INSTALLATION • OPERATION • MAINTENANCE

INSTRUCTIONS

SOLID STATE DIRECTIONAL COMPARISON BLOCKING SYSTEM WITH TC CARRIER (TYPE A2A1 and A2A2)

INTRODUCTION

This Instruction Leaflet describes the solid state directional comparison blocking system using TC carrier and the SKAU auxiliary relay.

Detailed description of operation, setting and maintenance of the individual relays are described in their respective Instruction Leaflets. The description here supplements these instructions and describes the overall coordinated systems.

CAUTION

Before placing equipment in service:

1. Secure the cabinets or panels to the floor before working with the system to prevent tripping of the cabinet or panel.

2. Be sure all printed circuit cards and multi-pin connector are well seated in their receptacles and the TC crystals are in place.

3. Adjust equipment and perform tests outlined under "Installation".

4. It is recommended that before proceeding to adjust the system, one become familiar with the information in this instruction leaflet and the information in the individual relay instruction leaflets.

APPLICATION

Solid State Pilot Relay Systems

High-speed relaying is required for modern transmission lines in order to improve transient stability, permit the highest speed reclosing commensurate with arc de-ionization time and to minimize conductor damage. By extending the basic principle of differential protection to line relaying, pilot relay systems provide high-speed clearing for all internal faults and restraint for all external faults. The pilot channel provides the communication link which enables comparison of current or power flow at all line terminals.

DIRECTIONAL COMPARISON BLOCKING SYSTEM

Basic System Concept

The system described in this instruction leaflet provides high-speed detection of transmission line phase and ground faults, initiates tripping, controls reclosing of the circuit breaker(s) provides and input to the breaker failure detection logic, and refrains from operating for any fault outside of the protected line section.

The tripping relays 21P and 21NP (or 67NP) are directional and one or both is responsive to all faults internal to the protected line. If fault current flows into all line terminals simultaneously, no blocking carrier is transmitted and high-speed tripping at all terminals of the faulted line takes place.

For faults external to the protected line, the phase and ground directional distance relays (or directional ground over-current relay) at one terminal will not operate. This prevents tripping at that terminal and permits transmission of a blocking carrier signal to all other terminals. Transmission of carrier is initiated by the 21S relay and/or by I_{OS} (in the 50 relay) which are set to reach beyond the tripping relays at the other terminals as shown in figure 1.

The factor that distinguishes the directional comparison blocking system from other similar pilot systems is that carrier is normally off and that a sustained blocking (i.e., trip preventing) carrier signal is transmitted upon the occurrence of any external fault for which the tripping relays operate.

It is possible for some internal fault conditions to produce operation of the "carrier start" relays. Also since voice communication or any other function can normally utilized the TC channel in this scheme, there is a possibility that carrier could be on when an internal fault occurs. To avoid any problem due to this, the tripping relays have predominant control and can stop carrier transmission at any time to provide high-speed fault tripping.

The fundamental concept of the system is that tripping takes place only if the tripping relays, which are directional, operate and if carrier is not received.

Options

Certain options exist in the system. The ground fault tripping relay may be either a distance relay or a directional overcurrent relay. The distance relay manifests a distinct reach cut-off, whereas the directional overcurrent relay reach is dependent on generation and switching. Since reach is not critical in this application either may be used satisfactorily. If the ground fault tripping relay also performs the optional backup function and drives a timer, its reach is more critical and the ground distance relay should be used. The ground distance relay is also less susceptible to zero sequence mutual effects. The ground directional overcurrent relay is more sensitive where fault resistance predominates.

Zone 1 phase and ground relays may also be incorporated in the system for all but the very shortest line applications to provide a high-speed direct (through the SRU) tripping function for faults within their reach.

The high-set instantaneous overcurrent unit, I_{BH}, must be used where line side potential devices are used to make certain tripping is possible when closing the line breaker into a bolted three-phase fault. With no voltage applied prior to this fault the SKDU memory action circuit is inoperative. I_{CH} high-set instantaneous overcurrent unit is also recommended. For most applications, the high-set instantaneous overcurrent unit, I_{OH}, may be used to provide a high-speed ground backup function.

I_{BH}, I_{CH} and I_{OH} must be set high enough not to operate for faults beyond the remote bus or behind the local bus. All but the very shortest lines allow effective use to be made of these units. An option exists to allow the high-set trips to be effective for only 50 milliseconds following breaker closure. This allows their use on even the shortest lines.

Several options exist for out-of-step relaying. The SKSU provides OS (out-of-step) blocking with delayed zone 1 tripping on OS. The SDBU-2,OS-2 scheme provides OS blocking of reclosing, and optional OS blocking of distance relays, and optional controlled angle OS tripping. These systems are described fully in I.L. 40-211.

OPERATION

Refer to Figures 2 and 3. Figure 2 is the ac schematic and Figure 3 shows the SKAU inputs and outputs

Internal phase Fault

For an internal (internal to the protected line section) 3-phase, phase-to-phase, or phase-to-phase-to-ground fault, the 21P relay at both terminals operate. Figure 5 shows that a 3ϕ unit operation accompanied by an output from the OS-2, signifying that 21B inner blinder has operated and the system is not out-of-step, produces an output from 21P, Where the SKSU (68) is used, it provides a blocking input to AND 1 when an out-of-step condition occurs. The $\phi\phi$ (phase-to-phase) unit need not be supervised by the inner blinder nor the out-of-step logic because that unit is not responsive to load at out-of-step conditions. Either output (3ϕ or $\phi\phi$) of the 21P provides and input to the SKAU.

Figure 6 shows the 8/0 timer control. This timer is driven by either 21P or I_A/I_C (relay 50). I_A-I_C operates for any A-phase or C-phase fault having a magnitude in excess of the pickup. This is set above maximum load current. The 8/0 timer provides a coordinating time delay to assure that a favorable fault incidence angle may not produce a premature trip initiation before carrier can block for an external fault. The I_A/I_C unit starts the timer to accommodate the case where the fault incidence angle is unfavorable and trip initiation would be delayed unnecessarily for an internal fault. It may optionally be used as a fault detector for the phase relay.

Figure 7A shows the normal (no fault) states of AND 5.

Figure 7B shows the inputs to AND 5 for an internal phase fault. 50 operates, the 8/0 timer times out, 21P operates and carrier is not received, producing an AND output.

Figures 7C and 7D show the inputs to AND 5 for forward and reverse external faults respectively.

EQUIPMENT COMPLEMENT
(for each terminal)

DEVICE NUMBER	TYPE	DESCRIPTION
		TYPICAL
21P	SKDU	Phase distance, tripping relay
21NP	SDGU-2	Alternate to 67N, Ground distance, tripping relay
67N	SRGU	Alternate to 21NP, carrier ground directional overcurrent, dual polarized
21S	SKDU-1	Phase distance, carrier starting relay
50	SIU	Instantaneous overcurrent relay with I_A/I_C, I_{OS}, I_O units
85	SKAU	Directional comparison blocking auxiliary
FTU	FTU	Functional test unit
95	SRU	Output package with 2 thyristor trips, reclose initiate, reclose block, breaker failure initiation, alarms and indication
TC	TC	Carrier
SPP	SPP	Surge protective package
VU or SU	VU or SU	Panel with mounting accessories
		OPTIONS
2		Zone 2 timer, phase and ground located in the SRU relay
21-1	SKDU	Zone 1 phase distance relay
21B	SDBU-2	Dual blinder relay
21N-1	SDGU-2	Zone 1 ground distance relay
50	I_{BH}/I_{CH}	High set phase instantaneous overcurrent units located in SIU
50	I_{OH}	High set ground instantaneous overcurrent unit, located in SIU
68	SKSU	Out-of-step blocking relay
–	OS-2	Out-of-step logic for dual blinder, located in SRU
50	$I_{A\text{-}OS}$	Instantaneous overcurrent unit for out-of-step trip supervision, located in SIU
VA	VA	Voice adapter for use with the TC carrier, including handset.
21NS	SDGU-4	Ground distance relay for directional carrier start.

AND 9, Figure 2, produces an output 4 milliseconds after AND 5 output appears for the internal fault, because the system is not in transient blocking (described later) and all inputs to AND 9 are satisfied. Tripping takes place through the SRU, Figure 4.

AS shown in Figure 3, carrier transmission is stopped by OR5 output when 21P operates. It is held off for 150 milliseconds following trip initiation. This is accomplished by clamping the carrier control lead to negative. Note in Figure 8 the manner in which the STOP function predominates over START. IF Q204 is conducting the carrier control lead is tied to negative whether Q203 is on or off.

Internal Ground Fault

21NP ground distance relay is supervised by I_O and I_{OS} in the SIU. The I_O unit supervises tripping while the I_{OS} unit supervises carrier stopping. Using I_O supervision at AND 2, Figure 3, assures that I_{OS} will always operate for any external fault for which tripping can be set up by the remote 21NP.

The I_O unit is set well above the I_{OS} at all locations.

The purpose of the I_{OS} supervision, at AND 3, is to allow carrier stopping for any internal fault that is sufficiently high in current magnitude to operate I_{OS} and not high enough to operate I_O. This carrier stopping function prevents false blocking at the remote terminal for this weak-feed internal fault.

Where 67N is used instead of the 21NP relay, it provides two outputs, one of which responds to fault direction (D) and the other of which responds to fault direction and overcurrent (D and I_O). The D output is ANDED with I_{OS} in the SIU for the carrier stopping function.

Figure 9A shows the normal (no fault) states of the inputs and output of AND 6.

For an internal ground fault the 21NP (or alternately the 67N) at both terminals operate. Figure 9B shows that AND 6 has an output if 21NP and I_O operate and carrier is not received.

Figure 9C shows how blocking of tripping by received carrier is accomplished at AND 6.

Figure 9D shows the states of the inputs and output with a reverse external ground fault.

AND 9, Figure 3, produces an output 4 milliseconds after AND 6 output appears for the internal fault because the system is not in transient blocking (described later) and all inputs to AND 9 are satisfied. Tripping takes place through the SRU, Figure 4.

External Fault

21S (or I_{OS}) operates for all faults external to the protected line section for which the remote 21P (or 21NP) operates as, for example, at X in Figure 10. This starts carrier at A to block tripping at the remote terminal B. Since the local 21P (or 21NP) at A does not operate, tripping does not take place at either terminal.

Transient Blocking

Transient blocking is applied to the pilot system to prevent false tripping due to a power reversal in the protected line following sequential clearing of a parallel line. An example of this may be seen in Figure 10. If breaker C opens before breaker D for a fault at F, a power reversal occurs in line AB. To assure that tripping cannot take place due to an unfavorable resetting sequence between the 21P at B and the 21S at A, transient blocking locks out AND 9 (See Figure3). If after the reversal, 21P (or 21NP) at A operates, transient blocking assures sufficient tripping delay to establish a new stable condition with carrier from B blocking tripping at A.

The mechanism by which transient blocking is initiated is that carrier starting or 21P (or 21NP) operation without tripping for 25 milliseconds signifies that an external fault exists. In Figure 3, it is seen that OR4 drives the 25/0 timer through AND 8. After 25 milliseconds transient blocking occurs.

For the rare occurrence of an internal fault following the external fault, a 25 millisecond tripping delay is imposed.

INSTALLATION

Relay Acceptance

The individual relay instruction leaflets should be referred to for specific acceptance tests. These tests should be performed to assure that no calibration change nor component damage has occurred in shipment. The tests may be performed with the relays in place by applying the appropriate quantities to the flexitest switches that are provided on the FTU for the input currents and voltages. Care should be exercised that current in excess of the continuous rating of any device is not applied for more than a few seconds.

System Acceptance

These tests may be performed with the functional test unit supplied with the system. User preference varies with respect to the type of device used for trip cutout TCO. Where the FT-1 switch is used for this function, the relay system test switch, RST, has a fixed handle and is pulled out to operate. Where a control switch is required for the TCO function, it is equipped with a handle that is removable only in the test position. This handle must be used to operate the RST switch. The system described in this Instruction Leaflet is the latter.

CAUTION: Where the trip cutout is an FT-1 switch, all handles must be operated to the test position before operating the RST switch. These switches have red handles to emphasize the importance of operating them first.

Functional tests are intended primarily for periodic overall maintenance checks. For these tests three-phase potential must be available. Any convenient 115/66.4, 4-wire wye supply may be used. Note that the power supply for the test transformer must be 115 volts and in phase or 30 degrees lagging V_{AN} (A to neutral voltage).

These tests are most satisfactorily accomplished with an operator at each station, called A and B for this description.

The TCO switch should first be moved at both stations to the TEST position. This inserts the proper loading resistors and isolates the equipment from all trip and control circuits. Next operate the TEST-RESET switch on the SRU to assure that all lamp filaments are sound.

At both stations, remove the operating handle from the TCO switch and place it in the RST switch. At station A, move RST to the reverse position, REV. The carrier milliammeter should indicate approximately 200 milliamperes at A and B. No indicating light should come on. The carrier alarm relay should pick up. Release the switch at A and move RST at B to reverse REV, with the same results.

Perform the external and internal fault simulations described under Functional Tests. If unsatisfactory results are obtained refer to Trouble Shooting Procedure.

If satisfactory results are obtained, restore RST to NORMAL, operate, then release the TEST-RESET switch on the SRU, and press the RESET push-button on the functional test panel. If the TRIP 1 or TRIP 2 lights on the SRU and on the FTU do not come on, the switch handle may be moved to TCO and the system placed in service by moving TCO to NORMAL. If either TRIP 1 or TRIP 2 lights do come on refer to TROUBLE SHOOTING PROCEDURE. Performance of the Functional Tests exercise a substantial portion of the entire system. However, for initial installation tests, it may be desired to circulate current of fault magnitude through the relays to confirm operating behaviour and connections of the remainder of the system. This can be done at the TS1 (FT-1) switch.

SETTINGS

Carrier

The carrier transmitter and receiver levels and tuning equipment should be adjusted in accordance with the appropriate Instruction Leaflets.

Pilot Relaying Criterion

It is essential that the local start units, which initiate blocking signal transmission, operate for any external fault for which the remote tripping units also operate. Otherwise, undesired tripping of the remote breaker may occur.

Phase Pilot Relays

The 21P relay should be set to substantially overreach the adjacent bus as shown in Figure 11. A typical setting is 150% of the line impedance (transformed into relay ohms, of course). Where 21P operates a timer, it must be set to underreach any adjacent line Zone 1 relay. The 21S relay must be set to reach farther than the 21P relay at the remote terminal. It is recommended that distance MN in Figure 11 be at least half of distance NP. In general, it is recommended that the 21S setting be made equal to the remote 21P setting.

Ground Pilot Relays

The 21NP relay may be set for the same reach as the 21P relay. Carrier starting for ground faults is accomplished with an instantaneous ground overcurrent unit, I_{OS}. Supervision of the ground distance relay must be provided with a second instantaneous ground overcurrent unit, I_O. The I_{OS} unit is customarily set for 0.5 amperes, and I_O is set for 0.75 amperes or more. If the maximum residual load unbalance current in the relays exceeds 0.5 ampere a high-setting must be used for I_{OS} and I_O, maintaining the 1.5 (or higher) ratio between the two. The use of the I_O unit for supervising 21NP assures that 21NP cannot set up tripping for any external fault for which the I_{OS} unit does not operate.

For long line applications, 100 miles or more, it will be necessary to use a ratio of 2.5 or more rather than the normal 1.5 ratio or I_O/I_{OS}. This is due to the distributed capacitance effect on external ground faults causing a substantially higher zero sequence current to flow in the relays remote from the fault than that which flows in the relays at the terminal close to the fault.

In a 3-terminal application with single terminal infeed for an external fault it may also be necessary to use a higher than normal ratio.

