SEL-221G-6, -7
SEL-121G-6, -7

Phase Distance Relay
Ground Directional
Overcurrent Relay
Fault Locator

Instruction Manual

19981217

SCHWEITZER ENGINEERING LABORATORIES, INC.

⚠CAUTION

Equipment components are sensitive to electrostatic discharge (ESD). Undetectable permanent damage can result if you do not use proper ESD procedures. Ground yourself, your work surface, and this equipment before removing any cover from this equipment. If your facility is not equipped to work with these components, contact SEL about returning this device and related SEL equipment for service.

⚠ATTENTION

Les composants de cet équipement sont sensibles aux décharges électrostatiques (DES). Des dommages permanents non-décelables peuvent résulter de l'absence de précautions contre les DES. Raccordez-vous correctement à la terre, ainsi que la surface de travail et l'appareil avant d'en retirer un panneau. Si vous n'êtes pas équipés pour travailler avec ce type de composants, contacter SEL afin de retourner l'appareil pour un service en usine.

⚠WARNING

Have only qualified personnel service this equipment. If you are not qualified to service this equipment, you can injure yourself or others, or cause equipment damage.

⚠AVERTISSEMENT

Seules des personnes qualifiées peuvent travailler sur cet appareil. Si vous n'êtes pas qualifiés pour ce travail, vous pourriez vous blesser avec d'autres personnes ou endommager l'équipement.

⚠WARNING

Use of this equipment in a manner other than specified in this manual can impair operator safety safeguards provided by this equipment.

⚠AVERTISSEMENT

L'utilisation de cet appareil suivant des procédures différentes de celles indiquées dans ce manuel peut désarmer les dispositifs de protection d'opérateur normalement actifs sur cet équipement.

⚠DANGER

Disconnect or de-energize all external connections before opening this device. Contact with hazardous voltages and currents inside this device can cause electrical shock resulting in injury or death.

⚠DANGER

Débrancher tous les raccordements externes avant d'ouvrir cet appareil. Tout contact avec des tensions ou courants internes à l'appareil peut causer un choc électrique pouvant entraîner des blessures ou la mort.

⚠DANGER

Contact with instrument terminals can cause electrical shock that can result in injury or death.

⚠DANGER

Tout contact avec les bornes de l'appareil peut causer un choc électrique pouvant entraîner des blessuers ou la mort.

PM121G-05

Warning

This device is shipped with default passwords. Default passwords should be changed to private passwords at installation. Failure to change each default password to a private password may allow unauthorized access. SEL shall not be responsible for any damage resulting from unauthorized access.

ATTENTION!

Cet équipement est expédié avec des mots de passe par défaut. A l'installation, les mots de passe par défaut devront être changés pour des mots de passe confidentiels. Dans le cas contraire, un accès non-autorisé à l'équipement pourrait être possible. SEL décline toute responsabilité pour tout dommage résultant de cet accès non-autorisé.

20001120

Standard Product Warranty – Ten Years

Definition of Terms

Product:	All items manufactured by SEL that are sold to a customer.
New Product:	A product manufactured by SEL that is sold for the first time.
Customer:	An end-user of the product.

New Product Warranty

All new products sold to customers are warranted against defects in design, materials, and workmanship for a period of ten (10) years from the date of first retail delivery to a customer. If it is determined that the new product defect is covered under this warranty, SEL will repair, replace, or substitute an identical unit at its own discretion to the customer at no charge.

SEL may, at its own discretion, require the customer to ship the unit back to the factory for diagnosis before making a determination as to whether it is covered by this warranty. In such event, SEL may, at its own discretion, decide to provide the customer with a substitute unit which may be sent to the customer either from the SEL factory or from an authorized representative or distributor from their inventory.

All expenses related to the shipment of defective units back to SEL or the provision of a substitute unit to the customer are the responsibility of the customer. This expense may include, but is not limited to, freight, insurance, Customs clearance, and duties. All expenses related to the shipment of repaired units back to customers (or the provision of a new unit to the customer) will be borne by SEL.

Product Upgrade Policy

From time to time, SEL makes product upgrades to add to or enhance the performance of the products. Customers of a particular product being issued an upgrade will be notified either by SEL directly or through its authorized representatives or distributors.

Customers who have purchased an annual upgrade policy will receive all upgrades during the calendar year free of charge. Customers who did not purchase the annual upgrade policy may purchase each unit upgrade individually. The annual upgrade policy can be purchased at any time. Regardless of whether the upgrade policy is purchased, SEL will make reasonable efforts to notify all customers of all available upgrades.

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Equipment Repair and Warranty

Repair costs of products not covered under this warranty are paid for by customers. Customers are responsible for the cost of shipping the products to SEL located at: 2350 NE Hopkins Court, Pullman, Washington 99163 USA.

All products repaired by SEL will be warranted against defects in material and workmanship for a period of one year from the date the equipment is returned to the customer or the remainder of the new product warranty, whichever is longer.

Limitations

SEL's warranty does not extend to (A) SEL's products subject to (i) improper installation, connection, operation, maintenance, or storage; (ii) accident, damage, abuse, or misuse; (iii) abnormal or unusual operating conditions or applications outside the specifications for the product; (iv) a purpose or application in any way different from that for which the products were designed; or (v) repairs conducted by persons other than SEL employees or an authorized representative or distributor; (B) Equipment and products not manufactured by SEL. Such equipment and products may be covered by a warranty issued by the respective manufacturer.

This warranty is in lieu of any other warranties, express or implied, including without limitation, any warranty of merchantability or fitness for a particular purpose, and is in lieu of any and all other obligations or liability of SEL. Under no circumstances shall SEL be liable for any accidential or consequential damages or for any other loss, injury, damage, or expense of any kind including loss of profits arising hereunder.

To the extent any court, arbitration panel, or other governmental body of competent jurisdiction shall declare any provision of this warranty invalid or unenforceable by reason of a rule of law or public policy, all the other provisions hereof shall remain in full force and effect.

MANUAL CHANGE INFORMATION

The date code at the bottom of each page of this manual reflects the creation or revision date. Date codes are changed only on pages that have been revised and any following pages affected by the revisions (i.e., pagination). If significant revisions are made to a section, the date code on all pages of the section will be changed to reflect the revision date.

Each time revisions are made, both the main table of contents and the affected individual section table of contents are regenerated and the date code is changed to reflect the revision date.

Changes in this manual to date are summarized below (most recent revisions listed at top).

Manual Creation Date: 940815

Revision Date	Summary of Revisions
The *Manual Change Information* section has been created to begin a record of revisions to this manual. All changes will be recorded in this Summary of Revisions table.	
981217	Incorporated "***ACB Phase Rotation Option***" and "***Kilometer Option***" addenda into ***Section 1: Introduction***. Incorporated "***New SEL-200 Series Optical Isolator Logic Input Rating***" addendum into ***Section 2: Specifications***. Title now reads "***Optoisolated Inputs***." Incorporated "***Jumper Installation Instructions***" addendum into ***Section 6: Installation***. Updated ***Figure 6.3: SEL-200 Series (Shallow) Relay Dimensions, Panel Cutout, and Drill Diagrams***. The figure caption now reads ***Relay Dimensions and Drill Plan***.

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INTRODUCTION

GETTING STARTED

This instruction manual applies to the SEL-121G-6, -7 and the SEL-221G-6, -7 Relays. The SEL-221G series and SEL-121G series relays have identical protection features, but use different hardware designs. Where there are differences between SEL-221G-6/121G-6 and SEL-221G-7/121G-7 relay models, the differences are described. Consult the model variations description in this section for information about the SEL-221G Relay and the models available. Firmware changes to the logic controlling front panel targeting, communication scheme timers, command access level, rear panel logic input function, and out-of-step mho characteristic diameter differentiate relay model variations.

If you are not familiar with the SEL-221G-6 Relay, we suggest that you read this introduction, then perform the Initial Checkout Procedure in Section 7: MAINTENANCE & TESTING.

RELAY OVERVIEW

The SEL-221G family of relays are designed to protect transmission, subtransmission, and distribution lines for all fault types. The following list outlines protective features, performance, and versatility gained when applying any SEL-221G Relay to your installations.

- Three zones of instantaneous/definite-time phase distance protection
- Residual time-overcurrent element with selectable curves
- Three instantaneous/definite-time residual overcurrent elements
- Negative- or zero-sequence polarization of ground directional elements
- Versatile user programmable logic for outputs and tripping
- Programmable switch-onto-fault logic
- Out-of-step blocking of selected zones for power swings
- Loss-of-potential detection logic
- Programmable three-shot reclosing
- Fault locating
- Metering
- EIA-232 Communication ports for local and remote access
- Automatic self-testing
- Demodulated IRIG-B time code input
- Target indicators for faults and testing
- Compact and economical

MODEL VARIATIONS COVERED BY THIS INSTRUCTION MANUAL

SEL offers several optional variations of the SEL-221G Relay logic for a wide range of applications. While this introduction includes a short description of each model variation, the remainder of the instruction manual pertains only to the -6 variation. Please consult the information sticker on the relay rear panel if you are unsure of the relay model number.

SEL-221G-6 Relay

The SEL-221G-6 Relay is intended for application in Directional Comparison Blocking (DCB) schemes. Zone 1 phase and ground timers of the basic SEL-221G Relay have been removed to provide two settable timers for the Zone 2 phase and ground elements. BT input assertion in the SEL-221G-6 Relay does not generate an event report as it would in the basic SEL-221G Relay. This eliminates event reports caused by carrier channel noise. The block trip input (BT) incorporates a one-quarter-cycle block trip input signal extension to provide added security for out-of-section faults. Zone 3 pickup extension logic is included to serve as block trip transmit extension. The logic output is indicated by the Z3X bit in the Relay Word (Z3X replaces 52AT in the SEL-221G Relay Word). Nondirectional instantaneous residual over-current element 50N3 is available in the Relay Word for high speed nondirectional carrier start function (50N3 replaces ALRM in the SEL-221G Relay Word). Logic for carrier stop over carrier start preference is also available for use with nondirectional overcurrent or offset mho element carrier start functions. The logic output is indicated by the STOP bit in the Relay Word (STOP replaces DF in the SEL-221G Relay Word). Independent nondirectional overcurrent fault detector supervision is provided for the Zone 3 and Zone 4 three-phase and the Zone 3 phase-phase elements. The new overcurrent fault detector element, 50L3, replaces the OSB element in the Relay Word. The offset Zone 4 three-phase element is fixed in the reverse direction for carrier start functions. The Zone 4 element has been incorporated into the block trip extension (Z3X) and the carrier stop (STOP) logic. Out-of-step blocking and those functions involving out-of-step blocking are not supported by the SEL-221G-6 Relay. Front panel LEDs are "trip only targets." Thus, target LEDs indicate only the zone element picked up when the TRIP output contacts assert and show only the most recent fault (basic SEL-221G Relay LEDs display cumulative targets).

SEL-221G-7 Relay

The SEL-221G-7 Relay differs from the standard SEL-221G-6 Relay model as follows: the Current-supervised Trip Unlatch has been removed, and the Trip Duration Timer (TDUR) functions as a Trip Dropout Timer.

OTHER SEL-221G RELAY MODEL VARIATIONS

These model variation descriptions are provided for comparison purposes.

SEL-221G Relay

The basic SEL-221G Relay employs each feature outlined in the preceding Relay Overview. The front panel target LEDs are cumulative, indicating all picked up zones instead of only the zone element picked up at the time of trip.

SEL-221G-3 Relay

SEL-221G-3 Relay front panel LEDs are "trip only targets." Thus, target LEDs indicate only the closest-in zone element picked up when the TRIP output contacts assert and show only the most recent fault (basic SEL-221G Relay LEDs display cumulative targets).

SEL-221G-4 Relay

The Zone 4 three-phase element diameter is two times that of the Zone 3 three-phase mho element. The Zone 4 three-phase element diameter in all other SEL-221G Relays is 1.5 times the diameter of the Zone 3 three-phase element. SEL-221G-4 Relay LED targeting is identical to that of the SEL-221G-3 Relay.

SEL-221G-5 Relay

The SEL-221G-5 Relay is intended for application in Directional Comparison Blocking (DCB) schemes. Zone 1 phase and ground timers of the basic SEL-221G Relay have been removed to provide two settable timers for the Zone 2 phase and ground elements. BT input assertion in the SEL-221G-5 Relay does not generate an event report as it would in the basic SEL-221G Relay. This eliminates event reports caused by carrier channel noise. The block trip input (BT) incorporates a one-quarter-cycle block trip input signal extension to provide added security for out-of-section faults. Zone 3 pickup extension logic is included to serve as block trip transmit extension. The logic output is indicated by the Z3X bit in the Relay Word (Z3X replaces 52AT in the SEL-221G Relay Word). Nondirectional instantaneous residual overcurrent element 50N3 is available in the Relay Word for high speed nondirectional carrier start function (50N3 replaces ALRM in the SEL-221G Relay Word). Logic for carrier stop over carrier start preference is also available for use with nondirectional overcurrent or offset mho element carrier start functions. The logic output is indicated by the STOP bit in the Relay Word (STOP replaces DF in the SEL-221G Relay Word). Front panel LEDs are "trip only targets." Thus, target LEDs indicate only the closest-in zone element picked up when the TRIP output contacts assert and show only the most recent fault (basic SEL-221G Relay LEDs display cumulative targets).

SEL-221G-8 Relay

The SEL-221G-8 Relay has several differences from the basic SEL-221G Relay model. A Level 2 access attempt does not pulse the ALARM contacts as in the SEL-221G Relay. Instead, the ALARM contacts pulse for four seconds after three unsuccessful Level 1 or 2 access attempts. DATE, TIME, TRIGGER, and IRIG command execution requires Level 2 access. In contrast, the basic SEL-221G Relay requires only Level 1 access for these commands. TARGET command execution from Level 1 only displays targets. TARGET command execution from Level 2 displays targets and allows the operator to change front panel LED assignments. Front panel LEDs are "trip only targets." Thus, target LEDs indicate only the closest-in zone element picked up when the TRIP output contacts assert and show only the most recent fault (basic SEL-221G Relay LEDs display cumulative targets). Excluding these differences, the SEL-221G-8 Relay is identical to the SEL-221G-5 Relay.

SEL-221G-9 Relay

The SEL-221G-9 Relay is identical to the SEL-221G-5 Relay except for permissive trip input (PT) assertion, which does not generate an event report. This feature eliminates unwanted event reports for noise bursts on the permissive trip communication channel and allows use of the input as a monitoring input only.

GENERAL DESCRIPTION

The SEL-221G-6 Phase Distance and Ground Directional Overcurrent Relay with fault locator simultaneously provides high-speed and time delayed protection for transmission, subtransmission, and distribution lines. A 32-bit Relay Word combines mho distance elements, overcurrent elements, directional element, timers, and data and control bits. You can program the logic through bit combinations to control tripping, communication channel keying, reclose initiation and cancellation, and four general purpose programmable outputs.

Because of its many relay elements, large setting ranges, programmability, and low cost, the relay meets the requirements of a broad spectrum of applications. Flexible yet simple programmability provides access to relay elements (before and after time delays) and logic results. Relay features include four zones of three-phase elements, three zones of phase-to-phase elements, three zones of ground elements, time delayed backup for Zones 2 and 3 phase and ground elements, time-overcurrent element, three shot reclosing with programmable initiate and reclose conditions, and loss-of-potential logic.

Without requiring an external initiating contact input, the relay provides time-stepped protection in parallel with communication-aided protection. The relay supports:

- Directional Comparison Blocking (DCB) schemes
- Permissive Overreach Transfer Trip (POTT) schemes
- Directional Comparison Unblocking (DCUB) schemes
- Permissive Underreaching Transfer Trip (PUTT) schemes
- Direct Underreaching Transfer Trip (DUTT) schemes
- Direct Transfer Trip (DTT) schemes

Analog inputs from current and voltage transformers are delivered to the protective relaying elements and saved for additional features such as metering and fault locating.

Relay elements process the analog data. Some intermediate logic is performed, such as overcurrent supervision of the mho elements, directional supervision of the residual overcurrent elements, and grouping of certain elements into zones.

The relay generates an eleven-cycle event report starting with information captured four cycles before fault detection through seven cycles afterward. Each event report resembles a sequence-of-events report; each includes the following information every quarter-cycle for eleven cycles:

- Voltages (VA, VB, and VC)
- Currents (IA, IB, IC, IR (residual), and IP (current polarizing input))
- Fault type and involved phases
- Fault location
- Secondary ohms to the fault location
- Maximum phase current measured near the middle of the fault
- Date and time of the event
- Relay element status
- External inputs (breaker status, block trip, etc.)
- Relay contact outputs

The information in each event report simplifies analysis of the most complex system operations.

The relay stores the latest twelve event reports, allowing retrieval and examination after the event. A user can retrieve any or all records remotely or locally through either of the two serial communications ports.

The metering function permits interrogation of the relay to obtain power system voltage, current, real power, and reactive power readings. The function also includes per-phase measurements of voltage and current. Metering is very valuable for unmanned or remote substations.

The CLOSE, A1, A2, A3, A4, and ALARM outputs may be specified as "a" or "b" type contacts. TRIP outputs are always an "a" type contact.

The relay is compatible with the SEL-PRTU Protective Relay Terminal Unit, the SEL-DTA Display/Transducer Adapter, the SEL-RD Relay Display, and the SEL-PROFILE Transmission Line Fault Analysis Program.

ACB PHASE ROTATION OPTION

The SEL relay instruction manuals are written for standard ABC phase rotation applications. If your SEL relay is ordered with the ACB phase rotation option, references made in the instruction manual to voltage and current phase angle should be noted accordingly. The firmware identification number (FID) may be used to verify whether your relay was ordered with ABC ("B") or ACB ("C") rotation.

All current and voltage inputs are connected to the SEL relay rear panel as shown in the instruction manual.

KILOMETER OPTION

The 221G/121G Relay instruction manual is written for fault locations in terms of miles. If your SEL-221G/121G Relay is ordered with the kilometer line length option, references made in the instruction manual to miles should be substituted with kilometers.

One exception to the straight substitution of kilometers for miles is the reference in the instruction manual to the effect of shunt capacitance on the fault location calculation. The line length equation and associated paragraphs, corrected for a 100-kilometer line, should read:

> Shunt capacitance of the transmission line is not taken into account. The capacitance causes the fault location to appear less remote by, approximately, a factor of 1/cos(bL), where bL is the line length in radians at 60 Hz. One wavelength at 60 Hz is 4989 kilometers. For example, the line length of a 100-kilometer line in radians, is:

$$(100/4989) * 2 * 3.14159 = 0.1260 \text{ radians}$$

The indication neglecting capacitance is about cos (0.1260) = 0.992 times the actual fault location, or about 0.8 kilometers short for a fault at the remote end of a 100-kilometer line.

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SPECIFICATIONS

This section is divided into three subsections. The first describes input parameters, mechanical specifications, and applicable standards. The second provides a functional specification, while the third details the technical features of each relay function.

RELAY STANDARDS AND INPUT PARAMETERS

Rated AC Input Voltage	115 volt nominal phase-to-phase, three-phase four-wire connection.
Rated AC Input Current	5 amps per phase nominal. 15 amps per phase continuous. 500 amps for one second thermal rating.
Output Contacts	*IEEE C37.90 Tripping Output Performance Requirements.* 30 A make. 6 A carry; MOV protected.
Optoisolated Inputs SEL-221G Relay	The following optoisolated inputs draw 4 mA when nominal control voltage is applied: 24 Vdc: 15 - 30 Vdc 48 Vdc: 30 - 60 Vdc 250 Vdc: 150 - 300 Vdc Fixed "Level-Sensitive" inputs are provided on relays with 125 Vdc opto-isolated inputs. The 125 Vdc optoisolated inputs each draw 6 mA when nominal control voltage is applied. 125 Vdc: on for 100 - 150 Vdc; off below 75 Vdc
Optoisolated Inputs SEL-121G Relay	The following optoisolated inputs draw 6 mA when nominal control voltage is applied: 24 Vdc: 10 - 30 Vdc 48 Vdc: 25 - 60 Vdc 125 Vdc: 60 - 200 Vdc 250 Vdc: 200 - 280 Vdc
Power Supply Ratings	24/48 Volt: 20 - 60 Vdc; 12 Watts. 125/250 Volt: 85 - 350 Vdc or 85 - 264 Vac; 12 Watts.
Dielectric Strength	Voltage and current inputs: 2500 Vac for 10 seconds. Power supply, logic inputs, and contact outputs: 3000 Vdc for 10 seconds.

Operating Temp.	-40° to 70°C (-40° to 158°F).
Unit Weight	SEL-200 Series: 5.4 kg (12 lbs). SEL-100 Series: 9.5 kg (21 lbs).
Shipping Weight	SEL 200 Series: 7.7 kg (17 lbs), including one instruction manual. SEL 100 Series: 11.8 kg (26 lbs), including one instruction manual.
Dimensions	SEL-200 Series: Refer to Figure 6.3. SEL-100 Series: 13.3 cm x 48.2 cm x 33.0 cm (5.25" x 19" x 13") (H x W x D).
Mounting	Mounts in standard EIA 48.2 cm (19") relay rack or panel cutout. Available in horizontal or vertical mounting configurations.

Type Tests and Standards

IEEE C37.90.1 IEEE Standard Surge Withstand Capability (SWC) Tests for Protective Relays and Relay Systems.

* *IEEE C37.90.2 IEEE Trial-Use Standard Withstand Capability of Relay Systems to Radiated Electromagnetic Interference from Transceivers.*

5.5.2 (2)	Performed with 200 frequency steps per octave.
5.5.3	*Digital Equipment Modulation Test* not performed.
5.5.4	Test signal turned off between frequency steps to simulate keying.

IEC 68-2-30 Basic environmental testing procedures,
Part 2: Tests.
Test Db and guidance: Damp heat, cyclic (12 + 12-hour cycle).
Humidity, 95% between 25°C and 55°C.

IEC 255-5 Electrical relays,
Part 5: Insulation tests for electrical relays,
Impulse voltage test: 0.5 Joule, 5000 volt.

IEC 255-6 Electrical relays,
Part 6: Measuring relays and protection equipment,
High frequency disturbance tests.

* *IEC 255-21-1 Electrical relays,*
Part 21: Vibration, shock, bump and seismic tests on measuring relays and protection equipment,
Section One - Vibration test (sinusoidal).

* *IEC 255-21-2 Electrical relays,*
Part 21: Vibration, shock, bump and seismic tests on measuring relays and protection equipment,
Section Two - Shock and bump tests.

IEC 801-2 Electromagnetic compatibility for industrial-process measurement and control equipment,
Part 2: Electrical discharge requirements.

IEC 801-4 Electromagnetic compatibility for industrial-process measurement and control equipment,
Part 4: Electrical fast transient/burst requirements.

\# *RFI.* Type tested in field from a ¼-wave antenna driven by 20 watts at 150 MHz and 450 MHz randomly keyed on and off one meter from relay.

* Applicable to SEL-200 series relays only
\# Applicable to SEL-100 series relays only

FUNCTIONAL SPECIFICATIONS

Expanded Mho Characteristics for Phase-Phase and Three-Phase Faults

- Three zones of phase-phase distance protection
- Four zones of three-phase distance protection
  - Zone 4 employed for carrier start function
  - Zone 4 concentric to Zone 3 and includes the origin. Zone 3 may be set forward or reversed, but Zone 4 always remains reversed.
- Zones 1, 2, and 3 three-phase distance elements memory polarized
  - Zone 4 does not require memory polarization due to its offset
- Carrier coordinating short timer for Zone 2 distance elements
- Independent long timers for Zone 2 and 3 distance elements (time-step backup protection)
- Fault detector elements supervise all distance elements
- Loss-of-potential logic supervises all distance elements when enabled
- Zone 3 reversible with a simple setting (all Zone 3 elements are reversed when ZONE3 = R in the relay settings)

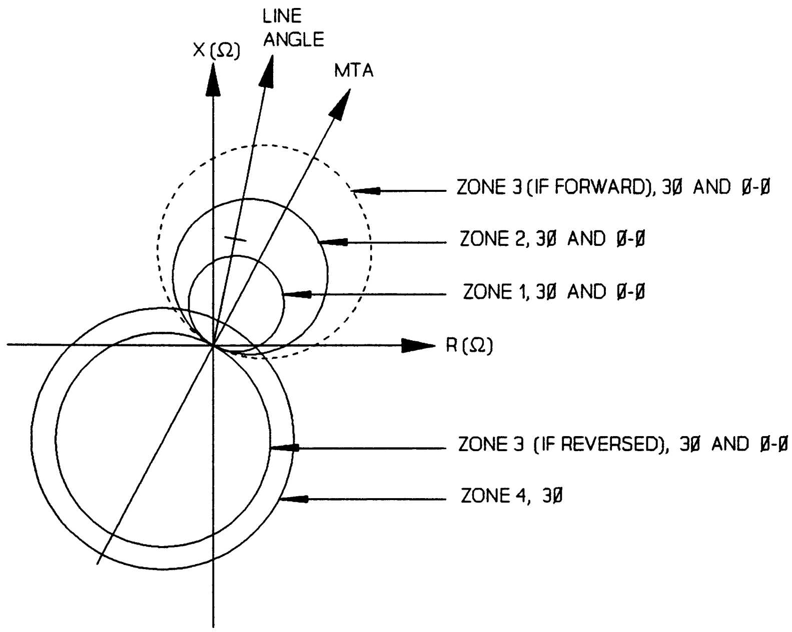


Figure 2.1: Phase-Phase and Three-Phase Mho Element Characteristics

Residual Overcurrent Protection for Ground Faults

- Time-overcurrent element
  - Four curve families (moderate, inverse, very inverse, and extremely inverse)
  - Nondirectional or forward reaching as enabled in relay settings
- Three residual overcurrent elements
  - Carrier coordinating short timer for Zone 2 element
  - Independent long timers for Zone 2 and 3 elements (time-step backup protection)
  - Zone 3 reversible with a simple setting
- Choice of three polarization techniques for directional control
  - Nondirectional if no polarization method is selected

Residual Overcurrent Directional Elements

- Three methods of residual overcurrent directional polarization:
  - Negative-sequence voltage and current
  - Zero-sequence voltage and residual current
  - External zero-sequence current and residual current
- May be dual zero-sequence polarized

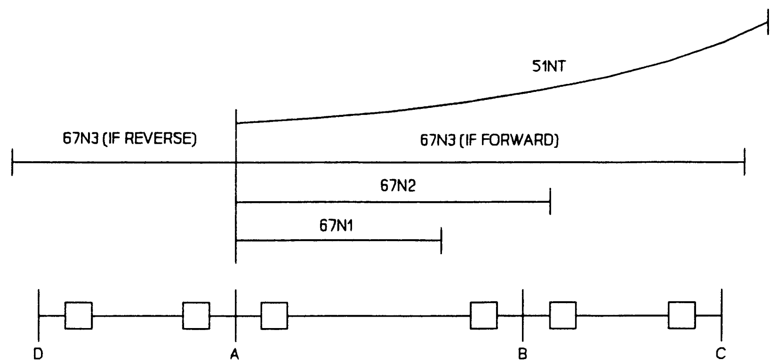


Figure 2.2: Residual Overcurrent Zones of Protection

Reclosing

- Three separate shots of reclosing with settable open interval timers
- Selectable reclose initiate and cancel conditions
- Settable reclose reset timer

Loss-of-Potential (LOP) Detection

- Detects blown secondary potential fuse(s) condition
- Enabled or disabled with a simple setting
- When enabled, an LOP condition blocks all mho distance elements
- LOP detection may be selected to close an output relay for alarming purposes

Nondirectional Phase Overcurrent Elements

- Two independent low-set phase overcurrent elements supervise the mho distance elements; one set of phase overcurrent elements supervise the Zone 1 and 2 mho distance elements and release the TRIP output contacts in conjunction with the low-set residual overcurrent element, and one set of phase overcurrent elements supervise the Zone 3 and 4 mho distance elements
- Medium-set phase overcurrent element for loss-of-potential (LOP) logic and nondirectional phase overcurrent protection during LOP conditions (or non-directional phase overcurrent protection when LOP is not enabled in the relay settings)
- High-set phase overcurrent element provides switch-onto-fault protection for close-in three-phase faults

Switch-Onto-Fault Protection

- User selected elements enabled to trip for 52BT time after the line breaker closes
- Functions independently from communications channel equipment

Zone 3 Pickup Extension (Z3X) Logic

- Zone 4 three-phase mho element and Zone 3 elements serve as inputs to the Z3X logic
- Z3X bit in the Relay Word may be used to extend a carrier start output for five cycles after the last Zone 3 or Zone 4 element drops out if Zone 3 or Zone 4 elements have been asserted for two cycles
- Relay trip condition resets Z3X logic timer for close-in in-section faults within the Zone 4 offset reach

Carrier Stop (STOP) Logic

- Inverted Z3X bit and MTB mask elements serve as inputs to STOP logic
- STOP bit in Relay Word may be used for carrier squelch (stop carrier over start carrier preference) when nondirectional overcurrent or offset mho relay elements are used to output a carrier start

IRIG-B Input

The relay accepts demodulated IRIG-B from an external clock source to set the internal clock automatically.

Relay Word

The Relay Word is the center of relay programmability. It consists of four rows of eight bit groups which represent the state of the relay elements (both instantaneous and timed), timer and logic outputs, and relay inputs. Each bit in the Relay Word has two states: logical 1 when the element is asserted, logical 0 when the element is deasserted.

Each quarter-cycle, the relay samples voltage and current data, performs intermediate logic to determine if an element is asserted, and sets the appropriate bit in the Relay Word.

After updating the Relay Word, the relay compares it to all programmable logic masks with a bitwise logical "AND" process. This process in turn controls the relay output contacts. Each TRIP, programmable output relay, reclose initiate and cancel condition has a corresponding logic mask (see Programmable Logic Masks). These masks determine the state of the output relay and reclosing sequence, depending on which elements are asserted in the Relay Word.

Table 2.1 shows the Relay Word for the relay.

Table 2.1: Relay Word

1ABC	2ABC	3ABC	4ABC	LOP	50H	50M	50L
51NT	67N1	67N2	67N3	51NP	Z1P	Z2P	Z3P
Z2PT	Z3PT	50L3	3P50	50MF	RC	RI	STOP
50N3	TRIP	TC	DT	52BT	Z3X	Z2GT	Z3GT

Logic Inputs

The relay has six opto-isolator inputs to sense external conditions: received permissive trip and block trip signals, breaker status, direct close, direct trip, and external event report trigger. Assert these logic inputs by applying control voltage to the corresponding rear panel input terminals.

Output Contacts

The relay has seven output contacts: TRIP, CLOSE, ALARM, and four programmable outputs (A1, A2, A3, and A4). Any output contact except TRIP may be configured as either "a" or "b." The TRIP output contact is always "a."

Event Reporting

The relay retains eleven-cycle data records for each of the last twelve events. The long form of each event record includes the following:

1.* Date and time of disturbance
2.* Terminal identifier
3. Input voltages and currents every quarter-cycle
4. Relay element status every quarter-cycle
5. Input and output contact status every quarter-cycle
6.* Fault Location
7.* Event type
8.* Maximum phase current magnitude near the middle of the fault
9.* Fault duration in cycles
10. Relay and logic settings

* Included in the summary event report and event history listing.

An event report is triggered when certain relay elements pick up, the TRIP output contacts close, the Direct Trip, Permissive Trip, External Trigger input contacts assert, or by execution of the TRIGGER or OPEN commands.

If tripping occurs after the end of the event report, the trip triggers a second report. For details on the contents and analysis of relay event reports, see Section 4: EVENT REPORTING.

Fault Location

The relay computes fault location using event report data stored for each fault or disturbance. The primary fault locating algorithm compensates for pre-fault current to improve fault locating accuracy for high-resistance faults. The relay uses two fault locating methods: the Takagi method where sound pre-fault data are available, or a simple reactance method when sound pre-fault data are not available.

Metering

The meter function shows the line-neutral and line-line ac voltage and current values, megawatts (P to represent real power), and megavars (Q to represent reactive power) in primary values. You can display these values locally or remotely with the METER command.

Targeting

The relay has seven target levels (0 - 6). In Target Level 0, the front panel target LEDs correspond to front panel markings. Under normal operating conditions, the enable (EN) LED is illuminated. If the relay trips, it illuminates the LED(s) for the highest priority zone and fault type at the time of trip. Target LEDs are latching, so the targets remain illuminated until you press the Target Reset button, execute the TARGET R command, or a trip with a different zone and fault type occurs.

The TARGET command and front panel LED display allow assignment of front panel LEDs to show the state of relay inputs, outputs, and Relay Word elements. See the TARGET command in Section 3: COMMUNICATIONS for more details.

Clear front panel targets locally by pressing the front panel TARGET RESET button or remotely with the TARGET RESET (TAR R) command when there is no trip condition. If a trip condition is present when you press the TARGET RESET button or issue the TARGET RESET command, front panel targets do not clear. This feature should always be used as a test before closing the trip cutout switch on the line terminal control panel. The TARGET RESET button also unlatches TRIP output contacts to prevent relay installation with TRIP contacts closed.

Self-Testing

The relay runs exhaustive self-tests which ensure reliable operation. If a test fails, the relay enters a warning or failure state, closes the ALARM output relay, and issues a status report to the port(s) designated automatic. The duration of ALARM output contact closure depends on which self-test warns or fails.

Self-tests check the following items:

- Analog Channel Offset (IP, IR, IA, IB, IC, VA, VB, and VC)
- +5 V Power Supply
- ±15 V Power Supplies
- Random-Access Memory (RAM)
- Read-Only Memory (ROM)
- A/D Conversion Time
- Master Offset
- Settings

See Detailed Specifications in this section for a complete description of self-tests.

DETAILED SPECIFICATIONS

Distance Elements

Phase-Phase Distance (Secondary Quantities)

21P1: 0.125 to 64 ohms
21P2: 0.125 to 64 ohms
21P3: 0.125 to 64 ohms

Three-Phase Distance (Secondary Quantities)

21ABC1: 0.125 to 64 ohms
21ABC2: 0.125 to 64 ohms
21ABC3: 0.125 to 64 ohms
21ABC4: reversed offset mho with diameter 1.500 times Zone 3

Maximum Torque Angle (MTA)

Adjustable from 47° - 90°.

Zone 2 and 3 settings are limited as follows:

For Zone 3 Forward: Zone 1 < Zone 2 < Zone 3
For Zone 3 Reverse: Zone 1 < Zone 2, Zone 1 < Zone 3

Accuracy

Steady-state Error:

- $\pm 5\%$ of set reach ± 0.01 ohm at MTA for $V > 5$ V and $I > 2$ A.
- $\pm 10\%$ of set reach ± 0.01 ohm at MTA for $1 < V < 5$ V and $0.5 < I < 2$ A.

Transient Overreach:

- $\pm 5\%$ of set reach, plus steady-state error.

Operating Speed

See operating time curves at the end of this section

Memory Polarization

Zone 1, 2, and 3 three-phase elements are memory polarized from a four-cycle memory filter.

Distance Element Timers

Zone 2 short timer (Z2SP) range: (0 - 60 cycles in quarter-cycle steps)
Zone 2 long timer (Z2DP) range: (0 - 2000 cycles in quarter-cycle steps)
Zone 3 long timer (Z3DP) range: (0 - 2000 cycles in quarter-cycle steps)

Note: The instantaneous and time delayed outputs of the distance elements are separate in the Relay Word, permitting access to both. This allows use of a time delay for time-stepped backup functions while maintaining the required instantaneous outputs for communication-based schemes. The short timer provides the necessary coordination time for Directional Comparison Blocking (DCB) schemes.

Overcurrent Elements

Nondirectional Phase Overcurrent Elements (secondary quantities)

- 50AL, 50BL, 50CL (Zone 1 and Zone 2 low-set phase fault detectors)
- 50AL3, 50BL3, 50CL3 (Zone 3 and Zone 4 low-set phase fault detectors)
- 50AM, 50BM, 50CM (medium-set phase fault detectors, used in LOP logic)
  Pickup: 0.5 to 40 A, ± 0.1 A $\pm 2\%$ of setting
  Transient overreach: 5% of set pickup
- 50AH, 50BH, 50CH (high-set phase overcurrent elements)
  Pickup: 0.5 to 80 A, ± 0.1 A $\pm 2\%$ of setting
  Transient overreach: 5% of set pickup

Ground Overcurrent Elements (secondary quantities)

51N residual time-overcurrent element

- Selectable curve shape (four curve families)
  - Moderately Inverse (curve family 1)
  - Inverse (curve family 2)
  - Very Inverse (curve family 3)
  - Extremely Inverse (curve family 4)
- Time dial: 0.50 to 15.00 in 0.01 steps
- Pickup: 0.25 to 6.3 A, ±0.05 A ±2% of setting
- Timing: ±4% and ±1 cycle for residual current magnitude between 2 and 20 multiples of pickup
- May be directionally controlled (51NTC setting)

50N1, 50N2, 50N3 residual overcurrent elements

- Pickup: 0.25 A to 48 times 51N pickup for 51N pickup < 3.15 A
  0.5 A to 48 times 51N pickup for 51N pickup ≥ 3.15 A
- Transient overreach: 5% of set pickup
- May be directionally controlled (32Q, 32V, and 32I enables)

Note: The Zone 3 residual instantaneous overcurrent element has both the directional (67N3) and nondirectional (50N3) elements available in the Relay Word. The 50N3 can be used as a high-speed nondirectional carrier start in directional comparison blocking schemes.

Ground Overcurrent Element Timers

Zone 2 short timer (Z2SG) range: (0 - 60 cycles in quarter-cycle steps)
Zone 2 long timer (Z2DG) range: (0 - 2000 cycles in quarter-cycle steps)
Zone 3 long timer (Z3DG) range: (0 - 2000 cycles in quarter-cycle steps)

Note: The instantaneous and time delayed outputs of the ground overcurrent elements are separate in the Relay Word, permitting access to both. This allows use of a time delay for time-stepped backup functions while maintaining the required instantaneous outputs for communication-based schemes. The short timer provides the necessary coordination time for directional comparison blocking schemes.

Ground Directional Elements

The relay provides four methods of polarizing the directional ground overcurrent elements:

1. negative-sequence voltage and current
2. zero-sequence voltage and measured residual current
3. external zero-sequence current and measured residual current
4. methods 2 and 3 combined

With negative-sequence polarization selected, you may not select zero-sequence polarization. The primary setting procedure of the relay performs this check.

Negative-Sequence Directional Element

- The angle between the measured negative-sequence voltage and current adjusted by the MTA setting determines fault direction (see Figure 2.3)
- Angle: MTA setting
- Sensitivity: see Table 2.2

Zero-Sequence Directional Element

Voltage Polarization

- The angle between the measured zero-sequence voltage and residual current adjusted by the MTA setting determines fault direction (see Figure 2.3)
- Angle: MTA setting
- Enabled with 32VE setting in the relay setting procedure
- Does not require an external voltage polarizing source
- Sensitivity: see Table 2.2

Current Polarization

- The relay measures the angle between measured residual current and zero-sequence current from an external source to determine fault direction (see Figure 2.4)
- Angle: 0°
- Enabled with the 32IE setting in the relay setting procedure
- Sensitivity: see Table 2.2

Note: If you want current polarization of the ground directional elements, wire an external zero-sequence current source to the Ipol inputs on the rear panel.

Table 2.2: Directional Element Sensitivities at Maximum Torque Angle (MTA)

Element	Negative-Sequence 32Q	Zero-Sequence 32D	
Sensitivity	0.10	(0.29)(51NP)	(0.44)(51NP)
Units	(V2)(I2)	(V0)(IR)	(IR)(IP)

Note: 32V and 32I sensitivities depend on the pickup setting of the residual time-overcurrent element 51NP.

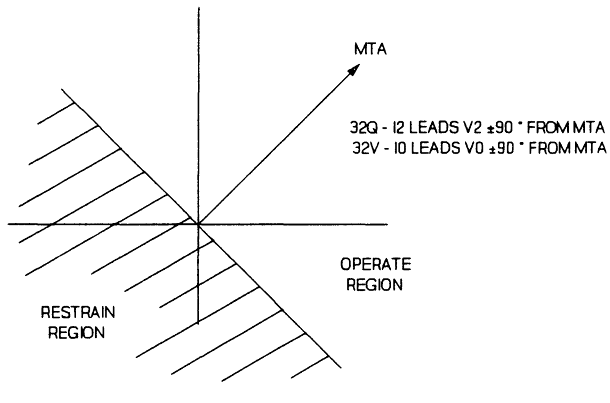


Figure 2.3: 32Q and 32V Polarization Criteria

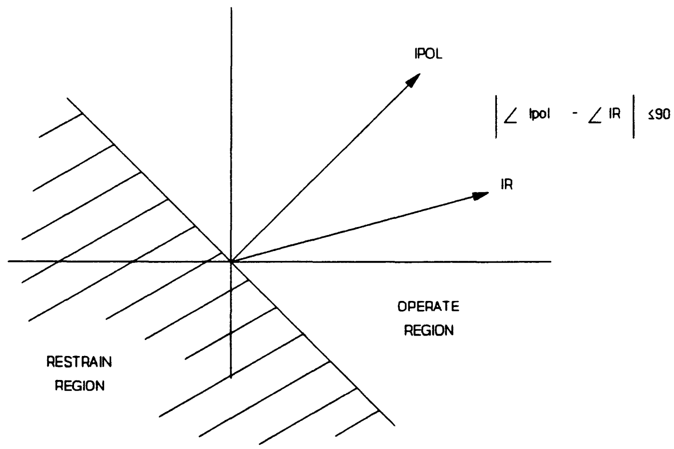


Figure 2.4: 32I Polarization Criteria

Please refer to the Functional Description portion of this section for equations to determine directional element sensitivities at fault angles other than maximum torque angle.

LOP Sequence-Component Elements

The following elements have fixed settings and are used in the loss-of-potential detection logic. All thresholds are in secondary quantities.

- Zero-sequence overvoltage element (47NL)
  Pickup: 14 volts of V0
- Zero-sequence overcurrent element (50NL)
  Pickup: I0 = 0.083 amps for 51N pickup < 3.15 amps
  I0 = (0.083 amps)(51N pickup/3.15 amps) for 51N pickup ≥ 3.15 amps
- Positive-sequence overvoltage element (47P)
  Pickup: 14 volts of V1

Miscellaneous Timers

All timers are set in cycles with quarter-cycle resolution.

• 790I1	- Reclose relay open interval 1	:	0.0 - 10,000
• 790I2	- Reclose relay open interval 2	:	0.0 - 10,000
• 790I3	- Reclose relay open interval 3	:	0.0 - 10,000
• 79RS	- Reclose relay reset time	:	60.0 - 8,000
• 50MFD	- Loss-of-potential enabled O/C, TDPU	:	0.0 - 60
• 52BT	- Switch-Onto-Fault timer, TDPU/TDDO	:	0.5 - 10,000
• TDUR	- Minimum trip duration timer	:	0.0 - 2,000 (0.0 Disables the OPEN Command)

TDPU ≡ Time delayed Pickup
TDDO ≡ Time delayed Dropout

Logic Inputs

Six logic inputs control relay functions. Assert a logic input by applying control voltage to the corresponding rear panel contact input terminals. Control voltage polarity is not important.

Direct Trip (DT)

Asserting the DT input immediately and unconditionally sets the DT bit in the Relay Word. The DT bit remains set until the DT input deasserts, dropping out about one-half cycle after DT deasserts. Applications include test trip and Direct Underreaching Transfer Trip (DUTT) schemes. Asserting this input generates an event report.

You can also use the DT input to enable the relay reclosing functions for line breaker trips by backup protection. For instance, if you desire to reclose when the backup protection trips the line breaker, the DT input should monitor the trip output from the backup protection. Mask the DT bit in the MTU logic mask to satisfy the condition that the relay must trip before the reclosing functions are enabled. To make this tripping condition a reclose initiate condition, mask the DT bit in the MRI logic mask as well.

The OPEN command has the same effect as the DT input but instead asserts the TC bit in the Relay Word.

Direct Close (DC)

The DC input shuts the CLOSE output if no fault is detected, a trip condition is not present, and the 52A input is not asserted. The CLOSE command has the same effect as the DC input. Asserting this input does not trigger an event report.

Permissive Trip (PT)

The PT input is normally used in Permissive Overreaching Transfer Tripping (POTT) schemes. When asserted, additional tripping conditions are allowed, as selected in the logic setting procedure (see the LOGIC MPT command). Asserting this input generates an event report.

Block Trip (BT)

The BT input is normally used in Directional Comparison Blocking (DCB) schemes. When not asserted, selected tripping conditions are allowed (see the LOGIC MTB command). This input does not trigger an event report. The BT input has a quarter-cycle dropout extension to assist scheme coordination.

Circuit Breaker Monitor (52A)

The 52A input indicates the state of the breaker. The 52A input is asserted when the breaker is closed and deasserted when the line breaker is open. The recloser CLOSE command and Switch-Onto-Fault logic use the status of this input. Asserting this input does not trigger an event report.

External Trigger for Event Report (ET)

Assertion of the external trigger input triggers an event report. Assertion does not influence the protective functions in any way. Applications include monitoring trips initiated by backup protection, breaker failure relaying, bus differential relaying, etc.

Relay Outputs

The relay has seven output relays. All outputs except the CLOSE and ALARM outputs can be programmed with the LOGIC command.

With the exception of the TRIP output relay, all outputs may be configured as either "a" or "b" contacts.

All relay contacts are rated for circuit breaker tripping duty.

TRIP Output (SEL-221G-6/121G-6 only)

This output closes for any number of conditions you select. Conditions are grouped as follows: unconditional (MTU logic mask), subject to PT input assertion (MPT logic mask), subject to the absence of BT input assertion (MTB logic mask), or subject to the breaker being just opened or closed (MTO logic mask). The TRIP output never closes for less than the fault condition duration or the TRIP Duration Timer interval (TDUR). After this, it opens when the fault condition is gone, as judged by the dropout of both the low-set phase (50L) and low-set residual overcurrent (50NL) elements.

TRIP Output (SEL-221G-7/121G-7 only)

This output closes for any number of conditions you select. Conditions are grouped as follows: unconditional (MTU logic mask), subject to PT input assertion (MPT logic mask), subject to the absence of BT input assertion (MTB logic mask), or subject to the breaker being just opened or closed (MTO logic mask). The TRIP output never closes for less than the fault condition duration plus the TRIP Duration Timer interval (TDUR). TDUR operates as a simple dropout timer.

CLOSE Output

This output closes for reclose operations, DC input assertion, and CLOSE command execution. The CLOSE output remains closed until the 52A input asserts or the 79RS timer expires, whichever occurs first. The 79RS timer is decremented when the CLOSE output relay asserts. No event report is triggered.

ALARM Output

The ALARM output closes for the following conditions:

- Three unsuccessful Level 1 access attempts: 1 second pulse
- Any Level 2 access attempt: 1 second pulse
- Self-test failure: permanent contact closure or 1 second pulse depending on which test fails (see Table 2.6)
- The ALARM output closes momentarily when relay settings, logic settings, or passwords are changed. It also closes when a date is entered, if the year stored in EEPROM differs from the year entered (see DATE command).

Programmable Outputs (A1, A2, A3, A4)

These four outputs may be assigned to any combination of bits in the Relay Word.

Logic Description

Relay logic includes relay elements, timers, and combinations of conditions. Many of these are recorded in the Relay Word (R), which forms the heart of the programmable mask logic. Elements and other quantities available in the Relay Word appear in boldface type.

Relay Elements

Single-phase O/C relays (Zones 1 and 2)	50AL 50BL 50CL	(fault detectors and TRIP unlatch)
Single-phase O/C relays (Zones 3 and 4)	50AL3 50BL3 50CL3	(fault detectors)
Medium-set single-phase O/C relays	50AM 50BM 50CM	(selectable for loss-of-potential)
High-set single-phase O/C relays	50AH 50BH 50CH	(always available)
Zone 4 three-phase mho distance	21ABC4	(reversed from Zone 1 direction)
Zone 3 three-phase mho distance	21ABC3	(reversible)
Zone 3 phase-phase mho distance	21P3	(reversible)
Zone 2 three-phase mho distance	21ABC2	
Zone 2 phase-phase mho distance	21P2	
Zone 1 three-phase mho distance	21ABC1	
Zone 1 phase-phase mho distance	21P1	
Residual time-overcurrent pickup	**51NP**	directional as enabled
Residual time-overcurrent trip	**51NT**	directional as enabled
Residual overcurrent	50N1	nondirectional
Residual instantaneous overcurrent	50N2	nondirectional
Residual instantaneous overcurrent	**50N3**	nondirectional
Negative-sequence directional	32Q	32QF=forward; 32QR=reverse
Zero-sequence dual pol. directional	32D	32DF=forward; 32DR=reverse
Zero-sequence overvoltage	47NL	LOP detection
Zero-sequence overcurrent	50NL	LOP detection and TRIP unlatch
Positive-sequence overvoltage	47P	LOP detection

Optically Coupled Contact Inputs

Direct trip	**DT**
Permissive trip	PT
Block trip	BT
Direct close	DC
Circuit breaker monitor	52A
External trigger for event report	EXT

Contact Outputs

Circuit breaker trip (two contacts)	**TRIP**
Circuit breaker close	CLOSE
Programmable output 1	A1
Programmable output 2	A2
Programmable output 3	A3
Programmable output 4	A4
System alarm	ALARM

Intermediate Logic

The logic equations below represent combinations of the relay elements and other conditions. In the following equations, "*" indicates a logical "and," while "+" indicates a logical "or."

Since so many binary variables are involved, we define the functioning with Boolean logic equations.

Loss-of-Potential (LOP) Logic

Set **LOP** = [47NL * NOT (50NL)] + NOT (47P) * NOT (50M)	Zero-sequence set condition includes a three-cycle pickup delay.
Clear **LOP** = NOT (47NL) * 47P	

Different set and clear conditions ensure that **LOP** stays latched during subsequent faults and clears when balanced voltages and currents return.

Phase Overcurrent Conditions

50L	= 50AL + 50BL + 50CL	Zones 1 and 2 phase fault current supervision
50L3	= 50AL3 + 50BL3 + 50CL3	Zones 3 and 4 phase fault current supervision
3P50	= 50AL * 50BL * 50CL	Zones 1 and 2 three-phase fault current supervision
3P503	= 50AL3 * 50BL3 * 50CL3	Zones 3 and 4 three-phase fault current supervision
50M	= 50AM + 50BM + 50CM	Medium-level overcurrent condition
50MF	= **50M** * [**LOP** + NOT(LOPE)] * 50MFD	Asserts a settable delay after **LOP** and **50M** overcurrent, or **50M** overcurrent only if **LOP** is disabled
50H	= 50AH + 50BH + 50CH	High-level overcurrent condition

Distance Relay Logic

Z4ABC	= 21ABC4 * 3P503 * NOT (LOP * LOPE)	4ABC in Relay Word
Z3ABC	= 21ABC3 * 3P503 * NOT (LOP * LOPE)	3ABC in Relay Word
Z2ABC	= 21ABC2 * 3P50 * NOT (LOP * LOPE) * Z2SP	2ABC in Relay Word
Z1ABC	= 21ABC1 * 3P50 * NOT (LOP * LOPE)	1ABC in Relay Word
Z3P	= 21P3 * 50L3 * NOT (LOP * LOPE)	
Z2P	= 21P2 * 50L * NOT (LOP * LOPE) * Z2SP	
Z1P	= 21P1 * 50L * NOT (LOP * LOPE)	
Z3PT	= (Z3P + Z3ABC) * Z3PTMR	Zone 3 timeout-phase
Z2PT	= (Z2P + Z2ABC) * Z2PTMR	Zone 2 timeout-phase

Residual Overcurrent Conditions

DF	= [(32QF + LOP * LOPE) * 32QE] + [32DF * 32IE] + [(32DF + LOP * LOPE) * 32VE] + NOT(32QE + 32VE + 32IE)	Direction Forward
DR	= 32QR * 32QE + 32DR * (32IE + 32VE)	Direction Reverse
D3	= DF	If Zone 3 is forward
D3	= DR	If Zone 3 is reverse
67N1	= 50N1 * DF	
67N2	= 50N2 * DF * Z2SG	
67N3	= 50N3 * D3	

Note: When all directional elements are disabled (32QE = 32VE = 32IE = N), the DF (Directional Forward) bit defaults forward. Under these conditions, the Zone 3 ground element does not operate if Zone 3 is reversed.

Z3GT	= 67N3 * Z3GTMR	Zone 3 timeout-ground
Z2GT	= 67N2 * Z2GTMR	Zone 2 timeout-ground
Z3X	= (67N3 + Z3P + 3ABC + 4ABC) * NOT(TRIP) (2-cycle TDPU, 5-cycle TDDO) (assertion of TRIP unconditionally resets the Z3X timer)	Zone 3 Extension
STOP	= (R * MTB) * NOT(Z3X)	STOP Carrier

Note: R is the 32-bit Relay Word and MTB is the mask for tripping with the Block Trip input deasserted

Output Equations and Logic

The relay has programmable logic for controlling the TRIP, A1, A2, A3 and A4 output relays for flexibility and testing. Two separate masks are provided for reclose initiation and cancellation. The logic is programmed by setting masks for various conditions. These masks are applied to the general Relay Word. The form for each output equation follows:

Let R= Relay Word

MTU = mask for trip		(unconditional)
MPT = mask for trip		(permissive trip)
MTB = mask for trip		(with no blocking)
MTO = mask for trip		(with breaker just opened or closed)

Then:

TRIP = [R * MTU	(unconditional tripping)
+ R * MPT * PT	(permissive tripping)
+ R * MTB * NOT (BT)	(tripping with BT input deasserted)
+ R * MTO * 52BT]	(breaker open/just closed tripping)
* NOT (TS)	(trip suspicion not detected)

Close TRIP contact = **TRIP**

(SEL-221G-6/121G-6 only):

Open TRIP contact = NOT (**TRIP**) * [NOT(50NL + 50L) +TARGET RESET button pushed] * (Minimum Trip Duration timer (TDUR) expired)

(SEL-221G-7/121G-7 only):

Open TRIP contact = NOT (**TRIP**) * (Minimum Trip DurationTimer (TDUR) expired)

Note: Minimum Trip Duration Timer (TDUR) operates as a Trip Dropout Timer in -7 relays.

Trip Suspicion Logic

Potential transfer switches temporarily remove the polarizing potentials from the relay when a substation operator transfers the potential source from one bus to another. Since it is undesirable to parallel secondary windings of potential transformers from separate sources, this occurrence is inherent to potential transfer switch installations. This temporary removal of polarizing voltages coupled with load currents above the 50L fault detector threshold may result in a race between the three-phase loss-of-potential pickup logic and the three-phase distance element pickup. Three-phase LOP logic is included to address the loss of three secondary potential fuses, not potential transfer switch applications.

The logic developed to address potential transfer switch applications is shown in Figure 2.5.

Note: The 52A input contact on the rear panel of the relay must be deasserted when the operator depresses the potential transfer switch.

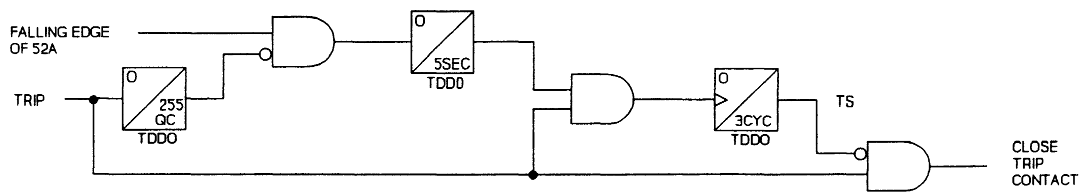


Figure 2.5: Trip Suspicion (TS) Logic

Please consult Section 5: APPLICATIONS for a description of the Trip Suspicion (TS) logic.

Close contact = (DC + 790I1 + 790I2 + 790I3 + CLOSE COMMAND) * NOT (52A) * NOT (TRIP)
Open CLOSE contact = NOT (CLOSE) + 79RS

A1 = R * MA1
A2 = R * MA2
A3 = R * MA3
A4 = R * MA4

The "*" indicates a logical "and," while the "+" indicates a logical "or."

Relay Word

The Relay Word consists of four eight-bit rows containing relay elements, intermediate logic results, logic inputs, and relay outputs. Each bit in the Relay Word is either a logical 1 or logical 0.

- 1 indicates a picked up element or true logic condition
- 0 indicates a dropped out element or false logic condition

The Logic Description defines logic conditions in the Relay Word.

Table 2.3: Relay Word

1ABC	2ABC	3ABC	4ABC	LOP	50H	50M	50L
51NT	67N1	67N2	67N3	51NP	Z1P	Z2P	Z3P
Z2PT	Z3PT	50L3	3P50	50MF	RC	RI	STOP
50N3	TRIP	TC	DT	52BT	Z3X	Z2GT	Z3GT

The Relay Word Bit Summary Table explains each bit in the Relay Word.

