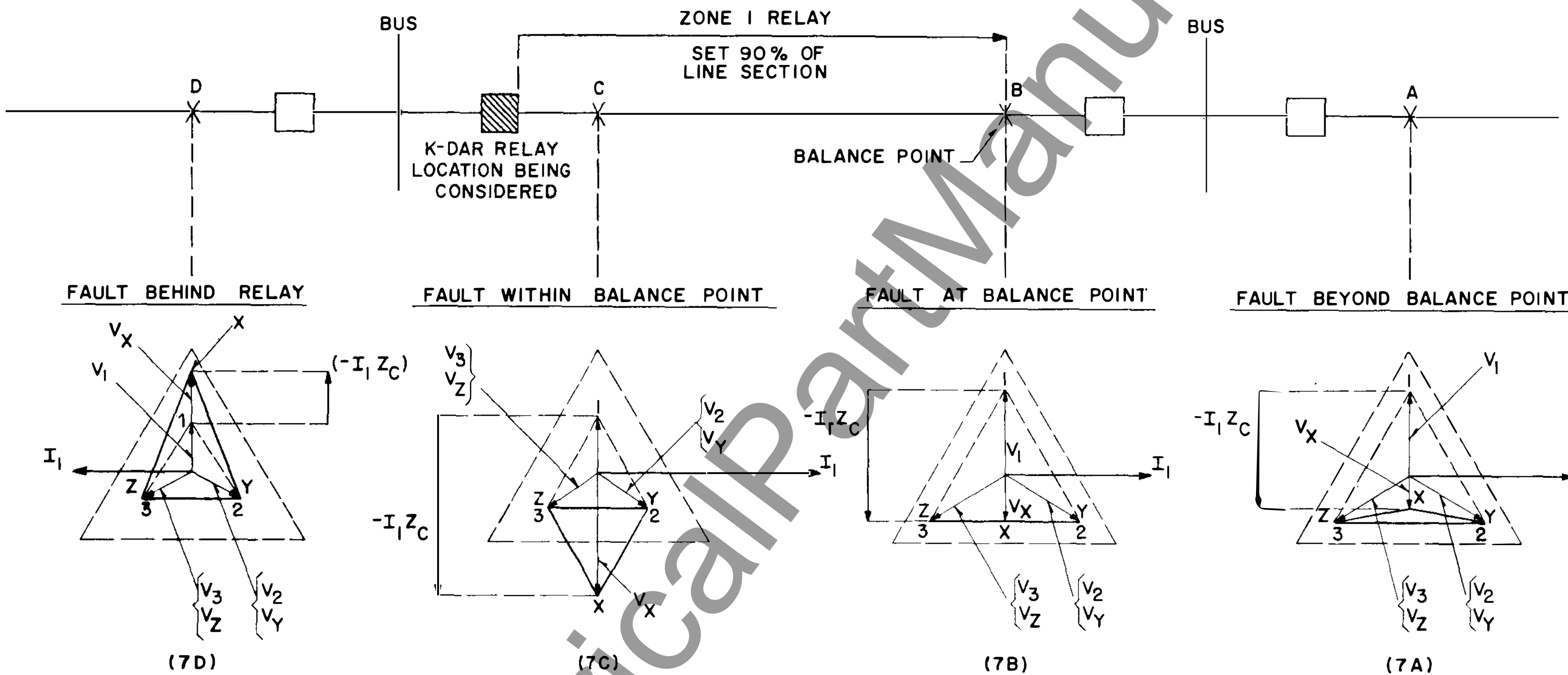

NOTE: THE VOLTAGE TRIANGLES AT EACH FAULT LOCATION (A,B,C&D) REPRESENT THE VOLTAGES SEEN BY THE K-DAR RELAY TERMINAL LOCATED AT THE SHADED BREAKER FOR 3 PHASE FAULTS OCCURING AT EACH LOCATION (A,B,C&D).

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Fig. 8 Voltage and Current Conditions for the Three-Phase Unit at the Shaded Breaker for Three Phase Faults at Various Locations

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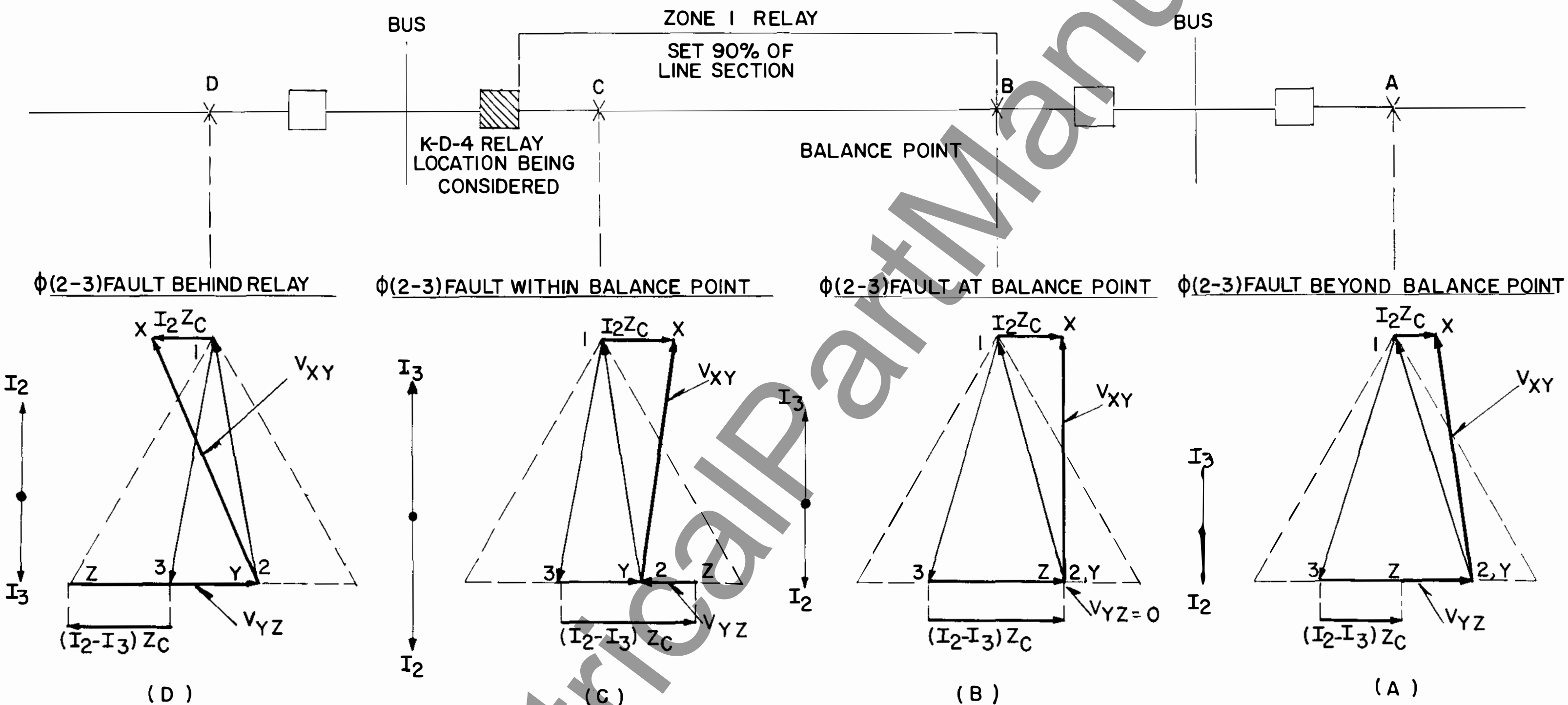

NOTE: THE VOLTAGE TRIANGLES AT EACH FAULT LOCATION (A,B,C&D) REPRESENT THE VOLTAGES SEEN BY THE KD4 RELAY TERMINAL LOCATED AT THE SHADED BREAKER FOR ϕ TO ϕ FAULTS AT EACH LOCATION (A,B,C &D)

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Fig. 9 Voltage and Current Conditions for the Phase-to-Phase Unit at the Shaded Breaker for 2-3 Faults at Various Locations

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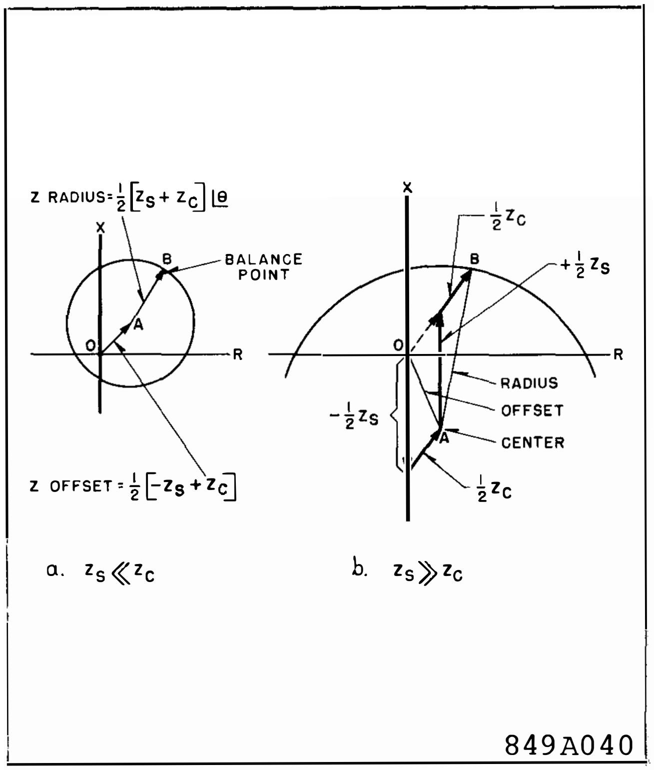

Fig. 10 Impedance Circles for Phase-to-Phase Unit in the Type KD-10 and KD-11 Relay

