INSTALLATION • OPERATION • MAINTENANCE

INSTRUCTIONS

TYPE SKDU-31 RELAY

CAUTION: It is recommended that the user of this equipment become acquainted with the information in these instructions before energizing the relay. Failure to do so may result in damage to the equipment. Before putting the relay into service, operate the relay to check the electrical connections.

APPLICATION

The SKDU-31 is used in a distance phase comparison relaying system with an SKBU-11 or SKBU-21 relay and SRU relay. It performs a phase comparison "arming" function and complements the fault detector in the phase comparison relay. It is used instead of the SKDU-3 relay in applications where reclose blocking is desired for all 3-phase faults. Logic is incorporated in the SKDU-31 to detect one high and two low voltages to identify a phase-to-phase-to ground fault.

Three outputs are available from the SKDU-31:

1. Single-phase distance unit output.
2. Single-phase distance unit output supervised by an external blinder or overcurrent unit.
3. Single-phase distance unit output supervised by the SRD (indicating that a $\phi\phi$ or $\phi\phi G$ fault has not occurred).

Logic in the SRU relay further imposes the restriction for reclose blocking that a ground fault has not occurred.

CONSTRUCTION

The SKDU-31 relay contains distance measuring logic of an SKDU-3 relay, phase-to-phase fault detector logic of an SRD relay, and "AND" logic mounted on a standard 19-inch wide panel, 5¼ inches high (3 rack units). Printed circuit boards may be plugged into a card extender, Style No. 849A534G01 to make test points accessible for in service checking.

Distance Logic

The distance logic consists of two single air gap transformers (Compensators T_A, T_C), two tapped auto-transformers TAB, TCB, two isloating transformers T1, T2, a phase shifting network, and three printed circuit boards designated as Operating Circuit, Polarizing Circuit, and Output Circuit.

Fault Detector Logic

The phase-to-phase fault detector logic consists of three isolating transformers T3, T4 and T5 and two printed circuit boards designated as fault discriminator and level detector.

"AND" Logic

The "AND" logic has three inputs. One input is buffered against surges and receives a signal from external logic such as an external fault detector or blinder relay. The other two inputs are from the internal fault detector logic and the distance logic. It has two outputs; one to SRU or pilot-trip auxiliary and one to reclose-block circuitry. The relay has an additional output from the distance unit which is unsupervised.

Compensator

Compensators TA and TC are two-winding air gap transformers (Fig.2). The primary or current winding of the compensator has seven taps which terminate at the tap black (Fig. 3). TA is the long reach compensator.

Tap markings for respective units are as follows;

TA	2.05	2.74	3.76	5.13	7.18	9.92	13.7
TC	1.64	2.19	2.75	4.1	5.78	7.94	10.9

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 product of tap setting and primary

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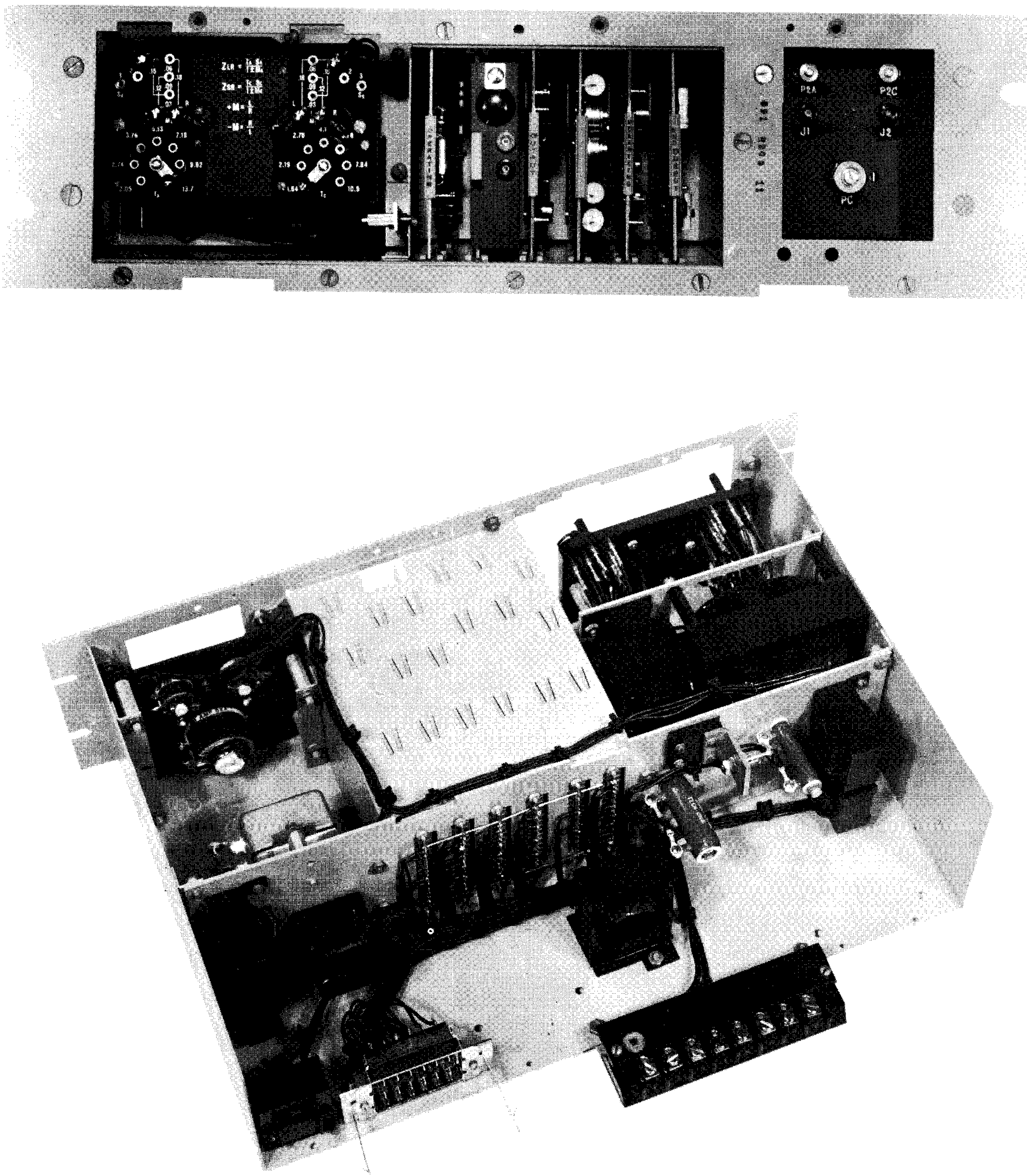


Fig. 1. SKDU-31 (Front View, Rear View)

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 disturbed 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 line current is subtracted vectorially from the relay terminal voltage. The second terminal is connected to the potentiometer and provides a means of adjusting the phase angle relation between primary current and the induced secondary voltage. The phase angle may be set for any value between 60° and 80° by adjusting the potentiometer between its minimum and maximum values respectively. The maximum sensitivity angle is set for 57° (current lagging voltage) at the factory.

Auto-transformer

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

The sign of M is negative when "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 the compensators by the multiplier of $\frac{S}{1 \pm M}$.

Therefore, any relay ohm setting can be made within ± 1.5 percent from 1.74 ohms to 50 ohms for long reach setting, and from 1.43 ohms to 40 phms for short reach setting by combining the compensator taps TA and TC with the auto-transformer taps AS and MA, and SC and MC.

Isolating Transformers (T3, T4, T5) & Phase Splitting Networks

Isolating transformers of the phase-to-phase fault detector are designated as T3, T4 and T5. Each of the three isolating transformers has a rated voltage 70 volts 50/60 hertz primary winding. The transformer secondary is a center tapped winding rated 70 volts open circuit and 35 volts to center tap.

Each of the three-phase splitting networks contain a capacitor ($4C_1$, $4C_2$ or $4C_3$), a resistor ($4R_1$, $4R_2$ or $4R_3$) and a potentiometer (4R11, 4R12, or 4R13). Located on the ϕ-ϕ fault discriminator circuit board, they are series connected across the transformer secondary. The potentiometer is adjusted so that the voltage drop across the resistor in series with the potentiometer is equal, in magnitude to the secondary tap voltage. Three voltages can then be measured to form a phasor triangle, the sides of which are nearly equal in magnitude and have a 60° phase angle between adjacent sides. The three voltages are: (1) Across 4R1 and potentiometer 4R11 (4TP1 to terminal 4 on the ϕ-ϕ fault discriminator circuit board for one phase); (2) From 4TP1 to transformer tap at terminal 6, and (3) from tap terminal 6 to terminal 4.

The resulting polyphase voltage drived from phase-A-to-neutral voltage is then applied to a three-phase bridge rectifier to obtain a low ripple d-c voltage. This d-c voltage is proportional to the a-c input voltage. In a similar manner the output from 4TP2, terminal 3 and 8 is proportional to phase-B-to-neutral voltage. From 4TP3 terminal 10 and 11, the voltage is proportional to phase-C-to-neutral voltage.

Printed Circuit Board Assembly

Taking front view of SKDU-31, from left to right, viewed from the front, the printed circuit boards are: (1) Operating circuit board; (2) polarizing circuit (3) output circuit board; (4) ϕ- ϕ fault discriminator board; (5) level detector circuit board, and (6) "AND-Output" circuit board. In Fig. 4 all the components are identified by the letters aXb-- the first letter, a, indicates circuit board position number; the second letter, X, is used to specify the type component and the "b" is the component number. In these circuit boards, the resistors are identified by "R", the diodes by "D" the Zener diode by "Z", transistors by "'Q", thyristors by "QS", capacitors by "C", and the test points by "TP". Boxed-in Q numbers indicate normally conducting transistors.

When facing the component side of the printed circuit board, with terminals at the bottom, terminals are numbered 1 to 14 from right to left. These terminal numbers are shown in the internal schematic.

Case Construction

The jack plug on the rear has 24 terminals numbered left to tight and top to bottom. Thus terminal #1 is located in the upper left-hand corner when viewed from the rear, and terminal #24 is in the lower right-hand corner. Terminal #1 is connected internally to the chassis ground and may be used for grounding the connecting cable shields.

There is also an 8-terminal strip used for current terminals which is located in the right-hand side of rear when viewed from the back. The terminals are numbered from left to right.

The chassis case, cover, and front panel have electrical connections established by the use of shakeproof washers which cut through any point or protective coating to make electrical contact with the base metal. The complete relay is then grounded to the switchboard or cabinet by an external wire connection which must be made by clamping the wire under a shakeproof washer which also serves to help hold the cover in place.

The door is hinged at the bottom and is secured at the top by two captive screws. It may be opened to 90 degrees where it is stopped by a slotted strap attached to the door and also to the frame of the case. To remove the door, release the strap by either unscrewing it or unhooking it from the door and then slide the door to the right to disengage the hinges.

Printed-circuit boards are connected into the electrical circuits of the relay through 14-terminal connectors. The boards can be disengaged by a steady pull outward. Sometimes a simultaneous up-and-down motion (if there is clearance) will help free the mating connections. The boards are keyed so that they cannot be pushed home into the wrong connector although they may be replaced into the guides of the wrong position.

OPERATION

SKDU-3

The SKDU-3 unit has two major components, the compensators and the tripping unit. In the internal schematic of Fig. 4, compensators T_A and T_C are shown connected so as to modify the voltage to the the long-reach coils T1 and short-reach coils T2 respectively.

Operation of the SKUD-3 unit can be explained by referring to Fig. 5. In this Figure, the addition of of voltage phasors at various fault locations, results in a set of phasors indicating predominantly positive sequence voltages so that voltage V_{ZY} leads V_{XY} for restraining the tripping unit or indicating predominantly negative sequence voltages so that voltage V_{ZY} lags V_{XY} for operating the tripping unit.

In Fig. 5 the short-reach setting Z_C is about 1/3 of the long-reach setting (Z_A) and is in the reverse direction. This produces an offset circle characteristic which includes the origin when plotted on an R-X diagram. Terms and symbols used in the diagrams are defined as follows:

V_{SM} = Output voltage from each individual autotransformer which receive phase to neutral voltage.

Z_A = Mutual impedance setting of the long-reach compensator

Z_C = Mutual impedance setting of the short-reach compensator

I = Phase current

V_{XY} = Operate circuit voltage (across T1 in Fig. 4)

V_{ZY} = Polarizing circuit voltage (across T2 in Fig. 4)

V_{ZY} leads V_{XY} = restraining condition

V_{ZY} lags V_{XY} = operating condition

Consider a fault at location "A" which is beyond the long reach setting. For the sake of simplicity, assume both the line angle and the relay maximum sensitivity angle to be 90°. Compensator Z_A modifies voltage V_{SM} by adding the mutual impedance drop IZ_A which leaves voltage V_{XY} across the input of transformer T_1 .Compensator Z_C modifies its voltage V_{SM} by adding IZ_C to produce V_{ZY}. This voltage is then advanced 90° by phase shifting action of capacitor C_2 to provide voltage V_{ZY} across the transformer T_2. The resulting diagram shows V_{ZY} leads V_{XY} and restrains the unit for this fault beyond the protection zone.

Using the same method of analysis for a fault at location "B", the long reach setting Z_A, it is shown that X, Y, and Z lie in a straight line to produce a balance point. Within the protected zone, for a fault at location "C", the V_{XY} voltage is reversed by compensator action and leads polarizing voltage V_{ZY} to produce a tripping condition. At location "D", which is behind the relay and within the short reach setting, the trip condition still exists even though I_1 is reversed because I_1Z_C is sufficiently large to reverse the polarizing quantity V_{ZY}. A fault at location "E", behind the relay and outside the protected zone causes a current reversal in both compensators. The restraining voltage V_{SM} is large enough so that V_{ZY} is not reversed. Thus V_{XY} & V_{ZY} have a restraint relation.

The combination of series resistor R_A and parallel capacitor C1 shown in Fig. 4 controls transients in the operating circuit and also provides a small amount of phase shift. In the polarizing circuit, capacitor C2 provides memory action to improve the operating characteristics for faults near the relay location. C2 also provides the major phase shifting effect which makes the voltage across T2 lead the voltage across T1 by 90° when only voltage is applied to the relay. The maximum sensitivity angle (75° or other angles up to 90°) can be adjusted with potentiometer PC.

Phase Angle Comparison Unit (Tripping Unit)

Referring to Fig. 4, the phase angle comparison unit is tripped when current flows into the base of transistor 3Q1 through Zener Diode 3Z1. Such tripping must come from the 20-volt bus, through either transistor 1Q2 or 1Q4 located in operating circuit board. The operating circuit, driven by transformer T_1, is continually trying to trip the unit by supply current through 1Q2 and 1Q4 on alternate half cycles. 1Q2 conducts when the polarity marked terminals of T_1 are positive.

When 1Q2 conducts, a portion of the current goes through 2R9. This current, IR9, may take either of two paths to the negative bus. If $2QS_1$ is in a conducting state, IR9, flows through it directly to the negative bus. If $2QS_1$ is in the blocking state, IR9 passes through diode 2D16 and then through 3Z1 to transistor 3Q1 to cause tripping. Thyristor $2QS_1$ is located in the "polarizing" circuit and is driven by transformer T_2.

To prevent the operating circuit from causing tripping, the polarity marked terminal of T2 must go positive before the polarity terminals of T1. This causes $2Q_1$ to conduct current through 2R5 and drive the base of 2Q4. 2Q4 then conducts the current through 2R6 to gate 2QS1 into conduction. When 2QS1 conducts, it short circuits the current which might otherwise pass through diode 2D16 to cause tripping. Once 2QS1 begins to conduct, the gate loses control and it remains in the conducting state until the current is turned of by 2Q1. No tripping output can develop as long as the T2 voltage leads T1 voltage.

The operating circuit switches for the next half-cycle so that transistors 1Q3 and 1Q4 conduct in an attempt to cause tripping. In the polarizing circuit, 2Q2, 2Q5 and 2QS2 prevent tripping by short circuit-which might otherwise pass through 2D1, 3Z1 and 3Q1.

Restraint Squelch

When the operating transistor 1Q2 conducts, approximately 18V is applied through diode 2D15 to back biased 2D14 and prevents 2Q4 from turning on. Thus a trip signal, initiated because the T1 voltage is leading cannot be improperly interrupted when the T2 polarity voltage goes positive. A full half-cycle tripping output is therefore produced by 1Q2. This back biasing connection is called the restraint squelch circuit. The same is true for 2D18, 2D17 and 2Q5.

Restraint-Signal Detectors:

If a condition should develop so that no polarizing voltage appears at transformer T2, then no gating signal would be available to switch 2QS1 and short circuit the 1Q2 current. This, of course, could cause incorrect tripping. A restraint-signal detector circuit prevents this from happening. Under normal conditions, no voltage is allowed to develop across Zener diode 2Z2 at Test Point 2TP1 because it is alternately short circuited to the negative bus by transistors 2Q1 and 2Q2 through diodes 2D5 and 2D6 respectively. When the voltage from T2 drops too low to drive 2Q1 and 2Q2 current flows from the 20-volt bus through 2R3 and 2Z2 into the base of 2Q3. With 2Q2 conducting, the bases of 2Q4 and 2Q5 are driven through diodes 2D8 and 2D13 respectively to maintain the gate drive of 2QS1 and 2QS2 respectively. Thus when the T2 voltage is near zero, thyristors 2QS1 and 2QS2 are maintained in a conducting state so that no output can develop.

SRD

SRD ϕ- ϕ fault detector is static voltage sensing logic which operates at high speed for ϕ-ϕ faults and ϕ- ϕ-G faults. This unit is restrained for single-phase-to-ground faults and for three-phase faults.

Tripping

Voltage from each of the three bridge rectifiers B_A (4D1 to 4D6), B_B (4D7 to 4D12), and B_C (4D13 to 4D18) is applied to potentiometer 5R10 through rectifiers 4D19, 4D22 and 4D25. This voltage from potentiometer 5R10 is applied through Zener diode 5Z2 to the base of transistor 5Q3 and the circuit is completed through one of the three trip diodes 4D28, 4D29 or 4D30) and one of the three voltage comparison resistors (4R7, 4R8 or 4R9).

Transistor 5Q3 is the first stage of an amplifire which operates the output driver circuit. Switch- is accomplished by current flowing in the base of transistor 5Q3.

Restraining

Voltage from two bridge rectifiers is applied to each of the voltage comparison resistors 4R7, 4R9, through rectifier pairs AR (4D20 and 4D21), BR (4D23 and 4D24), and CR (4D26 and 4D27) in different combinations. For instance, 4R8 has a restraint voltage from B_A and B_B impressed across it through rectifier AR and BR respectively. Tripping through 4R8 cannot occur unless the voltage B_C is sufficiently greater than the voltage from B_A and B_B so that current flows through 4D25, potentiometer 4R10, transistor 5Q3 and resistor 4R8.

Another resistor 4R9 has restraint voltage from B_B and B_C impressed across it through rectifiers B_R and C_R respectively. The third resistor 4R7 has restraint voltage impressed across it from B_C and B_A through rectifiers C_R and A_R respectively.

AND-OUTPUT Circuit Board

The logic block diagram of AND-OUTPUT circuit board is shown in Fig. 6. The output can be only obtained from terminal 13 when inputs to terminals 9 and 12 both are present. The output can be only obtained from terminal 3 when input at terminal 9 is present and absent at terminal 8. Referring to Fig. 4, transistors 6Q1, 6Q3, 6Q4, 6Q5, 6Q7 and 6Q8 are normally maintained in a non-conducting state and 6Q2, 6Q6 in a conducting state. Switching is accomplished by the inputs flowing in the base of 6Q6.

Impedance Unit Characteristics

1. Distance Characteristic

A characteristic circle is established by setting two points on the circle, diameterically opposite one another by means of the Long Reach (TA) and Short Reach (TC) compensators, as shown in Fig. 7.

2. Sensitivity

Fig. 8 is an impedance curve which demonstrates the relay sensitivity to values at the at the balance point for various values of voltage at the relay terminals.

3. General Characteristics

Impedance settings in ohms reach can be made for any value from 1.74 to 50 ohms for Z_{LR} and from 1.4 to 40 ohms for Z_{SR} in steps of 3 percent. The maximum sensitivity angle which is set for 75 degrees at the factory may be set for any value from 60 degrees to 80 degrees. A change in maximum sensitivity value angle will produce a slight change in reach for any given setting of the relay. Referring to Fig. 2, note that the compensator voltage output V is largest when V leads the primary current I by 90 degrees. This 90 degree relationship is approached when the compensator loading resistor (P2A or 02C) is open circuited. The effect of loading the the resistor, when connected, is to produce a drop in the compensator which is out of phase with the induced voltage. Thus, the output voltage of the compensator is phase-shifted to change the maximum sensitivity angle. As a result of this phase shift, the magnidute of V is reduced as shown in Fig. 2.

Tap markings in Fig. 3 are based upon a 75 degree compensator angle setting. If the potentiometers P2A and P2C are adjusted for some other maximum sensitivity angle, the nominal reach is different than indicated by the taps. The reach Z_θ varies with the maximum sensitivity angle θ as follows:

$$Z_\theta = \frac{TS \sin \theta}{(1 \pm M) \sin 75^\circ}$$

Tap Plate Markings:

T_A						
2.05	2.74	3.76	5.13	7.18	9.92	13.7

T_C						
1.64	2.19	2.75	4.1	5.75	7.94	10.9

S_A and S_C		
1	2	3

M_A and M_C		
0.03	0.09	0.06

4. Time Curve

The speed of operation for the SKDU-31 relay is shown by the time curves in Fig. 9. The curves indicate the time in milliseconds required for the relay to produce a 20-volt d-c output for tripping after the inception of a fault at any point on a line within the relay setting.

SRD Characteristics

The SRD ϕ- ϕ fault detector compares the magnitude of the three-phase to neutral voltages. When one of the three voltages is larger than the other two, as for a phase-to-phase fault, it produces a 20-volt d.c output. The unit is restrained for single-phase to ground faults and for three-phase faults. The pick-up voltage of SRD can be adjusted from 25V to 62V (phase-to-neutral) as desired. It operates when fault voltage of two phases (phase-to-neutral or ground) is smaller than the calibrated value of pick-up voltage.

The operating time of the SRD phase-to-phase fault detector depends on the setting of pick-up voltage and fault voltage or location of fault and varies from 3 ms to 12ms. The higher the setting of pick-up voltage, the faster the operating time. The higher the fault voltage, the slower the operating time.