Where a directional overcurrent relay, 67N, is used, the overcurrent unit is set in the same way as the I_O unit above.

High Set Overcurrents

The instantaneous overcurrent units I_{BH}, I_{CH} and I_{OH} must be set high enough to avoid operating on faults beyond the next terminal and for faults immediately "behind" the protected line terminal. Also they must not be allowed to operate on out-of-step conditions.

Where the system fault and out-of-step data indicates the fulfillment of these requirements to be impractical, the option should be elected to insert the phase units only for 50 milliseconds following breaker closure. This is accomplished with additional logic in the SIU, device 50.

Fault Detectors

I_A and I_C units in the SIU must be set above maximum load current and below minimum phase fault current if they are to be used to supervise phase pilot tripping. If they cannot be used for this function, tripping will occur on potential failure.

Zone 1 Relays

These phase and ground distance relays are set to reach "short" of the next bus. The SKDU may be set to reach 90% of the line length. In general, the SDGU-2 may be set to reach 85% of the line length, but should be shortened to 75% where PCA-5 potential devices or equivalent are used.

SDBU-2

The blinder units should be set so the inner blinder easily accommodates the maximum fault arc resistance and the outer unit is adequately spaced from the inner blinder to accommodate the maximum rate of ohmic swing during out of step conditions within the allowable OS-2 logic time of 50 milliseconds.

Out-of-Step Supervision OverCurrent

$I_{A\text{-}OS}$ must be set to restrict the reach of the blinder system to the desired extent and to block any possibility of false tripping during load pick-up.

Zone 2 Timer

The zone 2 timer in the SRU must be set sufficiently long to allow all adjacent line faults in the "forward" direction for 21P and 21NP to be isolated by the pilot or zone 1 relaying associated with those lines. This time must allow for the total clearing time of the breakers on these lines, for the reset time of the relays driving the timer, and for margin to allow for contingencies.

FUNCTIONAL TEST

General

The functional tests distort the voltages applied to the relays and circulate a current through them to impose an "operate" or "restraint" condition on them. The relays should have their "in-service" settings when these tests are made. For the following tests the C.T.'s are shorted by the TCO switch.

Single Terminal Tests

Refer to Figure 2. Moving the relay system test, RST, switch to the forward, FOR, position opens the normal A-phase potential supply and applies B-phase potential to the A-phase input of the phase distance relays. It connects the A-phase input of the ground distance relays to neutral. It then circulates current through the A-phase current circuit with return through neutral. All tripping distance relays operate, initiating indication of PILOT PHASE, PILOT GROUND, TRIP 1 and TRIP 2 on the SRU. The latter two indications are dependent on current flow in the tripping thyristors through test resistors inserted by the TCO switch. Indication is also obtained of trip output, breaker failure initiation outputs, and of reclose initiation outputs, by blue light operation on the FTU.

2000-ohm resistors parallel the NORMAL contacts in the A-Phase supply circuits to avoid an open transition of potential to the relays after the NORMAL contact opens and before the forward or reverse (F or R) contacts close. This prevents a false indication during a change of position of RST.

Though the SRU lights provide appropriate indication of functional test behavior, various test point voltages may be examined in conjunction with the functional test.

With RST in the forward, FOR, position outputs can also be measured, if desired, with the TCT test meter unit, on the 50-volt d.c. scale, of approximately 20 volts at the phase-to-phase unit output test point of the SKDU, at the SDGU-2 output test point, of the SKAU, and at the TRIP LOGIC output of the SRU. These voltages are measured with respect to any convenient negative test point since negative is common throughout. An output can also be measured at the SKDU-1 three-phase output. It responds to the "current-only" condition while the phase-to-phase unit responds to the simulated fault with restraint, sensing the fault in the non-operate direction because this relay is connected to see faults in a direction away from the protected line section. Also approximately 20 volts may be measured at the I_{OS} output. Neither the SKDU-1 nor the I_{OS} is able to start carrier because of the predominant STOP control of the tripping relays.

With RST in the reverse, REV, position, outputs may be measured at SKDU-1 three-phase and phase-to-phase output test points, at the I_{OS} output test point, and at the transient blocking test point in the SKAU, again, with respect to any convenient negative test point. Note that the transient blocking output goes more negative when it operates. Since the tripping relays do not operate for this condition, carrier starts and a reading of approximately 200 milliamperes should be evident on the carrier milliammeter at both terminals if the channel is intact.

I_A/I_C output will also be measured of approximately 20 volts d.c. if the test current, as adjusted by the tap on the test transformer, is sufficiently high.

Two Station Test

An external fault "behind" A, may be simulated by moving the RST switch to reverse, REV, at station A and to forward, FOR, at station B in that sequence. This causes SKDU-1 and I_{OS} (in the SIU) to operate and to start carrier transmission at A. The SKDU and SDGU-2 relays operate at B, but tripping should not take place because of the blocking carrier being received from A. Carrier reception may be confirmed by noting a 200 ma. reading on the milliammeter. The carrier alarm relay will operate. Also a transient blocking output may be measured in the SKAU relay. Return the RST switch at B to NORMAL first, then return RST switch to normal at A. No lamps should light on the SRU or on the functional rest unit, FTU.

An external fault "behind" B may be simulated by moving RST at B to REV and moving RST at A to FOR in that sequence. No lamps should light, 200 ma. should be indicated on the carrier milliammeter, the carrier alarm relay should operate and a transient blocking output (more negative state) should be measured in the SKAU.

For an internal fault simulation, move the RST at both stations to forward, FOR. At both stations TRIP 1, TRIP 2, PILOT PHASE, PILOT GROUND, lights should come on in the SRU, both reclose initiate (RI), both breaker failure initiate (BFI), and both trip lights should come on. Also device 30 in the SRU should operate.

Out-of-Step Simulation, SDBU-2

Where the SDBU-2 relay and the OS-2 logic in the SRU are included in the system, a contact of RST (closed in NORMAL) is connected in parallel with a pushbutton called OS and the combination is connected, as shown in Figure 4, in the inner blinder output.

Ground pilot and phase-to-phase unit pilot tripping would occur during this test due to the simplified representation of the out-of-step condition by this functional test. The ground relays and the phase-to-phase unit of the SKDU are not responsive to a real out-of-step condition. Blocking of pilot tripping during this test is accomplished by transmitting carrier from the remote terminal by operating RST to the REV position at that terminal.

Moving RST at the local station to FOR operates both blinder units (inner and outer), but only the outer blinder supplies a 1 input (approximately 20 volts) to the OS-2 logic because of the disconnection of the inner blinder output. If then with RST still in FOR position the OS pushbutton is pushed, the inner blinder input to the OS-2 goes to a 1 satisfying the out-of-step logic and turning on the OS indicating light and operating the reclose block, RB, relay and the corresponding blue lights on the functional test panel. When RST is restored to NORMAL, the outer blinder resets and tripping is initiated if the OS trip switch on the SRU is in the ON position. This causes TRIP 1 and TRIP 2, lights on the SRU to come on. Also the breaker failure initiate (BFI) lights on the functional test unit come on. The trip lights are sustained, but the BFI lights are momentary (0.5 second).

Out-of-Step Simulation SKSU

Where the SKSU relay is included in the system, a contact of RST (closed in Normal) is connected as shown in Figure 12 in series with the ground relay input to the SKSU. In making common use of the RST switch for fault and out-of-step simulation, blocking of tripping by the ground relay and the phase-to-phase unit to the SKDU must be effected by transmitting carrier from the remote terminal (by operating the remote RST to Reverse) The ground relay and the phase-to-phase unit of the SKDU are not responsive to a real out-of-step condition.

With carrier being received from the remote terminal, move the local RST to FOR operate the distance unit of the SKSU, 68. RST blocks the ground input to the SKSU logic. The 3-phase unit of the SKDU does not respond to the functional test. Therefore, the SKSU senses operation of the 68, and no operation of the 21P relay. After 50 ms, if OS pushbutton is pressed to simulate operation of the 21P relay, the OS indication output appears. This turns on the OS light in the SRU.

SRGU Option

The SRGU is often used in place of the SDGU-2. The functional test for this device using current polarizing is shown in Figure 13 and using potential polarizing is shown in Figure 14. In the forward, FOR, position, RST switch circulates a current in the operating and polarizing circuits with a relative direction that produces operation. In the reverse, REV, position a restraint condition is produced.

Panels

Figure 15 shows a typical panel layout. Either the VU or the SU panels are recommended. These are shown in Figures 16 and 17.

TROUBLE SHOOTING PROCEDURE

Any misoperation should be explored first by performing the related functional tests. Evidence obtained from these tests can assist in pinpointing the source of difficulty. The general philosophy followed in trouble shooting is to begin at the point of a known malfunction and by process of elimination, locate the source.

RECOMMENDED TEST EQUIPMENT

1. Oscilloscope
2. Frequency counter
3. AC vacuum tube voltmeter
4. TCT test meter unit
5. Carrier frequency signal generator
6. Carrier frequency tuned voltmeter
7. Apparatus described in "Applied Protective Relaying" published by Westinghouse Electric Corp., Chapter 12.

DESCRIPTION OF TROUBLE	POSSIBLE CAUSE	INVOLVED CIRCUITS	SUGGESTED PROCEDURE
Operate Test Reset on SRU & no light	Blown fuse or relay system power supply switch off	Functional Test Unit	1. Check power supply light. 2. If on, check fuses.
Continuous keying	Open circuit or false signal	Carrier start circuits	1. Determine which transmitter is transmitting. 2. Check SKAU to see if carrier control output is approx. 20 volts. 3. If so, determine which starting input relay is operated. 4. If none are operated, check for open circuit between the SKAU85/12 & negative. 5. Remove voice adapter
Carrier not transmitted on functional test	Coax grounded	Shorting switch	Open shorting switch
	Stop circuit energized	Arming	Check tripping relay outputs
		Squelch	1. Check 0/150 output 2. Check squelch input to SKAU
	Start circuit not operated	SKAU start circuit	1. Check SKAU keying output to see if approx. 20 volts 2. If not examine starting relay. 3. If so, check TC
Carrier not received or failure to block on functional test	Coax grounded	Shorting switch	Open shorting switch
	Defective receiver	TC	Check TC receiver
	Blocking circuit	SKAU AND's	Check blocking circuits in SKAU
Failure to trip on functional test	Capacitor on cathode of trip thyristor	SPP	Make certain there is no surge protective capacitor connected to the cathode (negative) side of the trip thyristor
	No trip output from SRU	Trip logic	1. Check outputs of SRU logic 2. Check inputs to SRU
	No SKAU output	Tripping AND or output amplifier	1. Check output circuitry of SKAU 2. Check inputs to tripping AND
	No trip input to 4/0 in SKAU	Phase or ground AND in SKAU	1. Check outputs of phase and ground AND's. 2. Check inputs to phase and ground AND's 3. Check appropriate SIU and tripping relay outputs
	No test current	Test current source	1. Insert ammeter in TS1 current jack C. 2. If no current, check continuity through RST contacts in test 3. Check voltage across test transformer 4. Check fuses supplying test transformer
No out-of-step trip on functional test	Inner blinder not blocked	OS Pushbutton	Check that RST/N contact in 21B/5 output circuit opens and OS pushbutton circuit is open.
	Timer faulty	0/500 in SRU	Check output of 0/500 MS timer following RST restoration to NORMAL. It should persist for approximately 500 ms.
Output not present at location where one should be expected.	Loading	External devices	The output of any device in this system is tailored to this system only. Limited ability exists to supply additional devices. Remove them.
Trips light stays on after test-reset PB is pushed	Thyristor still conducting	Trip output of SRU	1. Check to determine source of trip input to SRU trip board. 2. Check to assure there is no load on the thyristor cathode with PB operated. 3. Check tripping thyristor