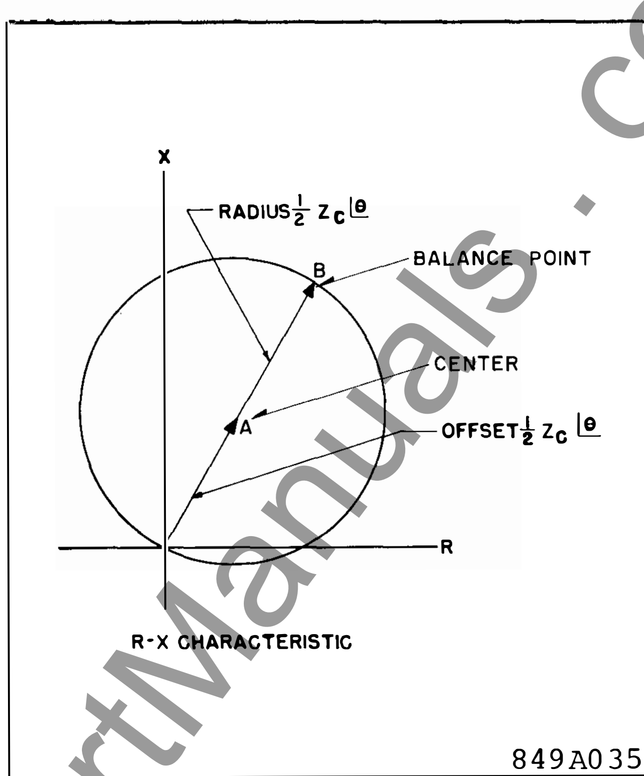

Fig. 11 Impedance Circle for Three-Phase Unit in the Type KD-10 Relay

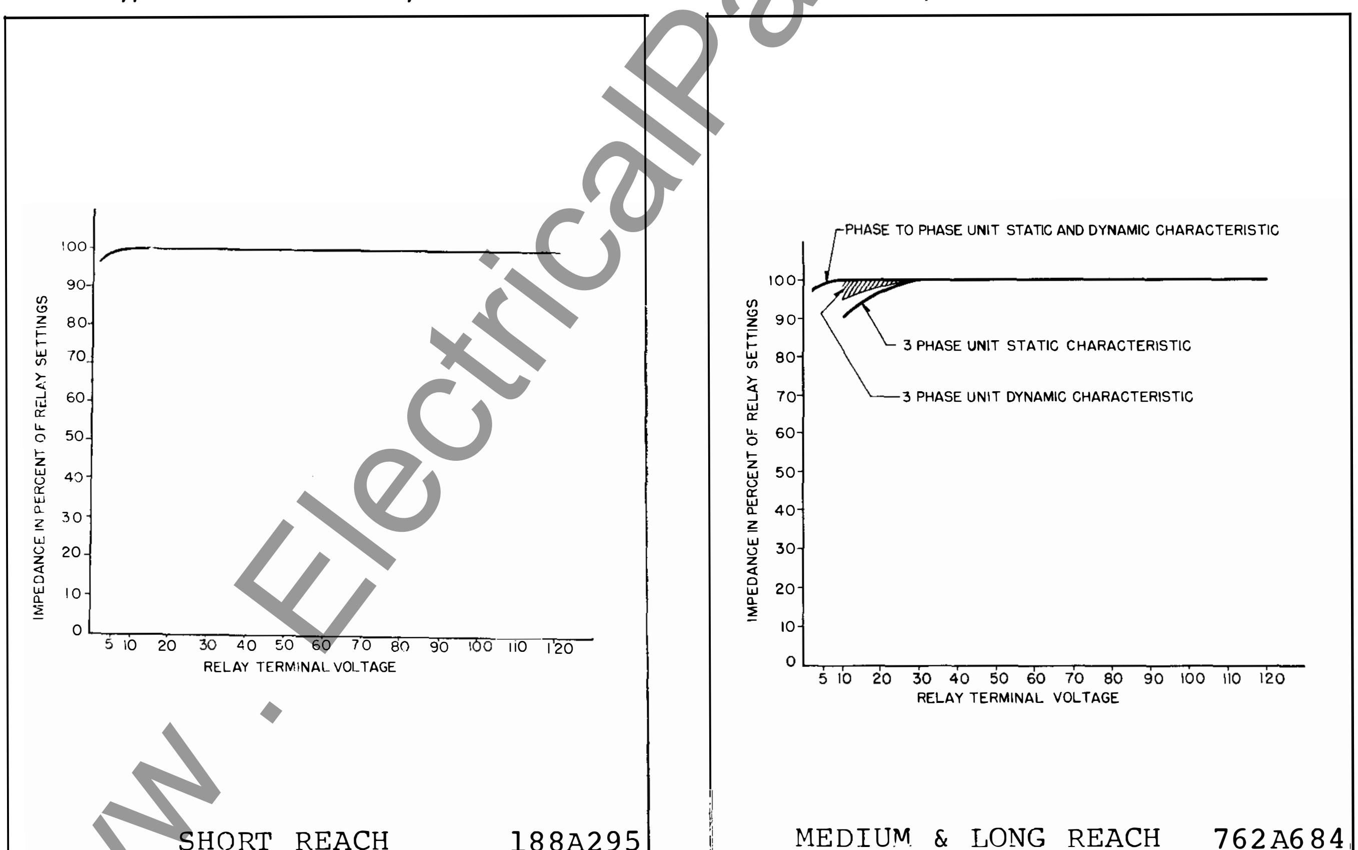

Fig. 12 Impedance Curves for KD-10 Relay

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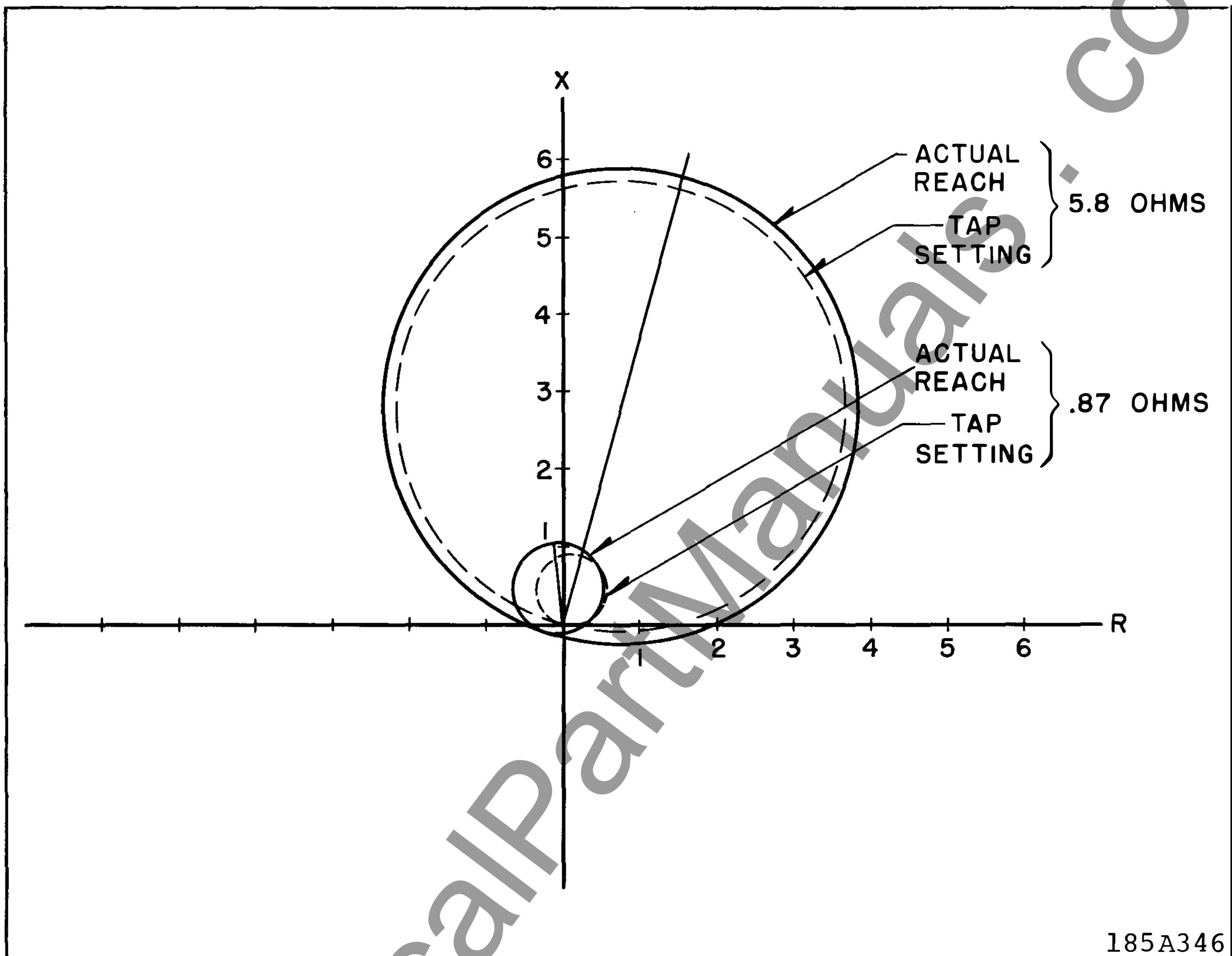

Fig. 13 Impedance Circle for Three Phase Unit in Type KD-11 Relay

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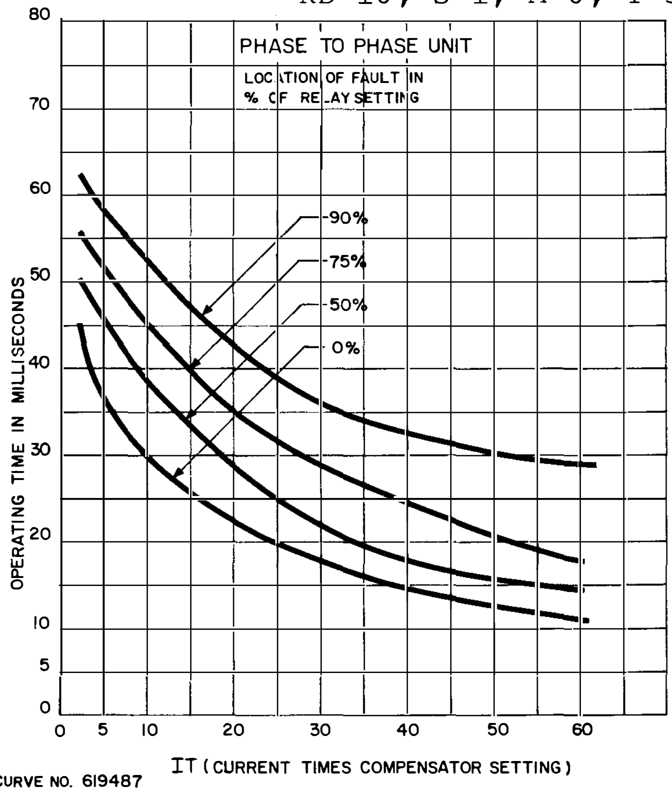
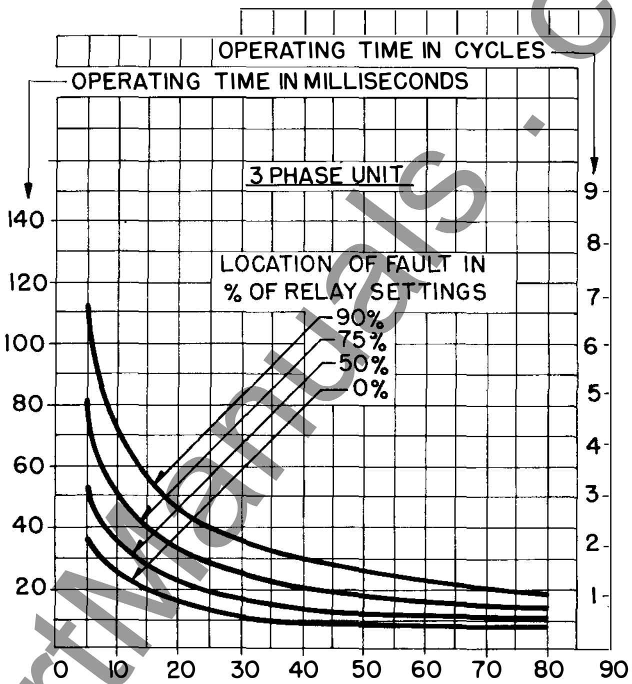
KD-10, S=1, M-0, T=5.8, Max Torque ∠ 75°

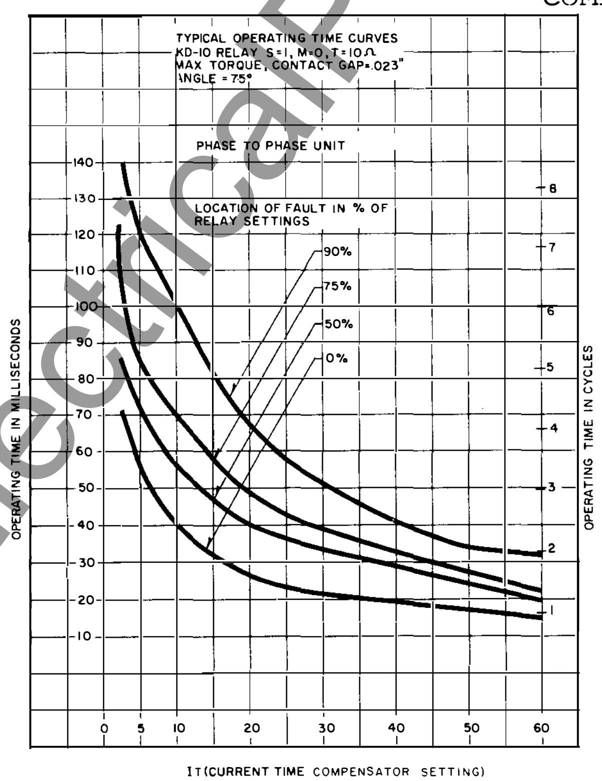


CURVE NO. 619487



762A685

IT (CURRENT TIMES COMPENSATOR SETTING)



619465

Fig. 14 Typical Operating Time Curves Normal Voltages Before Fault 120 Volts. Phase-to-Phase Unit