SRD Voltage Burden Data

V	I	VA	Degrees Voltage Lagging
69V	11.3 MA	.78	51°

VOLTAGE BURDEN
S= 1, V_{AN} = 69.4

X	I_{amp} = O			$I_{amp} = 5_A\ T_A + T_C$			$I_{amp} = 5_A\ T_A - T_C$		
TAP SETTING	VA	WATT	VAR	VA	WATT	VAR	VA	WATT	VAR
-.18	2.56	2.40	.93	3.66	3.14	1.88	5.55	5.5	.58
-.15	2.76	2.56	1.06	3.90	3.35	2.00	5.85	5.85	.71
-.12	2.95	2.72	1.18	4.1	3.50	2.12	6.18	6.15	.86
-.09	3.16	2.93	1.22	4.3	3.64	2.24	6.50	6.45	1.01
-.06	3.40	3.17	1.47	4.58	3.82	2.36	6.85	6.80	1.31
-.03	3.60	3.22	1.61	4.80	4.1	2.48	7.24	7.10	1.45
0	3.86	3.46	1.76	5.05	4.26	2.70	7.55	7.40	1.64
.03	4.10	3.70	1.90	5.28	4.45	2.86	7.90	7.75	1.74
.06	4.36	3.84	2.05	5.50	4.60	2.98	8.25	8.05	2.06
.09	4.60	4.08	2.2	5.75	4.82	3.22	8.60	8.35	2.24
.12	4.85	4.30	2.36	6.05	5.05	3.40	8.95	8.65	2.42
.15	5.10	4.42	2.54	6.30	6.30	5.25	9.30	8.95	2.64
.18	5.40	4.70	2.7	6.60	5.50	3.70	9.70	9.30	2.92

VOLTAGE BURDEN $S = 2,\ V_{AN} = 69.4$									
X	$I_{amp} = O$			$I_{amp} = 5_A\ T_A + T_C$			$I_{amp} = 5_A\ T_A + T_C$		
TAP SETTING	VA	WATT	VAR	VA	WATT	VAR	VA	WATT	VAR
-.18	2.52	2.32	.925	3.60	2.9	2.12	5.4	5.35	-.376
-.15	2.70	2.51	1.06	3.80	3.07	2.22	5.66	5.60	-.394
-.12	2.90	2.68	1.15	4.00	3.23	2.35	6.00	5.95	-.370
-.09	3.10	2.88	1.30	4.22	3.42	2.48	6.30	6.25	-.22
-.06	3.40	3.16	1.50	4.42	3.58	2.60	6.63	6.58	-.115
-.03	3.53	3.23	1.58	4.56	3.76	2.73	6.94	6.90	-.097
0	3.78	3.42	1.75	4.85	3.92	2.85	7.35	7.30	+.127
+.03	3.98	3.60	1.87	5.05	4.07	2.97	7.60	7.55	+.265
.06	4.24	3.80	2.05	5.27	4.28	3.10	8.00	7.95	+.416
.09	4.50	4.0	2.18	5.54	4.50	3.25	8.25	8.20	+.585
.12	4.73	3.2	2.28	5.80	4.70	3.40	8.60	8.55	+.75
.15	4.98	4.35	2.49	6.10	4.94	3.58	9.00	8.95	+.95
.18	5.25	4.56	2.63	6.38	5.15	3.76	9.35	9.30	+1.15

VOLTAGE BURDEN $S = 3,\ V_{AN} = 69.4$									
X	$I_{amp} = O$			$I_{amp} = 5_T\ T_A + T_C$			$I_{amp} = 5_A\ T_A - T_C$		
TAP SETTING	VA	WATT	VAR	VA	WATT	VAR	VA	WATT	VAR
-.18	2.53	2.39	.825	3.5	2.93	1.91	5.35	5.3	-1.11
-.15	2.70	2.53	.92	3.68	3.08	2.0	5.60	5.55	- .97
-.12	2.90	2.70	1.04	3.88	3.25	2.12	5.95	5.90	- .78
-.09	3.10	2.87	1.16	4.10	3.44	2.24	6.25	6.20	- .71
-.06	3.30	3.03	1.3	4.90	3.60	2.35	6.60	6.55	- .63
-.03	3.54	3.22	1.36	4.50	3.78	2.46	6.88	6.82	- .65
0	3.75	3.40	1.49	4.80	4.00	2.62	7.25	7.20	- .68
+.03	4.0	3.60	1.63	5.0	4.20	2.73	7.60	7.55	- .66
+.06	4.23	3.80	1.79	5.34	4.50	2.92	7.90	7.85	- .69
+.09	4.41	4.0	1.95	5.55	4.65	3.02	8.30	8.2	- .59
+.12	4.70	4.18	2.13	5.80	4.85	3.16	8.60	8.5	- .376
+.15	5.0	4.40	2.36	6.05	5.05	3.30	8.90	8.8	- .15
+.18	5.2	4.55	2.52	6.25	5.25	3.40	9.30	9.2	- .112

CURRENT BURDEN $S = 1, M = O, V_A = 69.4, I_A = 5_A\ 75°$				
TAP SETTING		CIRCUIT	OHMS	IMPEDANCE
TA	TC	Z	R	X
1.37	10.93	.54 /60°	.27	.467
9.92	7.94	.3 /56°	.167	.248
7.18	5.75	.16 /51°	.101	.124
5.13	4.1	.08 /37°	.063	.048
3.76	2.75	.038/14°	.049	.027
2.74	2.19	.038/14°	.037	.0092
2.05	1.64	.024/6°	.0238	.0025

Current Circuit Rating in Amperes

Tap Setting	Continuous S = 1	S = 2	S = 3	1 Second
10.9	5	8.5	8.5	240
7.94	5	8.5	8.5	240
5.75	10	10	10	240
4.1	10	10	10	240
2.75	10	10	10	240
2.19	10	10	10	240
1.64	10	10	10	240

SKDU-31 SETTING CALCULATIONS

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

TA						
2.05	2.74	3.76	5.13	7.18	9.92	13.7

TC						
1.64	2.19	2.75	4.1	5.75	7.94	10.9

S_A and S_C		
1	2	3

M_A and M_C		
.03	.09	.06

Maximum sensitivity angle is set in the factory for 75 degrees (current lags voltage). It should not be necessary to change this calibration unless the line angle is less than 65 °.

The general formula for setting the ohms reach of the relay is:

$$Z_\theta = Z \frac{(\text{Sin } \theta)}{(\text{Sin 75 degree})} = Z_{pri} \frac{R_C}{R_V}$$

The terms used in this formula are defined as follows:

Z_θ = the desired ohmic reach of the relay and relates equally to Long Reach ($Z_{\theta LR}$) and Short Reach ($Z_{\theta SR}$).

$Z = \frac{TS}{1 \pm M}$ = the tap plate setting

T = compensator tap value

S = autotransformer primary tap value

θ = maximum sensitivity angle setting of the relay (for a factory setting of 75°, then $\frac{\text{Sin } \theta}{\text{Sin } 75°} = 1$).

M = autotransformer 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).

Z_{pri} = ohms per phase of the line section to be protected

R_C = current transformer ratio

R_V = potential transformer ratio

The following procedure should be followed to obtain an optimum setting of the relay. Relate the general equation of Long Reach or Short Reach by sub-letter "A" and "C" respectively.

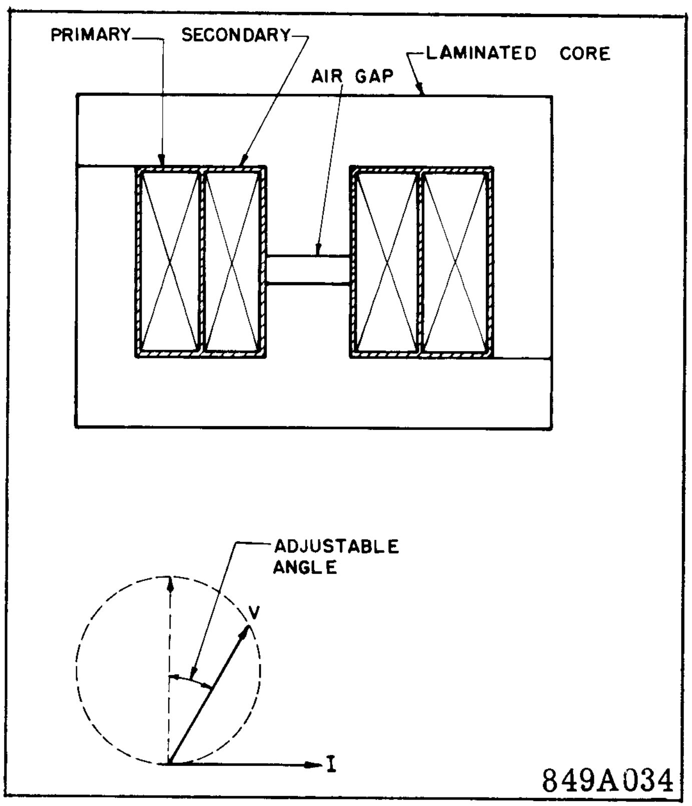
Now refer to Tables I and II which list optimum relay settings for relay range from 1.74 to 50 ohms for Long Reach and 1.4 to 40 ohms for Short Reach compensators.

a) Locate a table value for relay reach nearest to the desired value Z. (It will always be within 1.5% of the desired value).

b) Read from the Table "S","T", and "M" settings. "M" column cinludes additional information for "L" and "R" settings.

c) Recheck the obtained S, T, and M settings by using equation.

$$Z = \frac{TS}{1 \pm M}$$



2. *Compensator Construction*

TABLE I
RELAY SETTING FOR LONG REACH COMPENSATOR

	"S" = 1							"S" = 2		"S" = 3		"M"		LEAD CONNECTION	
T=	2.05	2.74	3.76	5.13	7.18	9.92	13.7	9.92	13.7	9.92	13.7	+M	-M	"L" LEAD	"R" LEAD
	1.74	2.32	3.18	4.35	6.1	8.4	11.6	16.8	23.2	-	34.8	+.18		.06	0
	1.78	2.38	3.27	4.47	6.25	8.62	11.9	17.3	23.8	-	35.8	+.15		.06	.03
	1.83	2.44	3.36	4.59	6.42	8.85	12.2	17.7	24.5	-	36.7	+.12		.09	0
	1.88	2.52	3.45	4.70	6.60	9.10	12.5	18.2	25.2	-	37.7	+.09		.09	.03
	1.93	2.58	3.55	4.84	6.78	9.35	12.9	18.7	25.9	-	38.8	+.06		.06	.09
	1.99	2.66	3.66	4.98	6.98	9.64	13.3	19.3	26.6	-	40.0	+.03		.03	0
	2.05	2.74	3.76	5.13	7.18	9.92	13.7	19.8	27.4	-	41.1	0	0	0	0
	2.12	2.82	3.88	5.30	7.40	10.3	14.1	20.4	28.3	-	42.4		-.03	0	.03
	2.18	2.92	4.00	5.46	7.65	10.6	14.5	21.1	29.2	-	43.6		-.06	.09	.06
	2.25	3.02	4.15	5.65	7.90	10.9	15.0	21.8	30.2	32.8	45.1		-.09	.03	.09
	-	3.12	4.27	4.82	8.16	11.3	15.5	22.6	31.2	33.8	47.8		-.12	0	.09
	-	-	-	-	-	-	16.1	-	32.3	-	48.4		-.15	.03	.06
	-	-	-	-	-	-	-	-		-	50		-.18	0	.06

TABLE II
RELAY SETTING FOR LONG REACH COMPENSATOR

	"S" = 1							"S" = 2		"S" = 3		"M"		LEAD CONNECTION	
T=	1.64	2.19	2.75	4.1	5.75	7.94	10.9	7.94	10.9	7.94	10.9	+M	-M	"L" LEAD	"R" LEAD
	1.39	1.86	2.33	3.47	4.95	6.72	9.25	-	-	-	27.8	+.18		.06	0
	1.43	1.91	2.39	3.57	5.10	6.9	9.48	13.8	19.0	-	28.4	+.15		.06	.03
	1.47	1.96	2.46	3.66	5.22	7.09	9.72	14.2	19.5	-	29.2	+.12		.09	0
	1.51	2.00	2.52	3.76	5.37	7.28	10.0	14.6	20	-	30.0	+.09		.09	.03
	1.55	2.07	2.60	3.87	5.52	7.46	10.3	15.1	20.6	-	30.9	+.06		.06	.09
	1.60	2.12	2.67	3.98	5.69	7.7	10.6	15.4	21.2	-	31.8	+.03		.03	0
	1.64	2.19	2.75	4.1	5.75	7.94	10.9	15.9	21.8	-	32.7	0	0	0	0
	1.68	2.26	2.84	4.22	6.04	8.16	11.2	16.4	22.5	-	33.8		-.03	0	.03
	1.74	-	2.93	4.36	6.21	8.44	11.6	16.9	23.2	-	34.8		-.06	.09	.06
	1.80	-	3.02	4.5	6.43	8.72	12.0	17.5	24.0	-	36.0		-.09	.03	.09
	-		3.12	4.66	6.65	9.00	12.4	18.1	24.8	27.0	37.2		-.12	0	.09
	-	-	3.24	4.82			12.8	18.7	25.7	-	38.5		-.15	.03	.06
	-		3.36	-	-		13.3		26.6	-	40		-.18	0	.06

For Example:

(Step 1a) Assume the desired reach, Z_θ, is 30 ohms for the Long Reach setting at 60 degrees.

(Step 1b) Making correction for maximum sensitivity angle of the line (60 degrees) that is different from factory setting of 75 degrees, find the relay tap setting Z = (30) (1.116) = 33.5 ohms.

Next, in table I, we find nearest value to 33.5 ohms: 33.8; that is $\frac{33.8}{33.5} \times 110 =$ 100.9 per cent of the desired reach.

(Step 2b) From Table I read off: S = 3, T = 99.2, M = .12, and "R" lead should be connected over "L" lead, with "L" lead connected on zero, and "R" lead on .09.

The last step is to recheck setting:

$$Z = \frac{TS}{1 \pm M} = \frac{(3)(9.92)}{1 - .12} = 33.8$$

$$Z_{60^\circ} = Z \frac{\text{Sin } 60}{\text{Sin } 75} = (33.8)(895) = 30.2 \text{ ohms which}$$

is within 1 per cent of the desired setting.

The same procedure can be followed for Short Reach Compensator.

SETTING THE RELAY

The impedance unit requires settings for each of the two compensators (T_A and T_C), each of the two auto-transformer primaries (S_A and S_C), and for the two auto-transformer secondaries (M_A and M_C). All of these settings are made with taps on the tap plate which is located inside the door and at the left-hand side of the relay. Figure 3 shows the tap plate. The SRD requires setting potentiometer 5R10 which is on LEVEL DETECTOR circuit board.

Compensator (T_A and T_C)

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 inset which is the Common Connection for all of the taps. Electrical connections between common inserts are made with a link that is held in place with two connector screws, one in the common and one in the tap.

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 but not hard enough to break the screw.

Autotransformer Primary (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 the taps and is held in place on the proper tap by a connector screw (Fig. 3).

An "S" setting is made by removing the connection 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.

Autotransformer Secondary (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 "M" value is determined by which lead is in the higher position on the tap plate. The sign is positive (+) if the "L" lead is higher and negative (-) if the "R" lead is in the higher position.

Line Angle Adjustment

Maximum sensitivity angle is set for 75 degrees (current lagging voltage) in the factory. It is not expected that this adjustment need be disturbed. However, if a change is desired, refer to Repair Calibration.

Potentiometer 5R10 - Setting the Pick-up Voltage

The setting of pick-up voltage of SRD phase-to-phase fault dector is dependent on the source and line impedance. The potentiometer 5R10 on LEVEL DECTECTOR circuit board is to set the pick-up voltage which could be setting from 25V to 62 V (phase-to-neutral). A clockwise rotation of 5R10 increases the pickup voltage and a counterclockwise rotation decreases the pickup voltage. The SRD operates when the ratio of faulted phase voltage (faulted phase-to-phase) to the unfaulted phase voltage is smaller than the pickup voltage setting.

Make connection per Test No. 4 as shown in Fig. 10. Adjust variable autotransformer B to the desired pick-up voltage. Use a high resistance d.c. voltmeter (at least 20,000 ohms per volt) to measure the output voltage between J_R and J_B on LEVEL DETECTOR Circuit Board. Adjust potentiometer 5R10 until an output of 20 volts is obtained. Then this low voltage is also the desired pick-up voltage using Test No. 5 and No. 6 in FIG. 10. Adjust the voltage with with the variable autotransformer to check the pick-up voltage. The pick-up voltage is set at the factory for 60V.

SRD Setting Example

In Fig. 11 assume the source impedance Z_S equal to 8 ohms (secondary) and line impedance, Z_L equal to 32 ohms. The P.T. normal secondary line-to-line voltage is 120V. If a $\phi\phi$ fault is at 75% of the line, the secondary line-to-line V_{LL} will be the P.T. normal secondary voltage. 120V times 75% of line impedance divided by the sum of source impedance and 75% of the line impedance, which is:

$$V_{L-L} = \frac{120 \times .75 \times 32}{8 + .75 \times 32} = \frac{120 \times 24}{8 + 24} = 90V$$

and the voltage from neutral to fault phases will be

$$56.7V \left(\sqrt{\frac{90^2}{2} + 34.6^2} = 56.7V\right.$$

For the relay voltage for phase-to-phase faults at various locations for this example, refer to the following table:

Z_S = 8 Ohms Z_L = 32 Ohms	Fault Location in % of Line			
	25%	50%	75%	100%
Secondary Phase-to-Phase Voltage V_{L-L} (Between faulted phases)	60	80	90	96
Secondary Phase-to-Neutral Voltage V_{L-N} (From faulted phases)	45.7	52.8	56.7	59.2

In this case (Z_S = 8 ohms Z_L = 32 ohms). The pick-up voltage of SRD should be a setting greater greater than 59.2V.

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 by means of the four slotted holes on the front of the case. Additional support should be provided toward the rear of the relay in addition to the front panel mounting. This will protect against warping of the front panel due to the weight of the relay.

ACCEPTANCE TESTS

Acceptance tests in general for SKDU-31 consists of:

(1) A visual inspection to make sure there are no loose connections or broken parts.

(2) An electrical test to make certain the relay measures the balance point conditions accurately.

Distance Unit

Check the electrical response of the relay by using the test connections for test number 10 shown in

Fig. 10. Set T_A for 13.7 ohms, T_C for 1.64 ohms, S_A and S_C for 1, and M_A.and M_C for zero.

A. Adjust the voltage V for 40 volts.

B. Connect a high sensitivity d-c voltmeter (at least 20,000 phms per volt) between Varicon terminals 5 and 3 to measure a 20 volt d-c output. (5 is pos.).

C. The current required to obtain a 20 volt d-c output for the long-reach balance point should be between 2.9 and 3.0 amperes at the maximum sensitivity angle of 75 degrees current lag.

D. The current required to trip for current polarity reversed should be between 18.3 and 19amperes at 75 degree current lag.

SRD Phase Splitting Network

E. Make connection for Test No. 1 as shown in Fig. 10. Use a vacumn--tube voltmeter to measure the voltages on the fault discriminator circuit board:

1. Across the series connection of 4R1 and potentiometer 4R11 (from 4TP1 to Printed Circuit Board terminal 4).

2. From 4TP1 to transformer tap at PCB terminal 6.

3. From PCB terminal 6 toPCBterminal 4.

to see that the three are within 1 volt of each other. If not, adjust potentiometer 4R11. Always read $V_{4TP1\text{-}4}$ when adjusting potentiometer 4R11.

F. Make connection for Test No. 2 as shown in Fig. 10. Use a vacuum-tube voltmeter to measure the voltages on fault discriminator circuit board: (1) Across 4R2 plus potentiometer 4R12 (from 4TP2 to PCB terminal 3); (2) from 4TP2 to transformer tap at PCB terminal 8, and (3) from PCB terminal 8 to PCB terminal 3 to see that the three are within 1 volt of each other. If not, adjust potentiometer 4R12. Always read $V_{4TP2\text{-}3}$ when adjusting potentiometer 4R12.

G. Make connection for Test No. 3 as shown in Fig. 10. Use a vacuum-tube voltmeter to measure the voltage on fault discriminator circuit board. (1) Across 4R3 plus potentiometer 4R13 (from 4RP3 to PCB terminal 11); (2) from 4TP3 to transformer tap at PCB terminal 10 and, (3) from PCB terminal 10 to PCB terminal 11 to see that the three are within 1 volt of each other. If not, adjust pointiometer 4R3. Always read $V_{4TP3\text{-}11}$ when adjusting potentiometer 4R13.

H. AND OUTPUT circuit Board Check

1. Impedance Unit

Set TA on 13.7 and TC on 10.9
SA and SC set on 1
"R" for MA and MC set for 0.0
"L" for MA and MC set for 0.0

2. SRD

Set the desired pick up voltage as described in setting the SKDU-31 (setting the pick-up voltage).

Connect as shown in Fig. 10. Rotate the phase shifter to 75 degrees. (Using phase angle meter to check the phase angle). The performance described in the following table should be obtained. For the measurements a d-c voltmeter having at least 20,000 ohms per volt should be used.

If the setting of the pick-up voltage of the SRD is 60V, test conditions and relay performance are shown in the following table.

V_1 Volts	V_2 Volts	Current Magnitude and Terminal Block Connection (From/To)	D.C. Output Voltage (Measured between terminal)		
			SKDU-3 3TP2/Neg.	SRD JR/JB	Reclose Block Varicon Term. 22/Neg.
70V	70V	4.45 Amps with $L_{2/1}$ and $I_{B/2}$	0	0	0
(59V & Less)	70V	4.45 Amps with $L_{2/1}$ and $I_{B/2}$	20	20	0
(59V & Less)	Same as V_1	4.45 Amps with $L_{2/1}$ and $I_{B/2}$	20	20	20
(59V & Less)	70V	Less Than (V_1/13.7) Amps with $L_{2/1}$ and $I_{B/2}$	0	20	0

Apply 20 volts d-c between Varicon terminals 19 and 3 (Neg.) to obtain the performance indicated in the following table.

V_1 Volts A/7	Current in Amps and Terminal Block Connect. (From/To)	Varicon Terminal 19/3	D.C. Output Voltage (Measured between terminal)	
			SKDU-3 3TP2/Neg.	Trip Output Varicon Term. 6/Neg.
70V	4.45 Amps with $L_{2/1}$ and $I_{B/2}$	0	0	0
(59 V & Less)	4.45 Amps with $L_{2/1}$ and $I_{B/2}$	0	20V	0
70V	4.45 Amps with $L_{2/1}$ and $I_{B/2}$	12.20V	0	0
(59V & Less)	4.45 Amps with $L_{2/1}$ and $I_{B/2}$	12-20V	20V	20V

ROUTINE MAINTENANCE

The SKDU-31 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.

CAUTION: Before making "hi-pot" test, jumper Varicon terminals 3, 4, 5, 6, 19 and 22 together to avoid destroying components in the static network.

When performing routine maintenance, the distance characteristic of the SKDU-131 relay can be checked by using the same procedure as outlined in "Acceptance Tests." The balance point impedance measured by the relay is $Z_R = \frac{V_{L-N}}{I_L}$ where V_{L-N} is the phase to neutral voltage applied to the relay terminals and I_L is the phase current.

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 11.

Distance Unit Calibration

1. SETTING: Check to see that....

   T_A set 13.7 and T_C set on 10.9
   S_A and S_C set on 1
   "R" for M_A and M_C set on 0.0
   "L" for M_A and M_C hangs free

Electrical Calibration

Compensator Angle Adjustment

Long Reach Compensator T_A: Refer to the Table of Test connections and connect the test circuit as per Test No. 7.

2. Connect the relay as per figure 10. Test No. 7

3. Connect a voltmeter between the "L" lead and and "O" tap of M_A.

4. Apply 40 volts between Varicon terminals 7 and 10 with polarity on terminal 7.

5. Apply 3.1 ± .1 amperes into terminal block 1 out of 2.

6. Adjust the potentiometer P_{2A} to obtain a "null" on the voltmeter when the phase shifter is on 75° ± 1° (current lags voltage).

Short Reach Compensator TC

7. Connect the relay as per table, Test 8.

8. Connect a voltmeter between "L" lead and "O" tap of M_C.

9. Reverse the voltage applied to the Varicon terminals 7 and 10, and apply 40 volts between them.

10. Circulate 3.76 amperes through terminal 1 and 2 of the terminal block in the rear of the SKDU-31.

11. Adjust the potentiometer P_{2C} to obtain a "null" on the voltmeter when the phase shifter is on 75° ± 1° (current lags voltage).

Auto-Transformer Check

12. Set S_A and S_C on tap number 3· Apply 60 (± 1) volts between Varicon terminals 7 and 10. Measure voltage from terminal 10 to the number 1 tap of S_A and S_C. It should be 20 (± 1) volts. From 10 to the number 2 tap of S_A and S_C should be 40 (± 1) volts.

13. Set S_A and S_C on 1 and apply a voltage V_T (which is equal to 60 volts ± 1 volt) between terminals 7 and 10. Measure the voltage drop from terminal 10 to each of the M_A and M_C taps. This voltage should be equal (± 1 volt) to the sum of V_T plus (the sum of digits between "R" and the tap being measured).