Table 2.4: Relay Word Bit Summary

1ABC - Zone 1 three-phase instantaneous element (set by Z1%)
2ABC - Zone 2 three-phase instantaneous element (set by Z2%)(delayed by Z2SP)
3ABC - Zone 3 three-phase instantaneous element (set by Z3%)
4ABC - Zone 4 three-phase instantaneous element (diameter equal to 1.5 x Z3%)
LOP - Loss-of-potential condition
50H - High-level overcurrent element (set by 50H)
50M - Medium-level overcurrent element (set by 50M)
50L - Zones 1 and 2 phase fault current supervision (set by 50L)

51NT - Residual time-overcurrent trip (set by 51NP, 51NTD, and 51NC)
67N1 - Residual instantaneous-overcurrent (pickup set by 50N1P)[1]
67N2 - Residual instantaneous-overcurrent (pickup set by 50N2P)[1] (delayed by Z2SG)
67N3 - Residual instantaneous-overcurrent (pickup set by 50N3P)[1]
51NP - Residual time-overcurrent pickup
Z1P - Zone 1 phase-phase element (set by Z1%)
Z2P - Zone 2 phase-phase element (set by Z2%) (delayed by Z2SP)
Z3P - Zone 3 phase-phase element (set by Z3%)

Z2PT - Zone 2 timeout phase (set by Z2DP)
Z3PT - Zone 3 timeout phase (set by Z3DP)
50L3 - Zones 3 and 4 phase fault current supervision (set by 50L3)
3P50 - Zones 1 and 2 three-phase fault current supervision
50MF - Asserts a settable delay after LOP and 50M pickup (delay set by 50MFD)
RC - Reclose cancel condition
RI - Reclose initiate condition
STOP - Carrier Stop Condition

50N3 - Nondirectional residual instantaneous-overcurrent (pickup set by 50N3P)
TRIP - Follows trip condition
TC - Trip (OPEN) Command
DT - Follows DT input
52BT - Time delayed inverse of 52A input (delay set by 52BT setting)
Z3X - Zone 3 and Zone 4 pickup extension
Z2GT - Zone 2 timeout-ground (set by Z2DG)
Z3GT - Zone 3 timeout-ground (set by Z3DG)

[1] The 50N elements are made directional by enabling any of the directional control methods, i.e. 32QE = Y, or either 32VE = Y or 32IE = Y.

Programmable Logic Masks

The relay uses programmable logic masks to control the TRIP and programmable output relays and reclosing initiation and cancellation. The following four masks control the TRIP output relay:

- Mask for Trip Unconditional (MTU)
- Mask for Permissive Trip (MPT)
- Mask for Trip Blocking (MTB)
- Mask for Trip while breaker Open (MTO)

Each of the four programmable output relays have separate logic masks: MA1, MA2, MA3, and MA4. To program each logic mask, select elements of the Relay Word which, when asserted, can close the associated output relay, cancel or initiate a reclosing sequence (see LOGIC command). For example, if an element in the Relay Word asserts and the same element is selected in a logic mask, the output contact associated with the logic mask closes.

Serial Interfaces

The SEL-221G Relay is equipped with two EIA-232 serial communication ports. PORT 2 has 9-pin connectors on both the front and rear panels, designated PORT 2F and PORT 2R, respectively.

PORT 2R, located on the relay rear panel, is typically used with an SEL-DTA Display/-Transducer Adapter, SEL-RD Relay Display, or local printer. PORT 2F is always available for short term local communications with a portable computer or printing terminal. Simply plug the device into the front panel port. The relay automatically discontinues communications with PORT 2R and addresses PORT 2F. When testing or data retrieval is complete, unplug the temporary device from PORT 2F. The relay automatically resumes communication with the device connected to PORT 2R.

Serial communications PORT 1 and the Auxiliary Input for demodulated IRIG-B time code input remain on the relay rear panel.

The baud rate for each port is set by jumpers near the front of the main board. You can access these jumpers by removing either the top cover or front panel. Available baud rates are 300, 600, 1200, 2400, 4800, or 9600.

Caution: Do not select two baud rates for the same port as this can damage the relay baud rate generator. The relay is shipped with PORT 1 set to 300 baud and PORT 2F/2R set to 2400 baud.

The serial data format is:

Eight data bits
Two stop bits (-E2 model) or One stop bit (-E1 model)
No parity

This format may not be changed. The serial communications protocol appears in Section 3: COMMUNICATIONS.

The SEL-121G-6 Relay does not include a front panel serial data interface.

Self-Tests

The relay runs a variety of self-tests. Some tests have warning and failure states; others only have failure states. The relay generates a report after any change in self-test status.

The relay closes the ALARM contacts after any self-test fails. When it detects certain failures, the relay disables the breaker control functions and places the relay output driver port in an input mode. No outputs may be asserted when the instrument is in this configuration. The relay runs all self-tests on power up and before enabling new settings. During normal operation, it performs self-tests at least every few minutes.

Offset

The relay measures the offset voltage of each analog input channel and compares the value against fixed limits. It issues a warning when offset is greater than 50 millivolts in any channel and declares a failure when offset exceeds 75 millivolts. Offset levels for all channels appear in the STATUS command format.

Power Supply

Power supply voltages are limit-checked. The table below summarizes voltage limits.

Table 2.5: Power Supply Self-Test Limits

Supply	Warning Thresholds		Failure Thresholds	
+5 V	+5.3 V	+4.7 V	+5.4 V	+4.6 V
+15 V	+15.8 V	+14.2 V	+16.2 V	+13.8 V
-15 V	-15.8 V	-14.2 V	-16.2 V	-13.8 V

The relay transmits a STATUS command response for any self-test failure or warning. A +5 volt supply failure de-energizes all output relays and blocks their operation. A ± 15 volt supply failure disables protective relay functions while control functions remain intact. The ALARM relay remains closed after a power supply failure.

Random-Access Memory

The relay checks random-access memory (RAM) to ensure that each byte can be written to and read from. There is no warning state for this test. If the relay detects a problem, it transmits a STATUS command message with the socket designation of the affected RAM IC. A RAM failure disables protective and control functions and closes the ALARM output relay contacts.

Read-Only Memory

The relay checks read-only memory (ROM) by computing a checksum. If the computed value does not agree with the stored value, the relay declares a ROM failure. It transmits a STATUS command response with the socket designation of the affected ROM IC. A ROM failure disables protective and control functions and closes the ALARM output relay contacts.

Analog-to-Digital Converter

The analog-to-digital converter (ADC) changes voltage signals derived from power system voltages and currents into numbers for processing by the microcomputer. The ADC test verifies converter function by checking conversion time. The test fails if conversion time is excessive or a conversion starts and never finishes. There is no warning state for this test. Though an ADC failure disables protective functions, control functions remain intact. The relay transmits a STATUS command response and closes the ALARM relay contacts.

Master Offset

The master offset (MOF) test checks offset in the multiplexer/analog to digital converter circuit. A grounded input is selected and sampled for dc offset. The warning threshold is 50 mV; failure threshold is 75 mV. A failure pulses the ALARM contact closed for one second.

Settings

The relay stores two images of the system settings in nonvolatile memory. These are compared when the relay is initially set and periodically thereafter. If the images disagree, the setting test fails and the relay disables all protective and control functions. It transmits the STATUS message to indicate a failed test. The ALARM relay remains closed after a setting failure.

Table 2.6 shows relay actions for any self-test condition: warning (W) or failure (F).

Table 2.6: Self-Test Summary

Self-Test	Limits	Status Message	Protection Disabled	Control Disabled	Alarm Output
RAM	—	F	YES	YES	permanent contact assertion
ROM	—	F	YES	YES	permanent contact assertion
SETTINGS	—	F	YES	YES	permanent contact assertion
A/D	—	F	YES	NO	permanent contact assertion
+5 V	±0.3 V	W	NO	NO	no ALARM contact assertion
	±0.4 V	F	YES	YES	permanent contact assertion
±15 V	±0.8 V	W	NO	NO	no ALARM contact assertion
	±1.2 V	F	YES	NO	permanent contact assertion
CHANNEL OFFSETS	50 mV	W	NO	NO	no ALARM contact assertion
	75 mV	F	NO	NO	one second contact pulse
MASTER OFFSET	50 mV	W	NO	NO	no ALARM contact assertion
	75 mV	F	NO	NO	one second contact pulse

Targets

The front panel targets illuminate for the following conditions:

Target LED	Conditions for Illumination
EN	Normal Operation
Ø1	Z1P + Z1ABC + 50H + 50MF
G1	67N1
Ø2	Z2P + Z2ABC
G2	67N2
Ø3	Z3P + Z3ABC
G3	67N3
51N	51NT

The LEDs for the relay elements illuminate on the rising edge of the TRIP output with the following priority:

51N : For 51N timeout (51NT)
G1, Ø1 : For 67N1 + Z1P + Z1ABC + 50H + 50MF, but no 51NT
G2, Ø2 : For 67N2 + Z2P + Z2ABC, but no Zone 1 or 51NT
G3, Ø3 : For 67N3 + Z3P + Z3ABC, but no Zone 2, Zone 1, or 51NT

If a new fault occurs, the target 0 LEDs clear and display the new fault targets.

Press the TARGET RESET button to clear the targets if a trip condition is not present. All eight indicators illuminate for a one second lamp test. Afterward, the fault targets clear and the enable light indicates that the relay is operational again. If a trip condition is present, the target LEDs do not clear. Pressing TARGET RESET also unlatches the TRIP output. This feature is useful during testing and reduces the possibility of relay installation with the TRIP output asserted.

IRIG-B Input Description

The port labeled J201 / AUX INPUT receives demodulated IRIG-B time code input. The IRIG-B input circuit is a 56 ohm resistor in series with an optocoupler input diode. The input diode has a forward drop of about 1.5 volts. Driver circuits should put approximately 10 mA through the diode when "on."

The IRIG-B serial data format consists of a one second frame containing 100 pulses and divided into fields. The relay decodes second, minute, hour, month, and day fields and sets the relay clock accordingly.

When IRIG-B data acquisition is activated either manually (with the IRIG command) or automatically, the relay reads two consecutive frames. It updates the older frame by one second and compares the frames. If they do not agree, the relay considers the data erroneous and discards it.

The relay reads the time code automatically about once every five minutes. It stops IRIG-B data acquisition ten minutes before midnight on New Year's Eve so the relay clock can implement the year change without interference from the IRIG-B clock.

Signal Processing

The filtering process passes frequency information from the power system, eliminates any dc offset introduced by the analog electronics, and reduces the decaying exponential offset present following a fault. This permits the relay to operate using only analog input signals at or near the power system frequency.

The relay low-pass filters all analog input channels to remove high frequency components. Next it samples each channel four times per power system cycle. After low-pass filtering, the relay digitally filters each sample with the CAL digital filter method.

Digital Filters

The digital filter has the properties of a double differentiator smoother and requires only addition and subtraction of data samples. Let the latest four samples of one channel be X1, X2, X3, and X4. Then the digital filter is defined:

$$P = X1 - X2 - X3 + X4.$$

This filter eliminates dc offsets. When all samples are set to the same value, the filter output is zero. It also eliminates ramps, which you may verify by setting the samples equal to 1, 2, 3, and 4. Again, the output is zero.

Every quarter-cycle, the relay computes a new value of P for each input. The current value of P combines with the previous value (renamed Q) to form a Cartesian coordinate pair. This pair represents the input signal as a phasor (P, Q). The relay processes these phasor representations of the input signals.

FUNCTIONAL DESCRIPTION

Mho Elements

The following settings affect mho circles: positive-sequence line impedances (R1, X1), maximum torque angle (MTA), set reach (Z1%, Z2%, and Z3%), and positive-sequence transmission line angle (arctan (X1/R1)). The non-expanded circles pass through the impedance-plane origin (except for the Zone 4 offset mho characteristic for three-phase faults). The diameter passing through the origin is at an angle of MTA (maximum torque angle) with respect to the resistance axis. The chord passing through the origin at the positive-sequence impedance (Z1) angle of the transmission line has a length equal to the set reach. Therefore, the mho circle diameter is calculated:

$$\text{DIAMETER} = \frac{\text{SET REACH}}{\cos(\text{T. L. ANGLE} - \text{MTA})}$$

where T. L. is defined as the positive-sequence transmission line angle. See Figure 2.6.

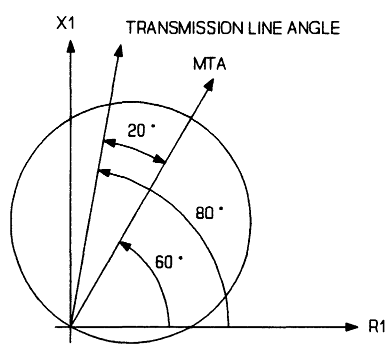


Figure 2.6: Mho Element Reach at Maximum Torque Angle

Mho elements are based on the general principles of operation presented in "Compensator Distance Relaying" by W. K. Sonnemann and H. W. Lensner (AIEE Transactions, Part III, vol. 77, pp. 372-382, June 1958). These principles have been applied successfully in the electromechanical and solid-state designs of several manufacturers. Electromechanical versions use induction cylinders for a product-type phase comparison between the measurands. Solid-state analog designs use coincident-timing phase comparators. In the relay, the microprocessor uses phasor multiplication to perform phase comparison.

Phase comparator inputs for the various distance functions are:

Function	Input A	Input B
phase-phase	Vab - Z1 x Iab	Vbc - Z1 x Ibc
three-phase	Vab - Z1 x Iab	-jVab - k x Vc(memory)
offset three-phase	Vab - (1 + k) x Z1 x Iab	-jVab - jk x Z1 x Iab

The constant Z1 is the reach of the relay element in positive-sequence ohms. The constant k is fixed at ¼ to give a diameter of the offset circle equal to 1.5 times the diameter of the Zone 3 three-phase mho circle.

Mho Element Expansion

Self-polarized mho elements (mho elements with no expansion capabilities) provide limited coverage for faults including resistance. The relay overcomes this problem with a compensator distance principle which expands the mho distance characteristics. The phase-phase elements do not require memory polarization due to strong polarization from the non-involved phase. The three-phase elements require memory polarization to achieve expanded characteristics. Figure 2.7 illustrates the expanded mho characteristics for phase-phase faults in front of the relay. Figure 2.8 illustrates the expanded mho characteristics for three-phase faults in front of the relay. In both figures, the amount of mho expansion depends on the relative strength of the source behind the relay. To determine the amount of expansion mho characteristics experience, relay reach and positive-sequence source impedance must be known. With these quantities known, the following equations for the circle center and radius may be used to plot the mho characteristics:

Phase-Phase Elements:

$$\text{CENTER} \equiv \tfrac{1}{2}(-ZS + ZR) \qquad \text{RADIUS} \equiv \tfrac{1}{2}(ZS + ZR)$$

Where:

ZS ≡ Positive-sequence source impedance behind the relay location
ZR ≡ Relay reach in positive-sequence ohms

For example, consider an application where the source impedance behind the relay is twice as great as the relay set reach. Plot the characteristics. Figures 2.8 and 2.9 illustrate this example and compare the expanded mho characteristic with the self-polarized mho characteristics.

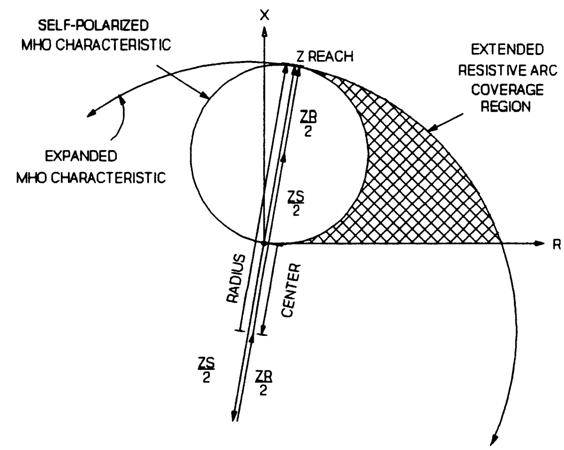


Figure 2.7: Expanded Two-Phase Mho Characteristics

Three-Phase Elements:

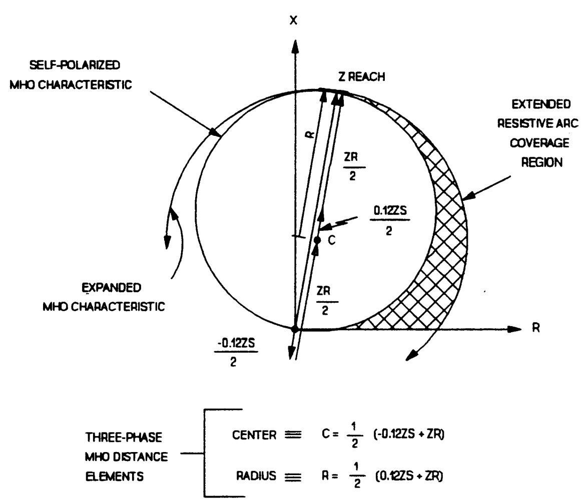


Figure 2.8: Expanded Three-Phase Mho Characteristics

Time-Overcurrent Element and Curves

The 51N time-overcurrent element provides directional forward or nondirectional protection as enabled. You can program its pickup (51NP) and trip (51NT) states into any mask. The 51NP bit appears in the Relay Word to provide a means of determining residual overcurrent element pickup.

The setting procedure includes time dial and curve shape selections. Four curve shapes are available: moderately inverse, inverse, very inverse, and extremely inverse. The curves and their equations appear in this section.

The 51N characteristic is formed by a recursive sum of the magnitude or magnitude-squared of the residual current adjusted by the pickup setting.

The time dial setting determines the limit the recursive sum must reach for a trip.

Directional Elements

You can enable either the negative-sequence or zero-sequence directional element to provide directional supervision of the residual overcurrent elements. The Zone 3 direction setting determines if 67N3 is enabled for forward or reverse faults.

When no directional elements are enabled, the direction forward (DF) bit is always set and the residual overcurrent elements are nondirectional.

Directional elements are phasor-product derived. For the negative-sequence element (32Q), the product is negative-sequence voltage times negative-sequence current adjusted by the maximum torque angle setting. The relay declares a fault forward when I2 leads V2 ±90° from the maximum torque angle.

For the zero-sequence directional element (32D), the product is the residual current adjusted by the MTA setting times the sum of the residual voltage, plus the polarizing current shifted in phase by the MTA setting. The result is a dual polarized zero-sequence directional element.

If you enable the zero-sequence voltage polarizing method (32VE = Y), the relay declares a fault forward when I0 leads V0 ±90° from the maximum torque angle.

If you enable the zero-sequence current polarizing method (32IE = Y), the relay declares a fault forward when the residual current from the faulted line is ±90° from the current measured in the Ipol input. The current in the Ipol input is typically derived from grounded-wye transformer neutrals or a transformer bank tertiary.

Table 2.7 shows the equations the relay uses to express the sensitivity of the directional elements in units of torque. These equations are useful in determining directional element sensitivities for fault angles which may differ from the MTA.

Table 2.7: Directional Element Torque Equations

$$32Q:\ T \equiv |V2| \times |I2| \times [\cos(\angle -V2 - (\angle I2 + MTA))]$$
$$32V:\ T \equiv |V0| \times |IR| \times [\cos(\angle -V0 - (\angle IR + MTA))]$$
$$32I:\ T \equiv |Ipol| \times |IR| \times [\cos(\angle Ipol - \angle IR)]$$

Where:

T ≡ Torque, positive for a forward fault
V2 ≡ Negative-sequence secondary voltage
I2 ≡ Negative-sequence secondary current
V0 ≡ Zero-sequence secondary voltage
IR ≡ Residual secondary current
Ipol ≡ Secondary current at Ipol input

Positive values of torque (T) indicate a forward fault declaration. Please consult your fault study to determine the polarizing method best suited for each application.

Fault Locator

Several events automatically trigger the fault locator. These include: pickup of certain relay elements, assertion of certain contact inputs or outputs, and execution of certain commands. The fault locator can be either enabled or disabled with LOCAT during the setting procedure.

Triggering events are:

(1) Relay Elements (high level trigger)
- Three-phase distance Zones 1, 2, or 3
- Phase-phase distance Zones 1, 2, or 3
- Ground overcurrent Zones 1, 2, or 3, and 51N pickup
- Phase overcurrent element 50H

(2) Contact Inputs (rising-edge trigger)
- External Trigger (ET)
- Direct Trip (DT)
- Permissive Trip (PT)

(3) Contact Outputs (rising-edge trigger)
- TRIP

(4) User Entered Commands (rising-edge trigger)
- TRIGGER
- OPEN

Relay elements trigger the fault locator in a level sensitive manner. The relay does not generate new event reports when additional relay elements pick up. Only the first relay element of any contiguous sequence triggers an event report.

All triggering relay elements must drop out for at least four cycles before they may initiate another event report. This helps eliminate triggering multiple records for boundary faults.

All other triggering events are rising-edge sensitive, so for these events, the relay generates additional reports even while any or all relay elements remain picked up. This strategy permits the relay to record fault clearing even when it occurs long after completion of the initial event report.

The relay calculates a fault location for event records in which any triggering relay elements are picked up, if they are not picked up in the first seven rows of pre-fault data or only in the last five rows of the event report. Whenever the locator is able to determine fault location, the corresponding record is labeled according to fault type, regardless of what actually triggered the event report. Event records taken with no triggering relay elements picked up are labeled as follows:

"EXT" for reports triggered externally via input contacts or "TRIGGER" command execution

or

"TRIP" for reports triggered by "TRIP" output contact assertion.

The actual fault location algorithm is composed of two steps. First the relay determines fault type, then it calculates location.

For event reports, the relay determines fault type independently of the relay element operations. Relay elements determine only the indicated zone, while fault current comparison determines the involved phases. This differs from the target data, which is completely derived from relay element operations.

Compared currents are taken from two rows at the middle of the stored fault data. If the uncompensated current magnitudes are in large ratios between phases (4:1 or more), the fault type becomes immediately apparent as single- or two-phase. If not, the same current is load compensated by the two corresponding pre-fault current rows in the first cycle of the event report.

If these fault current component magnitudes are in moderate ratios (1.5:1 or more), the relay lists a single- or two-phase fault. If the ratios are all less than 1.5, the relay lists a three-phase fault. Explicit fault classification logic is as follows, where "I" values are uncompensated mid-fault currents and "If" values are mid-fault currents compensated for load, yielding true fault current components:

```
     IF ( Imax  >   4 x Imed  ) THEN Single-phase
ELSE IF ( Imed  >   4 x Imin  ) THEN Two-phase
ELSE IF ( Ifmax > 1.5 x Ifmed ) THEN Single-phase
ELSE IF ( Ifmed > 1.5 x Ifmin ) THEN Two-phase
ELSE IF (  none of the above  ) THEN Three-phase
```

This algorithm is largely immune to load and system grounding variations.

Once the relay determines fault type, the fault locator uses the Takagi algorithm to locate the fault. Using pre-fault and fault data, it compensates for errors introduced by fault resistance in the presence of load flow. If the event record contains no sound pre-fault data, the relay calculates a location based on a simple reactance measurement.

The fault locator depends on accurate transmission line parameters and instrument transformer ratios. Pay special attention to these potential sources of difficulty:

- Instrument transformer errors due to overburden by other devices
- Capacitive potential transformer capacitor value
- Transmission line parameter errors

Although the fault location computation takes several seconds, the relay can handle several faults in quick succession. The relay stores all fault data, then processes each fault in turn. For example, suppose three faults occur within a few seconds. The relay stores data from them as they occur. The fault location computations begin with the first (oldest) fault and proceed until all three fault records are processed. The relay transmits each summary event report when the corresponding fault location is available.

The relay does not consider shunt capacitance of the transmission line. Capacitance causes the fault location to appear more remote by a factor of approximately 1/cos(bL), where bL is the line length in radians at 60 Hz. One wavelength at 60 Hz is 3100 miles. For example, the line length of a 100 mile line in radians is calculated:

$$(100/3100)(2)(3.14159) = 0.2027 \text{ radians.}$$

The indication neglecting capacitance is about cos (0.2027) = 0.98 times the actual location, or about two miles short for a fault at the far end of a 100 mile line.

When compensation using shunt reactors is employed, and when the measured current equals the reactor current plus the line current, the shunt reactors reduce the errors due to neglecting the shunt capacitance of the transmission line.

When series capacitor compensation is used, accurate performance is obtained for faults between the relay and the capacitors, and beyond the capacitors if the capacitor protective gaps flash. If the gaps do not flash, the measured impedance includes the line impedance and the capacitance impedance, and the errors can be substantial. This problem is aggravated by high-speed clearing and the excitation of eigenmodes or resonances of the line-capacitor system, which may not be much removed from 60 Hz. On the other hand, we have had success in cases where series capacitor gaps did not flash, by recomputing the fault location from the event-report data, using a voltage equal to the measured voltage minus the capacitor voltage drop. The latter is computed from the capacitance value and the measured current.

Event Report

The relay records an eleven-cycle event report in response to the following:

Zone 1 fault	Zone 2 fault	Zone 3 fault	50H pickup
Direct Trip	51N pickup	External trigger	
TRIP	Command (TRIGGER or OPEN)		

A single fault triggers a second report if the trip occurs after the first report expires. Thus, the relay records the beginning and end of each fault for which it trips. It does not generate a second event report if the TRIP output first asserts at or less than seven cycles after the first report is triggered (note that reports are triggered at the 16th quarter-cycle of data).

Triggering is recorded to the nearest quarter-cycle and referenced to the 16th row of data in the report. You can compute the duration of a long fault which triggers two events. Simply calculate the time difference between the report generated at fault inception and the report generated at the TRIP. The event report contains voltages, currents, system settings, and other information. See Section 4: EVENT REPORTING for additional details.

Executing the CLOSE command does not trigger an event. Asserting the DIRECT CLOSE input does not trigger an event.

The last twelve event reports are stored in memory and may be retrieved with the EVENT command. Use the HISTORY command to view summary reports for the last twelve events.

Programmable Logic Mask Concept

Figure 2.9 illustrates the concept of the programmable logic mask by comparing it to the connections of discrete relay elements. At the top, the figure shows relay element contacts X, Y, and Z connected to a common reference, such as the positive pole of the battery. The other ends of these contacts pass through knife switches, while the other side of the switches are connected to drive an auxiliary relay labeled A1. The knife switch positions select relay elements which can pick up the auxiliary relay.

In the figure, switches SX and SY are closed, so closure of either contact X or Y causes A1 to pick up. By connecting the X, Y, and Z contacts in parallel, their operation performs a logical "OR" function: if one contact closes, the A1 coil is energized. The figure expresses this process in Boolean terms next to the A1 output contact with the notation X + Y. The "+" indicates a logical "OR" operation.

The A1 contact control logic scheme may be modified by setting switches SX, SY, and SZ to other positions. If an application requires combinations of contacts X, Y, and Z to control other auxiliary relays, diodes must be used in each contact path. This ensures that the logic settings for this scheme do not affect other auxiliary relays. Since each output contact has a separate logic mask, this step is unnecessary in the microprocessor-based relay.

In the programmable mask logic, the states of all relay elements are collected into a single word of binary digits called the Relay Word. Each bit position reports the state of one relay element. A 0 indicates the element is not picked up; 1 indicates the element is picked up.

Figure 2.9 shows a three-bit Relay Word with elements X, Y, and Z. Each bit corresponds to one relay element contact in the contact logic equivalent. The operator sets or clears bits in the mask for the A1 output rather than using switches to select relay elements which control the A1 output (see Section 3: LOGIC command). In the figure, the operator sets the logic mask to bits (1,1,0), selecting only assertion of the X and Y elements.

The Z element is not selected, so its assertion cannot close the A1 output contact due to an open path from the positive to negative bus. The computer ANDs each bit in the Relay Word with the corresponding bit the operator set in the mask. Next it ORs all three outputs together, forming the condition which drives the output relay A1. A convenient shorthand expression for this bitwise AND followed by an OR operation is:

$$A1 = R * MA1$$
$$R = X + Y + Z$$

where R is the Relay Word (X,Y,Z), MA1 is the mask (1,1,0), "*" indicates the bitwise AND, and "+" indicates the bitwise OR operation.

While the mask elements are fixed, the Relay Word is updated each quarter-cycle. In this example, if the X or Y element is set to (1) in the Relay Word, the A1 contact will be closed. The A1 contact state is independent of the Z element state in the Relay Word because the corresponding Z element in the mask equals zero.

The user programmable logic masks in this relay control the TRIP and programmable output contacts. The logic masks are saved in nonvolatile memory with the other settings and retained through loss of control power.

The masking concept provides more flexibility than switch selectable logic, is more convenient than making wiring changes to hard wired discrete relay systems, and provides noticeable benefits during commissioning and routine testing.

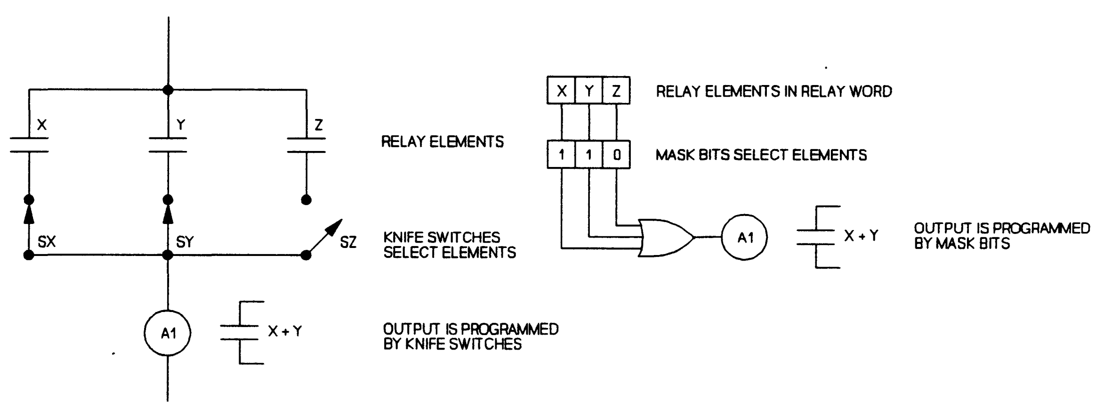


Figure 2.9: Programmable Logic Mask Analogy

RELAY ELEMENT OPERATING TIME CURVES

Figure 2.10 shows operating times for the relay phase-phase mho distance elements and the 50H instantaneous phase overcurrent element. At each reach percentage or current multiple, ten tests were run. The diagrams show maximum, average, and minimum operating times at each test point. Operating times include output contact closure time.

For the distance element test, a phase-phase fault was applied at a location representing a percentage of the Zone 1 relay reach setting. Tests were performed for source impedance ratios (SIR) of 0.1, 1.0, and 5.0. No pre-fault load current was included. System frequency is 60 Hz.

Balanced three-phase currents and no voltages were applied to the relay for the 50H overcurrent element tests. This test simulates a bolted 3 phase fault in front of the relay location when line side PTs are employed. Test currents are shown as a multiple of the pickup setting. No pre-fault load current was included. System frequency is 60 Hz.

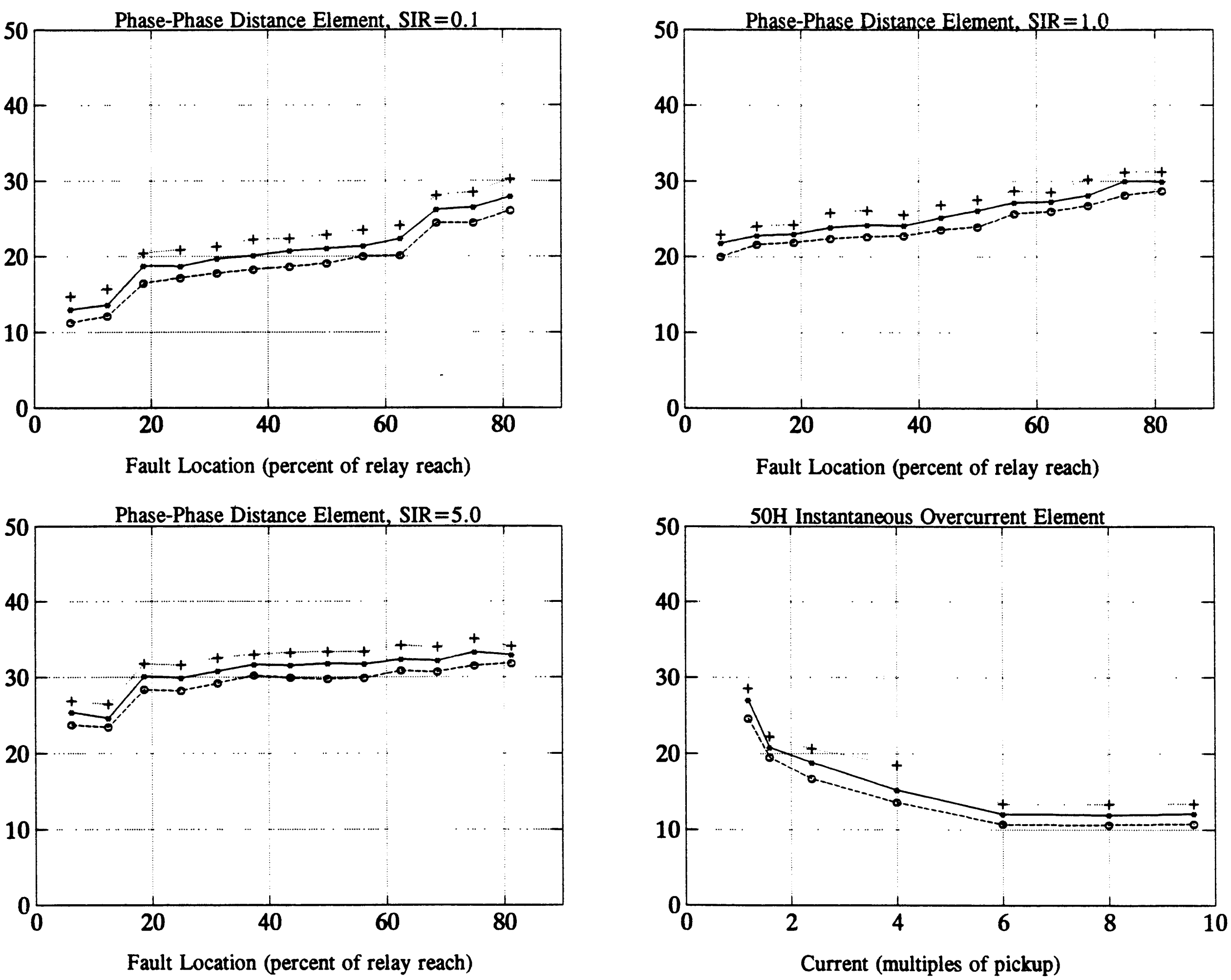


Figure 2.10: Phase Distance Speed Curves and Phase Overcurrent Speed Curve

TIME-OVERCURRENT CURVE EQUATIONS

Let t = operating time in seconds,
TD = time dial setting,
M = multiples of pickup.

Curve 1 -- Moderately Inverse - see Figure 2.11

$$t_M = TD \left[0.157 + \frac{0.668}{M-1} \right]$$

Curve 2 -- Inverse - see Figure 2.12

$$t_M = TD \left[0.180 + \frac{5.95}{M^2-1} \right]$$

Curve 3 -- Very Inverse - see Figure 2.13

$$t_M = TD \left[0.0963 + \frac{3.88}{M^2-1} \right]$$

Curve 4 -- Extremely Inverse - see Figure 2.14

$$t_M = TD \left[0.0352 + \frac{5.67}{M^2-1} \right]$$

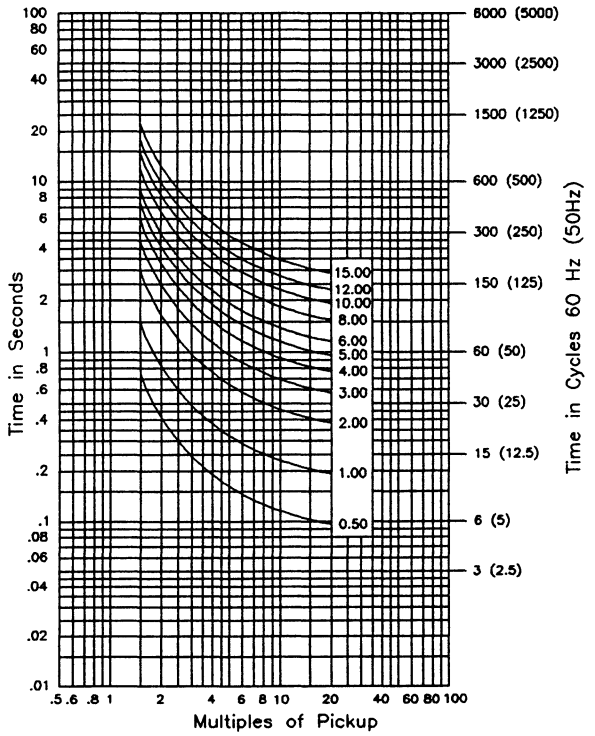


Figure 2.11: Moderately Inverse Curves

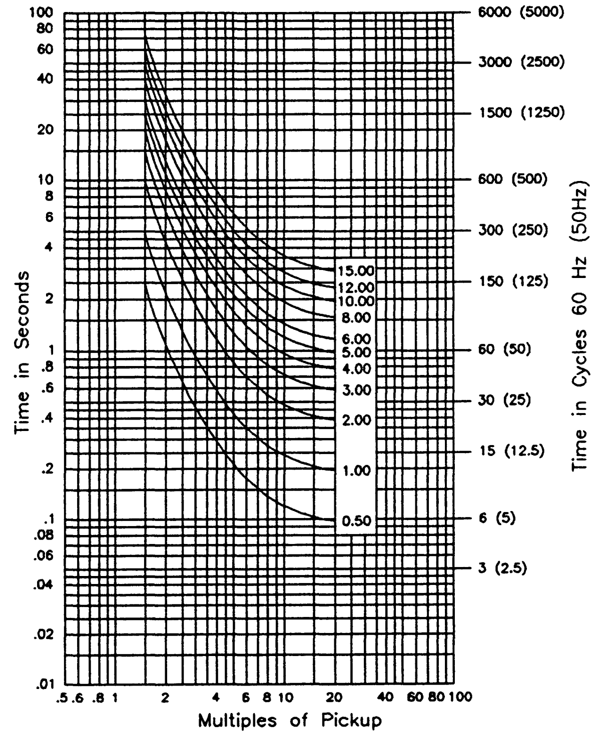


Figure 2.12: Inverse Curves

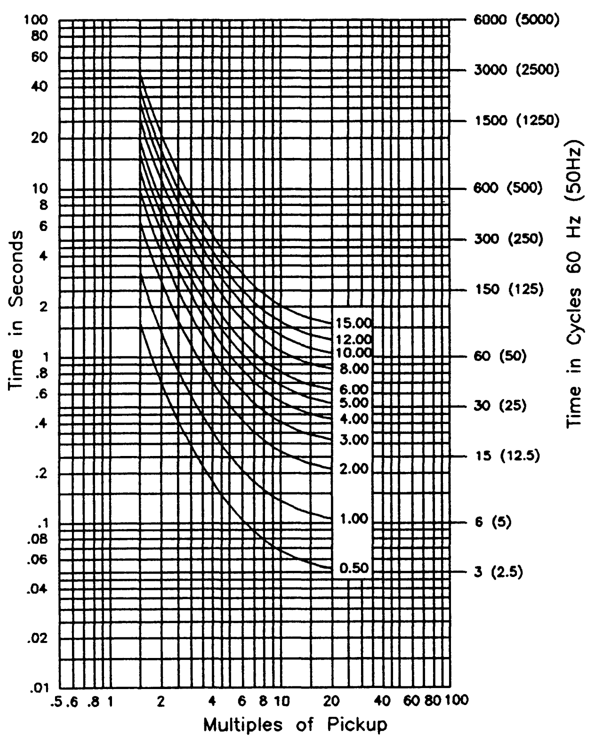


Figure 2.13: Very Inverse Curves

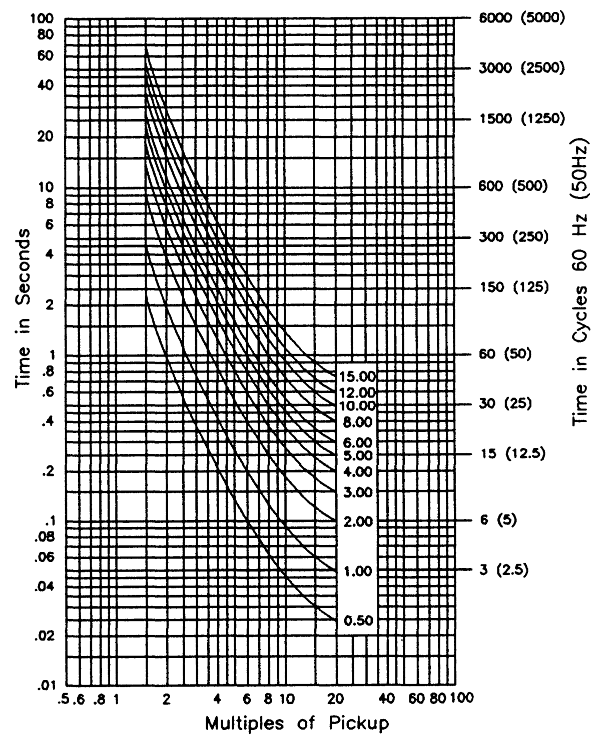
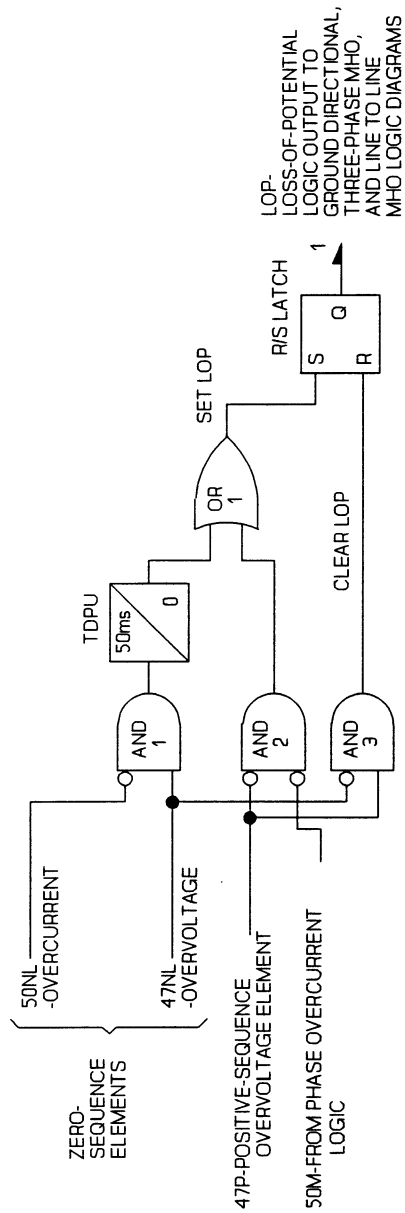
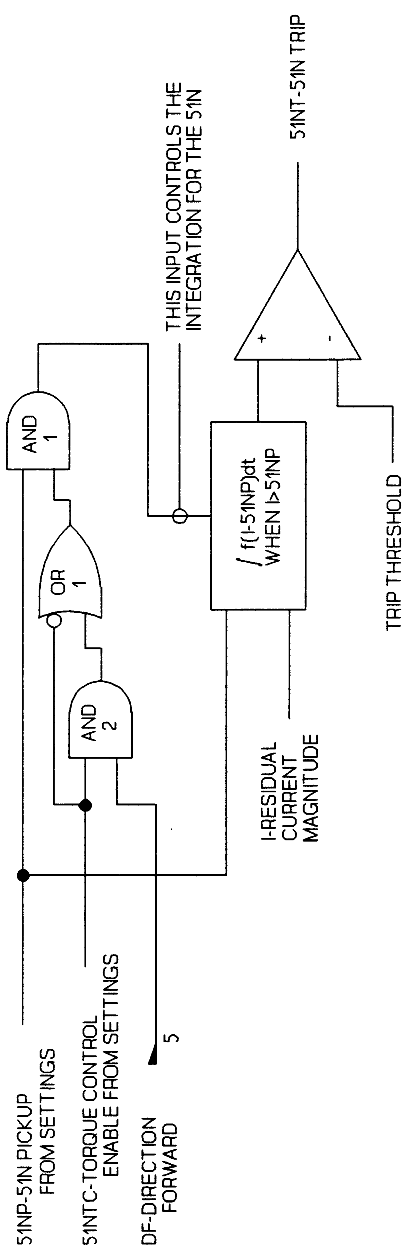


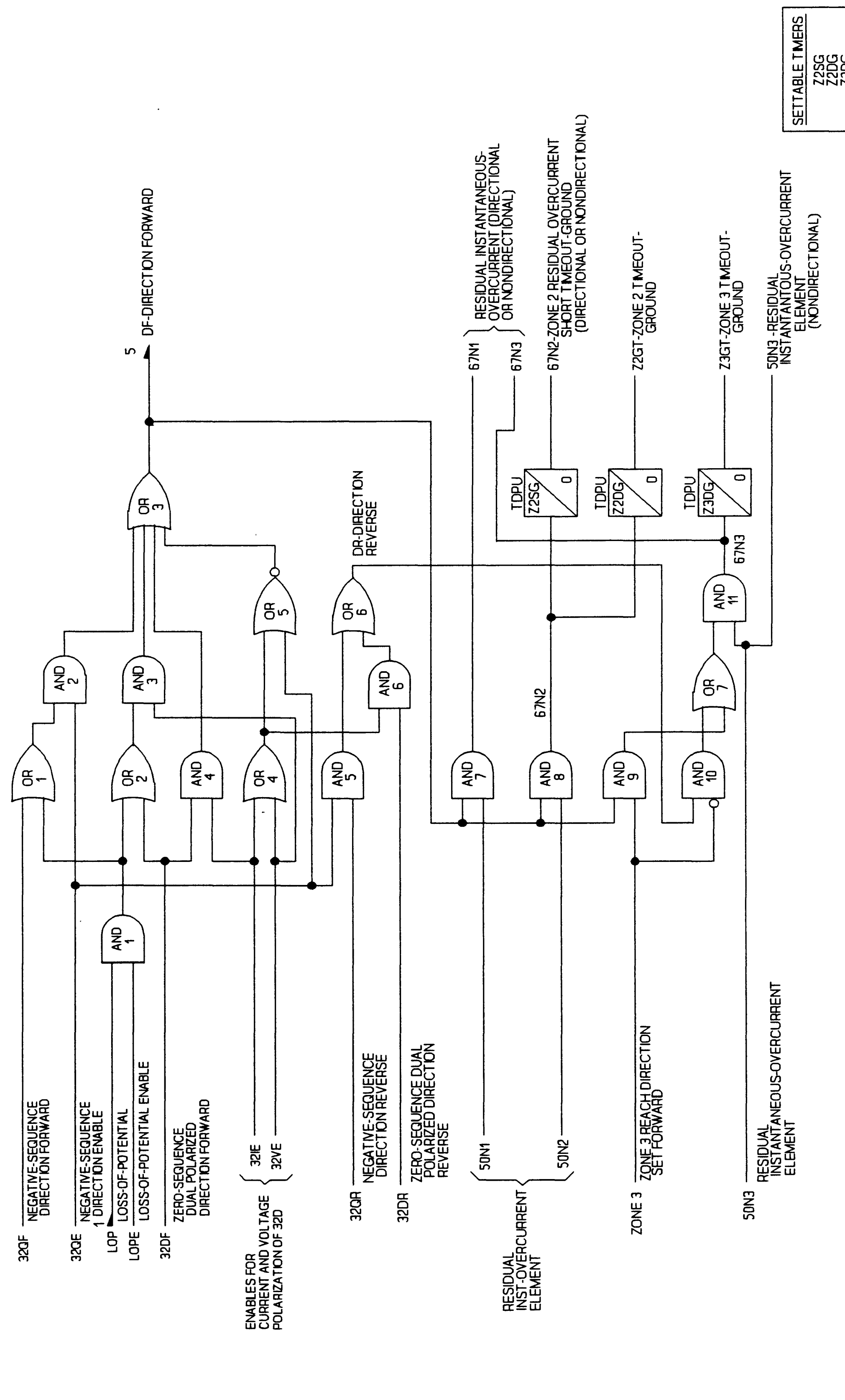
Figure 2.14: Extremely Inverse Curves



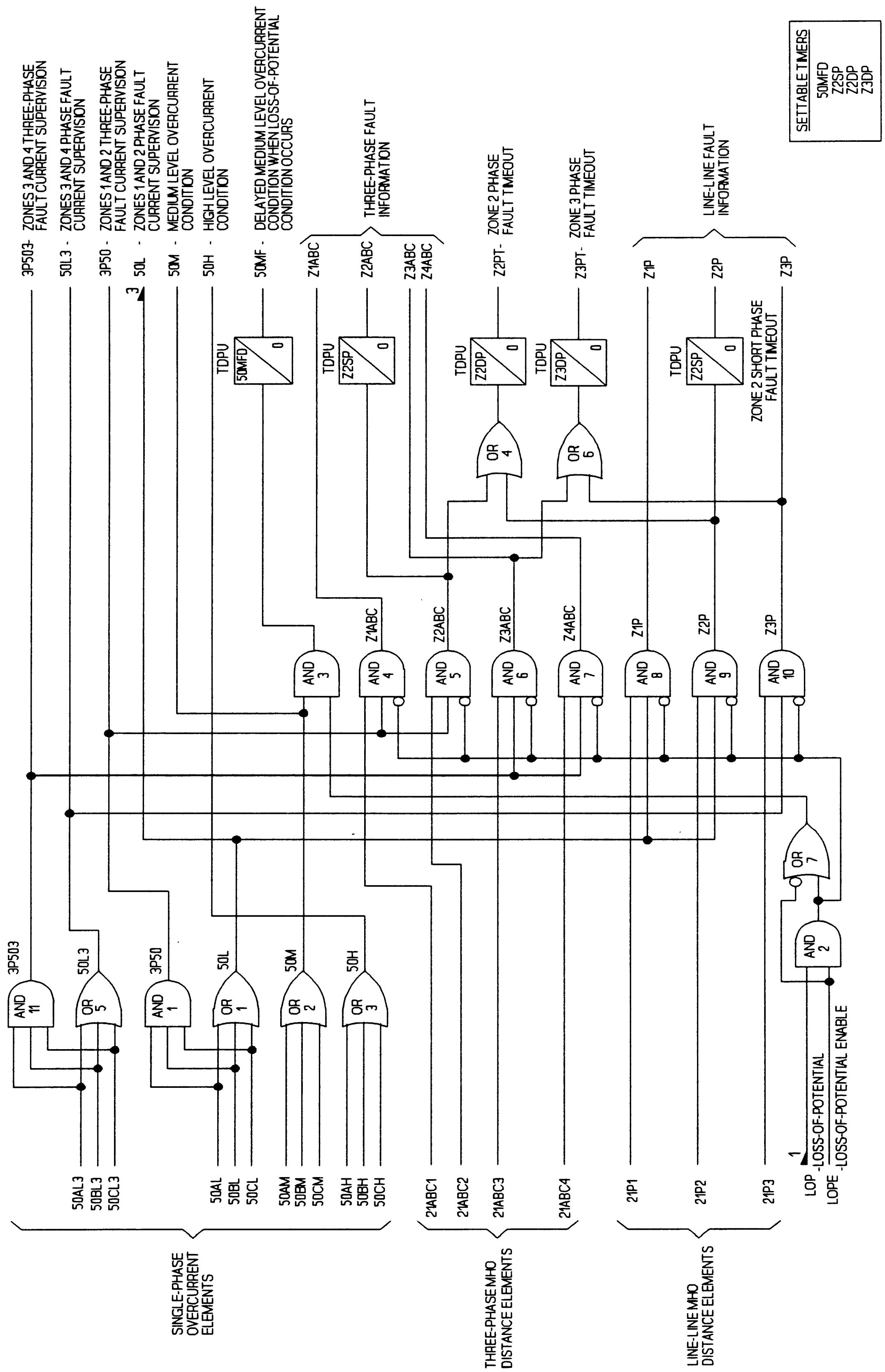
LOSS-OF-POTENTIAL LOGIC DIAGRAM



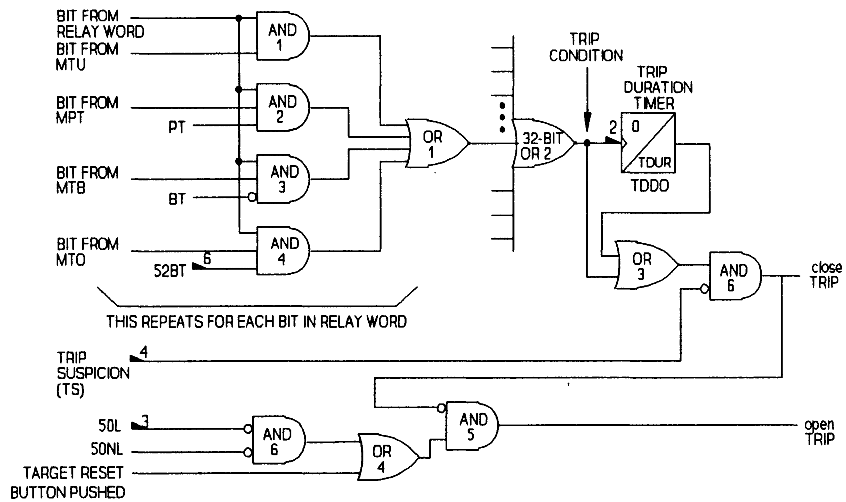
RESIDUAL TIME OVERCURRENT (51N) LOGIC DIAGRAM



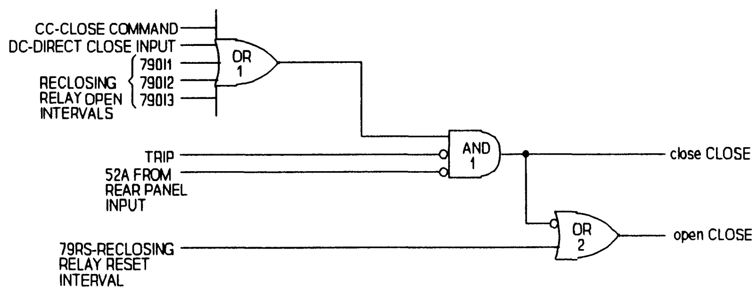
GROUND DIRECTIONAL AND GROUND OVERCURRENT LOGIC DIAGRAM



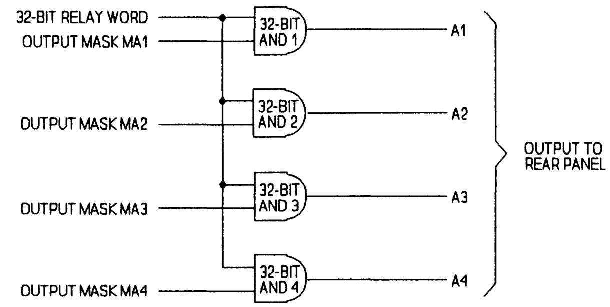
THREE-PHASE MHO, LINE-LINE MHO AND PHASE OVERCURRENT LOGIC DIAGRAM



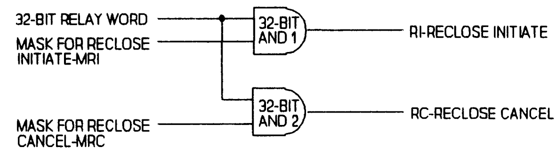
PROGRAMMABLE TRIP LOGIC DIGRAM



CLOSE LOGIC DIAGRAM



PROGRAMMABLE OUTPUT LOGIC DIAGRAM

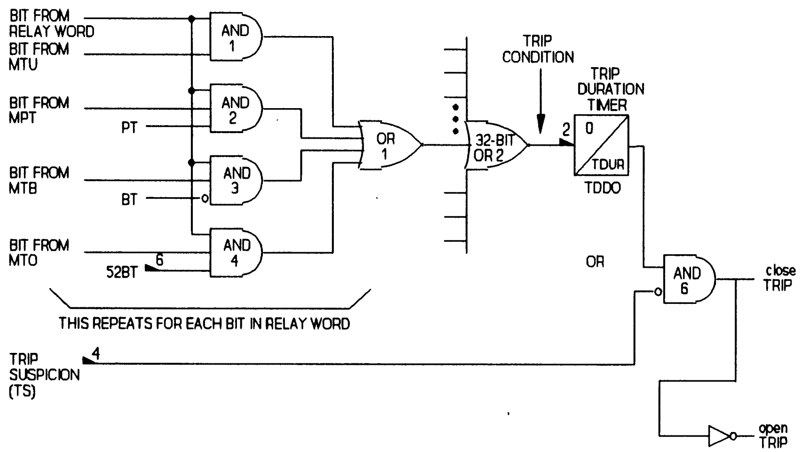


PROGRAMMABLE RECLOSE INITIATE AND CANCEL LOGIC DIAGRAM

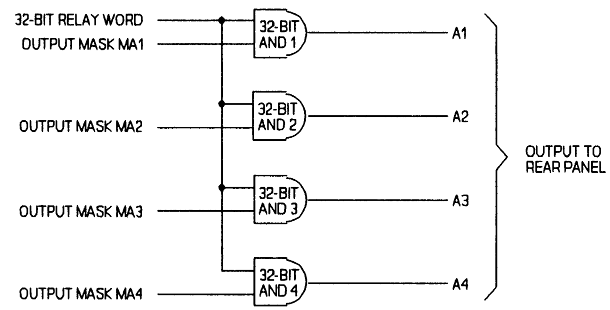
SETTABLE TIMERS
TDUR

MTU-MASK FOR UNCONDITIONAL TRIP
MPT-MASK FOR TRIP WITH PERMISSIVE-TRIP ASSERTED
MTB-MASK FOR TRIP WITH BLOCK-TRIP UNASSERTED
MTO-MASK FOR TRIP WITH BREAKER OPEN
PT-PERMISSIVE TRANSFER TRIP
BT-BLOCK TRIP
52BT-52A INPUT TIMER INVERTED OUTPUT

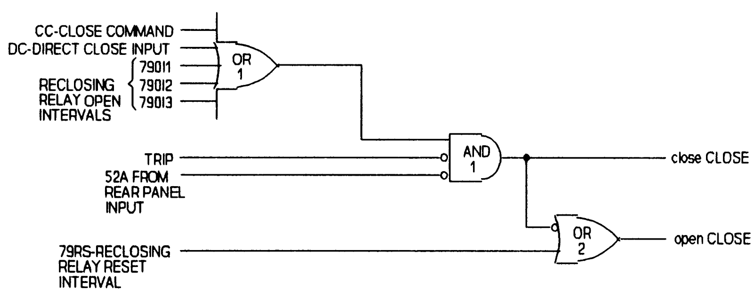
SEL221G-6 / 121G-6



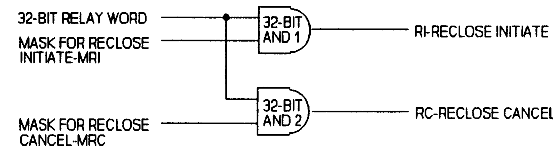
SEL-221G-7/121G-7 PROGRAMMABLE TRIP



PROGRAMMABLE OUTPUT LOGIC DIAGRAM



CLOSE LOGIC DIAGRAM

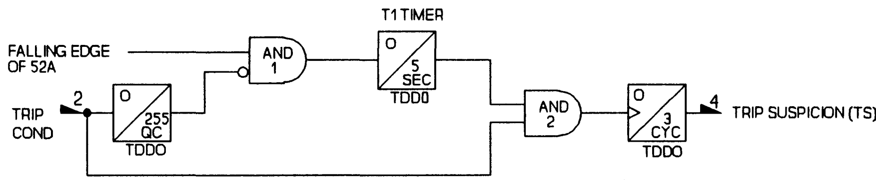


PROGRAMMABLE RECLOSE INITIATE
AND CANCEL LOGIC DIAGRAM

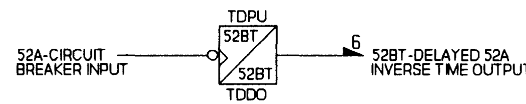
SETTABLE TIMERS
TDUR

MTU-MASK FOR UNCONDITIONAL TRIP
MPT-MASK FOR TRIP WITH PERMISSIVE-TRIP ASSERTED
MTB-MASK FOR TRIP WITH BLOCK-TRIP UNASSERTED
MTO-MASK FOR TRIP WITH BREAKER OPEN
PT-PERMISSIVE TRANSFER TRIP
BT-BLOCK TRIP
52BT-52A INPUT TIMER INVERTED OUTPUT

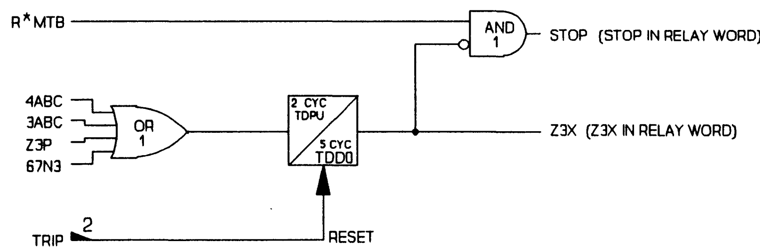
SEL221G-7 / 121G-7



TRIP SUSPICION LOGIC DIAGRAM



CIRCUIT BREAKER CONTACT DELAY LOGIC DIAGRAM



Z3X AND STOP BIT LOGIC DIAGRAM

SETTABLE TIMERS
52BT

COMMUNICATIONS
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COMMUNICATIONS

INTRODUCTION

The relay is set and operated via serial communications interfaces connected to a computer terminal and/or modem or the SEL-PRTU. Communication serves these purposes:

1. The relay responds to commands spanning all functions, e.g., setting, metering, and control operations.

2. The relay generates an event record for TRIP output assertions, for an event triggering command, or for pickup of any relay element that triggers an event record.