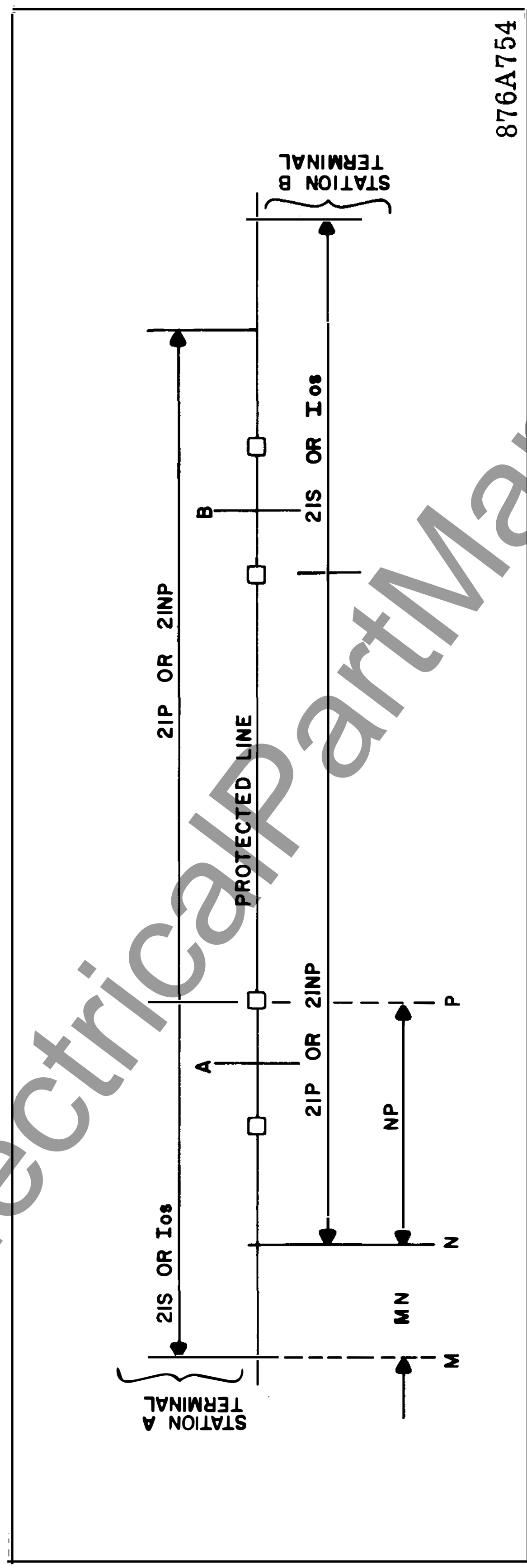


Fig. 1. Setting Criteria

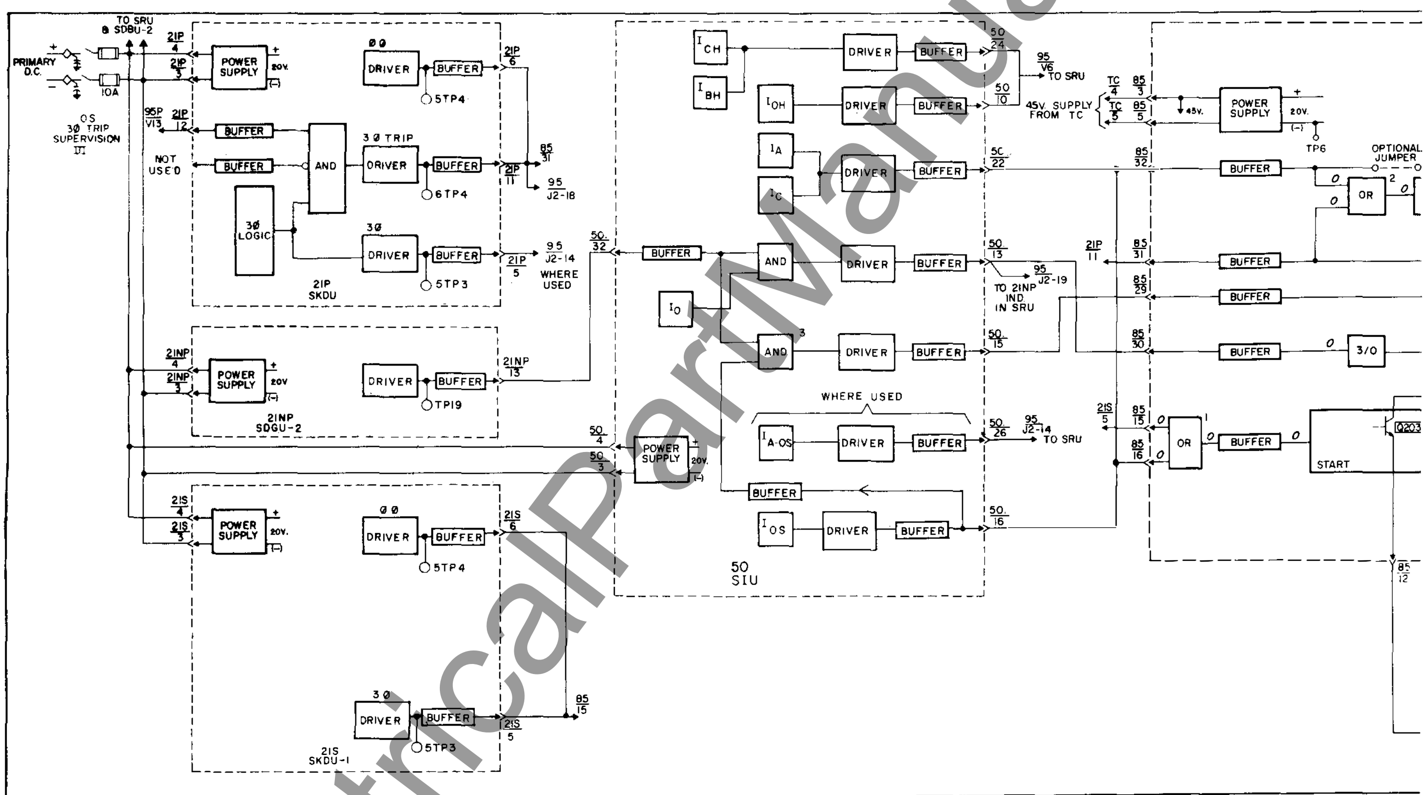
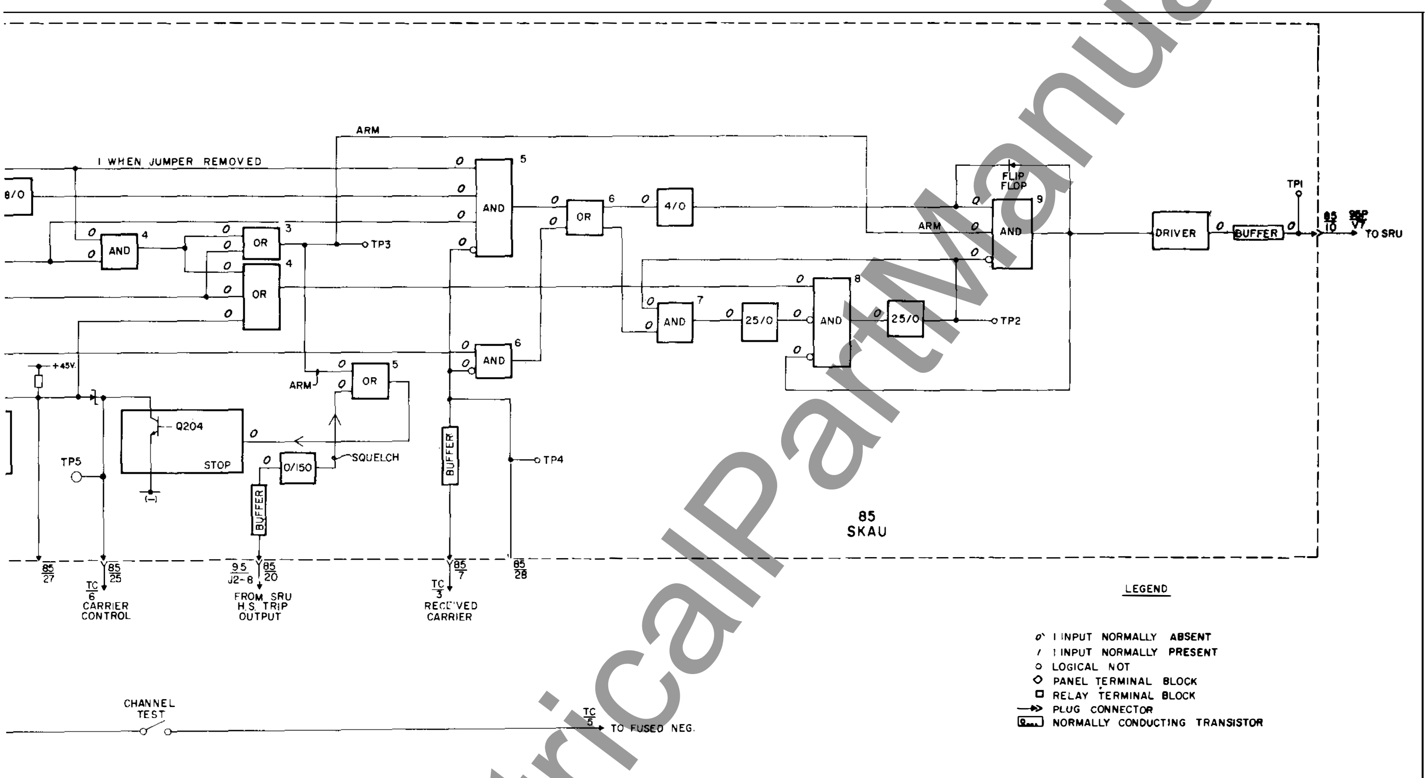

TO SRU
& SDBU-2
PRIMARY
D.C.
10A
OS
3Ø TRIP
SUPERVISION
NOT
USED
POWER
SUPPLY
20V.
ØØ
DRIVER
BUFFER
5TP4
3Ø TRIP
AND
6TP4
3Ø
LOGIC
5TP3
21P
SKDU
TO 21NP
IND
IN SRU
WHERE
USED
21NP
SDGU-2
TP19
21S
SKDU-1
ICH
IBH
IOH
IA
IC
IO
IA-OS
IOS
WHERE USED
TO SRU
45V. SUPPLY
FROM TC
50
SIU
OPTIONAL
JUMPER
TP6
OR
3/0
START
Q203