    Example: 60 + (.03 + .09 + 0.06) 60 = 70.8 volts. If the voltage reading is not within limits, then, either the turn ratio or the connection is wrong.

14. Set T_A on 13.7 and T_C on 1.64

    Set S_A and S_C on 1

    "R" for M_A and M_C set on 0.0

    "L" for M_A and M_C set on 0.0

Maximum Sensitivity Angle, Test 9

15. Set the phase shifter to 30° ± 2° (current lags

voltage). Apply 40 volts between terminals 7 and 10, and adjust the current to 3.8 ± 1 amperes. Measure the output voltage from terminal 5 to terminal 3 with a d-c voltmeter, and adjust the potentiometer P_C until a threshold 20 volt d-c output is obtained Turn the phase shifter until the d-c voltage drops to zero, this angle should be 120° ± 2°. (The total angle is 30° ± 120° = 150°).

16. Apply 40 volts across terminals 7 and 10. Turn the phase shifter to 225°, and apply approximately 24 amperes, the relay should "just" trip. (Do not leave 24 amperes on more than 5 seconds).

Impedance Curve, Test 10

17. With voltage adjusted to 40 volts, set the phase-shifter to 75° (current lags voltage). A 20-volt d-c output should be obtained at terminal 5) when the current is between 2.9 and 3.0 amperes.

SRD Phase Splitting Network Calibration

18. Described as E, F and G in Acceptance Tests.

Potentiometer 5R10 - Setting the Pick-up Voltage

19. Described under Setting the Relay

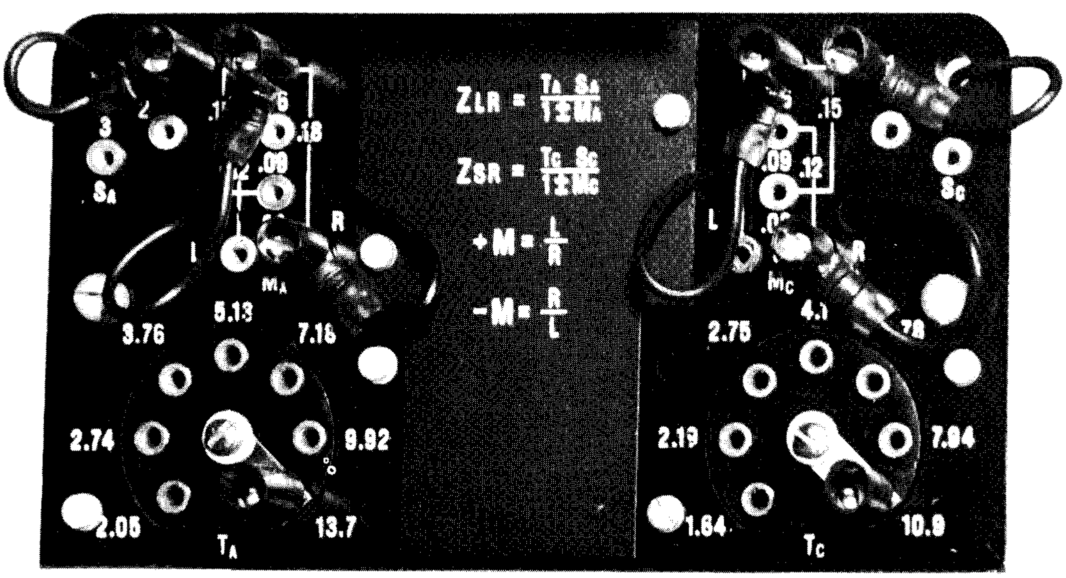
HI-POT TEST

20. Use jumpers to connect the terminals into groups as defined below. Apply standard test between the chassis and each group, and from group to group.

Group 1. Varicon connector terminals 7, 8, 9 and 10.
Group 2. Varicon connector terminals 3, 4, 5, 6, 19 and 22.
Group 3. Terminal block terminals 1.2.

RENEWAL PARTS

Repair work can be done most satisfactorily at the factory. However, interchangeable parts can be furnished to the customers who are equipped for doing repair work. When ordering parts, always give the complete nameplate data. For components mounted on the printed circuit boards, give the circuit symbol electrical value and style number.



3. *Tap Plate*

ELECTRICAL PARTS LIST

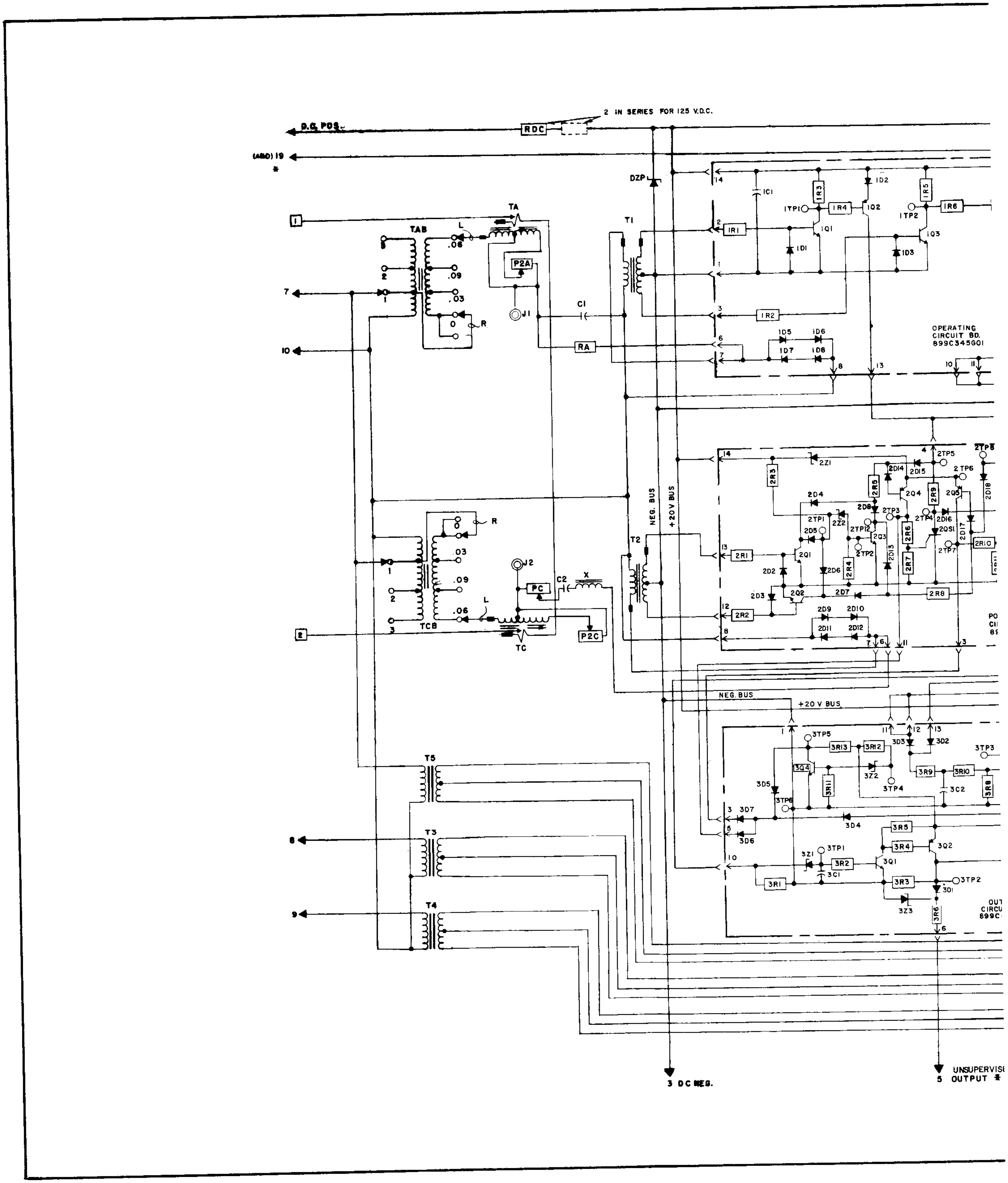
NOTE: The manufacturer reserves the right to change component values without prior notice

PRINTED CIRCUIT BOARDS	WESTINGHOUSE STYLE NO.
Operating Circuit Board	899C345G01
Polarizing Circuit Board	899C347G01
Output Circuit Board	899C477G01
ϕ-ϕ Fault Discriminator Circuit Board	5314D08G01
Level Detector Circuit Board	5314D09G01
AND-Output Circuit Board	201C204G01

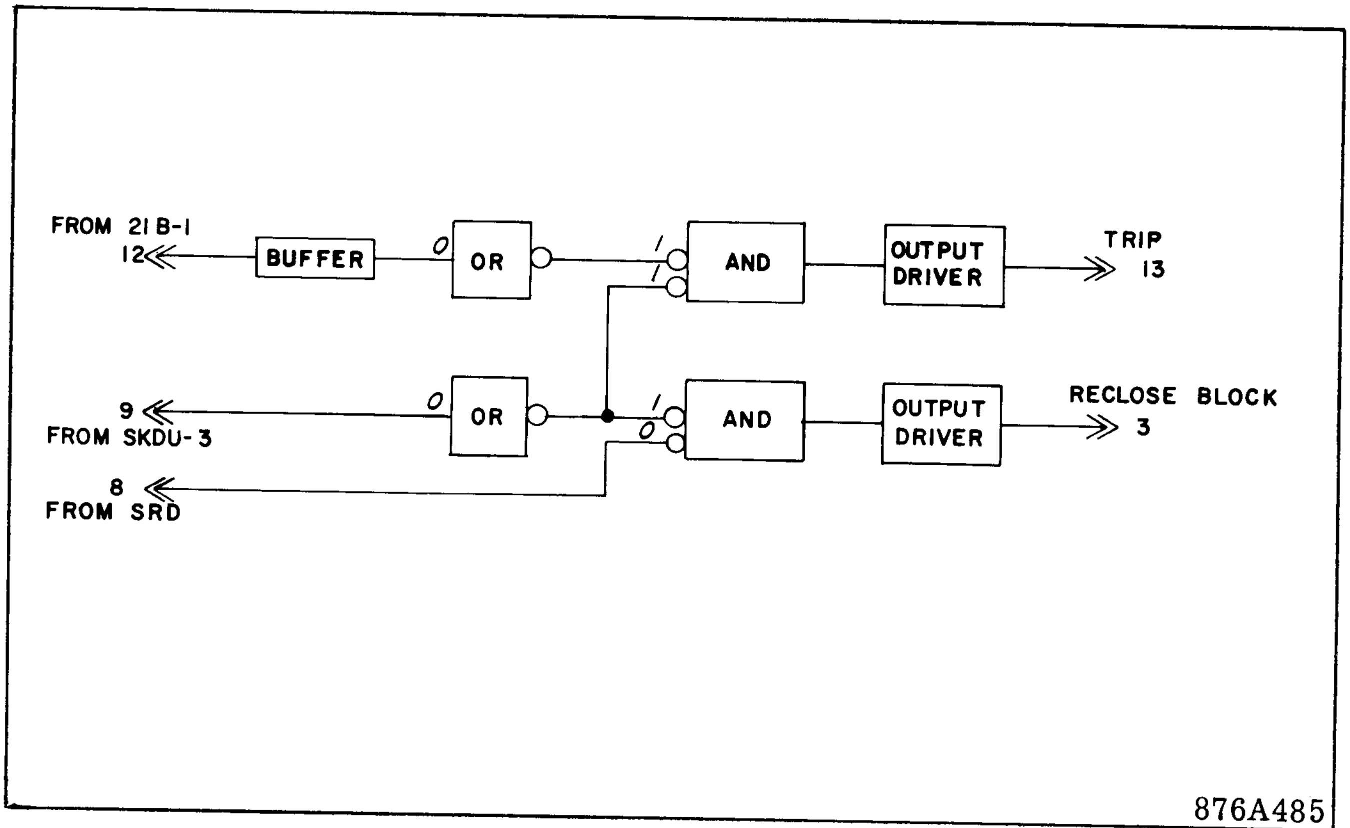
CIRCUIT SYMBOL	DESC.	WESTINGHOUSE STYLE NO.
RESISTORS		
2R7,2R9,2R11,2R12,3R13	2.7 K	1184A763H37
4R1 to 4R3	2 7 K	187A644H37
1R4,1R2,3R10	220 K	184A763H83
1R4.1R6, 2R5,2R8	8.2 K	184A763H49
2R4	22 K	184A763H59
2R1,2R2,3R9	100 K	184A763H75
2R3	33 K	184A763H63
2R6,2R10	2.7 K	629A531H42
1R3,1R5	1 MEG	184A763H99
3R1,3R2,4R4 to 4R6	56 K	184A763H69
3R6,6R6,6R9,6R21,6R24 6R40,6R54,6R58,5R2	27 K	629A531H66
3R4,6R5,6R8,6R12,6R20 6R23,6R27,5R4,5R5	6.8 K	629A531H52
3R5	6.8 K	184A763H47
3R6,6R15,6R30,5R1	150 Ohms	762A79H01
3R7	5.6 K	184A763H45
3R8,3R11	27 K	184A763H61
3R12	18 K	184A763H57
6R1,6R2	4.7 K	629A531H48
6R3,6R14,6R29,5R7	82 K	629A531H78
6R4,6R7,6R10,6R13,6R19	10 K	629A531H56
6R22,6R25,6R28,5R3	10 K	629A531H56
5R8	2 K	629A531H39
5R9	68 K	184A763H71
5R6	39 K	629A531H70
4R7 to 4R9	330 K	184A763H87
4R10	20 K	184A763H58
RA	2.8 K	1267210
RDC	300 Ohms (for 48VDC)	184A856H10
RDC	600 Ohms (2 in Series for 125 VDC)	1267283
ZENER DIODE		
2Z1,6Z2	1N957B	186A797H06
3Z1	1N752A	186A797H12
6Z1	1N3638B	185A212H06
6Z3,6Z6,5Z1,3Z3	1N3688A	186A797H13
4Z1 to 4Z3	1N3036B	188A302H09
DZP	1N2984B	762A631H01
DIODES		
1D1 to 1D8, 2D1 tp 2D18	CER69	188A342H06
3D1 to 3D7	CER69	188A342H06
4D1 to 4D30, 5D2	1N457A	184A855H07
6D1'6D2,6D4,5D1	1N645A	837A692H03
CAPACITORS		
1C1	18 Mfd	187A508H10
3C2,5C2	.25 Mfd	187A624H02
3C1	.015 Mfd	187A624H10
C1	.8 Mfd	14C9400H15
C2	1.0 Mfd	14C9400H28
6C1	.047 Mfd	849A437H04
6C2,6C4,5C1	.27 Mfd	188A669H95
4C1 to 4C3	.5 Mfd	187S624H11
TRANSISTORS		
1Q1,1Q3,2Q1,2Q2,3Q3	2N3391	848A851H01
2Q3,3Q1,3Q4	2N697	184A638H18
1Q2,1Q4,2Q4,2Q5,3Q2,5Q1, 6Q1 to 6Q3,6Q5 to 6Q7	2N1132	184A638H20
5Q2,5Q3	2N3417	848A851H02
6Q4,6Q8	2N3645	849A441H01
POTENTIOMETERS		
P2A,P2C	2500 Ohms	836A635H04
PC	5 Ohms	836A635H02
5R10	50 K	862A303H01
4R11 to 4R13	2.5 K	629A430H03
SWITCH		
2QS1, 2QS2	2N884	185A517H05
TRANSFORMER		
T1,T2		262B563G09
T3,T4,T5		292B563G14

TABLE OF CONNECTIONS FOR TEST CIRCUIT (FIG. 11)

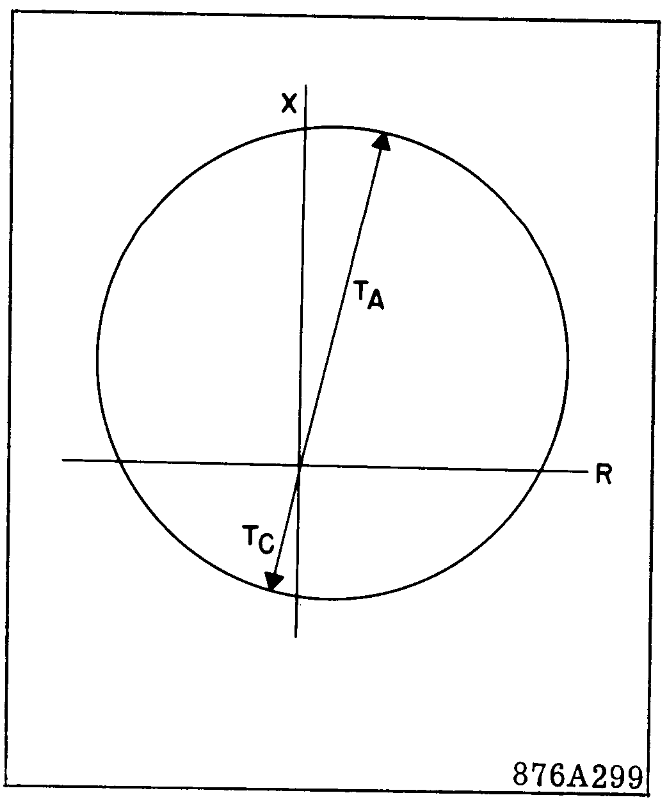
TEST NO.	TO CHECK OR ADJUST	V	LOW VOLTAGE	CONNECT FROM/TO									PHASE SHIFTER ANGLE
1.	4R11	$V_{7\text{-}10}$ = 70V		A/7	B/10								
2	4R12	$V_{8\text{-}10}$ = 70V		A/8	B/10								
3	4R13	$V_{9\text{-}10}$ = 70V		A/9	B/10								
4	5R10	$V_{8\text{-}10}$= 70V	$V_{9.7\text{-}10}$	A/7&9	B/10	C/8							
5	5R10	$V_{9\text{-}10}$= 70V	$V_{7.8\text{-}10}$	A/7&8	B/10	C/9							
6	5R10	$V_{7\text{-}10}$ = 70V	$V_{8.9\text{-}10}$	A/8&9	B/10	C/7							
7	P2A	$V_{7\text{-}10}$ = 40V		A/7	B/10		I_B/2	L_2/1	D/LA	E/0.0			75° ± 1
8	P2C	$V_{7\text{-}10}$ = 40V		A/10	B/7		I_B/2	L_2/1	D/LC	E/0.0			75° ± 1
9	PC	$V_{7\text{-}10}$ = 40V		A/7	B/10		I_B/2	L_2/1			F/5	G/3	30° ± 1 150-225°
10	IMP CURVE	$V_{7\text{-}10}$ = 40V		A/7	B/10		I_B/2	L_2/1			F/5	G/3	75° ± 1
AND OUTPUT CIRCUIT BD. TEST	D.C. OUTPUT VOLTAGE			A/7	B/10	C/8&9	I_B/2	L_2/1					75° ± 1



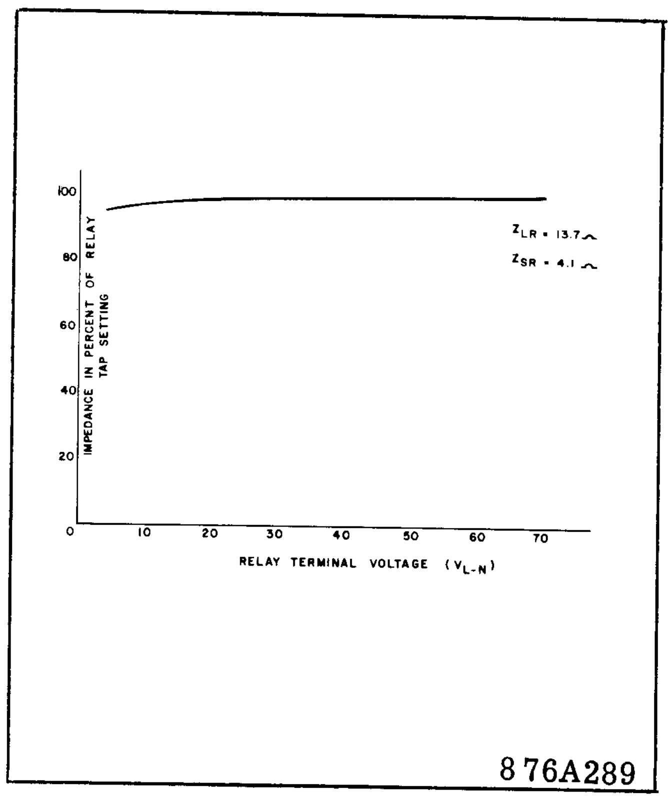
4. *Internal Sch*



6. *AND Output Circuit Board Logic Block Diagram*

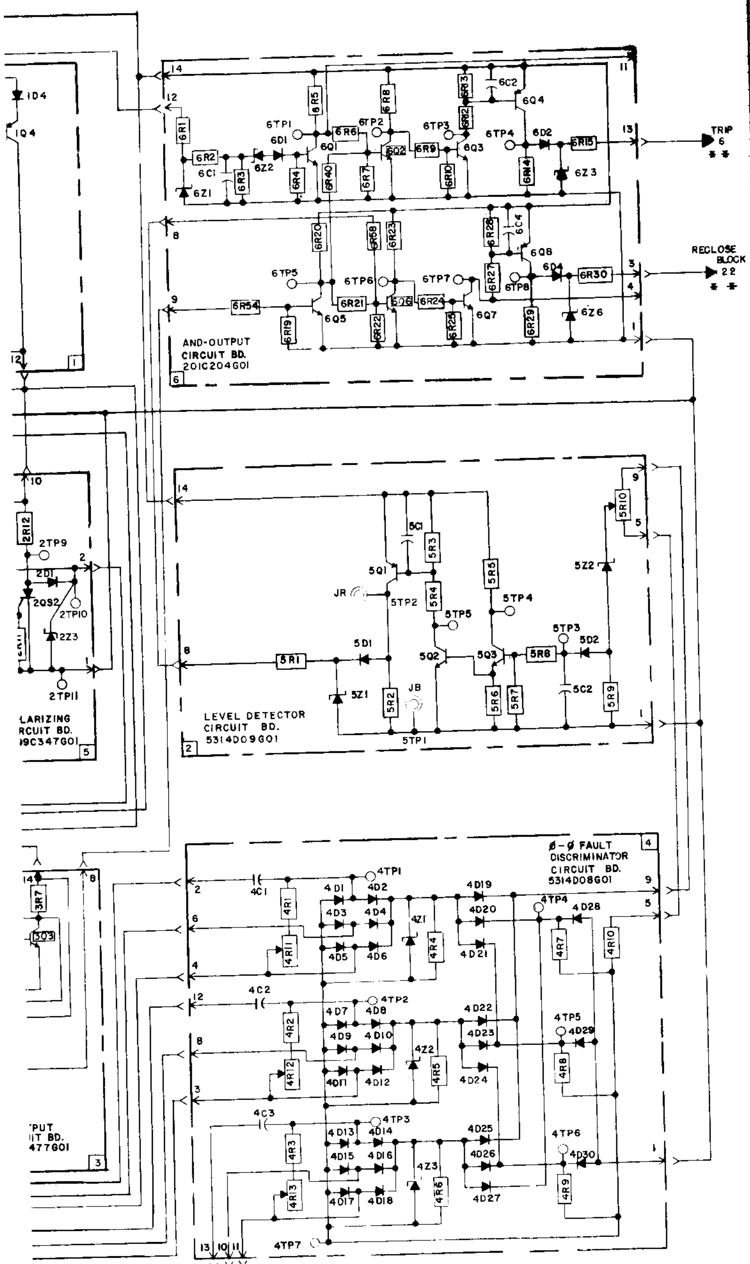


7. *Impedance Circle for the Type SKDU-31*



8. *Impedance Curve for the Type SKDU-3*

5. *Voltage & Current Conditions for the type SKDU-31 Relay for Faults at Various Locations*