3. The relay transmits messages in response to changes in system status, e.g., self-test warning.

It is impossible to disable any relaying or control functions via communications, unless a user enters erroneous or improper settings with the SET or LOGIC commands.

Note: In this manual, commands to type appear in bold/uppercase: **OTTER**. Keys to press appear in bold/uppercase/brackets: **<ENTER>**.

Relay output appears boxed and in the following format:

```
Example 230 kV Line                Date: 4/1/92       Time: 01:01:01
```

SERIAL PORT CONNECTIONS AND CONFIGURATIONS

The SEL-221G-6 Relay is equipped with two EIA-232 serial communications ports. PORT 2 has 9-pin connectors on both the front and rear panels, designated PORT 2F and PORT 2R, respectively.

Port 2R, located on the relay rear panel, is typically used with an SEL-DTA Display/Transducer Adapter, SEL-RD Relay Display, or local printer. PORT 2F is always available for short term local communications with a portable computer or printing terminal. Simply plug the device into the front panel port. The relay automatically discontinues communications with PORT 2R and addresses PORT 2F. When testing or data retrieval is complete, unplug the temporary device from PORT 2F. The relay automatically resumes communication with the device connected to PORT 2R.

Serial communications PORT 1 and the Auxiliary Input for demodulated IRIG-B time code input remain on the relay rear panel.

Communications port baud rate jumpers are located along the front edge of the circuit board. To select a baud rate for PORT 1 or PORT 2, remove the relay front panel. The jumpers are visible near the center of the relay drawout assembly, to the right of the target LEDs. Carefully move the jumpers using needle-nosed pliers.

Caution: Do not select two baud rates for the same port as this can damage the relay baud rate generator. The relay is shipped with PORT 1 set to 300 baud and PORT 2F/2R set to 2400 baud.

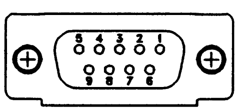
The baud rates of the ports are set by jumpers located near the front of the main board. They are accessible by removing the top cover or the front panel. Available rates are 300, 600, 1200, 2400, 4800, and 9600 baud.

The serial data format is:

Eight data bits
Two stop bits (-E2 model) or One stop bit (-E1 model)
No parity bit

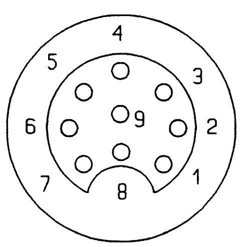
This format cannot be altered.

Note: The SEL-121G-6 Relay does not include a front panel serial interface port.



(female chassis connector, as viewed from outside panel)

Figure 3.1: SEL-221G-6 Relay 9-Pin Connector Pin Number Convention



(female chassis connector, as viewed from outside rear panel)

Figure 3.2: SEL-121G-6 Relay 9-Pin Connector Pin Number Convention

Table 3.1 lists SEL-221G-6 Relay port pin assignments and signal definitions.

Table 3.1: SEL-221G-6 Relay Serial Port Connector Pin Assignments

Pin	Port 1, PORT 2R	Port 2F	Description
1	+5 Vdc	N/C	+5 Vdc available if JPM12 installed.
2	RXD	RXD	Receive data input.
3	TXD	TXD	Transmit data output.
4	+12 Vdc	N/C	+12Vdc available if JMP13 installed.
5	GND	GND	
6	-12 Vdc	N/C	-12Vdc available if JMP14 installed.
7	RTS	RTS	The SEL-221G-6 Relay asserts this line under normal conditions. When its received-data buffer is full, the line is deasserted, and asserts again when the buffer has sufficient room to receive more data. Connected devices should monitor RTS (usually with their CTS input) and stop transmission whenever the line deasserts. If transmission continues, data may be lost.
8	CTS	CTS	The SEL-221G-6 Relay monitors CTS, and transmits characters only if CTS is asserted.
9	GND	GND	Ground for ground wires and shields

Table 3.2 lists SEL-121G-6 Relay port pin assignments and signal definitions.

Table 3.2: SEL-121G-6 Relay Serial Port Connector Pin Assignments

Pin	Name	Description
2	TXD	Transmit data output.
3	RTS	The relay asserts this line under normal conditions. When its received-data buffer is full, the line deasserts until the buffer has room to receive more data. Connected devices should monitor RTS (usually with their CTS input) and stop transmitting characters whenever the line deasserts. If transmission continues, data may be lost.
4	RXD	Receive data input.
5	CTS	The relay monitors CTS and transmits characters only when CTS is asserted.
6	+5 volts	
7	+12 volts	
8	-12 volts	
1, 9	GND	Ground for ground wires and shields.

COMMUNICATIONS PROTOCOL

Communications protocol consists of hardware and software features. Hardware protocol includes the control line functions described above. The following software protocol is designed for manual and automatic communications.

1. All commands received by the relay must be of the form:

   <command><CR> or <command><CRLF>

   Thus, a command transmitted to the relay should consist of the command followed by either a carriage return or a carriage return and line feed. You may truncate commands to the first three characters. Thus, EVENT 1 <ENTER> would become EVE 1 **<ENTER>**. Upper and lower case characters may be used without distinction, except in passwords.

Note: The ENTER key on most keyboards is configured to send the ASCII character 13 (^M) for a carriage return. This manual instructs you to press the ENTER key after commands, which should send the proper ASCII code to the relay.

2. The relay transmits all messages in the following format:

<STX> <MESSAGE LINE 1> <CRLF>
<MESSAGE LINE 2> <CRLF>
.
.
<LAST MESSAGE LINE> <CRLF> <PROMPT> <ETX>

Each message begins with the start-of-transmission character (ASCII 02) and ends with the end-of-transmission character (ASCII 03). Each line of the message ends with a carriage return and line feed.

3. The relay indicates the volume of data in its received data buffer through an XON/XOFF protocol.

The relay transmits XON (ASCII hex 11) and asserts the RTS output when the buffer drops below ¼ full.

The relay transmits XOFF (ASCII hex 13) when the buffer is over ¾ full. The relay deasserts the RTS output when the buffer is approximately 95% full. Automatic transmission sources should monitor for the XOFF character so they do not overwrite the buffer. Transmission should terminate at the end of the message in progress when XOFF is received and may resume when the relay sends XON.

4. You can use an XON/XOFF procedure to control the relay during data transmission. When the relay receives XOFF during transmission, it pauses until it receives an XON character. If there is no message in progress when the relay receives XOFF, it blocks transmission of any message presented to its buffer. Messages will be accepted after the relay receives XON.

The CAN character (ASCII hex 18) aborts a pending transmission. This is useful in terminating an unwanted transmission.

5. Control characters can be sent from most keyboards with the following keystrokes:

XON:	**<CTRL>Q**	(hold down the Control key and press Q)
XOFF:	**<CTRL>S**	(hold down the Control key and press S)
CAN:	**<CTRL>X**	(hold down the Control key and press X)

COMMAND CHARACTERISTICS

The relay responds to commands sent to either serial communications interface. A two-level password system provides security against unauthorized access.

When the power is first turned on, the relay is in Access Level 0 and honors only the ACCESS command. It responds "Invalid command" or "Invalid access level" to any other entry.

You may enter Access Level 1 with the ACCESS command and first password. The Level 1 password is factory-set to OTTER and may be changed with the PASSWORD command in Access Level 2. Most commands may be used in Access Level 1.

Critical commands such as SET operate only in Access Level 2. You may enter Access Level 2 with the 2ACCESS command and second password. The Level 2 password is factory-set to TAIL and may be changed with the PASSWORD command.

Startup

Immediately after power is applied, the relay transmits the following message to the port(s) designated automatic:

```
Example 230 kV Line                Date: 4/1/92       Time: 01:01:01

SEL-121G
=
```

The ALARM relay should pull in.

The = represents the Access Level 0 prompt.

The relays are shipped with PORT 2 designated automatic; you may use the SET command to change this designation (see SET command, AUTO setting). This allows you to select PORT 1, PORT 2, or both ports to transmit automatic responses from the relay.

To enter Level 1, type the following on a terminal connected to PORT 2:

```
=ACCESS <ENTER>
```

The response is:

```
Password: ? @@@@@@
```

Enter the Level 1 password: **OTTER** and press <ENTER>. The response is:

```
Example 230 kV Line                    Date: 4/1/92       Time: 01:01:44

Level 1
=>
```

The Access Level 1 prompt is =>. Now you can execute any Level 1 command.

Use a similar procedure to enter Access Level 2:

Type **2ACCESS <ENTER>**. The relay pulses the ALARM relay contact closed for approximately one second, indicating an attempt to enter Access Level 2. Enter the proper password, **TAIL**, when prompted. After you enter the second password, the relay opens access to Level 2, as indicated by the following message and Level 2 prompt (=>>):

```
=>2ACCESS <ENTER>
Password:   TAIL <ENTER>


Example 230 kV Line                    Date: 4/1/92       Time: 01:03:32

Level 2
=>>
```

You can enter any command at this prompt.

Command Format

Commands consist of three or more characters; only the first three characters of any command are required. You may use upper or lower case characters without distinction, except in passwords.

You must separate arguments from the command by spaces, commas, semicolons, colons, or slashes.

You can enter commands any time after the terminal displays an appropriate prompt.

COMMAND DESCRIPTIONS

Access Level 0 Command

ACCESS

ACCESS allows you to enter Access Level 1. The password is required unless you install jumper JMP103. The first password is set to OTTER at the factory; use the Level 2 command PASSWORD to change passwords.

The following display indicates successful access:

```
=ACCESS <ENTER>
Password:  OTTER <ENTER>


Example 230 kV Line                 Date:  4/1/92      Time: 14:03:57

Level 1
=>
```

The => prompt indicates Access Level 1.

If you enter incorrect passwords during three consecutive attempts, the relay pulses the ALARM contact closed for one second. This feature can alert personnel to an unauthorized access attempt if the ALARM contact is connected to a monitoring system.

Access Level 1 Commands

2ACCESS

2ACCESS allows you to enter Access Level 2. The password is required unless you install jumper JMP103. The second password is set to TAIL at the factory; use the Level 2 command PASSWORD to change passwords.

The following display indicates successful access:

```
=>2ACCESS <ENTER>
Password:   TAIL <ENTER>


Example 230 kV Line                    Date: 4/1/92       Time: 14:12:01

Level 2
=>>
```

You may use any command from the = > > prompt. The relay pulses the ALARM contact closed for one second after any Level 2 access attempt (unless an alarm condition exists).

DATE mm/dd/yy

DATE displays the date stored by the internal calendar/clock. To set the date, type DATE **mm/dd/yy <ENTER>**.

To set the date to April 17, 1992, enter:

```
=>DATE 4/17/92 <ENTER>
4/17/92
=>
```

The relay sets the date, pulses the ALARM relay closed as it stores the year in EEPROM (if the year input differs from the year stored), and displays the new date.

EVENT n

EVENT displays an event report. Type **EVENT N <ENTER>** to display an event report for the Nth event. The parameter N ranges from 1 for the newest event through 12 for the oldest event stored in the relay memory. If N is not specified, the default value is 1 and the relay displays the newest event report.

You can control transmissions from the relay with the following keystrokes:

- **<CTRL>S** Pause transmission
- **<CTRL>Q** Continue transmission
- **<CTRL>X** Terminate transmission

The following incidents clear the event buffers:

- Interruption of control power
- Changing any relay setting
- Changing any logic mask setting

All event data are lost when event buffers are cleared. If an event buffer is empty when you request an event, the relay returns an error message:

```
=>EVENT 12 <ENTER>
Invalid event
=>
```

Section 4: EVENT REPORTING explains the generation and analysis of event reports.

HISTORY

HISTORY displays the date, time, and type of event for each of the last twelve events. If the event is a fault, the distance, duration, and maximum phase current appear in the History readout.

```
=>HISTORY <ENTER>

Example 230 kV Line                Date: 4/1/92       Time: 07:38:12

#   DATE          TIME         TYPE  DIST   DUR   CURR

1  4/01/92    07:36:52.150  1AG   74.93  5.00  1070.1
2  4/01/92    07:36:18.400  1BC   74.53  4.75  1567.2
3  4/01/92    07:35:42.970  2BC   84.68  4.25  1411.8
4  4/01/92    07:35:23.783  EXT
5  4/01/92    07:35:07.958  TRIP
6
7
8
9
10
11
12

=>
```

Note that only five events have occurred since the relay was set or powered on.

The time is saved to the nearest quarter-cycle (4.17 ms) and referenced to the 16th row of data in the report. All reports trigger at row 16. If a long fault triggers two event reports, you can still determine its duration. Simply calculate the time difference between the first report generated at fault inception and the second report generated at the TRIP.

The TYPE column provides an abbreviated indication of the event type. This is the same data presented for EVENT in the event summary automatically generated for each fault.

For faults, the indication includes zone and phase involvement information. The zone is determined from the relay elements asserted at the middle of the first contiguous sequence of relay elements picked up in the report. For example, if relay elements are contiguously picked up from the 15th to the 24th rows, the zone will be determined from the 20th row. The zone is indicated by the left-most character of the TYPE string, and is one of the following:

1	:	For faults in which a Zone 1 element picked up
2	:	For Zone 2, but not Zone 1
3	:	For Zone 3, but not Zone 2 or 1
4	:	For Zone 4, but not Zone 3, 2, or 1
5	:	For 51N pickup, but not Zone 4, 3, 2, or 1
H	:	For 50H pickup, but not 51N or Zone 4, 3, 2, or 1
?	:	For none of the above picked up at mid-fault

Phase involvement is shown by the characters subsequent to the zone indication and is determined independently from relay elements. Phase involvement is determined solely from uncompensated and load compensated current magnitudes. These magnitudes are measured at the midpoint of the first contiguous relay pickup sequence in the event report (see the Fault Locator description in Section 2: SPECIFICATIONS for algorithmic details). The phase involvement is indicated as one of the list below.

AG	:	For A-phase to ground faults
BG	:	For B-phase to ground faults
CG	:	For C-phase to ground faults
AB	:	For A-B two-phase faults
BC	:	For B-C two-phase faults
CA	:	For C-A two-phase faults
ABG	:	For A-B two-phase to ground faults
BCG	:	For B-C two-phase to ground faults
CAG	:	For C-A two-phase to ground faults
ABC	:	For three-phase faults

Zone and phase involvement data are concatenated into a single string, completing the TYPE designation, as in "3BG" for a Zone 3 B-phase to ground fault. For event reports triggered by TRIP output assertion, the TYPE designation is appended with a "T." This aids in determining clearing times for faults which persist beyond the end of the first event report. For example, if the relay trips for a 3BG fault after completion of the initial report, the second report shows "3BGT" for TYPE.

For events other than faults, TYPE indication is either "TRIP" or "EXT." The TYPE is "TRIP" when the relay generates an event report in response to TRIP output assertion. This can occur after OPEN command execution during a no-fault condition. For all other events, TYPE shows "EXT," indicating a report generated in response to ET (External Trigger) input assertion or TRIGGER command execution.

The DIST column presents the equivalent distance to a fault in miles or kilometers. This is calculated using the Takagi algorithm or a reactance measurement, depending on whether pre-fault data are available in the event report. For some boundary faults of long duration, the fault locator may not be able to locate the fault for every report generated when relay operation is sporadic. The DIST column may contain "999999" in such cases. While this behavior can be contrived under test conditions, it is extremely rare in actual practice.

The DUR column gives a fault duration measurement for each event report. This is determined from the first pickup of a Zone 1, 2, 3, 4, 51N, or 50H relay element until the first dropout of all said relay elements. In other words, it is the duration of the first contiguous pickup of relay elements found in the long event report converted to units of cycles. The maximum duration measurement for an event report is 7.25 cycles.

The CURR column shows the magnitude of the maximum phase current measured at the middle of the fault in primary amperes. This information is useful for determining the row pair used by the relay for fault location calculations.

IRIG

IRIG directs the relay to read the demodulated IRIG-B time code input at J201 on the rear panel if a time code signal is input.

If the relay reads the time code successfully, it updates the internal clock/calendar time and date to the time code reading and the relay transmits a message with relay ID string, date, and time.

```
=>IRIG <ENTER>

Example 230 kV Line                 Date: 4/1/92       Time: 01:45:40

=>
```

If no IRIG-B signal is present or the code cannot be read successfully, the relay sends the error message "IRIGB DATA ERROR."

Note: Normally, it is not necessary to synchronize using this command because the relay automatically synchronizes every few minutes. The command is provided to prevent delays during testing and installation.

METER n

METER displays the phase-to-neutral and phase-to-phase voltages and currents in primary kilovolts and amperes. METER also displays real and reactive power in megawatts and megavars.

```
=>METER <ENTER>

Example 230 kV Line                 Date: 4/1/92       Time: 07:56:36

                A       B       C       AB      BC      CA
I (A)          202     198     197     349     339     344
V (kV)       134.0   133.8   133.6   231.5   230.9   231.9

P (MW)       78.61
Q (MVAR)     13.85

=>
```

P and Q are derived from the total power S. S is calculated from the sum of the phasor multiplication of each phase-to-neutral voltage and current:

$$S = (Va)(Ia) + (Vb)(Ib) + (Vc)(Ic)$$

P and Q are then taken as the real and imaginary components of S.

An example is 134 kilovolts in positive-sequence with 200 amperes of load current lagging the voltages by 10°.

$$S = (134{,}000)(202) + (133{,}800)(198) + (133{,}600)(197) = 79.88 \text{ MVA}$$

$$P = (S)(\cos(10^\circ)) = 78.67 \text{ MW}$$

$$Q = (S)(\sin(10^\circ)) = 13.87 \text{ MVAR}$$

P and Q are positive when the power flows in the direction of relay reach or out from the bus and into the line.

The optional parameter N selects the number of times the relay displays meter data. To display a series of eight meter readings, type **METER 8 <ENTER>**.

QUIT

QUIT returns control to Access Level 0 from Level 1 or 2 and resets targets to the Relay Targets (TAR 0). The command displays the relay I.D., date, and time of QUIT command execution.

Use this command when you finish communicating with the relay to prevent unauthorized access. Control returns to Access Level 0 automatically after a settable interval of no activity (see the TIME1 and TIME2 settings of the SET command).

```
=>QUIT <ENTER>

Example 230 kV Line                 Date: 4/1/92       Time: 01:45:40

=
```

SHOWSET

SHOWSET displays the current relay and logic settings. Settings cannot be entered or modified with this command. The SET command description provides complete information about changing settings.

```
=>SHOWSET <ENTER>

Settings for: Example 230 kV Line

R1   =8.56   X1   =77.77   R0   =35.12 X0   =236.96 LL   =100.00
CTR  =200.00 PTR  =2000.00 MTA  =83.72 LOCAT=Y
79OI1=40.00  79OI2=60.00   79OI3=80.00 79RS =240.00
Z1%  =80.00  Z2%  =120.00  Z3%  =120.00
Z2SP =0.75   Z2DP =20.00   Z3DP =60.00
50L3 =275.00 50L  =275.00  50M  =500.00 50MFD=20.00  50H  =3420.00
51NP =230.00 51NTD=4.00    51NC =3     51NTC=Y
50N1P=835.00 50N2P=276.00  50N3P=282.00
Z2SG =0.75   Z2DG =30.00   Z3DG =60.00 TDUR =9.00   LOPE =Y
52BT =20.00  ZONE3=R       32QE =Y     32VE =N      32IE =N
TIME =5      TIME2=0       AUTO =2     RINGS=7

Logic settings:

MTU  MPT  MTB  MTO  MA1  MA2  MA3  MA4  MRI  MRC
80   00   40   C4   30   00   00   08   00   E4
C4   00   22   E6   11   00   00   00   44   80
C8   00   00   00   00   01   04   00   00   C8
33   00   00   00   84   40   00   00   00   33

=>
```

A brief line-by-line description of the settings follows:

Line 1: Positive- and zero-sequence impedances of the transmission line (primary ohms) and line length (miles) for which the impedances are given.

Line 2: Current and voltage transformer ratios, maximum torque angle, and fault locator enable.

Line 3: Three reclosing open interval delays and recloser reset delay.

Line 4: Zone 1, 2, and 3 reach settings as percents of the positive-sequence line impedances.

Line 5: Zone 2 and 3 time delay settings for phase faults.

Line 6: Phase overcurrent element low, medium, and high pickup settings, and the time delay setting for 50M to trip with a loss-of-potential condition (LOPE=Y).

Line 7: Residual time-overcurrent pickup, time dial, curve, and torque control enable.

Line 8: Zone 1, 2, and 3 instantaneous residual overcurrent element pickup settings.

Line 9: Zone 2 and 3 time delay settings for ground faults detected by the residual overcurrent elements and Trip Duration timer.

Line 10: 52B time delay, Zone 3 direction, and the enables for the negative-sequence directional, voltage-polarized zero-sequence directional, and current-polarized zero-sequence directional elements.

Line 11: Enables for out-of-step blocking of Zones 1, 2, and 3 three-phase mhos, out-of-step timer, and the loss-of-potential enable.

Line 12: PORT 1 and 2 timeouts, the port(s) designated for automatically transmitted messages and the number of rings after which the relay instructs the modem to answer.

The SET command description includes a complete description of settings. Section 5: APPLICATIONS provides explanations and descriptions of setting calculations.

The LOGIC command description includes a detailed explanation of the logic settings.

Each logic settings display column shows the masks for the four rows of the Relay Word as follows:

Row 1, of any column:	1ABC	2ABC	3ABC	4ABC	LOP	50H	50M	50L
Row 2, of any column:	51NT	67N1	67N2	67N3	51NP	Z1P	Z2P	Z3P
Row 3, of any column:	Z2PT	Z3PT	50L3	3P50	50MF	RC	RI	STOP
Row 4, of any column:	50N3	TRIP	TC	DT	52BT	Z3X	Z2GT	Z3GT

Logic settings appear in hexadecimal format. Table 3.3 provides equivalencies between hexadecimal (hex) and binary numbers. Use the table when you examine logic settings in event reports and the SHOWSET display.

Table 3.3: Hexadecimal/Binary Conversion

Hexadecimal	Binary	Hexadecimal	Binary
0	0000	8	1000
1	0001	9	1001
2	0010	A	1010
3	0011	B	1011
4	0100	C	1100
5	0101	D	1101
6	0110	E	1110
7	0111	F	1111

For example, consider row 2 of mask MTU, which is set to C4 hex format. Using the table, convert C4 to binary:

C4 -> 1100 0100.

Now, build row 2 of the Relay Word for the MTU mask as follows:

51NT	67N1	67N2	67N3	51NP	Z1P	Z2P	Z3P
1	1	0	0	0	1	0	0
	C				4		

STATUS

STATUS allows inspection of self-test status. The relay automatically executes the STATUS command whenever a self-test enters a warning or failure state. If this occurs, the relay transmits a STATUS report from the port(s) designated automatic (see SET command, AUTO setting).

The STATUS report format appears below.

```
=>STATUS <ENTER>

Example 230 kV Line              Date: 4/1/92      Time: 01:08:44

SELF TESTS

W=Warn F=Fail
      IP   IR   IA   IB   IC   VA   VB   VC
OS    0    0    0    0    0    2    0    2
PS     5.11     15.15    -14.91
RAM    ROM    A/D    MOF    SET
OK     OK     OK     OK     OK

=>
```

The OS row indicates measured dc offset voltages in millivolts for the eight analog channels. An out-of-tolerance offset is indicated by a W (warning) or F (failure) following the displayed offset value.

The PS row indicates power supply voltages in volts for the three power supply outputs.

If a RAM or ROM test fails, the IC socket number of the defective part replaces OK.

The A/D self-test checks the analog-to-digital conversion time.
The MOF test checks dc offset in the MUX-PGA-A/D circuit when a grounded input is selected.

The SET self-test calculates a checksum of the settings stored in nonvolatile memory and compares it to the checksum calculated when settings were last changed.

Section 2: SPECIFICATIONS provides full definitions of the self-tests, their warning and failure limits, and the results of test warnings and failures.

TARGET n k

TARGET selects the information displayed on the target LEDs and communicates the state of the selected elements.

When the relay power is on, the LED display indicates the functions marked on the front panel. The default display shows fault information from the RELAY TARGETS row of the following table.

Using the TARGET command, you may select any one of the following seven sets of data to display on the LEDs.

Table 3.4: Target LED Assignment									
LED:	1	2	3	4	5	6	7	8	
N									
0	EN	PH1	G1	PH2	G2	PH3	G3	51N	RELAY TARGETS
1	1ABC	2ABC	3ABC	4ABC	LOP	50H	50M	50L	RELAY WORD row 1
2	51NT	67N1	67N2	67N3	51NP	Z1P	Z2P	Z3P	RELAY WORD row 2
3	Z2PT	Z3PT	50L3	3P50	50MF	RC	RI	STOP	RELAY WORD row 3
4	50N3	TRIP	TC	DT	52BT	Z3X	Z2GT	Z3GT	RELAY WORD row 4
5	52AT	.	ET	52A	DC	BT	PT	DT	CONTACT INPUTS
6	.	TRIP	CLOS	A1	A2	A3	A4	ALRM	CONTACT OUTPUTS

These selections are useful in testing, checking contact states, and reading targets remotely. "1" indicates an asserted element; "0" indicates a deasserted element.

The optional command parameter K selects the number of times the relay displays target data for parameter N. The example below shows a series of ten target readings for Relay Word row 3. Target headings repeat every eight rows.

```
=>TARGET 3 10 <ENTER>

 Z2PT Z3PT 50L3 3P50 50MF  RC    RI    STOP
 0    0    0    0    0     0     0     0
 0    0    0    0    0     0     0     0
 0    0    0    0    0     0     0     0
 0    0    0    0    0     0     0     0
 0    0    0    0    0     0     0     0
 0    0    0    0    0     0     0     0
 0    0    0    0    0     0     0     0
 0    0    0    0    0     0     0     0

 Z2PT Z3PT 50L3 3P50 50MF  RC    RI    STOP
 0    0    0    0    0     0     0     0
 0    0    0    0    0     0     0     0

=>
```

When finished, type **TAR 0 <ENTER>** to return to fault targets so field personnel do not misinterpret displayed data. Also, if the relay sends an automatic message to a timed out port, it clears the target display and displays the TAR 0 data.

Press the front panel TARGET RESET button to clear the TAR 0 data and illuminate all target LEDs for a one-second lamp test.

You can reset front panel targets to TAR 0 and clear them remotely or locally with the TARGET command. Type TARGET R <ENTER> to reset and clear the targets as shown below.

```
=>TARGET R <ENTER>
Targets reset

 EN   PH1  G1   PH2  G2   PH3  G3   51N
 1    0    0    0    0    0    0    0

=>
```

If you place the relay in service with the target level other than Level 0, it automatically reverts to target level 0 when an automatic message transmits to a timed out port. While this feature prevents confusion among station operators and readers, it can be inconvenient if the relay tester requires targets to remain on another level. Targets remain in the specified level if you assign the AUTO setting to a port with zero timeout or set both TIME1 and TIME2 to zero. This halts automatic message transmission to a port which may be timed out.

TIME hh:mm:ss

TIME checks the internal clock. To set the clock, type TIME and the desired setting, then press <ENTER>. Separate the hours, minutes, and seconds with colons, semicolons, spaces, commas, or slashes. To set the clock to 23:30:00, enter:

```
=>TIME  23:30:00 <ENTER>
23:30:00
=>
```

A quartz crystal oscillator provides the time base for the internal clock. You can set the time clock automatically with the relay time code input and a source of demodulated IRIG-B time code.

TRIGGER

TRIGGER generates an event record. After command entry, the relay responds "Triggered," and displays a record summary.

```
=>TRIGGER <ENTER>
Triggered

=>

Example 230 kV Line              Date: 4/1/92      Time:01:11:17.304

Event    : EXT    Location    :        mi       ohms sec
Duration:         Flt Current:


=>
```

Use TRIGGER to inspect the input voltages. For example, when the relay is first installed, execute the TRIGGER command, draw the phasors (Section 4: EVENT REPORTING gives an example of how to do this), and check for the proper polarity and phase-sequence of the inputs.

Access Level 2 Commands

While all commands are available from Access Level 2, the commands below are available only from Access Level 2. Remember, the relay pulses the ALARM contact closed for one second after any Level 2 access attempt.

CLOSE

The CLOSE command asserts the CLOSE output relay. You can also accomplish this by asserting the DIRECT CLOSE input as long as the 52A input or TRIP outputs are not asserted. The CLOSE output relay then remains closed until the 52A input is asserted (indicating that the circuit breaker is closed) or until the reclose reset timer (79RS) expires.

To close the circuit breaker with this command, type **CLOSE <ENTER>**. The prompting message "Close BREAKER (Y/N) ?" is displayed. **Y <ENTER>** yields a second prompting string: "Are you sure (Y/N) ?" Type **Y <ENTER>** to assert the CLOSE output relay, as long as the TRIP output and 52A input are not asserted. The relay transmits the message "Breaker CLOSED" once the breaker closes, or if it is already closed (as determined by the state of the 52A input). Typing **N <ENTER>** after either of the above prompts aborts the closing operation with the message "Aborted."

```
=>>CLOSE <ENTER>
Close BREAKER (Y/N) ? Y
Are you sure (Y/N) ? Y
Breaker CLOSED
=>>
```

LOGIC n

The LOGIC command programs the masks which control outputs and event report triggering.

The parameter N specifies a mask to program.

N		Mask
MTU	-	Mask for trip unconditional
MPT	-	Mask for trip with permissive trip asserted
MTB	-	Mask for trip with block trip deasserted
MTO	-	Mask for trip with breaker open (Switch-Onto-Fault logic)
MA1	-	Mask for A1 relay control
MA2	-	Mask for A2 relay control
MA3	-	Mask for A3 relay control
MA4	-	Mask for A4 relay control
MRI	-	Mask for reclose initiate
MRC	-	Mask for reclose cancel

The logic programming procedure requires you to enter changes to the mask or press <ENTER> to indicate no change. Each mask listed above is split into sections which correspond to the four rows of the Relay Word as follows:

RELAY WORD

Row 1	1ABC	2ABC	3ABC	4ABC	LOP	50H	50M	50L
Row 2	51NT	67N1	67N2	67N3	51NP	Z1P	Z2P	Z3P
Row 3	Z2PT	Z3PT	50L3	3P50	50MF	RC	RI	STOP
Row 4	50N3	TRIP	TC	DT	52BT	Z3X	Z2GT	Z3GT

The LOGIC command displays a header and settings for each row of the Relay Word. Next it displays a question mark prompt and waits for input. Enter only ones and zeros with no separating spaces as input; one selects and zero deselects a member of the Relay Word. Press <ENTER> when a group is satisfactory. If you wish to change any member of a group, you must re-enter all eight members, even if some remain the same. The relay repeats logic settings and the question mark prompt after entry of each row to allow corrections.

When all data are entered for each row, the relay displays the new settings and prompts for approval to enable the relay with them. **Y <ENTER>** enters the new data, pulses the ALARM contacts closed momentarily, and clears the event buffers. **N <ENTER>** retains the old settings.

LOGIC command example for the MTU mask:

```
=>>LOGIC MTU <ENTER>

1 selects, 0 deselects.

1ABC 2ABC 3ABC 4ABC LOP  50H  50M  50L
 0    0    0    0    0    0    0    0
 ? 10000000 <ENTER>
 1    0    0    0    0    0    0    0
 ? <ENTER>
51NT 67N1 67N2 67N3 51NP Z1P  Z2P  Z3P
 0    0    0    0    0    0    0    0
 ? 11000100 <ENTER>
 1    1    0    0    0    1    0    0
 ? <ENTER>
Z2PT Z3PT 50L3 3P50 50MF RC   RI   STOP
 0    0    0    0    0    0    0    0
 ? 11001000 <ENTER>
 1    1    0    0    1    0    0    0
 ? <ENTER>
50N3 TRIP TC   DT   52BT Z3X  Z2GT Z3GT
 0    0    0    0    0    0    0    0
 ? 00110011 <ENTER>
 0    0    1    1    0    0    1    1
 ? <ENTER>

New MTU :

1ABC 2ABC 3ABC 4ABC LOP  50H  50M  50L
 1    0    0    0    0    0    0    0
51NT 67N1 67N2 67N3 51NP Z1P  Z2P  Z3P
 1    1    0    0    0    1    0    0
Z2PT Z3PT 50L3 3P50 50MF RC   RI   STOP
 1    1    0    0    1    0    0    0
50N3 TRIP TC   DT   52BT Z3X  Z2GT Z3GT
 0    0    1    1    0    0    1    1

OK (Y/N) ? Y <ENTER>
Enabled

Example 230 kV Line              Date: 4/1/92       Time: 23:35:40


=>>
```

The previous example selects unconditional tripping for assertion of the Zone 1 three-phase, phase-phase, and ground elements, timeout of the 51N element, timeout of Zones 2 and 3 phase and ground timers executing the TRIP (OPEN) command, and assertion of the DT input. The 50MF selection enables unconditional tripping for loss-of-potential (LOP, when

LOPE is enabled) and 50M overcurrent conditions which persist for a settable time delay (50MFD).

Set the MPT, MTB, MTO, MA1, MA2, MA3, MA4, MRI, and MRC masks in a similar manner.

Note: You must set each programmable logic mask properly for your application. Please note that any mask identifier containing a "T" controls the TRIP output contacts.

OPEN (SEL-221G-6/121G-6 only)

The TRIP output relay closes in response to the OPEN command, as long as the TC (OPEN command) bit is selected in an appropriate trip mask (one or more of MTU, MPT, MTB, or MTO). The TRIP relay remains closed for a minimum duration (TDUR setting) starting with the rising edge of the trip output. The TRIP output drops out only if there is no low set overcurrent condition (50L or 50NL) or if you push the TARGET RESET button on the front panel.

OPEN (SEL-221G-7/121G-7 only)

The TRIP output relay closes in response to the OPEN command, as long as the TC (OPEN command) bit is selected in an appropriate trip mask (one or more of MTU, MPT, MTB, or MTO). The TRIP relay remains closed for the duration of the TDUR setting.

If the TDUR setting is zero, the OPEN command is disabled.

To open the power circuit breaker by command, type **OPEN <ENTER>**. The prompt "Open BREAKER (Y/N) ?" is transmitted. Answering **Y <ENTER>** yields a second prompt: "Are you Sure (Y/N) ?" Answering **Y <ENTER>** again closes the TRIP output relay as described above. The OPEN command aborts unless the remote open/close jumper (JMP104) is in place on the main board.

```
=>>OPEN <ENTER>
Open BREAKER (Y/N) ? Y<ENTER>
Are you sure (Y/N) ? Y<ENTER>
Breaker OPEN
=>>

Example 230 kV Line                Date: 4/1/92     Time: 23:36:10.887

Event   : TRIP   Location   :       mi       ohms sec
Duration:        Flt Current:


=>>
```

PASSWORD (1 or 2) [password]

PASSWORD allows you to inspect or change existing passwords. To inspect passwords, type **PASSWORD <ENTER>** as the following example shows:

```
=>>PASSWORD <ENTER>
1: OTTER
2: TAIL
=>>
```

To change the password for Access Level 1 to BIKE enter the following:

```
=>>PASSWORD 1 BIKE <ENTER>
Set
=>>
```

The relay sets the password, pulses the ALARM relay closed, and transmits the response "Set."

After entering new passwords, type **PASSWORD <ENTER>** to inspect them. Make sure they are what you intended and record the new passwords. There is no communications procedure to access the relay without the passwords.

Passwords can be any length up to six numbers, letters, or any other printable characters except delimiters (space, comma, semicolon, colon, slash). Upper and lower case letters are treated as different characters. Examples of valid, distinct passwords include:

OTTER otter Ot3456 +TAIL+ !@#$%^ 123456 12345. 12345

If the passwords are lost or you wish to operate the relay without password protection, install JMP103 on the main board. With no password protection, you may gain access without knowing the passwords and view or change current passwords and settings.

SET n

SET allows entry of relay settings. At the setting procedure prompts, enter new data or press **<ENTER>** to indicate no change. You can jump to a specific setting by entering the setting name as parameter N. If no setting is entered as an argument, the procedure initiates at the first setting, Relay ID.

The SET command prompts you for each setting. The relay checks new settings against established limits twice. If the setting is within primary setting range, the relay prompts you for the next setting. Press <ENTER> to retain an existing setting.

The first check is a primary setting limit check, the second is a secondary setting limit check. The primary check is intended as a rough guideline for individual settings and ensures that settings fall within a reasonable range. The secondary check compares the entire group of settings against the individual secondary setting limits shown in Section 2: SPECIFICATIONS.

When you finish entering setting changes, it is not necessary to scroll through the remaining settings. Type END <ENTER> after your last change to display the new settings and enable prompt. Do not use the END statement at the Relay ID setting; use <CTRL>X to abort the SET procedure from this point.

After you enter all data, the relay displays the new settings and prompts for approval to enable them. Answer Y <ENTER> to approve the new settings. Error messages notify you when entry combinations result in an out-of-range secondary setting. If all settings are acceptable, the relay enables them, closes the ALARM contact momentarily, and clears the event buffer.

A list of relay settings and the primary limit checks follow. Please note that each setting must also be within the secondary setting limit of the relay.

ID	39-character string to identify relay in event reports and SEL-DTA LCD display.
R1, X1	Positive-sequence primary impedance of line (0 - 9,999 ohms).
R0, X0	Zero-sequence primary impedance of line (0 - 9,999 ohms).
LL	Line length (0.1 - 999 miles).
CTR	CT ratio (e.g., for 600:5, enter 120) (1 - 5,000).
PTR	PT ratio (e.g., 1,200:1, enter 1200) (1 - 10,000).
MTA	Maximum torque angle (47° - 90°).
LOCAT	Do you want the fault locator enabled? (Y or N).
79OI1	Reclosing relay open interval 1 (¼ to 10,000 cycles; 0 disables shots 1, 2, and 3).
79OI2	Reclosing relay open interval 2 (¼ to 10,000 cycles; 0 disables shots 2 and 3).
79OI3	Reclosing relay open interval 3 (¼ to 10,000 cycles; 0 disables shot 3).
79RS	Reclosing relay reset time (60 to 8,000 cycles).
Z1%	Zone 1 reach (percent of positive-sequence line impedance: 0 - 2,000%).
Z2%	Zone 2 reach (percent of positive-sequence line impedance: 0 - 3,200%).
Z3%	Zone 3 reach (percent of positive-sequence line impedance: 0 - 3,200%).
Z2SP	Zone 2 short delay for phase and three-phase faults (0 - 60 cycles in quarter-cycle steps).
Z2DP	Zone 2 long delay for phase and three-phase faults (0 - 2,000 cycles in quarter-cycle steps).
Z3DP	Zone 3 delay for phase and three-phase faults (0 - 2,000 cycles in quarter-cycle steps).

50L3	Zones 3 and 4 phase overcurrent element low pickup (0.25 - 50,000 primary amperes).
50L	Zones 1 and 2 phase overcurrent element low pickup (0.25 - 50,000 primary amperes).
50M	Phase overcurrent element medium pickup (0.25 - 50,000 primary amperes).
50MFD	Phase overcurrent delay on loss-of-potential (0 - 60 cycles in quarter-cycle steps).
50H	Phase overcurrent element high pickup (0.25 - 50,000 primary amperes).
51NP	Residual time-overcurrent pickup (0.25 - 50,000 primary amperes).
51NTD	Residual time-overcurrent time dial (0.5 - 15).
51NC	Residual time-overcurrent curve index. Choices are as follows: 1 selects a moderately inverse curve 2 selects an inverse curve 3 selects a very inverse curve 4 selects an extremely inverse curve
51NTC	Do you want residual time-overcurrent torque control? (Y or N).
50N1P	Zone 1 instantaneous residual overcurrent pickup (0.25 - 50,000 primary amperes).
50N2P	Zone 2 instantaneous residual overcurrent pickup (0.25 - 50,000 primary amperes).
50N3P	Zone 3 instantaneous residual overcurrent pickup (0.25 - 50,000 primary amperes).
Z2SG	Zone 2 short delay for ground faults (0 - 60 cycles in quarter-cycle steps).
Z2DG	Zone 2 long delay for ground faults (0 - 2,000 cycles in quarter-cycle steps).
Z3DG	Zone 3 delay for ground faults (0 - 2,000 cycles in quarter-cycle steps).
TDUR	Minimum Trip Duration Timer (0 - 2,000 cycles in quarter-cycle steps).
LOPE	Block mho element tripping when loss-of-potential is detected? (Y or N).
52BT	52B time delay (0.5 to 10,000 cycles)
ZONE3	Zone 3 direction setting (F = forward or R = reverse).
32QE	Do you want negative-sequence directional supervision of the ground overcurrent elements? (Y or N).
32VE	Do you want to enable voltage polarization for the zero-sequence directional element? (Y or N).
32IE	Do you want to enable current polarization for the zero-sequence directional element? (Y or N).
TIME1	Timeout for PORT 1 communications (0 - 30 minutes, 0 = infinite timeout).
TIME2	Timeout for PORT 2 communications (0 - 30 minutes, 0 = infinite timeout).
AUTO	Destination for automatic messages (1 = PORT 1; 2 = PORT 2; 3 = both ports).
RINGS	Number of rings after which modem on PORT 1 answers (1 - 30 rings).

Refer to the functional description and be sure the settings you choose result in relay performance appropriate to your application.

The AUTO setting selects PORT 1, PORT 2, or both serial ports for automatically transmitted messages. If PORT 2 of the relay is connected to an SEL-DTA or SEL-PRTU, the AUTO setting must direct automatic messages to that port. The following table shows the effect of each possible setting:

Auto Setting	**Automatic Message Destination Port**
1	1
2	2
3	1 and 2

Event summaries and self-test warning and failure reports are automatically transmitted from port(s) designated automatic regardless of access level, if the designated port is not timed out. Enter zero as the timeout setting of the appropriate port if automatic transmissions will be monitored by a dedicated channel or printed on a dedicated printer.

SEL-221G/121G RELAY COMMAND SUMMARY

Access Level 0

ACCESS	Answer password prompt (if password protection is enabled) to enter Access Level 1. Three unsuccessful attempts pulse ALARM contacts closed for one second.

Access Level 1

2ACCESS	Answer password prompt (if password protection is enabled) to enter Access Level 2. This command always pulses the ALARM contacts closed for one second.
DATE m/d/y	Shows or set date. DAT 2/3/91 sets date to Feb. 3, 1991. IRIG-B time code input overrides existing month and day settings. DATE pulses ALARM contacts when year entered differs from year stored.
EVENT	Shows event record. EVE 1 shows newest event; EVE 12 shows oldest.
HISTORY	Shows DATE, TIME, TYPE, DIST (distance), DUR (duration), and CURR (maximum fault current) for the last twelve events.
IRIG	Forces immediate attempt to synchronize internal relay clock to time code input.
METER n	Displays primary phase-to-neutral and phase-to-phase voltages and currents and real and reactive power. Option n displays meter data n times.
QUIT	Returns control to Access Level 0; returns target display to Relay Targets.
SHOWSET	Displays settings without affecting them.
STATUS	Shows self-test status.
TARGET n k	Shows data and sets target LEDs as follows: TAR 0: Relay Targets — TAR 1: Relay Word row #1 TAR 2: Relay Word row #2 — TAR 3: Relay Word row #3 TAR 4: Relay Word row #4 — TAR 5: Contact Input States TAR 6: Contact Output States — TAR R: Clears Targets and returns to TAR 0 Option k displays target data k times.
TIME h/m/s	Shows or sets time. TIM 13/32/00 sets clock to 1:32:00 PM. IRIG-B synchronization overrides this setting.
TRIGGER	Triggers and saves an event record (event type is EXT).

Access Level 2

CLOSE	Closes circuit breaker, if allowed by jumper setting.
LOGIC n	Shows or sets logic masks MTU, MPT, MTB, MTO, MA1-MA4, MRI, and MRC. Command pulses ALARM contacts closed for one second and clears event buffers when new settings are stored.
OPEN	Opens circuit breaker, if allowed by jumper setting. TDUR=0 also disables the OPEN command.
PASSWORD	Shows or sets passwords. Command pulses ALARM contacts closed momentarily after password entry. PAS 1 OTTER sets Level 1 password to OTTER. PAS 2 TAIL sets Level 2 password to TAIL.
SET n	Initiates set procedure. Optional n directs relay to begin setting procedure at that setting. SET TDUR initiates setting procedure at TDUR setting. SET initiates setting procedure at beginning. Command pulses ALARM contacts closed and clears event buffers when new settings are stored.

EVENT REPORTING
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EVENT REPORTING

EVENT REPORT GENERATION

The relay generates a summary and long event report in response to actions listed in Table 4.1. The summary event report allows a quick review of the information necessary to determine the location and type of fault. The long event report displays eleven cycles of information for analyzing system and scheme performance.

Note: The relay need not trip to generate an event report.

Table 4.1: Event Report Triggering Actions

- Fault in any zone (except Zone 4)
- OPEN command execution (if a trip results)
- TRIGGER command execution
- DIRECT TRIP input assertion
- PERMISSIVE TRIP input assertion
- EXTERNAL TRIGGER input assertion
- TRIP output contact assertion

The relay generates a second summary and long event report for the same fault if the trip occurs after the end of the first report.

Actions listed in Table 4.2 do not trigger an event report.

Table 4.2: Non-Event Report Triggering Actions

- CLOSE command execution
- DIRECT CLOSE input assertion
- 52A input status changes
- BLOCK TRIP input assertion
- Pickup of the 50L overcurrent element
- Pickup of the 50L3 overcurrent element
- Fault within the Zone 4 reach
- Pickup of the 50M overcurrent element

Relay elements which trigger event reports must drop out for at least four cycles before they can initiate another event report. This helps to eliminate multiple records for boundary faults.

Triggering is recorded to the nearest quarter-cycle (4.17 ms) and referenced to the 16th row of data in the report. All reports trigger at row 16. This system allows you to determine the total duration of a long fault which triggers two event reports. Simply calculate the time difference between the report generated at fault inception and the report generated by the TRIP.

SUMMARY EVENT REPORT

The summary report is automatically transmitted from port(s) designated AUTOMATIC regardless of access level, as long as the designated port has not timed out. If automatic transmissions are monitored by a dedicated channel or printed on a dedicated printer, enter a timeout setting of zero for the appropriate port.

Due to the length of the full report, it is not automatically transmitted. You can display the full report with the EVENT command.

The summary event report includes:

- Relay terminal identifier
- Date and time
- Event type
- Fault location
- Secondary ohms from relay to fault location
- Duration relay elements are picked up
- Maximum phase current measured near the middle of fault

The following shows an example summary event report.

```
Example 230 kV Line             Date: 4/1/92     Time: 15:57:06.329

Event   : 1AG    Location   : 76.04  mi 6.11   ohms sec
Duration: 7.25   Flt Current: 1024.1


=>
```

The relay clears the event report and history buffer for the following conditions:

- Loss of control power
- Entry of a new setting via the SET or LOGIC commands

LONG EVENT REPORT

The long event report contains 44 quarter-cycles of pre-fault, fault, and post-fault voltage and current information. For each quarter-cycle of voltage and current information, the relay also records the states of all fault measuring elements, outputs, and inputs. This information is useful in reviewing fault inception and duration, relay element response, fault evolution, interaction with the communications equipment, and breaker reaction time.

The last twelve event records are stored in volatile memory. You can review the stored summary reports quickly with the HISTORY command; use the EVENT command to display the long form of each event report.

INTERPRETATION OF VOLTAGE AND CURRENT DATA

Voltage and current data in the event report are determined using the following steps. The process uses secondary quantities presented to the rear panel of the relay.

1. Input analog signals are filtered by two pole, low pass filters with cutoff frequencies of approximately 85 Hz.

2. Filtered analog signals are sampled four times per power system cycle and converted to numerical values.

3. A digital filter processes the sampled data and removes dc and ramp components. The unit sample response of this filter is:

   $$1, -1, -1, 1$$

   The filter has the property of a double differentiator smoother.

4. The latest four samples are processed through the digital filter every quarter-cycle. Successive outputs of the filter arrive every 90 degrees. With respect to the present value of the filter output, the previous value was taken one quarter-cycle earlier and appears to be leading the present value by 90 degrees.

   Filter output values can be used to represent the signals as phasors:

   The previous value of the output is the Y-component.
   The present value of the output is the X-component.

It may seem confusing to refer to the older data as the leading component of the phasor. The following example may help.

Consider a sinewave having zero phase shift with respect to t=0 and a peak amplitude of 1. Now consider two samples, one taken at t=0, the other taken 90 degrees later. They have values 0 and 1, respectively. By the above rules, the phasor components are (X,Y) = (1,0).

Now consider a cosine function. Its samples taken at t=0 and t+90 degrees are 1 and 0; its phasor representation is (0,1). The phasor (0,1) leads the phasor (1,0) by 90 degrees. This coincides with a 90 degree lead of the cosine function over the sine function.

To construct a phasor diagram of voltages and currents, select a pair of adjacent rows from an area of interest in the event report. On Cartesian coordinates, plot the lower row (newer data) as the X-components and the upper row (older data) as the Y-components. Rotate the completed diagram to any angle of reference. The magnitude of any phasor equals the square root of the sum of its squares.

Note that moving forward one quarter-cycle rotates all phasors 90 degrees. You can verify this by plotting the phasor diagram with rows 1 and 2, then rows 2 and 3 of an event report. Example Event 1 shows the process of converting the rectangular format voltages and currents displayed in the event report to polar format.

RELAYS

The states of all relay elements are indicated in the six columns headed "Relays." Active states of the various relay elements are indicated by designator symbols which correspond with the relay element names. The contents of the columns for active relay elements appear below. Assertion of the 50M, 50L, and LOP elements do not trigger an event report.

50P	:	Phase overcurrent elements	:	H	=	50H	high-set picked up
				M	=	50M	medium-set picked up
				L	=	50L	Zones 1 & 2 low-set picked up
				1	=	50L3	Zones 3 & 4 low-set picked up
213	:	Three-phase distance units	:	1	=	Z1	Zone 1 picked up
				2	=	Z2	Zone 2 picked up (delayed by Z2SP)
				3	=	Z3	Zone 3 picked up
				4	=	Z4	Zone 4 picked up
21P	:	Two-phase distance units	:	1	=	Z1	Zone 1 picked up
				2	=	Z2	Zone 2 picked up (delayed by Z2SP)
				3	=	Z3	Zone 3 picked up
67N	:	Residual overcurrent units	:	1	=	67N1	high-set picked up
				2	=	67N2	medium-set picked up (delayed by Z2SG)
				3	=	67N3	low set picked up

51N	:	Residual time-overcurrent	:	P	=	51NP	51N element picked up
				T	=	TRIP	51N trip threshold reached
LOP	:	Loss-of-Potential detect	:	*	=	LOP	

CONTACT OUTPUTS AND INPUTS

The next two columns (headed "Outputs" and "Inputs") show the states of all output and input contacts. The report indicates assertion of an output or input contact with an asterisk (*) in the corresponding column; a period indicates deassertion. The following list shows the contents of these columns.

OUTPUTS

TP : TRIP output
CL : CLOSE output
A1 : Programmable output #1
A2 : Programmable output #2
A3 : Programmable output #3
A4 : Programmable output #4
AL : ALARM output

INPUTS

DT : DIRECT TRIP input
PT : PERMISSIVE TRIP input
BT : BLOCK TRIP input
DC : DIRECT CLOSE input
52A : BREAKER AUXILIARY 52A SWITCH input
ET : EXTERNAL TRIGGER input

EXAMPLE EVENT REPORTS

One possible relay application is a Directional Comparison Blocking (DCB) scheme as shown in Figure 4.1. This figure shows two parallel transmission lines, each line protected by two SEL-121G-6 or SEL-221G-6 Relays using on/off power line carrier as the means of communication.

Zone 3 and 4 elements on each relay are reversed for use as carrier start elements. Each relay is set to trip independently from carrier as directed by the elements masked in the Mask for Unconditional Trip (MTU). Elements masked in the MTU logic mask include the instantaneous Zone 1 phase-phase (Z1P) and three-phase distance elements (1ABC), Zone 1 residual instantaneous element (67N1), the nondirectional time delayed 50MF element to protect the transmission line following a blown secondary potential fuse, Zone 2 and 3 phase distance and residual overcurrent timed elements (Z2PT, Z3PT, Z2GT and Z3GT respectively), and the residual time-overcurrent element (51NT). This logic provides time graded backup protection. The MTU logic mask also includes the TC bit, which asserts after OPEN command execution and the DT bit, which follows DT input assertion on the relay rear panel.

Each relay can also trip from its Mask for Trip Blocking (MTB) if forward Zone 2 elements (2ABC, Z2P, and 67N2) pick up and the Block Trip (BT) input is not asserted after the associated carrier coordinating time delays for these elements expire.

During line tests, each relay is enabled to trip from elements masked into the Mask for Trip while breaker Open (MTO). This logic serves as the switch-onto-fault protection. MTO elements include Zone 1 and 2 three-phase distance elements (1ABC and 2ABC), the high-set 50H phase overcurrent element, Zones 1 and 2 instantaneous residual overcurrent elements (67N1 and 67N2), and Zone 1 and 2 phase-phase distance elements (Z1P and Z2P).