Fig. 3. SKAU I



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iput and Output

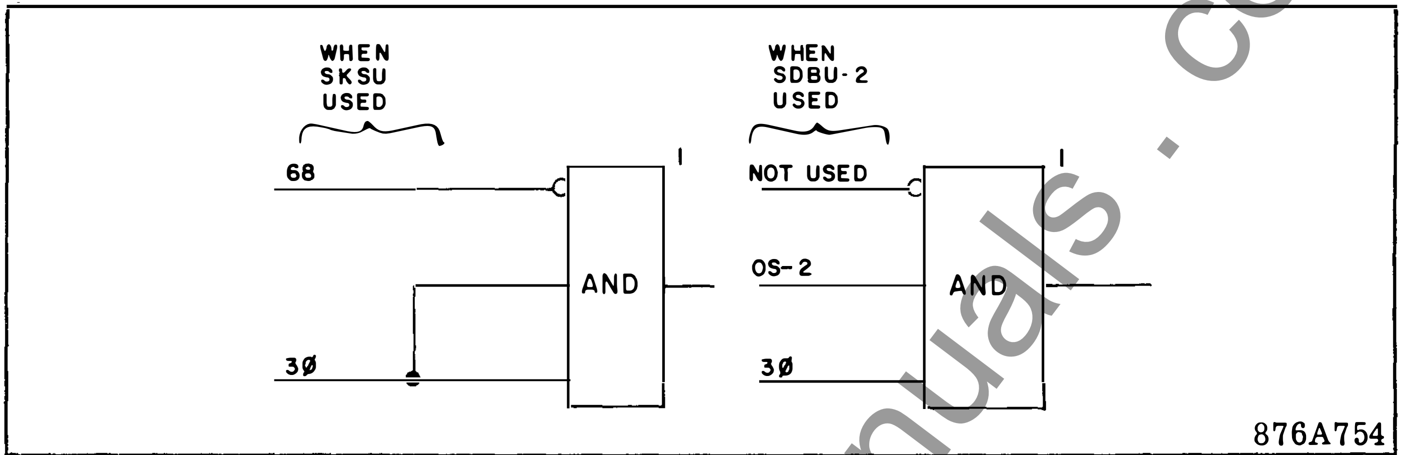

Fig. 5. Operation of AND 1

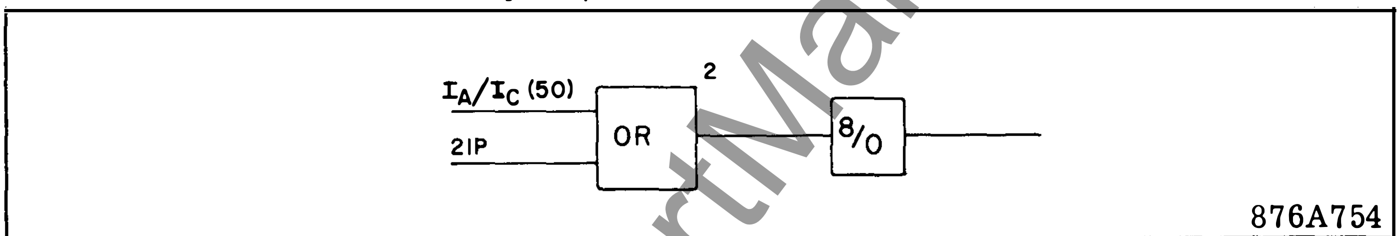

Fig. 6. 8/0 Control

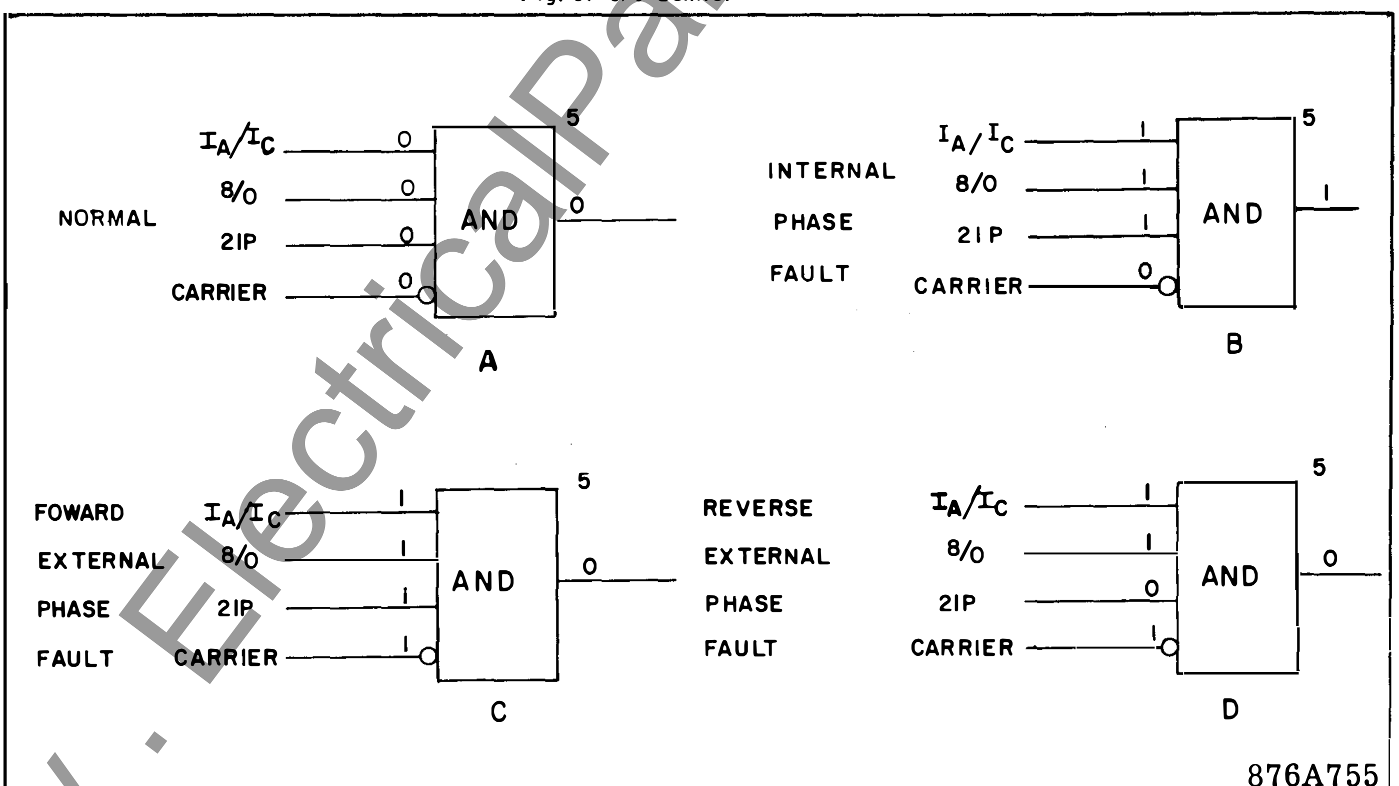

Fig. 7 Operation of AND 5

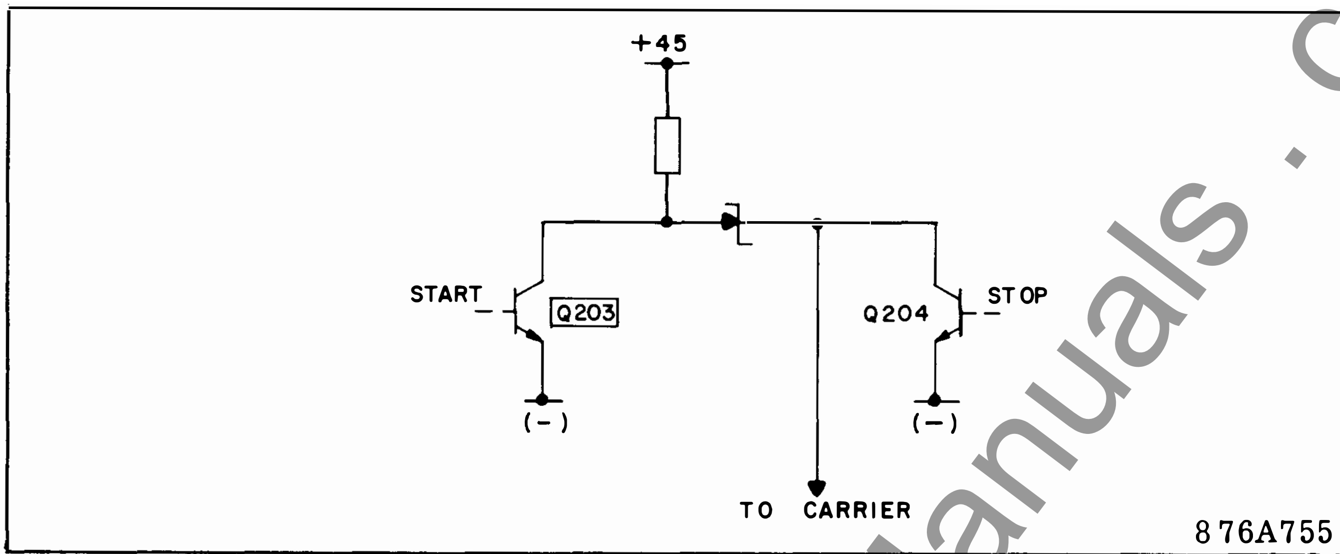

Fig. 8. Carrier Control

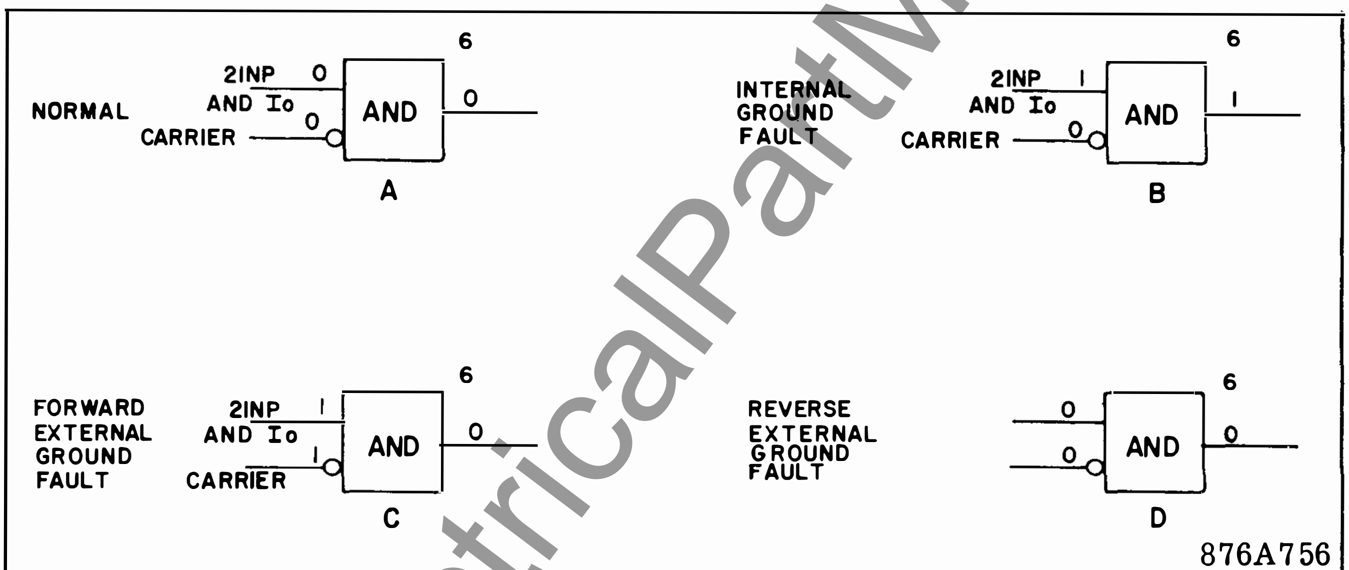

Fig. 9. Operation of AND 6

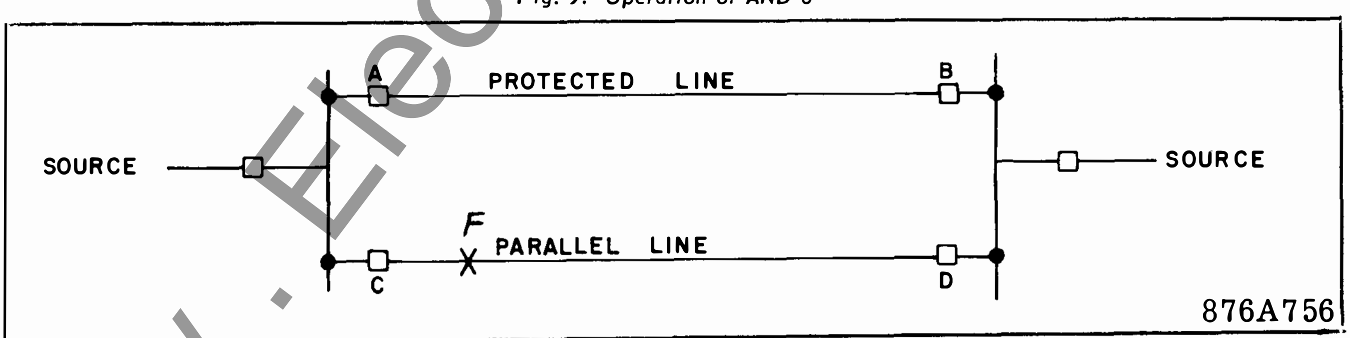

Fig. 10. Typical One Line Diagram

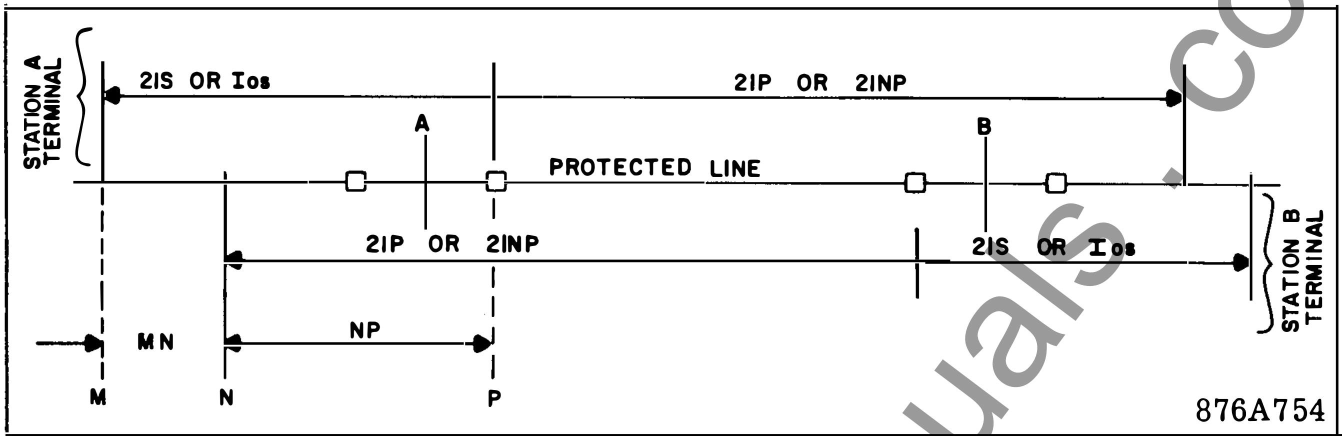

Fig. 11. Setting Criteria

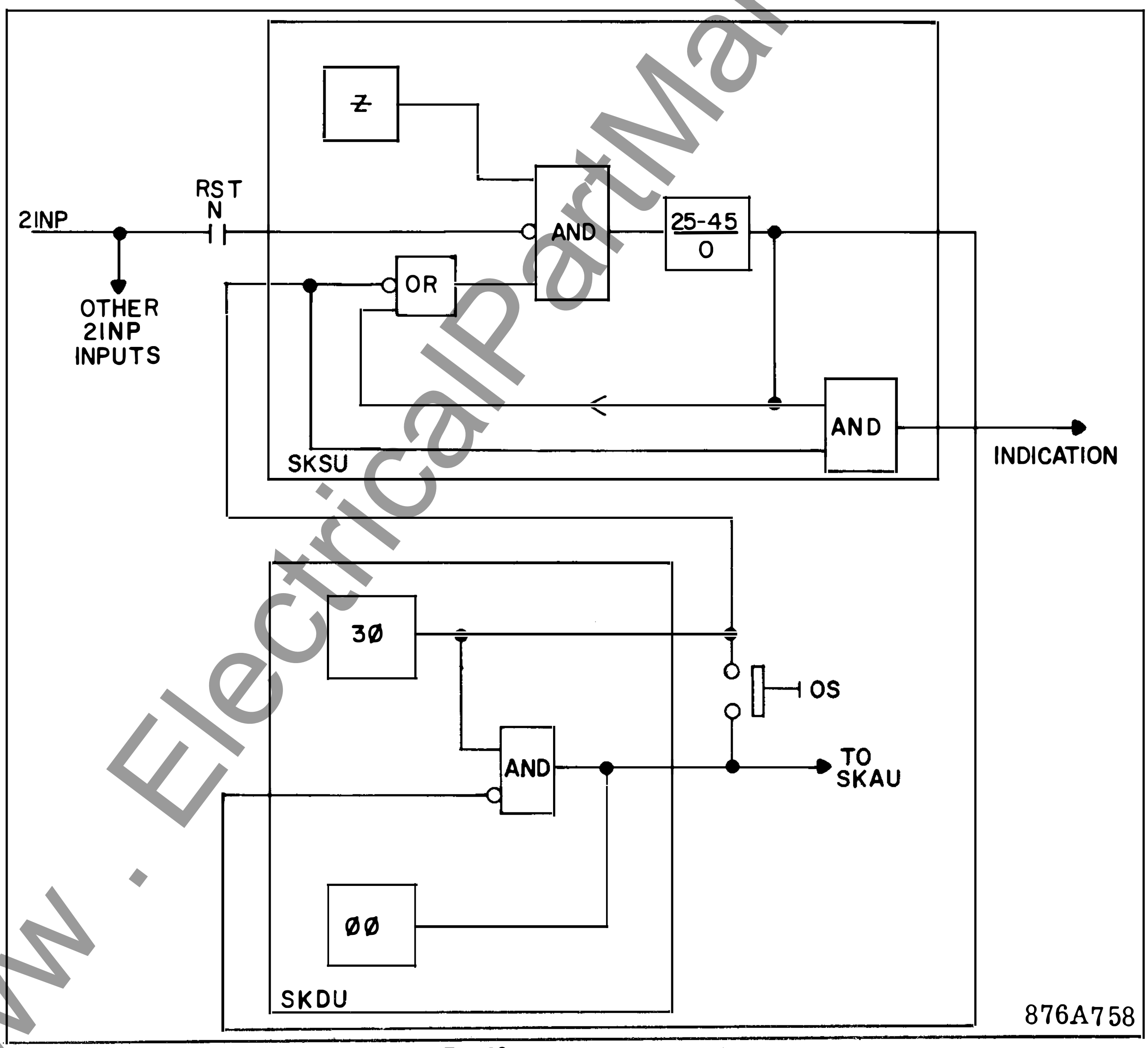

Fig. 12. DC Functional Test for SKSU

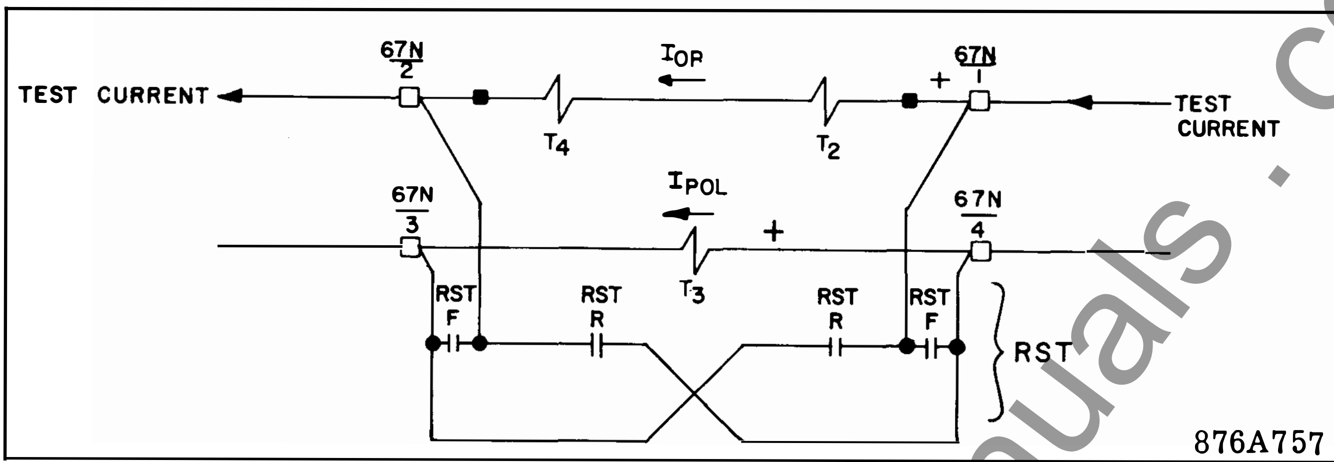

Fig. 13. Functional Test for SRGU Using Current Polarization

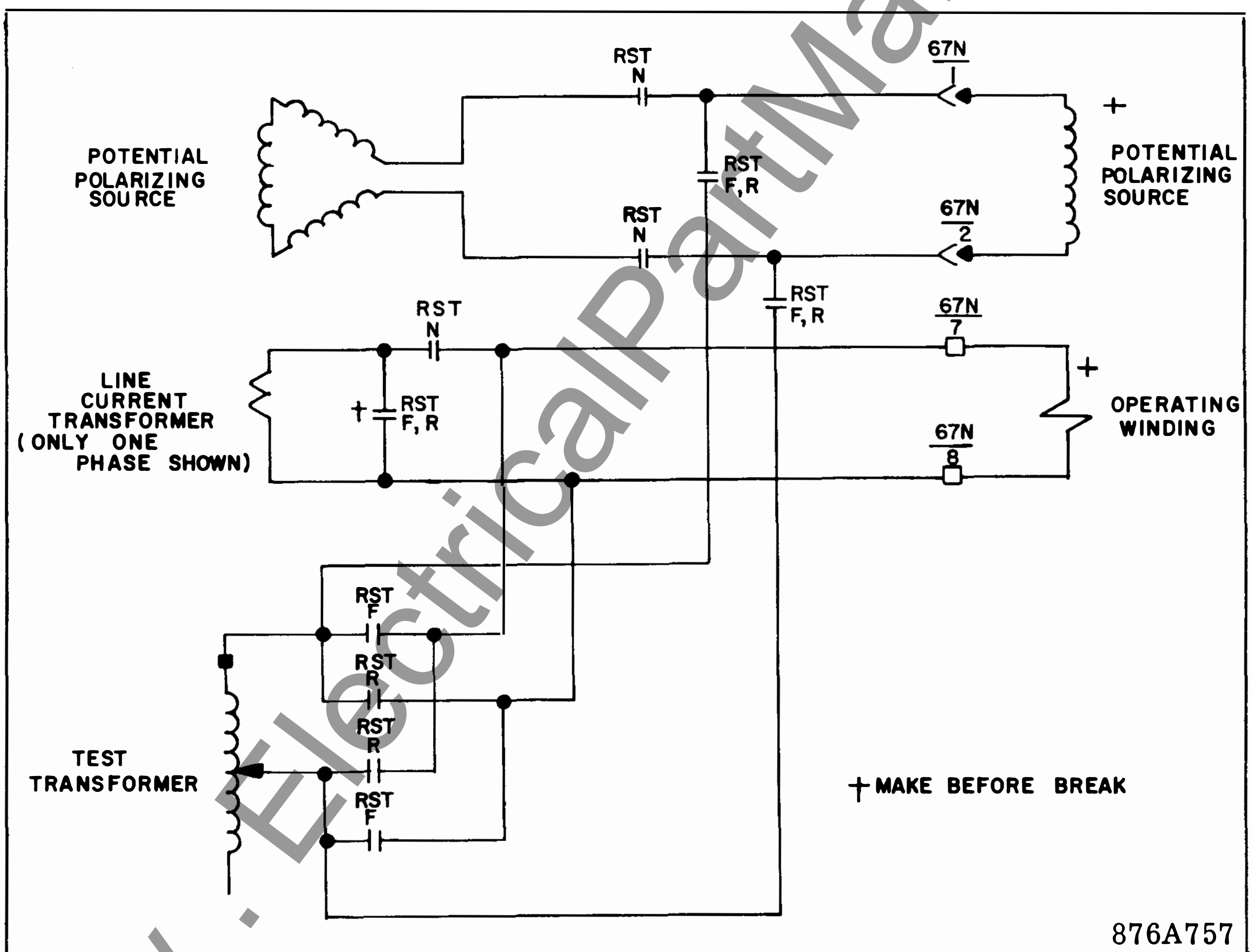

Fig. 14. Functional Test for SRGU Using Potential Polarization

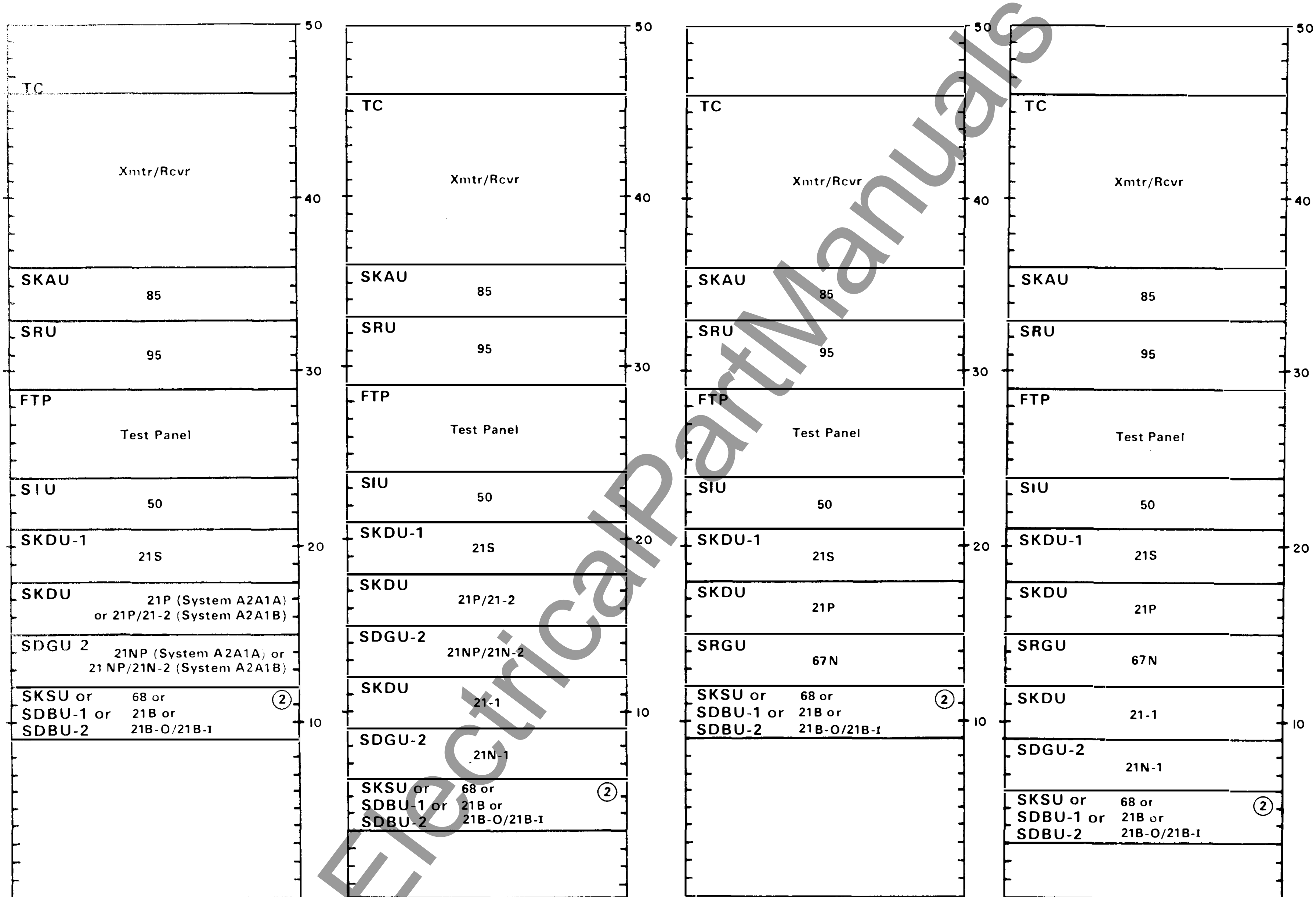

Fig. 15. Standard Layout of Component for Solid State Pilot Relay System

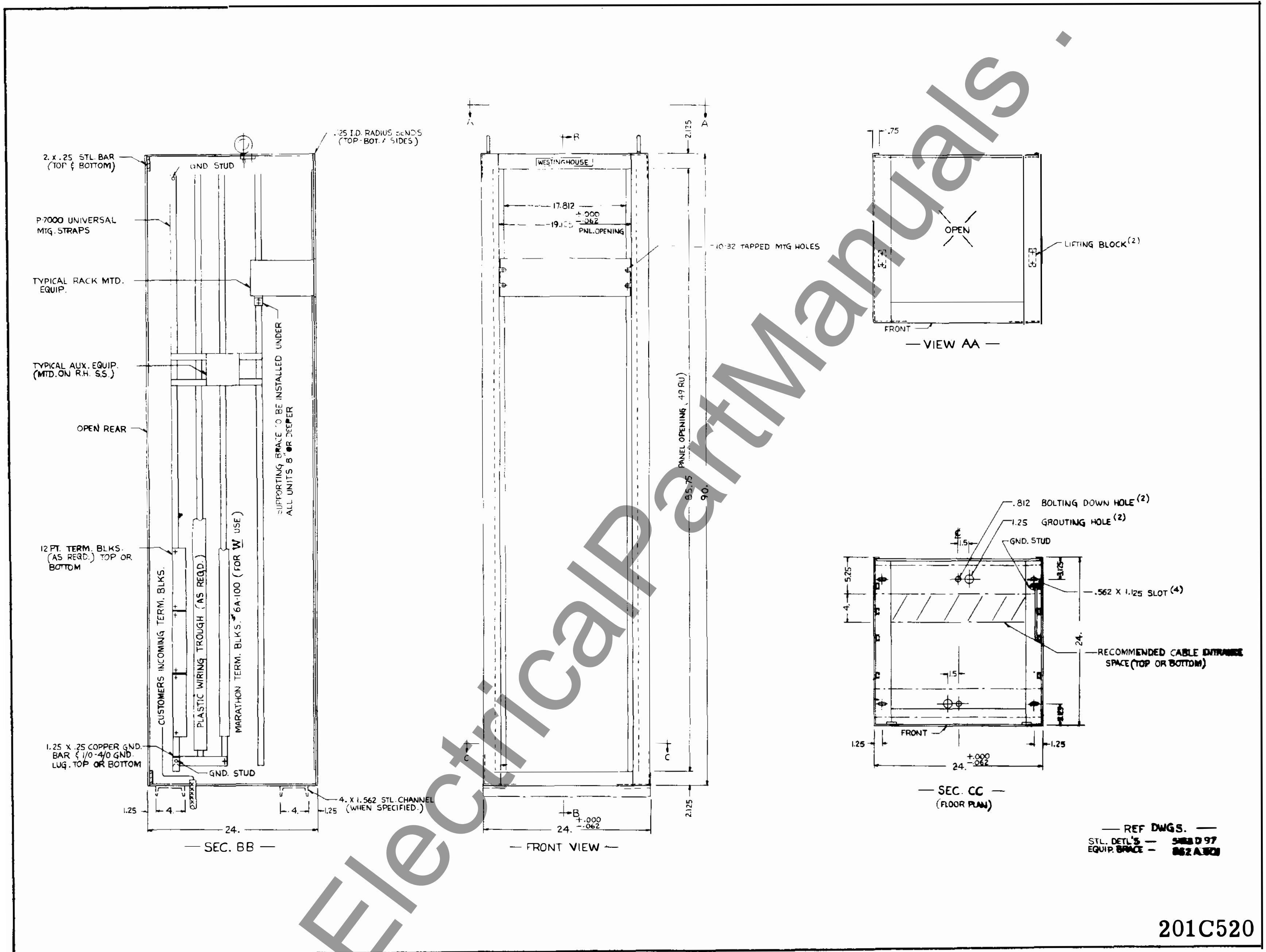

Fig. 16. Type VU Switchboard Panel

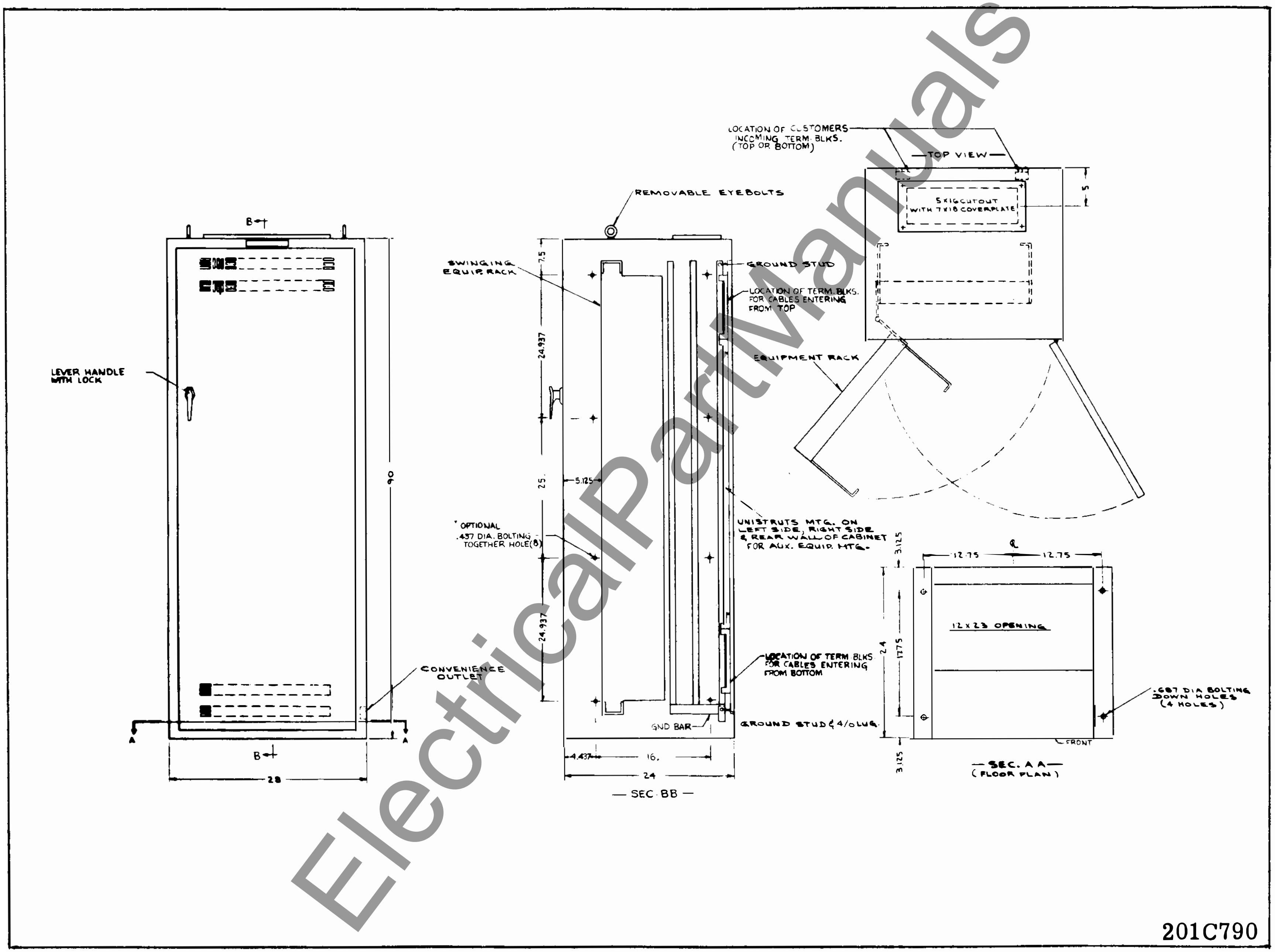

Fig. 17. Outline of Type SU Swing Rack Cabinet

WESTINGHOUSE ELECTRIC CORPORATION

RELAY-INSTRUMENT DIVISION **NEWARK, N. J.**

Printed in U.S.A.

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INSTRUCTIONS

K-DAR/KQS SINGLE POLE TRIP SYSTEM

The following is a description of the relaying system whose trip circuits are shown in Fig. 1. The system differs from the standard directional comparison blocking type described in I.L. 41-911 in that means are provided to trip only the faulted phase-breaker pole for single-line-to-ground faults. The specific directional-comparison system shown in the drawing is a 4-zone type.

The 4-zone scheme provides two separate trip circuits and, if desired, two separate current transformer circuits so that for a fault anywhere in the protected line section any one relay failure can be tolerated while still achieving fast tripping. In the case of phase faults in the immediate line section, trip circuit No. 1 in Fig. 1 provides instantaneous zone 1 protection over the first 90 percent of the line and a zone 2 delayed trip for the remainder. Trip circuit No. 2 for the same conditions provides instantaneous clearing over the entire line section by distance relay 21P working in conjunction with the carrier auxiliary relay (85) whose supervising contact RRP closes in the absence of a blocking signal to allow 21P to trip. Likewise, on ground faults trip circuit No. 1 provides instantaneous tripping for faults near the breaker and for a portion of the line extending from the breaker, and delayed tripping for the remainder. Circuit No. 2-67N relay trips instantaneously for all immediate line section ground faults. To provide selectivity it is supervised by the RRG contact of the 85 relay. This contact, like the RRP contact, remains open for external faults in the presence of a carrier blocking signal. The above operation is somewhat modified for single-pole tripping as described later.