RESISTOR	[illegible]	REQ.	[illegible]
2R7 · 2R9 · 2R11 · 2R12 · 3R13	[illegible]	5	[illegible]
4R1 TO 4R3	[illegible]	3	2.7 K
1R1 · 1R2 · 3R10	[illegible]	3	220 K
1R4 · 1R6 · 2R5 · 2R6	184A763H49	4	8.2 K
2R4	184A763H59	1	22 K
2R1 · 2R2 · 3R9	184A763H75	3	100 K
2R3	184A763H63	1	33 K
2R6 · 2R10	629A531H42	2	2.7 K
1R3 · 1R5	184A763H99	2	1 MEG
3R1 · 3R2 · 4R4 · TO 4R6	184A763H69	5	56 K
3R3 · 6R6 · 6R9 · 6R21 · 6R24 ·	629A531H66	9	27 K
6R40 · 6R54 · 6R58 · 5R2	"		"
3R4 · 6R5 · 6R8 · 6R12 · 6R20 ·	629A531H52	9	6.8 K
6R23 · 6R27 · 5R4 · 5R5	"		"
3R5	184A763H47	1	6.8 K
3R6 · 6R15 · 6R30 · 5R1	762A679H01	4	150 Ω
3R7	184A763H45	1	5.6 K
3R8 · 3R11	184A763H61	2	27 K
3R12	184A763H57	1	18 K
6R2	629A531H48	2	4.7 K
6R3 · 6R14 · 6R29 · 5R7	629A531H78	4	82 K
6R4 · 6R7 · 6R10 · 6R13 · 6R19 ·	629A531H56	9	10 K
6R22 · 6R25 · 6R28 · 5R3	"		"
5R8	629A531H39	1	2 K
5R9	184A763H71	1	68K
4R7 · 4R9 · 4R8	184A763H87	3	330K
4R10	184A763H58	1	20 K
RA	1267210	1	2.8 K
RDC	184A856H10	1	300 Ω 48 V.D.C.
RDC	1267283	2	125V.D.C. 600 Ω
6R1	184A763H43	1	4.7 K
5R6	629A531H70	1	39 K
ZENER DIODE			
2Z1 · 6Z2	186A797H06	2	1N957B
3Z1	186A797H12	1	1N752A
3Z2 - 2Z2 - 2Z3	186A797H01	3	1N758
6Z1	185A212H06	1	[illegible]
6Z3 · 6Z6 · 5Z1 · 3Z3	862A288H01	4	[illegible]
5Z2	186A797H13	1	1N748A
4Z1 TO 4Z3	188A302H09	3	[illegible]
DZP	762A631H01	1	[illegible]
DIODES			
1D1 TO 1D8 · 2D1 TO 2D18	188A342H06	33	CER69
3D1 TO 3D7	"		"
4D1 TO 4D30 · 5D2	184A855H07	31	1N457A
6D1 · 6D2 · 6D4 · 5D1	837A692H03	4	1N645A
CAPACITORS			
1C1	187A508H10	1	10 MFD
3C2 · 5C2	187A624H02	2	.25 MFD
3C1	187A624H10	1	.015 MFD
C1	14C9400H15	1	.8 MFD
C2	14C9400H28	1	1.0 MFD
6C1	849A437H04	1	.047 MFD
6C2 · 6C4 · 5C1	188A669H05	3	.27 MFD
4C1 TO 4C3	187A624H11	3	.5 MFD
TRANSISTOR			
1Q1 · 1Q3 · 2Q1 · 2Q2 · 3Q3	848A851H01	5	2N3391
2Q3 · 3Q1 · 3Q4	184A638H18	3	2N697
1Q2 · 1Q4 · 2Q4 · 2Q5 · 3Q2 · 5Q1	184A638H20	6	2N1132
6Q1 TO 6Q3 · 6Q5 TO 6Q7 · 5Q2	848A851H02	8	2N3417
5Q3			
6Q4 6Q8	849A441H01	2	2N3645
TRANSFORMER			
T1 · T2	262B563G09	2	
T3 · T4 · T5	292B563G14	3	
POTENTIOMETER			
P2A · P2C	836A635H04	2	2500 Ω
PC	836A635H08	1	2.5K
5R10	862A303H01	1	50K
4R11 TO 4R13	629A430H03	3	2.5K
SWITCH			
2QS1 2QS2	185A517H05	2	2N884

RECTANGLE AROUND TRANSISTOR DESIGNATION DENOTES CONDUCTION IN QUIESCENT (AT REST) STATE.

= TERMINAL BLOCK

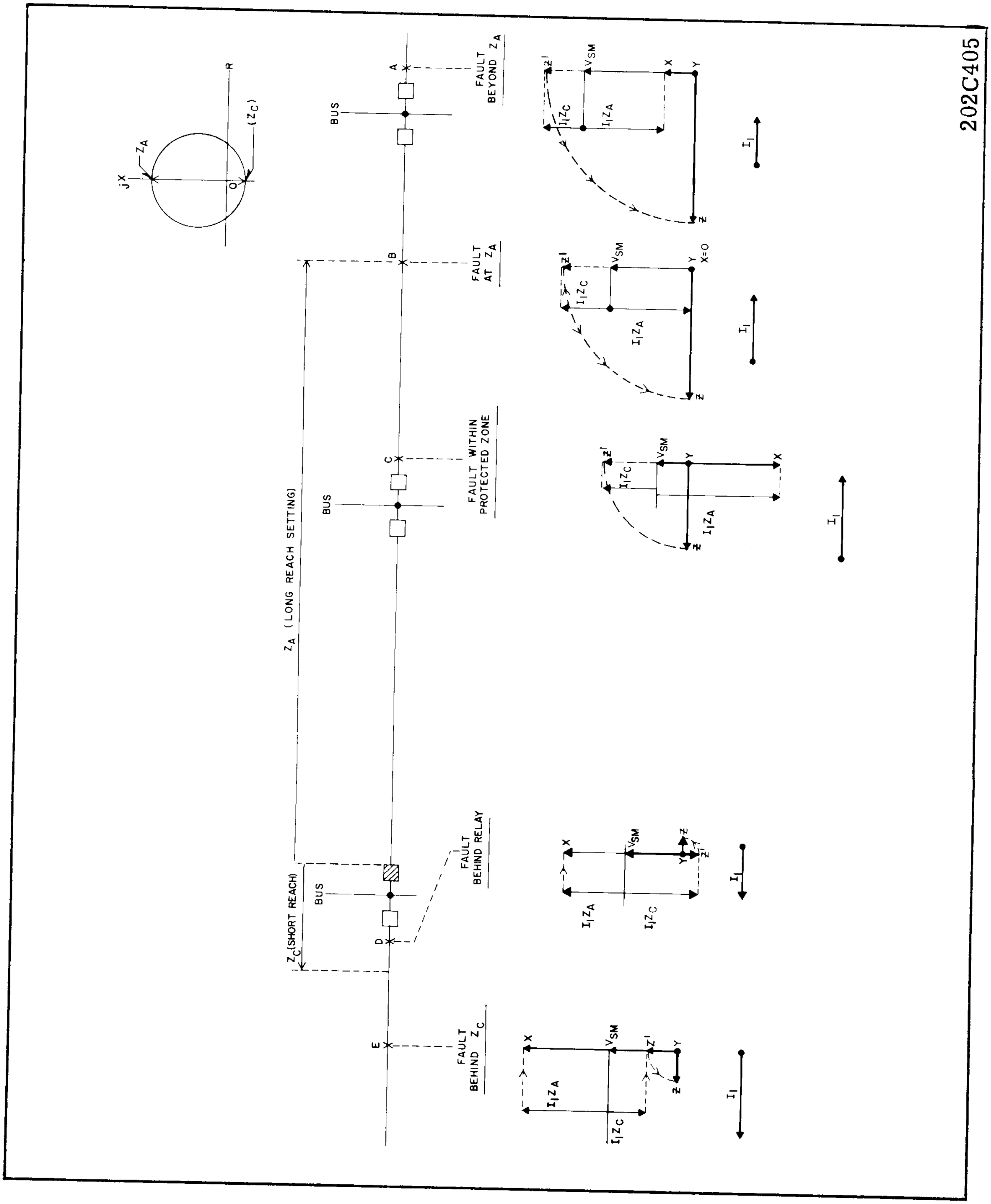
= VARICON CONNECTOR

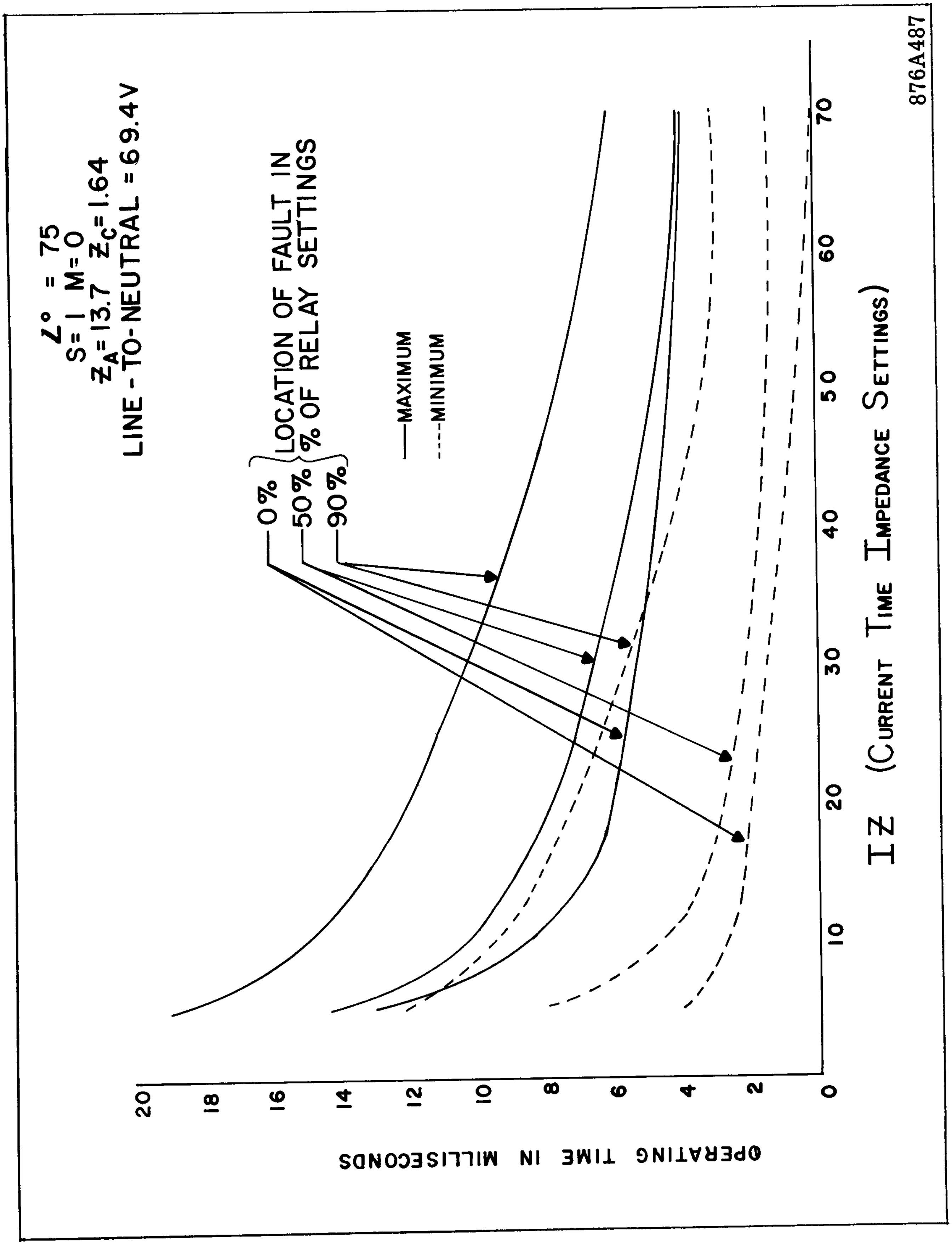
* = INPUT (REQ'S +12 TO +20 VOLTS D.C.)

** = OUTPUT (+15 TO +20 V.D.C. REFERRED TO D.C.NEG.)

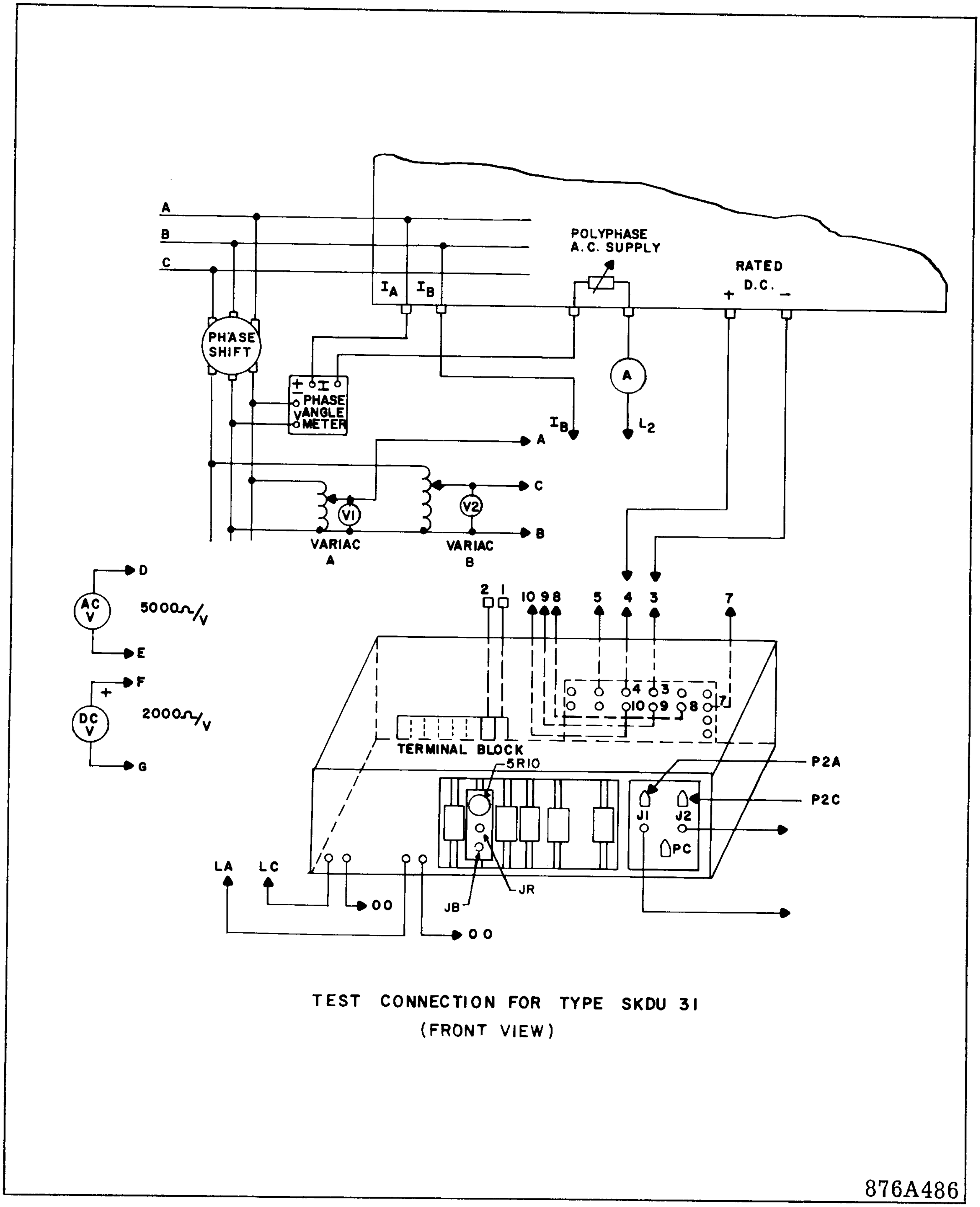
5315D81

ematic

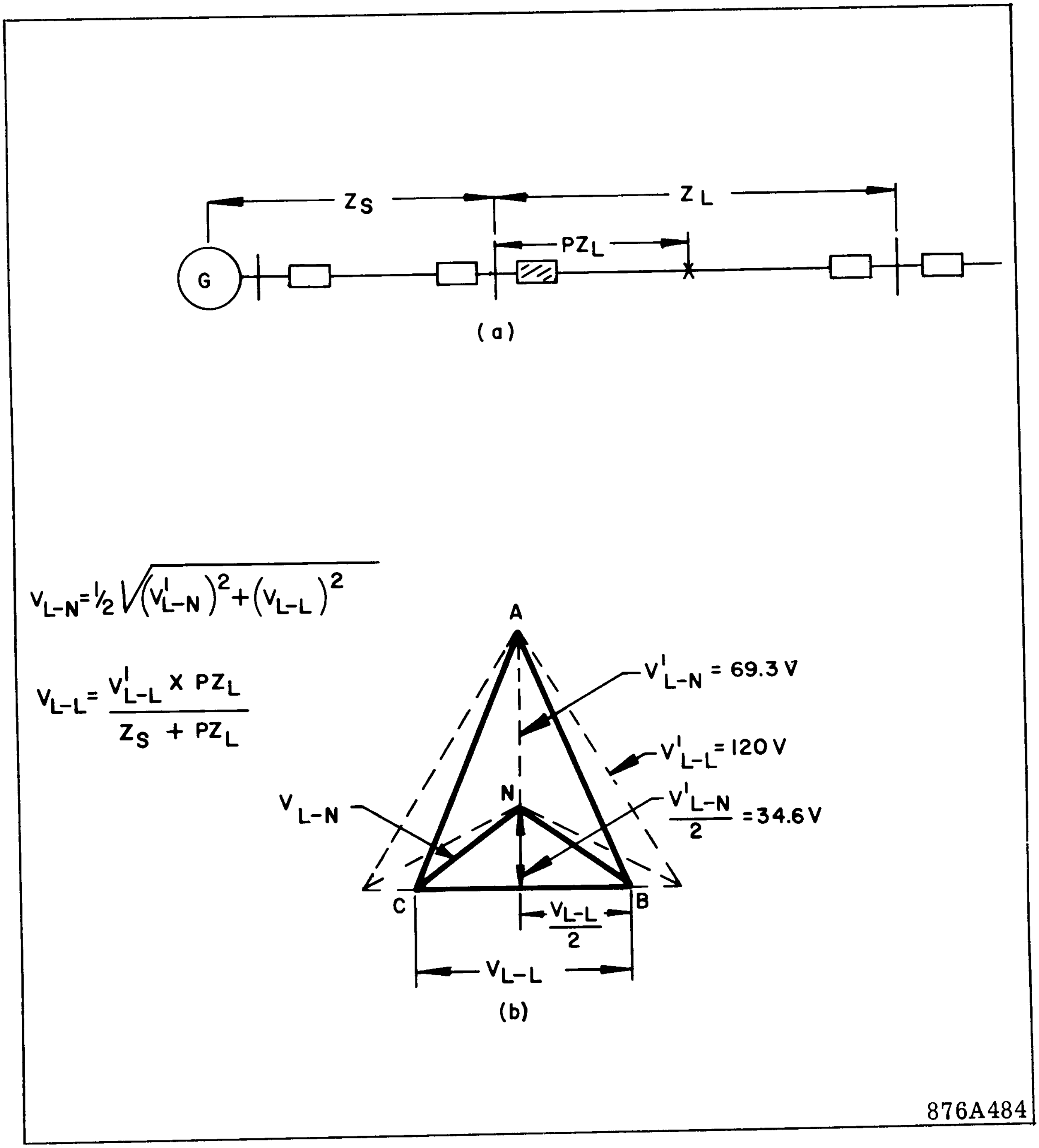

202C405
FAULT BEYOND Z_A
FAULT AT Z_A
FAULT WITHIN PROTECTED ZONE
FAULT BEHIND RELAY
FAULT BEHIND Z_C
BUS
Z_A (LONG REACH SETTING)
Z_C (SHORT REACH)



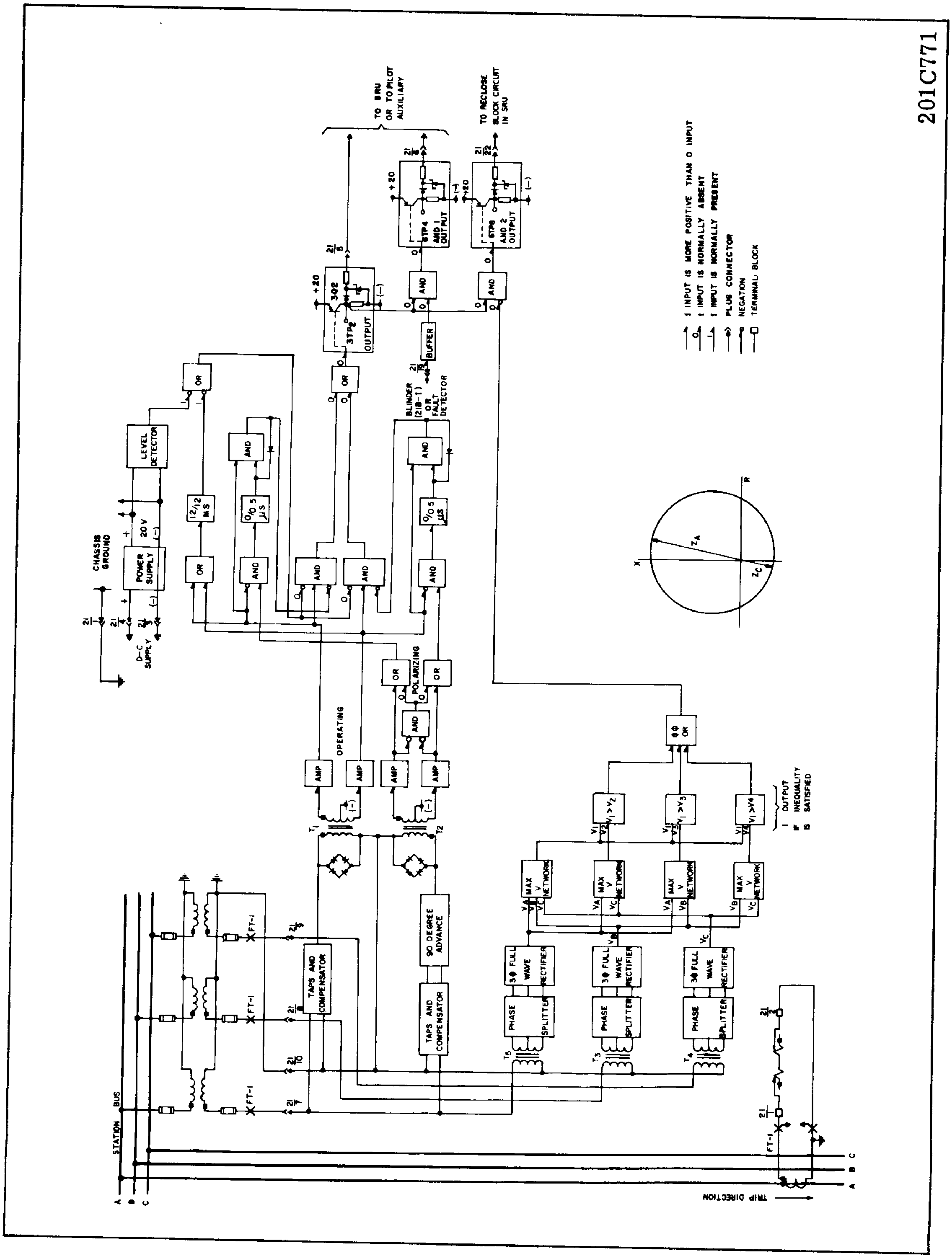
9. Typical Operating Time Curve of the Type SKDU-3 Relay



10. Test Circuit of SKDU-31



11.(a) Transmission Line (b) Phse-B-to Phase C Fault



12. External Schematic

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

INSTALLATION • OPERATION • MAINTENANCE

INSTRUCTIONS

TYPE SKDU-31 RELAY

CAUTION: It is recommended that the user of this equipment become acquainted with the information in these instructions before energizing the relay. Failure to do so may result in damage to the equipment. Before putting the relay into service, operate the relay to check the electrical connections.