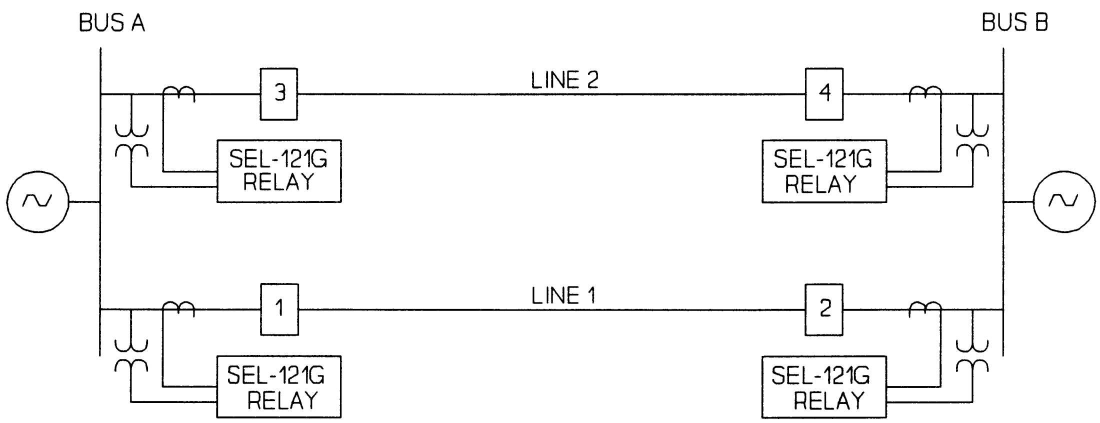


Figure 4.1: Example Transmission Line Protection

Externally Triggered Event Report

Recall from Section 3: COMMUNICATIONS that the relay records an eleven-cycle "snapshot" event report when you issue the TRIGGER command. This command does not affect the protective functions of the relay. The event type listing EXT signifies an externally triggered event. For events triggered by this command, the report does not include a fault location, fault impedance in secondary ohms, fault duration, or maximum fault current. Use the TRIGGER command to generate an event report for plotting voltage and current phasors during normal load conditions prior to releasing the relay for service.

Example Event Report 1

```
Example 230 kV Line                    Date: 4/1/92      Time: 09:43:06.395
FID=SEL-121G6-R400-V656mptr12syzr2-D920228-E2
                 Currents                   Voltages         Relays Outputs Inputs
                  (amps)                      (kV)
                                                             52265L TCAAAAA DPBD5E
  IPOL     IR     IA     IB     IC     VA     VB     VC      011710 PL1234L TTTC2T
                                                             P3PNNP               A

   0       -2   -101    195   -104  -85.4  131.5  -46.4     ...... ....... ....*.
   0        2   -170      0    176 -103.1  -22.1  125.8     ...... ....... ....*.
   0        2    101   -195    101   85.4 -131.5   46.4     ...... ....... ....*.
   0       -2    170      0   -176  103.1   22.1 -125.8     ...... ....... ....*.

Event    : EXT      Location    :        mi        ohms sec
Duration:           Flt Current:
```

SEL DIRECTION AND POLARITY CHECK FORM

STATION SEL DATE: 4 / 1 / 92 TESTED BY ____________

SWITCH NO. ____________ EQUIPMENT SEL-221G-6 Relay

INSTALLATION ________ ROUTINE X OTHER ____________

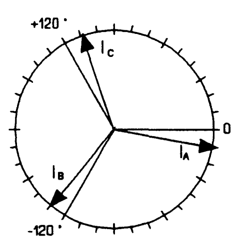
LOAD CONDITIONS:

STATION READINGS: ______ MW (OUT)(IN) ______ MVAR (OUT)(IN) ______ VOLTS ______ AMPS

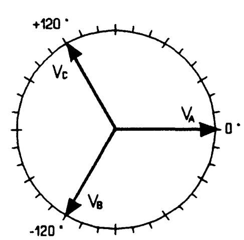
SEL READINGS: 155 MW (+)(-) 27 MVAR (+)(-)

AS SEEN ON SCREEN	Ia	Ib	Ic	Va	Vb	Vc	
COMPANY NOTATION	I(a)	I(b)	I(c)	V(a)	V(b)	V(c)	
1st LINE CHOSEN (Y COMPONENT)	-101	195	-104	-85.4	131.5	-46.4	
2nd LINE CHOSEN (X COMPONENT)	-170	0	176	-103.1	-22.1	125.8	
CALCULATED MAGNITUDE $\sqrt{X^2 + Y^2}$	197.74	195.00	204.43	133.88	133.34	134.08	ROW 1
ANGLE IN DEGREES ARCTAN Y/X	-149.28	+90	-30.58	-140.36	+99.54	-20.25	
VALUE OF Va DEGREES TO SUBTRACT TO OBTAIN Va DEGREES = 0	-219.64	-219.64	-219.64	-219.64	-219.64	-219.64	
@ Va DEGREES = 0, ANGLE USED TO DRAW PHASOR DIAGRAM	-8.92	-129.64	-250.22	0	-120.10	-239.89	ROW 2

USE THE VALUES IN ROWS 1 AND 2 ABOVE TO DRAW PHASOR DIAGRAMS BELOW



CURRENTS



VOLTAGES

Example Event Report 1 shows the first cycle of normal operating conditions for Breaker 1. The event report was generated with the TRIGGER command. From this excerpt, you can immediately see that load currents are balanced by the lack of current in the IR column. Also, note that the line breaker is closed, as signified by the asterisk in the 52A column.

Event report data for the voltages and currents is displayed in rectangular format. You can easily convert these rectangular values to polar format as described under Interpretation of Voltage and Current Data. Section 6: INSTALLATION includes a blank voltage and current polarity check form for plotting voltage and current phasors. A completed direction and polarity check form using the first two rows of data from the event report follows Example Event Report 1.

Using the voltage and current phasor diagrams at the end of the SEL Direction and Polarity Check Form, note that the current and voltage phase rotation is ABC in the clockwise direction. This phase rotation must match the rotation of your system. In addition, note that the load is flowing out from Breaker 1 as indicated by each phase current lagging the respective phase voltage by the load flow angle.

In-Section Zone 2 BC Fault

Example Event Report 2 shows an in-section fault as viewed from Breaker 1 at Bus A. This report was generated by assertion of the Zone 2 phase-phase distance element in the sixteenth row of data (after the timeout of the Z2SP timer for carrier coordination). The date and time tags at the top of the event report are referenced to this row of data. The relay labeled the event a Zone 2 BC fault and calculated a fault location 85.75 miles from the relay terminal. The relay is expected to trip for this fault. The fault detecting element is the Zone 2 phase-phase element. The qualifying condition is the lack of a blocking signal from Breaker 2 on Line 1 after the carrier coordinating time delay of Z2SP expires. Figure 4.2 shows the fault placement on Line 1.

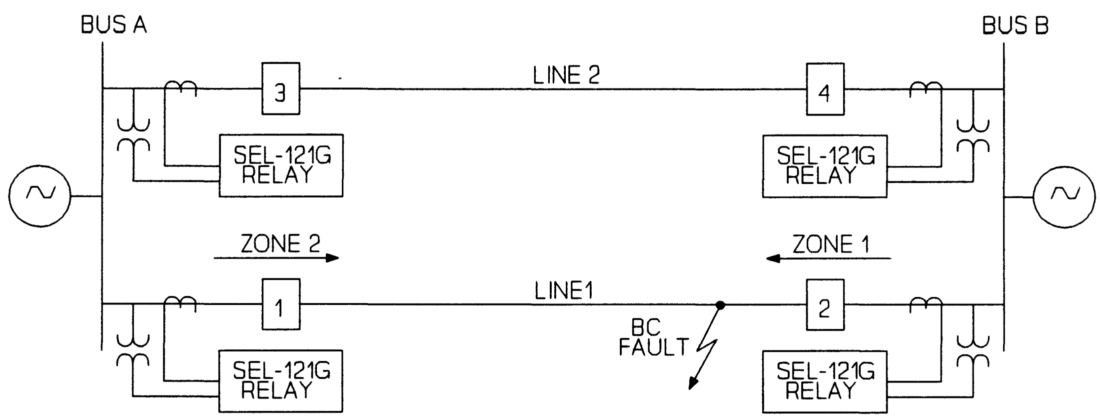


Figure 4.2: Zone 2 BC Fault 85 Miles from Breaker 1

Example Event Report 2

```
Example 230 kV Line                          Date: 4/1/92       Time: 09:23:26.141

FID=SEL-121G6-R400-V656mptr12syzr2-D920228-E2

                  Currents                      Voltages        Relays Outputs Inputs
                   (amps)                         (kV)
                                                                52265L TCAAAAA DPBD5E
  IPOL      IR      IA      IB      IC     VA      VB      VC   011710 PL1234L TTTC2T
                                                                P3PNNP              A

     0      -4     -88      85       0 -128.9    93.9    34.4   ...... ....... ....*.
     0       0     -44     -50      94  -34.2   -94.2   128.1   ...... ....... ....*.
     0       4      88     -82       0  128.9   -93.9   -34.4   ...... ....... ....*.
     0       0      44      50     -94   34.1    94.3  -128.0   ...... ....... ....*.

     0      -4     -85      82       0 -128.9    93.9    34.4   ...... ....... ....*.
     0       0     -47     -50      94  -34.1   -94.3   128.0   ...... ....... ....*.
     0       4      85     -79       0  128.9   -93.8   -34.4   ...... ....... ....*.
     0       0      47      50     -98   34.1    94.2  -127.9   ...... ....... ....*.

     0     -18     -85     349    -283 -129.0    89.5    38.8   L..... ....... ....*.
     0     -13     -47      13      22  -34.0   -86.4   120.2   L..... ....... ....*.
     0      53      85    -953     922  128.9   -86.7   -41.8   M..... ....... ....*.
     0      31      47    -132     116   34.0    76.4  -110.2   M..... ....... ....*.

     0     -75     -85    1328   -1321 -128.9    88.2    40.3   M..... ....... ....*.
     0     -38     -47     195    -186  -34.0   -73.7   107.5   M..... ....... ....*.
     0      77      85   -1378    1372  128.9   -88.3   -40.2   M..... ....... ....*.
     0      40      47    -198     195   34.0    73.4  -107.2   M.2... *..*... ....*.

     0     -80     -85    1381   -1378 -129.0    88.3    40.2   M.2... *..*... ....*.
     0     -40     -47     198    -195  -34.0   -73.3   107.1   M.2... *..*... ....*.
     0      80      85   -1378    1378  129.0   -88.3   -40.3   M.2... *..*... ....*.
     0      40      47    -201     195   33.9    73.4  -107.0   M.2... *..*... ....*.

     0     -80     -88    1378   -1378 -129.0    88.3    40.3   M.2... *..*... ....*.
     0     -42     -44     201    -195  -33.9   -73.4   107.0   M.2... *..*... ....*.
     0      82      88   -1378    1378  129.0   -88.3   -40.2   M.2... *..*... ....*.
     0      42      44    -204     198   33.9    73.5  -107.2   M.2... *..*... ....*.

     0     -69     -72    1082   -1085 -129.0    92.6    36.1   M.2... *..*... ....*.
     0     -29     -31     160    -154  -33.9   -81.3   114.9   M.2... *..*... ....*.
     0      31      31    -440     447  129.0   -95.3   -33.2   L..... *..*... ....*.
     0      11      13     -66      60   33.9    91.4  -124.8   L..... *..*... ....*.

     0      -7      -6      53     -57 -129.0    93.7    34.5   ...... *..*... ......
     0      -2      -3       9      -6  -33.8   -94.1   127.5   ...... *..*... ......
     0       4       3      -6       6  129.0   -93.6   -34.7   ...... *..*... ......
     0       0       0       0       0   33.8    94.4  -127.9   ...... *..*... ......

     0      -4       0       0       0 -129.0    93.6    34.7   ...... *..*... ......
     0       0       0       0       0  -33.8   -94.5   127.9   ...... *..*... ......
     0       4       0       0       0  129.0   -93.6   -34.7   ...... *..*... ......
     0       0       0       0       0   33.7    94.5  -127.9   ...... *..*... ......

     0      -4       0       0       0 -129.0    93.6    34.7   ...... *..*... ......
     0       0       0       0       0  -33.7   -94.6   127.9   ...... *..*... ......
     0       4       0       0       0  129.0   -93.5   -34.9   ...... *..*... ......
     0       0       0       0       0   33.7    94.6  -127.8   ...... *..*... ......

     0      -4       0       0       0 -129.0    93.4    34.9   ...... *..*... ......
     0       0       0       0       0  -33.7   -94.6   127.8   ...... *..*... ......
     0       4       0       0       0  129.0   -93.4   -34.9   ...... *..*... ......
     0       0       0       0       0   33.6    94.6  -127.8   ...... *..*... ......

Event   : 2BC      Location    : 85.75  mi   6.71    ohms sec
Duration: 2.75     Flt Current: 1392.6

R1   =8.56         X1   =77.77        R0   =35.12       X0   =236.96    LL   =100.00
CTR  =200.00       PTR  =2000.00      MTA  =83.72       LOCAT=Y
79OI1=40.00        79OI2=60.00        79OI3=80.00       79RS =240.00
Z1%  =80.00        Z2%  =120.00       Z3%  =120.00
Z2SP =0.75         Z2DP =20.00        Z3DP =60.00
50L3 =275.00       50L  =275.00       50M  =500.00      50MFD=20.00     50H  =3420.00
51NP =230.00       51NTD=4.00         51NC =3           51NTC=Y
50N1P=835.00       50N2P=276.00       50N3P=282.00
Z2SG =0.75         Z2DG =30.00        Z3DG =60.00       TDUR =9.00      LOPE =Y
52BT =20.00        ZONE3=R            32QE =Y           32VE =N         32IE =N
TIME1=5            TIME2=0            AUTO =2           RINGS=7

Logic settings:

MTU  MPT  MTB  MTO  MA1  MA2  MA3  MA4  MRI  MRC
80   00   40   C4   30   00   00   08   00   E4
C4   00   22   E6   11   00   00   00   44   80
C8   00   00   00   00   01   04   00   00   C8
33   00   00   00   84   40   00   00   00   33
```

The following is the first four cycles (quarter-cycles 1 - 16) of Event Report 2, showing pre-fault and fault inception conditions.

```
              Currents                          Voltages        Relays Outputs Inputs
               (amps)                             (kV)
                                                                52265L TCAAAAA DPBD5E
IPOL    IR      IA      IB      IC      VA      VB       VC     011710 PL1234L TTTC2T
                                                                P3PNNP              A        Quarter-Cycle

  0     -4     -88      85       0  -128.9    93.9     34.4    ...... ....... ....*.            1
  0      0     -44     -50      94   -34.2   -94.2    128.1    ...... ....... ....*.            2
  0      4      88     -82       0   128.9   -93.9    -34.4    ...... ....... ....*.            3
  0      0      44      50     -94    34.1    94.3   -128.0    ...... ....... ....*.            4

  0     -4     -85      82       0  -128.9    93.9     34.4    ...... ....... ....*.            5
  0      0     -47     -50      94   -34.1   -94.3    128.0    ...... ....... ....*.            6
  0      4      85     -79       0   128.9   -93.8    -34.4    ...... ....... ....*.            7
  0      0      47      50     -98    34.1    94.2   -127.9    ...... ....... ....*.            8

  0    -18     -85     349    -283  -129.0    89.5     38.8    L..... ....... ....*.            9
  0    -13     -47      13      22   -34.0   -86.4    120.2    L..... ....... ....*.           10
  0     53      85    -953     922   128.9   -86.7    -41.8    M..... ....... ....*.           11
  0     31      47    -132     116    34.0    76.4   -110.2    M..... ....... ....*.           12

  0    -75     -85    1328   -1321  -128.9    88.2     40.3    M..... ....... ....*.           13
  0    -38     -47     195    -186   -34.0   -73.7    107.5    M..... ....... ....*.           14
  0     77      85   -1378    1372   128.9   -88.3    -40.2    M..... ....... ....*.           15
  0     40      47    -198     195    34.0    73.4   -107.2    M.2... *..*... ....*.           16
```

The event report uses a sequence of event format which allows performance analysis of the system by quarter-cycles. Through this analysis, you can observe the pre-fault voltage and current conditions prior to the fault, determine whether or not the breaker was closed by the 52A Inputs column and line current magnitudes, and learn when the Zone 2 element asserted relative to the block trip signal arrival. Please note that assertion of the Zone 2 element is not displayed until the corresponding short timer expires. The following outline lists observed incidents shown in Example Event Report 2 by quarter-cycle.

Quarter-Cycle	Event Report Shows:
1-8	Pre-fault conditions: • No residual current in IR column indicates balanced load currents. • No protective relay elements are picked up. • * in 52A Inputs column verifies breaker closure (as does load current flow).
9-10	Fault Inception: • L in 50P column shows fault current reached 50L element pickup threshold.
11-15	• M in 50P column shows fault current reached 50M element pickup threshold. • Period in BT Inputs column indicates that no block trip signal has arrived from Breaker 2.
16	• 2 in 21P column shows when Zone 2 phase-phase element picked up. Also note that this output asserted after the Z2SP timer expired. • * in A2 Outputs column reveals A2 output contact closure. Logic settings below relay settings show the relay keyed the stop carrier input to the communications equipment when the STOP Relay Word bit asserted [STOP = ((Relay Word) * (MTB Mask)) * NOT(Z3X)]. • * in TP Outputs column indicates TRIP output contact assertion.

The relay closed the TRIP output in row 16 because a Zone 2 element was picked up for Z2SP time and the BT input was not asserted. The remaining quarter-cycles of the report show the breaker clearing the fault after being instructed to trip.

The following excerpt from Example Event Report 2 shows cycles five through seven (quarter-cycles 17 - 29). These cycles represent the mid-fault conditions.

```
             Currents                          Voltages         Relays Outputs Inputs
              (amps)                             (kV)
                                                                52265L TCAAAAA DPBD5E
IPOL    IR      IA      IB      IC      VA      VB      VC      011710 PL1234L TTTC2T
                                                                P3PNNP              A            Quarter-Cycle

  0    -80     -85    1381   -1378  -129.0    88.3    40.2     M.2... *..*... ....*.                 17
  0    -40     -47     198    -195   -34.0   -73.3   107.1     M.2... *..*... ....*.                 18
  0     80      85   -1378    1378   129.0   -88.3   -40.3     M.2... *..*... ....*.                 19
  0     40      47    -201     195    33.9    73.4  -107.0     M.2... *..*... ....*.                 20

  0    -80     -88    1378   -1378  -129.0    88.3    40.3     M.2... *..*... ....*.                 21
  0    -42     -44     201    -195   -33.9   -73.4   107.0     M.2... *..*... ....*.                 22
  0     82      88   -1378    1378   129.0   -88.3   -40.2     M.2... *..*... ....*.                 23
  0     42      44    -204     198    33.9    73.5  -107.2     M.2... *..*... ....*.                 24

  0    -69     -72    1082   -1085  -129.0    92.6    36.1     M.2... *..*... ....*.                 25
  0    -29     -31     160    -154   -33.9   -81.3   114.9     M.2... *..*... ....*.                 26
  0     31      31    -440     447   129.0   -95.3   -33.2     L..... *..*... ....*.                 27
  0     11      13     -66      60    33.9    91.4  -124.8     L..... *..*... ....*.                 28

  0     -7      -6      53     -57  -129.0    93.7    34.5     ...... *..*... ......                 29
```

Quarter-Cycle	Event Report Shows:
	Mid-fault conditions:
25	• * in 52A Inputs column indicates breaker auxiliary contacts are still closed.
	• 2 in 21P column indicates Zone 2 phase-phase element is picked up.
	• Period in BT Inputs column indicates no block trip receive signal is present. This input never asserts in this event report.
	• * in A2 Outputs column indicates that the relay is keying carrier stop. This output remains asserted until the TRIP output unlatches because the TRIP bit is masked into MA2.
	• * in TP Outputs column indicates TRIP output closure. TRIP output remains closed for at least TDUR duration. In this example, TDUR setting is nine cycles.
27-28	• Period in 21P column indicates that Zone 2 phase-phase element is dropped out.
	• L in 50P column indicates that 50M element is dropped out (50L is now the only overcurrent element picked up).
	• * in 52A Inputs column indicates breaker auxiliary contacts are still closed.
29	• Period in 50P column indicates phase currents below 50L setting threshold.
	• Period in 52A Inputs column indicates breaker auxiliary contacts have opened.

Reverse Out-of-Section Fault

Example Event Report 3 shows a reverse A-phase ground fault which does not result in a trip at Breaker 1. Referring to Figure 4.1, faults on Line 2 should be cleared by Breakers 3 and 4.

The relay at Breaker 1 sees the initial fault on Line 2 with a nondirectional 50N3 instantaneous ground overcurrent element. The relay at Breaker 3 trips instantaneously to clear its contributions to the fault. The pickup of the nondirectional element at Breaker 1 keys carrier to block the protection from operating at Breaker 2. Because the reverse Zone 3 67N3 directional ground overcurrent element asserts for more than two cycles, the Z3X bit in the A1 contact logic mask asserts for five cycles after 67N3 element dropout. This action gives additional security for out-of-section faults.

Example Event Report 3

```
Example 230 kV Line                              Date: 4/1/92      Time: 09:39:22.579
FID=SEL-121G6-R400-V656mptr12syzr2-D920228-E2

                   Currents                         Voltages          Relays  Outputs  Inputs
                    (amps)                            (kV)
                                                                      52265L  TCAAAAA  DPBD5E
   IPOL      IR      IA      IB      IC      VA      VB      VC       011710  PL1234L  TTTC2T
                                                                      P3PNNP                A

      0       0      13      79     -91   -15.3   122.6  -107.0       ......  .......  ....*.
      0      -4     -94      60      35  -133.1    53.2    79.0       ......  .......  ....*.
      0       0     -13     -79      91    15.5  -122.6   107.0       ......  .......  ....*.
      0       4      98     -60     -35   133.1   -53.2   -79.0       ......  .......  ....*.

      0       0       9      79     -91   -15.5   122.6  -107.0       ......  .......  ....*.
      0      -4     -98      60      35  -133.1    53.0    79.0       ......  .......  ....*.
      0       0      -9     -79      91    15.5  -122.6   107.0       ......  .......  ....*.
      0       4      94     -60     -35   133.1   -53.0   -79.0       ......  .......  ....*.

      0       0      13      79     -91   -15.5   122.6  -107.0       ......  .......  ....*.
      0      -4     -94      60      35  -133.0    53.0    79.0       ......  .......  ....*.
      0       0     -13     -79      91    15.5  -122.6   107.0       ......  .......  ....*.
      0       4      94     -60     -35   132.7   -53.0   -79.2       ......  .......  ....*.

      0     -44     -28      79     -91   -16.2   122.3  -107.2       ......  .......  ....*.
      0     -18    -110      60      35   -97.8    61.3    87.5       ......  .......  ....*.
      0     316     299     -79      91     7.9  -123.3   105.5       L.....  ..*....  ....*.
      0    -100      -3     -60     -35    35.6   -76.4  -102.5       L..3..  ..*....  ....*.

      0    -606    -595      79     -91     0.8   124.2  -103.8       M..3..  ..*....  ....*.
      0     246     148      60      35    -4.5    84.4   110.0       M..3..  ..*....  ....*.
      0     677     667     -79      91    -0.3  -123.8   104.0       M..3..  ..*....  ....*.
      0    -263    -164     -60     -35     0.6   -85.4  -111.1       M..3..  ..*....  ....*.

      0    -688    -676      79     -91     0.1   123.8  -104.0       M..3..  ..*....  ....*.
      0     268     167      60      35    -0.1    85.5   111.2       M..3..  ..*....  ....*.
      0     688     680     -79      91     0.0  -123.8   104.0       M..3..  ..*....  ....*.
      0    -268    -170     -60     -35     0.1   -85.5  -111.3       M..3..  ..*....  ....*.

      0    -688    -680      79     -91     0.0   123.8  -104.0       M..3..  ..*....  ....*.
      0     268     170      60      35    -0.1    85.5   111.3       M..3..  ..*....  ....*.
      0     688     676     -79      91     0.0  -123.8   104.0       M..3..  ..*....  ....*.
      0    -268    -167     -60     -35     0.4   -85.3  -111.2       M..3..  ..*....  ....*.

      0    -644    -632      76     -85     0.7   124.2  -103.8       M..3..  ..*....  ....*.
      0     281     201      35      35   -35.4    77.0   102.9       M..3..  ..*....  ....*.
      0     372     365     -41      50     7.7  -123.2   105.4       L..3..  ..*....  ....*.
      0    -164    -132      -6     -19    97.6   -61.9   -88.0       L..3..  ..*....  ....*.

      0     -82     -79       6     -13   -16.5   122.3  -107.2       ......  ..*....  ....*.
      0      18      13       0       0  -128.5    53.9    80.4       ......  ..*....  ....*.
      0       0     -13     -79      91    15.5  -122.6   107.0       ......  ..*....  ....*.
      0       4      98     -60     -35   133.1   -53.2   -79.0       ......  ..*....  ....*.

      0       0      13      79     -91   -15.3   122.6  -107.0       ......  ..*....  ....*.
      0      -4     -94      60      35  -133.1    53.2    79.0       ......  ..*....  ....*.
      0       0     -13     -79      91    15.5  -122.6   107.0       ......  ..*....  ....*.
      0       4      98     -60     -35   133.1   -53.2   -79.0       ......  ..*....  ....*.

      0       0       9      79     -91   -15.5   122.6  -107.0       ......  ..*....  ....*.
      0      -4     -98      60      35  -133.1    53.0    79.0       ......  ..*....  ....*.
      0       0      -9     -79      91    15.5  -122.6   107.0       ......  ..*....  ....*.
      0       4      94     -60     -35   133.1   -53.0   -79.0       ......  ..*....  ....*.

Event   : 3AG      Location   : -0.08  mi  -0.01  ohms sec
Duration: 4.25     Flt Current: 700.5

R1   =8.56       X1   =77.77      R0   =35.12      X0   =236.96     LL    =100.00
CTR  =200.00     PTR  =2000.00    MTA  =83.72      LOCAT=Y
790I1=40.00      790I2=60.00      790I3=80.00      79RS =240.00
Z1%  =80.00      Z2%  =120.00     Z3%  =120.00
Z2SP =0.75       Z2DP =20.00      Z3DP =60.00
50L3 =275.00     50L  =275.00     50M  =500.00     50MFD=20.00      50H   =3420.00
51NP =230.00     51NTD=4.00       51NC =3          51NTC=Y
50N1P=835.00     50N2P=276.00     50N3P=282.00
Z2SG =0.75       Z2DG =30.00      Z3DG =60.00      TDUR =9.00       LOPE  =Y
52BT =20.00      ZONE3=R          32QE =Y          32VE =N          32IE  =N
TIME1=5          TIME2=0          AUTO =2          RINGS=7

Logic settings:

MTU  MPT  MTB  MTO  MA1  MA2  MA3  MA4  MRI  MRC
80   00   40   C4   30   00   00   08   00   E4
C4   00   22   E6   11   00   00   00   44   80
C8   00   00   00   00   01   04   00   00   C8
33   00   00   00   84   40   00   00   00   33
```

The following excerpt shows the first 16 quarter-cycles of pre-fault data for Example Event Report 3.

IPOL	IR (Currents, amps)	IA	IB	IC	VA (Voltages, kV)	VB	VC	Relays 52265L 011710 P3PNNP	Outputs TCAAAAA PL1234L	Inputs DPBD5E TTTC2T A	Quarter-Cycle
0	0	13	79	-91	-15.3	122.6	-107.0	......	....	....*.	1
0	-4	-94	60	35	-133.1	53.2	79.0	......	....	....*.	2
0	0	-13	-79	91	15.5	-122.6	107.0	......	....	....*.	3
0	4	98	-60	-35	133.1	-53.2	-79.0	......	....	....*.	4
0	0	9	79	-91	-15.5	122.6	-107.0	......	....	....*.	5
0	-4	-98	60	35	-133.1	53.0	79.0	......	....	....*.	6
0	0	-9	-79	91	15.5	-122.6	107.0	......	....	....*.	7
0	4	94	-60	-35	133.1	-53.0	-79.0	......	....	....*.	8
0	0	13	79	-91	-15.5	122.6	-107.0	......	....	....*.	9
0	-4	-94	60	35	-133.0	53.0	79.0	......	....	....*.	10
0	0	-13	-79	91	15.5	-122.6	107.0	......	....	....*.	11
0	4	94	-60	-35	132.7	-53.0	-79.2	......	....	....*.	12
0	-44	-28	79	-91	-16.2	122.3	-107.2	......	....	....*.	13
0	-18	-110	60	35	-97.8	61.3	87.5	......	....	....*.	14
0	316	299	-79	91	7.9	-123.3	105.5	L.....	..*....	....*.	15
0	-100	-3	-60	-35	35.6	-76.4	-102.5	L..3..	..*....	....*.	16

Quarter-Cycle	Event Report Shows:
1-14	Pre-fault conditions: • No residual current in IR column indicates balanced load currents. • No protective relay elements are picked up. • * in 52A Inputs column verifies breaker closure (as does load current flow).
15	Fault Inception: • L in 50P column shows that fault current reached 50L element pickup threshold. • * in the A1 output column shows a contact closure to the carrier start signal in the communications equipment which sends the block signal to the remote relay at Breaker 2.

Note: This block signal comes from the nondirectional 50N3 element pickup. The 67N3 directional ground overcurrent element asserts in the next quarter-cycle when the directional element declares the fault in the reverse direction. The 50N3 nondirectional ground overcurrent element provides a faster means of asserting the carrier start signal.

Quarter-Cycle	Event Report Shows:
16	• L in 50P column shows that fault current reached 50L element pickup threshold. • 3 in 67N column shows 67N3 element pickup. Relay settings shown near the end of the event report indicate that the Zone 3 elements are reversed. These notes combined indicate that the fault is behind Breaker 1. • * in 52A Inputs column verifies that breaker was closed (as does load and fault current flow).

Starting at quarter-cycle 31 of the same event report, you can see the fault current begin to decrease. This indicates that Breaker 3 is clearing its contribution to the fault. Quarter-cycles 33 through 44 show the Z3X bit assertion in the A1 contact logic mask.

		Currents (amps)				Voltages (kV)		Relays	Outputs	Inputs	
IPOL	IR	IA	IB	IC	VA	VB	VC	52265L 011710 P3PNNP	TCAAAAA PL1234L	DPBD5E TTTC2T A	Quarter-Cycle
0	372	365	-41	50	7.7	-123.2	105.4	L..3..	..*....	....*.	31
0	-164	-132	-6	-19	97.6	-61.9	-88.0	L..3..	..*....	....*.	32
0	-82	-79	6	-13	-16.5	122.3	-107.2	......	..*....	....*.	33
0	18	13	0	0	-128.5	53.9	80.4	......	..*....	....*.	34
0	0	-13	-79	91	15.5	-122.6	107.0	......	..*....	....*.	35
0	4	98	-60	-35	133.1	-53.2	-79.0	......	..*....	....*.	36
0	0	13	79	-91	-15.3	122.6	-107.0	......	..*....	....*.	37
0	-4	-94	60	35	-133.1	53.2	79.0	......	..*....	....*.	38
0	0	-13	-79	91	15.5	-122.6	107.0	......	..*....	....*.	39
0	4	98	-60	-35	133.1	-53.2	-79.0	......	..*....	....*.	40
0	0	9	79	-91	-15.5	122.6	-107.0	......	..*....	....*.	41
0	-4	-98	60	35	-133.1	53.0	79.0	......	..*....	....*.	42
0	0	-9	-79	91	15.5	-122.6	107.0	......	..*....	....*.	43
0	4	94	-60	-35	133.1	-53.0	-79.0	......	..*....	....*.	44

Quarter-Cycle	Event Report Shows:
	Post-fault conditions:
31-32	• * in 52A Inputs column indicates breaker auxiliary contacts are still closed.
	• L in 50P column indicates that 50M element is dropped out (50L is now the only overcurrent element picked up).
	• 3 in 67N column indicates Zone 3 instantaneous overcurrent element is picked up.
	• * in A1 Outputs column indicates that the relay is keying carrier. This output remains asserted for the duration of the event report due to the Z3X bit.
	• * in 52A Inputs column indicates breaker auxiliary contacts are still closed.
33-44	• Period in 50P column indicates that phase current is below 50L setting threshold.
	• Period in the 67N column indicates dropout of all 67N elements.
	• * in 52A Inputs column indicates breaker auxiliary contacts are still closed.
	• * in A1 Outputs column indicates that the relay is continuing to key carrier.

Please note that the 67N3 element was asserted for two cycles at quarter-cycle 23. Therefore, in quarter-cycle 23 the Z3X bit was set in the A1 output contact mask. In quarter-cycle 33, the 67N3 element dropped out and the five-cycle TDDO Z3X timer began to decrement. No trip occurred at Breaker 1 due to the reverse Zone 3 67N3 element not remaining picked up for the Z3GT time (60 cycles).

Switch-Onto-Fault Example

Example Event Report 4 shows an example of Breaker 1 closing into a bolted three-phase fault during a manual line test. This type of fault is often caused when maintenance grounds are left on the transmission line. Note that Breaker 2 is open when Breaker 1 closes. Thus, Breaker 1 is testing the line on a radial basis. Under this circumstance, the protection at Breaker 1 does not have any coordination requirements except to remove the SOTF logic for a fixed time after the breaker closes.

The 52A input column is the primary indicator that the relay operated for a switch-onto-fault condition. Note that the 52A input was deasserted prior to the relay detecting fault current. This indicates that Breaker 1 was open and then closed into a fault.

Example Event Report 4

```
Example 230 Kv Line                        Date: 4/1/92      Time: 09:51:13.183
FID=SEL-121G6-R400-V656mptr12syzr2-D920228-E2

                 Currents                    Voltages        Relays  Outputs Inputs
                  (amps)                       (kV)
                                                             52265L  TCAAAAA DPBD5E
 IPOL     IR      IA      IB      IC      VA      VB      VC 011710  PL1234L TTTC2T
                                                             P3PNNP                A

   -3      0       0       0       0    -5.6   119.0  -113.6 ......  ....... ......
    3      0       3       0       0  -134.8    62.7    72.4 ......  ....... ......
    0      0       3       0       0     5.7  -119.1   113.4 ......  ....... ......
    0      0      -3       0       0   134.8   -62.4   -72.5 ......  ....... ......

    0      0      -3       0       0    -5.9   119.2  -113.4 ......  ....... ......
    0      0       3       0       0  -134.8    62.2    72.6 ......  ....... ......
    0      0       0       0       0     6.0  -119.1   113.4 ......  ....... ......
    0      0       0       0       0   134.7   -62.1   -72.8 ......  ....... ......

    0      0       0       0       0    -6.2   119.2  -113.2 ......  ....... ......
    0      0       0       0       0  -134.7    62.0    72.9 ......  ....... ......
    0      0       0       0       0     6.4  -119.3   113.1 ......  ....... ......
    0      0       0       0       0   134.5   -60.7   -74.0 ......  ....... ......

    0     -4     333     -98    -242    -8.1   111.2  -103.3 L.....  ....... ....*.
    0    -20     447     916   -1381  -100.3    30.3    69.9 M.....  ....... ....*.
    0     22   -2479     827    1677     3.9   -60.6    56.6 M.....  ....... ....*.
    0     42    -189   -3209    3432    37.3    -0.8   -36.4 H1....  *..**.. ....*.

    0    -27    4744   -1718   -3055     1.0    10.2   -11.1 H1....  *.***.. ....*.
    0    -42    -598    4760   -4191    -4.7     0.1     4.5 H1....  *.***.. ....*.
    0     15   -5257    2007    3266    -0.2    -1.2     1.3 H1....  *.***.. ....*.
    0     38     692   -4955    4288     0.6     0.0    -0.4 H1....  *.***.. ....*.

    3    -11    5323   -2039   -3294     0.1     0.1    -0.1 H1....  *.***.. ....*.
   -3    -35    -711    4980   -4298    -0.1     0.0     0.0 H1....  *.***.. ....*.
   -3      9   -5330    2036    3300     0.0     0.0     0.1 H1....  *.***.. ....*.
    3     35     720   -4983    4294     0.2    -1.2     0.9 H1....  *.***.. ....*.

    0     -4    4993   -1938   -3055     1.3     8.3   -10.0 H1....  *.***.. ....*.
    0    -15   -1164    4065   -2916   -34.5    31.1     3.5 H1....  *.***.. ....*.
    0    -13   -2844    1218    1614     3.3   -59.3    56.4 H1....  *.***.. ....*.
    0     -7     893   -1768     868    97.4   -60.1   -37.6 M1....  *.***.. ....*.

    0     18     582    -337    -236    -8.6   109.9  -101.4 M2....  *..**.. ....*.
    0      4     -98     220    -107  -130.0    60.5    69.8 M.....  *..*... ......
    0     -4     -76      47      28     7.9  -118.7   111.0 ......  *..*... ......
    0      0       6     -28       9   134.1   -60.5   -73.7 ......  *..*... ......

    0      0       9      -6      -3    -8.0   119.9  -112.1 ......  *..*... ......
    0      0       0       3       0  -134.6    60.4    74.2 ......  *..*... ......
    0      0       0       0       0     8.1  -120.2   112.2 ......  *..*... ......
    0      0       0       0       0   134.7   -60.2   -74.5 ......  *..*... ......

    0      0       0       0       0    -8.2   120.2  -112.1 ......  *..*... ......
    0      0       0       0       0  -134.6    60.1    74.7 ......  *..*... ......
    0      0       0       0       0     8.4  -120.3   112.0 ......  *..*... ......
    0      0       0       0       0   134.6   -60.0   -74.8 ......  *..*... ......

    0      0       0       0       0    -8.6   120.4  -112.0 ......  *..*... ......
    0      0       0       0       0  -134.6    59.9    74.9 ......  *..*... ......
    0      0       0       0       0     8.7  -120.5   111.9 ......  *..*... ......
    0      0       0       0       0   134.6   -59.8   -75.1 ......  *..*... ......

Event   : 1ABC    Location   : 0.01   mi  0.00    ohms sec
Duration: 3.50    Flt Current: 5418.6

R1   =8.56      X1   =77.77     R0   =35.12     X0   =236.96   LL    =100.00
CTR  =200.00    PTR  =2000.00   MTA  =83.72     LOCAT=Y
790I1=40.00     790I2=60.00     790I3=80.00     79RS =240.00
Z1%  =80.00     Z2%  =120.00    Z3%  =120.00
Z2SP =0.75      Z2DP =20.00     Z3DP =60.00
50L3 =275.00    50L  =275.00    50M  =500.00    50MFD=20.00     50H   =3420.00
51NP =230.00    51NTD=4.00      51NC =3         51NTC=Y
50N1P=835.00    50N2P=276.00    50N3P=282.00
Z2SG =0.75      Z2DG =30.00     Z3DG =60.00     TDUR =9.00      LOPE =Y
52BT =20.00     ZONE3=R         32QE =Y         32VE =N         32IE =N
TIME1=5         TIME2=0         AUTO =2         RINGS=7

Logic settings:

MTU  MPT  MTB  MTO  MA1  MA2  MA3  MA4  MRI  MRC
80   00   40   C4   30   00   00   08   00   E4
C4   00   22   E6   11   00   00   00   44   80
C8   00   00   00   00   01   04   00   00   C8
33   00   00   00   84   40   00   00   00   33
```

This excerpt from Example Event Report 4 shows the first 17 rows of data the relay recorded.

	Currents (amps)				Voltages (kV)			Relays	Outputs	Inputs	
IPOL	IR	IA	IB	IC	VA	VB	VC	52265L 011710 P3PNNP	TCAAAAA PL1234L	DPBD5E TTTC2T A	Quarter-Cycle
-3	0	0	0	0	-5.6	119.0	-113.6	......	....	......	1
3	0	3	0	0	-134.8	62.7	72.4	......	....	......	2
0	0	3	0	0	5.7	-119.1	113.4	......	....	......	3
0	0	-3	0	0	134.8	-62.4	-72.5	......	....	......	4
0	0	-3	0	0	-5.9	119.2	-113.4	......	....	......	5
0	0	3	0	0	-134.8	62.2	72.6	......	....	......	6
0	0	0	0	0	6.0	-119.1	113.4	......	....	......	7
0	0	0	0	0	134.7	-62.1	-72.8	......	....	......	8
0	0	0	0	0	-6.2	119.2	-113.2	......	....	......	9
0	0	0	0	0	-134.7	62.0	72.9	......	....	......	10
0	0	0	0	0	6.4	-119.3	113.1	......	....	......	11
0	0	0	0	0	134.5	-60.7	-74.0	......	....	......	12
0	-4	333	-98	-242	-8.1	111.2	-103.3	L.....	....	....*.	13
0	-20	447	916	-1381	-100.3	30.3	69.9	M.....	....	....*.	14
0	22	-2479	827	1677	3.9	-60.6	56.6	M.....	....	....*.	15
0	42	-189	-3209	3432	37.3	-0.8	-36.4	H1....	*..**..	....*.	16
0	-27	4744	-1718	-3055	1.0	10.2	-11.1	H1....	*.***..	....*.	17

Quarter-Cycle	Event Report Shows:
1-12	Pre-fault conditions: • No current in any current column indicates an open breaker. • No protective relay elements are picked up. • Period in 52A Inputs column verifies that breaker was open.
13	Breaker closure and fault inception: • L in 50P column indicates fault current reached 50L element pickup threshold. • * in 52A Inputs column indicates breaker closure (as does the current in the IA, IB, and IC current columns).
14	• M in 50P column indicates fault current reached 50M element pickup threshold. • * in 52A Inputs column verifies breaker closure (as does load and fault current flow).
16	• 1 in 213 column indicates pickup of the Zone 1 three-phase distance element. • * in TP column indicates TRIP output contact assertion. Trip was initiated by the 1ABC element in the MTO logic. TRIP contacts remain closed for the duration set by the TDUR timer. This contact remains closed for remainder of event report.
17	• Fault current reached 50H pickup threshold as shown by H in 50P column. • 1 in 213 column indicates pickup of the Zone 1 three-phase distance element. • * in TP column indicates TRIP output contacts are closed. • * in the A1 Outputs column follows assertion of the 4ABC bit in the Relay Word. • * in the A2 Outputs column follows assertion of the TRIP bit in the Relay Word. • * in the A3 Outputs column follows assertion of the RC bit in the Relay Word. • * in 52A Inputs column verifies breaker closure.

Rows 14 - 16 of the event report show that a trip signal was initiated 0.75 cycles after the line breaker closed into the fault.

FIRMWARE IDENTIFICATION

The relay provides a means of interpreting Firmware Identification Data (FID). The FID string is included near the top of each full length event report. The string format is as follows:

FID = [PN] - R[RN] - V[VS] - D[RD] - E[ER],

Where:

[PN] = Product Name (e.g., SEL-121G5)

[RN] = Revision Number (e.g., 401)

[VS] = Version Specifications (e.g., 656mpacllsy52)

[RD] = Release Date (e.g., YYMMDD=901227)

[ER] = Version Specification: EEROM

For the SEL-121G Relay family, version specifications are interpreted as follows:

V[VS] = V[ABCDEFGHI]

Option	Specifier	Specifier Meaning	Option Description
A	5, 6	50 Hz, 60 Hz	Power System Frequency
B	1, 5	1 amp, 5 amps	Nominal Amps per Phase
C	1, 6	120 volts, 67 volts	Nominal Volts per Phase
D	m, k	miles, kilometers	Fault Locator Distance Units
E	p, n	positive, negative	Phase-Sequence of Power System
F	a, t	all, trip only	Zones Reported on Target LEDs
G	c, r	cumulative, recent	Target LED Update Logic
H	1, 2	1.5, 2.0	Zone 4 size = [H] x Zone 3
I	1, 2	Zone 1, Zone 2	Zone with Carrier Coordinating Timer
J	s, m	standard, modified	Command access level
K	y, n	yes, no	PT Input Triggers Event Report
L	z, 5	Z3X, 52AT	Relay Word Bit is Z3X or 52AT
M	s, d	standard, tddo	Trip Duration Timer
N	1, 2	rev.1, rev. 4	Main board Configuration

EEROM version specifications are interpreted as follows:

E[ER] = E[Z]

Option	Specifier	Specifier Meaning	Option Description
Z	1, 2	1 stop bit, 2 stop bits	Communications Protocol Stop Bits

Please contact Schweitzer Engineering Laboratories, Inc. for more information concerning available versions of the SEL-221G Relay. Section 1: INTRODUCTION includes a description of all available configurations. Version specifications provided above are not intended for ordering purposes but to aid in identification of software installed in a relay.

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APPLICATIONS

SCHEMES INVOLVING COMMUNICATIONS

The relay is ideal for communications-based schemes, especially Directional Comparison Blocking. Dedicated trip masks allow selection of relay elements to perform specific functions when external conditions are met. In addition to the communication scheme logic, the relay provides time-stepped backup protection without external wiring modifications or dedicated input contacts.

In Directional Comparison Blocking schemes, the SEL-221G-6 Relay has special logic to eliminate the need for a carrier auxiliary relay. This logic includes:

- Carrier coordinating timers for the Zone 2 phase distance and ground overcurrent elements
- Carrier block trip continue logic to extend the block trip signal duration to the remote terminal
- One quarter-cycle extension of the block trip input signal for the local relay
- Carrier stop logic when nondirectional overcurrent or offset mho elements are used for carrier start

The SEL-221G-6 Relay logic listed above eliminates the need for carrier auxiliary relays in DCB applications and increases scheme security. If communications equipment is removed from service via a cutout switch, a contact from the same switch should energize the relay Block Trip (BT) input. This disables tripping via the blocking logic. When the communications channel is out of service (and the BT input is energized), the relay provides time-stepped backup protection.

Event reporting and fault-locating features provide an important system performance analysis tool. The event report shows voltages, currents, relay elements, inputs (including block trip signal arrival) and outputs (including carrier start and stop contacts). This information simplifies scheme performance evaluation.

Replacement of Outdated Protective Relays

The relay is an ideal replacement for aging or obsolete electromechanical relays. If protective relays are to be upgraded at one terminal only, it is important that relays have measuring principles compatible with surrounding terminals. The relay meets this requirement by utilizing the widely used compensator distance measuring principles for phase distance elements. It also includes residual instantaneous and time-overcurrent elements. The residual time-overcurrent element curve shape is selectable from four curve families to permit the best possible coordination with residual time-overcurrent protection at other line terminals. The relay also provides three means of polarizing the residual overcurrent elements to match the polarizing method with the rest of the system.
Compact size and simple field wiring make replacing electromechanical relays with this relay especially convenient in crowded substations. Both horizontal and vertical mounting configu-

rations are available. Event-reporting and fault-locating features economically provide valuable engineering and operating information, eliminating the need for event recorders and oscillographs in most applications. A negligible instrument transformer burden makes the SEL-221G-6 Relay an attractive alternative for overburdened current and potential transformers.

Time-Step Relaying

This relay provides three zones of time-step protection with separate timers for phase and ground faults in Zones 2 and 3. In such applications, this relay is the only instrument needed for primary relaying. Please note that while a communications scheme may not be required, the standard logic provided by the relay allows you to expand the time-stepped protective scheme to a communications aided scheme simply by adding communications equipment. Exhaustive self-testing and communications capabilities reduce dependence on local and remote backup schemes.

CHOICE OF LINE IMPEDANCES

For optimal performance, the relay requires accurate values of positive- and zero-sequence impedances for the protected transmission line. The relay uses positive-sequence impedance settings in establishing mho distance element reaches and calculating fault location. Similarly, the relay uses zero-sequence impedances in conjunction with positive-sequence impedances to calculate line-ground fault location.

You can obtain values for the positive- and zero-sequence line impedances from transmission line modeling programs, existing fault studies, or hand calculations. Only the positive- and zero-sequence impedances for the protected transmission line are entered as relay settings R1, X1, R0, and X0. Values entered for R1 and X1 represent the positive-sequence resistance and reactance for the entire transmission line. The R0 value represents transmission line zero-sequence resistance; the X0 value represents transmission line zero-sequence reactance.

CHOOSING CURRENT AND POTENTIAL TRANSFORMER RATIOS

Current transformer ratio (CTR) selection for line protection is often based on the transmission line current carrying capability. CTR selections also determine the magnitude of secondary fault current presented to the relay.

It is desirable to keep secondary CT currents between 50 and 100 amperes during maximum short circuit conditions. This reduces the likelihood of CT saturation and allows the current transformer to deliver a reliable secondary representation of the primary current during a fault condition.

The potential transformer ratio (PTR) setting should be selected to match the primary voltage ratio (l-n) to 66.4 V_{l-n}.

CHOICE OF MAXIMUM TORQUE ANGLE (MTA)

The maximum torque angle (selected in the setting procedure) is common for all protective elements. A typical maximum torque angle setting is at or less than the positive-sequence transmission line angle.

SELECTING DISTANCE ELEMENT REACHES

The following subsections refer to the system shown in Figure 5.1. Percentage reaches listed are provided only as guidelines. Actual distance element reaches for your application may differ from these figures. For every installation, consult a fault study to determine optimum relay settings.

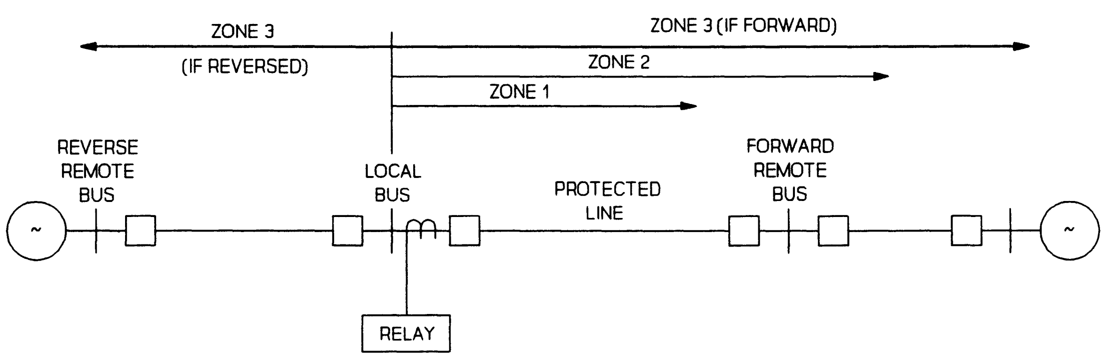


Figure 5.1: System Single Line Diagram

CHOICE OF ZONE 1 DISTANCE ELEMENT REACH

The Zone 1 reach is typically set short of the forward remote terminal. Thus, the Zone 1 elements provide instantaneous protection for phase-phase and three-phase faults in the first 80-90% of the transmission line, independently from the communication scheme selected. The remainder of the line is protected by the overreaching Zone 2 elements. While the percent error of the impedance element reach is less than 5%, errors in the CT and PT ratios, modeled transmission line data, and fault study data do not permit Zone 1 element settings of 100%.

CHOICE OF ZONE 2 DISTANCE ELEMENT REACH

The Zone 2 elements provide protection for the transmission line portion not included in Zone 1. These elements also serve as backup protection for close-in faults on the next line section. In Directional Comparison Blocking (DCB) applications, Zone 2 elements must detect all internal faults and stop carrier. In three terminal applications this relates to detecting faults at both remote terminals. This example uses a two terminal line application. To assure detection of end-of-line faults where parallel source infeeds may increase the apparent impedance to the fault location, set the Zone 2 elements to reach 50% into the next shortest line section. Zone 2 elements should never extend past the Zone 1 reach of the next line terminal. This prevents race conditions between Zone 2 time delayed elements of the two line terminals. Typical settings for the Zone 2 phase distance elements are 120 - 130% of the protected line. When Zone 2 reach settings exceed 150% of the protected line impedance, you must address current reversal conditions for sequentially cleared faults on parallel lines.

CHOICE OF ZONE 3 DISTANCE ELEMENT REACH

The instantaneous Zone 3 elements can be set reverse for Directional Comparison Blocking (DCB) schemes to detect out-of-section faults and start carrier. Time delayed outputs of the Zone 3 elements can also serve as remote backup for faults behind the relay location.

In DCB applications, the Zone 3 element reach setting must be long enough to detect any fault sensed by the overreaching Zone 2 elements at the remote terminal. Typically, Zone 3 element reaches are set to match the reach setting of remote terminal Zone 2 elements.

When set to reach forward, the time delayed Zone 3 elements provide remote backup for faults at remote buses two line sections from the local terminal.

CHOICE OF ZONE 2 AND ZONE 3 TIME DELAY SETTINGS

Time delayed Zone 2 and Zone 3 elements provide time-step backup protection. Time delay selections must coordinate with protection at the remote terminal and local bus. Instantaneous and time delayed outputs of the phase distance and residual overcurrent elements are available in the Relay Word. You can include the time delayed output of the Zone 2 and 3 elements in the Mask for Trip Unconditional (MTU). You can include the instantaneous Zone 2 elements in the Mask for Permissive Trip (MPT), the Mask for Trip Block (MTB), or the Mask for Trip while breaker Open (MTO), depending on the scheme selected. A typical setting for Zone 2 phase time delay is 20 to 30 cycles. This allows time for remote Zone 1 elements to pick up plus breaker operating time. Settings for the Zone 2 residual overcurrent element depend on the strength of zero-sequence current sources behind the relay location.

The Zone 3 time delay must coordinate with the Zone 2 protection at the local bus when Zone 3 is reversed. It must also coordinate with the remote Zone 2 elements when Zone 3 is forward reaching. A typical Zone 3 phase distance time delay setting is 60 cycles.

For more information regarding the short timer setting, please refer to DCB Complications and Concerns later in this section.

CHOICE OF PHASE OVERCURRENT PICKUP SETTINGS

The relay has three phase overcurrent element levels: low-, medium-, and high-set. The following descriptions explain the use of each phase overcurrent element in the relay logic.

50L, Low-Set Phase Overcurrent Elements (Zone 1 and 2 Supervison)

The 50L elements provide fault detector supervision of the Zone 1 and 2 mho distance elements and must pick up for all fault conditions where the Zone 1 and Zone 2 distance elements are expected to operate. The ideal setting for the 50L element is above load but below minimum fault duty. Although it is not ideal, you can set 50L below load to permit distance element operation for end-of-line faults with magnitudes below load.

For phase-phase faults, at least one current magnitude must exceed the 50L pickup threshold before the phase-phase distance elements are allowed to output. For three-phase faults, the current magnitude in all three phases must exceed the 50L pickup threshold before the three-phase distance elements give an output.

The 50L elements are also used in the trip unlatch logic (see Section 2: SPECIFICATIONS). Before the TRIP output can open, the trip condition must vanish and the current in all phases must drop below the 50L and 50NL element thresholds. This assures that the TRIP output contact does not attempt to interrupt full trip coil current for the full duration of the fault.

50L3, Low-Set Phase Overcurrent Elements (Zone 3 and 4 supervision)

The 50L3 element provides fault detector supervision of the Zone 3 and 4 mho distance elements and must pickup for all fault conditions where the Zone 3 and Zone 4 distance elements are expected to operate. The ideal setting for the 50L3 element is above expected load current but below minimum fault duty within the Zone 3 or Zone 4 reach. Although it is not ideal, the 50L3 element may be set below load current to permit distance element operation for low magnitude faults.

For phase-phase faults, at least one current magnitude must exceed the 50L3 pickup threshold before the phase-phase distance elements are allowed to output. For three-phase faults, the current magnitude in all three phases must exceed the 50L3 pickup threshold before the three-phase distance elements give an output.

50M, Medium-Set Phase Overcurrent Element

The 50M element is a conditional in the loss-of-potential (LOP) logic for three blown PT fuses. 50M provides non-directional phase overcurrent protection after an LOP condition is declared. When enabled, an LOP condition blocks mho distance elements from operating due to the loss of a sound voltage reference for these elements. To protect the transmission line locally until the blown potential fuse condition can be remedied, nondirectional time delayed phase overcurrent protection is enabled if the 50MF bit in the Relay Word is masked to trip.

The relay requires that phase current exceed the 50M pickup threshold to assure that three-phase loss-of-potential conditions are not confused with fault conditions. Once an LOP condition is declared, it remains latched until balanced three-phase voltages are restored. The following LOP logic equation shows the role of the 50M element in the SET LOP logic:

SET LOP = NOT(47P)*NOT(50M)

where the 47P element picks up for the positive-sequence voltage greater than 14 V secondary.

The 50M element setting must be above load, but below the minimum phase-phase or three-phase fault duty for a protected transmission line where the positive-sequence voltage is below 14 V of V1. If the maximum load is above minimum phase fault duty, the 50M setting must still be below the fault duty where the positive-sequence voltage is reduced to 14 V of V1. The below fault duty setting requirement prevents setting LOP during a fault. In most applications, a fault location close enough to reduce the positive-sequence voltage below the 47P setting of 14 V also brings a large magnitude of current from the local terminal. Thus, the 50M setting can still be above load current.

To allow time coordination with the surrounding line terminals, 50M element pickup after a loss-of-potential condition starts a definite timer labeled 50MFD. Once 50MFD expires, the 50MF bit in the Relay Word is set and may be used for tripping the local breaker. The 50MF bit is typically included in the MTU logic mask.

50H, High-Set Phase Overcurrent Element

The 50H element is intended for use as a high set non-directional phase overcurrent detector in the switch-onto-fault logic (see LOGIC MTO mask). If closing a line breaker into a close-in three-phase bolted fault where line-side potential transformers are used, the level of polarizing voltage required by the three-phase distance elements is never established. In this situation, the distance elements are blocked from operating. The 50H element is provided to prevent such a failure to trip the line breaker. The 50H element measures current magnitude in each phase with no dependence on polarizing voltages. This element is nondirectional and should be used only in the switch-onto-fault logic mask (MTO) where the line breaker is testing the line on a radial basis. However, if fault duty in front of the line terminal is much greater than behind it, the 50H element can also be used in the unconditional trip logic mask (MTU) to provide rapid clearance of close-in faults.

Typical 50H settings are one-half to one-third of three-phase fault duty at the local bus.