With carrier in service, the carrier ground relay is permitted to trip only the faulted-phase pole if the fault is a single line to ground fault. For all other types of faults the relays are permitted to trip all three poles. An alternative arrangement would provide tripping of two poles for faults involving two phases. For example, if the fault were to involve phases A and B, only those poles would be tripped. This "selective-pole" arrangement has been provided in a few instances with previous schemes. However, experience has shown that the improvement to stability occasioned by leaving one pole in service is not of sufficient benefit to justify the increased order of complexity in the relaying circuits necessary to provide this feature.

In addition to the relays described in the aforementioned literature for three pole tripping, the scheme in Fig. 1 shows the following additional relays: KQS(83G), SRD(83P, 83S)and SC (50N), AR (94-), AR (62X, Y, Z), TT-18 (94X), TT-19 (21X) and TD-5 (62). These relays working in conjunction with the KD-4 phase distance relays and the directional overcurrent ground relays provide the single pole tripping protection. Of the various phase and ground relays, the 67N relay, the instantaneous unit I of 67NT and the phase-to-phase unit of relay 21P remain in service during the single-phasing period (one pole open) to provide sound-phase protection. These relays provide fast protection should a phase-to-phase or ground fault occur on one or two phases not originally faulted. The functioning of each of the additional relays required for single pole tripping will now be described.

<u>KQS (83G)</u>

This relay working in conjunction with an external negative-sequence current filter detects which of the three phases is grounded for a single line to ground fault. Three high-speed induction cylinder units compare the phase angle of the negative sequence current and the zero sequence current. The phase A unit (SA) receives phase A negative sequence current while the other two phase selectors receive their respective negative sequence currents. For example, for a phase A to ground fault the phase A negative sequence current is almost in phase with the zero sequence current thus causing operation of the SA unit. At the same time the sound-phase negative sequence currents are 120° out of phase with the zero sequence current, producing contact opening torque on SB and SC. Thus, The KQS phase selectors tell the 67N directional overcurrent carrier ground relay which breaker pole to trip. Thier sensitivity is 0.33 amperes negative and zero-sequence current. This is compatible with the normal $3I_0$ pickup of 1.0 amp. on the I_0 unit of 67N. On a two phase to ground fault the phase selector on the sound phase is operated due to the nature of the fault. This means that the carrier ground relay trips the sound-phase pole. At the same time the 21P phase distance relay is operating to trip all three poles, so that KQS operation is irrelevant for double line to ground faults.