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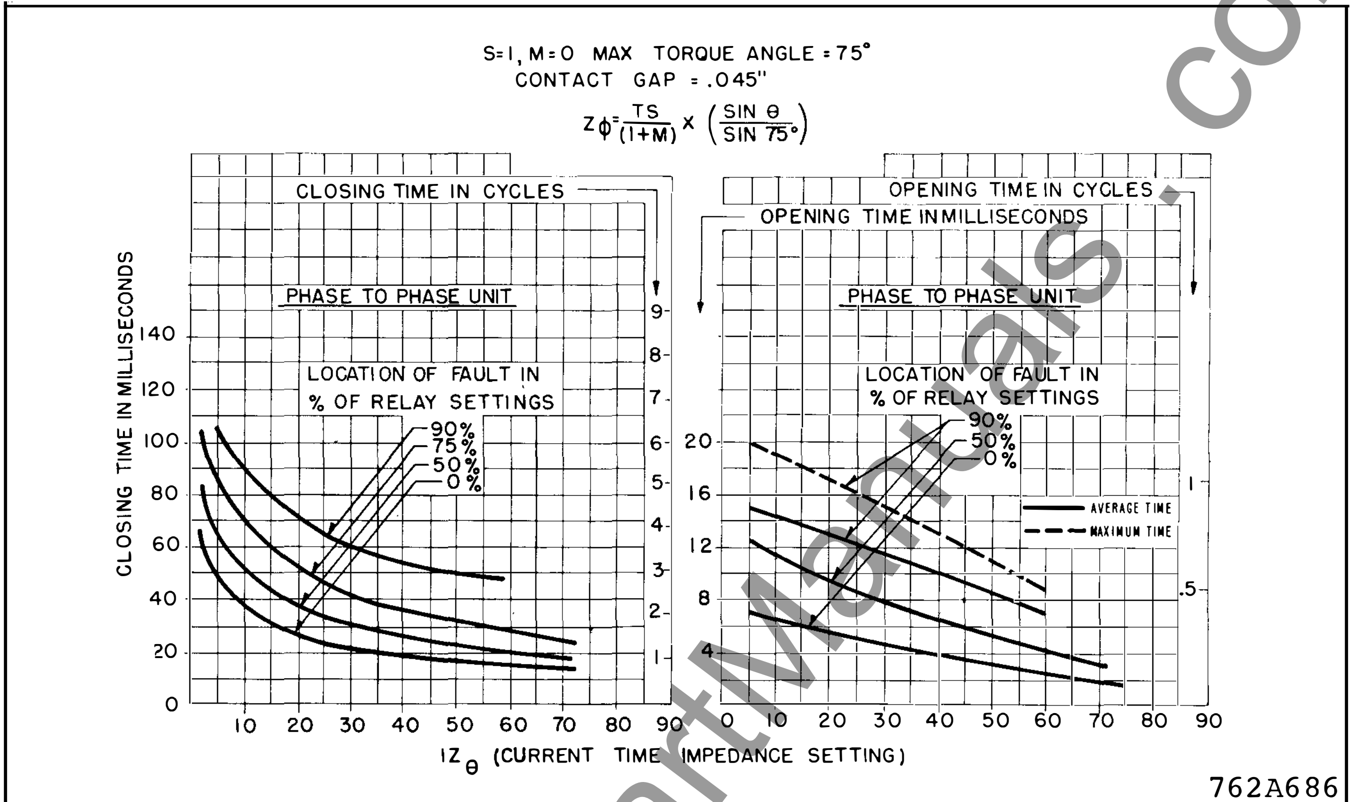
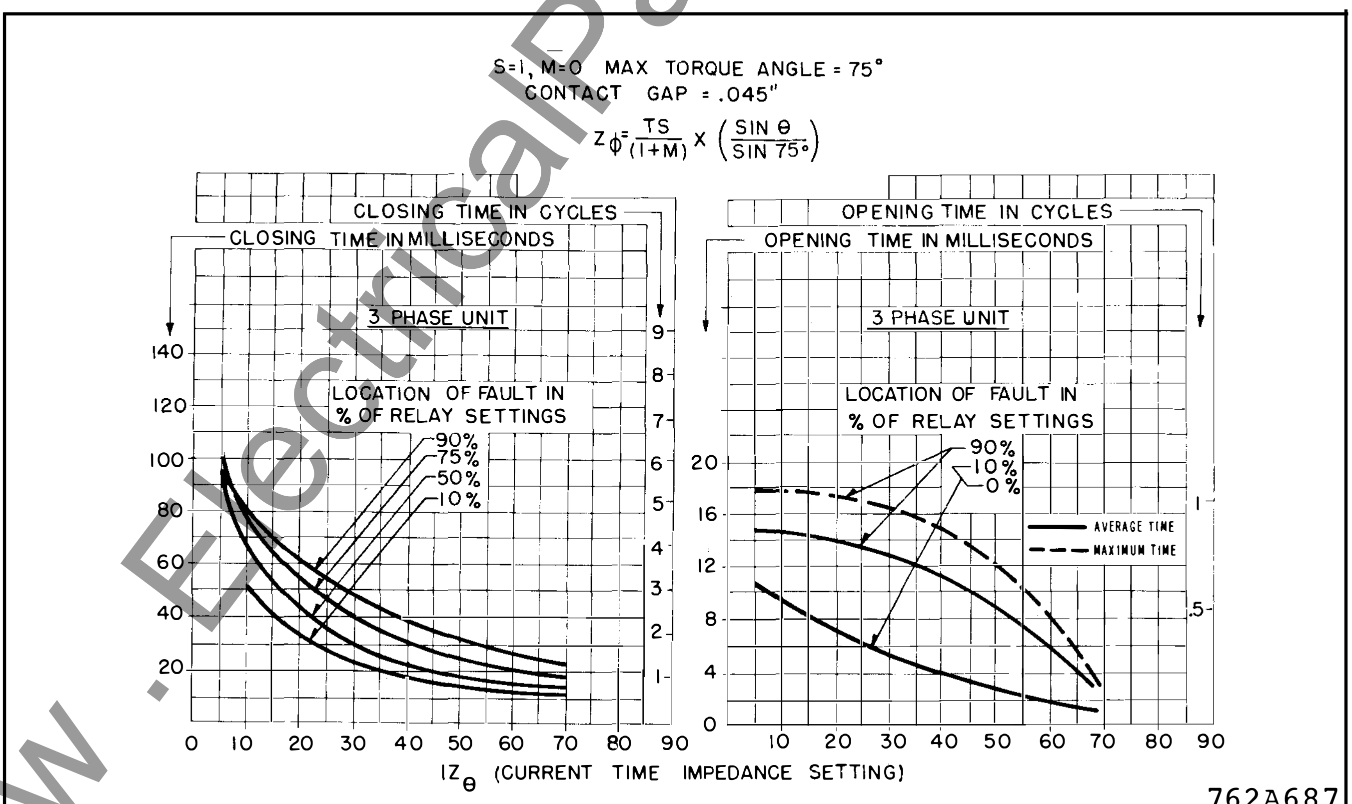


Fig. 15. Typical Operating Time Curves for KD-11 Phase-to-Phase Unit



* *Fig. 16. Typical Operating Time Curves of Type KD-11 Relay Three-Phase Unit (.75-20 ohms)*

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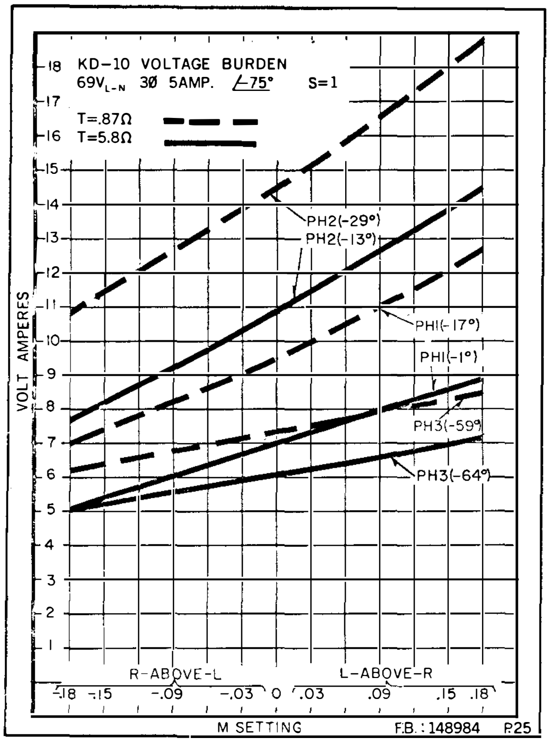

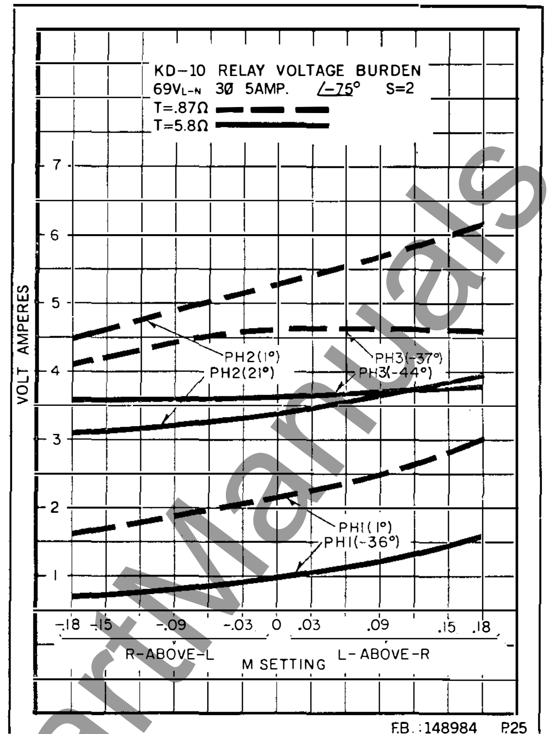

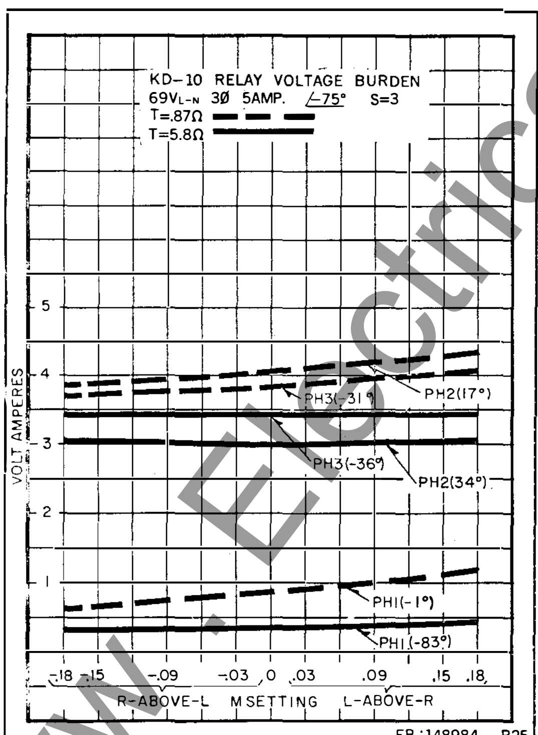

RELAY
KD-10 CURRENT BURDEN TABLE

POTENTIAL CIRCUIT $69V_{L-N}$ 3Ø CURRENT=5∠-75° AMPS. S=1

	Ta			Tb(BOTH)			Tc			T		
TAP SET	V.A.	VARS	WATT	V.A.	VARS	WATT	V.A.	VARS	WATT	V.A.	VARS	WATT
.87	4 92	.303	.387	1.00	.515	.857	.644	.242	.597	.449	.416	.168
1.16	.594	.434	.405	1.23	.740	.983	.806	.315	.742	.618	.611	.096
1.45	.644	.552	.332	1.48	.990	1.10	.966	.423	.868	.838	.837	.044
2.03	.930	.841	.410	2.04	1.44	1.44	1.32	.640	1.155	1.37	1.36	.144
2.9	1.41	1.37	.341	3.09	2.33	2.03	1.93	1.03	1.64	2.39	2.39	0.00
4.06	2.24	2.22	.311	4.66	3.76	2.74	2.91	1.63	2.41	4.13	4.12	.289
5.8	3.76	3.75	.263	7.52	6.31	4.10	4.57	2.62	3.74	7.42	7.41	.126

F.B. : 148984
P27

1426C53

Fig. 17A Type KD-10 Burden Curves

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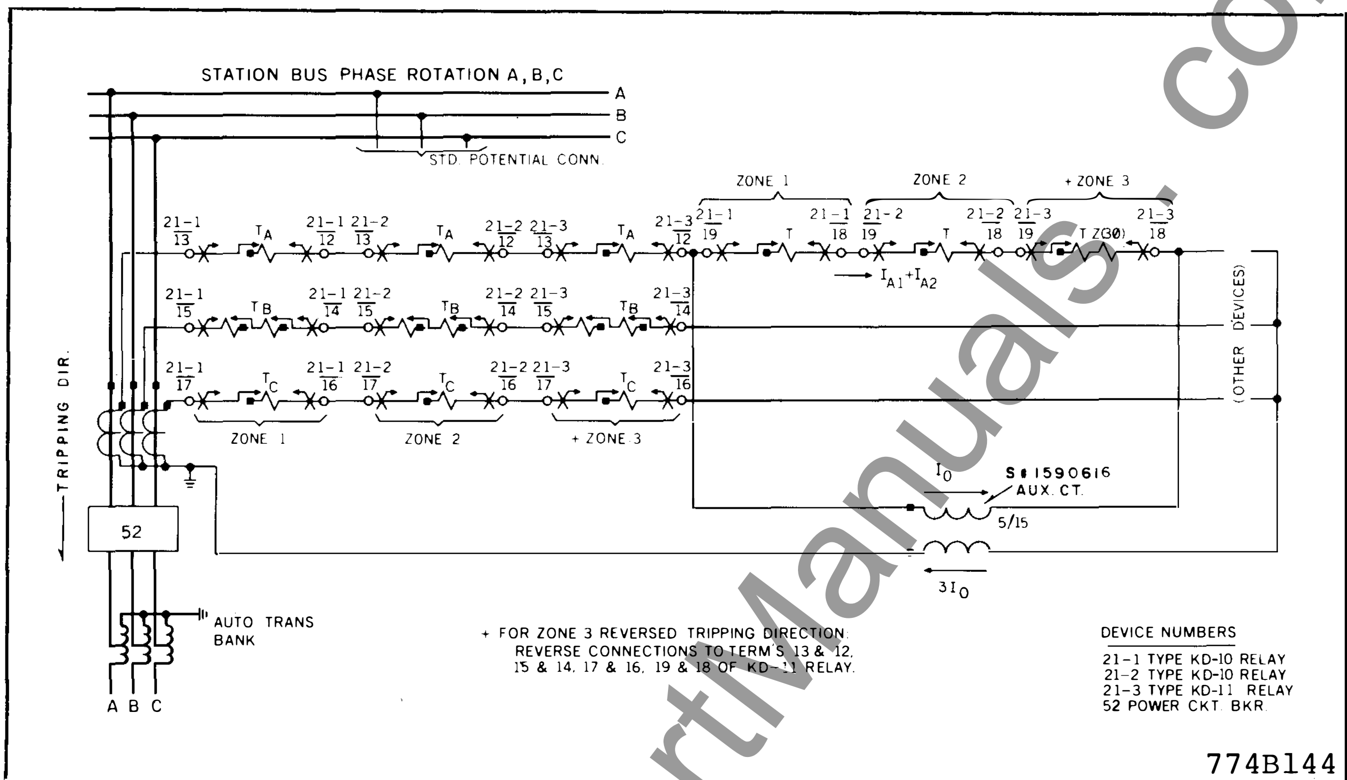

Fig. 20 External Schematic — Two KD-10 Relays, One KD-11 Relay. Autotransformer Termination.