CHOICE OF RESIDUAL TIME-OVERCURRENT PICKUP SETTING

Consult a fault study to select the residual time-overcurrent element pickup setting. The residual time-overcurrent element provides current dependent time delayed clearance of faults along the protected line and serves as backup protection for remote terminals. Because the measure of residual current varies with system switching configuration, fault location, and fault resistance, a complete fault study is necessary to determine the minimum pickup setting, appropriate time dial, and curve characteristic. When enabled as directional, consider only faults in front of the line terminal for coordinating purposes.

CHOICE OF ZONES 1, 2, AND 3 RESIDUAL OVERCURRENT PICKUP SETTINGS

The relay provides three separate instantaneous residual overcurrent elements: 50N1P, 50N2P, and 50N3P. You can make these overcurrent elements directional by selecting a residual polarizing method: 32QE, 32VE, or 32IE. Both Zones 2 and 3 have an associated timer to provide time-stepped protection. Zone 2 has an additional timer to facilitate coordination of carrier elements for internal and external faults.

The Zone 1 residual overcurrent element is always instantaneous and forward looking. The pickup setting for this element should always be greater than the maximum end-of-line (EOL) ground fault current level. A typical setting for the 50N1P element is 120% of this maximum EOL single-line-to-ground (SLG) fault duty.

The Zone 2 residual overcurrent element is always forward looking. This element provides protection for the transmission line portion the Zone 1 element does not protect and time delayed backup protection for close-in faults on the next line section(s). This element has two associated timers: 1) Z2SG for carrier coordination, and 2) Z2DP for time-stepped backup protection. A typical setting for the 50N2P element is 50 - 60% of the minimum EOL SLG fault duty to account for fault resistance and fault study modeling errors.

The Zone 3 residual overcurrent element may be either forward or reverse looking as directed by the ZONE3 setting. Whether Zone 3 is forward or reverse, the time delayed output of the 67N3 element can provide backup protection for local or remote buses. The pickup setting requirement for the 50N3P element depends on the direction of Zone 3. If Zone 3 is reversed, the 67N3 element must (at a minimum) pick up for all SLG faults detected by the remote terminal Zone 2 residual elements. If Zone 3 is forward, the 67N3 element must pick up for SLG faults at the farthest remote bus the Zone 3 element is expected to protect.

When a nondirectional carrier start element is used for ground faults (50N3), the 50N3P setting should be set as sensitive as possible so that the nondirectional overcurrent element operates in the fastest possible time. However, care should be taken not to set the 50N3P element too sensitive since the 50N3P setting also determines the 67N3 sensitivity.

SWITCH-ONTO-FAULT LOGIC (MTO LOGIC MASK)

The relay has switch-onto-fault logic for use during testing. This logic allows you to enable very sensitive overreaching elements for a short duration after line breaker closure. Switch-onto-fault logic permits instantaneous line breaker tripping for end-of-line faults which would normally be cleared in Zone 2 time. The following list specifies the four tripping masks and differences in their qualifying logic:

MTU ≡ Mask for Trip Unconditional (no logic qualifiers)
MPT ≡ Mask for trip with the Permissive Trip input asserted
MTB ≡ Mask for Trip with the Block trip input not asserted
MTO ≡ Mask for Trip while the 52BT element is asserted

Elements selected in the MTO mask are typically non-time delay overreaching elements. The 52BT time delay setting dictates the interval during which switch-onto-fault logic is enabled. The 52BT element may be considered an inverted time delayed follower of the 52A input. When the 52A input changes from the asserted (breaker closed) to deasserted state (breaker open), the 52BT element remains low for 52BT time. After the 52BT timer expires, the 52BT element changes its logic state from '0' to '1' and enables the switch-onto-fault logic. When the breaker is closed (from an open state) to test the line, 52BT remains high for 52BT time. Thus, for 52BT time after the breaker is closed, assertion of any element selected in the MTO logic mask closes the TRIP output contacts. This logic provides Switch-Onto-Fault (SOTF) protection.

Figure 5.2 illustrates the timing relationship of the 52A input and 52BT element.

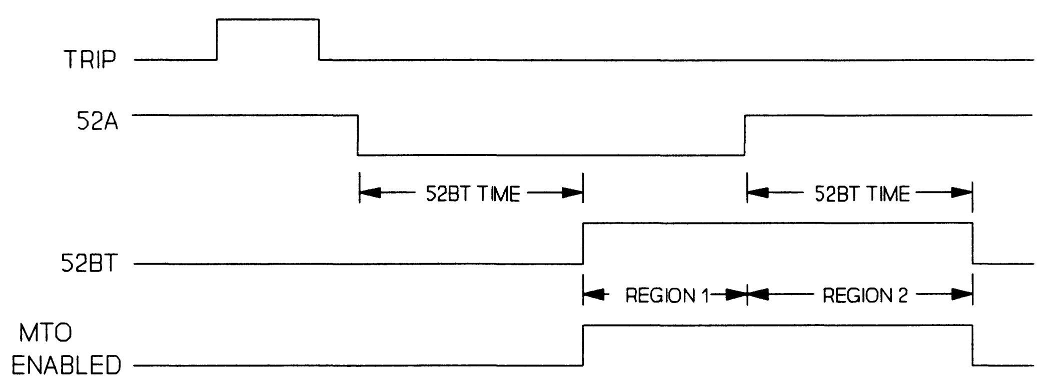


Figure 5.2: 52A Input and 52BT Timing Diagram

MTO logic is enabled during the time period shown for Regions 1 and 2. During Region 1, the MTO logic is enabled to protect the open line breaker. For line breaker tank faults, the relay can issue the trip signal required for breaker failure schemes.

Region 2 shows the time period where MTO logic is performing true switch-onto-fault protection for the transmission line. The 52BT element serves as a permissive signal for very sensitive elements to trip the line breaker during the 52BT time interval. Tripping occurs after the line breaker is closed. Normally, these sensitive elements are used only for tripping with a qualifying permissive signal from the remote line end (POTT schemes), during the absence of a block trip signal (DCB schemes), or are time delayed to provide coordination.

For example, the circuit shown in Figure 5.3 has a phase-phase fault close to Breaker 2. Suppose that Breaker 1 is the preferred source for testing the line (Breaker 2 is to remain open until Breaker 1 energizes the line). If standard time-stepped distance protection is employed without SOTF protection, the fault would have to be cleared in Zone 2 time. Using the relay MTO logic, the non-time delayed Zone 2 phase elements detect the fault and instantly issue a trip signal. This reduces the amount of time the transmission line is exposed to the fault energy. There is no possibility of overreaching the remote terminal with the instantaneous Zone 2 element because Breaker 2 is open while the Breaker 1 MTO logic is enabled (see Figure 5.4). If the fault is not present when Breaker 1 tests the line, the MTO logic of Breaker 1 resets after 52BT time. Then Breaker 2 can synchronize and close. This emphasizes the need to limit the time during which MTO mask elements can trip the breaker. Remember: the 52BT time setting must be long enough for the sensitive elements in the MTO logic mask to assert, yet shorter than the time allowed for Breaker 2 to parallel.

When setting the 52BT timer, you must consider the three shot reclosing feature. The 52BT timer start is keyed from the 52A input state change, whereas each open interval timer is started when the breaker has opened and the trip output contacts open. Because the open interval timer can start after the 52BT timer, a coincidence state is possible. In this state, the 452BT and the open interval timer expire. As a result, the 52BT timer which eliminates switch-onto-fault tripping logic for that reclosing shot is reset.

If switch-onto-fault protection is required for all reclose shots, remember to set the 52BT time interval equal to or shorter than the first reclose interval. If you want to cancel switch-onto-fault logic for a particular shot, set the 52BT timer longer than the open interval timer by the maximum expected breaker opening time. Typical 52BT settings are 15 - 20 cycles where high speed reclosing is not required.

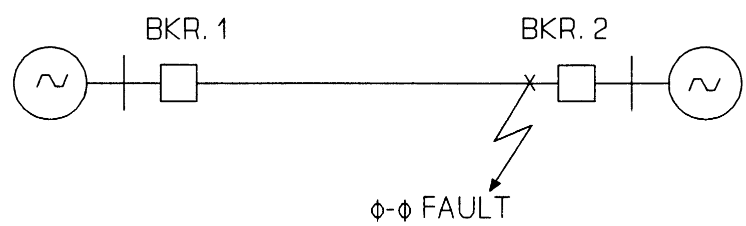


Figure 5.3: Faulted Line With All Sources In

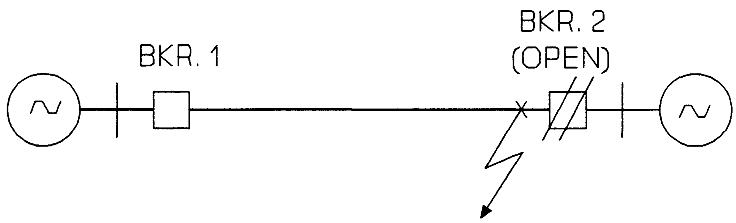


Figure 5.4: Faulted Line With Breaker 2 Open

SELECTION OF RESIDUAL OVERCURRENT RELAY POLARIZATION

The relay offers three different methods of polarizing the residual overcurrent elements:

1. Negative-sequence voltage (V2) and negative-sequence current (I2)
2. Zero-sequence voltage (V0) with measured residual current (IR)
3. Zero-sequence current from external source (Ipol) with measured residual current (IR)

Methods 2 and 3 may be combined to achieve a fourth dual polarized zero-sequence characteristic.

The three methods use distinctly separate measurands, each with their own benefits.

Negative-Sequence Polarization

1. Where strong zero-sequence mutual coupling exists between adjacent transmission lines, consider the negative-sequence method if sufficient polarizing quantities exist.

2. If there is a possibility that one end of a transmission line is a strong positive- and negative-sequence source but a weak zero-sequence source while the other end of the same line is a weak positive- and negative-sequence source but a strong zero-sequence source, consider negative-sequence again.

   One example of such an arrangement is a three winding autotransformer at a weak positive-sequence bus with the other end of the same line connected to a strong generation source. When a parallel circuit has a double line-to-ground fault in a double circuit line configuration, the strong positive- and negative-sequence source end of the healthy line can issue a permissive signal from its phase distance relaying. Meanwhile, the other end of the healthy line issues a permissive signal from its ground relaying elements polarized from zero-sequence. This scenario is only of concern where the ground overcurrent relaying is polarized from zero-sequence quantities.

Zero-Sequence Voltage Polarization

If protection at one line terminal is being upgraded without upgrading the remote terminal, it is desirable to match the polarization methods at both ends of the transmission line. If the existing ground overcurrent polarization method is zero-sequence and will remain zero-sequence for at least one terminal, retain zero-sequence. This assumes adequate levels of polarizing quantities exist at all terminals.

Zero-sequence voltage polarization is a viable method where adequate levels of residual voltage may be measured for all ground faults to give proper discrimination and the conditions outlined for negative-sequence polarization methods are not valid for your application.

Zero-Sequence Current Polarization

If measured zero-sequence voltage or negative-sequence quantities are insufficient to polarize residual elements for ground faults, polarization can be achieved with the residual current from an external source. Typical external sources are the neutral of a local transformer connected in grounded-wye, the tertiary winding of a grounded transformer, or the neutral current from a grounding transformer.

Before selecting zero-sequence current polarizing, examine fault studies to see that the residual current in the polarizing source always flows in the proper direction. This requirement assures that for forward faults, the external current source is in the proper phase orientation with the measured residual current of the faulted line.

LOSS-OF-POTENTIAL LOGIC

Fuses or molded case circuit breakers often protect the secondary windings of the power system potential transformers. A failure of one or more fuses or molded case circuit breaker operation results in a loss-of-potential of polarizing inputs to the relay. Loss of one or more phase voltages disables relay distance elements and directional decisions; it can no longer discriminate fault direction properly.

While loss-of-potential to the relay is unavoidable, detection of this condition is desirable. Once a true loss-of-potential condition is detected, you may elect to block distance element operation and issue an alarm. To do so, set LOPE = Y in the relay settings. Set the relay to alarm by programming the LOP bit in the Relay Word to an output relay contact. The relay discriminates between faults (which may reduce the voltage magnitude(s) to nearly zero) and loss-of-potential conditions. The following equation shows the loss-of-potential (LOP) detection logic for the relay:

SET LOP = [47NL*NOT(50NL)] :	Detects the presence of zero-sequence voltage in the absence of zero-sequence current

+ [NOT(47P)*NOT(50M)] : Detects the absence of positive-sequence voltage without measuring current above the 50M setting

Where:

47NL ≡ Low-set zero-sequence overvoltage detector
50NL ≡ Low-set zero-sequence overcurrent detector
47P ≡ Low-set positive-sequence overvoltage detector
50M ≡ Medium-set phase overcurrent element

For one or more blown PT fuses, the relay declares a loss-of-potential condition when the measured zero-sequence voltage exceeds 14 V of V0 and measured zero-sequence current is below 0.083 A secondary (for 51NP<3.15 A secondary). For three blown PT fuses, the relay declares an LOP condition when the measured positive-sequence voltage is below 14 V of V1 and the medium-set phase overcurrent detector (50M) is not picked up.

Installations Employing Potential Transfer Switches

Potential transfer switches temporarily remove the polarizing potentials from the relay when a substation operator transfers the potential source from one bus to another. Since it is undesirable to parallel secondary windings of potential transformers from separate sources, this occurrence is inherent to potential transfer switch installations. This temporary removal of polarizing voltages coupled with load currents well above the 50L fault detector threshold may result in a race between the three-phase loss-of-potential pickup logic and the three-phase distance element pickup. Three-phase LOP logic is included to address the loss of three secondary potential fuses, not potential transfer switch applications.

Figure 5.5 shows the solution developed to address this race condition. A description of the circuit follows the figure.

Note: The 52A input contact on the rear panel must be deasserted when the operator depresses the potential transfer switch.

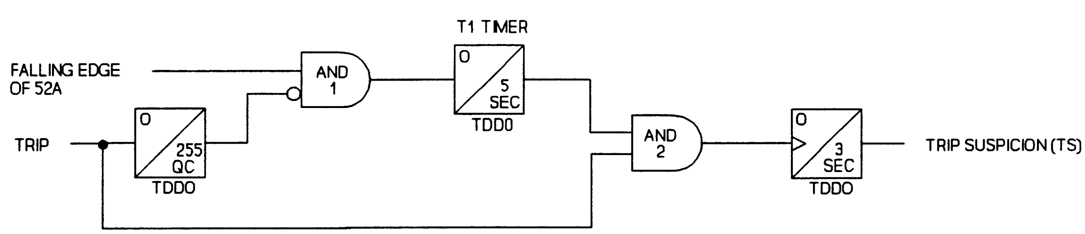


Figure 5.5: Potential Transfer Switch Logic

The following two scenarios illustrate Trip Suspicion logic:

Scenario 1) A trip issued by the relay for an actual fault on the transmission line.
Scenario 2) A trip resulting from the temporary loss-of-potential created by an operator moving a bus potential transfer switch from one bus position to another.

Scenario 1 - Actual Transmission Line Fault

When the relay issues a trip with the 52A input energized, the five second timer (T1) is not loaded due to relay initiated trip cancellation. Thus, this new logic does not interfere with the normal relay trip operation.

Scenario 2 - Potential Transfer Operation

When the relay senses the falling edge of a 52A input without a trip issued by the relay in the previous 255 quarter-cycles, the T1 timer is loaded and begins to decrement. The T1 timer allows the operator five seconds after depressing the potential transfer switch to transfer the relay potentials from one bus to another. Remember that the loss-of-potential condition only occurs when the potential transfer switch is twisted left or right while the switch is fully depressed. Rather than try to detect when potentials are lost, the relay identifies a window of possible loss using the deasserted 52A input with no trip condition present. This prevents any possible race conditions between voltage detect logic and distance element assertion. If the relay issues a trip during this five second window, tripping is restrained for three cycles. This three cycle time period is greater than the time required for the three-phase LOP logic to assert or for the polarizing potential magnitude of the second bus to stabilize.

Trip suspicion (TS) logic output is included in the Boolean logic for the TRIP output. The close TRIP output contact logic is as follows:

close TRIP contact ≡ [(R*MTU) + (R*MPT*PT) + (R*MTB*(NOT BT) +
(R*MTO*52BT)] * NOT(TS)

The Trip Suspicion logic adds the critical level of security necessary for bus arrangements utilizing a potential transfer switch. This logic does not depend upon the speed of the actual potential transfer operation, but does require that the procedure last less than five seconds.

This potential transfer switch logic presents an additional benefit if an operator inadvertently transfers potentials to a de-energized or "dead" bus. When the relay is transferred to a dead bus, assuming LOPE = Y and the LOP bit in the Relay Word is masked to an output relay contact, an alarm condition results and the TRIP outputs do not close. If the relay is connected to an alarm, output contact closure alerts the operator of the dead bus condition rather than tripping the relay.

DIRECTIONAL COMPARISON BLOCKING CONSIDERATIONS

The line shown in Figure 5.6 is to be protected by phase distance relays and ground directional overcurrent relays aided by directional comparison blocking logic. Forward reaching Zone 2 and reverse reaching Zone 3 relay elements are used at each end of the protected line. By overreaching the remote terminal, the Zone 2 elements cover the entire line section between Bus A and Bus B. By requiring the Zone 2 elements at each terminal to overreach the remote terminal, you are assured of detecting all in-section faults.

The Zone 3 element at each terminal reaches in the reverse (out-of-section) direction, and overreaches the Zone 2 element at the opposite end of the protected line. That is, Zone 3 at Breaker 3 reaches farther to the right of Bus B than the Zone 2 elements of Breaker 2. In this discussion, assume that Zone 3 has no forward (in-section) reach, as is the case for the Zone 3 element in this relay.

Figure 5.7 shows the fundamental logic involved. Pilot tripping time occurs for an internal fault if the local Zone 2 element operates and a block trip signal from the remote Zone 3 element does not. For the internal fault shown in the figure, the Zone 2 element at Breaker 3 and the Zone 1 element at Breaker 2 operate. The Zone 3 elements at Breakers 2 and 3 do not operate to start carrier, so both ends of the protected line trip. In all internal fault cases, the terminal with the Zone 1 element operation trips instantaneously and independently from carrier. The terminal with the Zone 2 operation trips in pilot time.

Faults to the right of Bus B and within the reach of the Zone 2 element of Breaker 2 are also within the reach of the Zone 3 element of Breaker 3. This assures that the Zone 3 protection at Breaker 3 always issues a block trip signal to the protection at Breaker 2. From the placement of the external fault in the figure, you will notice that the fault is closer to the boundary of the Zone 2 element than that of the Zone 3 element. This allows the Zone 3 element to operate faster than the Zone 2 element. This point is further supported by the fact that the voltage at Bus B is lower than that at Bus A. Therefore, lower voltage, same current, and a fault located in a smaller percentage of the Zone 3 reach allow the Zone 3 element to start carrier prior to pickup of the remote Zone 2 elements.

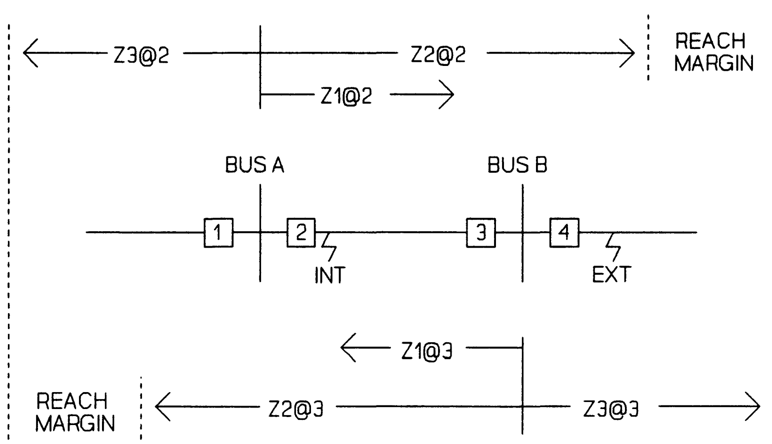


Figure 5.6: DCB Single Line Diagram

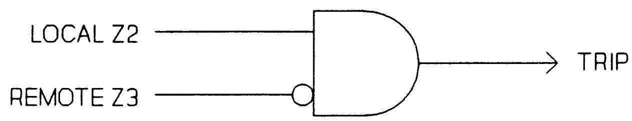


Figure 5.7: Basic DCB Logic

DCB COMPLICATIONS AND CONCERNS

Coordinating Time On Fault Detection

To ensure that Breaker 2 is not tripped for the external fault beyond Breaker 4, the Zone 2 element at Breaker 2 must be blocked before tripping the breaker. As mentioned earlier, the Zone 3 element of the remote breaker generally operates more quickly than the Zone 2 element of the local breaker. However, communication channel delay time reduces the lead of Zone 3 element pickup over Zone 2. Delay time varies between four and eight milliseconds, depending on the channel.

To account for this possible race condition, the Zone 2 elements at the local terminal must wait for a possible blocking signal from the remote terminal. The relay includes the timers required for this purpose, eliminating the need for an external carrier auxiliary relay. The relay contains two groups of timers for phase and ground. One timer from each group can be set short for the coordinating time discussed above, while the other can be set for the normal Zone 2 time-step backup protection.

Stop Preference over Start

This is required when the start function is nondirectional. The relay start functions are normally directional. Therefore, a stop preference circuit is not required except in special situations (an example is discussed later under stop carrier logic).

Coordinating Time on Clearing of External Fault

Consider again the external fault to the right of Breaker 4. When that fault clears, the blocking elements (Zone 3) at Breaker 3 and the tripping element (Z2) at Breaker 2 are racing to drop out. If the block signal is lost at Breaker 2 before its Zone 2 elements drop out, an unwanted trip occurs at Breaker 2.

The same factors that allowed the remote Zone 3 element to operate faster than the local forward reaching Zone 2 element make the reverse reaching Zone 3 element drop out after the Z2 element. The channel reset time further biases the dropout race in a favorable direction.

Driving the Block Trip input from the receiver provides an additional time margin between the dropout time (8 ms) of the output relay keying the transmitter and the fast read-in time of the Block Trip input.

In back-to-back tests of two relays (both relays were presented the same series current and parallel voltages), the minimum internal coordinating time delay on dropout observed was three milliseconds, with typical times of twelve milliseconds observed. Please note that this test was implemented to demonstrate worst case conditions. In reality, the Zone 3 element will have a lower voltage presented to it and the minimum coordinating time delay will be greater, as explained above.

When the channel reset time is added in, the minimum time margin at dropout is about one-half cycle (using the 3 ms time margin).

The relay further enhances security by providing a one-quarter-cycle dropout time extension on its Block Trip input. This time may then be added to the favorable coordinating time delays outlined above.

Block Trip Extension Logic

Many communication sets have timers to hold or extend the receiver output for expanded security. However, these timers are not required for applying the SEL-221G-6 Relay in a DCB scheme. Figure 5.8 illustrates the block trip extension logic for the relay. This logic also serves as current reversal logic. The coordinating time delays for the Zone 2 phase and ground elements are not affected by this logic, labeled Z3X. The Z3X logic is comprised of two fixed timers driven by the Zone 4 three-phase and Zone 3 elements which control the Z3X bit in the Relay Word. The Z3X bit should be masked into the logic for the programmable output relay which will key the communications equipment.

Z3X Logic Description

When the reverse-reaching Zone 4 three-phase element or the Zone 3 elements detect a fault, carrier block is immediately keyed. Keying occurs via the Zone 4 three-phase element or the Zone 3 elements masked into one of the four programmable output contacts. The Z3X bit should also be masked into the same programmable output contact. If the Zone 4 three-phase element or Zone 3 elements remain asserted for two or more cycles, the Z3X bit asserts and remains asserted for five cycles after the last reverse reaching element drops out. This logic serves as a carrier continuation timer. The two cycle qualifying time assures carrier continuation just prior to a three-cycle line breaker on an adjacent faulted line clearing its contribution to the fault.

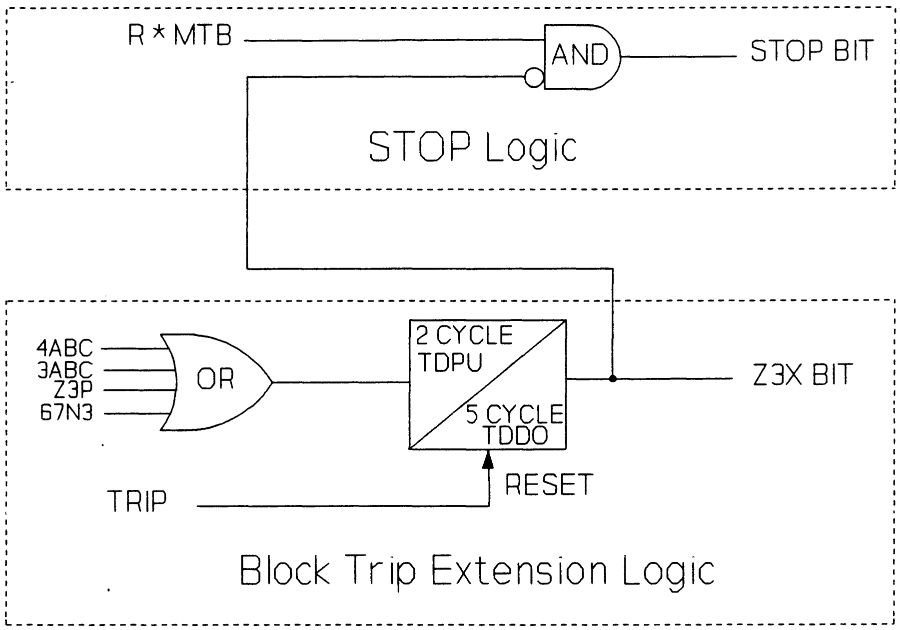


Figure 5.8: Bock Trip Extension (Z3X) and STOP Logic

Figure 5.9 illustrates the current reversal and assertion of the Z3X bit in the Relay Word.

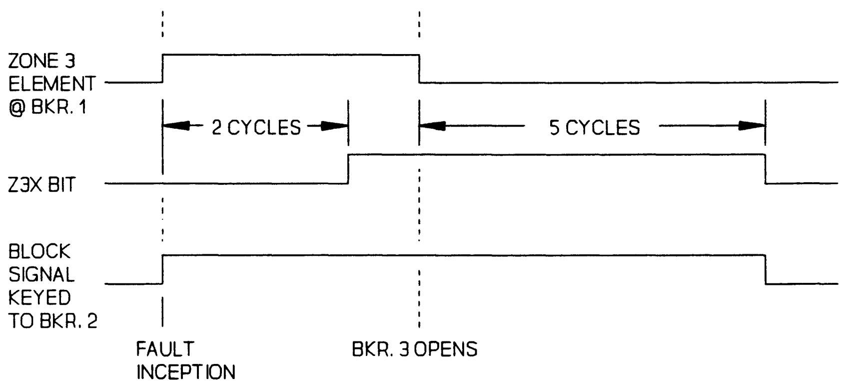


Figure 5.9: Current Reversal and Z3X Logic Timing Diagram

Failure to Clear an External Fault

Breaker failure relaying should clear Bus B if Breaker 4 fails to clear the indicated external fault in Figure 5.6. This breaker failure scheme may consist of a time delayed Zone 3 output or external breaker failure relays. If Bus B is not equipped or set up for breaker failure, Breaker 2 will clear its contribution to the fault by the time delayed Zone 2 operation.

If load is tapped off at points between Breakers 2 and 3, it may be of concern if blocking is lost and Breaker 2 trips. With this relay, this is possible only for a very close-in three-phase fault, and only after the Zone 3 three-phase element memory expires (four cycles minimum). There are at least two solutions:

1) Use a carrier-continue timer set beyond the breaker-failure delay. The timer can be operated from the three-phase Z3 element only, so carrier is discontinued when not needed. Please note that the Z3X bit extends the block trip signal for an additional five cycles. This carrier continue timer should only be used if the sum of relay memory polarization time (four cycles), five cycles for the Z3X logic, and channel reset time minus the pickup time of the Zone 1 protection at Breaker 4 is less than the breaker failure time for Breaker 4.

2) Start carrier on the Zone 4 three-phase or nondirectional ground overcurrent elements (as well as the Zone 3 elements), and stop it on the Zone 2 elements. Note that if Zone 4 or a nondirectional ground overcurrent is used to start carrier, coordinating delays on dropout should be minimized at the receiving end. Otherwise, in-section fault clearing is slowed by the extended carrier-dropout time. Because these elements are nondirectional (Zone 4 includes the origin), stop preference over start must be employed so the Zone 2 element can stop any unnecessary carrier start for an internal fault. Stop usually overrides start in carrier blocking schemes.

Stop Carrier Logic

In applications where a nondirectional or offset mho element is used for carrier start function at the time the trip decision is made and no reverse reaching elements are picked up, the blocking signal is shut off (squelched). Figure 5.8 illustrates the STOP bit logic in the SEL-221G-6 Relay. The STOP bit should be masked into the logic for the programmable output relay connected to the carrier squelch on the communications equipment.

STOP Logic Description

When nondirectional overcurrent or offset three-phase mho elements are used for carrier start, a block trip signal is sent for every fault that picks up those elements, whether it be internal or external. For internal faults, the carrier block signal is squelched as soon as the relay makes the trip decision and there are no reverse reaching elements picked up. The STOP logic uses the inverse of the Z3X logic to verify that the fault is not in the reverse direction. This is ANDed with the output of the elements set in the MTB logic mask. When an in-section fault occurs, the STOP bit asserts when forward reaching Zone 2 elements assert in the MTB mask. The programmable output masked with the STOP bit asserts and squelches the carrier block signal.

When a close-in in-section three-phase fault occurs the offset Zone 4 element may pick up and set the Z3X logic. This causes the Z3X bit to override the STOP logic. Deasserting the

STOP bit would allow the carrier block signal to reassert and may prevent the remote end from tripping. The relay avoids this potential problem by overidding the Z3X output from the relay TRIP condition.

Figure 5.10 illustrates the carrier stop logic and assertion of the STOP bit in the Relay Word.

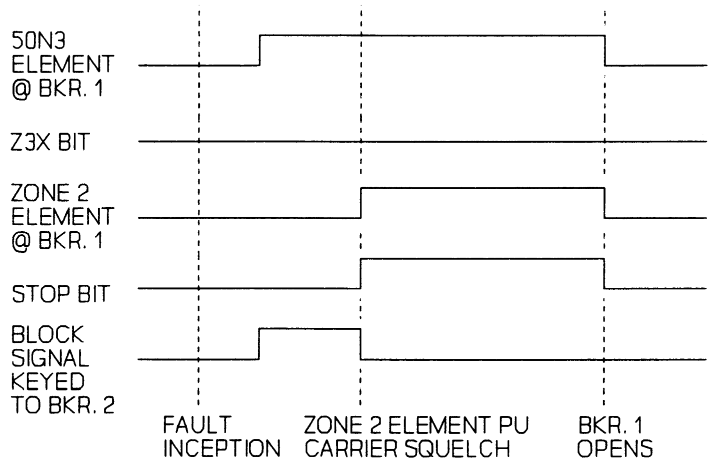


Figure 5.10: Carrier Stop and STOP Logic Timing Diagram

GENERAL NOTES ON COMMUNICATIONS EQUIPMENT AND INTERFACES

A review of interfaces on tone and carrier equipment from three major manufacturers resulted in the general observations below. These comments are included to indicate the range of possibilities and do not replace careful study of the formal drawings for a particular communications transceiver.

Transmitter Keying

Most transmitters are keyed by applying control voltage to the diode side of an opto-coupler. External build-out resistors may be required to limit the current. Typical "ON" currents are 20 to 30 mA.

A start and a stop input may be provided. The stop input usually has preference over the start input.

Keying tone to "trip" where this tone is used to block is probably universally accomplished by applying voltage.

Keying carrier "on" has two conventions: either application or removal of control voltage. Most communications equipment has jumpers so that either convention can be established. If removal of voltage is required, one of the programmable output contacts may be converted to a "b" contact. With the exception of the TRIP contacts, any output contact may be converted from "a" to "b."

Receiver Outputs

Most receivers include contacts and/or switching transistor outputs. Tone or carrier received causes the output device to conduct.

When switching transistors are used, their current-carrying capacity ranges from 100 to 1000 mA.

Operate and Reset Times

Tone sets with ± 85 Hz shift operate/reset in about eight milliseconds. Tone sets with ± 170 Hz shift operate/reset in about five milliseconds. Carrier sets with ± 250 Hz shift operate/reset in about four milliseconds. Narrowband sets with 600 Hz bandwidth operate/reset in 2.2/3.2 milliseconds. Wideband sets with 1500 Hz bandwidth operate/reset in 1.7/2.7 milliseconds.

"Trip"-Hold Timer (Block Continue Function)

At least one manufacturer of communications equipment provides a trip-hold timer in the receiver logic (again, when using tones in a blocking scheme, trip implies block). This timer may be useful in augmenting the inherent security of the blocking scheme by stretching the block at the receiver end of the system. The Z3X logic described above extends the block signal at the sending end.

The Trip-Hold timer of the communications equipment may also be a problem if a transient blocking signal can be transmitted, e.g. due to a faster start/slower stop arrangement at the sending end. In such applications, the Trip-Hold timer setting should be as short as possible. When slow-reset times are involved (greater than eight milliseconds), the trip hold timer may be set to zero. With faster reset times (four milliseconds or less), the timer may be set between zero and four milliseconds.

Pre-"Trip" Timer

At least one manufacturer of tone equipment provides a pre-trip timer. This should be set to zero to ensure the fastest blocking.

Receiving Your Own Signal

When using tones, the transmitter and receiver at one end are separated by frequency or by circuit. If they are on the same frequency, a four-wire (two channel) arrangement is used, and the local receiver does not detect the local transmitter.

With carrier, the transmitter and receiver are usually on the same frequency, so when the local transmitter operates, both the local and remote receivers detect the signal.

230 kV SETTING EXAMPLE FOR DCB SCHEME WITH TIME-STEPPED BACKUP

Purpose

This example shows the steps for setting the relay at Breaker 3 to protect Line 2 in Figure 5.11 between Buses B and C. The basic criteria for protecting this line appear below:

- The communications scheme is Directional Comparison Blocking (DCB)
- Zone 2 and Zone 3 serve as time-step backup
- The maximum expected load is less than 450 A.

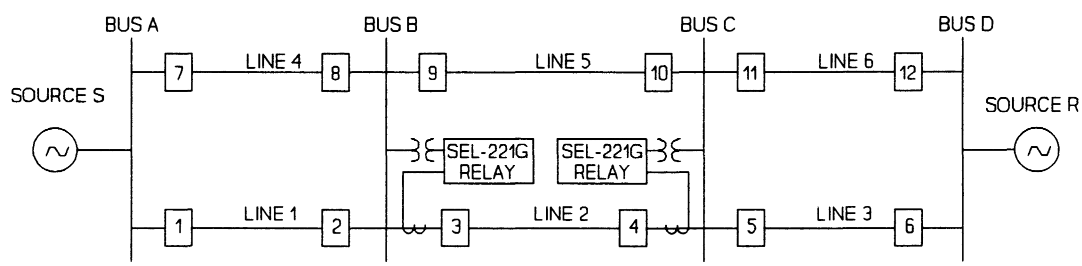


Figure 5.11: 230 kV Setting Example System Single-Line Diagram

System Data

Nominal System Voltage	: 230 kV (132.8 kV line-neutral)		
Line Length	: 100 miles		
Line 2 and Line 5 Impedances:			
Positive-sequence	: Z1	$= 78.24 \angle 83.72°$	(primary Ω)
		$= 8.56 + j77.77$	(primary Ω)
Zero-sequence	: Z0	$= 239.55 \angle 81.56°$	(primary Ω)
		$= 35.12 + j236.96$	(primary Ω)
Line 1 and Line 4 Impedances	: Z1	$= 78.24 \angle 83.72°$	(primary Ω)
	: Z0	$= 239.55 \angle 81.56°$	(primary Ω)

Line 3 and Line 6 Impedances	:	$Z1 = 39.12 \angle 83.72°$	(primary Ω)
	:	$Z0 = 119.78 \angle 81.56°$	(primary Ω)
Source Impedances:			
Source S = Source R	:	$Z1S = Z1R = 29.34 \angle 83.72°$	(primary Ω)
	:	$Z0S = Z0R = 3 \times Z1S$	
Current Transformer	:	1200:5 multi-ratio	
Potential Transformer Ratio	:	2000:1	

Relay Settings

Fault voltages and currents in this example were derived from a fault study of the system in Figure 5.11.

Values to enter during the actual setting procedure appear in bold immediately after the "=" prompt in the dashed boxes.

■ Identifier

The relay tags each event report with a label in the identifier string. This allows you to distinguish the event report as one generated for a specific breaker and substation. Typical identifiers include an abbreviation of the substation name and line terminal. Where an SEL-DTA is used in conjunction with the relay, the identifier string is displayed on the screen. This feature helps in recognizing the associated line terminal when multiple SEL-DTAs are stacked behind an operator console.

```
ID = BUS B, 230 KV LINE 2
```

- Setting Limit Check

The identifier string is limited to 39 characters. Characters entered after the 39th character are ignored.

- Other Settings Affected

None.

■ R1, X1, R0, X0, and Line Length (LL)

The positive- and zero-sequence primary impedance values should match those calculated for Line 2. The line length should also match the distance between Bus B and Bus C.

```
R1 = 8.56
X1 = 77.77
R0 = 35.12
X0 = 236.96
LL = 100.00
```

- Setting Limit Check

The primary limit check performed while entering the relay settings allows primary values of R1, X1, R0, and X0 in the range of 0 - 9999 ohms and a line length between 0.1 and 999 miles.

There are no secondary setting limits for the impedance or line length settings. However, you should perform a cursory check to be sure the minimum Zone 1, Zone 2, or Zone 3 secondary reaches at MTA are not below the minimum setting of 0.125 Ω secondary or above the maximum setting limit of 64 Ω secondary.

- Other Settings Affected

Z1%, Z2%, Z3%

■ Current and Potential Transformer Ratio Selection

The current transformer ratio must be selected from those available in the multi-ratio current transformer. The ratio selected for this example is 1000/5 or 200:1. This ratio allows 1000 A of load to flow without exceeding five amperes of secondary current, while limiting the secondary current to below 50 A for the maximum available fault duty.

```
CTR = 200.00
```

The system voltage is 230 kV line-line or 132.8 kV line-neutral. The relay requires a nominal phase voltage of approximately 66.4 $V_{l\text{-}n}$ or 115 $V_{l\text{-}l}$. The PTR selected for this example is 2000:1.

$$PTR = \frac{(230\ kV)}{(115\ V)} = 2000:1$$

```
PTR = 2000.00
```

- Setting Limit Check

The primary limit check for the CTR and PTR settings allows you to enter values from 1 - 5000 and 1 - 10,000 respectively.

There are no secondary setting range checks for these settings.

- Other Settings Affected

CTR - All overcurrent pickup settings   Ratio of PTR/CTR: Z1%, Z2%, Z3%

■ Maximum Torque Angle (MTA)

The Maximum Torque Angle (MTA) setting should be below the positive-sequence angle of the transmission line to extend the amount of resistive coverage for the mho circles (this is also true for the expanded mho characteristics). MTA selected for this example is 83.72°. Note that this value matches the positive-sequence line angle of 83.72°.

```
MTA = 83.72
```

- Setting Limit Check

The primary setting range check allows MTA settings from 47° - 90°. There is no secondary check for this setting.

- Other Settings Affected

Zone 1, Zone 2, and Zone 3 reach if MTA does not equal the positive-sequence transmission line angle.

■ Fault Locator Enable (LOCAT)

This setting allows you to enable or disable the fault locating ability of the relay. In this example, as with most applications, fault locating is desired.

```
LOCAT = Y
```

- Setting Limit Check

There is no limit check for this setting. The fault locator is either enabled (Y) or disabled (N).

- Other Settings Affected

None.

■ Reclosing Open Intervals and Reset Time (79OI1, 79OI2, 79OI3, and 79RS)

Open interval timers control each of the three reclosing shots. The recloser must coordinate with remote reclosing schemes.

The first open interval must be longer than the 52BT time (SOTF time). For this example, the first reclose attempt is 40 cycles after the TRIP condition is gone. Second and third reclose attempts are 60 and 80 cycles after the second and third TRIPs, respectively.

The reset time (79RS) must be at least as long as it takes the breaker to completely close. The 79RS timer also serves to block automatic reclosing for 79RS time period after an operator (or SCADA) closes the line breaker. This feature serves to maintain control of the line breaker with the local operator. For this example, the 79RS timer is set for 240 cycles or four seconds. For more information, please refer to Reclose Logic at the end of this section.

```
79OI1 = 40,        79OI2 = 60,        79OI3 = 80,          79RS = 240
```

- Setting Limit Check

79OI1, 79OI2, and 79OI3 have primary limit checks of 0 to 10,000 cycles. 79RS has a primary limit check of 60 to 8,000 cycles. There is no secondary limit check for 79OI1, 79OI2, 79OI3, or 79RS. For this example, each open interval and 79 reset timer setting lies within the relay setting limits.

- Other Settings Affected

Please note that the 52BT timer should be set less than the shortest open interval timer to assure enabling the switch-onto-fault logic for each shot.

■ Zone 1 Reach Setting (Z1%)

The required reach for the Zone 1 three-phase and phase-phase elements is 80% of the positive-sequence impedance of Line 2 between Bus B and Bus C.

$$\text{Z1 Reach} = 0.80 \times 78.24\ \Omega \text{ primary @ } 83.72° = 62.59\ \Omega \text{ primary @ } 83.72°$$

The reach settings for the mho distance elements are a percentage of the positive-sequence line impedance settings along the line angle. When the MTA setting differs from the positive-sequence line angle, the relay calculates the mho circle diameter with the following equation:

$$\text{Diameter} = \frac{\text{Set Reach}}{\cos(\text{Angle of Z1 - MTA})}$$

For this example, the diameter of the Zone 1 mho circle along the MTA is:

$$\text{Diameter} = \frac{62.59\ \Omega}{\cos(83.72° - 83.72°)}$$

$$= 62.59\ \Omega \text{ primary along the MTA}$$

```
Z1% = 80.00
```

- Setting Limit Check

The primary limit check allows Zone 1 percent reach settings of 0 - 2000%. The secondary setting check allows secondary reach settings of 0.125 - 64 ohms secondary along the MTA.

Calculations: PTR = 2000:1 PTR/CTR = 10
CTR = 200:1

$$\text{Secondary Ohms} = \frac{62.59\ \Omega\ \text{primary}}{10} = 6.259\ \Omega\ \text{secondary along the MTA}$$

The Z1% setting of 80 for this example lies within primary and secondary setting limits of the relay.

- Other Settings Affected

Zone 1 must be less than Zone 2 and Zone 3. The 1ABC and Z1P bits of the Relay Word depend on the Z1% setting.

■ Zone 2 Reach Setting (Z2%)

The Zone 2 elements must have adequate reach to detect all phase faults along Line 2, but cannot overreach the Zone 1 elements for faults on Line 3 or Line 6. In this example, the impedances for Lines 3 and 6 are identical.

ZL for Line 2 = 78.24 Ω primary ZL for Line 3 = ZL for Line 6 = 39.12 Ω primary

Zone 2 element settings with a reach of 120% of protected line impedance account for the effects of infeed. This point must be verified using a fault study to calculate the apparent ohms at the local terminal for a fault at the remote end of the transmission line. In the example system, 120% is selected for the Zone 2 elements with assurance that all faults in Line 2 are detectable, even with infeed from the remote terminals.

Assuming Zone 1 reach for the line protection at Breakers 5 and 11 is set for 80% of the line impedances of Lines 3 and 6 respectively, verify that a Zone 2 reach of 120% for Breaker 3 does not overreach the Zone 1 elements at Breakers 5 and 11.

Line 2 Impedance + [0.8 x Line 3 Impedance] = 78.24 Ω + [0.8 x 39.12 Ω]
= 109.54 Ω primary

When Zone 2 at Breaker 3 has a set reach of 120%, the effective reach is:

Zone 2 @ Bkr. 3 = 1.20 x 78.24 Ω = 93.89 Ω along the line angle

Since 93.89 Ω < 109.54 Ω, the Zone 2 setting of 120% at Breaker 3 does not overreach the Zone 1 protection of Lines 3 and 6. Any effect of infeed tends to increase the apparent ohms seen at Breaker 3 for faults on Lines 3 and 6.

As for the Zone 1 element, the MTA setting is the same as the positive-sequence line angle. Calculate the diameter of the Zone 2 mho circle with the following equation:

$$\text{Diameter} = \frac{\text{Set Reach}}{\cos(\text{Angle of Z1 - MTA})}$$

For this example, the Zone 2 mho circle diameter along the MTA becomes:

$$\text{Diameter} = \frac{93.89\ \Omega}{\cos(83.72° - 83.72°)}$$

$$= 93.89\ \Omega \text{ along the MTA}$$

```
Z2% = 120.00
```

- Setting Limit Check

The primary limit check allows Zone 2 percent reach settings of 0 - 3200% with the requirement that the Zone 2 reach be equal to or greater than that of Zone 1. The secondary check allows secondary reach settings of 0.125 - 64 ohms secondary along the MTA.

Calculations: PTR = 2000:1 PTR/CTR = 10
CTR = 200:1

$$\text{Secondary Ohms} = \frac{93.89\ \Omega \text{ primary}}{10} = 9.389\ \Omega \text{ secondary along the MTA}$$

The Z2% setting of 120 for this example lies within the secondary setting limits of the relay.

- Other Settings Affected

If Zone 3 is forward, Zone 2 must be less than Zone 3. The 2ABC, Z2P, and Z2PT bits of the Relay Word depend on the Z2% setting.

■ Zone 3 Reach Setting (Z3%)

This example uses a Directional Comparison Blocking (DCB) communication scheme. The Zone 3 element reach at Breaker 3 must be selected to detect out-of-section faults which are also detected by the overreaching elements at Breaker 4. At a minimum, the Zone 3 reach setting must equal impedance behind Breaker 3 seen by the overreaching element at Breaker 4.

A second requirement dictates that the reverse looking Zone 3 elements must serve as time delayed backup protection for faults on Lines 1 and 4. Therefore, reverse looking Zone 3 elements must see faults along the entire length of Lines 1 and 4. Considering this requirement, the Zone 3 elements should be set for 120% of the apparent impedance for faults at Bus A. The impedances of Lines 1 and 4 are identical and equal to the impedance of Line 2.

```
Z3% = 120.00
```

- Setting Limit Check

The primary limit check allows Zone 3 percent reach settings of 0 - 3200%, with the requirement that Zone 3 reach exceed Zone 1 reach when Zone 3 is reversed. When Zone 3 is selected as forward, the Zone 3 distance element reach must exceed that of Zone 2. The secondary check allows secondary reach settings of 0.125 - 64 ohms secondary along the MTA.

Calculations: PTR = 2000:1 PTR/CTR = 10
CTR = 200:1

$$\text{Secondary Ohms} = \frac{93.89\ \Omega\ \text{primary}}{10} = 9.389\ \Omega \text{ secondary along the MTA}$$

The Z3% setting of 120 for this example is within primary and secondary setting limits of the relay.

- Other Settings Affected

This setting affects Zone 4 reach. Zone 4 is internally set to 1.5 x Zone 3. The 3ABC, 4ABC, Z3PT, and Z3P bits in the Relay Word depend on the Z3% setting.

■ Zone 2 Short Phase Time Delay (Z2SP)

The Z2SP timer adds a settable delay to the Zone 2 phase-phase (Z2P) and three-phase (2ABC) elements. This timer provides the necessary carrier coordination to assure that the local terminal does not trip for an out-of-section fault by delaying pickup of the Zone 2 distance elements to wait for a possible block signal. The time selection should be slightly longer than the maximum time a blocking signal takes to arrive from Breaker 4. This time includes remote Zone 3 element pickup time plus channel transmit time minus local Zone 2 distance element pickup time. Typical settings for this timer range from 0.5 to 1.0 cycles. This example uses a conservative setting of 0.75 cycles.

```
Z2SP = 0.75
```

- Setting Limit Check

The primary limit check allows Zone 2 short time delay settings of 0 - 60 cycles. The Z2SP setting of 0.75 cycles lies within relay setting limits. There is no secondary limit check for this setting.

- Other Settings Affected

2ABC and Z2P bits in the Relay Word.

■ Zone 2 Phase Time Delay (Z2DP)

The Z2DP timer adds a settable delay to the Zone 2 phase-phase and three-phase distance element instantaneous outputs. Please note that the Z2DP time is not in addition to the short time delay introduced by the Z2SP timer. The time delayed output of the Zone 2 phase-phase and three-phase distance elements is represented by the Z2PT bit in the Relay Word. The time selection should coordinate with the protection at Bus C. The Zone 2 phase distance delay selected in this example is 20 cycles.

```
Z2DP = 20.00
```

- Setting Limit Check

The limit check allows Zone 2 time delays of 0 - 2000 cycles. The Z2DP of 20 cycles lies within the relay setting limits. There is no secondary limit check for this setting.

- Other Settings Affected

Z2PT bit in the Relay Word.

■ Zone 3 Phase Time Delay (Z3DP)

The Z3DP timer adds a settable delay to the instantaneous outputs of the Zone 3 phase-phase (Z3P) and three-phase (3ABC) elements. The time delayed output of the Zone 3 phase-phase and three-phase distance elements are represented by the Z3PT bit in the Relay Word. The time selection should coordinate with the Zone 2 protection at Bus B to provide time-step backup protection for Lines 1 and 4. The Zone 3 phase delay selected in this example is one second or 60 cycles.

```
Z3DP = 60.00
```

- Setting Limit Check

The limit check allows Zone 3 time delays of 0 - 2000 cycles. The Z3DP of 60 cycles lies within the relay setting limits. There is no secondary limit check for this setting.

- Other Settings Affected

Z3PT bit in the Relay Word.

■ Low-Set Phase Overcurrent Setting for Zone 3 and 4 Supervision (50L3)

The primary function of the 50L3 element is to supervise the Zone 3 and 4 phase distance elements. For three-phase faults, the current in each phase must exceed the 50L3 setting. Recall from the intermediate logic for the Zone 3 and 4 mho distance elements that the three-phase distance elements are logically ANDed with the 3P503 element (the 3P503 element is asserted when the current magnitude in each phase exceeds the 50L3 setting threshold). For phase-phase faults, the current in at least one phase must exceed the 50L3 setting threshold. Again, recall from the intermediate logic that the phase-phase elements are logically ANDed with the 50L3 element.

For the system shown in Figure 5.11, the governing fault condition is a phase-phase fault at Bus A. The fault study revealed that the lowest phase fault current equals 452 A primary for this fault. To ensure that the 50L3 element picks up for the calculated fault current, select some current value below the calculated 452 ampere value for the 50L3 setting. This setting must account for arc resistance, errors in fault study calculations, and CT performance errors. This value for the 50L3 setting may be below load. In this example, the value selected for the 50L3 setting is 275 A (approximately 60% of the minimum phase-phase fault current).

```
50L3 = 275.00
```

- Setting Limit Check

The primary limit check allows for 50L settings of 0.25 - 50,000 A. The secondary check allows for a secondary amp setting of 0.5 - 40 A.

Calculations: CTR = 200:1

$$\text{50L3 secondary amps} = \frac{275 \text{ A primary}}{200} = 1.38 \text{ A secondary}$$

The 50L3 setting of 275 A for this example lies within the relay setting limits.

- Other Settings Affected

50L3 bit in the Relay Word and the Zone 3 and Zone 4 phase distance mhos: Relay Word bits 3ABC, 4ABC, and Z3P.

■ Low-Set Phase Overcurrent Setting for Zone 1 and 2 Supervision (50L)

The primary function of the 50L element is to supervise the Zone 1 and Zone 2 phase distance elements. For three-phase faults, the current in each phase must exceed the 50L setting. Recall from the intermediate logic for the Zone 1 and 2 mho distance elements that the three-phase distance elements are logically ANDed with the 3P50 element (the 3P50 element is asserted when the current magnitude in each phase exceeds the 50L setting threshold). For phase-phase faults, the current in at least one phase must exceed the 50L setting threshold. Again, recall from the intermediate logic that the phase-phase elements are logically ANDed with the 50L element.

For the system shown in Figure 5.11, the governing fault condition is a phase-phase fault at Bus D. The fault study revealed that the lowest phase fault current equals 452 A primary for this fault. To ensure that the 50L element picks up for the calculated fault current, select some current value below the calculated 452 ampere value for the 50L setting. This setting must account for arc resistance, errors in fault study calculations, and CT performance errors. This value for the 50L setting may be below load. In this example, the value selected for the 50L setting is 275 A (approximately 60% of the minimum phase-phase fault current).

```
50L = 275.00
```

- Setting Limit Check

The primary limit check allows for 50L settings of 0.25 - 50,000 A. The secondary check allows for a secondary amp setting of 0.5 - 40 A.

Calculations: CTR = 200:1

$$50L\ \text{secondary amps} = \frac{275\ \text{A primary}}{200} = 1.38\ \text{A secondary}$$

The 50L setting of 275 A for this example lies within the relay setting limits.

- Other Settings Affected

50L bit in the Relay Word and the Zone 1 and 2 phase distance mhos: Relay Word bits 1ABC, 2ABC, Z1P, and Z2P.

■ Medium-Set Phase Overcurrent Setting (50M)

The setting for the 50M pickup value requires that the element must never be picked up for load current conditions. The setting must also be below the minimum fault current level for which the relay is required to trip following an LOP condition. In this example, the application should detect a fault at Bus C after an LOP condition is detected. It is important to remember that the 50M element is nondirectional and requires a coordinating time delay setting for the 50MF bit to use in tripping. The maximum expected load for this circuit is 450 A. The minimum fault current level for a fault at Bus C is 535 A. Faults at Bus C do not drop the positive-sequence voltage at Bus B below 14 V. With a small margin for fault study and CT performance error, the 50M setting for this example is 500 A.

```
50M = 500.00
```

- Setting Limit Check

The primary limit check allows 50M settings of 0.25 - 50,000 A. The secondary check allows secondary amp settings of 0.5 - 40 A.

Calculations: CTR = 200:1

$$\text{50M secondary amps} = \frac{\text{500 A primary}}{200} = \text{2.5 A secondary}$$

The 50M setting of 500 A for this example lies within the relay setting limits.

- Other Settings Affected

50M and 50MF bits in the Relay Word.

■ High-Set Phase Overcurrent Setting

The 50H setting requirement dictates that this element asserts when the line circuit breaker is reclosed into a bolted fault close to Bus B. In Figure 5.11, the difference in fault duty on either side of Breaker 3 is small. This requires the 50H element be masked only in the MTO logic mask.

The three-phase fault duty for a fault at Bus B is 6842 A primary. To assure rapid clearance of this fault, a 50H setting of 3420 A is selected for this example.

```
50H = 3420.00
```

- Setting Limit Check

The primary limit check allows 50H settings of 0.25 - 50,000 A. The secondary check allows a secondary amp setting of 0.5 - 80 A.

Calculations: CTR = 200:1

$$\text{50H secondary amps} = \frac{\text{3420 A primary}}{200} = \text{17.10 A secondary}$$

The 50H setting of 3420 A for this example lies within the setting limits of the relay.

- Other Settings Affected

50H bit in the Relay Word.

■ Residual Time-Overcurrent Settings (51NP, 51NC, 51NTD, 51NTC)

In this example, a single line to ground fault at Bus C dictates the sensitivity required for the residual time-overcurrent pickup. The residual current magnitude for this fault is 460.3 A primary. To allow for ground fault resistance, a value of 50% of 460.3 A is selected as the residual time-overcurrent element pickup. The pickup (51NP), time dial (51NTD), and family of curves (51NC) selections are assumed to coordinate with the remaining residual time- overcurrent elements of the example system.

```
51NP = 230.00
51NTD= 4.00
51NC = 3
51NTC= Y
```

- Setting Limit Check

The primary limit check for the residual time-overcurrent element allows 51NP settings of 0.25 - 50,000 A. The secondary check allows for secondary amp settings of 0.25 - 6.3 A. The 51NC setting check allows settings of 1, 2, 3, or 4 for the family of curves. The 51NTD setting check allows settings from 0.5 to 15 in increments of 0.01. The 51NTC setting allows the residual time-overcurrent element to be torque controlled (Y for directional) or non-torque controlled (N for nondirectional).

Calculations: CTR = 200:1

$$\text{51NP secondary amps} = \frac{230 \text{ A primary}}{200} = 1.15 \text{ A secondary}$$

The 51NP, 51NTD, 51NC, and 51NTC settings are all within the setting limits of the relay.

- Other Settings Affected

The 51NP setting affects the 50N1P, 50N2P, 50N3P, and 50NL pickup setting range. The 51NP setting dictates the sensitivity of the ground directional element when either 32V or 32I is selected. Relay Word bit 51NT and 51NP depend on the 51NP, 51NTD, 51NC and 51NTC settings.

■ 50N1P Residual Overcurrent Setting (50N1P)

The 50N1P setting requirement dictates that this element must not overreach Bus C under the maximum single line to ground fault conditions because it serves as the pickup of the ground instantaneous element. The maximum residual current measured at Breaker 3 for a fault at Bus C equals 695 A. To ensure that the instantaneous element does not overreach Bus C, the 50N1P setting should be 120% of 695 A. This 120% factor accounts for differences between the modeled and actual system, CT ratio errors, etc.

```
50N1P = 835.00
```

- Setting Limit Check

The primary limit check allows 50N1P settings of 0.25 - 50,000 A. The secondary check allows a secondary amp setting of 0.25 A to 48 times the 51NP setting if the 51NP setting is below 3.15 A secondary. If the 51NP setting equals or exceeds 3.15 A secondary, the lower setting limit of the 50N1P element becomes 0.5 A secondary.