For a single line to ground fault with one pole opening on each breaker the 52a-52b disagreement circuit in Fig. 1 energizes auxiliary unit X3 of the KQS relay. Note that auxiliary switches are shown for two breakers as would be the case, for example, for a ring bus. Unit X3 blocks the sound-phase selector trip circuits to avoid the possibility of these phases being tripped at the time that the faulted phase pole is opening.

SRD (83P, 83S) and SC (50N)

The SRD relay operates for faults involving two phases but will not operate for a three-phase or a single-phase-to-ground fault. It compares the magnitude of the three voltages (phase-to-ground). When one of three voltages is larger than the other two the relay contacts close to permit the KD-4 zone 1 and KD-4 carrier trip relay 21P to clear the fault. One of three phase-to-ground voltages will be larger than the other two for phase-to-phase and two phase-to-ground faults. For a single phase-to-ground fault one of the three phase voltages will be smaller than the other two and the SRD relay will not operate. The SRD operates on a minimum of 10 volts difference between the largest voltage and the larger of the remaining two voltages. Rated potential is 70V.

SRD contacts are inserted in series with the KD-4 zone 1 and 21P carrier phase trip paths, to prevent a 3-pole trip for a single-line-ground fault. Since the SRD (83P) will not operate for 3-phase faults an SC (50N) break contact bypasses the SRD contact. The 50N relay is energized with residual current to sense ground faults. Thus, the parallel combination of 83P and 50N contacts provides a trip path except for single-phase-to-ground faults.

Another SRD contact bypasses the X contact interlock in series with the 85 CSG coil, to provide sound-phase protection as will be described later.

AR (94) Relays 94-1, 2, 3, 4 & 5 provide a 2 ms auxiliary trip function. Each relay has four make contacts. Relays 94-1 and 94-2 trip all three poles, while 94-3, 94-4 & 94-5 each trip their associated breaker pole. Spare contacts of 94-3, 4 & 5 may be used to initiate breaker closing. If two sets of breakers must be tripped (e.g., ring bus) 6 contacts may be needed, so the 94-1 and 94-2 functions may require two AR relays each.

TT-18 (94X)

Telephone type relays X, X2, X4 and X5 are packaged in the TT-18 relay. X and X2 relays perform transient blocking functions to eliminate the possibility of undesired trips during various periods enumerated in Table II "Trip Schedule". Relay X2 also sets up 21P, 67N and the instantaneous unit (I) of 67NT relay for the purpose of providing sound-phase protection during single phasing. In addition, the X2 unit sets up relay 67N for a three pole trip should the single breaker pole reclose into a permanent fault. This is accomplished by connecting the 67N trip circuit to the auxiliary trip relay 94-2.

Unit X4 introduces a coordinating delay in the tripping of the instantaneous unit of 67NT in trip circuit No. 1. This delay insures that the initial fault will be cleared by opening only the affected phase for single line to ground faults. Otherwise faults within the range of this instantaneous unit will be three-pole tripped. Unit X5 introduces a coordinating delay in the 21P trip circuit during the single-phasing period. In particular, this delay functions at the time of a single-pole reclose to insure that possible operation of 21P due to transients will not incorrectly cause tripping. The delay of X5 is inserted only during the single-phasing period and is not present during normal operation.

TT-19 (21X)

This relay grounds the open-phase potential terminals of certain relays during the single-phasing period. With line-side potential applications the 21P, 68 and 83P relay terminals are grounded. With bus-side potential applications only 83P needs to be grounded.

With potential taken from the line side the open phase voltage during single phasing is determined by the interphase capacitance between the faulted phase and the two sound phases. The exact potential is a function of the line configuration. The rotation of the three voltages could actually be negative sequence or a very small positive sequence triangle, providing insufficient restraint for the distance relays. For this reason the distance relays may have their contacts closed during the single phasing period if line side potential is utilized. This condition is tolerable if the trip circuits of these relays are disabled by relay X of the TT-18 relay. However, the 21P relay phase-to-phase unit provides sound phase protection, so the TT-19 disconnects the 21P relay (and 68) from the potential source on the phase with the open breaker pole and grounds that terminal. For example, as shown in Fig. 1 if phase A pole opens, terminal 7 is grounded.

Regardless of the potential source location, the TT-19 relay switches the SRD, so that the SRD can operate for a ground fault on one of the "sound" phases during the single-phasing period. With one SRD potential pole grounded & normal voltage to ground on the other two phases, the SRD is reset; however, should one of the latter phases become grounded, the SRD would see a 1 large-2 small voltage condition.

TD-5 (62)

This relay limits the duration of single phasing to prevent excessive heating of rotating equipment due to unbalanced current flow and to prevent undesired tripping of overcurrent ground relays in the vicinity of the protected line due to the zero sequence current flow throughout the system as a result of the single phasing operation.

AR (62X, 62Y, 62Z)

These are 0.2 sec. drop-out relays used primarily to initiate breaker-failure timing. The latter must be used in conjunction with a breaker-failure timer set for 0.17 sec or less and with 3 independent phase current detectors as shown in Fig. 2. Time delay on dropout of 62X/Y is needed since RRG, RRP and X unit contacts can otherwise deenergize 62X/Y prematurely during a breaker failure.

Spare contacts from these relays may be used for such things as reclose block (in the case of 62X & Y) and carrier squelch in the case of 62Y. The latter performs the same function as the SQ unit of relay 85 in preventing a carrier blocking signal from being transmitted during and immediately after local breaker tripping.

These relays have delayed drop-out in order to maintain energization of 62BF in Fig. 2. Even though a breaker failure occurs the 62X, Y, Z relays will be deenergized in Fig. 1 by X or by the opening of RRG and RRG contacts before 62BF has timed out.

The KC-4 relay consists of three current detector units I_1 I_2 & I_3 energized by the phase A, B & C breaker currents, respectively. Following a single-pole trip the sound phase current detectors may be operated by load current; therefore, the TRB-1 blocking diodes in Fig. 2 prevent undesired 62BF energization. For example, if phase C is tripped open successfully 62BF could be energized by I_2 or I_1 plus 62Z-C unless the TRB-1 diodes are used.

Summary of Operation

For a phase to ground fault in the protected line with carrier in service, the faulted phase pole will be tripped by the 67N carrier ground relay through the 85-CO contact A5-B5 and the RRG carrier supervising contact of the KA relay and through the phase selector unit SA, SB or SC of the KQS relay. Simultaneously the 67N relay energizes relay units X, X3 and 62. Relay X and X3 operate immediately to block other trip paths which otherwise could produce a three pole trip. When the breaker poles on the faulted phase open, their 52b contacts close to keep the X, X3 and 62 relays energized. At this point X2 is also energized by the 52a-52b disagreement circuit. Shortly thereafter (See Table I "Auxiliary Unit Times), relay X2 inserts relay X5 delay in the 21P trip path and at the same time bypasses the 50N contact in the same path. Another X2 contact bypasses the X4 delay of the directional ground relay instantaneous unit in trip circuit No. 1. Another X2 contact connects the 67N trip circuit to auxiliary tripping relay 94-2 so that a sound phase ground fault can be cleared by 67N and so that 67N can initiate a 3-pole trip if the open breaker pole closes into a fault.

Returning now to the instant when tripping was initiated, the faulted-phase selector unit of the KQS relay energizes unit AX, BX or CX of the TT-19 relay, grounding a potential terminal of the SRD and of distance relays 21P & 68 (line-side potential only). This grounding allows the trip circuit of 21P to be reestablished to provide sound-phase protection during the remainder of the single phasing interval.

Should a ground occur on one of the energized phases during the single phasing period relay 67NT instantaneous unit I can immediately trip if the fault produces enough current to pick it up. If not, 67N can initiate 3 pole tripping. If the ground occurs soon after the single-pole trip, unit X2 will not have had time to pick up; in this case 67N tripping will be delayed.

After X2 operates, 67N can energize CSG through the 83P contact (which closes at inception of the sound-phase fault). When the remote carrier transmitter turns off, RRG closes, energizing 94-2. Note that carrier is transmitted continuously during the single-phasing period (unless CSP or CSG is operated) due to the unbalanced load-current operation of I_{OS} of relay 85. So either 67N plus 83P or I of 67NT must operate at both ends to turn off both transmitters in order to effect a 67N carrier trip. The phase-to-phase unit of 21P may also operate for a sound phase groung; however, this is not too likely.

Should a phase fault occur involving the two sound phases, relay 21P will trip all three poles through contacts RRP, X2 (make) or SRD or 50N, X5 or X2 (break). Before X2 operates, 50N will provide a trip path unless ground is involved in the fault. After X2 operates, tripping will be delayed by X5.

For a two phase to ground fault with all poles closed the 67N relay trips the sound phase pole while the phase distance relays trip all three poles. Phase relay operation is as described in I.L. 41-911 except for the fact that the SRD ratio discriminator senses one large and two small voltages to permit KD-4 distance relay tripping.

For a phase-to-phase fault with all poles closed the phase distance relays and the SRD relay operate, tripping all three poles. Should a three-phase fault develop in the protected line the KD-4 three-phase units function in a conventional fashion. In the case of 21P, or 21-1 the three-phase unit trips through the break contact of 50N (SC relay).

Unbalanced load flow during the single phasing period operates the I_{OS} carrier-start unit of relay 85. This action is beneficial during the interval at the end of the single-phasing period. When the first pole closes the disagreement circuit at that end of the line deenergizes the X unit of 94X. If X resets before the remote breaker pole recloses, 67N will still be operated by the unbalanced load current; however, the carrier signal prevents RRG closure, avoiding misoperation.

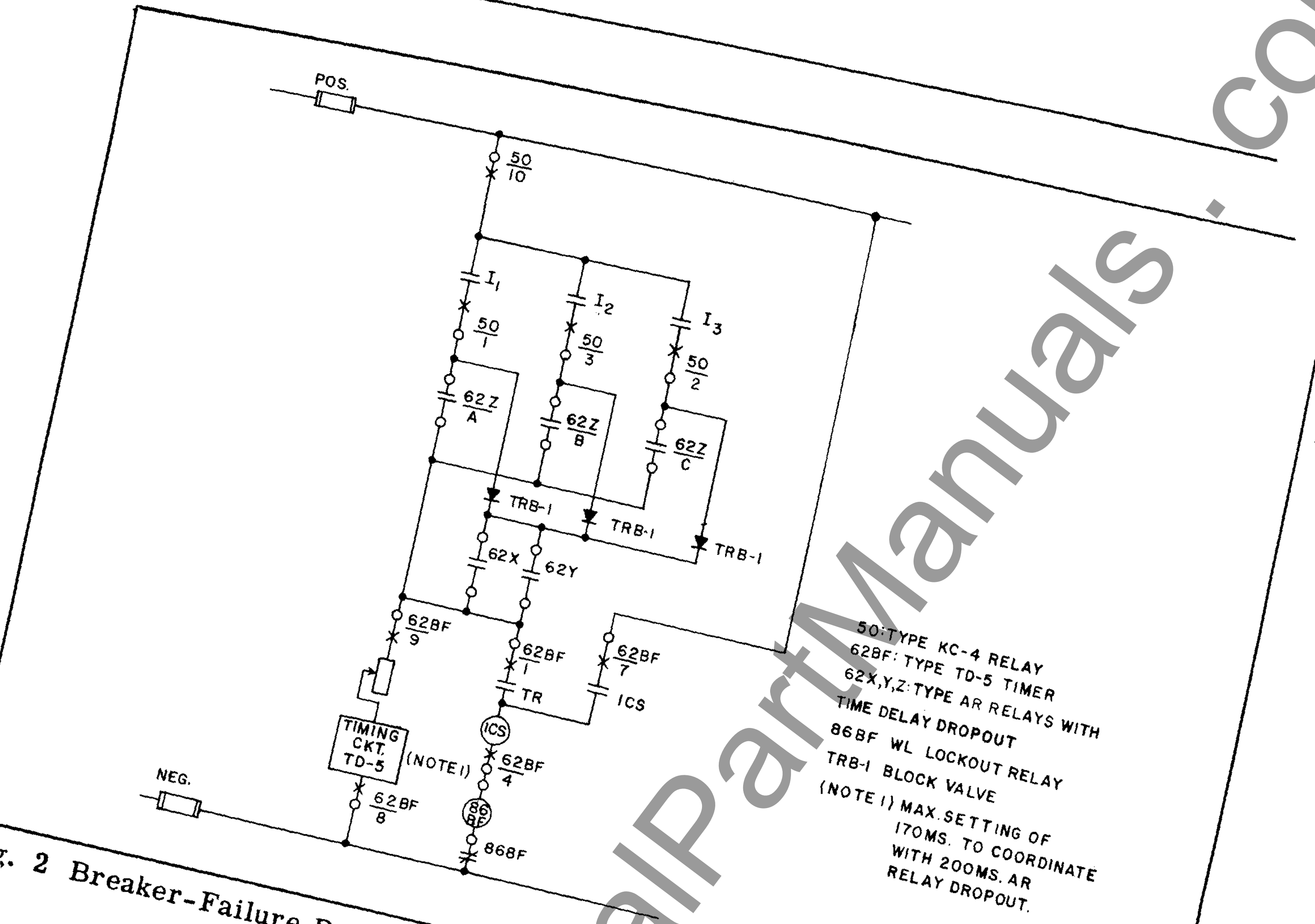
If the single-pole reclose is unsuccessful all three poles will be tripped. If the fault is beyond the 67NT I-unit range, tripping by 67N will be delayed until X resets. Unless the remote 67NT I-unit operates to squelch carrier, local 67N trip might have to await X unit reset at both stations; this is true since I_{OS} will not begin to reset until the laggard breaker pole closes. On the other hand, although not likely, the ØØ unit of 21P might see the ground fault & immediately stop carrier. Thus, a fault not cleared by the 67NT I-units at both stations might not be cleared until after about 100 ms or more upon reclose.

Remote Backup Protection

Faults on adjacent lines will be detected and cleared on backup operation by the 67NT time delay unit and by either 21-2 or relay 21P after the T3 delay provided by TD-4 timer (device 2). The trip path for the phase-fault remote-backup protection is 21P relay energizing auxiliary unit TX-Z3 which eventually closes contact TR to trip 94-2. The fact that 67NT is connected in trip circuit No. 1 and 21P in trip circuit No. 2 should be only incidental on the basis that we can assume that both trip circuits will be available when remote backup protection is required. This assumption is valid on the basis that the first contingency is a failure of the protection system on the adjacent line and any other failure at the location in question would result in a double-contingency failure. Stating the above in a different manner, if we assume a failure of the d.c. supply to trip circuit No. 1 or to trip circuit No. 2 it is not legitimate to also assume a failure of the protection system at the remote station on the adjacent line; this would be a double-contingency assumption.

Operation with Carrier Out of Service

If the carrier set is being maintained or otherwise unserviceable, the carrier on-off switch (85-CO) should be turned to the OFF position. This will disable the 21P and 67N carrier trip circuits. In addition, contact A6-B6 and C6-D6 bypass interlocks in trip circuit No. 1 which are not required when single-pole tripping is removed. Contact A1-B1 of this switch is available for reclosing circuit use to block high-speed reclosing when carrier is out of service if this feature is required.



...g. 2 Breaker-Failure Protection for Single-Pole Trip System (For each breaker).