APPLICATION

The SKDU-31 is used in a distance phase comparison relaying system with an SKBU-11 or SKBU-21 relay and SRU relay. It performs a phase comparison "arming" function and complements the fault detector in the phase comparison relay. It is used instead of the SKDU-3 relay in applications where reclose blocking is desired for all 3-phase faults. Logic is incorporated in the SKDU-31 to detect one high and two low voltages to identify a phase-to-phase-to ground fault.

Three outputs are available from the SKDU-31:

1. Single-phase distance unit output.
2. Single-phase distance unit output supervised by an external blinder or overcurrent unit.
3. Single-phase distance unit output supervised by the SRD (indicating that a $\phi\phi$ or $\phi\phi$G fault has not occurred).

Logic in the SRU relay further imposes the restriction for reclose blocking that a ground fault has not occurred.

CONSTRUCTION

The SKDU-31 relay contains distance measuring logic of an SKDU-3 relay, phase-to-phase fault detector logic of an SRD relay, and "AND" logic mounted on a standard 19-inch wide panel, 5¼ inches high (3 rack units). Printed circuit boards may be plugged into a card extender, Style No. 849A534G01 to make test points accessible for in service checking.

Distance Logic

The distance logic consists of two single air gap transformers (Compensators T_A, T_C), two tapped auto-transformers TAB, TCB, two isloating transformers T1, T2, a phase shifting network, and three printed circuit boards designated as Operating Circuit, Polarizing Circuit, and Output Circuit.

Fault Detector Logic

The phase-to-phase fault detector logic consists of three isolating transformers T3, T4 and T5 and two printed circuit boards designated as fault discriminator and level detector.

"AND" Logic

The "AND" logic has three inputs. One input is buffered against surges and receives a signal from external logic such as an external fault detector or blinder relay. The other two inputs are from the internal fault detector logic and the distance logic. It has two outputs; one to SRU or pilot-trip auxiliary and one to reclose-block circuitry. The relay has an additional output from the distance unit which is unsupervised.

Compensator

Compensators TA and TC are two-winding air gap transformers (Fig.2). The primary or current winding of the compensator has seven taps which terminate at the tap black (Fig. 3). TA is the long reach compensator.

Tap markings for respective units are as follows;

TA	2.05	2.74	3.76	5.13	7.18	9.92	13.7
TC	1.64	2.19	2.75	4.1	5.78	7.94	10.9

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 product of tap setting and primary

SUPERSEDES I.L. 41-495.3
*Denotes change from superseded issue.

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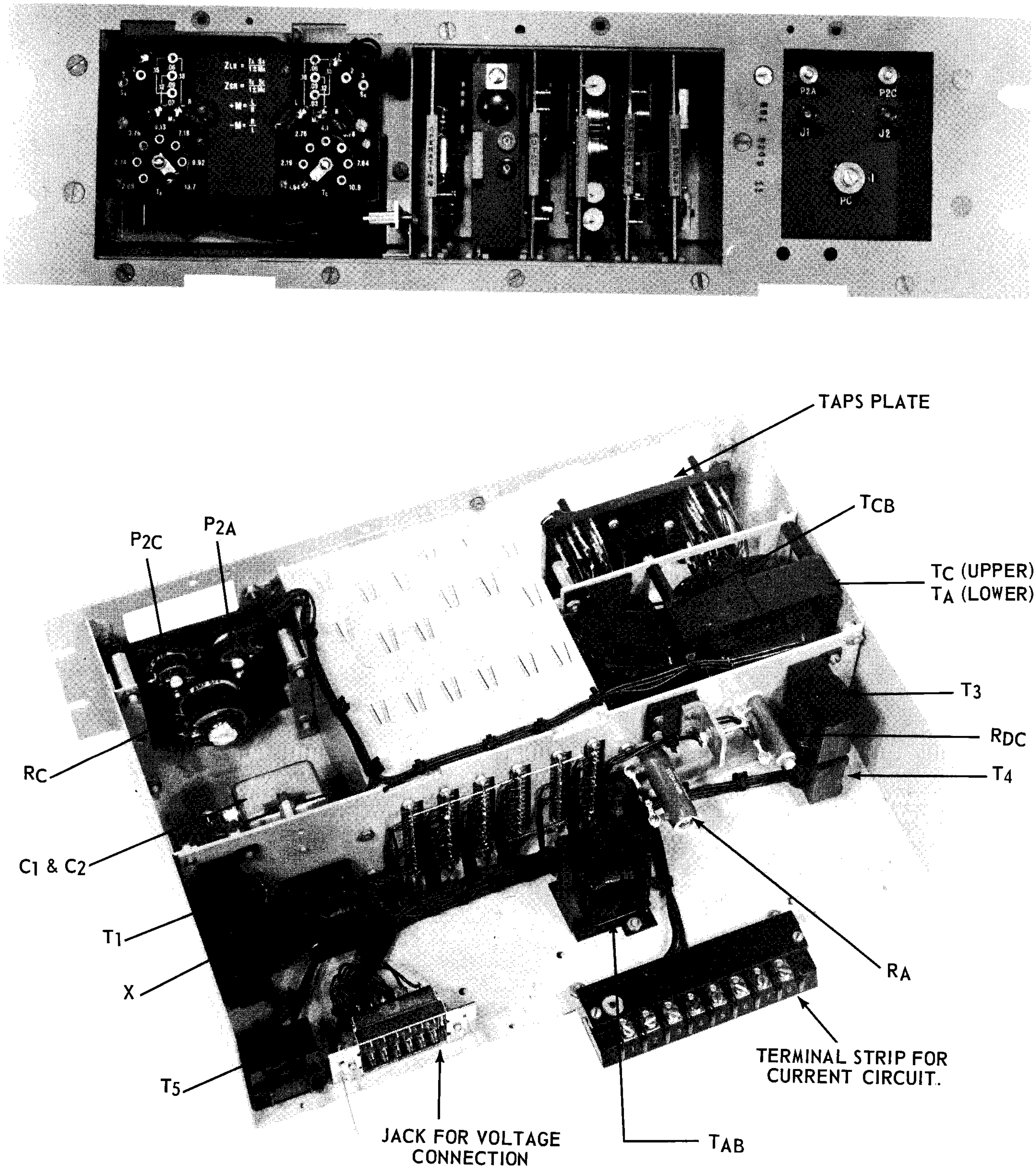


* *Fig. 1. SKDU-31 (Front View, Rear View)*

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 disturbed 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 line current is subtracted vectorially from the relay terminal voltage. The second terminal is connected to the potentiometer and provides a means of adjusting the phase angle relation between primary current and the induced secondary voltage. The phase angle may be set for any value between 60° and 80° by adjusting the potentiometer between its minimum and maximum values respectively. The * maximum sensitivity angle is set for 75° (current lagging voltage) at the factory.

Auto-transformer

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

The sign of M is negative when "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 the compensators by the multiplier of $\frac{S}{1 \pm M}$.

Therefore, any relay ohm setting can be made within ± 1.5 percent from 1.74 ohms to 50 ohms for long * reach setting, and from 1.43 ohms to 40 ohms for short reach setting by combining the compensator * taps TA and TC with the auto-transformer taps S_A and MA, and SC and MC.

Isolating Transformers (T3, T4, T5) & Phase Splitting Networks

Isolating transformers of the phase-to-phase fault detector are designated as T3, T4 and T5. Each of the three isolating transformers has a rated voltage 70 volts 50/60 hertz primary winding. The transformer secondary is a center tapped winding rated 70 volts open circuit and 35 volts to center tap.

Each of the three-phase splitting networks contain a capacitor ($4C_1$, $4C_2$ or $4C_3$), a resistor ($4R_1$, $4R_2$ or $4R_3$) and a potentiometer (4R11, 4R12, or 4R13). Located on the ϕ-ϕ fault discriminator circuit board, they are series connected across the transformer secondary. The potentiometer is adjusted so that the voltage drop across the resistor in series with the potentiometer is equal, in magnitude to the secondary tap voltage. Three voltages can then be measured to form a phasor triangle, the sides of which are nearly equal in magnitude and have a 60° phase angle between adjacent sides. The three voltages are: (1) Across 4R1 and potentiometer 4R11 (4TP1 to terminal 4 on the ϕ-ϕ fault discriminator circuit board for one phase); (2) From 4TP1 to transformer tap at terminal 6, and (3) from tap terminal 6 to terminal 4.

The resulting polyphase voltage drived from phase-A-to-neutral voltage is then applied to a three-phase bridge rectifier to obtain a low ripple d-c voltage. This d-c voltage is proportional to the a-c input voltage. In a similar manner the output from 4TP2, terminal 3 and 8 is proportional to phase-B-to-neutral voltage. From 4TP3 terminal 10 and 11, the voltage is proportional to phase-C-to-neutral voltage.

Printed Circuit Board Assembly

Taking front view of SKDU-31, from left to right, viewed from the front, the printed circuit boards are: (1) Operating circuit board; (2) polarizing circuit (3) output circuit board; (4) ϕ- ϕ fault discriminator board; (5) level detector circuit board, and (6) "AND-Output" circuit board. In Fig. 4 all the components are identified by the letters aXb-- the first letter, a, indicates circuit board position number; the second letter, X, is used to specify the type component and the "b" is the component number. In these circuit boards, the resistors are identified by "R", the diodes by "D" the Zener diode by "Z", transistors by "Q", thyristors by "QS", capacitors by "C", and the test points by "TP". Boxed-in Q numbers indicate normally conducting transistors.

When facing the component side of the printed circuit board, with terminals at the bottom, terminals are numbered 1 to 14 from right to left. These terminal numbers are shown in the internal schematic.

Case Construction

The jack plug on the rear has 24 terminals numbered left to tight and top to bottom. Thus terminal #1 is located in the upper left-hand corner when viewed from the rear, and terminal #24 is in the lower right-hand corner. Terminal #1 is connected internally to the chassis ground and may be used for grounding the connecting cable shields.

There is also an 8-terminal strip used for current terminals which is located in the right-hand side of rear when viewed from the back. The terminals are numbered from left to right.

The chassis case, cover, and front panel have electrical connections established by the use of shakeproof washers which cut through any point or protective coating to make electrical contact with the base metal. The complete relay is then grounded to the switchboard or cabinet by an external wire connection which must be made by clamping the wire under a shakeproof washer which also serves to help hold the cover in place.

The door is hinged at the bottom and is secured at the top by two captive screws. It may be opened to 90 degrees where it is stopped by a slotted strap attached to the door and also to the frame of the case. To remove the door, release the strap by either unscrewing it or unhooking it from the door and then slide the door to the right to disengage the hinges.

Printed-circuit boards are connected into the electrical circuits of the relay through 14-terminal connectors. The boards can be disengaged by a steady pull outward. Sometimes a simultaneous up-and-down motion (if there is clearance) will help free the mating connections. The boards are keyed so that they cannot be pushed home into the wrong connector although they may be replaced into the guides of the wrong position.

OPERATION

SKDU-3

The SKDU-3 unit has two major components, the compensators and the tripping unit. In the internal schematic of Fig. 4, compensators T_A and T_C are shown connected so as to modify the voltage to the the long-reach coils T1 and short-reach coils T2 respectively.

Operation of the SKUD-3 unit can be explained by referring to Fig. 5. In this Figure, the addition of of voltage phasors at various fault locations, results in a set of phasors indicating predominantly positive sequence voltages so that voltage V_{ZY} leads V_{XY} for restraining the tripping unit or indicating predominantly negative sequence voltages so that voltage V_{ZY} lags V_{XY} for operating the tripping unit.

In Fig. 5 the short-reach setting Z_C is about 1/3 of the long-reach setting (Z_A) and is in the reverse direction. This produces an offset circle characteristic which includes the origin when plotted on an R-X diagram. Terms and symbols used in the diagrams are defined as follows:

* V_{SM} = Output voltage from each individual autotransformer which receive phase to neutral voltage. (originates from point Y)

Z_A = Mutual impedance setting of the long-reach compensator

Z_C = Mutual impedance setting of the short-reach compensator

I = Phase current

V_{XY} = Operate circuit voltage (across T1 in Fig. 4)

* V_{ZY} = Compensated polarizing voltage (not phase shifted)

* V_{ZY} = Polarizing circuit voltage (across T2 in Fig. 4) phase shifted 90°

V_{ZY} leads V_{XY} = restraining condition

V_{ZY} lags V_{XY} = operating condition

Consider a fault at location "A" which is beyond the long reach setting. For the sake of simplicity, assume both the line angle and the relay maximum sensitivity angle to be 90°. Compensator Z_A modifies voltage V_{SM} by adding the mutual impedance drop IZ_A which leaves voltage V_{XY} across the input of transformer T_1 .Compensator Z_C modifies its voltage V_{SM} by adding IZ_C to produce V_{ZY}. This voltage is then advanced 90° by phase shifting * action of capacitor C_2 to provide voltage V_{ZY} across the transformer T_2. The resulting diagram shows V_{ZY} leads V_{XY} and restrains the unit for this fault beyond the protection zone.

Using the same method of analysis for a fault at location "B", the long reach setting Z_A, it is shown that X, Y, and Z lie in a straight line to produce a balance point. Within the protected zone, for a fault at location "C", the V_{XY} voltage is reversed by compensator action and leads polarizing voltage V_{ZY} to produce a tripping condition. At location "D", which is behind the relay and within the short reach setting, the trip condition still exists even though I_1 is reversed because I_1Z_C is sufficiently large to reverse the polarizing quantity V_{ZY} . A fault at location "E", behind the relay and outside the protected zone causes a current reversal in both compensators. The restraining voltage V_{SM} is large enough so that V_{ZY} is not reversed. Thus V_{XY} & V_{ZY} have a restraint relation.

The combination of series resistor R_A and parallel capacitor C1 shown in Fig. 4 controls transients in the operating circuit and also provides a small amount of phase shift. In the polarizing circuit, capacitor C2 provides memory action to improve the operating characteristics for faults near the relay location. C2 also provides the major phase shifting effect which makes the voltage across T2 lead the voltage across T1 by 90° when only voltage is applied to the relay. The maximum sensitivity angle (75° or other angles up to 90°) can be adjusted with potentiometer PC.

Phase Angle Comparison Unit (Tripping Unit)

Referring to Fig. 4, the phase angle comparison unit is tripped when current flows into the base of transistor 3Q1 through Zener Diode 3Z1. Such tripping must come from the 20-volt bus, through either transistor 1Q2 or 1Q4 located in operating circuit board. The operating circuit, driven by transformer T_1, is continually trying to trip the unit by supply current through 1Q2 and 1Q4 on alternate half cycles. 1Q2 conducts when the polarity marked terminals of T_1 are positive.

When 1Q2 conducts, a portion of the current goes through 2R9. This current, IR9, may take either of two paths to the negative bus. If $2QS_1$ is in a conducting state, IR9, flows through it directly to the negative bus. If $2QS_1$ is in the blocking state, IR9 passes through diode 2D16 and then through 3Z1 to transistor 3Q1 to cause tripping. Thyristor $2QS_1$ is located in the "polarizing" circuit and is driven by transformer T_2.

To prevent the operating circuit from causing tripping, the polarity marked terminal of T2 must go positive before the polarity terminals of T1. This causes $2Q_1$ to conduct current through 2R5 and drive the base of 2Q4. 2Q4 then conducts the current through 2R6 to gate 2QS1 into conduction. When 2QS1 conducts, it short circuits the current which might otherwise pass through diode 2D16 to cause tripping. Once 2QS1 begins to conduct, the gate loses control and it remains in the conducting state
* until the current is turned off by 2Q1. No tripping output can develop as long as the T2 voltage leads T1 voltage.

The operating circuit switches for the next half-cycle so that transistors 1Q3 and 1Q4 conduct in an attempt to cause tripping. In the polarizing circuit, 2Q2, 2Q5 and 2QS2 prevent tripping by short circuit-which might otherwise pass through 2D1, 3Z1 and 3Q1.

Restraint Squelch

When the operating transistor 1Q2 conducts, approximately 18V is applied through diode 2D15 to back biased 2D14 and prevents 2Q4 from turning on. Thus a trip signal, initiated because the T1 voltage is leading cannot be improperly interrupted when the T2 polarity voltage goes positive. A full half-cycle tripping output is therefore produced by 1Q2. This back biasing connection is called the restraint squelch circuit. The same is true for 2D18, 2D17 and 2Q5.

Restraint-Signal Detectors:

If a condition should develop so that no polarizing voltage appears at transformer T2, then no gating signal would be available to switch 2QS1 and short circuit the 1Q2 current. This, of course, could cause incorrect tripping. A restraint-signal detector circuit prevents this from happening. Under normal conditions, no voltage is allowed to develop across Zener diode 2Z2 at Test Point 2TP1 because it is alternately short circuited to the negative bus by transistors 2Q1 and 2Q2 through diodes 2D5 and 2D6 respectively. When the voltage from T2 drops too low to drive 2Q1 and 2Q2 current flows from the 20-volt bus through 2R3 and 2Z2 into the base of 2Q3. With 2Q2 conducting, the bases of 2Q4 and 2Q5 are driven through diodes 2D8 and 2D13 respectively to maintain the gate drive of 2QS1 and 2QS2 respectively. Thus when the T2 voltage is near zero, thyristors 2QS1 and 2QS2 are maintained in a conducting state so that no output can develop.

SRD

SRD ϕ- ϕ fault detector is static voltage sensing logic which operates at high speed for ϕ-ϕ faults and ϕ- ϕ-G faults. This unit is restrained for single-phase-to-ground faults and for three-phase faults.

Tripping

Voltage from each of the three bridge rectifiers B_A (4D1 to 4D6), B_B (4D7 to 4D12), and B_C (4D13 to 4D18) is applied to potentiometer 5R10 through rectifiers 4D19, 4D22 and 4D25. This voltage from potentiometer 5R10 is applied through Zener diode 5Z2 to the base of transistor 5Q3 and the circuit is completed through one of the three trip diodes 4D28, 4D29 or 4D30) and one of the three voltage comparison resistors (4R7, 4R8 or 4R9).

Transistor 5Q3 is the first stage of an amplifire which operates the output driver circuit. Switch- is accomplished by current flowing in the base of transistor 5Q3.

Restraining

Voltage from two bridge rectifiers is applied to each of the voltage comparison resistors 4R7, 4R9, through rectifier pairs AR (4D20 and 4D21), BR (4D23 and 4D24), and CR (4D26 and 4D27) in different combinations. For instance, 4R8 has a restraint voltage from B_A and B_B impressed across it through rectifier AR and BR respectively. Tripping through 4R8 cannot occur unless the voltage B_C is sufficiently greater than the voltage from B_A and B_B so that current flows through 4D25, potentiometer 4R10, transistor 5Q3 and resistor 4R8.

Another resistor 4R9 has restraint voltage from B_B and B_C impressed across it through rectifiers B_R and C_R respectively. The third resistor 4R7 has restraint voltage impressed across it from B_C and B_A through rectifiers C_R and A_R respectively.

AND-OUTPUT Circuit Board

The logic block diagram of AND-OUTPUT circuit board is shown in Fig. 6. The output can be only obtained from terminal 13 when inputs to terminals 9 and 12 both are present. The output can be only obtained from terminal 3 when input at terminal 9 is present and absent at terminal 8. Referring to Fig. 4, transistors 6Q1, 6Q3, 6Q4, 6Q5, 6Q7 and 6Q8 are normally maintained in a non-conducting state and 6Q2, 6Q6 in a conducting state. Switching is accomplished by the inputs flowing in the base of 6Q6.

Impedance Unit Characteristics

1. Distance Characteristic

A characteristic circle is established by setting two points on the circle, diameterically opposite one another by means of the Long Reach (TA) and Short Reach (TC) compensators, as shown in Fig. 7.

2. Sensitivity

* Fig. 8 is an impedance curve which demonstrates the relay sensitivity to values at the balance point for various values of voltage at the relay terminals.

3. General Characteristics

* Impedance settings in ohms reach can be made for any value from 1.74 to 50 ohms for Z_{LR} and from 1.4 to 40 ohms for Z_{SR} in steps of 3 percent. The maximum sensitivity angle which is set for 75 degrees at the factory may be set for any value from 60 degrees to 80 degrees. A change in maximum sensitivity value angle will produce a slight change in reach for any given setting of the relay. Referring to Fig. 2, note that the compensator voltage output V is largest when V leads the primary current I by 90 degrees. This 90 degree relationship is approached when the compensator loading resistor (P2A or 02C) is open circuited. The effect of loading the the resistor, when connected, is to produce a drop in the compensator which is out of phase with the induced voltage. Thus, the output voltage of the compensator is phase-shifted to change the maximum sensitivity angle. As a result of this phase shift, the magnitude of V is reduced as shown in Fig. 2. *

Tap markings in Fig. 3 are based upon a 75 degree compensator angle setting. If the potentiometers P2A and P2C are adjusted for some other maximum sensitivity angle, the nominal reach is different than indicated by the taps. The reach Z_θ varies with the maximum sensitivity angle θ as follows:

$$Z_\theta = \frac{TS \sin \theta}{(1 \pm M) \sin 75^\circ}$$

Tap Plate Markings:

T_A						
2.05	2.74	3.76	5.13	7.18	9.92	13.7

T_C						
1.64	2.19	2.75	4.1	5.75	7.94	10.9

S_A and S_C		
1	2	3

M_A and M_C		
0.03	0.09	0.06

4. Time Curve

The speed of operation for the SKDU-31 relay is shown by the time curves in Fig. 9. The curves indicate the time in milliseconds required for the relay to produce a 20-volt d-c output for tripping after the inception of a fault at any point on a line within the relay setting.

SRD Characteristics

The SRD ϕ- ϕ fault detector compares the magnitude of the three-phase to neutral voltages. When one of the three voltages is larger than the other two, as for a phase-to-phase fault, it produces a 20-volt d.c output. The unit is restrained for single-phase to ground faults and for three-phase faults. The pick-up voltage of SRD can be adjusted from 25V to 62V (phase-to-neutral) as desired. It operates when fault voltage of two phases (phase-to-neutral or ground) is smaller than the calibrated value of pick-up voltage.

The operating time of the SRD phase-to-phase fault detector depends on the setting of pick-up voltage and fault voltage or location of fault and varies from 3 ms to 12ms. The higher the setting of pick-up voltage, the faster the operating time. The higher the fault voltage, the slower the operating time.