Calculations: CTR = 200:1

$$\text{50N1P secondary amps} = \frac{835 \text{ A primary}}{200} = 4.18 \text{ A secondary}$$

The 50N1P setting of 835 A for this example is greater than 0.25 A secondary (51NP < 3.15 A secondary) and less than 48 times the 51NP setting.

- Other Settings Affected

67N1 bit in the Relay Word.

■ **50N2P Residual Overcurrent Setting (50N2P)**

The 50N2P setting requirement dictates that this element must overreach Bus C under the minimum single line to ground fault conditions. The instantaneous output of this element delayed by the Z2SG timer stops carrier and trips the local breaker when the Block Trip (BT) input is not asserted. Based on fault study, the minimum residual current measured at Breaker 3 for a fault at Bus C equals 460.3 A with all sources in. To ensure that this element overreaches Bus C, the 50N2P setting should be 60% of 460 A. This 60% factor accounts for differences between the modeled and actual system, CT ratio errors, fault resistance, etc. The setting must be checked against the protection for Lines 3, 5, and 6 to assure that it does not reach past the instantaneous pickup of the ground fault protection on these lines. In this example, it is assumed to coordinate.

```
50N2P = 276.00
```

- Setting Limit Check

The primary limit check allows 50N2P settings of 0.25 - 50,000 A. The secondary check allows secondary amp settings of 0.25 A to 48 times the 51NP setting if 51NP is less than 3.15 A secondary. If 51NP equals or exceeds 3.15 A secondary, the lower setting threshold becomes 0.5 A secondary.

Calculations: CTR = 200:1

$$50N2P \text{ secondary amps} = \frac{276 \text{ A primary}}{200} = 1.38 \text{ A secondary}$$

The 50N2P setting of 276 A for this example is greater than 0.25 A secondary and less than 48 times the 51NP setting.

- Other Settings Affected

67N2 bit in the Relay Word.

■ 50N3P Residual Overcurrent Setting (50N3P)

The 50N3P setting requirement dictates that this element must detect all faults sensed by the overreaching Zone 2 ground fault protection at Bus C under the minimum single line to ground fault conditions. Based on fault study, the minimum residual current measured at Breaker 3 for a fault at Bus A equals 470 A with all sources in. To assure this element overreaches Bus A, the 50N3P setting should be 60% of 470 A. This 60% factor accounts for differences between the modeled and actual system, CT ratio errors, fault resistance, etc.

```
50N3P = 282.00
```

- Setting Limit Check

The primary limit check allows 50N3P settings of 0.25 - 50,000 A. The secondary check allows secondary amp settings of 0.25 A to 48 times the 51NP setting if 51NP is less than 3.15 A secondary. If 51NP equals or exceeds 3.15 A secondary, the lower setting limit becomes 0.5 A secondary.

Calculations: CTR = 200:1

$$50N3P \text{ secondary amps} = \frac{282 \text{ A primary}}{200} = 1.41 \text{ A secondary}$$

The 50N3P setting of 282 A for this example is greater than 0.25 A secondary (51NP < 3.15 A secondary) and less than 48 times the 51NP setting. Therefore, the 282 A setting for the 50N3P element lies within the secondary setting limits of the relay.

- Other Settings Affected

67N3 bit in the Relay Word.

■ Zone 2 Short Residual Overcurrent Time Delay (Z2SG)

The Z2SG timer adds a settable delay to the Zone 2 instantaneous residual overcurrent element (67N2). This timer provides the necessary carrier coordination to ensure that the local terminal does not trip for an out-of-section fault by delaying the pickup of the Zone 2 instantaneous residual overcurrent element. The time selection should be slightly longer than the maximum time expected for a blocking signal to arrive from Breaker 4. This time includes the pickup of the remote Zone 3 elements plus channel transmit time minus the pickup time of the local Zone 2 overcurrent elements. Typical settings for this timer range from 0.5 to 1.0 cycles. A conservative setting of 0.75 cycles is selected for this example.

```
Z2SG = 0.75
```

- Setting Limit Checks

The primary limit check allows Zone 2 time delays of 0 - 60 cycles. The Z2SG of 0.75 cycles lies within the relay setting limits. There is no secondary limit check for this setting.

- Other Settings Affected

67N2 bit in the Relay Word.

■ **Zone 2 Residual Overcurrent Time Delay (Z2DG)**

This Zone 2 timer adds a settable definite delay to the overreaching Zone 2 instantaneous residual overcurrent element (67N2). Please note that the Z2DG time is not in addition to the short time delay introduced by the Z2SG timer. The timer must coordinate with the residual overcurrent protection at Bus C. For this example, a time delay of 30 cycles is selected and assumed to coordinate.

```
Z2DG = 30.00
```

- Setting Limit Check

The primary limit check allows Zone 2 time delay settings of 0 - 2000 cycles. The Z2DG of 30 cycles lies within the relay setting limits. There is no secondary limit check for this setting.

- Other Settings Affected

Z2GT bit in the Relay Word.

■ **Zone 3 Residual Overcurrent Time Delay (Z3DG)**

This Zone 3 timer adds a settable definite time delay to the Zone 3 instantaneous residual overcurrent element (67N3). The timer must coordinate with the local residual overcurrent protection at Bus B to provide time delay backup protection for faults at Bus A (Zone 3 reversed for this example). For this example, a time delay of 60 cycles is selected and assumed to coordinate.

```
Z3DG = 60.00
```

- Setting Limit Check

The primary limit check allows Zone 3 time delays of 0 - 2000 cycles. The Z3DG of 60 cycles lies within the relay setting limits. There is no secondary limit check for this setting.

- Other Settings Affected

Z3GT bit in the Relay Word.

■ Trip Duration Timer (TDUR)

The trip duration timer setting is determined by the minimum length of time you wish to close the TRIP output contacts. The TRIP output contacts close for the greater of the TDUR time or the duration of the trip condition. Typical settings for this timer are 150 msec or nine cycles.

```
TDUR = 9.00
```

- Setting Limit Check

The primary limit check allows TDUR time delay settings of 0 - 2000 cycles. The TDUR setting of 9.00 cycles lies within the relay setting limits. There is no secondary limit check for this setting.

- Other Settings Affected

TRIP bit in the Relay Word.

■ Loss-of-Potential (LOP) Enable Setting, (LOPE)

The loss-of-potential logic detects blown potential transformer PT secondary fuse conditions. If an LOP condition is detected, the mho distance elements are blocked from operating and the ground directional element defaults forward. Loss-of-potential is enabled with the setting LOPE = Y. With LOP enabled, the 50MF bit in the Relay Word is set after the following conditions are met:

1. A loss-of-potential condition is detected
2. Current exceeds the 50M pickup
3. 50MFD timer expires (requires conditions 1 and 2 to start timing; only condition 2 is required if LOPE=N)

When LOP is not enabled, LOPE = N. The 50MFD timer is initiated when the current exceeds the 50M pickup. For this example, both LOP detection and non-directional phase overcurrent protection after an LOP condition are desired.

```
LOPE = Y
```

- Setting Limit Check

The primary limit check allows LOPE settings of Y (enabled) or N (not enabled).

- Other Settings Affected

The operating mode of the 50MF bit in the Relay Word. If LOPE=N, the mho distance elements are not blocked from operating during an LOP condition.

■ 52BT Setting (52BT)

The 52BT timer setting determines the length of time switch-onto-fault logic is enabled. The 52BT timer setting must be shorter than the time for the first reclose attempt or line breaker closure at the remote terminal. At the same time, it must be long enough for the fault detecting elements to assert and generate a trip output. Typical high speed reclosure times are 20 - 30 cycles to allow dispersal of ionized fault gases. In this example, the first reclose occurs at 40 cycles. To ensure that the 52BT element is asserted before the line breaker recloses, a 52BT time of 20 cycles is selected.

```
52BT = 20.00
```

- Setting Limit Check

The limit check allows 52BT time delay settings of 0.5 - 10,000 cycles. The 52BT setting of 20.00 cycles lies within the relay setting limits. There is no secondary limit check for this setting.

- Other Settings Affected

52BT bit in the Relay Word, the lesser of 79OI1, 79OI2, and 79OI3 settings.

■ **Zone 3 Direction Setting**

The Zone 3 elements must be reversed in this application due to the role of the reverse looking elements in the DCB scheme. The reverse Zone 3 elements also provide time-step backup protection for Bus A.

```
ZONE3 = R
```

- Setting Limit Check

The ZONE3 setting must be set for either F (forward) or R (reverse).

- Other Settings Affected

Z2% and Z3% reach limitations.

■ **Residual Overcurrent Polarization Method Selection (32QE, 32VE, 32IE)**

The polarization method selected for this example is negative-sequence. This prevents the influences of zero-sequence mutual coupling with Line 5. For all single-line-to-ground faults, the negative-sequence polarizing volt-amperes exceed 0.10 VA secondary and are sufficient to polarize the ground directional element. It is further assumed that the residual overcurrent protection of the surrounding system is negative-sequence polarized.

```
32QE = Y
32VE = N
32IE = N
```

- Setting Limit Check

The relay allows you to select between three methods of residual overcurrent polarization. When you select negative-sequence, you can not use zero-sequence methods. When you select zero-sequence polarization, you can use one or both of the zero-sequence voltage and current polarization methods.

- Other Settings Affected

None.

■ **Serial Port(s) Timeout Settings (TIME1, TIME2)**

The TIME1 and TIME2 settings allow their respective ports to time out after the relay detects a period of inactivity for that port. After timing out, access for the port returns to Level 0 and no automatic messages are transmitted to it. In this example, a modem is connected to PORT 1. This requires a definite time setting for the port to prevent accumulation of toll charges if an operator does not hang up. PORT 2 is to be connected to an SEL-DTA and must never time out. This allows the SEL-DTA to receive any automatic message transmitted by the relay.

```
TIME1= 5   TIME2 = 0
```

- Setting Limit Check

The TIME1 and TIME2 limit check allows settings of 0 - 30 minutes. A zero setting signifies that the port never times out. There is no secondary limit check for this setting.

- Other Settings Affected

None.

■ Autoport Designation Setting (AUTO)

The AUTO setting specifies the port to which the relay directs automatically generated messages. The example has a modem connected to PORT 1 and an SEL-DTA connected to PORT 2. Since only the SEL-DTA is required to receive automatic messages, the AUTO setting is 2.

```
AUTO = 2
```

- Setting Limit Check

The limit check allows messages to be sent to PORT 1 only, (AUTO = 1), PORT 2 only (AUTO = 2), or both ports (AUTO = 3).

- Other Settings Affected

None.

■ Modem Answer Ring Setting (RINGS)

The RINGS setting specifies the number of rings a modem connected to PORT 1 waits to answer. This permits use of a single substation telephone line by both substation personnel and the relay. In this example, personnel have seven rings to answer the phone before the modem answers.

```
RINGS = 7
```

- Setting Limit Check

The limit check allows for the modem to answer between 1 and 30 rings.

- Other Settings Affected

None.

■ Programmable Output Contact Mask Settings

The Relay Word is the center of relay programmability. It contains four rows of eight bit groups which represent the state of relay elements, timer and logic outputs, and relay inputs. Each bit in the Relay Word has two states: logical 1 when the element is asserted, logical 0 when the element is deasserted.

Each quarter-cycle, the relay samples voltage and current data, performs intermediate logic to determine if an element is asserted, and sets the appropriate bit in the Relay Word.

After updating the Relay Word, the relay compares it to all programmable logic masks with a logical "AND" process. This process in turn controls the relay output contacts. Each TRIP and programmable output relay has a corresponding logic mask. In addition to these masks, the relay has two masks to control initiation and cancellation of the three shot recloser. These masks determine the state of the output contacts and reclosing progression.

Table 5.1 shows the Relay Word.

Table 5.1: Relay Word

1ABC	2ABC	3ABC	4ABC	LOP	50H	50M	50L
51NT	67N1	67N2	67N3	51NP	Z1P	Z2P	Z3P
Z2PT	Z3PT	50L3	3P50	50MF	RC	RI	STOP
50N3	TRIP	TC	DT	52BT	Z3X	Z2GT	Z3GT

The Relay Word Bit Summary Table explains each bit in the Relay Word.

The relay employs ten separate logic masks. Four of these masks are directly related to controlling the TRIP output contacts (MTU, MPT, MTB, and MTO). The masks labeled MA1, MA2, MA3, and MA4 control the four programmable output contacts. The masks for reclose initiation (MRI) and reclose cancel (MRC) are used as inputs for controlling the three shot recloser.

Communication Scheme Use of the Logic Masks

In addition to DCB schemes, the relay supports a large variety of protective schemes, some of which are shown below:

- Time-stepped distance
- Permissive-overreaching Transfer Trip (POTT) schemes
- Directional comparison unblocking (DCUB) schemes
- Direct underreaching transfer trip (DUTT) schemes
- Permissive underreaching transfer trip (PUTT) schemes
- Direct transfer trip (DTT) schemes

The Relay Word and programmable masks provide great flexibility in applying the relay without rewiring panels or changing jumpers on circuit boards. Interfacing the relay with each of the various schemes involves three simple steps: 1) connecting the communications equipment to the appropriate logic input (DT, PT, or BT) on the relay rear panel, 2) selecting the appropriate mask and bits for the tripping scheme (MTU, MPT, MTB, or MTO), and 3) depending on which scheme is selected, determining the number of programmable output contacts required to interface with the communications equipment and the appropriate Relay Word bit. Please note that each mask is independent from the other tripping masks. This allows multiple schemes to function simultaneously.

The following guideline shows typical usage of bits in each mask.

Please note that each application requires a careful study of the bit used in each mask. This guideline is included as a reference of typical Relay Word bit usage.

MTU: Mask for Trip Unconditional

Elements selected in this mask do not require that external conditions be met to initiate a trip. If an element masked in the MTU logic mask picks up, the TRIP output contacts close. You must be certain that elements used in this mask coordinate with the remainder of the power system. Unless your application permits, it is not advisable to mask non-directional elements into the MTU logic mask.

Typical bits masked in the MTU logic mask include Zone 1 instantaneous elements (1ABC, Z1P, and 67N1) if they underreach the remote terminal, time delayed Zone 2 elements (Z2PT and Z2GT), time delayed Zone 3 elements (Z3PT and Z3GT), 50MF, the TC bit to close TRIP output contacts upon OPEN command execution, and the Direct Trip (DT) bit if an external tripping source energizes the DT input. The external tripping source is often a backup protective relay, breaker failure relaying, or a direct trip signal from communications equipment. In each example listed (except breaker failure), energizing the DT input allows you to utilize the reclosing functions by forcing the relay to trip.

Note: Never mask the TRIP bit into the MTU logic mask. This causes an undesirable seal-in of TRIP output contacts.

MPT: Mask for Trip with Permissive Trip Input Asserted

Elements selected in this mask are permitted to close the TRIP output contacts when they pick up in conjunction with Permissive Trip (PT) input assertion. PT input assertion serves as an external qualifying condition. As with the MTU logic mask, it is not advisable to mask non-directional elements in the MPT logic mask unless your application permits.

Typical bits masked in the MPT logic mask include Zone 2 instantaneous elements (2ABC, Z2P, and 67N2).

Note: Never mask the TRIP bit into the MPT logic mask. This causes an undesirable seal-in of TRIP output contacts when the PT input is asserted.

MTB: Mask for Trip with Block Trip Input Deasserted

Elements selected in this mask are permitted to close the TRIP output contacts when they are picked up and the Block Trip (BT) input is not asserted. BT input assertion serves as an external qualifying condition. As with the MTU logic mask, it is not advisable to mask non-directional elements in the MTB logic mask unless your application permits.

Typical bits masked in the MTB logic mask include Zone 2 instantaneous elements (2ABC, Z2P, and 67N2).

Note: Never mask the TRIP bit into the MTB logic mask. This causes an undesirable seal-in of the TRIP output contacts when the BT input is not asserted.

MTO: Mask for Trip with the 52BT Element Asserted

Elements selected in this mask are permitted to close the TRIP output contacts when they are picked up and the 52BT element is asserted. The 52BT element is a time delayed, inverted follower of the 52A input (see switch-onto-fault logic explanation for a detailed timing explanation of the 52BT element). This tripping mask differs from the MTU, MPT, and MTB tripping masks because it is acceptable to mask sensitive nondirectional elements into MTO. Such masking is advisable except in applications where the line breaker is closed into a line energized from the remote terminal (i.e. synchronized closures).

Typical bits masked in the MTO logic mask include Zone 1 instantaneous elements (1ABC, Z1P, and 67N1), the nondirectional high-set element (50H), Zone 2 instantaneous elements (2ABC, Z2P, and 67N2), and the Direct Trip (DT) bit if an external tripping source energizes the DT input of the relay.

Note: Never mask the TRIP bit into the MTO logic mask. This causes an undesirable seal-in of TRIP output contacts when the 52BT element is asserted.

MA1, MA2, MA3, and MA4 Programmable Output Contact Masks

Any element listed in the Relay Word may be masked into these programmable output contacts. Guidelines to follow when masking elements into each mask depends on equipment wired to the contact outputs. If external connections are not wired to the contact outputs, it is advisable to mask elements into these masks to enhance event report analysis.

For commissioning purposes, you may mask the TC bit into an individual output contact and use the OPEN command to verify contact closure.

MRI: Mask for Reclose Initiation

If an element masked in the MRI mask is asserted when the TRIP output contacts close, reclosing is initiated unless a reclose cancel condition invalidates initiation. Reclose initiation is subordinate to reclose cancel. See Reclose Logic at the end of this section for more details.

MRC: Mask for Reclose Cancellation

If an element masked in the MRC mask is asserted when the TRIP output contacts close, reclosing is cancelled even if a reclose initiate condition is present. Reclose initiation is subordinate to reclose cancellation. See Reclose Logic at the end of this section for more details.

Relay Word Bits Intended for Relay Testing

Each bit in the Relay Word has a designated purpose. The following bits are included to assist in relay testing: 50M, 50L, 51NP, 50L3, 3P50, and TC. This does not exclude the use of these bits in one of four trip or programmable output contacts if required by your application.

Note: Each mask must be properly configured for your application.

■ **Mask for Trip Unconditional (MTU)**

								Event Report Hexadecimal Code
1ABC	2ABC	3ABC	4ABC	LOP	50H	50M	50L	
1	0	0	0	0	0	0	0	80
51NT	67N1	67N2	67N3	51NP	Z1P	Z2P	Z3P	
1	1	0	0	0	1	0	0	C4
Z2PT	Z3PT	50L3	3P50	50MF	RC	RI	STOP	
1	1	0	0	1	0	0	0	C8
50N3	TRIP	TC	DT	52BT	Z3X	Z2GT	Z3GT	
0	0	1	1	0	0	1	1	33

The example Mask for Unconditional Trip (MTU) selects tripping by the Zone 1 three-phase (1ABC), Zone 1 phase-phase (Z1P), Zone 1 residual instantaneous overcurrent element

(67N1), 51N element (51NT) timeout, Zone 2 and 3 phase distance (Z2DP and Z3DP) timeout, residual overcurrent element (Z2DG and Z3DG) timeout, the 50MF element, the OPEN command (TC ≡ Trip Command), and Direct Trip input (DT) assertion.

In this example, the DT input will be energized by the trip output of the local breaker failure protection for event report generation. Where primary and secondary protection trip output contacts are routed to separate trip coils of the line breaker, cross tripping is achieved by routing the trip output of each set of protection to trip the other. When cross tripping is desirable, route the trip output from the secondary line protection relays to the DT input.

- **Mask Permissive Trip (MPT)**

								Event Report Hexadecimal Code
1ABC	2ABC	3ABC	4ABC	LOP	50H	50M	50L	
0	0	0	0	0	0	0	0	00
51NT	67N1	67N2	67N3	51NP	Z1P	Z2P	Z3P	
0	0	0	0	0	0	0	0	00
Z2PT	Z3PT	50L3	3P50	50MF	RC	RI	STOP	
0	0	0	0	0	0	0	0	00
50N3	TRIP	TC	DT	52BT	Z3X	Z2GT	Z3GT	
0	0	0	0	0	0	0	0	00

The example mask for permissive tripping contains all zeros because POTT is not selected.

- **Mask for Trip Block (MTB)**

								Event Report Hexadecimal Code
1ABC	2ABC	3ABC	4ABC	LOP	50H	50M	50L	
0	1	0	0	0	0	0	0	40
51NT	67N1	67N2	67N3	51NP	Z1P	Z2P	Z3P	
0	0	1	0	0	0	1	0	22
Z2PT	Z3PT	50L3	3P50	50MF	RC	RI	STOP	
0	0	0	0	0	0	0	0	00
50N3	TRIP	TC	DT	52BT	Z3X	Z2GT	Z3GT	
0	0	0	0	0	0	0	0	00

The example mask for block tripping (MTB) selects tripping by the Zone 2 three-phase (2ABC), Zone 2 phase-phase (Z2P), and Zone 2 residual instantaneous overcurrent element (67N2) when the BT input is not asserted. Please note these bits include the time delay of the associated short timers (Z2SP or Z2SG).

■ Mask for Trip Breaker Open (MTO)

								Event Report Hexadecimal Code
1ABC	2ABC	3ABC	4ABC	LOP	50H	50M	50L	
1	1	0	0	0	1	0	0	C4
51NT	67N1	67N2	67N3	51NP	Z1P	Z2P	Z3P	
1	1	1	0	0	1	1	0	E6
Z2PT	Z3PT	50L3	3P50	50MF	RC	RI	STOP	
0	0	0	0	0	0	0	0	00
50N3	TRIP	TC	DT	52BT	Z3X	Z2GT	Z3GT	
0	0	0	0	0	0	0	0	00

The MTO mask selects elements to trip when 52BT is asserted. The example mask for trip while breaker open (MTO) selects tripping by Zone 1 and 2 three-phase elements (1ABC and 2ABC), high set phase overcurrent element (50H), instantaneous Zone 1 and 2 phase-phase elements (Z1P and Z2P), residual instantaneous overcurrent elements (67N1 and 67N2), and timeout of the 51N element (51NT).

■ Mask for the A1 Output Contact (MA1)

								Event Report Hexadecimal Code
1ABC	2ABC	3ABC	4ABC	LOP	50H	50M	50L	
0	0	1	1	0	0	0	0	30
51NT	67N1	67N2	67N3	51NP	Z1P	Z2P	Z3P	
0	0	0	1	0	0	0	1	11
Z2PT	Z3PT	50L3	3P50	50MF	RC	RI	STOP	
0	0	0	0	0	0	0	0	00
50N3	TRIP	TC	DT	52BT	Z3X	Z2GT	Z3GT	
1	0	0	0	0	1	0	0	84

The A1 output contact connects to the carrier start keying input of the communications equipment. The example mask setting for the A1 contact permits A1 output contact closure when the reverse looking instantaneous elements, Z3X logic conditions, nondirectional residual instantaneous-overcurrent element, or the reverse looking offset Zone 4 element set.

■ Mask for the A2 Output Contact (MA2)

								Event Report Hexadecimal Code
1ABC	2ABC	3ABC	4ABC	LOP	50H	50M	50L	
0	0	0	0	0	0	0	0	00
51NT	67N1	67N2	67N3	51NP	Z1P	Z2P	Z3P	
0	0	0	0	0	0	0	0	00
Z2PT	Z3PT	50L3	3P50	50MF	RC	RI	STOP	
0	0	0	0	0	0	0	1	01
50N3	TRIP	TC	DT	52BT	Z3X	Z2GT	Z3GT	
0	1	0	0	0	0	0	0	40

The A2 output contact is masked to stop carrier whenever a forward looking Zone 2 element asserts (after the carrier coordinating time delays of Z2SP and Z2SG expire) via the STOP bit or the TRIP output asserts.

■ **Mask for the A3 Output Contact (MA3)**

								Event Report Hexadecimal Code
1ABC	2ABC	3ABC	4ABC	LOP	50H	50M	50L	
0	0	0	0	0	0	0	0	00
51NT	67N1	67N2	67N3	51NP	Z1P	Z2P	Z3P	
0	0	0	0	0	0	0	0	00
Z2PT	Z3PT	50L3	3P50	50MF	RC	RI	STOP	
0	0	0	0	0	1	0	0	04
50N3	TRIP	TC	DT	52BT	Z3X	Z2GT	Z3GT	
0	0	0	0	0	0	0	0	00

The A3 output contact is masked to show a reclose cancel condition in the event report. The example mask setting for the A3 contact permits closure of the A3 output contact when the RC bit is set.

■ **Mask for the A4 Output Contact (MA4)**

								Event Report Hexadecimal Code
1ABC	2ABC	3ABC	4ABC	LOP	50H	50M	50L	
0	0	0	0	1	0	0	0	08
51NT	67N1	67N2	67N3	51NP	Z1P	Z2P	Z3P	
0	0	0	0	0	0	0	0	00
Z2PT	Z3PT	50L3	3P50	50MF	RC	RI	STOP	
0	0	0	0	0	0	0	0	00
50N3	TRIP	TC	DT	52BT	Z3X	Z2GT	Z3GT	
0	0	0	0	0	0	0	0	00

The A4 output contact connects to the local annunciator panel to alarm for loss-of-potential conditions. The example mask setting for the A4 contact permits A4 output contact closure when the LOP bit is set.

■ **Mask for Reclose Initiation (MRI)**

								Event Report Hexadecimal Code
1ABC	2ABC	3ABC	4ABC	LOP	50H	50M	50L	
0	0	0	0	0	0	0	0	00
51NT	67N1	67N2	67N3	51NP	Z1P	Z2P	Z3P	
0	1	0	0	0	1	0	0	44
Z2PT	Z3PT	50L3	3P50	50MF	RC	RI	STOP	
0	0	0	0	0	0	0	0	00
50N3	TRIP	TC	DT	52BT	Z3X	Z2GT	Z3GT	
0	0	0	0	0	0	0	0	00

The mask for Reclose Initiation (RI) selects elements from the Relay Word to start the reclosing relay. The example mask for reclose initiation selects the Zone 1 residual instantaneous-overcurrent (67N1) element and the Zone 1 phase-phase element (Z1P) for reclose initiation.

■ **Mask for Reclose Cancel (MRC)**

								Event Report Hexadecimal Code
1ABC	2ABC	3ABC	4ABC	LOP	50H	50M	50L	
1	1	1	0	0	1	0	0	E4
51NT	67N1	67N2	67N3	51NP	Z1P	Z2P	Z3P	
1	0	0	0	0	0	0	0	80
Z2PT	Z3PT	50L3	3P50	50MF	RC	RI	STOP	
1	1	0	0	1	0	0	0	C8
50N3	TRIP	TC	DT	52BT	Z3X	Z2GT	Z3GT	
0	0	1	1	0	0	1	1	33

The mask for Reclose Cancel (RC) selects elements from the Relay Word to cancel the reclosing relay. The example mask for reclose cancel stops reclosing for three-phase faults in Zone 1, 2, and 3, a 50H high-set overcurrent condition, timeout of the residual overcurrent element 51NT, timeout of the Zone 2 and Zone 3 phase timers Z2PT and Z3PT, the Trip Command (TC), assertion of the Direct Trip (DT) input, and timeout of the Zone 2 and Zone 3 ground timers (Z2GT and Z3GT, respectively).

Table 5.2: Relay Word Bit Summary

1ABC - Zone 1 three-phase instantaneous element (set by Z1%)
2ABC - Zone 2 three-phase instantaneous element (set by Z2%)(delayed by Z2SP)
3ABC - Zone 3 three-phase instantaneous element (set by Z3%)
4ABC - Zone 4 three-phase instantaneous element (diameter equal to 1.5 x Z3%)
LOP - Loss-of-potential condition
50H - High-level overcurrent element (set by 50H)
50M - Medium-level overcurrent element (set by 50M)
50L - Zone 1 and Zone 2 phase fault current supervision (set by 50L)

51NT - Residual time-overcurrent trip (set by 51NP, 51NTD, and 51NC)
67N1 - Residual instantaneous-overcurrent (set by 50N1P)[1]
67N2 - Residual instantaneous-overcurrent (set by 50N2P)[1](delayed by Z2SG)
67N3 - Residual instantaneous-overcurrent (set by 50N3P)[1]
51NP - Residual time-overcurrent pickup
Z1P - Zone 1 phase-phase element (set by Z1%)
Z2P - Zone 2 phase-phase element (set by Z2%)(delayed by Z2SP)
Z3P - Zone 3 phase-phase element (set by Z3%)

Z2PT - Zone 2 phase-phase or three-phase timeout (set by Z2DP)
Z3PT - Zone 3 phase-phase or three-phase timeout (set by Z3DP)
50L3 - Zone 3 and Zone 4 phase fault current supervision (set by 50L3)
3P50 - Zone 1 and Zone 2 three-phase fault current supervision
50MF - Asserts a settable delay after LOP and 50M pickup (delay set by 50MFD)
RC - Reclose cancel
RI - Reclose initiate
STOP - Carrier Stop Condition

50N3 - Nondirectional residual instantaneous-overcurrent (pickup set by 50N3P)
TRIP - Trip condition
TC - Trip (OPEN) Command
DT - Direct Trip (or other user defined external purposes)
52BT - Inverted time delayed 52A follower (delay set by 52BT setting)
Z3X - Zone 3 logic condition asserted
Z2GT - Zone 2 timeout-ground (set by Z2DG)
Z3GT - Zone 3 timeout-ground (set by Z3DG)

[1] The 50N elements are made directional by enabling any of the directional control methods, i.e., 32QE = Y, or either 32VE = Y or 32IE = Y.

RECLOSE LOGIC

Introduction

All SEL-221G series relays include a reclosing relay capable of one to three shots of automatic reclosing for selectable fault types. The relay uses a mask logic principle to allow programmable output contact for tripping and communication equipment interfaces. It uses the same logic to control initiation or cancellation of a reclosing sequence.

Reclosing schemes have traditionally required a separate reclosing relay for each terminal. These relays controlled the timing of the breaker reclosing scheme. The reclosing sequence was cancelled using one of two methods: 1) a reclose block signal sent to the recloser from protective relays, or 2) external relays to control a reclose block contact in series with the recloser close contact. The reclosing function of the SEL-221G Relay eliminates the need for a separate recloser and the associated external cancellation/initiation circuitry.

Basic Automatic Reclosing Philosophy

Most faults occurring on transmission line networks are transient. Thus, after the circuit breakers on either end of the transmission line have removed the fault energy, the line may be successfully re-energized. A short time period is required between opening of the circuit breaker poles and the reclose to allow dispersal of the fault arc. This reclosing time can also be used to coordinate line testing from designated sources. The time period is usually controlled by the reclosing dead time for each automatic shot.

Automatic reclosing schemes substantially improve the continuity of transmission line service without requiring operator intervention.

For faults such as three-phase faults, automatic reclosing may not be desirable. The chance of such faults being permanent is much greater than phase-to-phase or single line-to-ground faults. A permanent three-phase fault can occur when line crews do not remove safety grounds after working on a transmission line. Other instances for which reclosing may not be desirable include faults cleared by either time delayed Zone 2 or 3 elements or a ground time-overcurrent element in a communication aided protection scheme. Programmable logic masks permit you to select a fault type and/or zone for which you wish to initiate/cancel circuit breaker reclosure.

Basic SEL-221G Relay Recloser Operating Logic

The SEL-221G reclosing relay allows one to three shots of automatic reclosing for selectable fault types. Reclosure timing is controlled by three open interval timers (79OI1, 79OI2, and 79OI3). If a reclose is unsuccessful due to external constraints, a timer (79RS) resets the recloser to prevent a standing close (please see Example 7 for a detailed explanation of the 79RS timer function). Each timer is individually settable.

Table 5.3: Trace Assignments for Example 1	
Trace Assignment	Description of Trace
A	Trip
B	Close
C	Reclose Initiate, RI
D	Reclose Cancel, RC

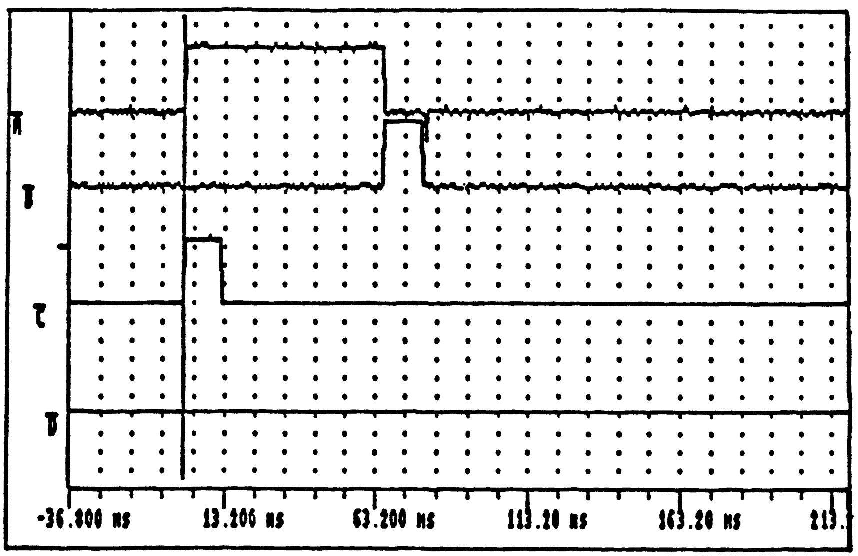


Figure 5.12: Successful Reclose Sequence after Zone 1 Phase-to-Phase Fault

The oscillograph in Figure 5.12 shows that the reclose sequence does not begin until after the trip output deasserts, even though the RI was issued much earlier (also note that reclose cancel never asserted). For this example, the Z1P is enabled in the RI mask, while 3ABC is enabled in the RC mask.

TRIP output duration is always a minimum of TDUR cycles. This feature allows you to determine the minimum TRIP contact closure duration to ensure that the circuit breaker trip coil receives a strong, steady trip signal. Thus, the open interval timing may start several milliseconds after the fault clears and the breaker opens. Figure 5.13 shows the edge triggered Trip Duration Timer (TDUR) in the close TRIP logic for the SEL-221G-6/121G-6. For the SEL-221G-7/121G-7 (see the logic diagram in Section 2: SPECIFICATIONS) the TDUR operates as a trip dropout timer.

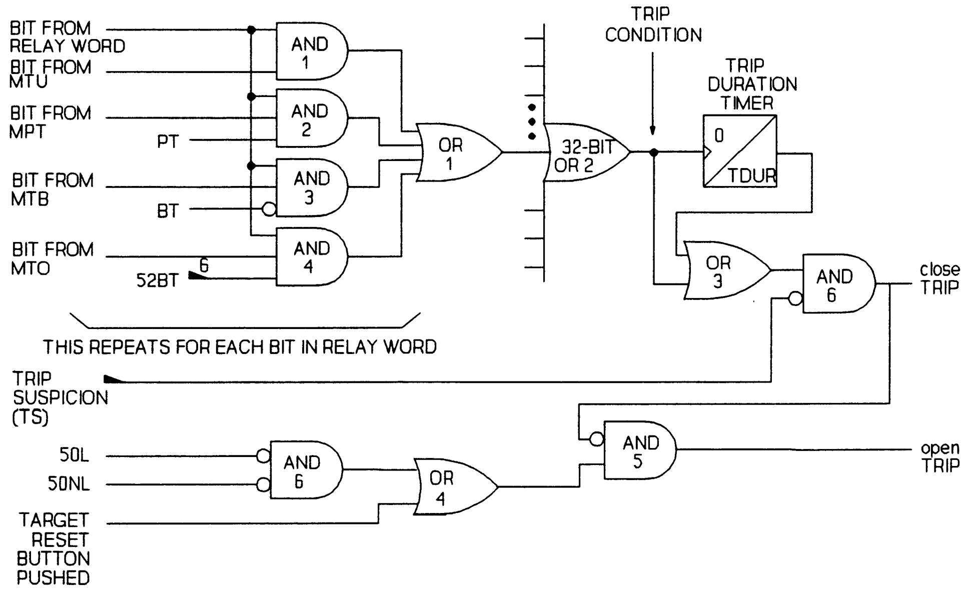


Figure 5.13: Programmable Trip Logic Diagram

Example 2: Reclose Cancel Hierarchy over Reclose Initiate

The oscillograph in Figure 5.14 shows an unsuccessful reclosing sequence for the same Zone 1 phase-to-phase fault used in Example 1. Relay settings were the same as Example 1 except that the element initiating reclose in the MRI mask now also initiates cancel in the MRC mask. This shows that the reclose cancel mask MRC has hierarchy over the reclose initiate mask. The following examples explain this feature.

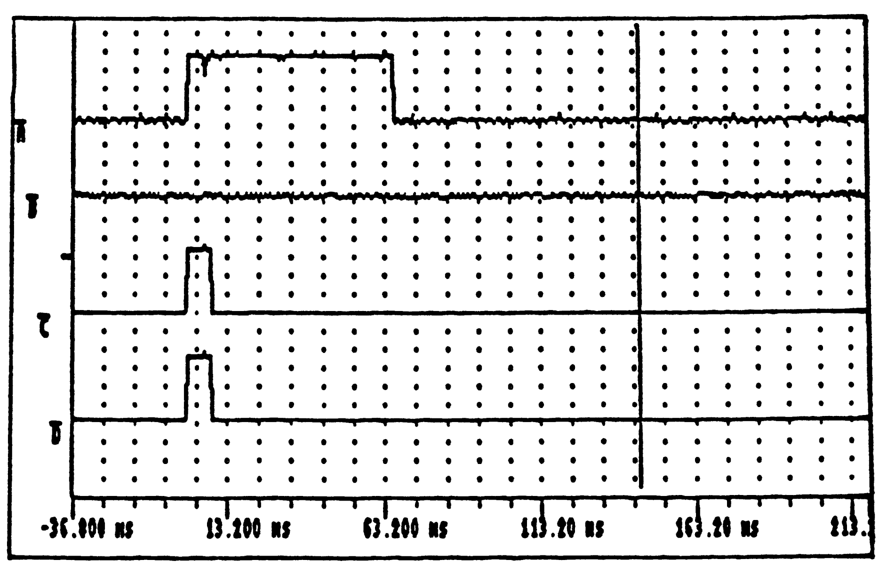


Figure 5.14: Unsuccessful Reclose Sequence after Zone 1 Phase-to-Phase Fault

Example 3: Reclose Cancel Due to Breaker Open (52A contact not asserted)

The oscillograph in Figure 5.15 shows an unsuccessful reclosing sequence for the same Zone 1 phase-to-phase fault used in Example 1 with the breaker open (52A input not asserted). This fulfills the requirement that the recloser must see a change in 52A contact state before the 79OI timer can begin timing. Trace assignments are identical to those in Table 5.3. Note that the RI signal is initiated as in Example 1 but no close signal is ever issued to the CLOSE output contact.

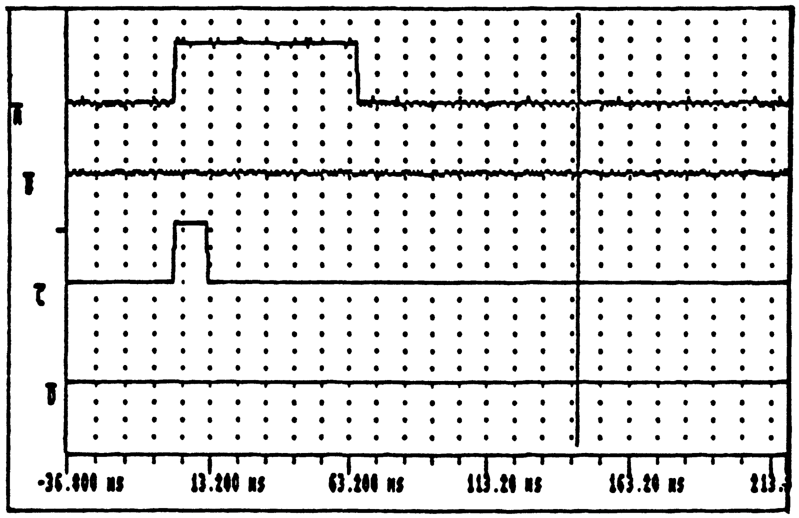


Figure 5.15: Unsuccessful Reclose Sequence after Zone 1 Phase-to-Phase Fault

Example 4: Evolving Fault Reclose Cancellation

The oscillograph in Figure 5.16 shows an unsuccessful reclosing sequence for a Zone 1 phase-to-phase fault evolving into a Zone 1 three-phase fault. Note that the relay issues the RI signal, followed by an RC signal. No close signal is issued for this case. The RC was issued before the trip output deasserted, cancelling the reclosing sequence. This action is based on the precedence of the MRC mask over the MRI mask. Trace assignments are the same as those in Table 5.3 for Example 1.

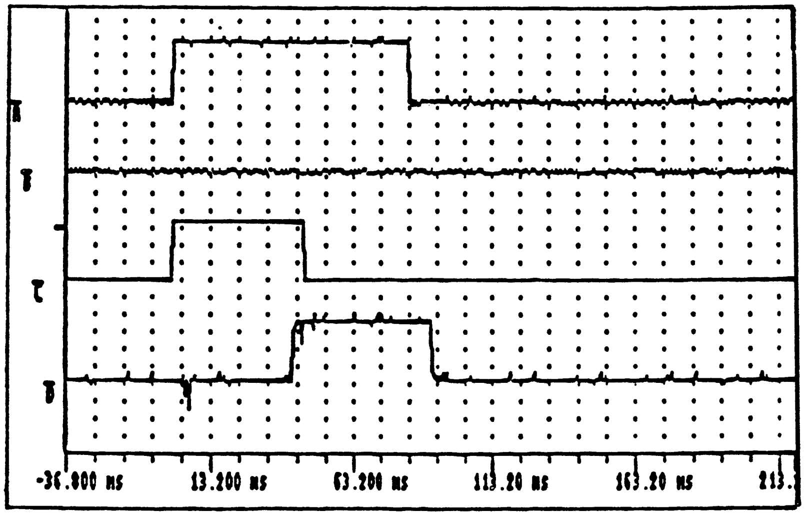


Figure 5.16: Unsuccessful Reclose Sequence, Zone 1 Phase-Phase to Three-Phase Fault

The oscillograph in Figure 5.17 also shows an unsuccessful reclosing sequence for a Zone 1 three-phase fault evolving into a Zone 1 phase-to-phase fault. Although this is a highly unlikely situation, it is included to demonstrate the recloser cancellation logic. Note that the RC signal is issued, followed by an RI signal. No close signal is issued for this case. The RC is issued while the trip output is asserted, cancelling the reclosing sequence. Trace assignments are identical to those in Table 5.3 for Example 1.

The reclose initiating condition in the MRI mask is the Zone 1 phase-to-phase element. The reclose cancelling condition in the MRC mask is the Zone 3 three-phase instantaneous element (Zone 3 forward). When a reclose cancelling condition becomes true while the trip output is asserted, the reclosing cycle is cancelled.

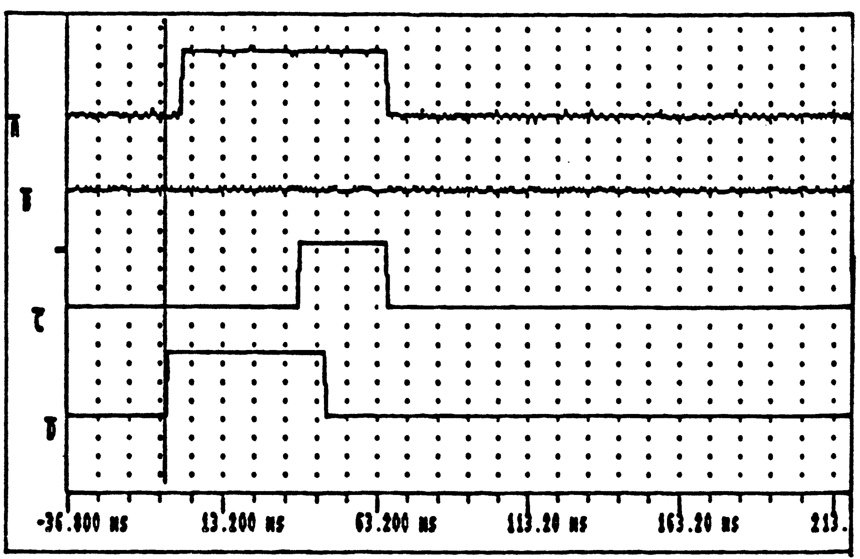


Figure 5.17: Unsuccessful Reclose Sequence, Zone 1 Three-Phase to Phase-Phase Fault

In this case, problems can occur if a user masks a Zone 1 element in the RI mask and the same fault type Zone 2 instantaneous element in the RC mask, expecting the Zone 1 element to initiate a reclose. Since the Zone 2 element has a greater forward reach than the Zone 1 element, it picks up before the Zone 1 element. It remains picked up while the Zone 1 element is picked up and cancels reclosing. However, if the Zone 2 (or forward Zone 3, or Zone 4) instantaneous element is not masked into the RC mask and the fault is within Zone 1 reach, the reclosing cycle proceeds as expected (providing no other reclose cancelling conditions are met). This is true even if the Zone 2 instantaneous element initiates the trip before the Zone 1 element picks up (as in carrier-based schemes). Figure 5.18 demonstrates a successful reclosing sequence for a Zone 1 fault where the trip is first initiated by the farther reaching Zone 2 element (not in the MRC mask). The element issues a reclose initiate signal because the Zone 1 element asserts while the trip signal is asserted.

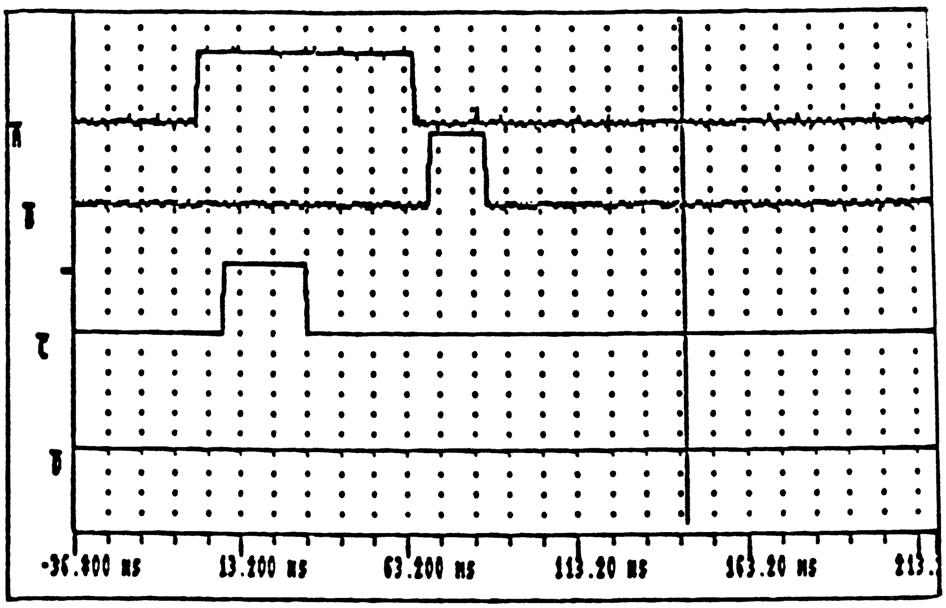


Figure 5.18: Successful Reclose Sequence, Zone 1 Phase-to-Phase Trip Initiated by Zone 2

Example 5: Recloser Interval Time References

The oscillograph in Figure 5.19 demonstrates a two shot reclosing sequence for a Zone 1 phase-to-phase fault. Five- and 15-cycle reclosing intervals are shown (79OI1 = 5 cycles, 79OI2 = 15 cycles). The Zone 1 element issues an RI signal for each shot while the trip element is asserted, but timing does not begin until the TRIP contact opens.

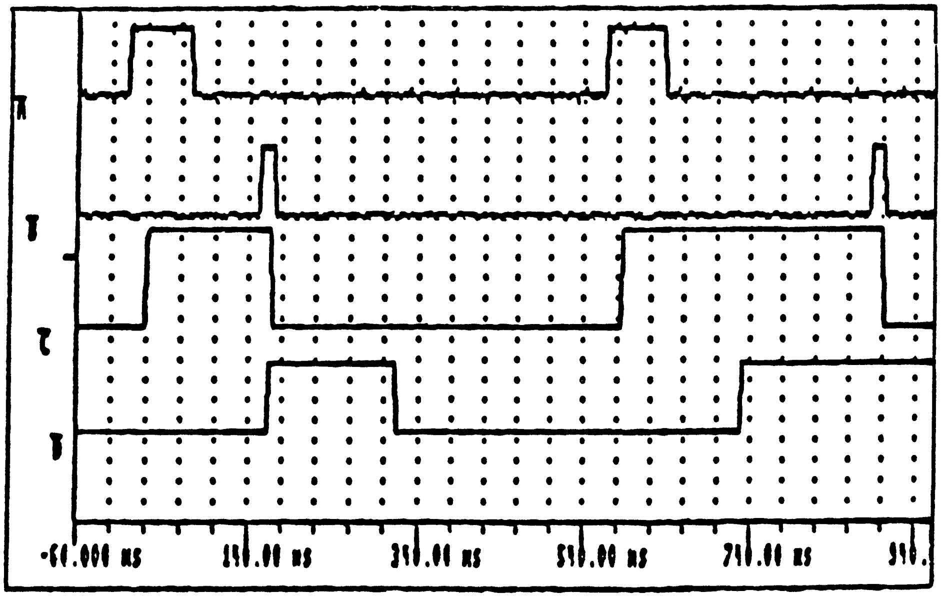


Figure 5.19: Two Shot Reclosing Sequence Timing Diagram

Table 5.4: Trace Assignments for Examples 5 and 6 (except Figures 5.24 and 5.25)	
Trace Assignment	Description of Trace
A	Trip
B	Close
C	Inverted 52A Status Input
D	52BT

<u>Example 6: Coordination of 52BT and 79OI Timers</u>

It is important to distinguish between the four separate trip masks of the SEL-221G Relay. The masks are:

MTU ≡ Mask for Trip Unconditional (no logic qualifiers)
MPT ≡ Mask for trip with the Permissive Trip input asserted
MTB ≡ Mask for Trip with the Block trip input not asserted
MTO ≡ Mask for Trip while the 52BT element is asserted

MTU: Mask for Trip Unconditional. Elements selected in this mask do not require an external or conditional input to close the trip output contact.

MPT: Mask for Permissive Trip. Elements selected for this mask require that a permissive signal be present (or asserted) at the Permissive Trip input on the SEL-221G Relay rear panel.

MTB: Mask for Trip Block. Elements selected for this mask, combined with the absence of a block signal at the rear panel Block Trip input, allow the SEL-221G Relay to perform Directional Comparison Blocking (DCB) protective functions.

MTO: Mask for Trip while the 52BT element is asserted. Elements selected in this mask regulate breaker tripping using very sensitive elements. Tripping occurs during line testing or when a line is energized for the first time. The 52BT time setting determines the time during which the relay enables switch-onto-fault logic. The 52BT element is an inverted time delayed follower of the 52A input. When the 52A input to the relay goes from a high state (breaker closed) to a low state (breaker trips), the 52BT element remains low for the 52BT time selected in the setting procedure. When the breaker is closed (from an open state), the 52BT element remains high for 52BT time. Thus, for 52BT time after the breaker is closed, the elements selected in the MTO logic mask can sense fault conditions, providing switch-onto-fault protection.

The graph in Figure 5.20 shows the timing relationship between the 52BT and 79OI timers.

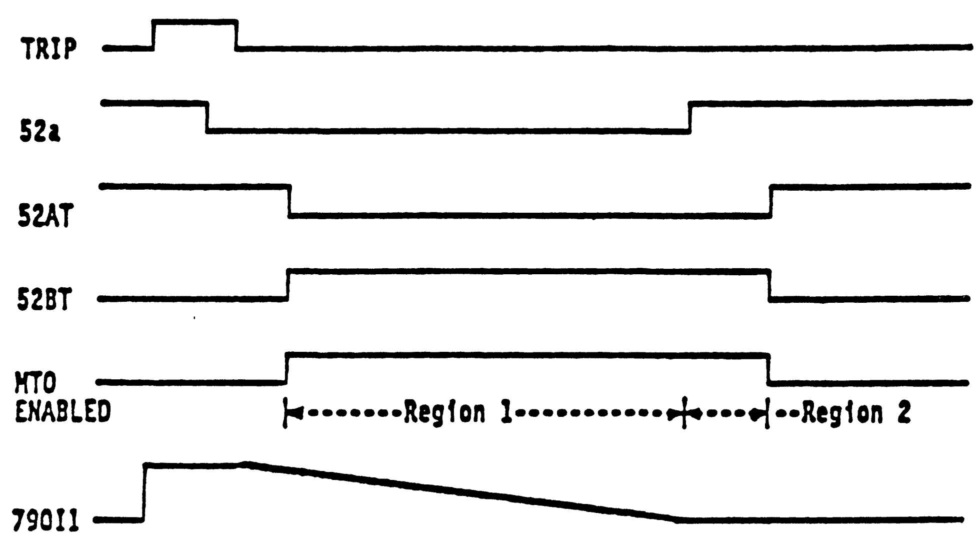


Figure 5.20: 52BT and 79OI Timing Diagram

During the time period shown for Regions 1 and 2, MTO logic is enabled because the 52BT element is asserted. Region 1 shows the time during which MTO logic is enabled to protect the open line breaker. Thus, for line breaker tank faults, the SEL-221G Relay can issue a trip signal required for breaker backup schemes.

Region 2 shows the time during which the MTO logic is performing true switch-onto-fault (SOTF) protection for the line. This feature allows the instantaneous elements to trip the line breaker immediately upon detecting a fault for a set amount of time. Normally, these elements are only used for tripping in conjunction with either a qualifying permissive signal from the remote end of the line (POTT schemes), or the absence of a block signal (DCB schemes).

Figure 5.21 shows a circuit with a phase-to-phase fault close to Breaker 2. Suppose that Breaker 1 is the preferred source for testing the line, while Breaker 2 is to remain open until Breaker 1 energizes the line. If standard time-stepped distance protection is used without SOTF protection, the fault would have to be cleared in Zone 2 time. However, using the MTO logic of the SEL-221G Relay, the non-time delayed Zone 2 phase elements can detect the fault and issue a trip signal very rapidly. This reduces the amount of time that the transmission line is faulted. The possibility of overreaching the remote terminal with the instantaneous Zone 2 element is non-existent because Breaker 2 is open while the Breaker 1 MTO logic is enabled (see Figure 5.22). If the fault is not present when Breaker 1 tests the line, the Breaker 1 MTO logic resets and Breaker 2 is allowed to synchronize and close. Note that you must limit the time during which elements of the MTO mask can trip the breaker. The 52BT time must be long enough for the sensitive elements masked into the MTO logic mask to assert, but shorter than the time allowed for Breaker 2 to parallel.

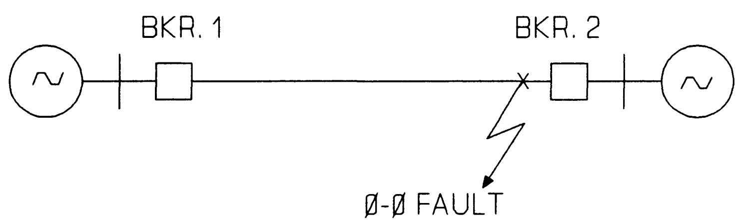


Figure 5.21: Faulted Line With All Sources In

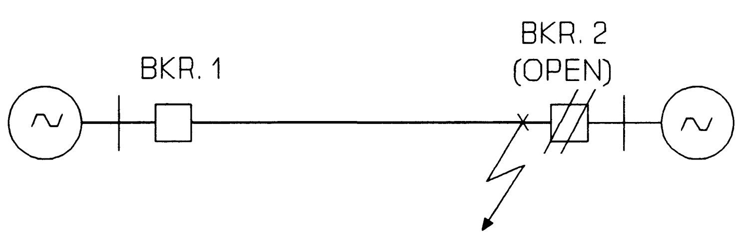


Figure 5.22: Faulted Line With Breaker 2 Open

Figures 5.23 and 5.24 show the timing relationship for a B-C fault detected before and after the first open interval expires. The 79OI1 period is set for 20 cycles. Table 5.5 shows the trace assignments for these figures.

Table 5.5: Oscillograph Trace Assignments for Figures 5.23 and 5.24

Trace ID	Description of Trace
A	B-Phase Fault Current
B	Trip Output
C	Inverted 52A Status Input
D	Close signal

The oscillograph in Figure 5.23 shows a successful two shot reclose sequence. The sequence was successful because the second fault occurred after the 79OI1 timing interval expired. The oscillograph in Figure 5.24 shows an unsuccessful reclose sequence because the fault was detected prior to 79OI1 time interval expiration.