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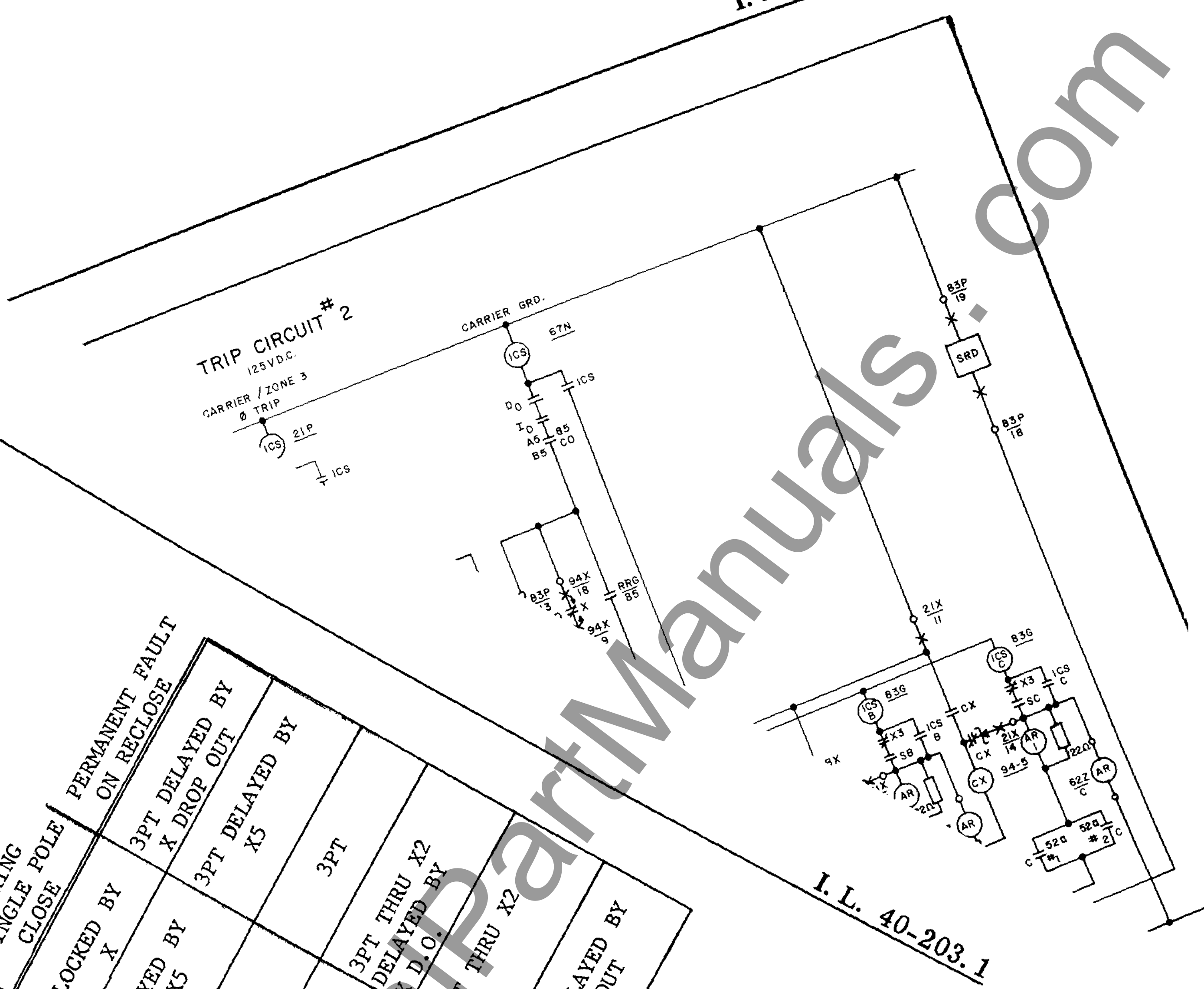
TABLE I
AUXILIARY UNIT TIMES - MILLISECONDS

RELAY	UNIT	PICKUP	DROPOUT
TT-18	X	10-20	70-100
TT-18	X2	100-200	150-250
KQS	X3	20-30	30-70
T-18	X4	45-80	10-40
-18	X5	45-80	10-40
9	AX, BX, CX	5-15	10-30

TABLE II
TRIP SCHEDULE

RELAY	PREFAULT PERIOD CARRIER IN SERVICE



	...SRD	...PASSED ...5 CO	...RING SINGLE POLE TRIP	(NOTE 6) DURING SINGLE PHASING	DURING SINGLE POLE CLOSE	PERMANENT FAULT ON RECLOSE
		BLOCKED BY 85 CO	BLOCKED BY X	BLOCKED BY X	BLOCKED BY X	3PT DELAYED BY X DROP OUT
...OS ...ISION	3PT	3PT		3PT-DELAYED BY X5-SRD BYPASSED BY X2	DELAYED BY X5	3PT DELAYED BY X5
...N FAILS ...AYED	BLOCKED BY 85 CO	SOUND PHASES BLOCKED BY X3	3PT THRU SRD & X2	3PT	3PT	3PT
	IMMEDIATE 3PT THRU 85 CO	BLOCKED BY X	3PT THRU X2	BLOCKED BY X3 OF KOS	3PT THRU X2	3PT THRU X2 DELAYED BY X D.O.
...GLE POLE TRIP ...E TRIP	3PT	BLOCKED BY X	BLOCKED BY X	BLOCKED BY X	3PT THRU X2	3PT DELAYED BY X DROP OUT

...ystem.

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K-DAR/KQS SINGLE POLE TRIP SYSTEM

The following is a description of the relaying system whose trip circuits are shown in Fig. 1. The system differs from the standard directional comparison blocking type described in I.L. 41-911 in that means are provided to trip only the faulted phase-breaker pole for single-line-to-ground faults. The specific directional-comparison system shown in the drawing is a 4-zone type.

The 4-zone scheme provides two separate trip circuits and, if desired, two separate current transformer circuits so that for a fault anywhere in the protected line section any one relay failure can be tolerated while still achieving fast tripping. In the case of phase faults in the immediate line section, trip circuit No. 1 in Fig. 1 provides instantaneous zone 1 protection over the first 90 percent of the line and a zone 2 delayed trip for the remainder. Trip circuit No. 2 for the same conditions provides instantaneous clearing over the entire line section by distance relay 21P working in conjunction with the carrier auxiliary relay (85) whose supervising contact RRP closes in the absence of a blocking signal to allow 21P to trip. Likewise, on ground faults trip circuit No. 1 provides instantaneous tripping for faults near the breaker and for a portion of the line extending from the breaker, and delayed tripping for the remainder. Circuit No. 2-67N relay trips instantaneously for all immediate line section ground faults. To provide selecttivity it is supervised by the RRG contact of the 85 relay. This contact, like the RRP contact, remains open for external faults in the presence of a carrier blocking signal. The above operation is somewhat modified for single-pole tripping as described later.

With carrier in service, the carrier ground relay is permitted to trip only the faulted-phase pole if the fault is a single line to ground fault. For all other types of faults the relays are permitted to trip all three poles. An alternative arrangement would provide tripping of two poles for faults involving two phases. For example, if the fault were to involve phases A and B, only those poles would be tripped. This "selective-pole" arrangement has been provided in a few instances with previous schemes. However, experience has shown that the improvement to stability occasioned by leaving one pole in service is not of sufficient benefit to justify the increased order of complexity in the relaying circuits necessary to provide this feature.

In addition to the relays described in the aforementioned literature for three pole tripping, the scheme in Fig. 1 shows the following additional relays: KQS(83G), SRD(83P, 83S) and SC(50N), AR(94-), AR(62X, Y, Z), TT-18(94X), TT-19(21X) and TD-5 (62). These relays working in conjunction with the HD-4 phase distance relays and the directional overcurrent ground relays provide the single pole tripping protection. Of the various phase and ground relays, the 67N relay, the instantaneous unit I of 67NT and the phase-to-phase unit of relay 21P remain in service during the single-phasing period (one pole open) to provide sound-phase protection. These relays provide fast protecttion should a phase-to-phase or ground fault occur on one or two phases not originally faulted. The functioning of each of the additional relays required for single pole tripping will now be described.

KQS (83G)

This relay working in conjunction with an external negative-sequence current filter detects which of the three phases is grounded for a single line to ground fault. Three high-speed induction cylinder units compare the phase angle of the negative sequence current and the zero sequence current. The phase A unit (SA) receives phase A negative sequence current while the other two phase selectors receive their respective negative sequence currents. For example, for a phase A to ground fault the phase A negative sequence current is almost in phase with the zero sequence current thus causing operation of the SA unit. At the same time the sound-phase negative sequence currents are 120° out of phase with the zero sequence current, producing contact opening torque

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*Denotes change from superseded issue.

EFFECTIVE APRIL 1970

on SB and SC. Thus, the KQS phase selectors tell the 67N directional overcurrent carrier ground relay which breaker pole to trip. Their sensitivity is 0.33 amperes negative and zero-sequence current. This is compatible with the normal $3I_0$ pick-up of 1.0 amp. on the I_0 unit of 67N. On a two phase to ground fault the phase selector on the sound phase is operated due to the nature of the fault. This means that the carrier ground relay trips the sound-phase pole. At the same time the 21P phase distance relay is operating to trip all three poles, so that KQS operation is irrelevant for double line to ground faults.

For a single line to ground fault with one pole opening on each breaker the 52a-52b disagreement circuit in Fig. 1 energizes auxiliary unit X3 of the KQS relay. Note that auxiliary switches are shown for two breakers as would be the case, for example, for a ring bus. Unit X3 blocks the sound-phase selector trip circuits to avoid the possibility of these phases being tripped at the time that the faulted phase pole is opening.

SRD (83P, 83S) and SC (50N)

The SRD relay operates for faults involving two phases but will not operate for a three-phase or a single-phase-to-ground fault. It compares the magnitude of the three voltages (phase-to-ground). When one of three voltages is larger than the other two the relay contacts close to permit the KD-4 zone 1 and KD-4 carrier trip relay 21P to clear the fault. One of three phase-to-ground voltages will be larger than the other two for phase-to-phase and two phase-to-ground faults. For a single phase-to-ground fault one of the three phase voltages will be smaller than the other two and the SRD relay will not operate. The SRD operates on a minimum of 10 volts difference between the largest voltage and the larger of the remaining two voltages. Rated potential is 70V.

SRD contacts are inserted in series with the KD-4 zone 1 and 21P carrier phase trip paths, to prevent a 3-pole trip for a single-line-ground fault. Since the SRD (83P) will not operate for 3-phase faults an SC (50N) break contact bypasses the SRD contact. The 50N relay is energized with residual current to sense ground faults. Thus, the parallel combination of 83P and 50N contacts provides a trip path except for single-phase-to-ground faults.

Another SRD contact bypasses the X contact interlock in series with the 85 CSG coil, to provide sound-phase protection as will be described later.

AR (94) Relays 94-1, 2, 3, 4, & 5 provide a 2 ms auxiliary trip function. Each relay has four make contacts. Relays 94-1 and 94-2 trip all three poles, while 94-3, 94-4, & 94-5 each trip their associated breaker pole. Spare contacts of 94-3, 4, & 5 may be used to initiate breaker closing. If two sets of breakers must be tripped (e.g., ring bus) 6 contacts may be needed, so the 94-1 and 94-2 functions may require two AR relays each.

TT-18 (94X)

Telephone type relays X, X2, X4, and X5 are packaged in the TT-18 relay. X and X2 relays perform transient blocking functions to eliminate the possibility of undesired trips during various periods enumerated in Table II "Trip Schedule". Relay X2 also sets up 21P, 67N and the instantaneous unit (I) of 67NT relay for the purpose of providing sound-phase protection during single phasing. In addition, the X3 unit sets up relay 78N for a three pole trip should the single breaker pole reclose into a permanent fault. This is accomplished by connecting the 67N trip circuit to the auxiliary trip relay 94-2.

Unit X4 introduces a coordinating delay in the tripping of the instantaneous unit of 67NT in trip circuit No. 1 This delay insures that the initial fault will be cleared by opening only the affected phase for single line to ground faults. Otherwise faults within the range of this instantaneous unit will be three-pole tripped. Unit X5 introduces a coordinating delay in the 21P trip circuit during the single-phasing period. In particular, this delay functions at the time of a single-pole reclose to insure that possible operation of 21P due to transients will not incorrectly cause tripping. The delay of X5 is inserted only during the single-phasing period and is not present during normal operation.

TT-19 (21X)

This relay grounds the open-phase potential terminals of certain relays during the single-phasing period. With line-side potential applications the 21P, 21S, 68 and 83P relay terminals are grounded. With bus-side potential applications only 83P needs to be grounded.

With potential taken from the line side the open phase voltage during single phasing is determined by the interphase capacitance between the faulted phase and the two sound phases. The exact potential is a function of the line configuration. The rotation of the three voltages could actually be negative sequence or a very small positive sequence triangle, providing insufficient restraint for the distance relays. For this reason the distance relays may have their contacts closed during the single phasing period if line side potential is utilized. This condition is tolerable if the trip circuits of these relays are disabled by relay X of the TT-18 relay. However, the 21P relay phase-to-phase unit provides sound phase protection, so the TT-19 disconnects the 21P, 21S, and 68 relays from the potential source on the phase with the open breaker pole and grounds that terminal. For example as shown in Fig. 1 if phase A pole opens, terminal 7 is grounded.

Regardless of the potential source location, the TT-19 relay switches the SRD, so that the SRD can operate for a ground fault on one of the "sound" phases during the single-phasing period. With one SRD potential pole grounded and normal voltage to ground on the other two phases, the SRD is reset; however, should one of the latter phases become grounded, the SRD would see a 1 large 2 small voltage condition.

TD-5 (62)

This relay limits the duration of single-phasing to prevent excessive heating of rotating equipment due to unbalanced current flow and to prevent undesired tripping of overcurrent ground relays in the vicinity of the protected line due to the zero sequence current flow throughout the system as a result of the single phasing operation.

AR (62X, 62Y, 62Z)

These are 0.2 sec. drop-out relays used primarily to initiate breaker-failure timing. The latter must be used in conjunction with a breaker-failure timer set for 0.17 sec. or less and with 3 independent phase current detectors as shown in Fig. 2. Time delay on dropout of 62X/Y is needed since RRG, RRP and X unit contacts can otherwise deenergize 62X/Y prematurely during a breaker failure.

Spare contacts from these relays may be used for such things as reclose block (in the case of 62X and Y) and carrier squelch in the case of 62Y. The latter performs the same function as the SQ unit of relay 85 in preventing a carrier blocking signal from being transmitted during and immediately after local breaker tripping.

These relays have delayed drop-out in order to maintain energization of 62BF in Fig. 2. Even though a breaker failure occurs the 62X, Y, Z relays will be deenergized in Fig. 1 by X or by the opening of RRG and RRG contacts before 62BF has timed out.

The KC-4 relay consists of three current detector units I_1, I_2, and I_3 energized by the phase A, B, and C breaker currents, respectively. Following a single-pole trip the sound phase current detectors may be operated by load current; therefore, the TRB-1 blocking diodes in Fig. 2 prevent undesired 62BF energization. For example, if phase C is tripped open successfully 62BF could be energized by I_2 or I_1 plus 62Z-C unless the TRB-1 diodes are used.

Summary of operation

For a phase to ground fault in the protected line with carrier in service, the faulted phase pole will be tripped by the 67N carrier ground relay through the 85-CO contact A-5 B-5 and the RRG carrier supervising contact or the KA-4 relay and through the phase selector unit SA, SB, or SC of the KQS relay. Simultaneously the 67N relay energizes relay units X, X3 and 62. Relay X and X3 operate immediately to block other trip paths which otherwise could produce a three pole trip. When the breaker poles on the faulted phase open, their 52b contacts close to keep the X, X3 and 62 relays energized. At this point X2 is also energized by the 52a-52b disagreement circuit. Shortly thereafter (See Table I "Auxiliary Unit Times"), relay X2 inserts relay X5 delay in the 21P trip path and at the same time bypasses the 50N contact in the same path. Another X2 contact bypasses the X4 delay of the directional ground relay instantaneous unit in trip circuit No. 1. Another X2 contact connects the 67N trip circuit to auxiliary tripping relay 94-2 so that a sound phase ground fault can be cleared by 67N and so that 67N can initiate a 3-pole trip if the open breaker pole closes into a fault.