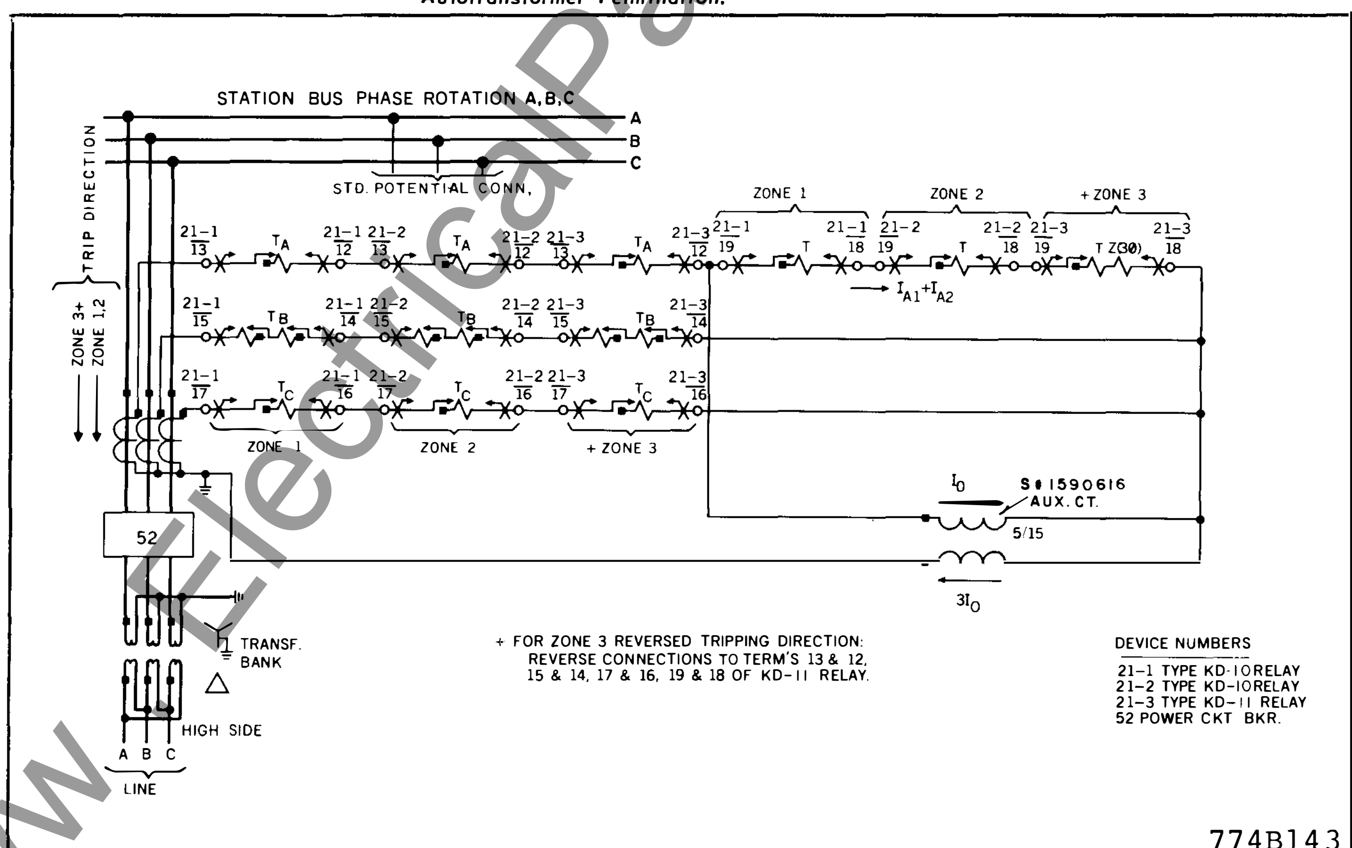

Fig. 21 External Schematic — Two KD-10 Relays, One KD-11 Relay. Wye-Delta Bank Termination with Grounded Wye on Relay Side

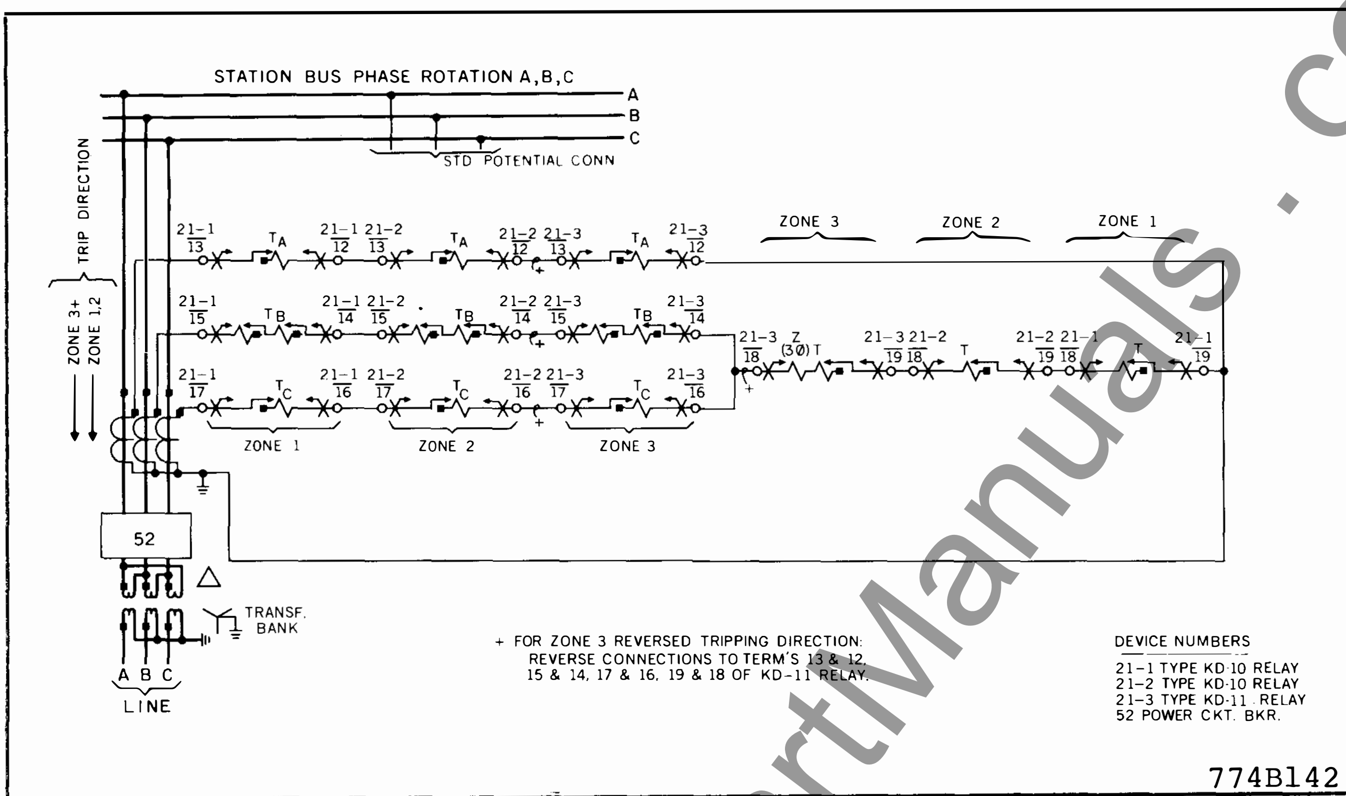

Fig. 22 External Schematic – Two Type KD-10 Relays, One KD-11 Relay. Wye-Delta Bank Termination with Delta on Relay Side

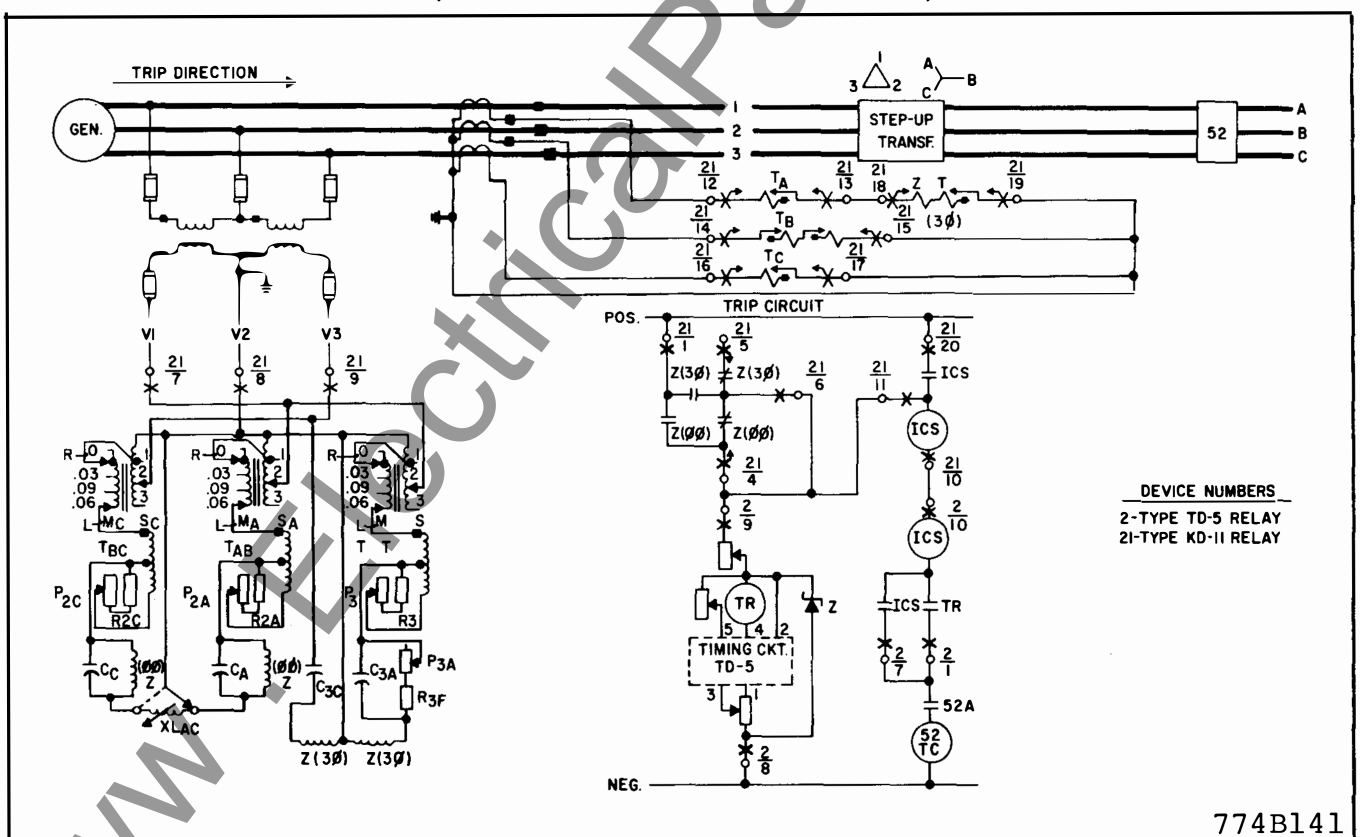

Fig. 23 External Schematic – Type KD-11 Relay with Type TD-5 Timing Relay for Generator Back Up Protection

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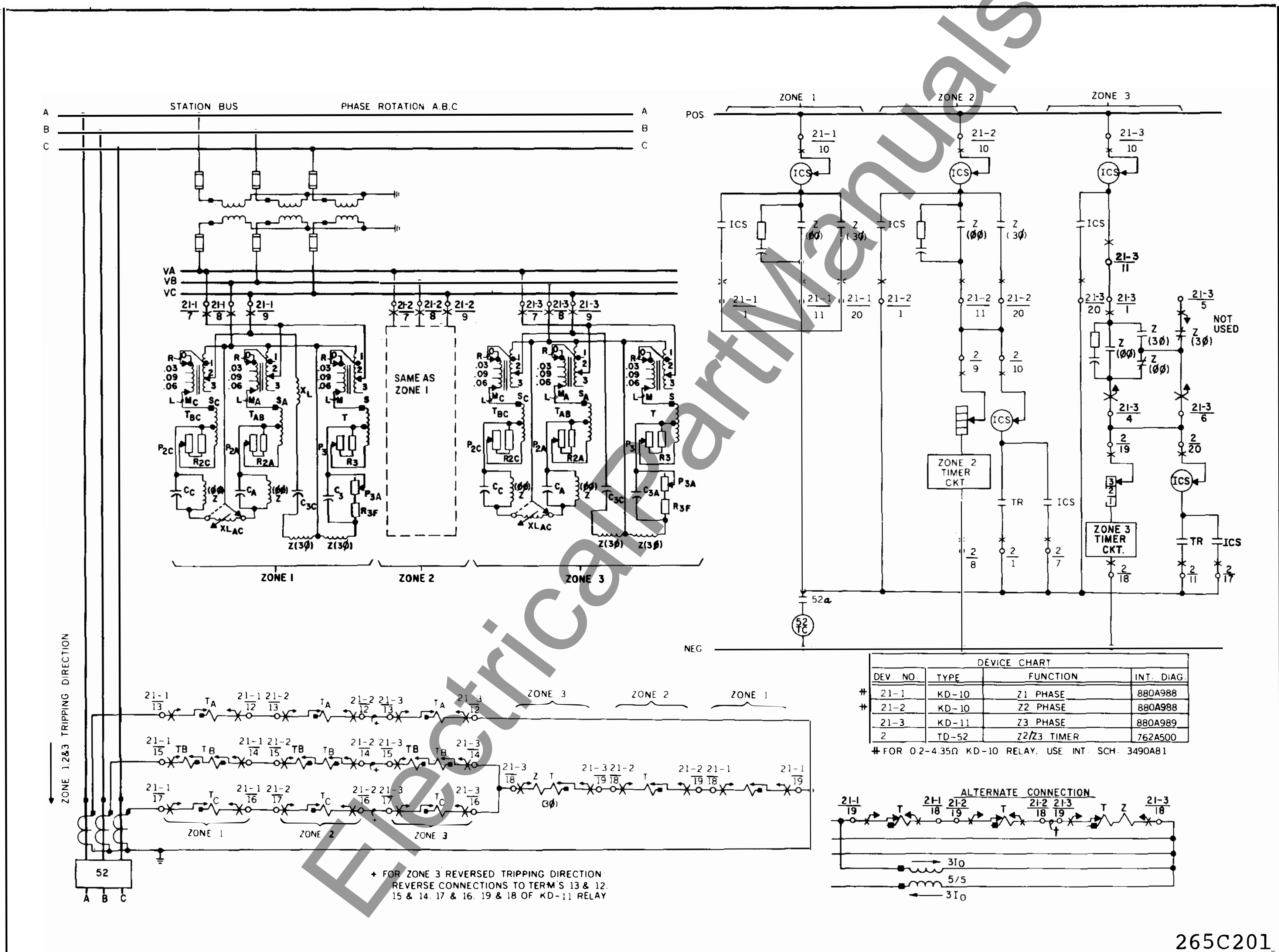