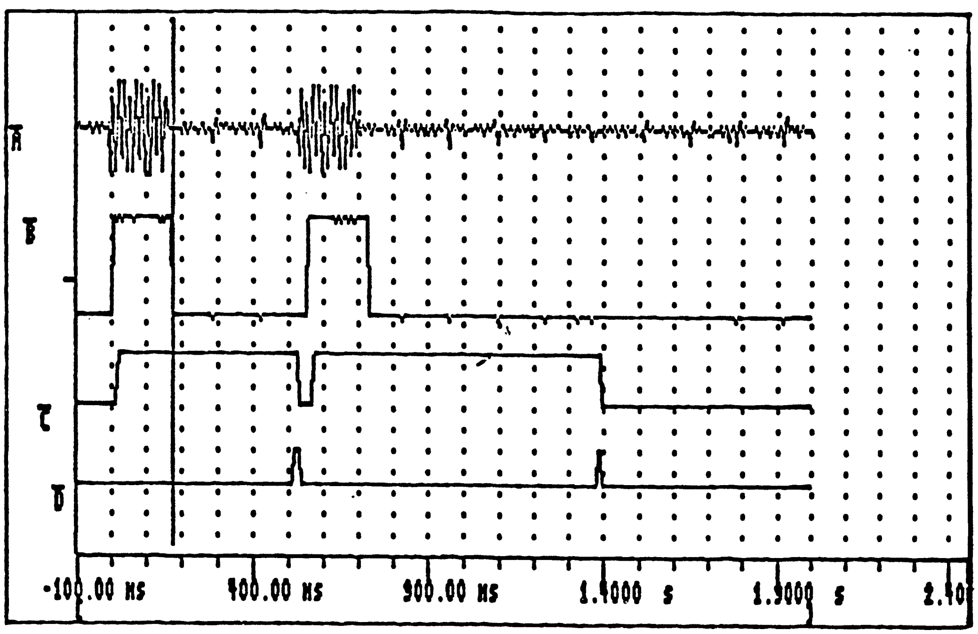


Figure 5.23: Successful Two Shot Reclosing Sequence

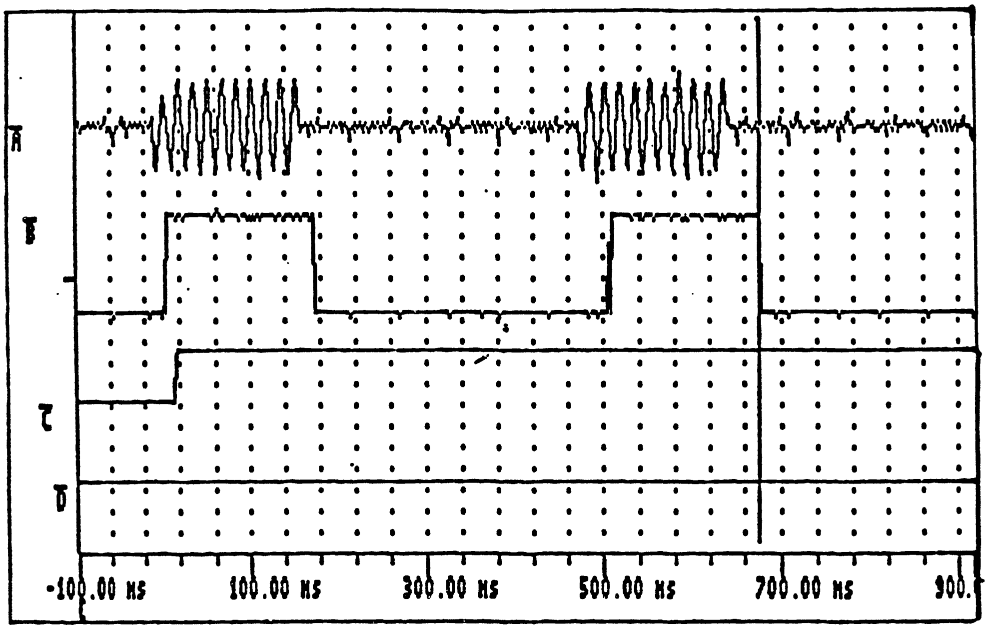


Figure 5.24: Unsuccessful Two Shot Reclosing Sequence

Oscillographs in Figures 5.25 and 5.26 show a two shot reclosing sequence for the same Zone 1 phase-to-phase fault used in Example 5. Reclosing intervals shown in Figures 5.25 and 5.26 are 5 and 15 cycles respectively (79OI1 = 5 cycles, 79OI2 = 15 cycles). However, the 52BT element setting was not the same in both figures. In Figure 5.25, the 52BT timer was set for five cycles (the same as the first reclose interval). In Figure 5.26, the 52BT timer was set for 10 cycles (longer than the first reclose interval but shorter than the second reclose interval). Note that in Figure 5.25, the 52BT element was asserted for each shot. In Figure 5.26, the 52BT element was only asserted for the second shot. The 52BT element was asserted for both shots in Figure 5.25 because the 52BT timer setting was equal to the first reclose interval.

Remember that the 52BT timer start is keyed by the 52A input state change, while the 79OI timer is keyed by trip output signal deassertion (remember: the 52A input must be present prior to TRIP signal assertion before reclosing is permitted). Since the open interval timer may start after the 52BT timer, a coincidence state may occur. This happens when the 52BT timer tries to start upon 52A contact breaker closure when the open interval timer expires. This chain of events resets the 52BT timer and eliminates use of switch-onto-fault logic. The 52BT element must be asserted high as a conditional for the elements programmed into the MTO logic mask.

A rule of thumb for setting the 52BT timer: when you want switch-onto-fault protection for all shots, set the 52BT element equal to or shorter than the first reclose interval. If you only want switch-onto-fault logic for second or third shots, set the 52BT timer longer than the reclose interval timer for the shot where switch-onto-fault logic is not desired.

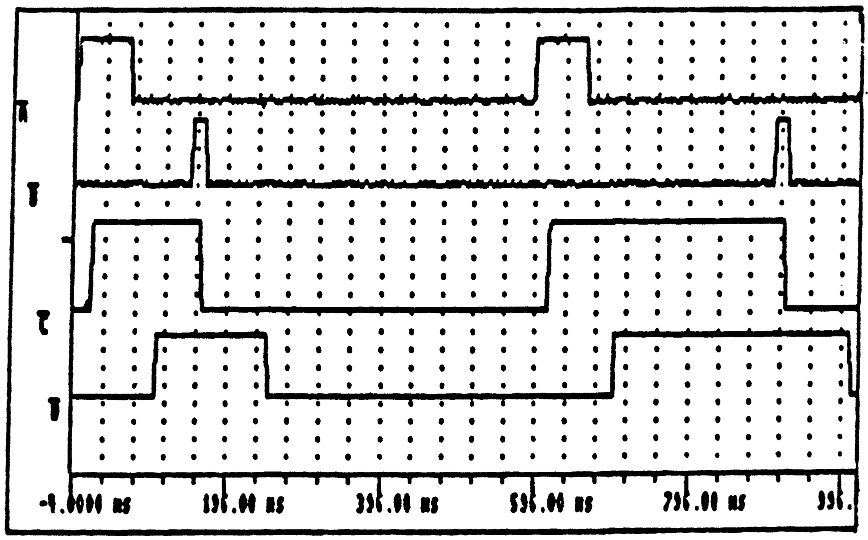


Figure 5.25: 52BT and 52A Contact Timing Diagram #1

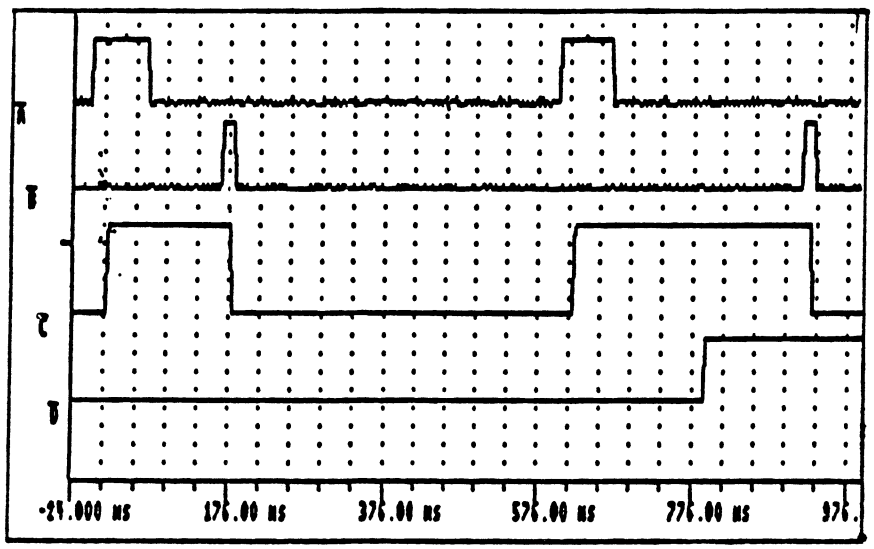


Figure 5.26: 52BT and 52A Contact Timing Diagram #2

Example 7: 79RS Timer Eliminates Standing Close

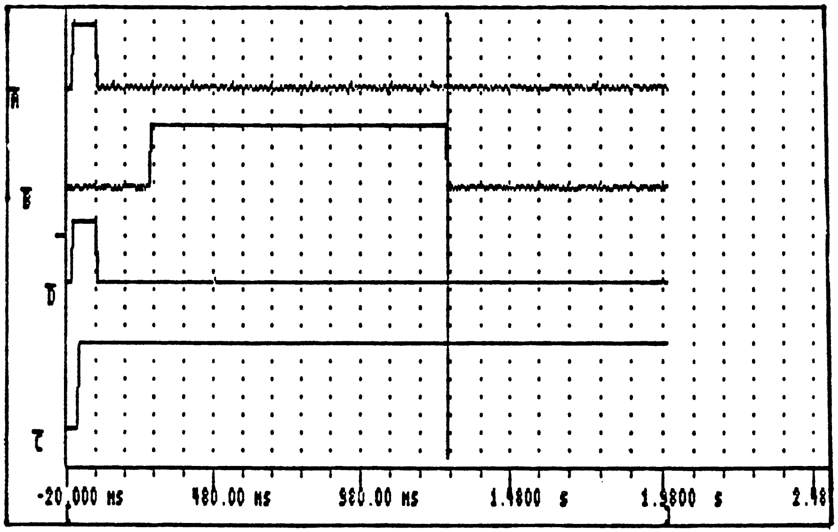
The 79RS element serves three purposes:

Purpose 1: Resets CLOSE contact after 79RS expires to prevent a standing close condition if the circuit breaker never closes.

Purpose 2: Resets recloser after 79RS time period.

Purpose 3: Prevents reclosing sequence if an operator manually closes the circuit breaker into a fault.

The oscillograph in Figure 5.27 demonstrates Purpose 1: the 79RS element reset the CLOSE contact after 60 cycles. In this example, an open in the close coil path prevented circuit breaker closure. The first reclose interval was set for ten cycles. Sixty cycles after CLOSE contact assertion, the 79RS element reset the CLOSE contact. Note that the 52A contact never asserted after opening.



Note: The 79RS element begins timing at CLOSE contact closure.

Figure 5.27: 79RS Element Reset of the CLOSE Contact

Purpose 3 prevents the SEL-221G Relay recloser from initiating an automatic reclosing sequence after an operator (or SCADA) closes a circuit breaker into a fault. Circuit breaker close control always remains with the local operator. For a period equal to the 79RS timer after manual breaker closure, the recloser is prohibited from operating. If an operator notices a circuit breaker trip, the event report can assist in a decision to manually reclose again.

SETTINGS SHEET
FOR SEL-221G-6, SEL-221G-7 RELAYS

DATE ______

SUBSTATION ______ CIRCUIT ______

BREAKER ______ DEVICE NO. ______

FUNCTION ______

MAKE ______ C.T. SETTING ______

MODEL/STYLE NO. ______ P.T. SETTING ______

PART # ______ SOFTWARE VERSION ______

SERIAL #______ POWER SUPPLY ______ VOLTS ac/dc LOGIC INPUT ____ Vdc

SECONDARY INPUTS: V/ø = 67L-N, NOMINAL AMPS = 5, Hz = 60

MASK: MTU (UNCONDITIONAL TRIP)

									HEXADECIMAL REPRESENTATION SETTING
ROW #1: RELAY WORD BINARY REPRESENTATION	1ABC	2ABC	3ABC	4ABC	LOP	50H	50M	50L	
ROW #2: RELAY WORD BINARY REPRESENTATION	51NT	67N1	67N2	67N3	51NP	Z1P	Z2P	Z3P	
ROW #3: RELAY WORD BINARY REPRESENTATION	Z2PT	Z3PT	50L3	3P50	50MF	RC	RI	STOP	
ROW #4: RELAY WORD BINARY REPRESENTATION	50N3	TRIP	TC	DT	52BT	Z3X	Z2GT	Z3GT	

MASK: MPT (PERMISSIVE TRIP)

									SETTING
ROW #1: RELAY WORD BINARY REPRESENTATION	1ABC	2ABC	3ABC	4ABC	LOP	50H	50M	50L	
ROW #2: RELAY WORD BINARY REPRESENTATION	51NT	67N1	67N2	67N3	51NP	Z1P	Z2P	Z3P	
ROW #3: RELAY WORD BINARY REPRESENTATION	Z2PT	Z3PT	50L3	3P50	50MF	RC	RI	STOP	
ROW #4: RELAY WORD BINARY REPRESENTATION	50N3	TRIP	TC	DT	52BT	Z3X	Z2GT	Z3GT	

MASK: MTB (BLOCK TRIP)

									SETTING
ROW #1: RELAY WORD BINARY REPRESENTATION	1ABC	2ABC	3ABC	4ABC	LOP	50H	50M	50L	
ROW #2: RELAY WORD BINARY REPRESENTATION	51NT	67N1	67N2	67N3	51NP	Z1P	Z2P	Z3P	
ROW #3: RELAY WORD BINARY REPRESENTATION	Z2PT	Z3PT	50L3	3P50	50MF	RC	RI	STOP	
ROW #4: RELAY WORD BINARY REPRESENTATION	50N3	TRIP	TC	DT	52BT	Z3X	Z2GT	Z3GT	

SETTINGS SHEET
FOR SEL-221G-6, SEL-221G-7 RELAYS

MASK: MTO (SWITCH ONTO FAULT)

									HEXADECIMAL REPRESENTATION SETTING
ROW #1: RELAY WORD BINARY REPRESENTATION	1ABC	2ABC	3ABC	4ABC	LOP	50H	50M	50L	
ROW #2: RELAY WORD BINARY REPRESENTATION	51NT	67N1	67N2	67N3	51NP	Z1P	Z2P	Z3P	
ROW #3: RELAY WORD BINARY REPRESENTATION	Z2PT	Z3PT	50L3	3P50	50MF	RC	RI	STOP	
ROW #4: RELAY WORD BINARY REPRESENTATION	50N3	TRIP	TC	DT	52BT	Z3X	Z2GT	Z3GT	

MASK: MA1 (A1 CONTACT)

									SETTING
ROW #1: RELAY WORD BINARY REPRESENTATION	1ABC	2ABC	3ABC	4ABC	LOP	50H	50M	50L	
ROW #2: RELAY WORD BINARY REPRESENTATION	51NT	67N1	67N2	67N3	51NP	Z1P	Z2P	Z3P	
ROW #3: RELAY WORD BINARY REPRESENTATION	Z2PT	Z3PT	50L3	3P50	50MF	RC	RI	STOP	
ROW #4: RELAY WORD BINARY REPRESENTATION	50N3	TRIP	TC	DT	52BT	Z3X	Z2GT	Z3GT	

MASK: MA2 (A2 CONTACT)

									SETTING
ROW #1: RELAY WORD BINARY REPRESENTATION	1ABC	2ABC	3ABC	4ABC	LOP	50H	50M	50L	
ROW #2: RELAY WORD BINARY REPRESENTATION	51NT	67N1	67N2	67N3	51NP	Z1P	Z2P	Z3P	
ROW #3: RELAY WORD BINARY REPRESENTATION	Z2PT	Z3PT	50L3	3P50	50MF	RC	RI	STOP	
ROW #4: RELAY WORD BINARY REPRESENTATION	50N3	TRIP	TC	DT	52BT	Z3X	Z2GT	Z3GT	

MASK: MA3 (A3 CONTACT)

									SETTING
ROW #1: RELAY WORD BINARY REPRESENTATION	1ABC	2ABC	3ABC	4ABC	LOP	50H	50M	50L	
ROW #2: RELAY WORD BINARY REPRESENTATION	51NT	67N1	67N2	67N3	51NP	Z1P	Z2P	Z3P	
ROW #3: RELAY WORD BINARY REPRESENTATION	Z2PT	Z3PT	50L3	3P50	50MF	RC	RI	STOP	
ROW #4: RELAY WORD BINARY REPRESENTATION	50N3	TRIP	TC	DT	52BT	Z3X	Z2GT	Z3GT	

SETTINGS SHEET
FOR SEL-221G-6, SEL-221G-7 RELAYS

MASK: MA4 (A4 CONTACT)

									HEXADECIMAL REPRESENTATION SETTING
ROW #1: RELAY WORD BINARY REPRESENTATION	1ABC	2ABC	3ABC	4ABC	LOP	50H	50M	50L	
ROW #2: RELAY WORD BINARY REPRESENTATION	51NT	67N1	67N2	67N3	51NP	Z1P	Z2P	Z3P	
ROW #3: RELAY WORD BINARY REPRESENTATION	Z2PT	Z3PT	50L3	3P50	50MF	RC	RI	STOP	
ROW #4: RELAY WORD BINARY REPRESENTATION	50N3	TRIP	TC	DT	52BT	Z3X	Z2GT	Z3GT	

MASK: MRI (RECLOSE INITIATE)

									SETTING
ROW #1: RELAY WORD BINARY REPRESENTATION	1ABC	2ABC	3ABC	4ABC	LOP	50H	50M	50L	
ROW #2: RELAY WORD BINARY REPRESENTATION	51NT	67N1	67N2	67N3	51NP	Z1P	Z2P	Z3P	
ROW #3: RELAY WORD BINARY REPRESENTATION	Z2PT	Z3PT	50L3	3P50	50MF	RC	RI	STOP	
ROW #4: RELAY WORD BINARY REPRESENTATION	50N3	TRIP	TC	DT	52BT	Z3X	Z2GT	Z3GT	

MASK: MRC (RECLOSE CANCEL)

									SETTING
ROW #1: RELAY WORD BINARY REPRESENTATION	1ABC	2ABC	3ABC	4ABC	LOP	50H	50M	50L	
ROW #2: RELAY WORD BINARY REPRESENTATION	51NT	67N1	67N2	67N3	51NP	Z1P	Z2P	Z3P	
ROW #3: RELAY WORD BINARY REPRESENTATION	Z2PT	Z3PT	50L3	3P50	50MF	RC	RI	STOP	
ROW #4: RELAY WORD BINARY REPRESENTATION	50N3	TRIP	TC	DT	52BT	Z3X	Z2GT	Z3GT	

BINARY	HEXADECIMAL
0000	0
0001	1
0010	2
0011	3
0100	4
0101	5
0110	6
0111	7
1000	8
1001	9
1010	A
1011	B
1100	C
1101	D
1110	E
1111	F

ACCESS Command passwords: (6 Characters excluding "SPACE, COMMA, SEMI-COLON and SLASH")

LEVEL 0: "=" **ACCESS <ENTER>**
PASSWORD: ____________________

LEVEL 1: "=>" **2ACCESS <ENTER>**
PASSWORD: ____________________

LEVEL 2: "=>>"
ENTER SETTINGS PER MATRIX TABLE

NOTE: FOR NEW RELAYS BEGIN WITH LEVEL 1 PASSWORD = OTTER AND LEVEL 2 PASSWORD = TAIL. WHEN IN LEVEL 2 MODIFY PASSWORDS VIA PASSWORD 1 AND 2 COMMANDS.

SETTINGS SHEET
FOR SEL-221G-6, SEL-221G-7 RELAYS

DESCRIP.	POS-SEQ. IMPEDANCE		ZERO-SEQ. IMPEDANCE		LINE LENGTH*
RANGE	0-9999 (PRI. OHMS)		0-9999 (PRI. OHMS)		0.1-999 MILES
ABBREV.	**R1**	**X1**	**R0**	**X0**	**LL**
SETTING					
DESCRIP.	C. T. RATIO	P. T. RATIO	MAX. TORQUE ANGLE	ENABLE FAULT LOCATOR	
RANGE	1-5000:1	1-10,000:1	47°-90°	(Y OR N)	
ABBREV.	**CTR**	**PTR**	**MTA**	**LOCAT**	
SETTING					
DESCRIP.	RECL. OPEN INTERVAL 1	RECL. OPEN INTERVAL 2	RECL. OPEN INTERVAL 3	RECL. RESET TIME	
RANGE	0-10,000 CYCLES (¼-CYCLE STEPS)	0-10,000 CYCLES (¼-CYCLE STEPS)	0-10,000 CYCLES (¼-CYCLE STEPS)	60-8,000 CYCLES (¼-CYCLE STEPS)	
ABBREV.	**79OI1**	**79OI2**	**79OI3**	**79RS**	
SETTING					
DESCRIP.	ZONE 1 REACH	ZONE 2 REACH**	ZONE 3 RECH**		
RANGE	(0.125-64Ω SEC) 0-2000% OF R1+jX1	(0.125-64Ω SEC) 0-3200% OF R1+jX1	(0.125-64Ω SEC) 0-3200% OF R1+jX1		
ABBREV.	**Z1%**	**Z2%**	**Z3%**		
SETTING					
DESCRIP.	ZONE 2 ØØ & 3Ø SHORT TIMER	ZONE 2 ØØ & 3Ø TIME-STEP BACKUP TIMER	ZONE 3 ØØ & 3Ø TIME-STEP BACKUP TIMER		
RANGE	0-60 CYCLES (¼-CYCLE STEPS)	0-2000 CYCLES (¼-CYCLE STEPS)	0-2000 (¼-CYCLE STEPS)		
ABBREV.	**Z2SP**	**Z2DP**	**Z3DP**		
SETTING					
DESCRIP.	PHASE O/C LOW-SET PICKUP (ZONES 3 & 4 SUPERVISION)	PHASE O/C LOW-SET PICKUP (ZONES 1 & 2 SUPERVISION)	PHASE O/C MEDIUM-SET PICKUP	PHASE O/C LOP DELAY (LOSS-OF-POTENTIAL)	PHASE O/C HIGH-SET PICKUP
RANGE	(0.5-40A SEC.) 0.25-50,000 AMP PRI.	(0.5-40A SEC.) 0.25-50,000 AMP PRI.	(0.5-40A SEC.) 0.25-50,000 AMP PRI.	0-60 CYCLES (¼-CYCLE STEPS)	(0.5-80A SEC.) 0.25-50,000 AMPS PRI.
ABBREV.	**50L3**	**50L**	**50M**	**50MFD**	**50H**
SETTING					
DESCRIP.	GND TIME O/C PICKUP	GND TIME O/C TIME DIAL	GND TIME O/C CURVE SHAPE	GND TIME O/C TORQUE CONTROL	
RANGE	(0.25-6.3A SEC) 0.25-50,000 AMP PRI.	0.5-15 (0.01 STEPS)	1, 2, 3, OR 4	(Y OR N)	
ABBREV.	**51NP**	**51NTD**	**51NC**	**51NTC**	
SETTING					

DATE ________

SETTINGS SHEET
FOR SEL-221G-6, SEL-221G-7 RELAYS

DESCRIP.	ZONE 1 GND INST. O/C ***	ZONE 2 GND INST. O/C ***	ZONE 3 GND INST. O/C ***		
RANGE	(0.25A-48x51NP 0.25-50,000 AMP PRI.	(0.25A-48x51NP 0.25-50,000 AMP PRI.	(0.25A-48x51NP 0.25-50,000 AMP PRI.		
ABBREV. SETTING	**50N1P**	**50N2P**	**50N3P**		
DESCRIP.	ZONE 2 GND SHORT TIMER	ZONE 2 GND TIME-STEP BACKUP TIMER	ZONE 3 GND TIME-STEP BACKUP TIMER	MINIMUM TRIP DURATION TIMER	LOSS-OF-POT. ENABLE
RANGE	0-60 CYCLES (¼-CYCLE STEPS)	0-2000 CYCLES (¼-CYCLE STEPS)	0-2000 CYCLES (¼-CYCLE STEPS)	0-2000 CYCLES (¼-CYCLE STEPS)	(Y OR N)
ABBREV. SETTING	**Z2SG**	**Z2DG**	**Z3DG**	**TDUR**	**LOPE**
DESCRIP.	52BT TIME DELAY	ZONE 3 DIRECTION	GND O/C NEGATIVE SEQ. POLAR.	GND O/C ZERO SEQ. VOLTAGE POLAR.	GND O/C ZERO SEQ. CURRENT POLAR.
RANGE	0.5-10,000 CYCLES	(F OR R)	(Y OR N)	(Y OR N)	(Y OR N)
ABBREV. SETTING	**52BT**	**ZONE 3**	**32QE**	**32VE**	**32IE**
DESCRIP.	SEL-221G PORT #1 TIMEOUT	SEL-221G PORT #2 TIMEOUT	AUTOMATIC MESSAGE TRANSMIT AUTOPORT SELECTION	# RINGS AFTER WHICH MODEM ANSWERS	
RANGE	0-30 MINUTES	0-30 MINUTES	PORT 1, 2, OR 3(BOTH)	1-30	
ABBREV. SETTING	**TIME1**	**TIME2**	**AUTO**	**RINGS**	

SETTINGS SHEET
FOR SEL-221G-6, SEL-221G-7 RELAYS

* Line Length = Station #1 (relay location) to Station #2; the full distance in miles between stations.

NOTE: Length can also be represented in metric units, primary or secondary ohms, etc., but conversion to miles would be required.

** Zones 2 and 3 are limited as follows: ohmic range is 0.125 to 64 ohms secondary.

(a) For Zone 3 Forward: Zone 1 < Zone 2 < Zone 3
(b) For Zone 3 Reverse: Zone 1 < Zone 2 and Zone 1 < Zone 3

*** Lower setting limit for 50N1P, 50N2P, and 50N3P:
0.25 A for 51NP < 3.15 A secondary
0.5 A for 51NP ≥ 3.15 A secondary

Comments: ______________________________

____

____

____

____

____

____

____

____

____

Settings recommended by ______________________________

Settings approved by ______________________________

Settings approved by ______________________________

Settings performed by ______________________________

Test printout required ___ Yes ___ No Substation ______________

INSTALLATION
TABLE OF CONTENTS

TABLES

FIGURES

INSTALLATION

Mounting

The relay is designed for mounting by its front vertical flanges in a 19" vertical relay rack. It may also be mounted semi-flush in a switchboard panel. Use four #10 screws for mounting. Front and rear panel drawings are included in this manual.

Frame Ground Connection

Terminal 35 or 36 on the rear panel must be connected to frame ground for safety and performance. These terminals connect directly to the chassis ground of the instrument.

Power Connections

Terminals 37 and 38 on the rear panel must be connected to a source of control voltage. Control power passes through these terminals to the fuse(s) and a toggle switch, if installed. The power continues through a surge filter and connects to the switching power supply. The control power circuitry is isolated from the frame ground.

Secondary Circuits

The relay presents a very low burden to the secondary potential and current circuits. It requires four-wire wye potentials and three currents from the power system current transformer secondaries.

Control Circuits

The control inputs are dry. For example, to assert the 52A input, you must apply control voltage to the 52A input terminals. Each input is individually isolated, and a terminal pair is brought out for each input. There are no internal connections between control inputs.

Control outputs are dry relay contacts rated for tripping duty. A metal-oxide varistor protects each contact.

Communications Circuits

Connections to the two EIA-232 serial communications ports are made via the two 9-pin connectors labeled PORT 1 and PORT 2 on the rear panel. Pins 1 and 9 connect directly to frame (chassis) ground.

Warning: Do not rely upon pins 1 and 9 for safety grounding, since their current-carrying capacity is less than control-power short circuit current and protection levels.

The communications circuits are protected by low-energy, low-voltage MOVs and passive RC filters. You can minimize communications-circuit difficulties by keeping the length of the EIA-232 cables as short as possible. Lengths of twelve feet or less are recommended, and the cable length should never exceed 100 feet. Use shielded communications cable for lengths greater than ten feet. Modems are required for communications over long distances.

Route the communications cables well away from the secondary and control circuits. Do not bundle the communications wiring with secondary or control circuit wiring. If these wires are bundled, switching spikes and surges can cause noise in the communications wiring. This noise may exceed the communications logic thresholds and introduce errors. The IRIG-B clock cable should also be routed away from the control wiring and secondary circuits.

Jumper Selection

All jumpers are on the front edge of the main board. They are easily accessed by removing the top cover or front panel.

EIA-232 Jumpers

JMP105 provides EIA-232 baud rate selection. Available baud rates are 300, 600, 1200, 2400, 4800, and 9600. To select a baud rate for a particular port, place the jumper so it connects a pin labeled with the desired port to a pin labeled with the desired baud rate.

Caution: Do not select two baud rates for the same port. This can damage the baud rate generator.

Password Protection Jumper

Put JMP103 in place to disable password protection. This feature is useful if passwords are not required or when passwords are forgotten.

OPEN/CLOSE Command Enable Jumper

With jumper JMP104 in place, the OPEN and CLOSE commands are enabled. If you remove jumper JMP104, executing OPEN and CLOSE commands results in the message: "Aborted."

Output Contact Soldered Wire Jumpers

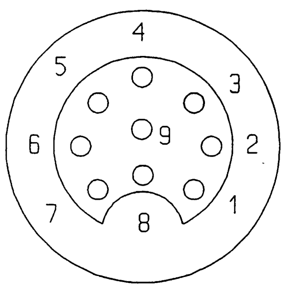
All the output contacts except TRIP can be configured as "a" or "b" contacts with soldered wire jumpers K501 through K506 (each jumper has positions A and B). The output contact/ soldered wire jumper correspondence is as follows:

Output Contact	Jumper SEL-121G-6, -7
TRIP (terminals 1,2)	No Jumper
TRIP (terminals 3,4)	No Jumper
CLOSE	K506
A1	K505
A2	K504
A3	K503
A4	K502
ALARM	K501

EIA-232 And IRIG-B Installation

The following information contains specific details regarding communications port pinouts.

A pin definition of the 9-pin port connectors and cabling information for the EIA-232 ports appears in Figure 6.1. The following cable listings show several types of EIA-232 cables. These and other cables are available from SEL. Cable configuration sheets are also available at no charge for a large number of devices. Contact the factory for more information.



(female chassis connector, as viewed from outside rear panel)

Figure 6.1: 9-Pin Connector Pin Number Convention

EIA-232 Cables

(SEL CABLE 127)

SEL Relay		25-Pin *DTE DEVICE	
GND	1	7	GND
TXD	2	3	RXD
RTS	3	5	CTS
RXD	4	2	TXD
CTS	5	4	RTS
+5	6		
+12	7		
-12	8		
GND	9	1	GND
		6	DSR
		8	DCD
		20	DTR

(SEL CABLE 422)

SEL Relay		25-Pin **DCE DEVICE	
GND	1	7	GND
TXD	2	2	RXD
RTS	3	20	DTR
RXD	4	3	TXD
CTS	5	8	CD
GND	9	1	GND

(SEL CABLE 134)

SEL Relay		9-Pin *DTE DEVICE	
GND	1	5	GND
TXD	2	2	RXD
RTS	3	8	CTS
RXD	4	3	TXD
CTS	5	7	RTS
		1	DCD
		4	DTR
		6	DSR
		9	RI

(SEL CABLE 331A - 338A)

SEL Relay		PRTU	
GND	1	1	GND
TXD	2	4	RXD
RXD	4	2	TXD
CTS	5	7	+12
+12	7	5	CTS
GND	9	9	GND

* DTE = Data Terminal Equipment (terminals, printers, computers, etc.)

** DCE = Data Communications Equipment (modems, etc.)

IRIG-B Input Description

The port labeled J201/AUX INPUT receives demodulated IRIG-B input. Pin definitions appear in Table 6.1.

Table 6.1: AUX INPUT Pin Definition

Pin	Name	Description
2	IRIGIN HI	Positive IRIGB input
3	IRIGIN LOW	Negative IRIGB input
6	+5 *	
7	+12 *	
8	-12 *	
1,5,9	GND	Ground

* Consult the factory before using these power supply outputs

The actual IRIG-B input circuit is a 56 ohm resistor in series with a optocoupler input diode. The input diode has a forward drop of about 1.5 volts. Driver circuits should put approximately 10 mA through the diode when "on."

The IRIG-B serial data format consists of a one second frame containing 100 pulses and divided into fields. The relay decodes the second, minute, hour, and day fields and sets the internal relay clock accordingly.

When IRIG-B data acquisition is activated either manually (with the IRIG command) or automatically, two consecutive frames are taken. The older frame is updated by one second and the two frames are compared. If they do not agree, the relay considers the data erroneous and discards it.

The relay reads the time code automatically about once every five minutes. The relay stops IRIG-B data acquisition ten minutes before midnight on New Year's Eve so the relay clock may implement the year change without interference from the IRIG-B clock. Ten minutes after midnight, the relay restarts IRIG-B data acquisition.

INSTALLATION CHECKOUT

You may follow the suggestions below or combine them with your standard procedures. Never implement recommendations prohibited by the rules of your normal practice.

The following equipment is required for initial checkout:

- portable terminal or computer
- control power to the relay power connections
- source of three-phase voltages and at least one current source
- ohmmeter or contact opening/closing sensing device

1. Apply control power and make sure the terminal displays the startup message. If not, set AUTO = 2 with the SET command in Access Level 2. Check the settings with the ACCESS and SHOWSET commands. Use the TIME command to set the clock. Note that the A2 relay is closed due to the loss-of-potential condition.

2. Apply three-phase voltages in positive-sequence rotation. Execute the METER command and make sure the readings are accurate. If they are not, be sure the correct PT ratio was entered. Remember that displayed values are in primary line-to-neutral and line-to-line kV.

3. Use the TRIGGER command to generate an event record. Type **EVENT 1 <ENTER>** and examine the event record. Refer to the top row of data as the "Y" components and the next row as the "X" components. Plot the three voltage phasors to ensure that they are 120 degrees apart, of reasonable magnitudes, and rotating in the positive-sequence direction. The zero-sequence voltage Y and X components (times a factor of three) are the totals of the three Y components and the three X components. These sums should be near zero if balanced three-phase potentials are present. See the SEL Direction and Polarity Check Form at the end of this section for this purpose.

4. Use the TARGET command to check the state of all contact inputs and outputs.

5. Proceed to Access Level 2 with the 2ACCESS command and second password. Be sure the ALARM relay contacts close and open when the relay executes 2ACCESS. The ALARM pulse will not be detectable if the ALARM contacts are closed due to an alarm condition.

6. Test the tripping function in three ways. First, be sure the circuit breaker can be tripped by OPEN command execution. Verify that the TC bit is set in the MTU mask. Second, the circuit breaker may be tripped by DIRECT TRIP input assertion if the DT bit is selected in the MTU mask. Third, the circuit breaker may be tripped by applying voltages and currents representing a fault condition for which the relay should respond. Here, the TRIP relay closes regardless of the 52A contact state, and opens when there are no currents above the 50L condition, zero-sequence current is

below the 50NL threshold, and fault conditions no longer exist. The TRIP output always remains closed for at least the TDUR setting.

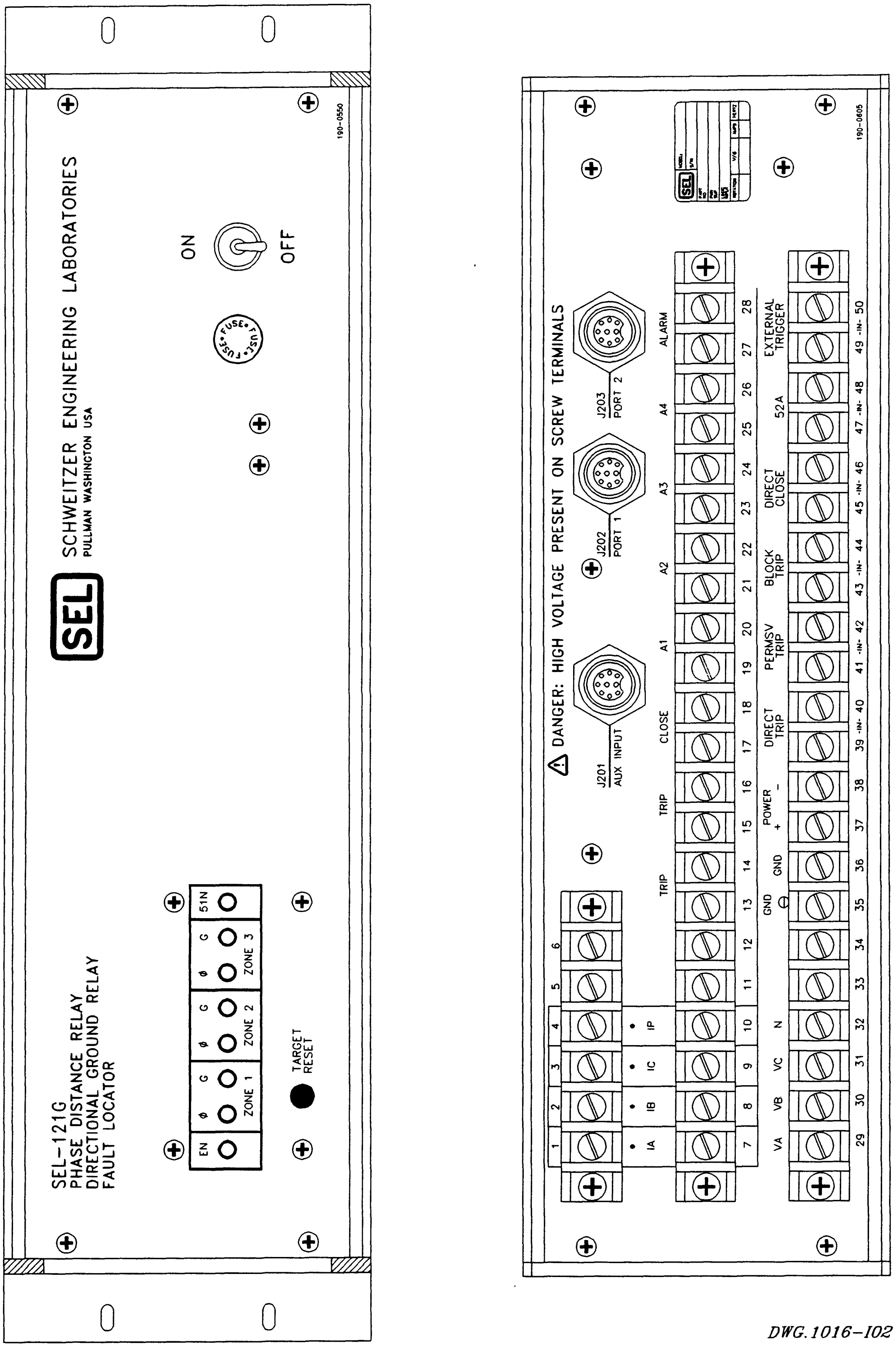
7. There are three ways the circuit breaker is closed: by CLOSE command execution, a reclose attempt by the reclosing relay, or DIRECT CLOSE input assertion. The CLOSE output relay closes for all of these conditions if the 52A input is not asserted (indicating the circuit breaker is open) and no trip condition is present. The CLOSE relay opens when the 52A input is asserted or the 79RS timer expires, whichever occurs first.

8. If the Permissive Trip and Block Trip inputs are used, check them for proper operation (see the LOGIC MPT and LOGIC MTB settings in Section 3: COMMUNICATIONS). An event record should be generated after PT input assertion.

9. Assert the External Trigger input. This should trigger an event record, but does not affect the protective relaying functions in any way.

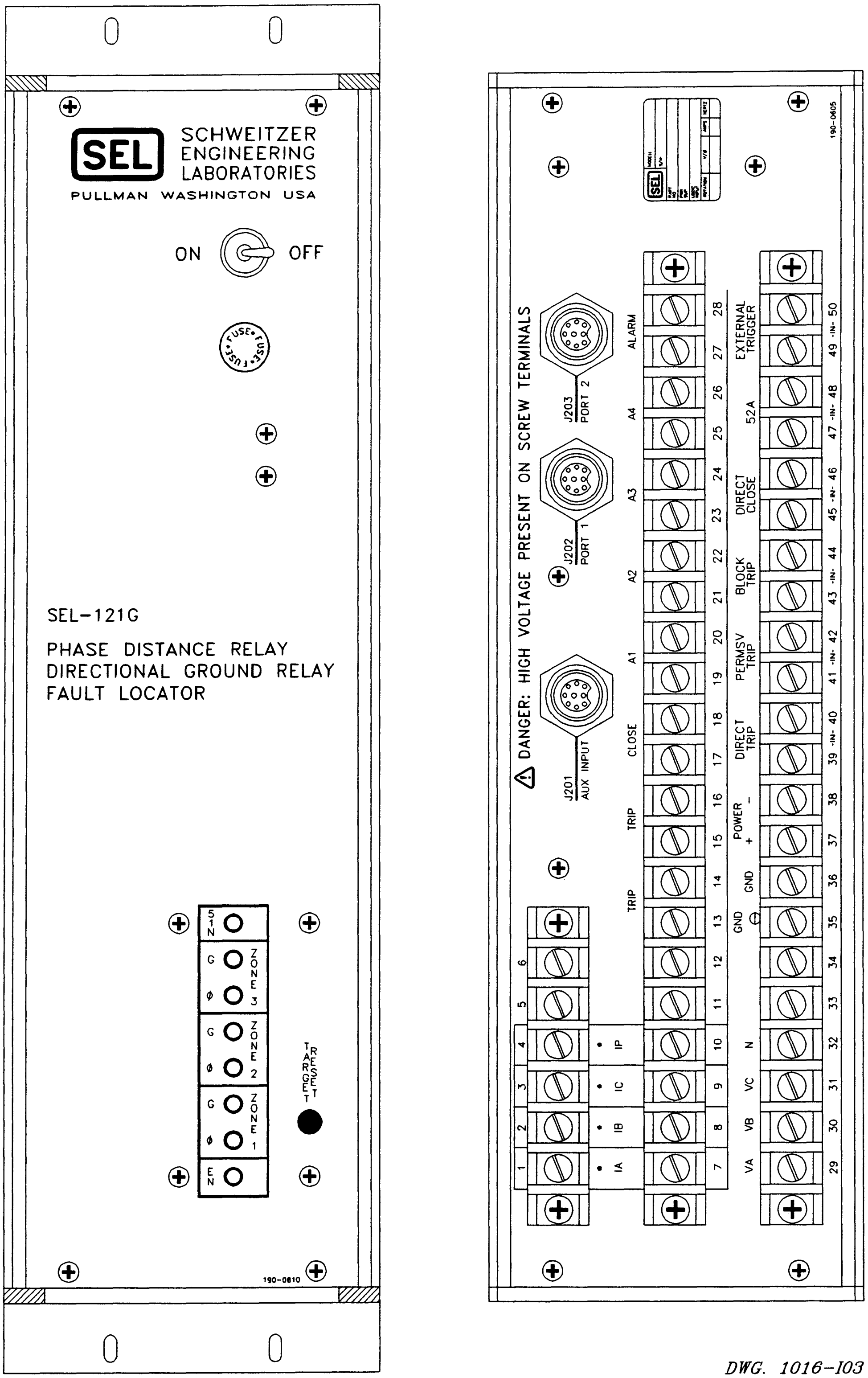
10. Use the STATUS command to inspect the self-test status. You may wish to save the reading as part of an "as-left" record.

When local checkout is complete, check communications with the instrument via a remote interface (if used). Make sure the automatic port is properly assigned and that desired timeout intervals are selected for each port. Also, be sure to record password settings.



DWG. 1016–I02

Figure 6.2: Horizontal Front and Rear Panel Drawings



DWG. 1016-103

Figure 6.3: Vertical Front and Rear Panel Drawings

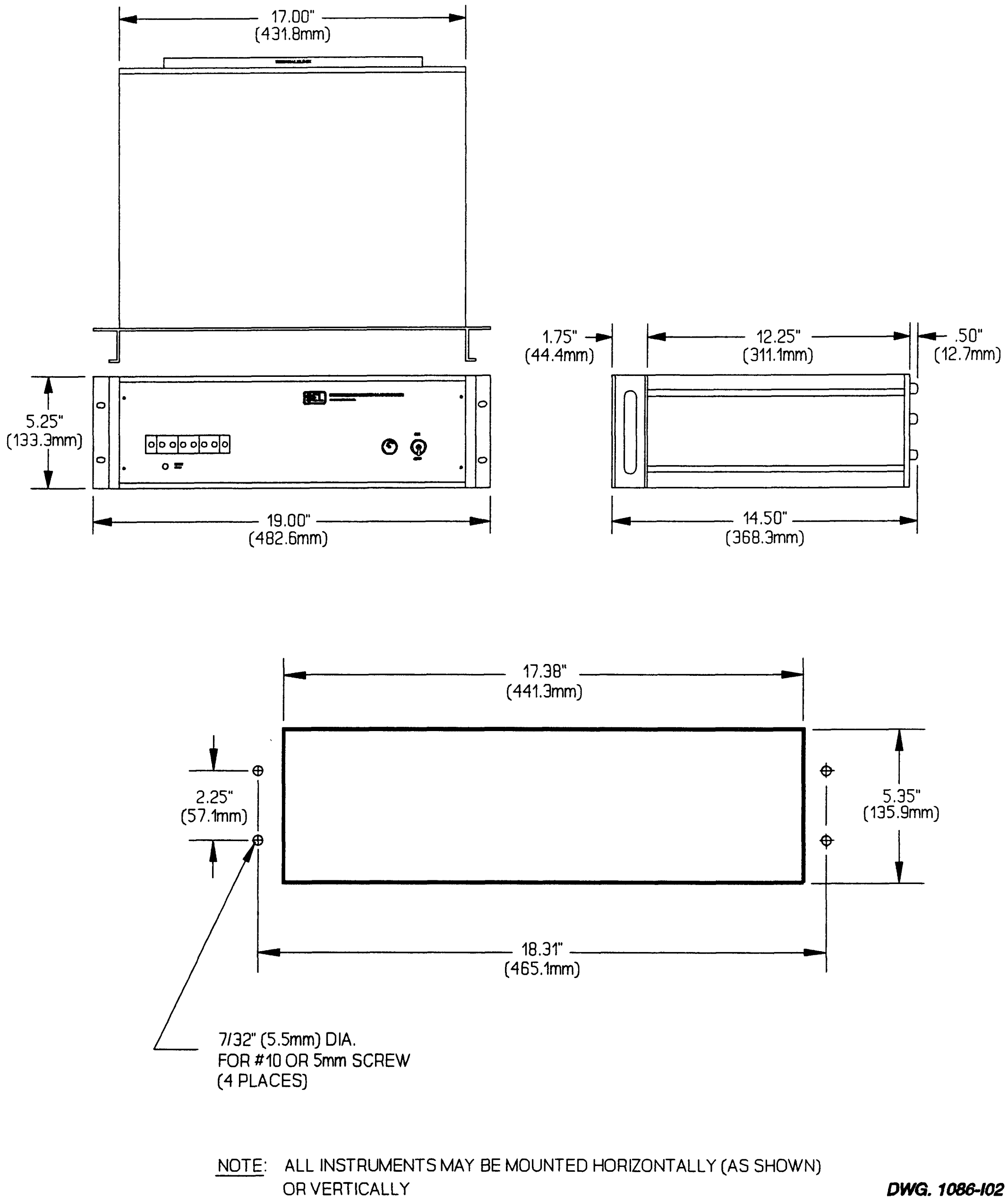


Figure 6.4: Relay Dimensions, Panel Cutout, and Drill Plan

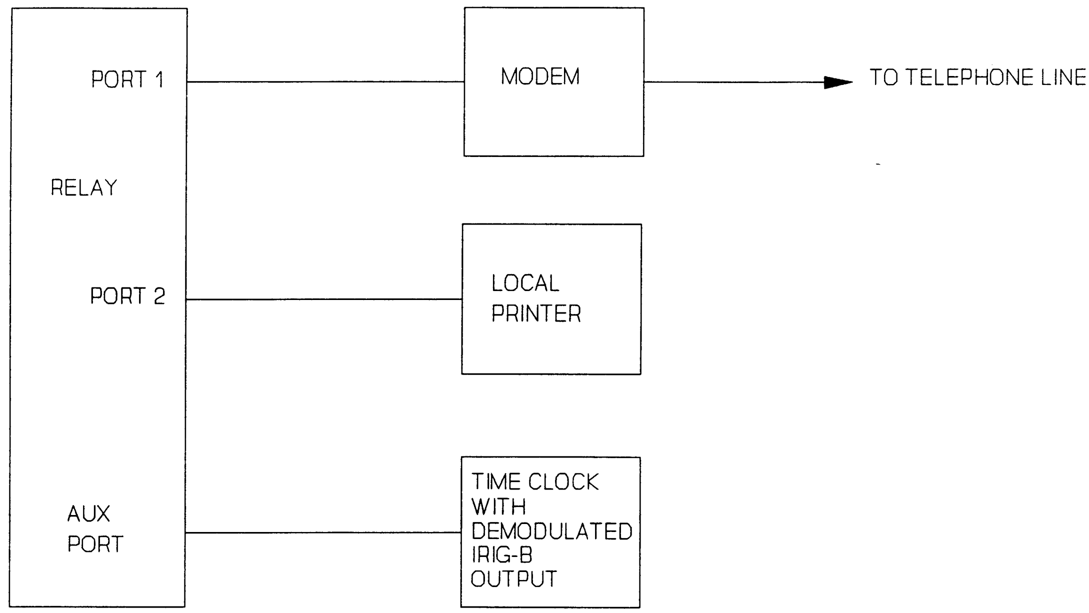


Figure 6.5: Communications and Clock Connections - One Unit at One Location

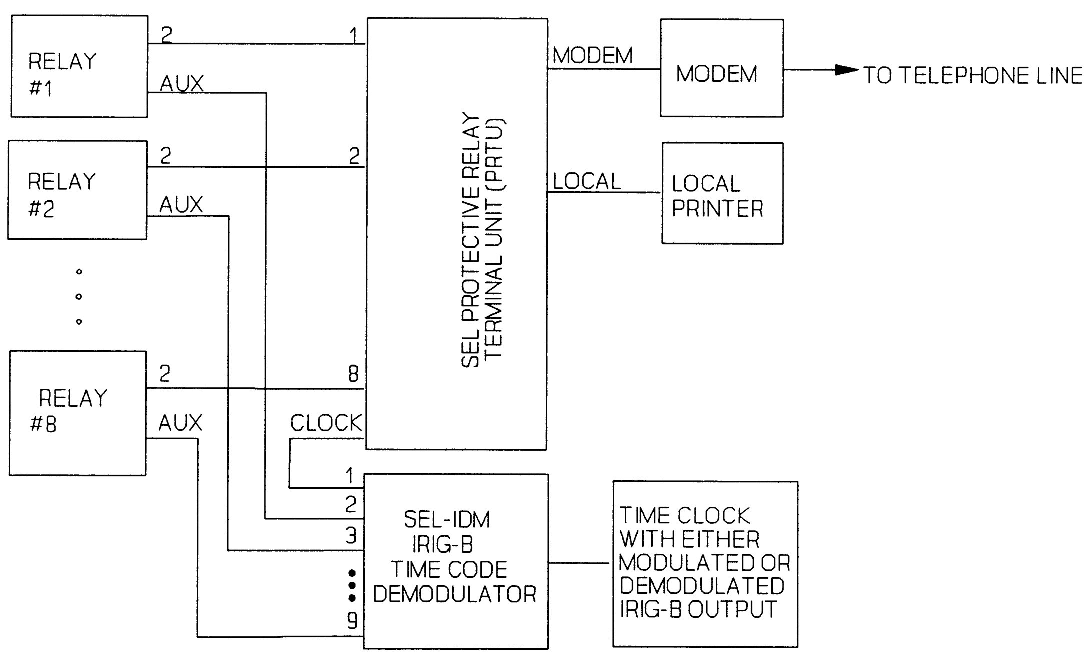


Figure 6.6: Communications and Clock Connections - Multiple Units at One Location

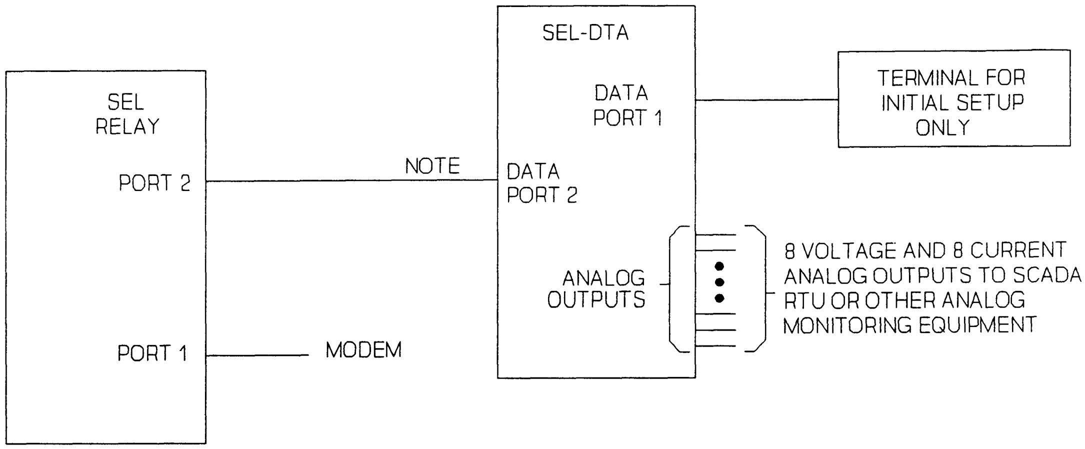


Figure 6.7: SEL Relay Communications Diagram for Connection to the SEL-DTA

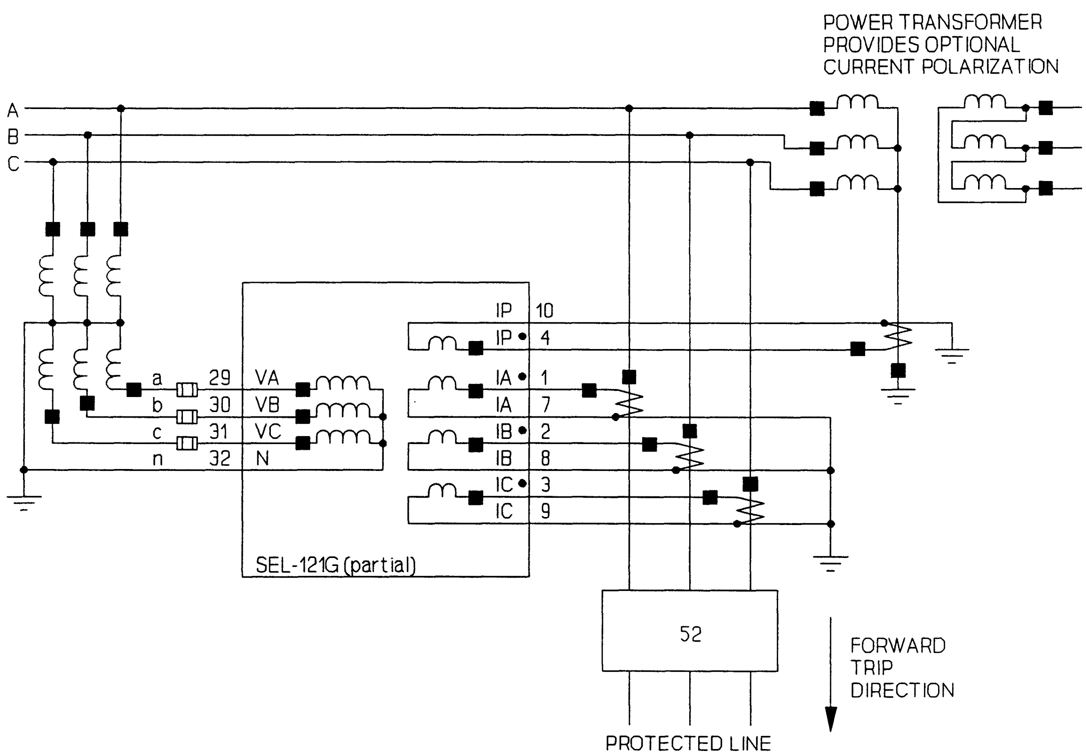


Figure 6.8: External Current and Voltage Connections

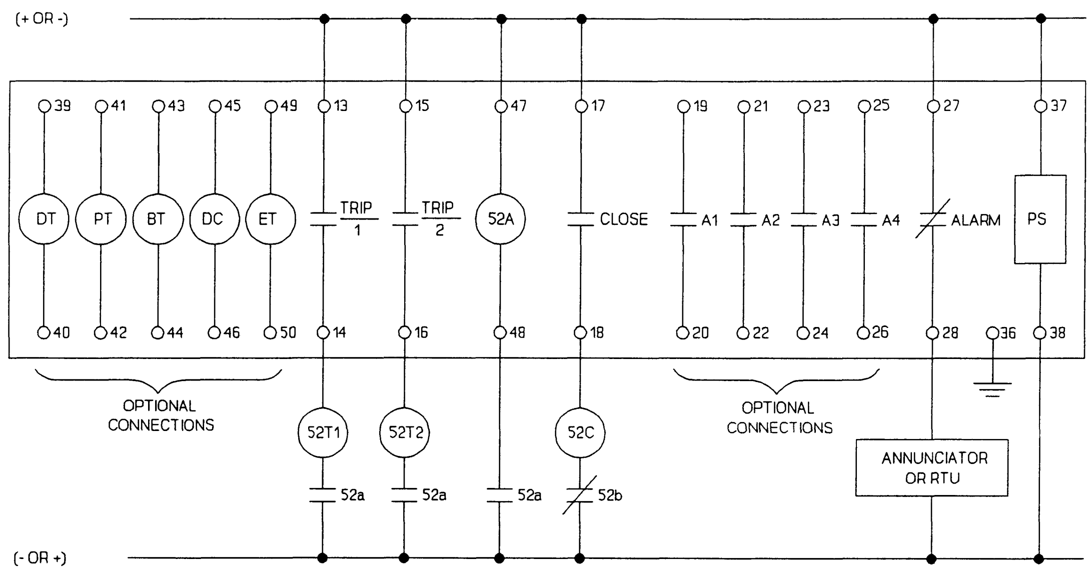


Figure 6.9: DC External Connection Diagram (Typical)

SEL DIRECTION AND POLARITY CHECK FORM

STATION ______________________________ DATE: ___/___/___ TESTED BY ____________________

SWITCH NO. __________________ EQUIPMENT ____

INSTALLATION ________ ROUTINE ________ OTHER ______________________________________

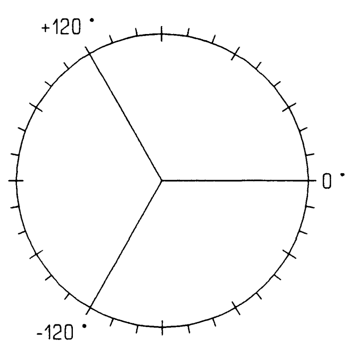
LOAD CONDITIONS:

STATION READINGS: ________ MW (OUT)(IN) ________ MVAR (OUT)(IN) ________ VOLTS ________ AMPS

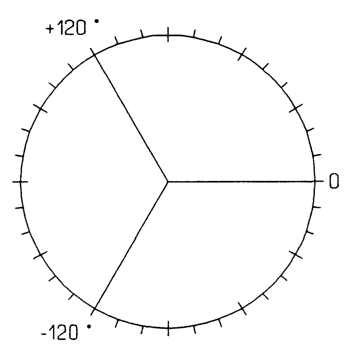
SEL READINGS: ________ MW (+)(-) ________ MVAR (+)(-)

AS SEEN ON SCREEN	Ia	Ib	Ic	Va	Vb	Vc	
COMPANY NOTATION	I( )	I( )	I( )	V( )	V( )	V( )	
1st LINE CHOSEN (Y COMPONENT)							
2nd LINE CHOSEN (X COMPONENT)							
CALCULATED MAGNITUDE $\sqrt{X^2 + Y^2}$							ROW 1
ANGLE IN DEGREES ARCTAN Y/X							
VALUE OF Va DEGREES TO SUBTRACT TO OBTAIN Va DEGREES = 0							
@ Va DEGREES = 0, ANGLE USED TO DRAW PHASOR DIAGRAM							ROW 2

USE THE VALUES IN ROWS 1 AND 2 ABOVE TO DRAW PHASOR DIAGRAMS BELOW



CURRENTS



VOLTAGES

SEL DIRECTION AND POLARITY CHECK FORM

STATION ______________________ DATE: ___/___/___ TESTED BY ______________

SWITCH NO. ______________ EQUIPMENT ______________________________

INSTALLATION ________ ROUTINE ________ OTHER ______________________

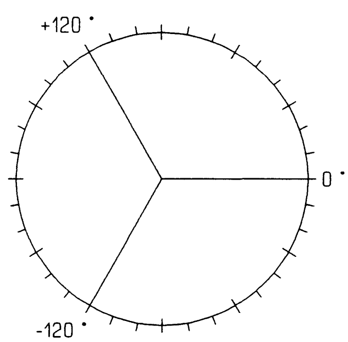
LOAD CONDITIONS:

STATION READINGS: ________ MW (OUT)(IN) ________ MVAR (OUT)(IN) ________ VOLTS ________ AMPS

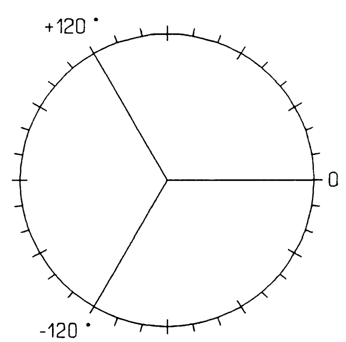
SEL READINGS: ________ MW (+)(-) ________ MVAR (+)(-)

AS SEEN ON SCREEN	Ia	Ib	Ic	Va	Vb	Vc	
COMPANY NOTATION	I( )	I( )	I( )	V( )	V( )	V( )	
1st LINE CHOSEN (Y COMPONENT)							
2nd LINE CHOSEN (X COMPONENT)							
CALCULATED MAGNITUDE $\sqrt{X^2 + Y^2}$							ROW 1
ANGLE IN DEGREES ARCTAN Y/X							
VALUE OF Va DEGREES TO SUBTRACT TO OBTAIN Va DEGREES = 0							
@ Va DEGREES = 0, ANGLE USED TO DRAW PHASOR DIAGRAM							ROW 2

USE THE VALUES IN ROWS 1 AND 2 ABOVE TO DRAW PHASOR DIAGRAMS BELOW



CURRENTS



VOLTAGES

MAINTENANCE & TESTING
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MAINTENANCE & TESTING

TEST PROCEDURES

Test Aids Provided by the Relay

The following features assist you during relay testing and calibration.