Returning now to the instant when tripping was initiated, the faulted-phase selector unit of the KQS relay energizes unit AX, BX or CX of the TT-19 relay, grounding a potential terminal of the SRD and of distance relays 21P and 68 (line-side potential only). This grounding allows the trip circuit of 21P to be reestablished to provide sound-phase protection during the remainder of the single phasing interval.

Should a ground occur on one of the energized phases during the single phasing period relay 67NT instantaneous unit I can immediately trip if the fault produces enough current to pick it up. If not, 67N can initiate 3 pole tripping. If the ground occurs soon after the single-pole trip, unit X2 will not have had time to pick up; in this case 67N tripping will be delayed. After X2 operates, 67N can energize CSG through the 83P contact (which closes at inception of the sound-phase fault). When the remote carrier transmitter turns off, RRG closes, energizing 94-2. Note that carrier is transmitted continuously during the single-phasing period (unless CSP or CSG is operated) due to the unbalanced load-current operation of I_{OS} of relay 85. So either 67N plus 83P or I of 67NT must operate at both ends to turn off both transmitters in order to effect a 67N carrier trip. The phase-to-phase unit of 21P may also operate for a sound phase ground; however, this is not too likely.

The directional unit of 67N (type KRD-4 or KRQ) in some cases, may have a contact opening torque during a sound-phase fault while single phasing due to the phase angle shift of the polarizing voltage (V_0 in KRD-4 or V_2 in KRQ) if line side potential is used. The angle shift causes the potential polarizing effect to produce a contact opening torque which may overcome the contact closing torque produced by current polarizing in KRD-4 application. There are two alternatives recommended as follows:

1. Reverting KRD-4 to current polarizing only during single phasing. See note 12 on figure 1 for detailed connections. This alternative is not recommended unless a current polarizing source is utilized.
2. Bypass D-contact of KRD-4 (or KRQ) during single phasing. See note 13 on Fig. 1 for detailed connections. This alternative may cause tripping for an external fault on a phase other than the open phase during single phasing, but this would be a double contingency assumption.

Should a phase fault occur involving the two sound phases, relay 21P will trip all three poles through contacts RRP, X2 (make) or SRD or 50N, X5 or X2 (break). Before X2 operates, 50N will provide a trip path unless ground is involved in the fault. After X2 operates tripping will be delayed by X5.

For a two phase to ground fault with all poles closed the 67N relay trips the sound phase pole while the phase distance relays trip all three poles. Phase relay operation is as described in I.L. 41-911 except for the fact that the SRD ratio discriminator senses one large and two small voltages to permit KD-4 distance relay tripping.

For a phase-to-phase fault with all poles closed the phase distance relays and the SRD relay operate, tripping all three poles. Should a three-phase fault develop in the protected line the KD-4 three-phase units function in a conventional fashion. In the case of 21P or 21-1 the three-phase unit trips through the break contact of 50N (SC relay).

Unbalanced load flow during the single phasing period operates the I_{OS} carrier-start unit of relay 85. This action is beneficial during the interval at the end of the single-phasing period. When the first pole closes the disagreement circuit at that end of the line deenergizes the X unit of 94X. If X resets before the remote breaker pole recloses, 67N will still be operated by the unbalanced load current; however, the carrier signal prevents RRG closure, avoiding misoperation.

If the single-pole reclose is unsuccessful all three poles will be tripped. If the fault is beyond the 67NT I-unit range, tripping by 67N will be delayed until X resets. Unless the remote 67NT I-unit operates to squelch carrier, local 67N trip might have to await X unit reset at both stations; this is true since I_{OS} will not begin to reset until the laggard breaker pole closes. On the other hand, Although not likely, the $\phi\phi$ unit of 21P might see the ground fault and immediately stop carrier. Thus, a fault not cleared by the 67NT I-units at both stations might not be cleared until after about 100 ms or more upon reclose.

Remote Backup Protection

Faults on adjacent lines will be detected and cleared on backup operation by the 67NT time delay unit and by either 21-2 or relay 21P after the T3 delay provided by TD-4 timer (device 2). The trip path for the phase-fault remote-backup protection is 21P relay energizing auxiliary unit TX-Z3 which eventually closes contact TR to trip 94-2. The fact that 67NT is connected in trip circuit No. 1 and 21P in trip circuit No. 2 should be only incidental on the basis that we can assume that both trip circuits will be available when remote backup protection is required. This assumption is valid on the basis that the first contingency is a failure of the protection system on the adjacent line and any other failure at the location in question would result in a double-contingency failure. Stating the above in a different manner, if we assume a failure of the d.c. supply to trip circuit No 1 or to trip circuit No. 2 it is not legitimate to also assume a failure of the protection system at the remote station on the adjacent line; this would be a double-contingency assumption.

Operation with Carrier Out of Service

If the carrier set is being maintained or otherwise unserviceable, the carrier on-off switch (85-CO) should be turned to the OFF position. This will disable the 21P and 67N carrier trip circuits. In addition, contact A6-B6 and C6-D6 bypass interlocks in trip circuit No. 1 which are not required when single-pole tripping is removed. Contact A1-B1 of this switch is available for reclosing circuit use to block high-speed reclosing when carrier is out of service if this feature is required.

TABLE I

AUXILIARY UNIT TIMES – MILLISECONDS			
RELAY	UNIT	PICKUP	DROPOUT
TT-18	X	10- 20	70-100
TT-18	X2	65-200	150-250
KQS	X3	20- 30	30- 70
TT-18	X4	45- 80	10- 40
TT-18	X5	45- 80	10- 40
TT-19	AX,BX,CX	5- 15	10- 30

TABLE II

TRIP SCHEDULE

RELAY	PREFAULT PERIOD — CARRIER IN SERVICE	PREFAULT PERIOD — CARRIER OUT	DURING SINGLE POLE TRIP	(NOTE 6) DURING SINGLE PHASING	DURING SINGLE POLE CLOSE	PERMANENT FAULT ON RECLOSE
21-1	3PT $\phi\phi$ UNIT SUPERVISED BY SRD	SRD BYPASSED BY 85 CO	BLOCKED BY X	BLOCKED BY X	BLOCKED BY X	3PT DELAYED BY X DROP OUT
21P CARRIER TRIP	3PT 3ϕ & $\phi\phi$ UNITS SUPERVISED BY SRD + 50N	BLOCKED BY 85 CO		3PT DELAYED BY X5-SRD BYPASSED BY X2	DELAYED BY X5	3PT DELAYED BY X5
21P ZONE 3	3PT	3PT	3PT	3PT	3PT	3PT
67N	SPT KQS SUPERVISION	BLOCKED BY 85 CO	SOUND PHASES BLOCKED BY X3	3PT THRU SRD AND X2	BLOCKED BY X3 OF KQS	3PT THRU X2 DELAYED BY X D.O.
67NT INST.	3PT IF 67N FAILS TO SPT-DELAYED BY X4	IMMEDIATE 3PT THRU 85 CO	BLOCKED BY X	3PT THRU X2	3PT THRU X2	3PT THRU X2
67NT TIMED TRIP	3PT 3PT	3PT	BLOCKED BY X	BLOCKED BY X	BLOCKED BY X	3PT DELAYED BY X DROP OUT

SPT = SINGLE POLE TRIP

3PT = 3 POLE TRIP

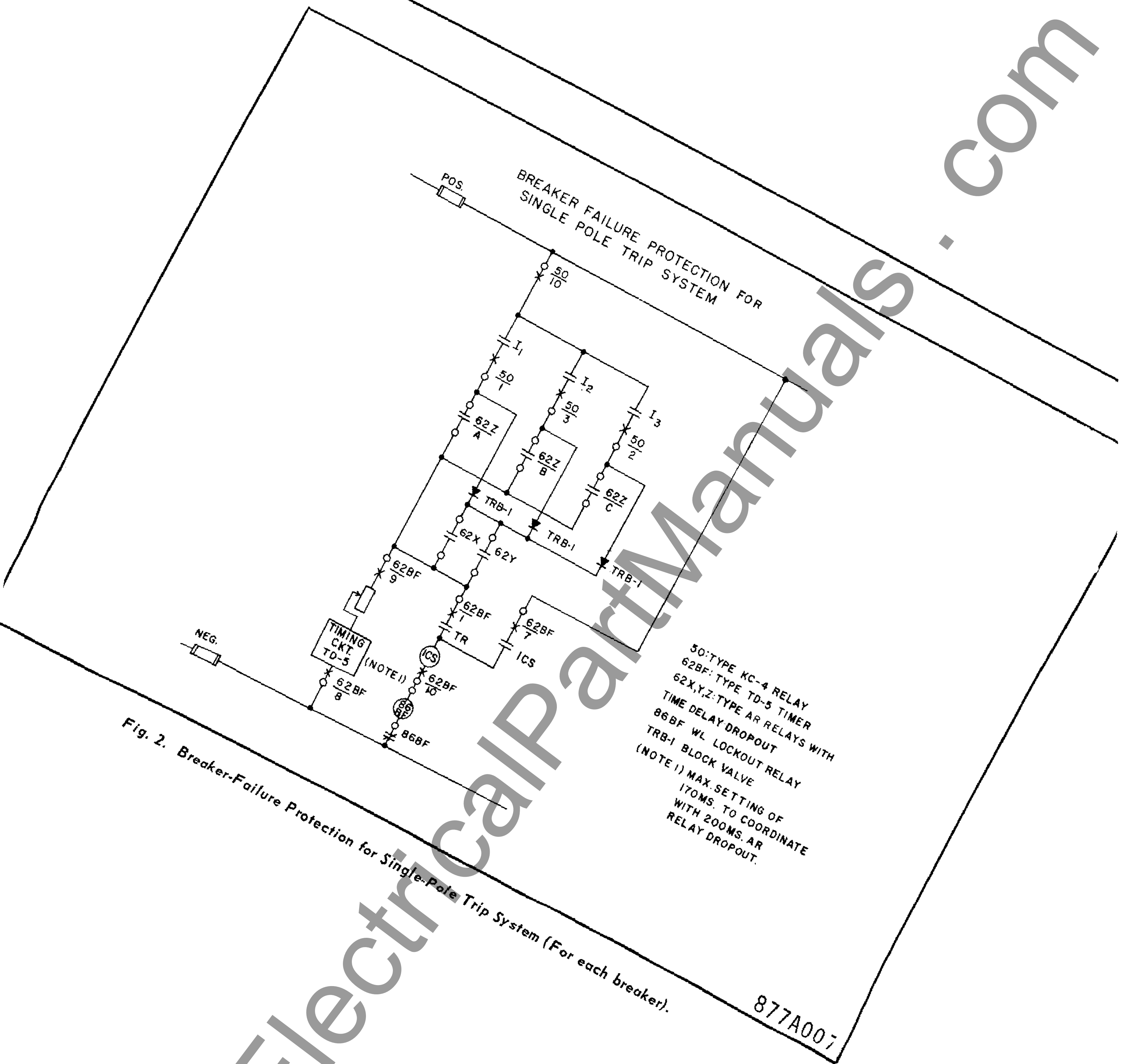
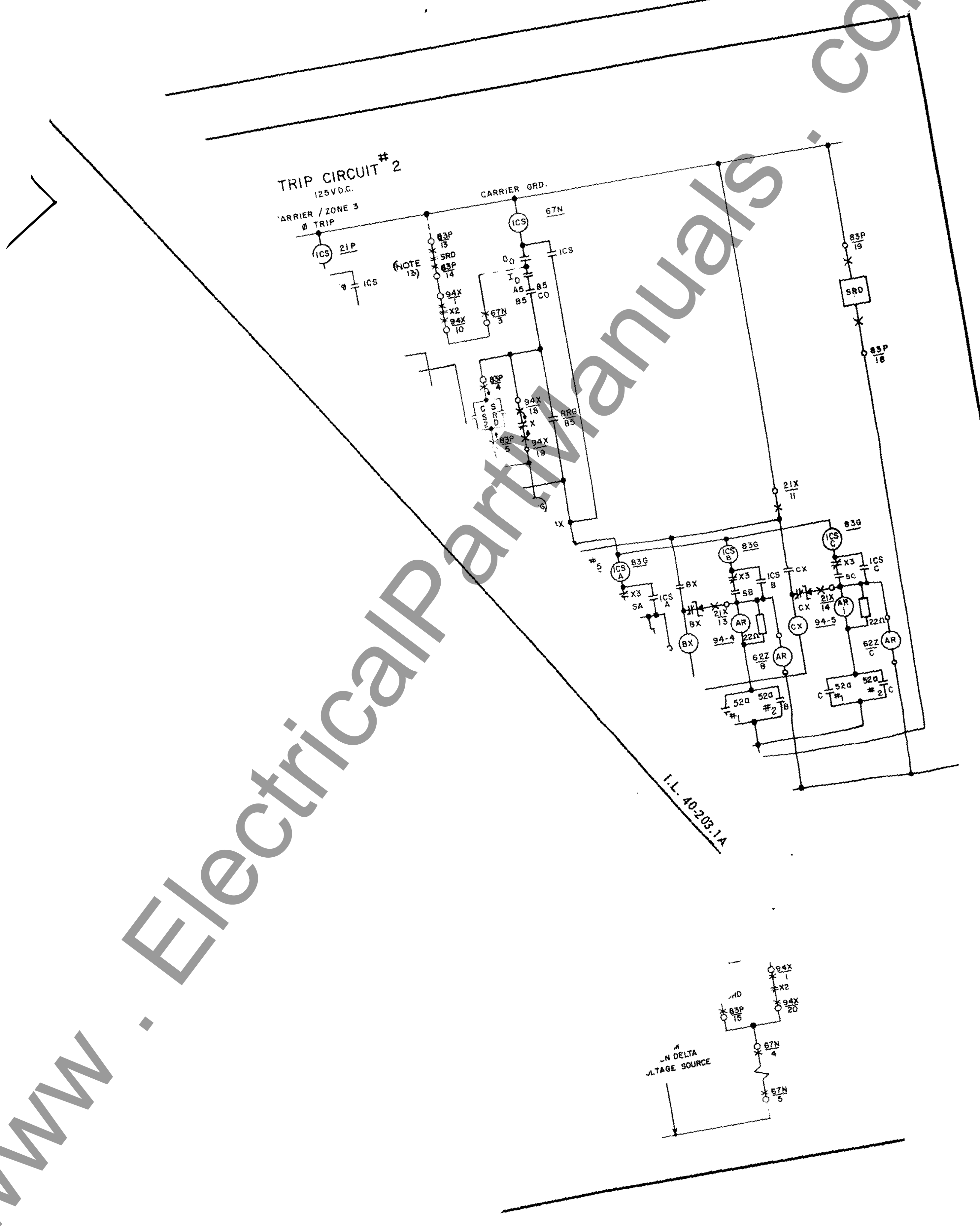


Fig. 2. Breaker-Failure Protection for Single-Pole Trip System (For each breaker).


TRIP CIRCUIT # 2
125 V D.C.
CARRIER GRD.
CARRIER / ZONE 3
Ø TRIP
ICS
21P
67N
(NOTE 13)
83P 13
SRD
83P 14
94X 1
X2
94X 10
67N 3
83P 4
CS SRD
83P 5
94X 18
X
94X 19
RRG 85
21X 11
83G
ICS A
ICS B
ICS C
BX
CX
AR
94-4
94-5
22Ω
62Z B
62Z C
52a
SRD
83P 19
83P 18
94X 20
83P 15
67N 4
67N 5
DELTA
VOLTAGE SOURCE
I.L. 40-203.1A

ystem.