SRD Voltage Burden Data

V	I	VA	Degrees Voltage Lagging
69V	11.3 MA	.78	51°

* IMPEDANCE UNIT BURDEN

VOLTAGE BURDEN
S= 1, V_{AN} = 69.4

X	I_{amp} = O			I_{amp} = 5A T_A + T_C			I_{amp} = 5A T_A - T_C		
TAP SETTING	VA	WATT	VAR	VA	WATT	VAR	VA	WATT	VAR
-.18	2.56	2.40	.93	3.66	3.14	1.88	5.55	5.5	.58
-.15	2.76	2.56	1.06	3.90	3.35	2.00	5.85	5.85	.71
-.12	2.95	2.72	1.18	4.1	3.50	2.12	6.18	6.15	.86
-.09	3.16	2.93	1.22	4.3	3.64	2.24	6.50	6.45	1.01
-.06	3.40	3.17	1.47	4.58	3.82	2.36	6.85	6.80	1.31
-.03	3.60	3.22	1.61	4.80	4.1	2.48	7.24	7.10	1.45
0	3.86	3.46	1.76	5.05	4.26	2.70	7.55	7.40	1.64
.03	4.10	3.70	1.90	5.28	4.45	2.86	7.90	7.75	1.74
.06	4.36	3.84	2.05	5.50	4.60	2.98	8.25	8.05	2.06
.09	4.60	4.08	2.2	5.75	4.82	3.22	8.60	8.35	2.24
.12	4.85	4.30	2.36	6.05	5.05	3.40	8.95	8.65	2.42
.15	5.10	4.42	2.54	6.30	6.30	5.25	9.30	8.95	2.64
.18	5.40	4.70	2.7	6.60	5.50	3.70	9.70	9.30	2.92

VOLTAGE BURDEN S = 2, V_{AN} = 69.4									
X	I_{amp} = O			$I_{amp} = 5_A\ T_A + T_C$			$I_{amp} = 5_A\ T_A + T_C$		
TAP SETTING	VA	WATT	VAR	VA	WATT	VAR	VA	WATT	VAR
-.18	2.52	2.32	.925	3.60	2.9	2.12	5.4	5.35	-.376
-.15	2.70	2.51	1.06	3.80	3.07	2.22	5.66	5.60	-.394
-.12	2.90	2.68	1.15	4.00	3.23	2.35	6.00	5.95	-.370
-.09	3.10	2.88	1.30	4.22	3.42	2.48	6.30	6.25	-.22
-.06	3.40	3.16	1.50	4.42	3.58	2.60	6.63	6.58	-.115
-.03	3.53	3.23	1.58	4.56	3.76	2.73	6.94	6.90	-.097
0	3.78	3.42	1.75	4.85	3.92	2.85	7.35	7.30	+.127
+.03	3.98	3.60	1.87	5.05	4.07	2.97	7.60	7.55	+.265
.06	4.24	3.80	2.05	5.27	4.28	3.10	8.00	7.95	+.416
.09	4.50	4.0	2.18	5.54	4.50	3.25	8.25	8.20	+.585
.12	4.73	3.2	2.28	5.80	4.70	3.40	8.60	8.55	+.75
.15	4.98	4.35	2.49	6.10	4.94	3.58	9.00	8.95	+.95
.18	5.25	4.56	2.63	6.38	5.15	3.76	9.35	9.30	+1.15

VOLTAGE BURDEN S = 3, V_{AN} = 69.4									
X	I_{amp} = O			$I_{amp} = 5_T\ T_A + T_C$			$I_{amp} = 5_A\ T_A - T_C$		
TAP SETTING	VA	WATT	VAR	VA	WATT	VAR	VA	WATT	VAR
-.18	2.53	2.39	.825	3.5	2.93	1.91	5.35	5.3	-1.11
-.15	2.70	2.53	.92	3.68	3.08	2.0	5.60	5.55	- .97
-.12	2.90	2.70	1.04	3.88	3.25	2.12	5.95	5.90	- .78
-.09	3.10	2.87	1.16	4.10	3.44	2.24	6.25	6.20	- .71
-.06	3.30	3.03	1.3	4.90	3.60	2.35	6.60	6.55	- .63
-.03	3.54	3.22	1.36	4.50	3.78	2.46	6.88	6.82	- .65
0	3.75	3.40	1.49	4.80	4.00	2.62	7.25	7.20	- .68
+.03	4.0	3.60	1.63	5.0	4.20	2.73	7.60	7.55	- .66
+.06	4.23	3.80	1.79	5.34	4.50	2.92	7.90	7.85	- .69
+.09	4.41	4.0	1.95	5.55	4.65	3.02	8.30	8.2	- .59
+.12	4.70	4.18	2.13	5.80	4.85	3.16	8.60	8.5	- .376
+.15	5.0	4.40	2.36	6.05	5.05	3.30	8.90	8.8	- .15
+.18	5.2	4.55	2.52	6.25	5.25	3.40	9.30	9.2	- .112

CURRENT BURDEN $S = 1, M = O, V_A = 69.4, I_A = 5_A\ 75°$				
TAP SETTING		CIRCUIT	OHMS	IMPEDANCE
TA	TC	Z	R	X
1.37	10.93	.54 /60°	.27	.467
9.92	7.94	.3 /56°	.167	.248
7.18	5.75	.16 /51°	.101	.124
5.13	4.1	.08 /37°	.063	.048
3.76	2.75	.038/14°	.049	.027
2.74	2.19	.038/14°	.037	.0092
2.05	1.64	.024/6°	.0238	.0025

Current Circuit Rating in Amperes

Tap Setting	Continuous S = 1	Continuous S = 2	Continuous S = 3	1 Second
10.9	5	8.5	8.5	240
7.94	5	8.5	8.5	240
5.75	10	10	10	240
4.1	10	10	10	240
2.75	10	10	10	240
2.19	10	10	10	240
1.64	10	10	10	240

SKDU-31 SETTING CALCULATIONS

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

TA						
2.05	2.74	3.76	5.13	7.18	9.92	13.7

TC						
1.64	2.19	2.75	4.1	5.75	7.94	10.9

S_A and S_C		
1	2	3

M_A and M_C		
.03	.09	.06

Maximum sensitivity angle is set in the factory for 75 degrees (current lags voltage). It should not be necessary to change this calibration unless the line angle is less than 65 °.

The general formula for setting the ohms reach of the relay is:

$$Z_\theta = Z \frac{(\text{Sin } \theta)}{(\text{Sin 75 degree})} = Z_{pri} \frac{R_C}{R_V}$$

The terms used in this formula are defined as follows:

Z_θ = the desired ohmic reach of the relay and relates equally to Long Reach ($Z_{\theta LR}$) and Short Reach ($Z_{\theta SR}$).

$Z = \frac{TS}{1 \pm M}$ = the tap plate setting

T = compensator tap value

S = autotransformer primary tap value

θ = maximum sensitivity angle setting of the relay (for a factory setting of 75°, then $\frac{\text{Sin } \theta}{\text{Sin } 75°} = 1$).

M = autotransformer 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).

Z_{pri} = ohms per phase of the line section to be protected

R_C = current transformer ratio

R_V = potential transformer ratio

The following procedure should be followed to obtain an optimum setting of the relay. Relate the general equation of Long Reach or Short Reach by sub-letter "A" and "C" respectively.

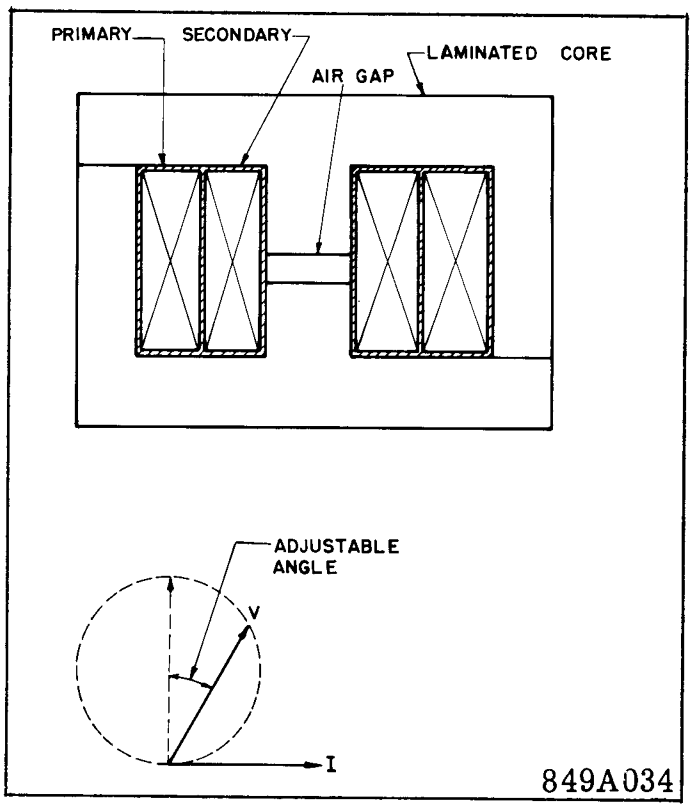
Now refer to Tables I and II which list optimum relay settings for relay range from 1.74 to 50 ohms for Long Reach and 1.4 to 40 ohms for Short Reach compensators.

a) Locate a table value for relay reach nearest to the desired value Z. (It will always be within 1.5% of the desired value).

b) Read from the Table "S", "T", and "M" settings. "M" column cinludes additional information for "L" and "R" settings.

c) Recheck the obtained S, T, and M settings by using equation.

$$Z = \frac{TS}{1 \pm M}$$



2. *Compensator Construction*

TABLE I
RELAY SETTING FOR LONG REACH COMPENSATOR

	"S" = 1							"S" = 2		"S" = 3		"M"		LEAD CONNECTION	
T=	2.05	2.74	3.76	5.13	7.18	9.92	13.7	9.92	13.7	9.92	13.7	+M	-M	"L" LEAD	"R" LEAD
	1.74	2.32	3.18	4.35	6.1	8.4	11.6	16.8	23.2	-	34.8	+.18		.06	0
	1.78	2.38	3.27	4.47	6.25	8.62	11.9	17.3	23.8	-	35.8	+.15		.06	.03
	1.83	2.44	3.36	4.59	6.42	8.85	12.2	17.7	24.5	-	36.7	+.12		.09	0
	1.88	2.52	3.45	4.70	6.60	9.10	12.5	18.2	25.2	-	37.7	+.09		.09	.03
	1.93	2.58	3.55	4.84	6.78	9.35	12.9	18.7	25.9	-	38.8	+.06		.06	.09
	1.99	2.66	3.66	4.98	6.98	9.64	13.3	19.3	26.6	-	40.0	+.03		.03	0
	2.05	2.74	3.76	5.13	7.18	9.92	13.7	19.8	27.4	-	41.1	0	0	0	0
	2.12	2.82	3.88	5.30	7.40	10.3	14.1	20.4	28.3	-	42.4		-.03	0	.03
	2.18	2.92	4.00	5.46	7.65	10.6	14.5	21.1	29.2	-	43.6		-.06	.09	.06
	2.25	3.02	4.15	5.65	7.90	10.9	15.0	21.8	30.2	32.8	45.1		-.09	.03	.09
	-	3.12	4.27	* 5.82	8.16	11.3	15.5	22.6	31.2	33.8	47.8		-.12	0	.09
	-	-	-	-	-	-	16.1	-	32.3	-	48.4		-.15	.03	.06
	-	-	-	-	-	-	-	-		-	50		-.18	0	.06

TABLE II
RELAY SETTING FOR LONG REACH COMPENSATOR

	"S" = 1							"S" = 2		"S" = 3		"M"		LEAD CONNECTION	
T=	1.64	2.19	2.75	4.1	5.75	7.94	10.9	7.94	10.9	7.94	10.9	+M	-M	"L" LEAD	"R" LEAD
	1.39	1.86	2.33	3.47	4.95	6.72	9.25	-	-	-	27.8	+.18		.06	0
	1.43	1.91	2.39	3.57	5.10	6.9	9.48	13.8	19.0	-	28.4	+.15		.06	.03
	1.47	1.96	2.46	3.66	5.22	7.09	9.72	14.2	19.5	-	29.2	+.12		.09	0
	1.51	2.00	2.52	3.76	5.37	7.28	10.0	14.6	20	-	30.0	+.09		.09	.03
	1.55	2.07	2.60	3.87	5.52	7.46	10.3	15.1	20.6	-	30.9	+.06		.06	.09
	1.60	2.12	2.67	3.98	5.69	7.7	10.6	15.4	21.2	-	31.8	+.03		.03	0
	1.64	2.19	2.75	4.1	5.75	7.94	10.9	15.9	21.8	-	32.7	0	0	0	0
	1.68	2.26	2.84	4.22	6.04	8.16	11.2	16.4	22.5	-	33.8		-.03	0	.03
	1.74	-	2.93	4.36	6.21	8.44	11.6	16.9	23.2	-	34.8		-.06	.09	.06
	1.80	-	3.02	4.5	6.43	8.72	12.0	17.5	24.0	-	36.0		-.09	.03	.09
	-		3.12	4.66	6.65	9.00	12.4	18.1	24.8	27.0	37.2		-.12	0	.09
	-	-	3.24	4.82			12.8	18.7	25.7	-	38.5		-.15	.03	.06
	-		3.36	-	-		13.3		26.6	-	40		-.18	0	.06

For Example:

(Step 1a) Assume the desired reach, Z_θ, is 30 ohms for the Long Reach setting at 60 degrees.

(Step 1b) Making correction for maximum sensitivity angle of the line (60 degrees) that is different from factory setting of 75 degrees, find the relay tap setting

$$Z = \frac{(30) \text{ Sin } 75}{\text{Sin } 60}$$

$$Z = (30)\ (1.116) = 33.2 \text{ ohms.}$$

* Next, in table I, we find nearest value to 33.2 ohms: 33.8; that is $\frac{33.8}{33.2} \times 100 =$ 100.2 per cent of the desired reach.

* (Step 2b) From Table I read off: S = 3, T = 9.92, M = .12, and "R" lead should be connected over "L" lead, with "L" lead connected on zero, and "R" lead on .09.

The last step is to recheck setting:

$$Z = \frac{TS}{1 \pm M} = \frac{(3)\ (9.92)}{1 - .12} = 33.8$$

* $$Z_{60^\circ} = Z \frac{\text{Sin } 60}{\text{Sin } 75} = (33.8)\ (.895) = 30.2 \text{ ohms which}$$

is within 1 per cent of the desired setting.

The same procedure can be followed for Short Reach Compensator.

SETTING THE RELAY

The impedance unit requires settings for each of the two compensators (T_A and T_C), each of the two auto-transformer primaries (S_A and S_C), and for the two auto-transformer secondaries (M_A and M_C). All of these settings are made with taps on the tap plate which is located inside the door and at the left-hand side of the relay. Figure 3 shows the tap plate. The SRD requires setting potentiometer 5R10 which is on LEVEL DETECTOR circuit board.

Compensator (T_A and T_C)

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 inset which is the Common Connection for all of the taps. Electrical connections between common inserts are made with a link that is held in place with two connector screws, one in the common and one in the tap.

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 but not hard enough to break the screw.

Autotransformer Primary (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 the taps and is held in place on the proper tap by a connector screw (Fig. 3).

An "S" setting is made by removing the connection 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.

Autotransformer Secondary (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 "M" value is determined by which lead is in the higher position on the tap plate. The sign is positive (+) if the "L" lead is higher and negative (-) if the "R" lead is in the higher position.

Line Angle Adjustment

Maximum sensitivity angle is set for 75 degrees (current lagging voltage) in the factory. It is not expected that this adjustment need be disturbed. However, if a change is desired, refer to Repair Calibration.

SRD Setting Example

* The setting of pick-up voltage of SRD phase-to-phase fault detector is dependent on the source and line impedance. The potentiometer 5R10 on LEVEL DETECTOR circuit board is to set the pick-up voltage which could be setting from 25 V to 62 V (phase-to-neutral). A clockwise rotation of 5R10 increases the pickup voltage and a counterclockwise rotation decreases the pickup voltage. The SRD operates when the ratio of faulted phase voltage (faulted phase-to-phase) to the unfaulted phase voltage is smaller than the pickup voltage setting.

In Fig. 11 assume the source impedance Z_S equal to 8 ohms (secondary) and line impedance, Z_L equal to 32 ohms. The P.T. normal secondary line-to-line voltage is 120V. If a $\phi\phi$ fault is at 75% of the line, the secondary line-to-line V_{LL} will be the P.T. normal secondary voltage. 120V times 75% of line impedance divided by the sum of source impedance and 75% of the line impedance, which is:

$$V_{L-L} = \frac{120 \times .75 \times 32}{8 + .75 \times 32} = \frac{120 \times 24}{8 + 24} = 90V$$

* and the voltage from neutral to fault phases will be 56.7 V.

* $$\sqrt{\left(\frac{90}{2}\right)^2 + (34.6)^2} = 56.7\text{ V}$$

For the relay voltage for phase-to-phase faults at various locations for this example, refer to the following table:

Z_S = 8 Ohms Z_L = 32 Ohms	Fault Location in % of Line			
	25%	50%	75%	100%
Secondary Phase-to-Phase Voltage V_{L-L} (Between faulted phases)	60	80	90	96
Secondary Phase-to-Neutral Voltage V_{L-N} (From faulted phases)	45.7	52.8	56.7	59.2

In this case (Z_S = 8 ohms Z_L = 32 ohms). The pick-up voltage of SRD should be a setting greater greater than 59.2V.

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 by means of the four slotted holes on the front of the case. Additional support should be provided toward the rear of the relay in addition to the front panel mounting. This will protect against warping of the front panel due to the weight of the relay.

ACCEPTANCE TESTS

Acceptance tests in general for SKDU-31 consists of:

(1) A visual inspection to make sure there are no loose connections or broken parts.

(2) An electrical test to make certain the relay measures the balance point conditions accurately.

Distance Unit

Check the electrical response of the relay by using the test connections for test number 10 shown in

Fig. 10. Set T_A for 13.7 ohms, T_C for 1.64 ohms, S_A and S_C for 1, and M_A.and M_C for zero.

A. Adjust the voltage V for 40 volts.

B. Connect a high sensitivity d-c voltmeter (at least 20,000 phms per volt) between Varicon terminals 5 and 3 to measure a 20 volt d-c output. (5 is pos.).

C. The current required to obtain a 20 volt d-c output for the long-reach balance point should be between 2.9 and 3.0 amperes at the maximum sensitivity angle of 75 degrees current lag.

D. The current required to trip for current polarity reversed should be between 18.3 and 19amperes at 75 degree current lag.

SRD Phase Splitting Network

E. Make connection for Test No. 1 as shown in Fig. 10. Use a vacumn--tube voltmeter to measure the voltages on the fault discriminator circuit board:

1. Across the series connection of 4R1 and potentiometer 4R11 (from 4TP1 to Printed Circuit Board terminal 4).

2. From 4TP1 to transformer tap at PCB terminal 6.

3. From PCB terminal 6 toPCBterminal 4.

to see that the three are within 1 volt of each other. If not, adjust potentiometer 4R11. Always read voltage between $4TP_1$ and P.C.B. terminal 4 when adjusting potentiometer 4R11. *

F. Make connection for Test No. 2 as shown in Fig. 10. Use a vacuum-tube voltmeter to measure the voltages on fault discriminator circuit board: (1) Across 4R2 plus potentiometer 4R12 (from 4TP2 to PCB terminal 3); (2) from 4TP2 to transformer tap at PCB terminal 8, and (3) from PCB terminal 8 to PCB terminal 3 to see that the three are within 1 volt of each other. If not, adjust potentiometer 4R12. Always read voltage between potentiometer $4TP_2$ and P.C.B. terminal 4 when adjusting potentiometer 4R12. *

G. Make connection for Test No. 3 as shown in Fig. 10. Use a vacuum-tube voltmeter to measure the voltage on fault discriminator circuit board. (1) Across 4R3 plus potentiometer 4R13 (from 4RP3 to PCB terminal 11); (2) from 4TP3 to transformer tap at PCB terminal 10 and, (3) from PCB terminal 10 to PCB terminal 11 to see that the three are within 1 volt of each other. If not, adjust pointiometer 4R3. Always read voltage between $4TP_3$ and P.C.B. terminal terminal 4 when adjusting potentiometer 4R13. *

* Make connection per Test No. 4 as shown in Fig. 10. Adjust variable autotransformer B to the desired pick-up voltage. Use a high resistance d.c. voltmeter (at least 20,000 ohms per volt) to measure the output voltage between J_R and J_B on LEVEL DETECTOR Circuit Board. Adjust potentiometer 5R10 until an output of 20 volts is obtained. Then this low voltage is also the desired pick-up voltage using Test No. 5 and No. 6 in FIG. 10. Adjust the voltage with the variable autotransformer to check the pick-up voltage. The pick-up voltage is set at the factory for 60V.

H. AND OUTPUT circuit Board Check

* 1. Impedance Unit Setting

Set TA on 13.7 and TC on 10.9
SA and SC set on 1
"R" for MA and MC set for 0.0
"L" for MA and MC set for 0.0

* 2. SRD SETTING

Set the desired pick up voltage as described in setting the SKDU-31 (setting the pick-up voltage).

Connect as shown in Fig. 10. Rotate the phase shifter to 75 degrees. (Using phase angle meter to check the phase angle). The performance described in the following table should be obtained. For the measurements a d-c voltmeter having at least 20,000 ohms per volt should be used.

If the setting of the pick-up voltage of the SRD is 60V, test conditions and relay performance are shown in the following table.

V_1 Volts	V_2 Volts	Current Magnitude and Terminal Block Connection (From/To)	D.C. Output Voltage (Measured between terminal)		
			SKDU-3 3TP2/Neg.	SRD JR/JB	Reclose Block Varicon Term. 22/Neg.
70V	70V	4.45 Amps with $L_{2/1}$ and $I_{B/2}$	0	0	0
(59V & Less)	70V	4.45 Amps with $L_{2/1}$ and $I_{B/2}$	20	20	0
(59V & Less)	Same as V_1	4.45 Amps with $L_{2/1}$ and $I_{B/2}$	20	* 0	20
(59V & Less)	70V	Less Than (V_1/13.7) Amps with $L_{2/1}$ and $I_{B/2}$	0	20	0

Apply 20 volts d-c between Varicon terminals 19 and 3 (Neg.) to obtain the performance indicated in the following table.

V_1 Volts A/7	Current in Amps and Terminal Block Connect. (From/To)	Varicon Terminal 19/3	D.C. Output Voltage (Measured between terminal)	
			SKDU-3 3TP2/Neg.	Trip Output Varicon Term. 6/Neg.
70V	4.45 Amps with $L_{2/1}$ and $I_{B/2}$	0	0	0
(59 V & Less)	4.45 Amps with $L_{2/1}$ and $I_{B/2}$	0	20V	0
70V	4.45 Amps with $L_{2/1}$ and $I_{B/2}$	* 12-20V	0	0
(59V & Less)	4.45 Amps with $L_{2/1}$ and $I_{B/2}$	12-20V	20V	20V

ROUTINE MAINTENANCE

The SKDU-31 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.

CAUTION: Before making "hi-pot" test, jumper Varicon terminals 3, 4, 5, 6, 19 and 22 together to avoid destroying components in the static network.

When performing routine maintenance, the dis- * tance characteristic of the SKDU-31 relay can be checked by using the same procedure as outlined in "Acceptance Tests." The balance point impedance measured by the relay is $Z_R = \frac{V_{L-N}}{I_L}$ where V_{L-N} is the phase to neutral voltage applied to the relay terminals and I_L is the phase current.

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 11.

Distance Unit Calibration

1. SETTING: Check to see that....

   T_A set 13.7 and T_C set on 10.9
   S_A and S_C set on 1
   "R" for M_A and M_C set on 0.0
   "L" for M_A and M_C hangs free

Electrical Calibration

Compensator Angle Adjustment

Long Reach Compensator T_A: Refer to the Table of Test connections and connect the test circuit as per Test No. 7.

2. Connect the relay as per figure 10. Test No. 7
3. Connect a voltmeter between the "L" lead and and "O" tap of M_A.
4. Apply 40 volts between Varicon terminals 7 and 10 with polarity on terminal 7.
5. Apply 3.1 ± .1 amperes into terminal block 1 out of 2.
6. Adjust the potentiometer P_{2A} to obtain a "null" on the voltmeter when the phase shifter is on 75° ± 1° (current lags voltage).

Short Reach Compensator TC

7. Connect the relay as per table, Test 8.
8. Connect a voltmeter between "L" lead and "O" tap of M_C.
9. Reverse the voltage applied to the Varicon terminals 7 and 10, and apply 40 volts between them.
10. Circulate 3.76 amperes through terminal 1 and 2 of the terminal block in the rear of the SKDU-31.
11. Adjust the potentiometer P_{2C} to obtain a "null" on the voltmeter when the phase shifter is on 75° ± 1° (current lags voltage).

Auto-Transformer Check

12. Set S_A and S_C on tap number 3· Apply 60 (± 1) volts between Varicon terminals 7 and 10. Measure voltage from terminal 10 to the number 1 tap of S_A and S_C. It should be 20 (± 1) volts. From 10 to the number 2 tap of S_A and S_C should be 40 (± 1) volts.
13. Set S_A and S_C on 1 and apply a voltage V_T (which is equal to 60 volts ± 1 volt) between terminals 7 and 10. Measure the voltage drop from terminal 10 to each of the M_A and M_C taps. This voltage should be equal (± 1 volt) to the sum of V_T plus (the sum of digits between "R" and the tap being measured).