DEVICE CHART

	DEV. NO.	TYPE	FUNCTION	INT. DIAG.
#	21-1	KD-10	Z1 PHASE	880A988
#	21-2	KD-10	Z2 PHASE	880A988
	21-3	KD-11	Z3 PHASE	880A989
	2	TD-52	Z2/Z3 TIMER	762A500

FOR 0.2-4.35Ω KD-10 RELAY. USE INT. SCH. 3490A81

Fig. 24 External Schematic — Two Type KD-10 Relays, One Type KD-11 with TD-52 Timing Relay

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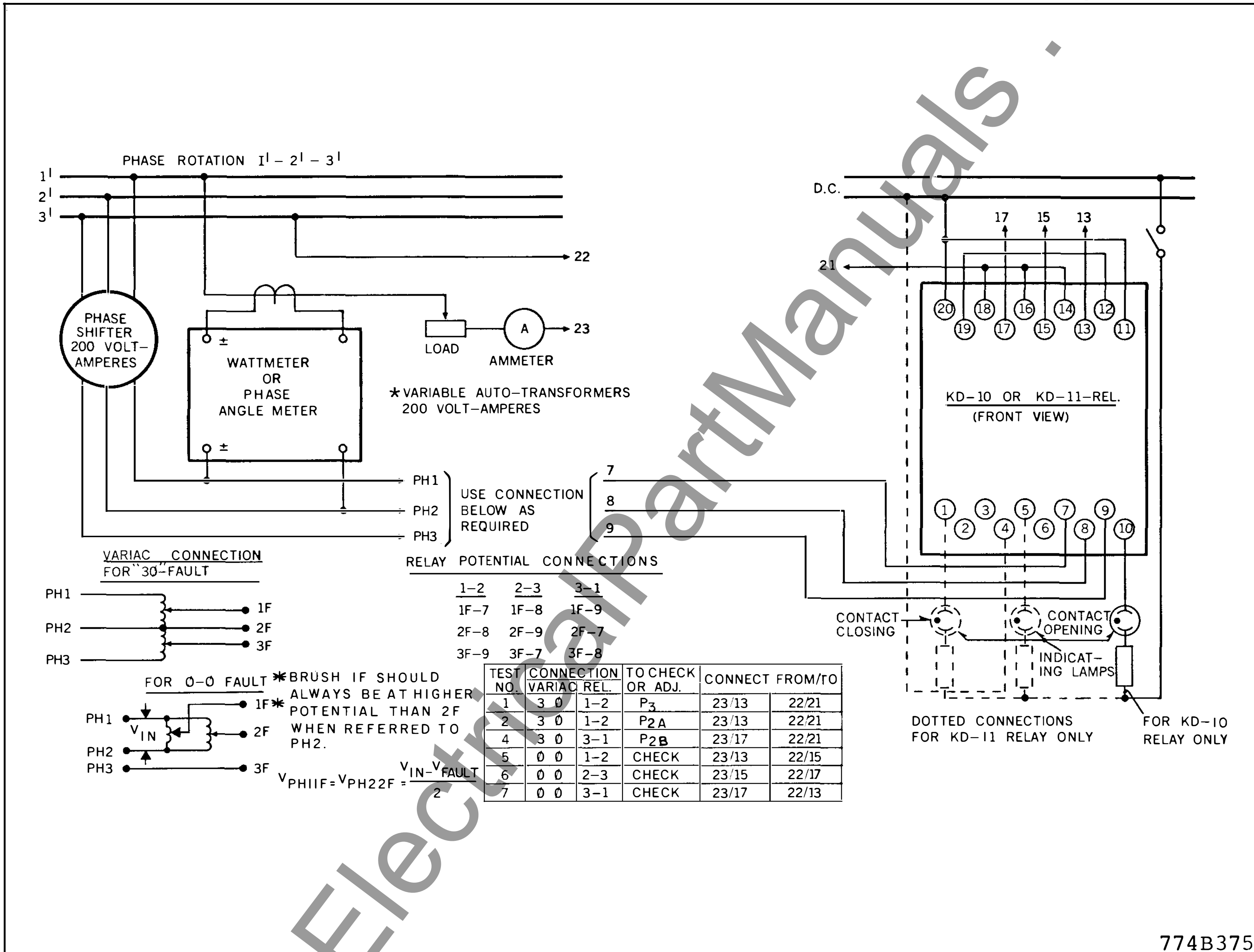

RELAY POTENTIAL CONNECTIONS

1-2	2-3	3-1
1F-7	1F-8	1F-9
2F-8	2F-9	2F-7
3F-9	3F-7	3F-8

$$V_{PH1\,1F} = V_{PH2\,2F} = \frac{V_{IN} - V_{FAULT}}{2}$$

TEST NO.	CONNECTION VARIAC	CONNECTION REL.	TO CHECK OR ADJ.	CONNECT FROM/TO	
1	3 Ø	1-2	P_3	23/13	22/21
2	3 Ø	1-2	P_{2A}	23/13	22/21
4	3 Ø	3-1	P_{2B}	23/17	22/21
5	Ø Ø	1-2	CHECK	23/13	22/15
6	Ø Ø	2-3	CHECK	23/15	22/17
7	Ø Ø	3-1	CHECK	23/17	22/13

Fig. 25 Basic Test Connections for Type KD-10 and KD-11 Relays

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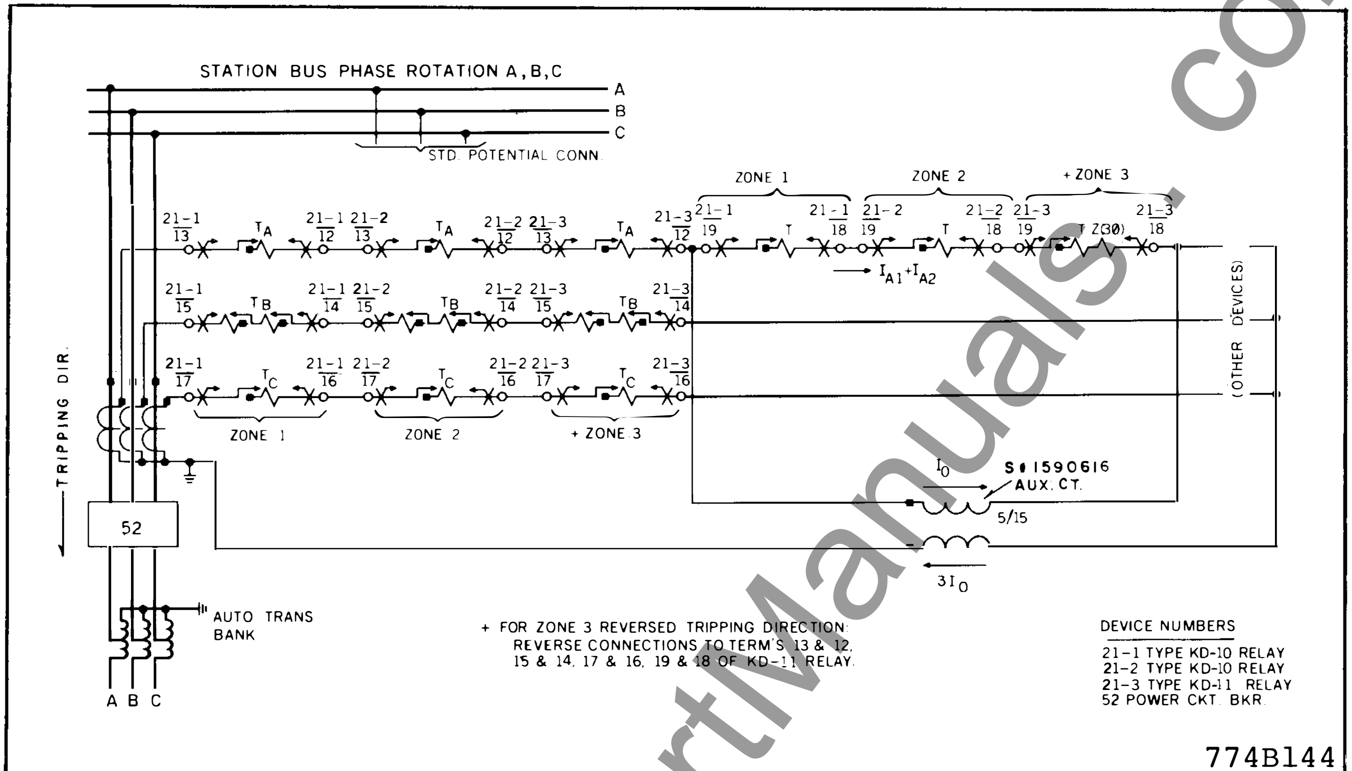

Fig. 20 External Schematic – Two KD-10 Relays, One KD-11 Relay. Autotransformer Termination.

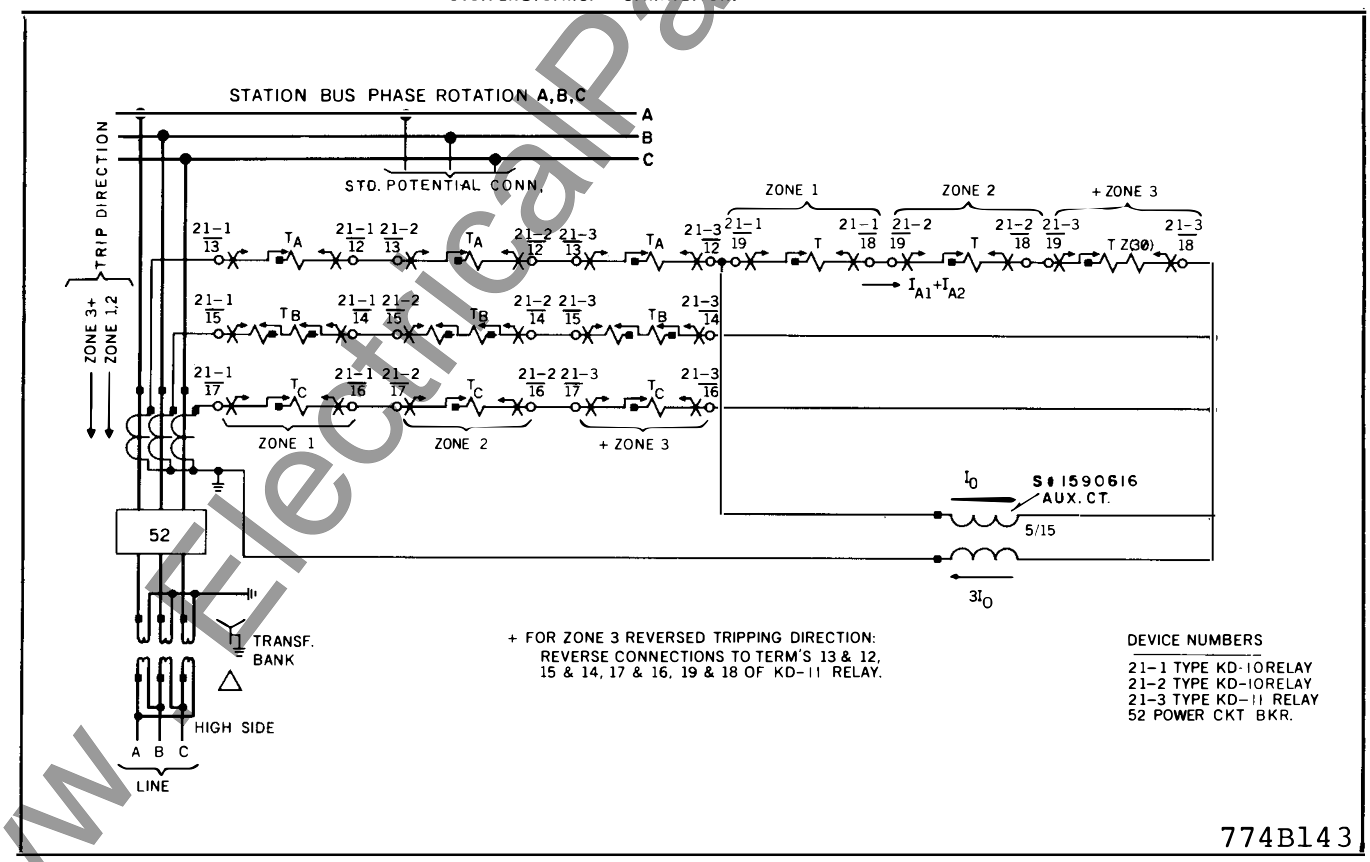

Fig. 21 External Schematic – Two KD-10 Relays, One KD-11 Relay. Wye-Delta Bank Termination with Grounded Wye on Relay Side