    Example: 60 + (.03 + .09 + 0.06) 60 = 70.8 volts. If the voltage reading is not within limits, then, either the turn ratio or the connection is wrong.
14. Set T_A on 13.7 and T_C on 1.64

    Set S_A and S_C on 1

    "R" for M_A and M_C set on 0.0

    "L" for M_A and M_C set on 0.0

Maximum Sensitivity Angle, Test 9

15. Set the phase shifter to 30° ± 2° (current lags

voltage). Apply 40 volts between terminals 7 and
* 10, and adjust the current to 3.8 ± .1 amperes. Measure the output voltage from terminal 5 to terminal 3 with a d-c voltmeter, and adjust the potentiometer P_C until a threshold 20 volt d-c output is obtained Turn the phase shifter until the d-c voltage drops to zero, this angle should be 120° ± 2°. (The total angle is 30° ± 120° = 150°).

16. Apply 40 volts across terminals 7 and 10. Turn the phase shifter to 225°, and apply approximately 24 amperes, the relay should "just" trip. (Do not leave 24 amperes on more than 5 seconds).

Impedance Curve, Test 10

17. Connect the relay as test #10, the relay should
* trip within the current listed for the given test voltage when current lags voltage by 75°.

Volts	Amps to Trip at 75°	
	Imin	Imax
10	7.5	7.7
30	2.22	2.3
60	4.4	4.5

SRD Phase Splitting Network Calibration

18. Described as E, F and G in Acceptance Tests.

Potentiometer 5R10 - Setting the Pick-up Voltage

19. Described under Setting the Relay

HI-POT TEST

20. Use jumpers to connect the terminals into groups as defined below. Apply standard test between the chassis and each group, and from group to group.

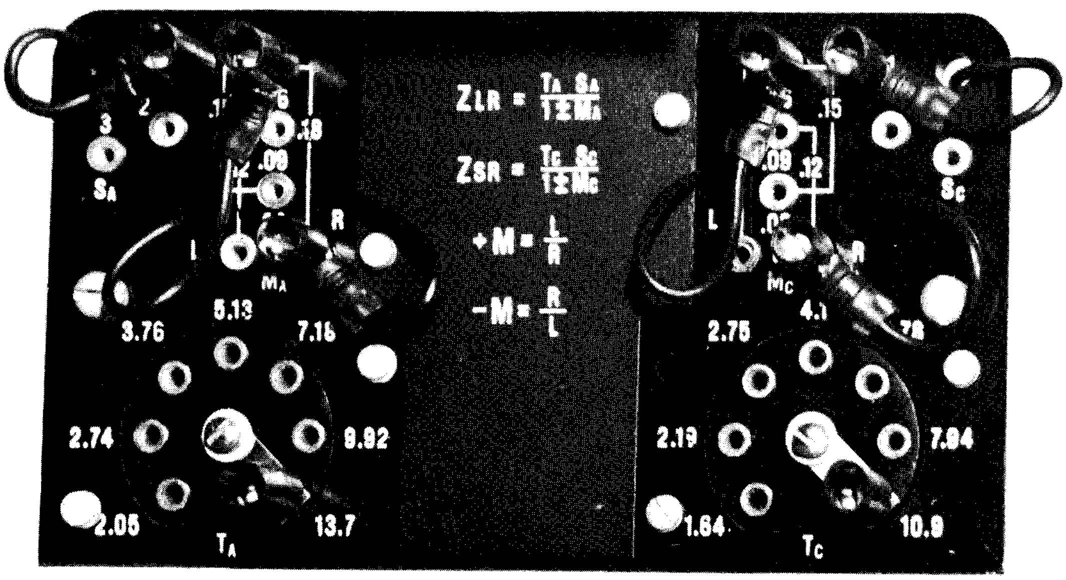
Group 1. Varicon connector terminals 7, 8, 9 and 10.

Group 2. Varicon connector terminals 3, 4, 5, 6, 19 and 22.

Group 3. Terminal block terminals 1.2.

RENEWAL PARTS

Repair work can be done most satisfactorily at the factory. However, interchangeable parts can be furnished to the customers who are equipped for doing repair work. When ordering parts, always give the complete nameplate data. For components mounted on the printed circuit boards, give the circuit symbol electrical value and style number.



3. Tap Plate

ELECTRICAL PARTS LIST

NOTE: The manufacturer reserves the right to change component values without prior notice

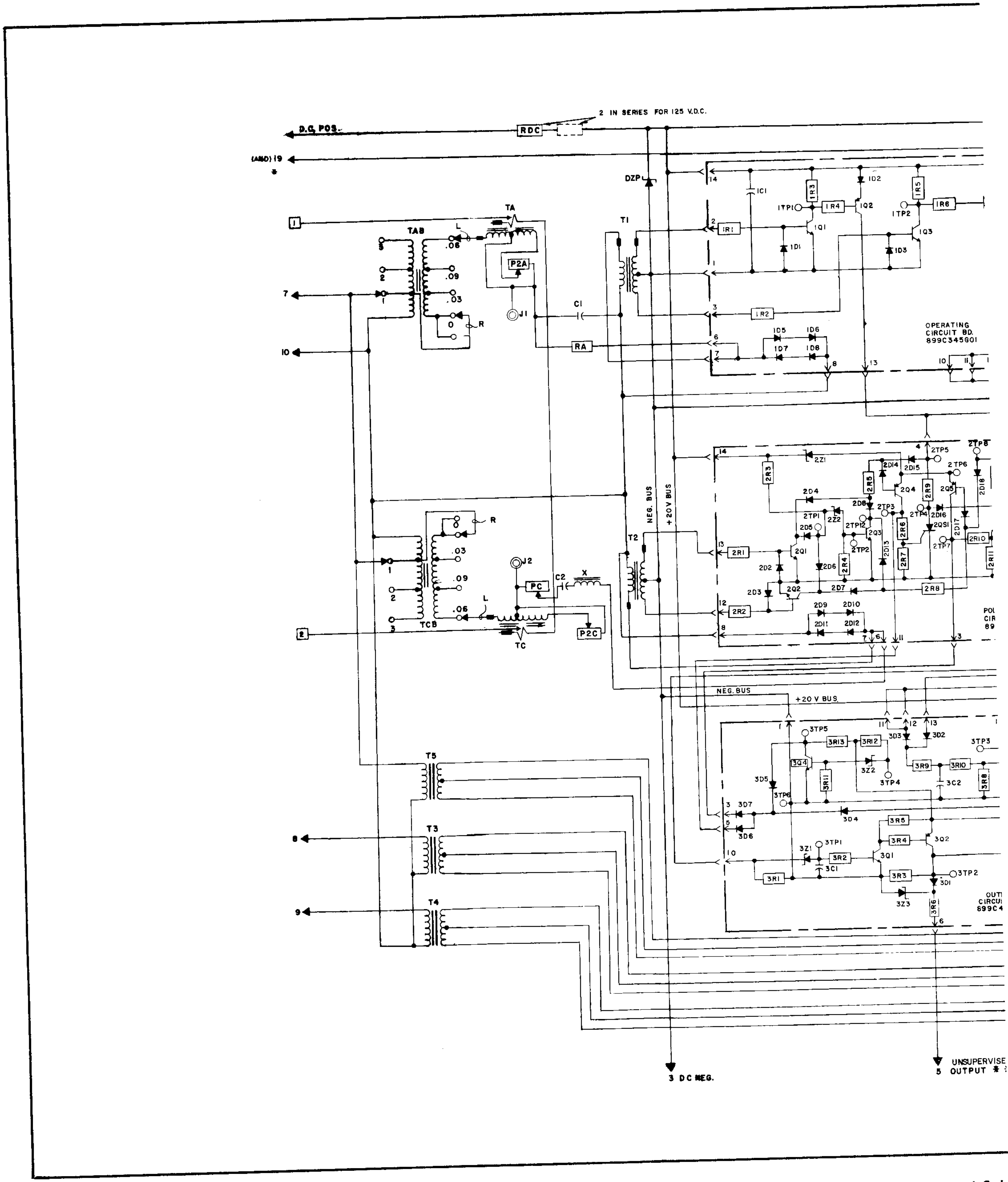
PRINTED CIRCUIT BOARDS	WESTINGHOUSE STYLE NO.
Operating Circuit Board	899C345G01
Polarizing Circuit Board	899C347G01
Output Circuit Board	899C477G01
ϕ-ϕ Fault Discriminator Circuit Board	5314D08G01
Level Detector Circuit Board	5314D09G01
AND-Output Circuit Board	201C204G01

CIRCUIT SYMBOL	DESC.	WESTINGHOUSE STYLE NO.
RESISTORS		
2R7,2R9,2R11,2R12,3R13	2.7 K	1184A763H37
4R1 to 4R3	2 7 K	187A644H37
1R4,1R2,3R10	220 K	184A763H83
1R4.1R6, 2R5,2R8	8.2 K	184A763H49
2R4	22 K	184A763H59
2R1,2R2,3R9	100 K	184A763H75
2R3	33 K	184A763H63
2R6,2R10	2.7 K	629A531H42
1R3,1R5	1 MEG	184A763H99
3R1,3R2,4R4 to 4R6	56 K	184A763H69
3R6,6R6,6R9,6R21,6R24 6R40,6R54,6R58,5R2	27 K	629A531H66
3R4,6R5,6R8,6R12,6R20 6R23,6R27,5R4,5R5	6.8 K	629A531H52
3R5	6.8 K	184A763H47
3R6,6R15,6R30,5R1	150 Ohms	762A 79H01
3R7	5.6 K	184A763H45
3R8,3R11	27 K	184A763H61
3R12	18 K	184A763H57
6R1,6R2	4.7 K	629A531H48
6R3,6R14,6R29,5R7	82 K	629A531H78
6R4,6R7,6R10,6R13,6R19	10 K	629A531H56
6R22,6R25,6R28,5R3	10 K	629A531H56
5R8	2 K	629A531H39
5R9	68 K	184A763H71
5R6	39 K	629A531H70
4R7 to 4R9	330 K	184A763H87
4R10	20 K	184A763H58
RA	2.8 K	1267210
RDC	300 Ohms (for 48VDC)	184A856H10
RDC	600 Ohms (2 in Series for 125 VDC)	1267283

CIRCUIT SYMBOL	DESC.	WESTINGHOUSE STYLE NO.
ZENER DIODE		
2Z1,6Z2	1N957B	186A797H06
3Z1	1N752A	186A797H12
6Z1	1N3638B	185A212H06
6Z3,6Z6,5Z1,3Z3	1N3688A	186A797H13
4Z1 to 4Z3	1N3036B	188A302H09
DZP	1N2984B	762A631H01
DIODES		
1D1 to 1D8, 2D1 tp 2D18	CER69	188A342H06
3D1 to 3D7	CER69	188A342H06
4D1 to 4D30, 5D2	1N457A	184A855H07
6D1'6D2,6D4,5D1	1N645A	837A692H03
CAPACITORS		
1C1	18 Mfd	187A508H10
3C2,5C2	.25 Mfd	187A624H02
3C1	.015 Mfd	187A624H10
C1	.8 Mfd	14C9400H15
C2	1.0 Mfd	14C9400H28
6C1	.047 Mfd	849A437H04
6C2,6C4,5C1	.27 Mfd	188A669H95
4C1 to 4C3	.5 Mfd	187S624H11
TRANSISTORS		
1Q1,1Q3,2Q1,2Q2,3Q3	2N3391	848A851H01
2Q3,3Q1,3Q4	2N697	184A638H18
1Q2,1Q4,2Q4,2Q5,3Q2,5Q1, 6Q1 to 6Q3,6Q5 to 6Q7	2N1132	184A638H20
5Q2,5Q3	2N3417	848A851H02
6Q4,6Q8	2N3645	849A441H01
POTENTIOMETERS		
P2A,P2C	2500 Ohms	836A635H04
PC	5 Ohms	836A635H02
5R10	50 K	862A303H01
4R11 to 4R13	2.5 K	629A430H03
SWITCH		
2QS1, 2QS2	2N884	185A517H05
TRANSFORMER		
T1,T2		262B563G09
T3,T4,T5		292B563G14

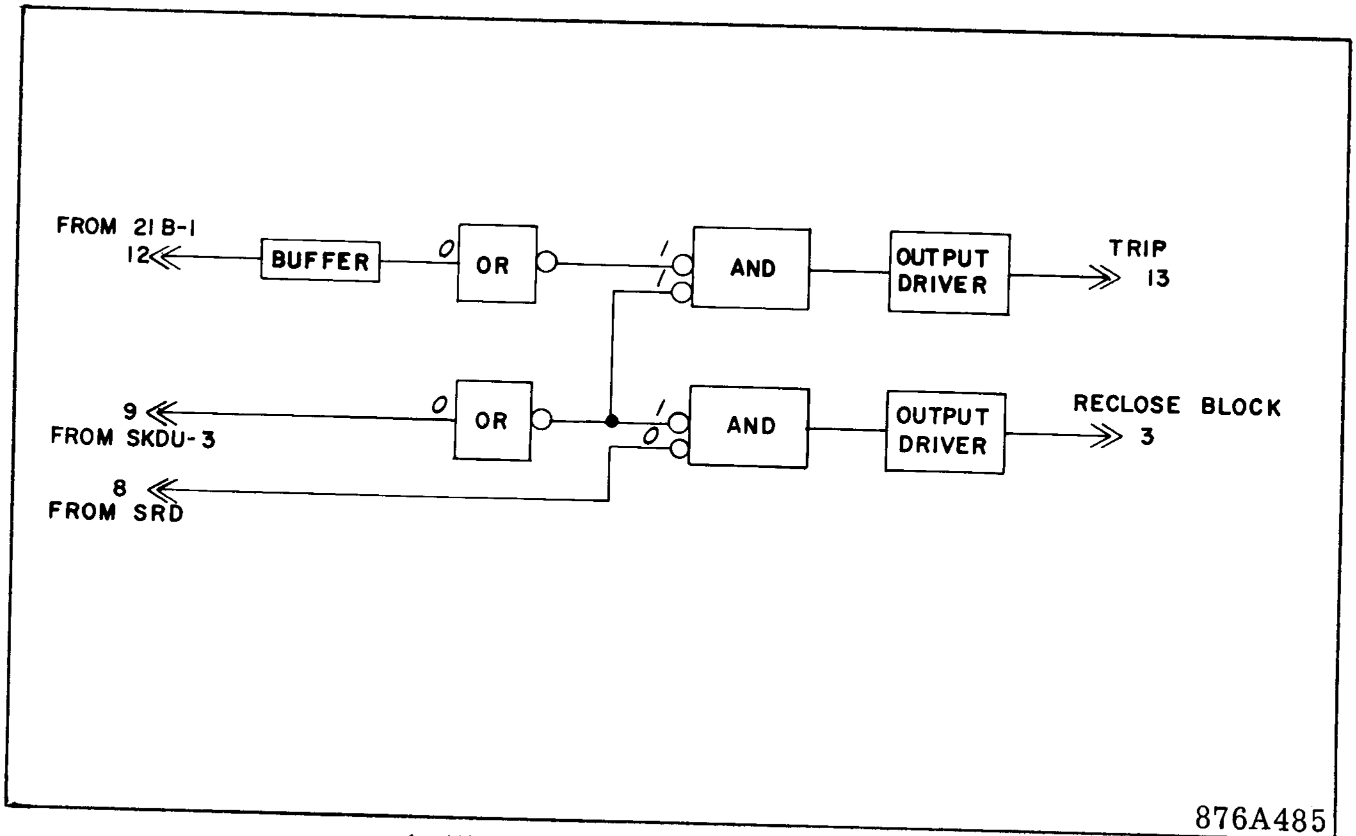
TABLE OF CONNECTIONS FOR TEST CIRCUIT (FIG. 11)

TEST NO.	TO CHECK OR ADJUST	V	LOW VOLTAGE	CONNECT FROM/TO									PHASE SHIFTER ANGLE
1.	4R11	$V_{7-10} = 70V$		A/7	B/10								
2	4R12	$V_{8-10} = 70V$		A/8	B/10								
3	4R13	$V_{9-10} = 70V$		A/9	B/10								
4	5R10	$V_{8-10} = 70V$	$V_{9.7-10}$	A/7&9	B/10	C/8							
5	5R10	$V_{9-10} = 70V$	$V_{7.8-10}$	A/7&8	B/10	C/9							
6	5R10	$V_{7-10} = 70V$	$V_{8.9-10}$	A/8&9	B/10	C/7							
7	P2A	$V_{7-10} = 40V$		A/7	B/10		I_B/2	L_2/1	D/LA	E/0.0			75° ± 1
8	P2C	$V_{7-10} = 40V$		A/10	B/7		I_B/2	L_2/1	D/LC	E/0.0			75° ± 1
9	PC	$V_{7-10} = 40V$		A/7	B/10		I_B/2	L_2/1			F/5	G/3	30° ± 1 150-225°
10	IMP CURVE	$V_{7-10} = 40V$		A/7	B/10		I_B/2	L_2/1			F/5	G/3	75° ± 1
AND OUTPUT CIRCUIT BD. TEST	D.C. OUTPUT VOLTAGE			A/7	B/10	C/8&9	I_B/2	L_2/1					75° ± 1

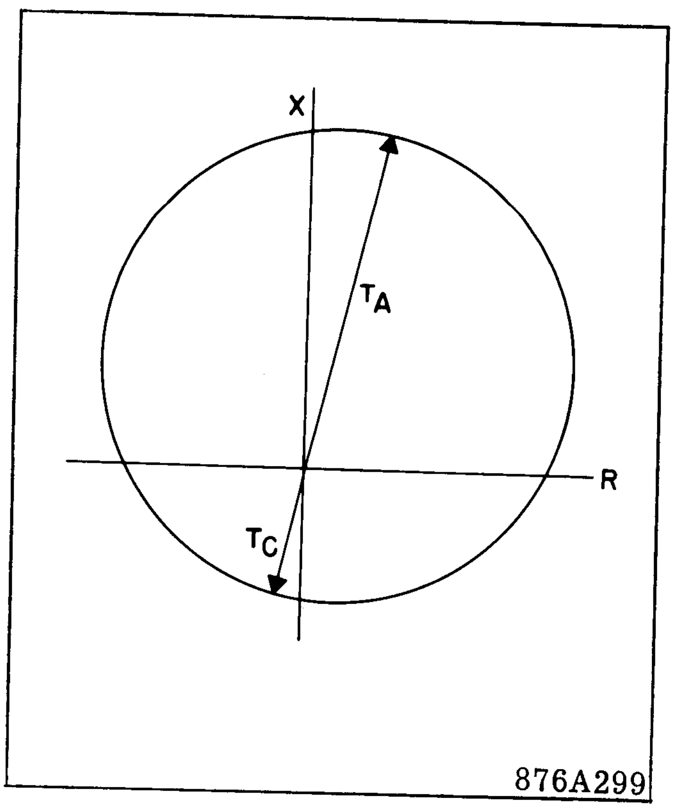


4. *Internal Sch*

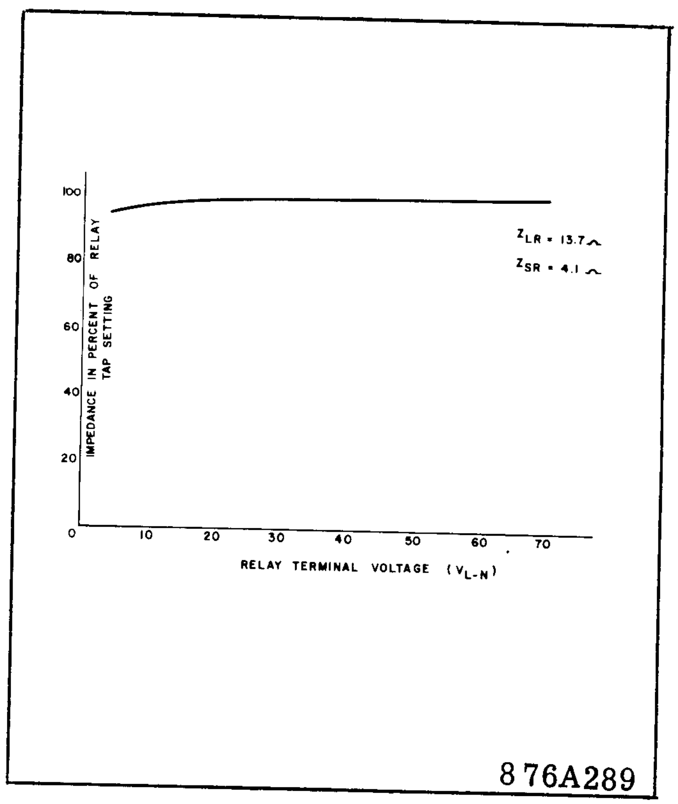
5. Voltage & Current Conditions for the type SKDU-31 Relay for Faults at Various Locations



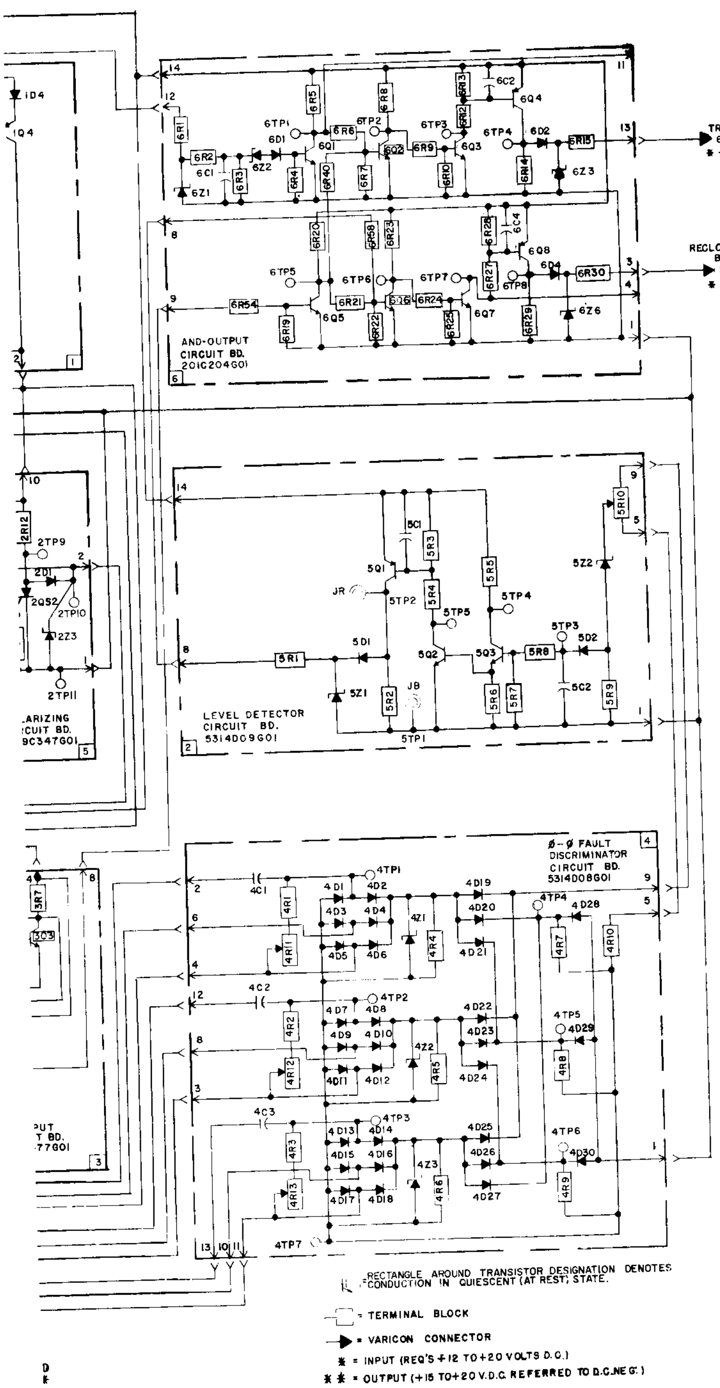
6. AND Output Circuit Board Logic Block Diagram