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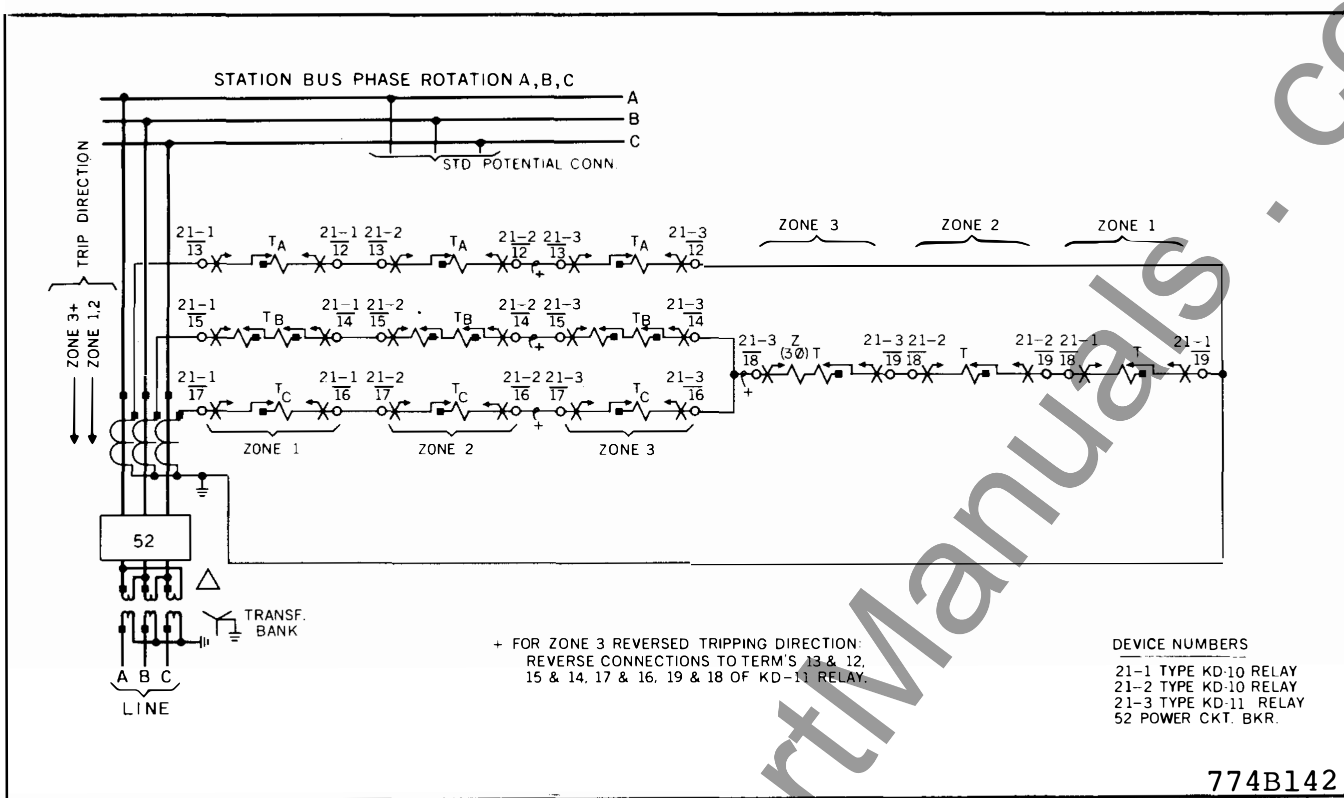

Fig. 22 External Schematic – Two Type KD-10 Relays, One KD-11 Relay. Wye-Delta Bank Termination with Delta on Relay Side

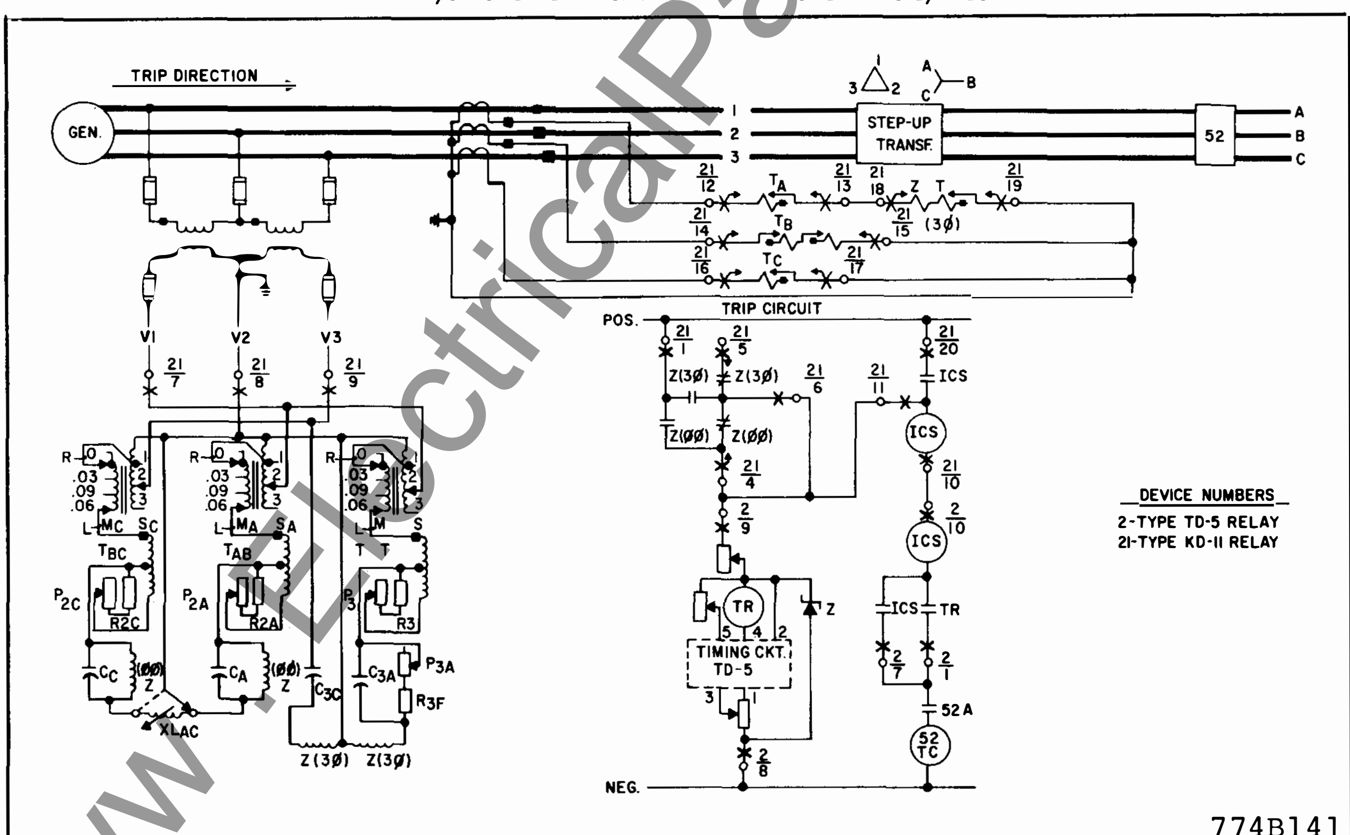

Fig. 23 External Schematic – Type KD-11 Relay with Type TD-5 Timing Relay for Generator Back Up Protection

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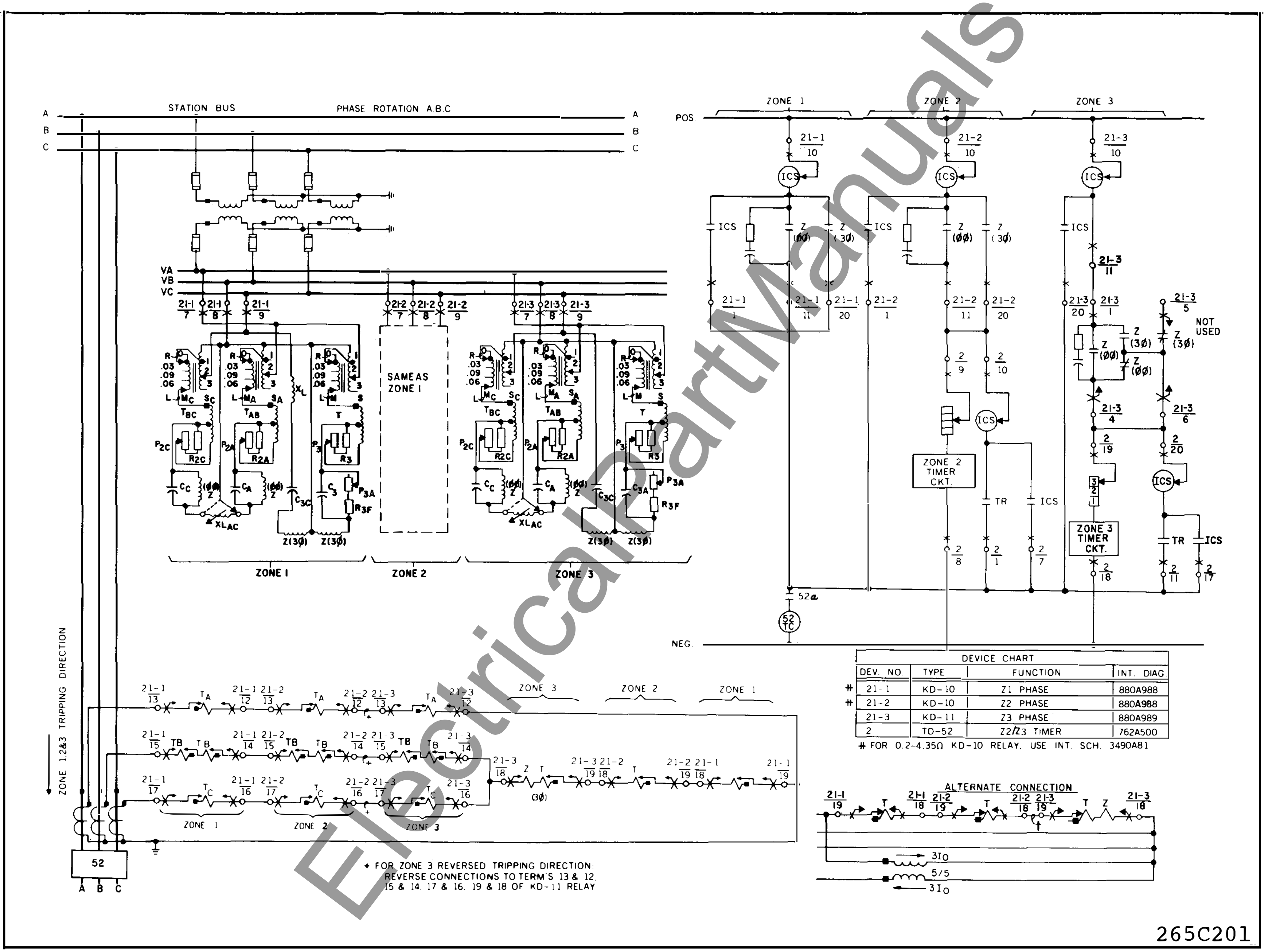

Fig. 24 External Schematic – Two Type KD-10 Relays, One Type KD-11 with TD-52 Timing Relay