7. Impedance Circle for the Type SKDU-31



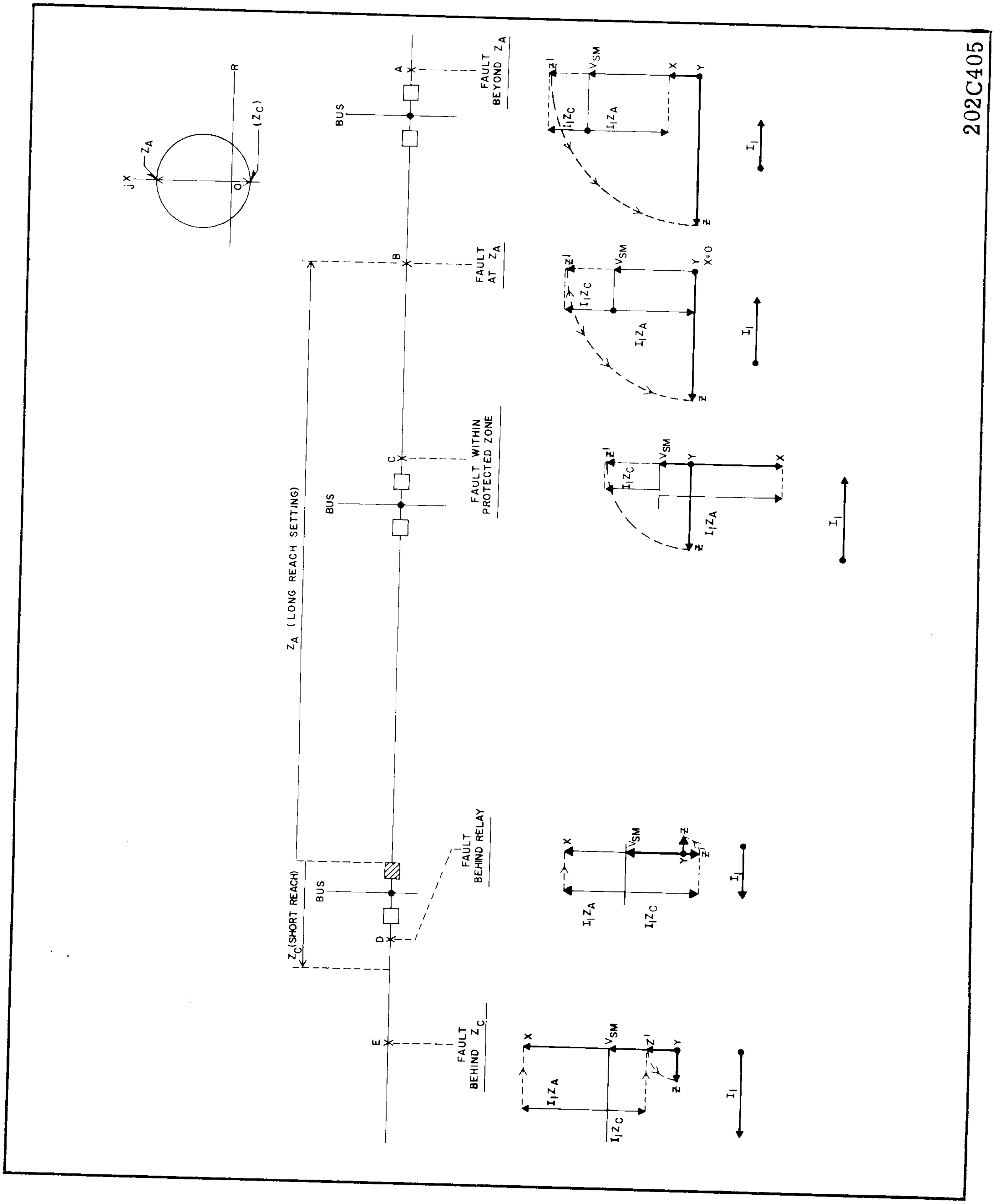
8. Impedance Curve for the Type SKDU-3

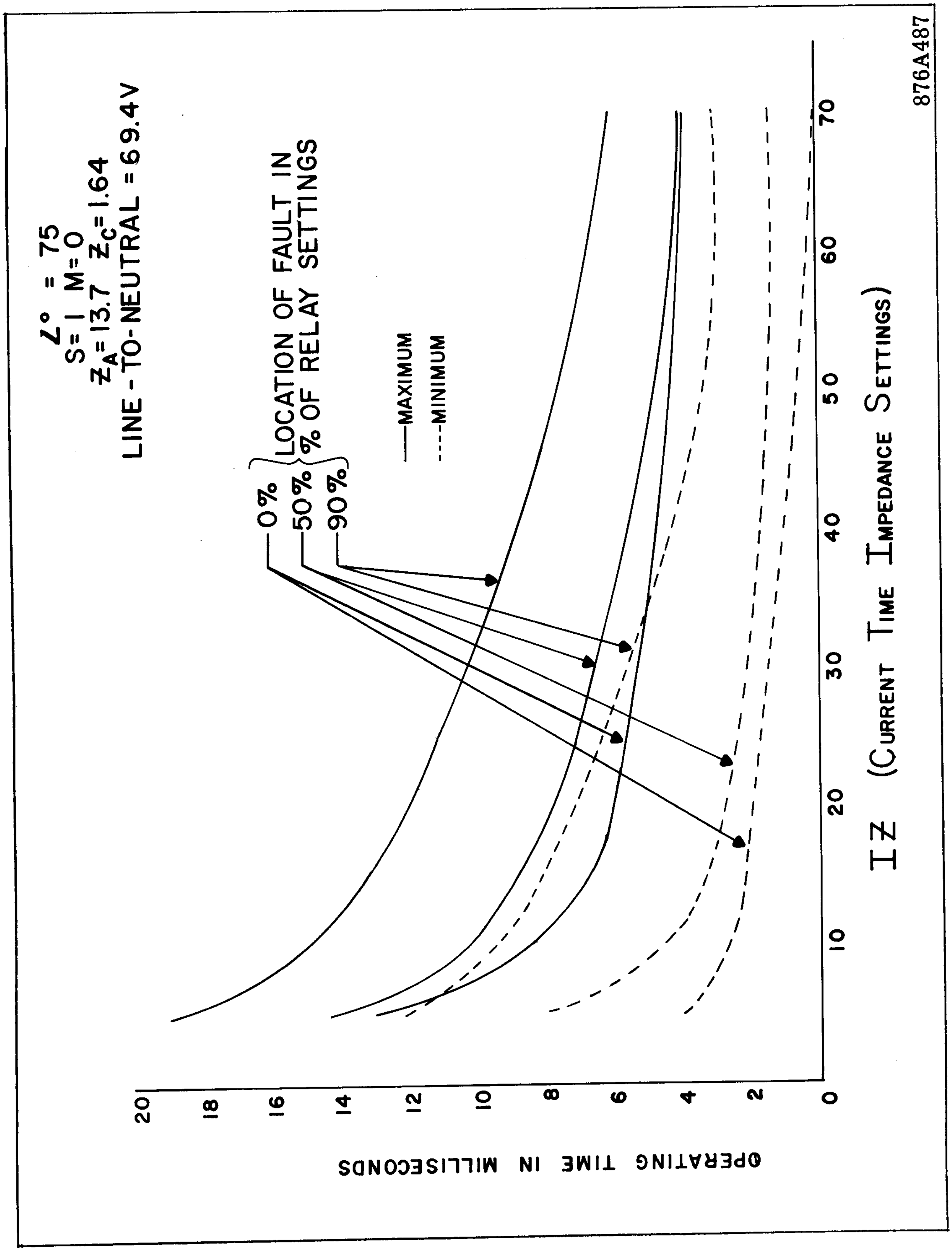


RESISTOR	[illegible]	REQ.	[illegible]
2R7·2R9·2R11·2R12·3R13	[illegible]	5	[illegible].7 K
4R1 TO 4R3	[illegible]	3	2.7 K
1R1·1R2·3R10	184A763H[illegible]	3	220 K
1R4·1R6·2R5·2R8	184A763H49	4	8.2 K
2R4	184A763H59	1	22 K
2R1·2R2·3R9	184A763H75	[illegible]	100 K
2R3	184A763H63	[illegible]	33 K
2R6·2R10	629A531H42	2	2.7 K
1R3·1R5	184A763H99	2	1 MEG
3R1·3R2·4R4·TO 4R6	184A763H69	[illegible]	56 K
3R3·6R6·6R9·6R21·6R24·	629A531H66	9	27 K
6R40·6R54·6R58·5R2·	"		"
3R4·6R5·6R8·6R12·6R20·	629A531H52	9	6.8 K
6R23·6R27·5R4·5R5	"		"
3R5	184A763H47	1	6.8 K
3R6·6R15·6R30·5R1	762A679H01	4	150 Ω
3R7	184A763H45	1	5.6 K
3R8·3R11	184A763H61	2	27 K
3R12	184A763H57	1	18 K
6R2	629A531H48	2	4.7 K
6R3·6R14·6R29·5R7	629A531H78	4	82 K
6R4·6R7·6R10·6R13·6R19·	629A531H56	9	10 K
6R22·6R25·6R28·5R3	"		"
5R8	629A531H39	1	2 K
5R9	184A763H71	1	68K
4R7·4R9·4R8	184A763H87	3	330K
4R10	184A763H58	1	20 K
RA	1267210	1	2.8 K
RDC	184A856H10	1	300 Ω 48 V.D.C.
RDC	1267283	2	125V.D.C. 600 Ω
6R1	184A763H43	1	4.7 K
5R6	629A531H70	1	39 K
ZENER DIODE			
2Z1·6Z2	186A797H06	2	1N957B
3Z1	186A797H12	1	1N752A
3Z2-2Z2-2Z3	186A797H01	3	1N759
6Z1	185A212H06	1	1N[illegible]
6Z3·6Z6·5Z1·3Z3	862A288H01	4	1N3688A
5Z2	186A797H13	1	1N748A
4Z1 TO 4Z3	188A302H09	3	1N3050B
DZP	762A631H01	1	1N2984B
DIODES			
1D1 TO 1D8·2D1 TO 2D18	188A342H06	33	CER69
3D1 TO 3D7	"		"
4D1 TO 4D30·5D2	184A855H07	31	1N457A
6D1·6D2·6D4·5D1	837A692H03	4	1N645A
CAPACITORS			
1C1	187A508H10	1	16 MFD
3C2·5C2	187A624H02	2	.25MFD
3C1	187A624H10	1	.015 MFD
C1	14C9400H15	1	.8MFD
C2	14C9400H28	1	1.0MFD
6C1	849A437H04	1	.047MFD
6C2·6C4·5C1	188A669H05	3	.27 MFD
4C1 TO 4C3	187A624H11	3	.5 MFD
TRANSISTOR			
1Q1·1Q3 2Q1·2Q2·3Q3	848A851H01	5	2N3391
2Q3 3Q1·3Q4	184A638H18	3	2N697
1Q2·1Q4·2Q4·2Q5·3Q2·5Q1	184A638H20	6	2N1132
6Q1 TO 6Q3·6Q5 TO 6Q7·5Q2·	848A851H02	8	2N3417
5Q3			
6Q4 6Q8	849A441H01	2	2N3645
TRANSFORMER			
T1·T2	262B563G09	2	
T3·T4·T5	292B563G14	3	
POTENTIOMETER			
P2A·P2C	836A635H04	2	2500 Ω
PC	836A635H08	1	2.5K
5R10	862A303H01	1	50K
4R11 TO 4R13	629A430H03	3	2.5K
SWITCH			
2QS1·2QS2	185A517H05	2	2N884

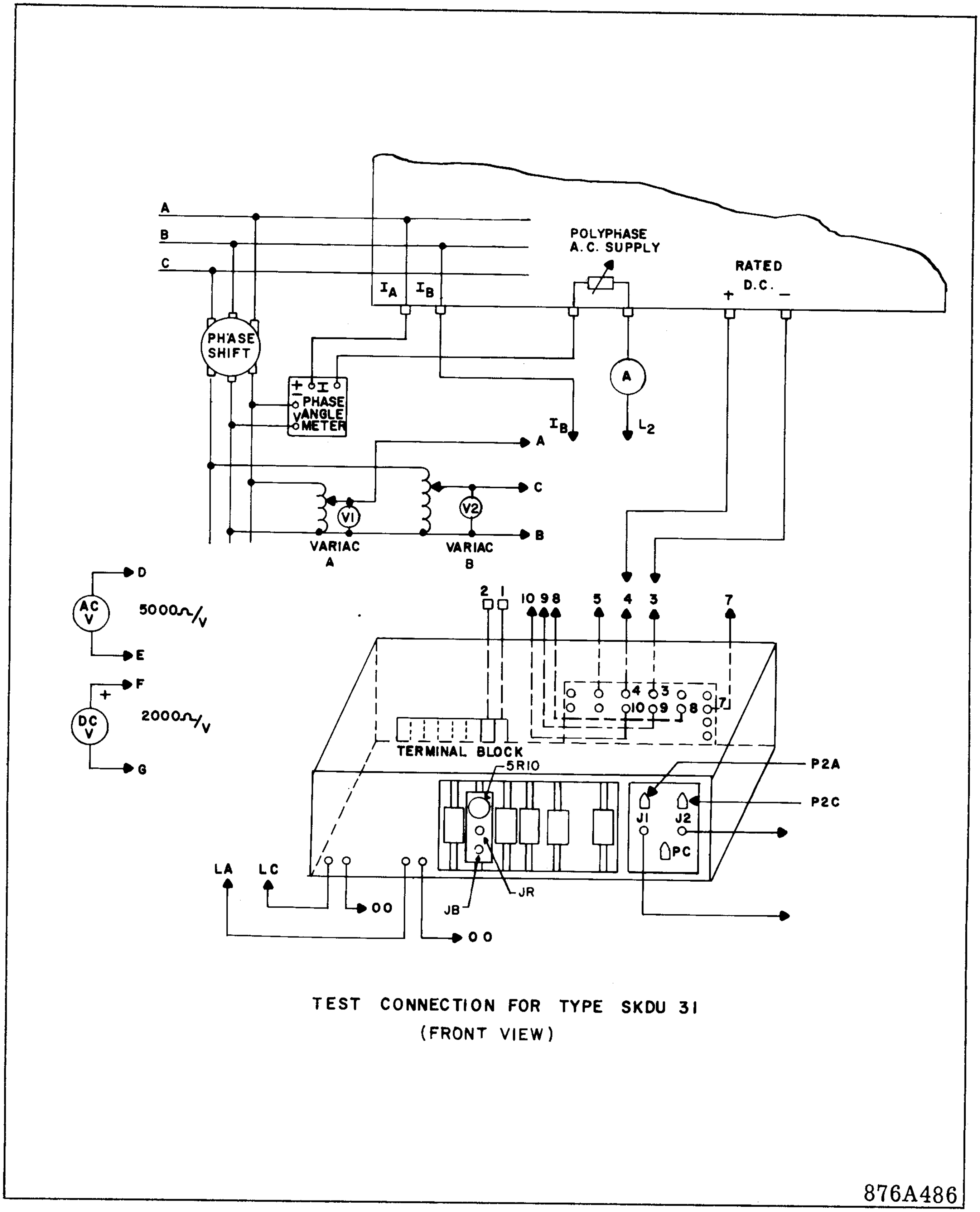
5315D81

ematic

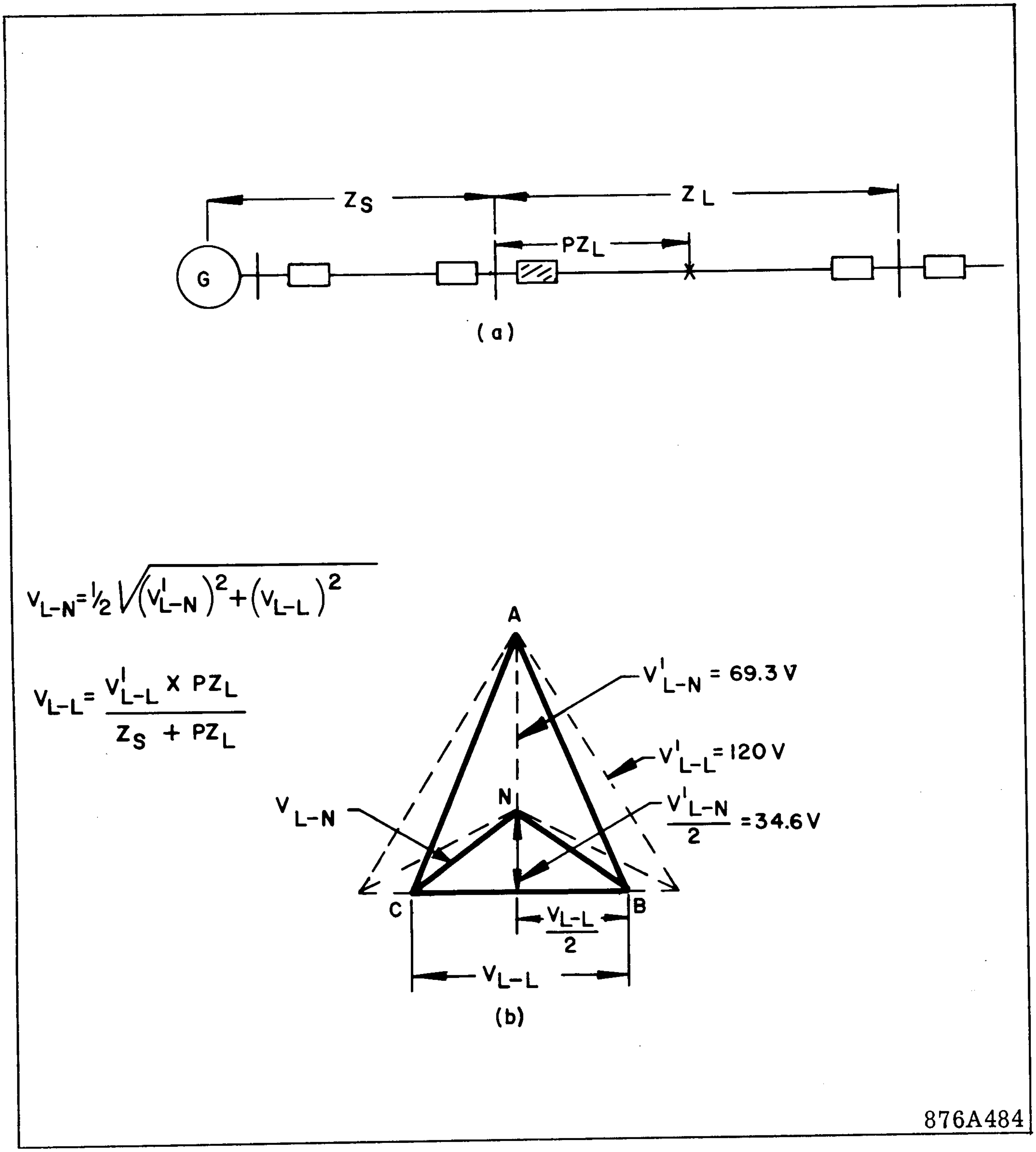

202C405
FAULT BEYOND Z_A
FAULT AT Z_A
FAULT WITHIN PROTECTED ZONE
FAULT BEHIND RELAY
FAULT BEHIND Z_C
Z_A (LONG REACH SETTING)
Z_C (SHORT REACH)
BUS
BUS
BUS
A
B
C
D
E
jX
R
O
Z_A
(Z_C)
V_SM
I_1Z_A
I_1Z_C
I_1
X=0



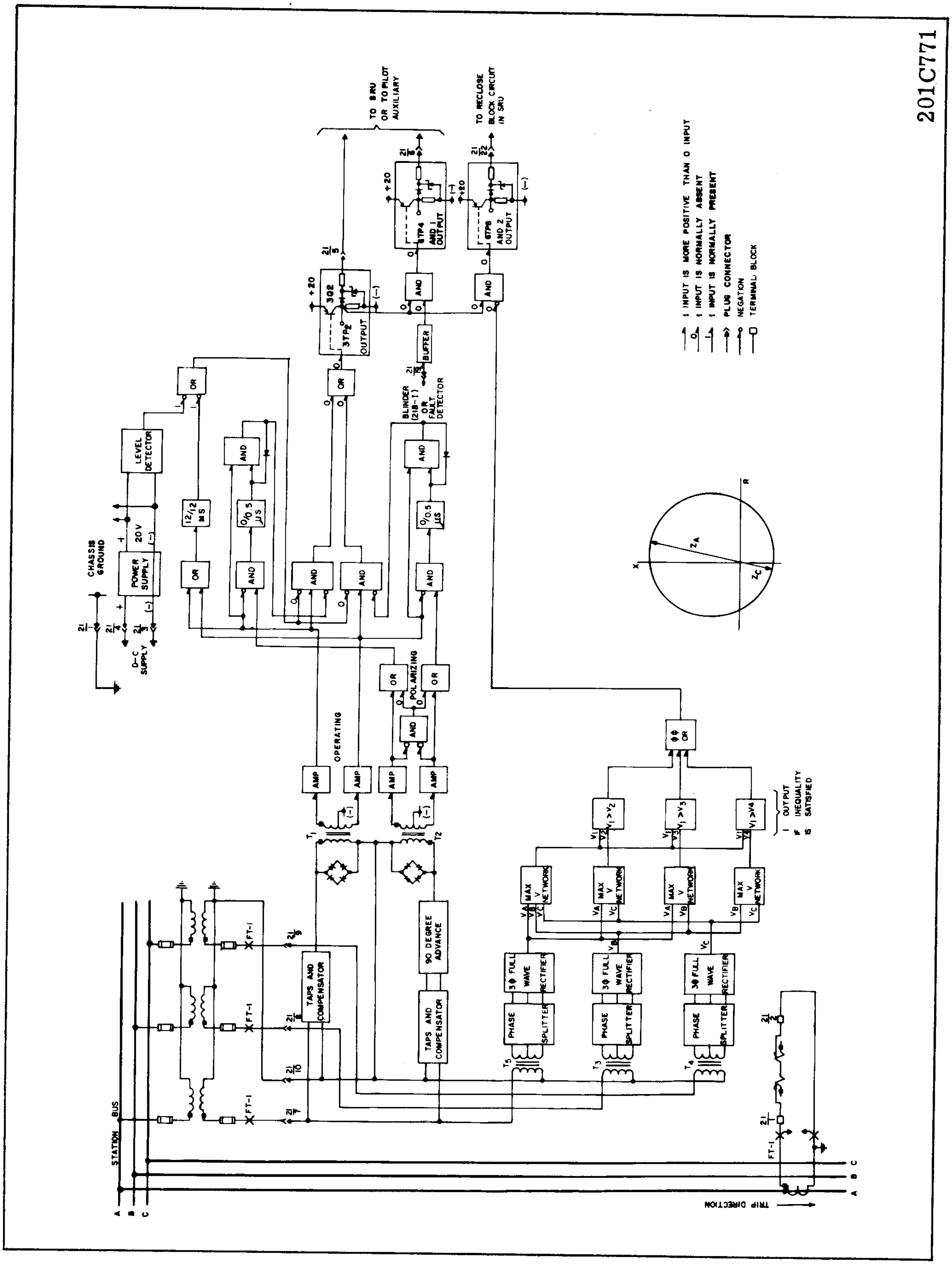
* 9. Typical Operating Time Curve of the Type SKDU-31 Relay



10. Test Circuit of SKDU-31



11.(a) Transmission Line (b) Phse-B-to Phase C Fault



12. External Schematic

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