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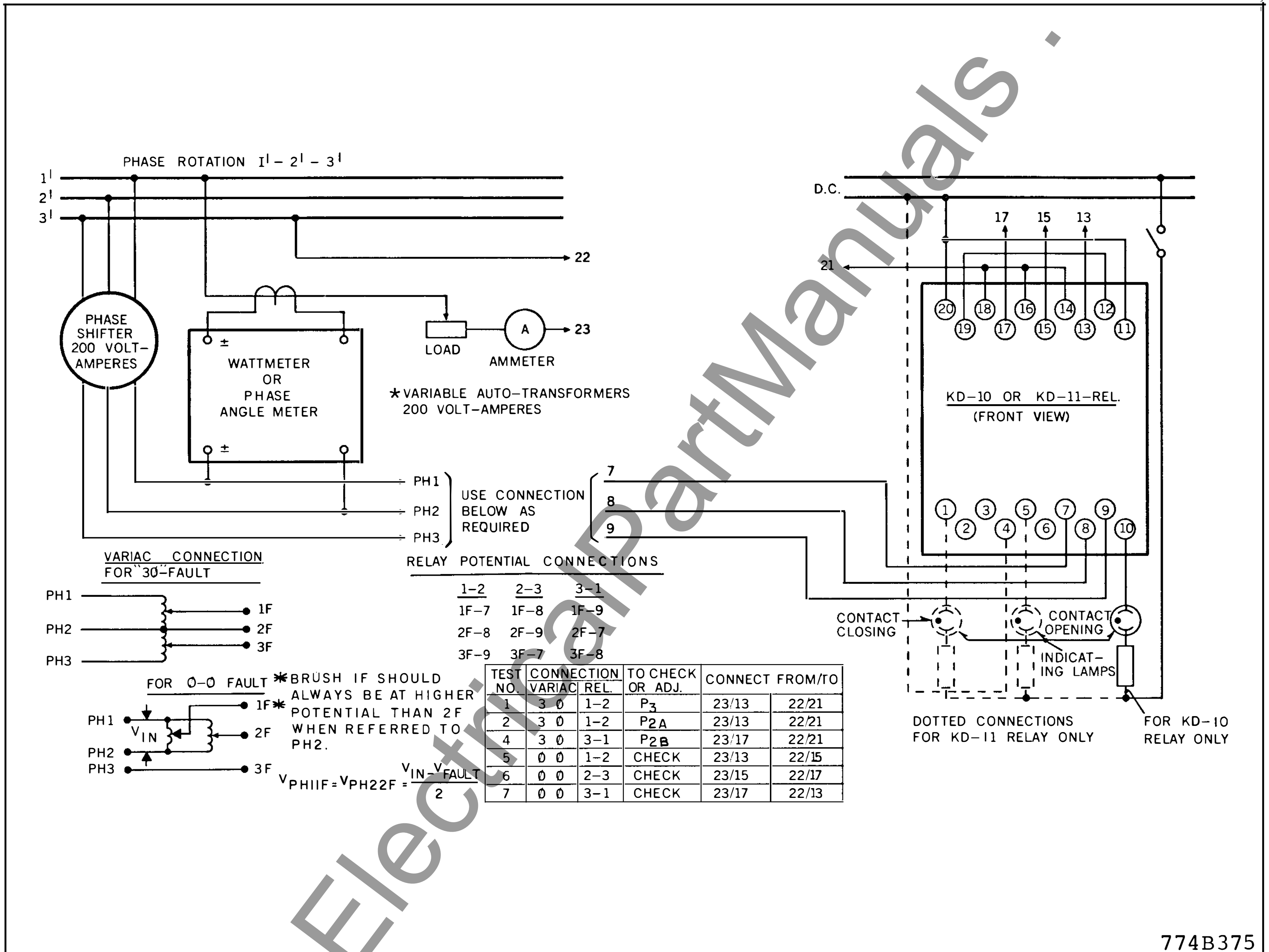

RELAY POTENTIAL CONNECTIONS

1-2	2-3	3-1
1F-7	1F-8	1F-9
2F-8	2F-9	2F-7
3F-9	3F-7	3F-8

$$V_{PH1\,1F} = V_{PH2\,2F} = \frac{V_{IN} - V_{FAULT}}{2}$$

TEST NO.	CONNECTION VARIAC	CONNECTION REL.	TO CHECK OR ADJ.	CONNECT FROM/TO	
1	3 Ø	1-2	P_3	23/13	22/21
2	3 Ø	1-2	P_{2A}	23/13	22/21
4	3 Ø	3-1	P_{2B}	23/17	22/21
5	Ø Ø	1-2	CHECK	23/13	22/15
6	Ø Ø	2-3	CHECK	23/15	22/17
7	Ø Ø	3-1	CHECK	23/17	22/13

Fig. 25 Basic Test Connections for Type KD-10 and KD-11 Relays

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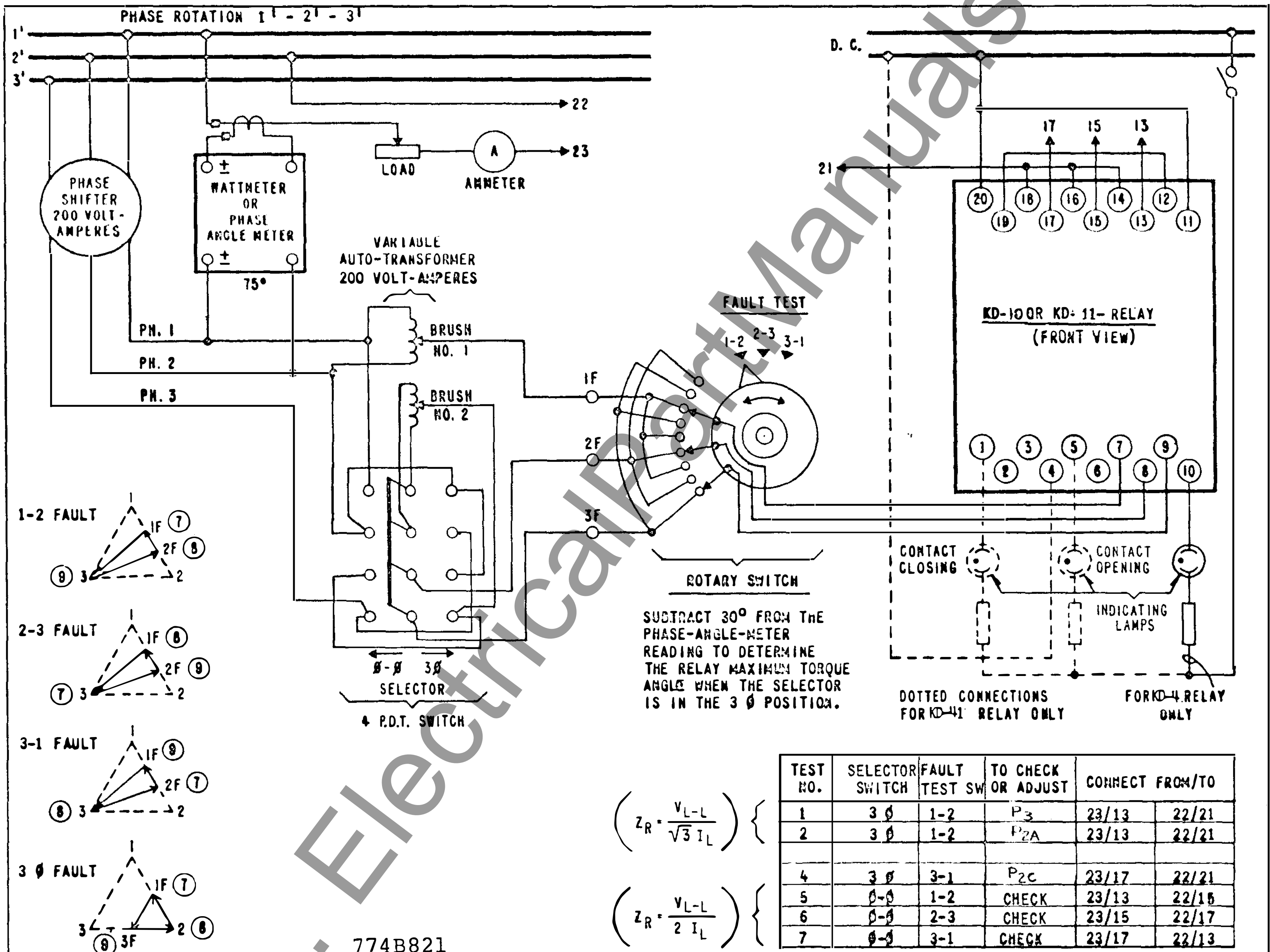

$$\left(Z_R = \frac{V_{L-L}}{\sqrt{3}\, I_L}\right) \text{ (tests 1–4)} \qquad \left(Z_R = \frac{V_{L-L}}{2\, I_L}\right) \text{ (tests 5–7)}$$

TEST NO.	SELECTOR SWITCH	FAULT TEST SW	TO CHECK OR ADJUST	CONNECT FROM/TO	
1	3 Ø	1-2	P_3	23/13	22/21
2	3 Ø	1-2	P_{2A}	23/13	22/21
4	3 Ø	3-1	P_{2C}	23/17	22/21
5	Ø-Ø	1-2	CHECK	23/13	22/15
6	Ø-Ø	2-3	CHECK	23/15	22/17
7	Ø-Ø	3-1	CHECK	23/17	22/13

Fig. 26 Test Connections for Type KD-10 and KD-11 Relays using Auxiliary Switches

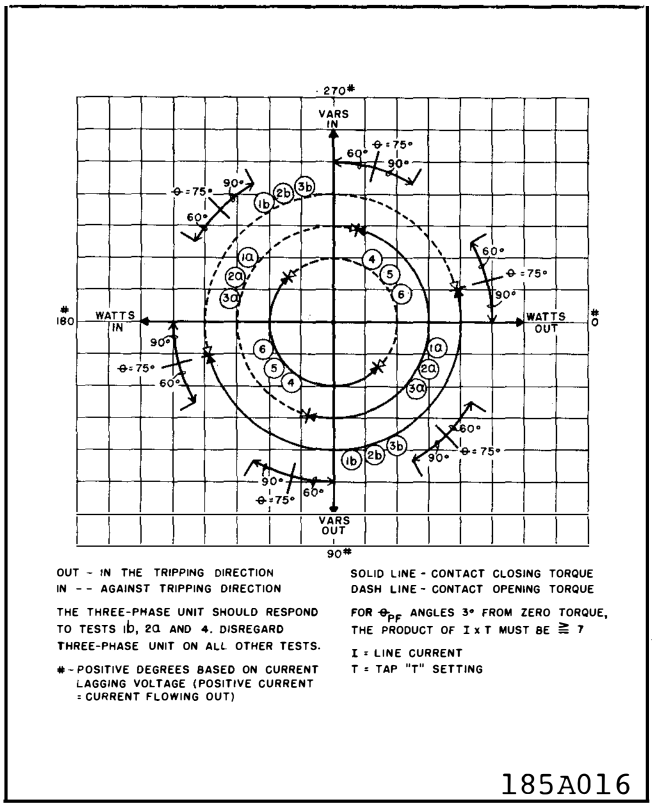

Fig. 27 Phase Diagram for Current Circuit Verification and Identification

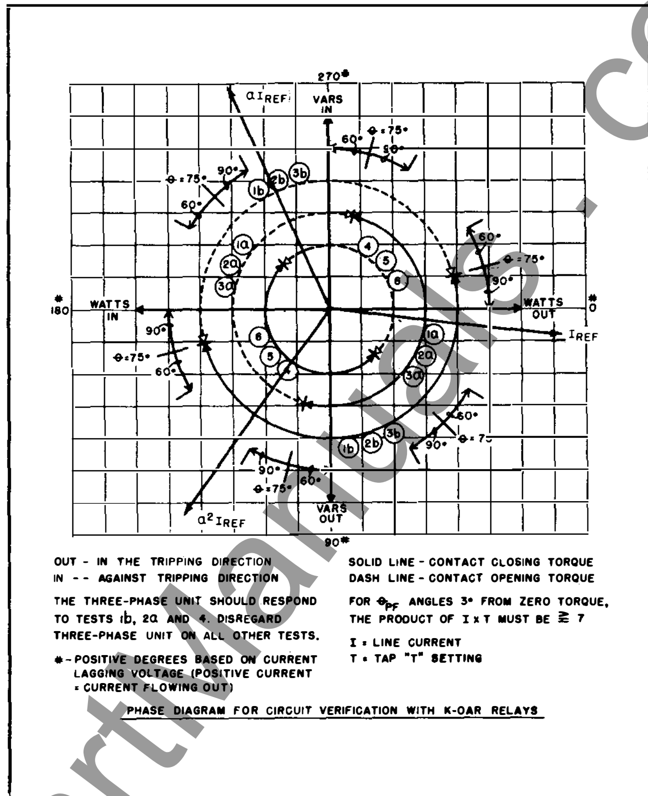

Fig. 28 Phase Diagram Showing Assumed Load Conditions

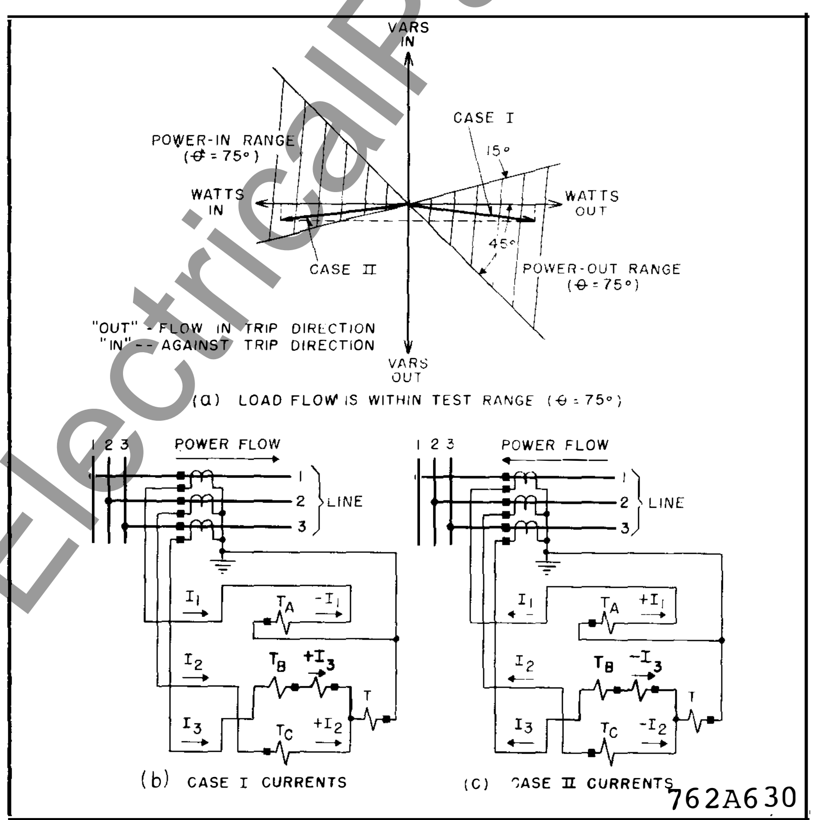

Fig. 29 Actual Wiring for the Assumed Test Results

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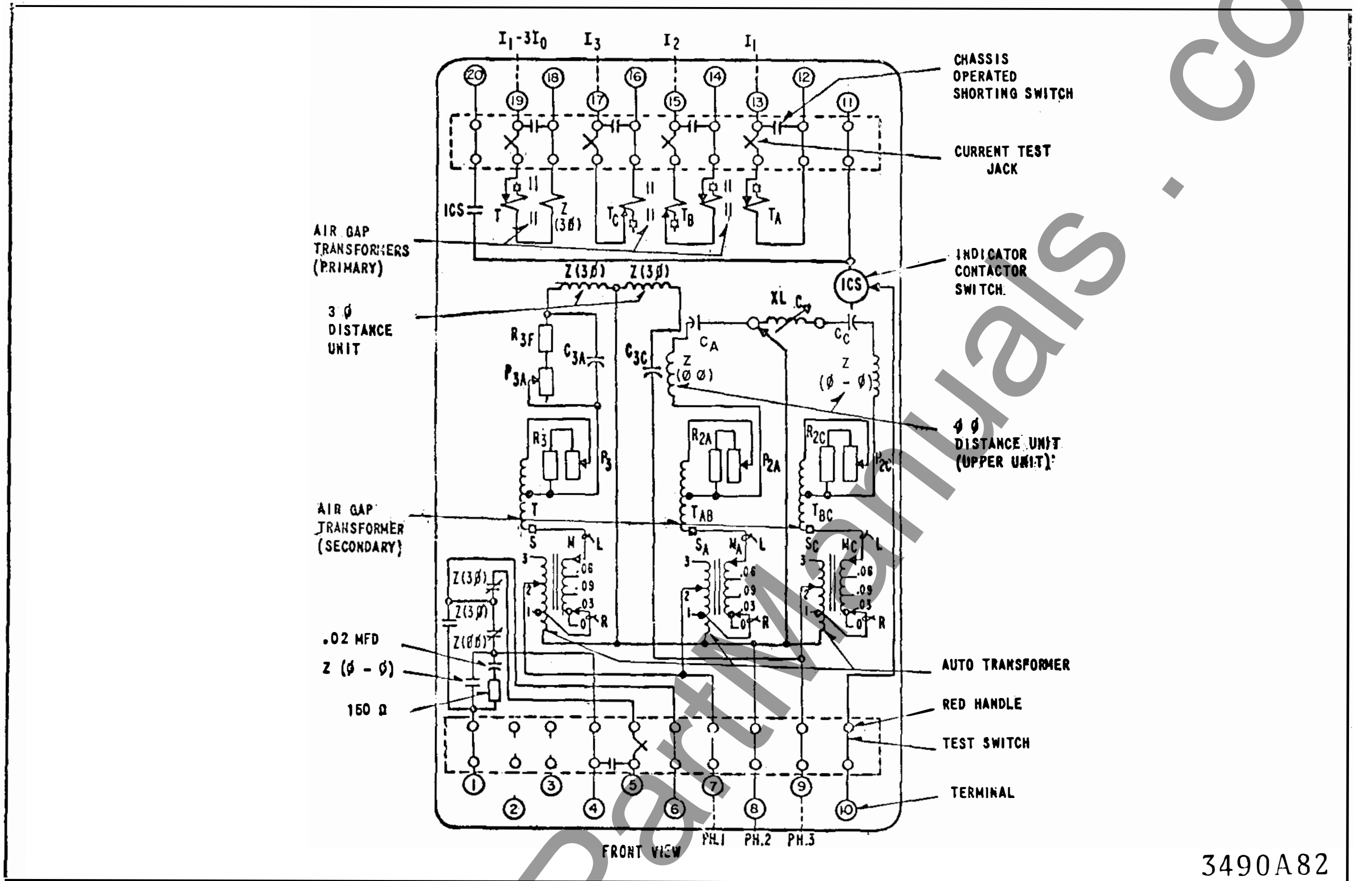

Fig. 30. Internal Schematic of KD-10 Relay (.75-21.0 Ohm Range).

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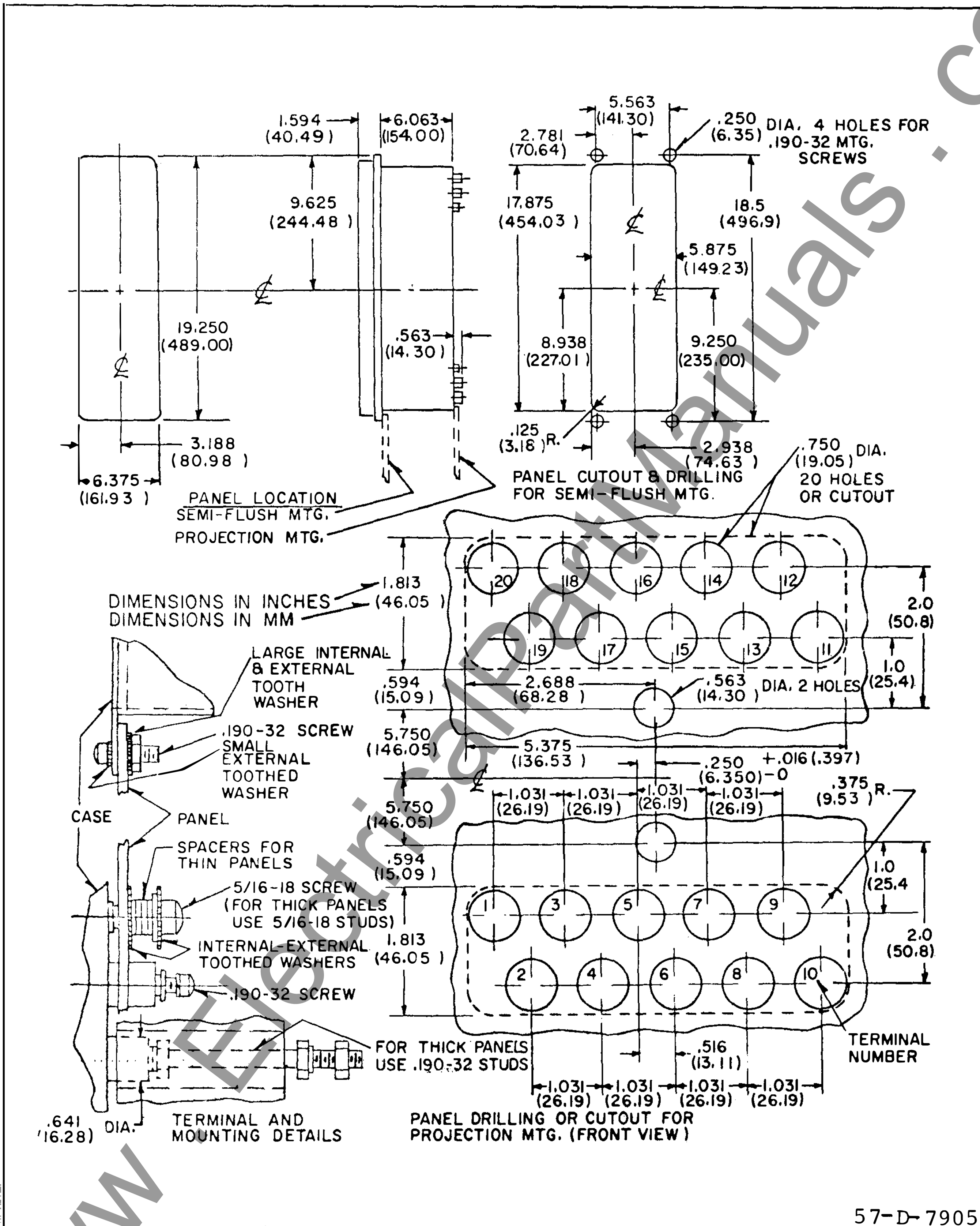
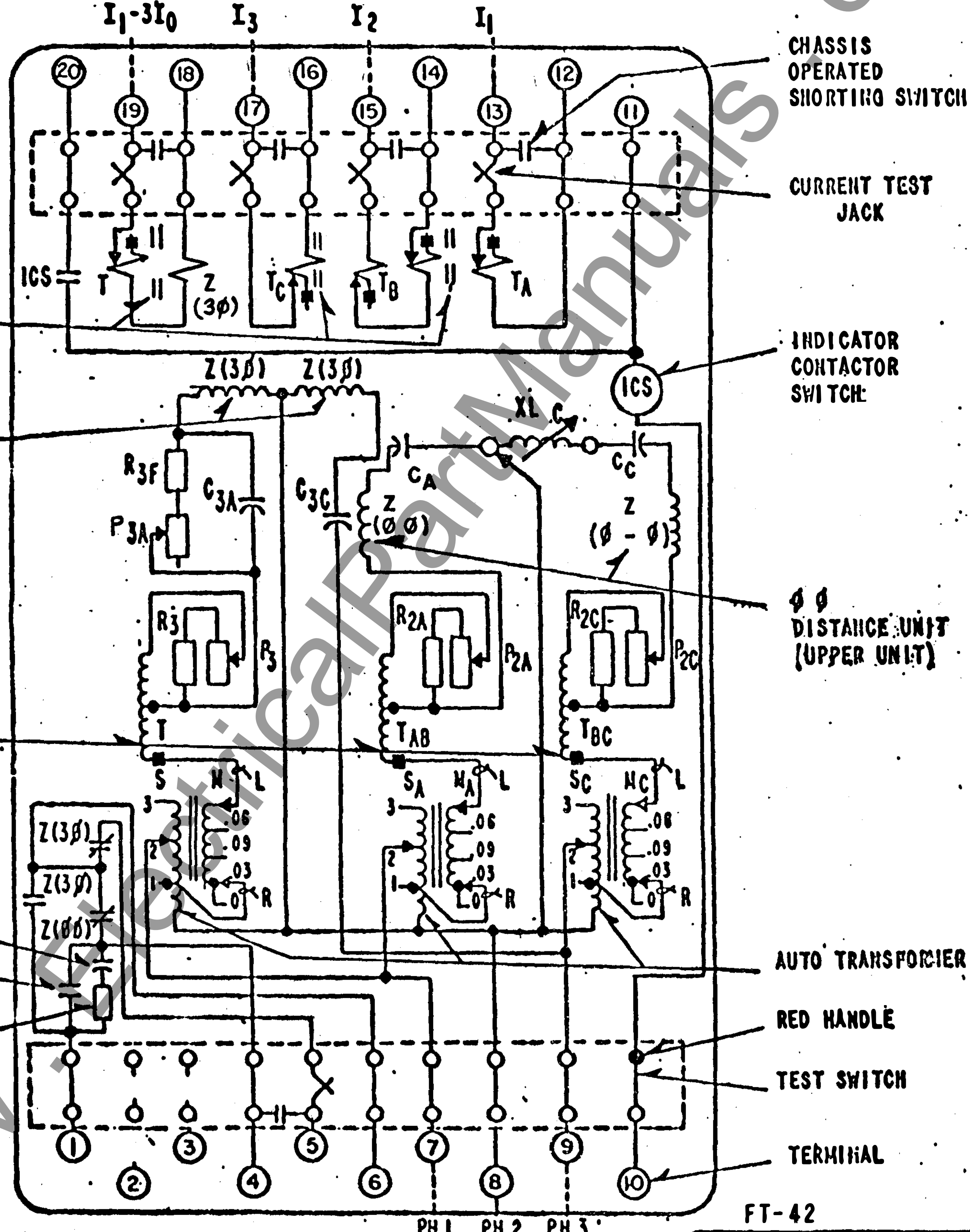


Fig. 31 Outline and Drilling Plan for KD-10 and KD-11 in FT-42 Case

DISTANCE RELAY-TYPE KD-11 (1 AMP I.C.S.)
IN TYPE FT-42 CASE
INTERNAL SCHEMATIC



FT-42

FRONT VIEW

MFG. DWG. 1318D80 REF. 4100 DWG. NO. 3514A68

WESTINGHOUSE ELECTRIC CORPORATION - RELAY-INSTRUMENT DIVISION - NEWARK, N.J., U.S.A.

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INSTALLATION • OPERATION • MAINTENANCE

INSTRUCTIONS

TYPE KD-10 AND KD-11 COMPENSATOR DISTANCE RELAYS

CURRENT VOLTAGE RELAYS WITH MUTUAL REACTOR-PRECAUTIONS

Relays which include compensators to modify the applied voltage (such as the KD types) will produce an output at their voltage terminals when the current circuits are energized.

Thus, it would be possible to pull potential fuses and still have voltage appear on the relay side of the fuses. The magnitude of this voltage is dependent on magnitude of load or fault current, relay settings, relay impedance, and other potential circuit burden connected in parallel with the relay containing the mutual reactor.

To avoid any difficulties due to interaction between current and voltage circuits, it is recommended that when PT fuses have been pulled to permit work on voltage circuits, that these circuits should not be considered safe until the current circuits have been de-energized, or until the voltage circuits have been shorted on the relay side of the fuses.

All possible contingencies which may arise during installation, operation, or maintenance, and all details and variations of this equipment do not purport to be covered by these instructions. If further information is desired by purchaser regarding his particular installation, operation or maintenance of his equipment, the local Westinghouse Electric Corporation representative should be contacted.

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