METER Command

The METER command shows the voltages and currents presented to the relay in primary values. The relay calculates Megawatts (MW) and Megavars (MVAR) from these voltages and currents. These quantities are useful for comparing relay calibration against other meters of known accuracy.

When testing the relay, first verify relay calibration. Consider all tests invalid if you determine that the relay is out of calibration. Each relay is calibrated at the factory prior to shipment and should not require further adjustments on your part. If calibration is necessary, refer to the Calibration portion of this section.

TARGET Command

The relay allows you to reassign front panel targets to indicate elements and intermediate logic results in the Relay Word as well as input and output contact status. Use the TARGET command to reassign the front panel LEDs. Once target LEDs are reassigned from the default targets, the front panel targets are no longer latching. This means the targets follow the pickup and dropout condition in much the same manner as an output contact. See Section 3: COMMUNICATIONS for more information about the TARGET command.

By using the target LEDs for testing, you need not change the relay settings during testing.

Event Reporting

The relay generates an eleven-cycle event report in response to faults or disturbances. Each event report contains voltage and current information, relay element states, and input/output contact information in quarter-cycle resolution. If you question the relay response or your test method, use the event report for more information.

Each event report is date and time tagged relative to the sixteenth quarter-cycle. Each report is triggered upon assertion of designated relay elements and/or contact inputs and outputs. If the timeout of a protective element results in TRIP output contact closure, the trip generates a second event report. Thus, the relay generates two event reports: the first when the instantaneous element asserted, the second when the TRIP output contact closes. Where time delayed pickup (TDPU) timers are concerned, the time tag in the event reports may be used to determine the validity of a TDPU timer setting. Simply subtract the latest event report time tag from the previous event report time tag. Section 2: SPECIFICATIONS has further details concerning event report generation.

Programmable Logic

Programmable logic allows you to isolate individual relay elements. See the LOGIC command description in Section 3: COMMUNICATIONS for further details.

Low-Level Test Interface (patents pending) (available only in SEL-200 series relays)

The relay has low-level test interface between the calibrated input module and the separately-calibrated processing module. You may test the relay in either of two ways: conventionally, by applying ac current signals to the relay inputs; or by applying low magnitude ac voltage signals to the low-level test interface. Access the test interface by removing the relay front panel.

Figure 7.1 shows the interface connections. This drawing also appears on the inside of the relay front panel. Remove the ribbon cable between the two modules to access the outputs of the input module and the inputs to the processing module (relay main board).

You can test the relay processing module using signals from the SEL-RTS Low-Level Relay Test System. Never apply voltage signals greater than 20 volts peak-peak to the low-level test interface. Figure 7.1 shows the signal scaling factors.

You can test the input module two different ways:

- Measure the outputs from the input module with an accurate voltmeter, and compare the readings to accurate instruments in the relay input circuits, or

- replace the ribbon cable, execute the METER command, and compare the relay readings to accurate instruments in the relay input circuits.

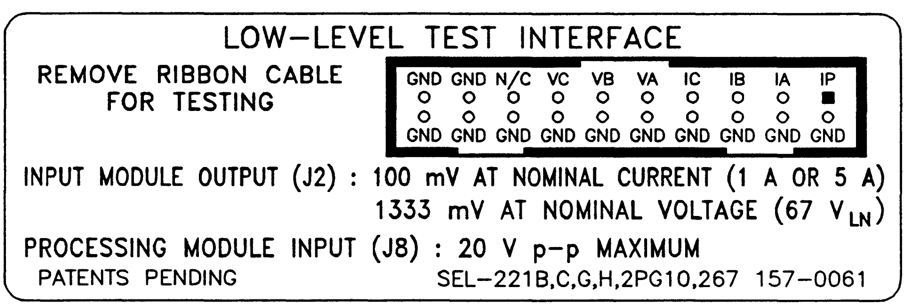


Figure 7.1: Low-Level Test Interface

Test Methods

There are two means of determining the pickup and dropout of relay elements: target lamp illumination and output contact closure.

Testing Via Target LED Illumination

During testing you can use target lamp illumination to determine relay element status. Using the TARGET command, set the front panel targets to display the element under test. For example, the Zone 1 three-phase distance element appears in Relay Word row 1. When you type the command TARGET 1 <ENTER>, the LEDs display the status of the elements in Relay Word row 1. Thus, with Target 1 displayed, if the Zone 1 three-phase distance element (1ABC) asserts, the left most LED illuminates. Using LED illumination as an indicator, you can measure the element operating characteristics.

When the TARGET command sets the target LED output to a level other than 0 (Relay Targets), the front panel target markings are no longer relative to illuminated LEDs and the LEDs do not latch.

If you place the relay in service with the target level other than Level 0, it automatically reverts to target level 0 when an automatic message transmits to a timed out port. While this feature prevents confusion among station operators and readers, it can be inconvenient if the relay tester does not want targets to revert to level 0. Targets remain in the specified level if you set the communications port AUTO setting timeout equal to 0. This prevents automatic message transmission to a port which may be timed out.

Testing Via Output Contact Assertion

To test using this method, set one programmable output contact to assert when the element under test picks up. With the LOGIC [N] command, set a 1 in the mask for the element under test. Set all other elements in that mask to 0.

For an "a" contact, when the condition asserts, the output contact closes. When the condition deasserts, the output contact opens.

For a "b" contact, when the condition asserts, the output contact opens. When the condition deasserts, the output contact closes. Programmable contacts can be specified at the factory as either an "a" or "b." Using contact operation as an indicator, you can measure element operating characteristics, stop timers, etc.

Tests in this chapter use the output contact method and assume an "a" output contact.

Using a Breaker Simulator

Because the switch-onto-fault and recloser logic depend on whether the breaker is open (52A deenergized) or closed (52A energized), it is important to use a breaker simulator for these tests. We recommend testing the relay with a latching relay to simulate line breaker auxiliary contact action. This ensures proper assertion and deassertion of the 52A input contact on the back panel. If you do not have a means of simulating breaker action and status, zero out the MTO logic mask and omit the recloser tests.

INITIAL CHECKOUT

The initial checkout procedure should familiarize you with the relay and ensure that all functions are operational. For a complete understanding of the relay capabilities, study Functional Specification and Description in Section 2: SPECIFICATIONS, command descriptions in Section 3: COMMUNICATIONS, and Section 4: EVENT REPORTING.

Minimum Equipment Required

The following equipment is necessary for initial checkout.

1. Terminal with EIA-232 serial interface
2. Interconnecting cable between terminal and relay
3. Source of control power
4. Source of three-phase voltages and at least two currents
5. Ohmmeter or contact opening/closing sensing device

Checkout Procedure

In the procedure below, you will use several relay commands. Section 3: COMMUNICATIONS provides a full explanation of all commands. The following information should allow you to complete the checkout without referring to the detailed descriptions in Section 3.

Note: In this manual, commands to type appear in bold/uppercase: **OTTER**. Keys to press appear in bold/uppercase/brackets: **<ENTER>**.

Relay output appears in the following format:

```
Example 230 kV Line          Date: 4/1/92     Time: 01:01:01
```

- **Step 1**

Purpose: Be sure you received the relay in satisfactory condition.

Method: Inspect the instrument for physical damage such as dents or rattles.

■ **Step 2**

Purpose: Verify the requirements for the relay logic inputs, control power voltage level, and voltage and current inputs.

Method: Refer to the information sticker on the rear panel of the relay. Figure 7.2 provides an example. Information on this sticker is important to note before applying power to the relay or starting tests. Be sure your dc supply is correctly adjusted for the control and logic input requirements.

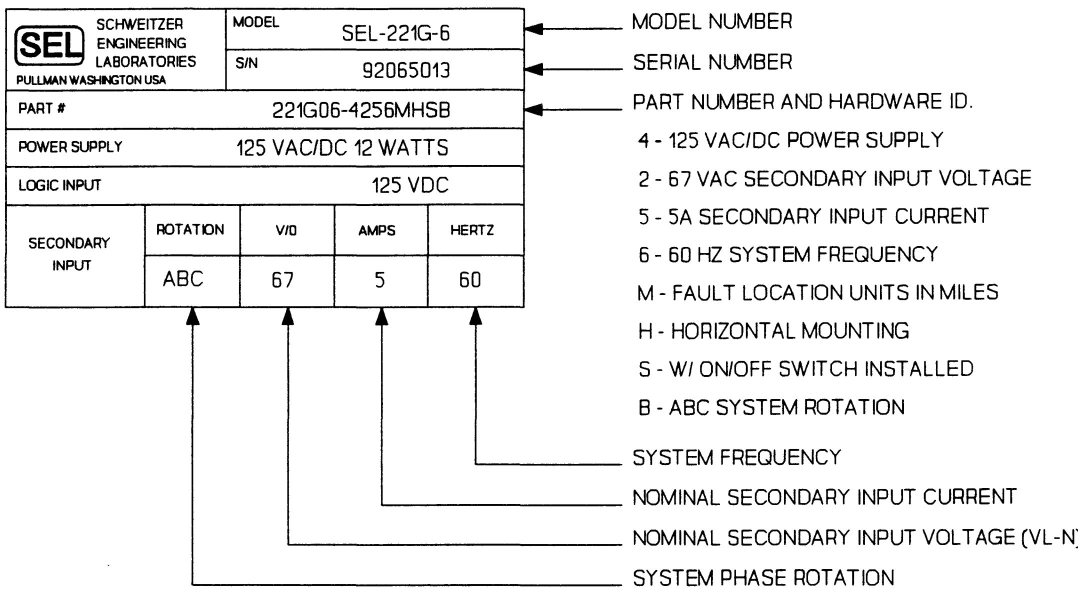


Figure 7.2: Relay Part Number and Hardware Identification Sticker

■ **Step 3**

Purpose: Verify the communications interface setup.

Method: Connect a computer terminal to PORT 2 on the relay front or rear panel. The terminal should be configured to 2400 baud, eight data bits, and no parity. The terminal should be set to two stop bits for standard (-E2) versions, or one stop bit for special ordered (-E1) relays. The relay is shipped from the factory with PORT 2 set to 2400 baud and PORT 1 set to 300 baud. Section 3: COMMUNICATIONS provides additional information about port configurations. Baud rate selection is described under Jumper Selection in Section 6: INSTALLATION. Figure 7.3 shows the typical communication interface setup for testing purposes.

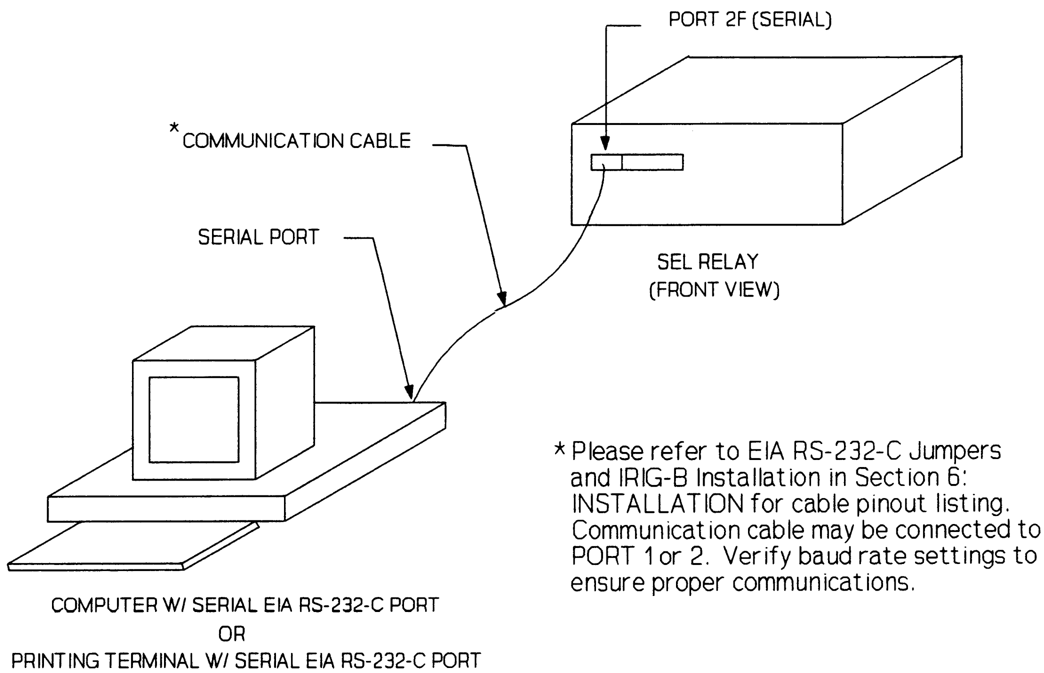


Figure 7.3: SEL-221G Relay Communication Interface Setup

- **Step 4**

Purpose: Establish control power connections.

Method: Connect a frame ground to the terminal marked GND on the rear panel and connect rated control power to the + and - terminals. Polarity is unimportant. Relays supplied with 125 or 250 V power supplies may be powered from a 115 Vac wall receptacle for testing. In the final installation, we recommend that the relay receive control power from the station dc battery to avoid losing events stored in volatile memory when station service is lost.

- **Step 5**

Purpose: Apply control voltage to the relay and start Access Level 0 communications.

Method: Turn on the relay power. The enable target (EN) should illuminate. If not, be sure that power is present and check the fuse or fuses. The following message should appear on the terminal:

```
Example 230 kV Line          Date: 4/1/92    Time: 01:01:01

SEL-121G
=
```

The ALARM relay should pull in, holding its "b" contacts open. Since the LOP bit of the MA4 mask is set, output relay A4 (set to follow LOP) should remain closed until the loss-of-potential problem is rectified. If the relay pulls in but no message is received, check the terminal configuration. If neither occurs, turn off the power and refer to Troubleshooting later in this section.

The = prompt indicates that communications with the relay are at Access Level 0, the first of three levels. The only command accepted at this level is ACCESS, which opens communications on Access Level 1.

Note: If you are using a battery simulator, be sure the simulator voltage level is stabilized before turning the relay on. This assures that the relay power supply self-test procedure is not confused by the current limiting action of the battery simulator.

- **Step 6**

Purpose: Establish Access Level 1 communications.

Method: Type ACCESS and press <ENTER>. At the prompt, enter the Access Level 1 password **OTTER** and press <ENTER>. The => prompt should appear, indicating that you have established communications at Access Level 1.

- **Step 7**

Purpose: Verify self-test status of the relay.

Method: Type STATUS and press <ENTER>. The following display should appear on the terminal:

```
Example 230 kV Line          Date: 4/1/92    Time: 01:04:56

SELF TESTS

W=Warn   F=Fail

      IP   IR   IA   IB   IC   VA   VB   VC
OS    0    0    0    0    0    0    0    0
PS     5.08      14.92      -14.99
RAM    ROM    A/D     MOF    SET
OK     OK     OK      OK     OK

=>
```

- **Step 8**

Purpose: View the demonstration settings entered before shipment.

Method: The relay is shipped with demonstration settings; type SHOWSET **<ENTER>** to view the settings. The terminal should display the following:

```
=>SHOWSET <ENTER>

Settings for: Example 230 kV Line

R1   =8.56    X1   =77.77    R0   =35.12   X0   =236.96 LL   =100.00
CTR  =200.00  PTR  =2000.00  MTA  =83.72   LOCAT=Y
79OI1=40.00   79OI2=60.00    79OI3=80.00   79RS =240.00
Z1%  =80.00   Z2%  =120.00   Z3%  =120.00
Z2SP =0.75    Z2DP =20.00    Z3DP =60.00
50L3 =275.00  50L  =275.00   50M  =500.00  50MFD=20.00   50H  =3420.00
51NP =230.00  51NTD=4.00     51NC =3       51NTC=Y
50N1P=835.00  50N2P=276.00   50N3P=282.00
Z2SG =0.75    Z2DG =30.00    Z3DG =60.00   TDUR =9.00    LOPE =Y
52BT =20.00   ZONE3=R        32QE =Y       32VE =N       32IE =N
TIME =5       TIME2=0        AUTO =2       RINGS=7

Logic settings:

MTU  MPT  MTB  MTO  MA1  MA2  MA3  MA4  MRI  MRC
80   00   40   C4   30   00   00   08   00   E4
C4   00   22   E6   11   00   00   00   44   80
C8   00   00   00   00   01   04   00   00   C8
33   00   00   00   84   40   00   00   00   33

=>
```

The SET and LOGIC command descriptions in Section 3: COMMUNICATIONS include a complete explanation of the settings.

Each column in the logic settings display shows masks for the four rows of the Relay Word as follows:

Relay Word row 1	1ABC	2ABC	3ABC	4ABC	LOP	50H	50M	50L
Relay Word row 2	51NT	67N1	67N2	67N3	51NP	Z1P	Z2P	Z3P
Relay Word row 3	Z2PT	Z3PT	50L3	3P50	50MF	RC	RI	STOP
Relay Word row 4	50N3	TRIP	TC	DT	52BT	Z3X	Z2GT	Z3GT

Logic settings appear in hexadecimal format. A table and example of hexadecimal to binary conversion appears with the SHOWSET command description in Section 3: COMMUNICATIONS.

- **Step 9**

Purpose: Connect voltage and current sources to the relay.

Method: Turn power off and connect a source of three-phase voltages to the relay at the terminals VA, VB, VC, and VN (See Figure 7.9b). Apply 67 volts per phase (line-to-neutral) in positive-sequence rotation. Wye-connect the two current sources as shown in Figure 7.9b to generate balanced positive-sequence currents:

9a. Connect the A-phase and B-phase current sources to the dotted A and B current input terminals.

9b. Connect both undotted A and B current input terminals to the undotted C current input terminal.

9c. Connect the dotted C current input terminal to both the A and B current source returns.

9d. Set the A-phase current source to 2 amperes, at the same angle as the A-phase voltage. Set the B-phase current source to 2 amperes, at the same angle as the B-phase voltage.

- **Step 10**

Purpose: Verify that a loss-of-potential condition is not present with balanced three-phase voltages applied to the relay.

Method: Turn the relay power on and enter Access Level 1. With balanced positive-sequence potentials applied to the relay, the A4 relay should open.

■ **Step 11**

Purpose: Verify correct voltage and current connections and levels.

Method: Use the METER command to measure the voltages and currents applied in Step 10. With applied voltages of 67 volts per phase and a potential transformer ratio of 2000:1, the displayed line-to-neutral voltages should be 134 kV. With applied currents of 2.0 amperes per phase and a current transformer ratio of 200:1, the displayed line-to-neutral currents should be 400 amperes. All line-to-line quantities should be balanced, differing from the line-to-neutral measurements by a factor of 1.73. Real power P should be approximately 160.1 MW; reactive power Q should be approximately 0 MVAR.

```
=> METER <ENTER>

Example 230kV Line          Date: 4/1/92       Time: 00:01:00

                A        B        C        AB        BC       CA
I (A)         401      398      399       695       690      691
V (kV)      134.4    134.4    134.4     233.1     232.8    232.9

P (MW)     161.01
Q (MVAR)     1.02

=>
```

If you inadvertently switched a pair of voltages or currents, the MW reading should be near zero.

■ **Step 12**

Purpose: Test the fault locator.

Method: Test the fault locator using the voltages and currents in Table 7.1. These voltages and currents were obtained for various locations and fault types assuming a radial line with a source impedance of 0.42 times the total 100 mile line impedance. A listing of this BASIC program is included at the end of this section.

Note: To simplify this step, apply rated logic voltage across the 52A input prior to applying each fault. These inputs should remain energized for the duration of this step to block the switch-onto-fault (mho) and block trip (MTB) logic from operating. If a circuit breaker simulator is not available, set all elements in the MTO logic mask to zero.

Table 7.1: Fault Locator Test Values

LOCATION	TYPE	VA	VB	VC	IA	IB	IC	UNITS
75 miles (forward direction fault)	AG	42.95	72.14	72.66	4.34	0.00	0.00	V or A
		0.00	-126.9	126.6	-82.4	0.00	0.00	Degrees
	BC	67.00	50.06	50.06	0.00	6.34	6.34	V or A
		0.00	-132.0	132.0	0.00	-173.7	6.3	Degrees
85 miles (forward direction fault)	AG	44.84	71.70	72.18	4.00	0.00	0.00	V or A
		0.00	-126.4	126.1	-82.4	0.00	0.00	Degrees
	BC	67.00	51.29	51.29	0.00	5.84	5.85	V or A
		0.	-130.8	130.8	0.00	-173.7	6.3	Degrees
-85 miles (reverse direction fault)	AG	44.84	71.70	72.18	4.00	0.00	0.00	V or A
		0.00	-126.4	126.1	97.6	0.00	0.00	Degrees
	BC	67.00	51.29	51.29	0.00	5.84	5.84	V or A
		0.00	-130.8	130.8	0.00	6.3	-173.7	Degrees

Phase faults at 75 miles are within Zone 1, since the Zone 1 phase distance element reach setting is 80.0% of the 100 mile positive-sequence line impedance (see Z1% in the settings). Phase faults at 85 miles are beyond Zone 1, but within the 120% setting of Zone 2 (see Z2% in the settings). Faults at -85 miles are behind the relay terminal and within Zone 3, set to 120% (see Z3% in the settings).

Faults listed in Table 7.1 cause certain combinations of output relays to close and front panel LEDs to illuminate. Table 7.2 shows the results.

Table 7.2: Output Contact and Target LED Results

Location	Type	Output Relays	Target LED
75 mi	AG	TRIP, A2	G1
75 mi	BC	TRIP, A2	Ø1
85 mi	AG	TRIP, A2	G2
85 mi	BC	TRIP, A2	Ø2
-85 mi	AG	TRIP, A1	G3
-85 mi	BC	TRIP, A1	Ø3

Output Contact Explanation

The TRIP output closes in response to any of the following:

1. Any Zone 1 three-phase, phase-phase, or line-to-ground fault
2. Any Zone 2 three-phase or phase-phase fault which persists for 20 cycles
3. Any Zone 2 line-to-ground fault which persists for 30 cycles
4. Any Zone 3 three-phase or phase-phase fault which persists for 60 cycles
5. Any Zone 3 line-to-ground fault which persists for 60 cycles
6. Any forward line-to-ground fault which results in the expiration of the residual time-overcurrent element (51NT)
7. Any overcurrent condition where the current exceeds the 50M threshold for 50MFD time following a loss-of-potential condition
8. DT input assertion
9. The OPEN command

The A1 output relay is set to key block trip for any Zone 3 fault. As shown in Table 7.2, output relay A1 should close for all reverse faults.

The A2 output relay is set to stop carrier for any fault detected by the forward reaching Zone 2 elements. From the table, the A2 output relay should close for all faults except reverse direction faults.

The programming of output relays A1 - A4 and four trip logic masks is explained in detail in the LOGIC command description, Section 3: COMMUNICATIONS.

Target LED Explanation

G1: For the AG ground fault at 75 miles the Zone 1 ground fault target (G1) should illuminate. In general, displayed targets are selected from the picked-up relay elements at the quarter-cycle when the TRIP output is first asserted. In this sense, the targets show which elements actually caused the TRIP, even though other elements may also time out after that.

G2: The AG ground fault at 85 miles should illuminate only the G2 target.

G3: The AG ground fault at -85 miles should illuminate only the G3 target.

∅1: The Zone 1 BC fault at 75 miles should illuminate only the ∅1 Target.

∅2: The Zone 2 BC fault at 85 miles should illuminate only the ∅2 Target.

∅3: The Zone 3 BC fault at -85 miles should illuminate only the ∅3 Target.

Note: The target level must be at Level 0 to display the fault targets. See the TARGET command description in Section 3: COMMUNICATIONS for more details.

Each fault generates a short event report. To see the full event report for the last fault, type **EVENT 1** and press <ENTER>. Each event report provides an eleven-cycle record of the currents, voltages, relay element states, and all contact input and output states. The twelve newest reports are saved.

- **Step 13**

Purpose: Test the loss-of-potential logic.

Method: The relay includes a check for loss-of-potential, which might occur when a secondary fuse in the potential circuit blows. To demonstrate the instrument response, be sure the currents are balanced. Turn off one of the three-phase potentials. The relay should respond by lighting the LOP bit in Relay Word row 1 (TAR 1 command).

This checkout procedure demonstrates only a few relay features. For a complete understanding of relay capabilities, study Functional Description in Section 2: SPECIFICATIONS, the Command Descriptions in Section 3: COMMUNICATIONS, and Section 4: EVENT REPORTING. For more test procedures, see the Full Functional Test portion of this section.

FULL FUNCTIONAL TEST

This procedure allows you to test the protective and control functions of the relay more fully than the initial checkout procedure does.

Equipment Required

The following equipment is necessary to complete a full functional test:

1. Communications terminal with EIA-232 serial interface
2. Data cable to connect terminal and relay
3. Source of relay control power
4. Source of synchronized three-phase voltages and at least two currents
5. Ohmmeter or contact opening/closing sensing device
6. Timer with contact inputs for start and stop

What Should Be Tested

A full functional test includes the initial checkout procedure and the additional steps described below. In general, these tests assure that the relay settings match your application rather than checking relay performance. For commissioning purposes, your company policy may require you to perform the full functional test. For maintenance purposes, a quick test of selected fault types and zones should suffice. For example, test a Zone 1 AG fault, Zone 2 BC fault, and a Zone 3 ABC fault.

SETTING TEST

Purpose: Ensure that the relay accepts settings.

Method:

1. Gain Level 2 Access (see ACCESS and 2ACCESS commands in Section 2: COMMUNICATIONS).

2. Change one setting. For example, change the Zone 1 reach from 80 to 82%.

   Type **SET Z1%** and press <ENTER>.

   Following the Z1% prompt, type 82 and press <ENTER>.

3. To complete the setting procedure, type END and press <ENTER>. Type **Y <ENTER>** at the prompt: "OK (Y or N) ?" The relay computes internal settings and compares them against fixed limits. If all settings are within acceptable ranges, the ALARM contact closes momentarily as the new settings are enabled unless an alarm condition already exists (e.g., self-test failure).

4. Use the SHOWSET command to inspect settings. Make sure your change was accepted.

   Type **SHOWSET** and press <ENTER>.

5. Use SET and SHOWSET again to restore the initial values and check the settings.

6. Type **LOG MTU** and press <ENTER>.

7. Change one bit in the MTU logic mask. For example, remove the TC bit from the fourth row of the Relay Word as shown in the following example.

```
=>>LOG MTU <ENTER>

1 selects, 0 deselects.

1ABC 2ABC 3ABC 4ABC LOP  50H  50M  50L
 1    0    0    0    0    0    0    0
? <ENTER>
51NT 67N1 67N2 67N3 51NP Z1P  Z2P  Z3P
 1    1    0    0    0    1    0    0
? <ENTER>
Z2PT Z3PT Z3RB 50L3 50MF RC   RI   STOP
 1    1    0    0    1    0    0    0
? <ENTER>
50N3 TRIP TC   DT   52BT Z3X  Z2GT Z3GT
 0    0    1    1    0    0    1    1
? 00010011 <ENTER>
 0    0    0    1    0    0    1    1
? <ENTER>

New MTU:

1ABC 2ABC 3ABC 4ABC LOP  50H  50M  50L
 1    0    0    0    0    0    0    0
51NT 67N1 67N2 67N3 51NP Z1P  Z2P  Z3P
 1    1    0    0    0    1    0    0
Z2PT Z3PT Z3RB 50L3 50MF RC   RI   STOP
 1    1    0    0    1    0    0    0
50N3 TRIP TC   DT   52BT Z3X 2Z2GT Z3GT
 0    0    0    1    0    0    1    1

OK (Y/N) ? Y <ENTER>
=>>
```

8. Type **LOG MTU** and press <ENTER>. Make sure the bit change is present.

9. Use LOG MTU and SHOWSET to restore the initial values and check settings.

METER TEST

Purpose: Verify the magnitude accuracy and phase balance. This test only requires a single voltage and current test source.

Method: 1. Parallel all voltage inputs by connecting terminals VA, VB, and VC with a jumper. See Figure 7.4 for the test connections.

2. Series all current inputs as shown in Figure 7.4.

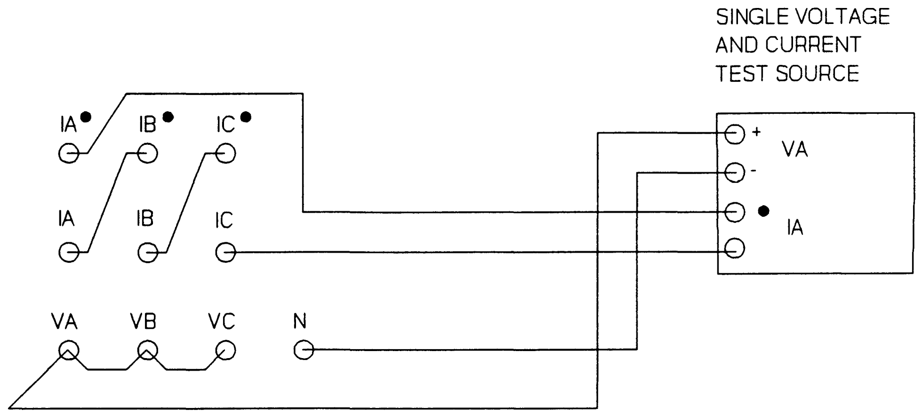


Figure 7.4: METER Test Connections

3. Apply a voltage of 50 Vac between the paralleled voltage inputs to the neutral point and a current of five amperes through the three inputs. The phase angle of the voltage and current source should be set to 0°.

4. Use the METER command to inspect measured voltages, currents, and power. Voltages VA, VB, and VC should equal the applied voltage times the potential transformer ratio setting. With the Example 230 kV Line settings, you should obtain:

$$\begin{aligned} VA = VB = VC &= (50\ V)(2000) \\ &= 100\ kV\ (\pm 0.5\%). \end{aligned}$$

Voltages VAB, VBC, and VCA should read less than 1.5 kV.

Similarly, currents IA, IB, and IC should equal the applied current times the current transformer ratio. With the Example 230 kV Line settings, you should obtain:

$$\begin{aligned} IA = IB = IC &= (5\ A)(200) \\ &= 1000\ A\ (\pm 1\%). \end{aligned}$$

Difference currents IAB, IBC, and ICA should be less than 20 amperes. The power reading, P (MW), should read:

$$(VA)(IA) + (VB)(IB) + (VC)(IC) = 300\ MW.$$

The reactive power reading Q (MVAR) should be less than 5 MVAR.

MHO ELEMENT TESTING

Before you begin testing the mho distance elements, determine the test quantities. Refer to the end of this section for a simple program (called ONEBUS) to calculate voltages and currents required to simulate a power system fault at the line angle.

Note: ONEBUS is not required to test the relay but is included as a test aide.

During mho element tests, we recommend disabling the loss-of-potential (LOP) logic by setting LOPE = N in the relay set procedure. This prevents an LOP condition from blocking mho distance elements. You must enable the LOP feature during LOP testing.

A. Determining Fault Simulation Values - Phase-Phase and Phase-Ground Faults

All line impedance entries for the ONEBUS program must be entered in secondary values. Convert the primary impedance settings from your relay setting sheet or SHOWSET printout to secondary values with the following formula:

$$\text{R1 secondary} = \text{R1}\left(\frac{\text{Current Transformer Ratio}}{\text{Potential Transformer Ratio}}\right)$$

$$\text{X1 secondary} = \text{X1}\left(\frac{\text{Current Transformer Ratio}}{\text{Potential Transformer Ratio}}\right)$$

$$\text{R0 secondary} = \text{R0}\left(\frac{\text{Current Transformer Ratio}}{\text{Potential Transformer Ratio}}\right)$$

$$\text{X0 secondary} = \text{X0}\left(\frac{\text{Current Transformer Ratio}}{\text{Potential Transformer Ratio}}\right)$$

Next, calculate required voltages and currents for a single-line-to-ground and phase-phase fault at the boundary of the Zone 1 reach using the example settings provided with the relay. Enter the data shown in bold face from Figure 7.5 into the ONEBUS program:

```
ENTER Z1: R,X? 0.856,7.777
ENTER Z0: R,X? 3.512,23.696
ENTER RF FOR GND FLTS? 0
DIST SOURCE TO BUS (PU OF LINE)? 0.2
DIST BUS TO FAULT (PU OF LINE)? 0.8
```

Figure 7.5: Example ONEBUS Input Data for Phase-Phase and Ground Faults

ONEBUS should produce the following output:

```
    VA      VB      VC      IA      IB      IC
  53.60   69.74   70.04    5.08    0.00    0.00     A-G
    0.0  -124.0   123.8   -82.4     0.0     0.0

    VA      VB      VC      IA      IB      IC
  67.00   57.24   57.24    0.00    7.42    7.42     B-C
    0.0  -125.8   125.8     0.0  -173.7     6.3

       IMP BUS FAULT OR QUIT (I,B,F,Q)?
```

Figure 7.6: Example ONEBUS Result Screen for Phase-Phase and Ground Faults

B. Onebus Input Description

Line 1: On the first line, enter the real and reactive values of the secondary positive-sequence impedance for the entire transmission line. Separate each value with a comma.

Line 2: On the second line, enter the real and reactive values of the secondary zero-sequence impedance for the entire transmission line.

Line 3: The "RF FOR GROUND FAULTS" input allows you to introduce ground fault resistance into the line-ground fault cases. In most instances RF will be zero.

Line 4: The "DIST SOURCE TO BUS" input models the source strength behind the relay location as a source to line impedance ratio. This setting is entered as a per unit value. For example, for a radial system with a source impedance equal to 20% of the line impedance, enter 0.2 for the per unit distance from the source to the bus. Variations of the source impedance ratio (SIR) affect the magnitude and phase angle of the calculated voltages and currents.

The source impedance ratio may be used to adjust the current magnitude in cases where calculated currents exceed the output range of your current source. For example, on a short transmission line with a low source impedance, high current magnitudes result. Raising the source impedance ratio in ONEBUS results in a lower calculated current combined with a lower voltage.

If the source impedance ratio is unknown, enter a source impedance ratio of one to determine whether calculated currents are within the range of the current source. It is desirable to keep the source impedance ratio as realistic as possible.

Line 5: The final input is the "DIST BUS TO FAULT." This is the distance from the relay terminal to the fault location. To obtain the voltages and currents for a fault at 80% of the line, enter 0.8 for the per unit distance from the bus to fault.

C. Determining Fault Simulation Values - Three-Phase Faults

Three-phase fault voltages and currents can be calculated with the ONEBUS program. Enter the positive-sequence line impedance values at the prompt for zero-sequence values and set the source impedance ratio to zero. The following example uses the example relay settings:

```
ENTER Z1: R,X? 0.856,7.777
ENTER Z0: R,X? 0.856,7.777
ENTER RF FOR GND FLTS? 0
DIST SOURCE TO BUS (PU OF LINE)? 0.0
DIST BUS TO FAULT (PU OF LINE)? 0.8
```

Figure 7.7: Example ONEBUS Input Data for Three-Phase Faults

The following output should result:

```
   VA     VB     VC     IA     IB     IC
67.00  67.00  67.00  10.70   0.00   0.00    A-G
  0.0 -120.0  120.0  -83.7    0.0    0.0

   VA     VB     VC     IA     IB     IC
67.00  67.00  67.00   0.00   9.27   9.27    B-C
  0.0 -120.0  120.0    0.0 -173.7    6.3

      IMP BUS FAULT OR QUIT (I,B,F,Q)?
```

Figure 7.8: Example ONEBUS Result Screen for Three-Phase Faults

Use the calculated single-phase fault (AG) values to simulate a three-phase fault. Voltages are applied as indicated in the program. The calculated A-phase current magnitude is applied to all three relay current inputs. Each current is applied lagging the corresponding voltage phase angle by the transmission line angle. These values are shown in Table 7.3.

Table 7.3: Three-Phase Fault Voltages and Currents at MTA

VA	VB	VC	IA	IB	IC	
67.00	67.00	67.00	10.70	10.70	10.70	Volts/Amps
0.00°	-120.00°	120.00°	-83.70°	156.30°	36.30°	Degrees

Two methods of observing element status were described earlier in the Test Procedures; these are target LEDs and programmable output contacts. For the purposes of driving an external sense contact, the remainder of the test procedure will use the programmable output contact method.

D. Three-Phase Mho Relay Test

Purpose: Determine the pickup of each three-phase distance element at three points on the mho characteristic: MTA, MTA +45°, and MTA -45°.

Method:

1. Program the desired programmable output contact (A1 - A4) to follow the appropriate instantaneous three-phase distance element using the LOGIC command. Select one of the three-phase elements from the first row of the Relay Word as indicated below:

   1ABC = Zone 1 Instantaneous Three-Phase Mho Element
   2ABC = Zone 2 Instantaneous Three-Phase Mho Element
   3ABC = Zone 3 Instantaneous Three-Phase Mho Element
   4ABC = Zone 4 Instantaneous Three-Phase Mho Element

   Please note that the 2ABC element includes any delay set by the Z2SP timer setting.

   The Zone 4 offset mho circle diameter is 1.5 times the Zone 3 mho circle diameter. Therefore, the reverse reach of Zone 4 is 1.25 times that of Zone 3, while the forward reach is 0.25 times the Zone 3 setting. Zone 3 may be forward or reversed but Zone 4 always remains reversed.

   The following example outlines the procedure for testing the Zone 1 three-phase distance element.

2. Connect the sources of voltage and current to the rear panel terminals of the relay as per Figure 7.9a or Figure 7.9b. Figure 7.9a uses three current sources, while Figure 7.9b uses only two.

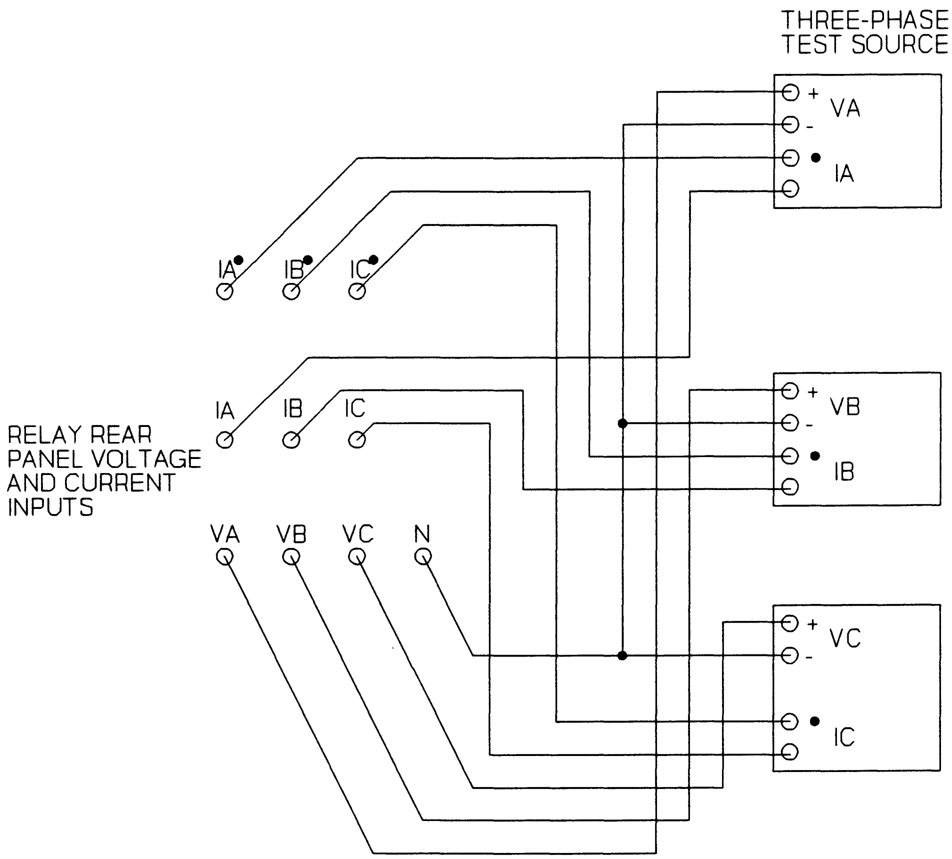


Figure 7.9a: Three-Phase Voltage and Current Source Test Connections for Three-Phase Mho Test

The two current source method yields the same results as does the three current source method but requires one less current source. For balanced three-phase faults, the residual or 3I0 is zero. From this you can see why two current sources are adequate for three-phase element testing:

$$3I0 = IA + IB + IC = 0$$

Therefore,

$$-IC = (IA + IB)$$

This has the same effect as performing the following steps:

a. Connect the dotted output of A and B current sources to the dotted IA and IB inputs of the relay.

b. Jumper together the undotted IA and IB current inputs of the relay. This forms the (IA + IB) quantity.

c. Connect a jumper between the undotted IA and IB current inputs to the undotted IC current input of the relay.

d. Connect the dotted IC current input of the relay to the common current source return of current Source A and B.

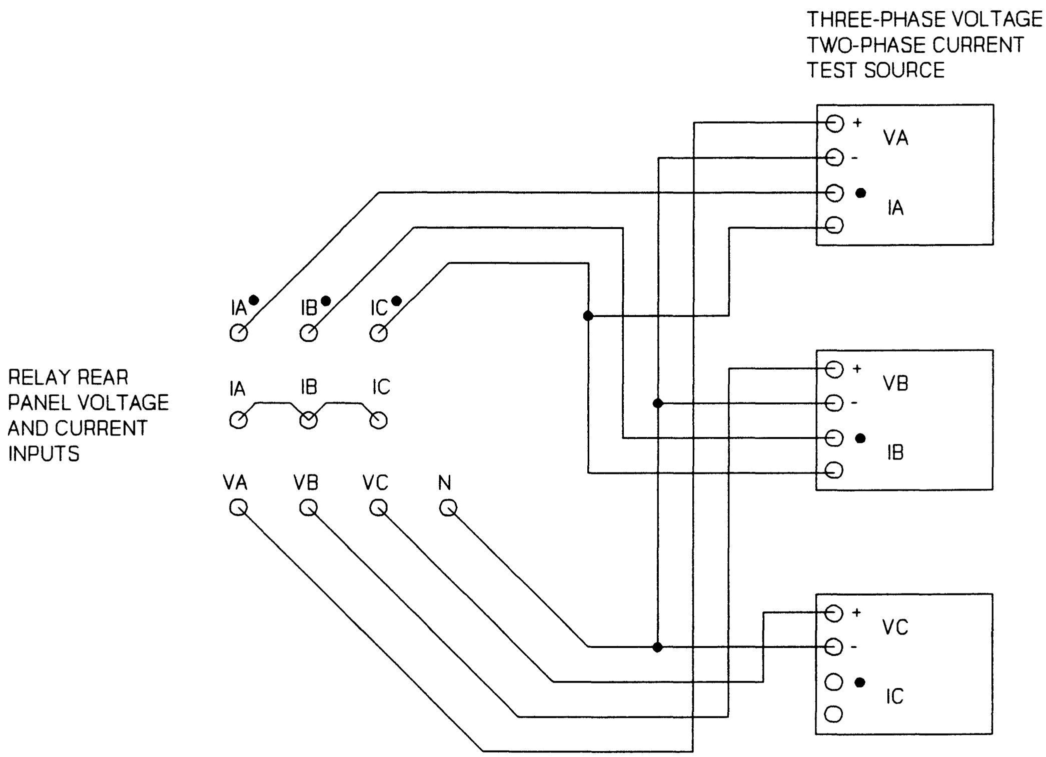


Figure 7.9b: Three-Phase Voltage and Two-Phase Current Source Test Connections for Three-Phase Mho Test

3. Determine the voltages and currents required to simulate a fault at the boundary of the desired relay reach (using ONEBUS or similar method). Table 7.4 shows currents and voltages required to test the example Zone 1 reach at MTA. These quantities were calculated using ONEBUS.

Table 7.4: Zone 1 Three-Phase Element Test Quantities at MTA

VA	VB	VC	IA	IB	IC	
67.00	67.00	67.00	10.7	10.7	10.7	Volts/Amps
0.00°	-120.00°	120.00°	-83.7°	156.3°	36.3°	Degrees

4. Adjust the voltages and currents of the test set to the values shown in Table 7.4. Do not turn on the currents at this point.

5. Turn on the voltage sources VA, VB, and VC.

6. Apply current to the relay and ramp the current source magnitudes together until the monitored output contact toggles, indicating pickup. Record the pickup current threshold and compare to the calculated threshold.

   To calculate the three-phase element reach you need only consider a single phase. For example, if the A-phase voltage magnitude is 67 $V_{l\text{-}n}$, and the current magnitude for the boundary characteristic is 10.7 A, calculate the three-phase distance element reach as follows:

   Zone 1 reach secondary,

   $$Z1_{sec} = \frac{67V \angle 0°}{10.7A \angle -83.7°} = 6.26\Omega \angle 83.7° \text{ secondary along the MTA}$$

   In primary ohms,

   Zone 1 reach primary along the MTA,

   $$Z1_{pri} = (6.26\Omega \angle 83.7°)\left(\frac{PTR}{CTR}\right) = 62.6\Omega \angle 83.7° \text{primary}$$

   Where PTR = 2000 and CTR = 200.

7. Obtain two other convenient test points. Consider a square inscribed in a mho circle with one diagonal being the diameter along the MTA. The two corners of that square on the other diagonal are reached by increasing the current by a factor of 1.414 at angles of ±45° away from the angle obtained using the BASIC program.

   For the three-phase example, the required voltages remain unchanged. The current magnitudes are 10.7 A (1.414) = 15.1 A, at the angles listed as follows:

Table 7.5: Zone 1 Three-Phase Test Quantities at MTA ±45°

	Angle IA	Angle IB	Angle IC
MTA +45°	-38.7°	-158.7°	81.3°
MTA -45°	-128.7°	111.3°	-8.7°

8. Test the relay at the two additional current phase angle settings (MTA +45° and MTA -45°). Record the results.

E. Phase-Phase Mho Element Tests

Purpose: Determine the pickup of the phase-phase distance element at three points on the mho characteristic: MTA, MTA +45° and MTA -45°.

Method:

1. Use the LOGIC command to program a single output relay (A1-A4) to follow the appropriate instantaneous phase-phase distance element. Select a phase-phase element from the Relay Word as indicated below:

   Z1P = Zone 1 Instantaneous Phase-Phase Element
   Z2P = Zone 2 Instantaneous Phase-Phase Element
   Z3P = Zone 3 Instantaneous Phase-Phase Element

   Please note the Z2P element includes any delay set by the Z2SP timer.

   The following example outlines the test procedure for the Zone 1 phase-phase distance element.

2. Connect the sources of voltage and current to the relay rear panel terminals (see Figure 7.10a or Figure 7.10b). Note that two current sources are employed in Figure 7.10a, while only one current source is used in Figure 7.10b.

   The single current source method yields the same results as the two current source method but requires one less source. Single current source method also assures that the phase angle of the two involved currents is always 180° apart.

   These steps connect a single current source to the relay for a BC phase-phase fault test.

   a. Connect B current source dotted output to dotted relay IB input.

   b. Jumper undotted relay IB and IC current inputs together.

c. Connect dotted relay IC current input to common current source return of current Source B.

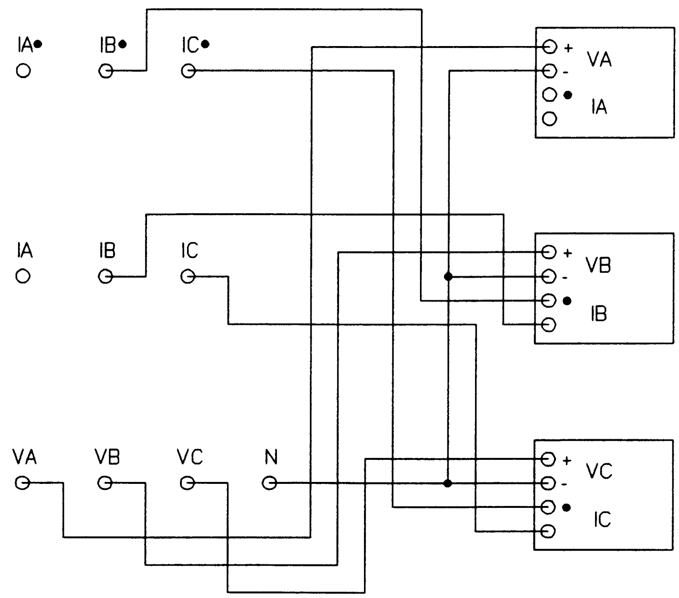


Figure 7.10a: Three-Phase Voltage and Two-Phase Current Source Test Connections for Phase-Phase Mho Test

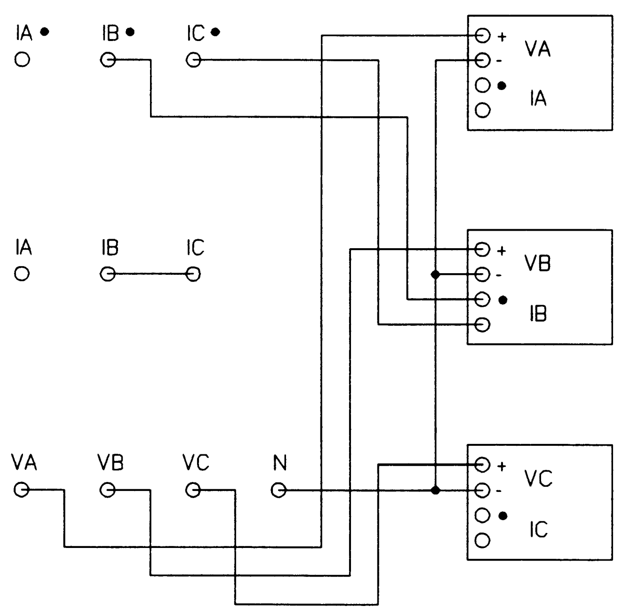


Figure 7.10b: Three-Phase Voltage and One-Phase Current Source Test Connections for Phase-Phase Mho Test

3. Determine the voltages and currents required to simulate a phase-phase fault at the boundary of the desired relay reach (using ONEBUS or similar method). Currents and voltages required to test the Zone 1 phase-phase element reach of the example settings appear in Table 7.6:

Table 7.6: Zone 1 Phase-Phase Test Voltages and Currents, BC Fault

VA	VB	VC	IA	IB	IC	
67.00	57.24	57.24	0.00	7.42	7.42	Volts/Amps
0.0°	-125.8°	125.8°	0.0°	-173.7°	6.3°	Degrees

4. Adjust the test set voltages and currents to the values in Table 7.6. Do not turn on the currents at this point.

5. Turn on the voltage sources VA, VB, and VC.

6. Apply current to the relay and ramp the current source magnitudes together until the monitored output contact toggles, indicating pickup. Record the pickup current threshold and compare it to the calculated threshold.

   To calculate the phase-phase element reach, first calculate the resultant test voltage (VBC) and current (IBC).

   <u>BC Fault</u>

   $VB = 57.24\ V\ \angle -125.8°$
   $VC = 57.24\ V\ \angle 125.8°$
   $VBC = VB - VC = 92.85\ V\ \angle -90°$

   $IB = 7.42\ A\ \angle -173.7°$
   $IC = 7.42\ A\ \angle 6.3°$
   $IBC = IB - IC = 14.84\ A\ \angle -173.7°$

   Zone 1 reach secondary along the MTA,

   $$Z1_{sec} = \frac{VBC}{IBC} = \frac{92.85\ V\ \angle -90°}{14.84A\ \angle -173.7°} = 6.26\Omega\ \angle 83.7°\ \text{secondary}$$

In primary ohms,

Zone 1 reach primary along the MTA,

$$Z1_{pri} = (6.26\Omega \angle 83.7°)\left(\frac{PTR}{CTR}\right) = 62.6\Omega \angle 83.7° \text{ primary}$$

Where PTR = 2000 and CTR = 200.

7. Find two other convenient test points. Consider a square inscribed in a mho circle with one diagonal being the diameter along the MTA. The two corners of that square on the other diagonal are reached by increasing the current by a factor of 1.414 at angles of ±45° from the angle obtained using the ONEBUS program.

   For our Zone 1 BC phase-phase example, the required voltages remain unchanged. The current magnitudes are (7.42)(1.414) = 10.49 amperes at the angles listed as follows:

Table 7.7: Zone 1 Phase-Phase Test Quantities at MTA ±45°

	Angle IB	Angle IC
MTA +45°	-128.7°	51.3°
MTA -45°	141.3°	-38.7°

8. Test the relay at the two additional current phase angle settings (MTA +45°, MTA -45°). Record the results.

DIRECTIONAL ELEMENT TESTS

Purpose: Verify the operate and restrain boundaries of the directional element for each residual overcurrent polarizing method enabled in the relay settings: 32Q, 32V, or 32I. In the example settings, the negative-sequence polarizing method is enabled (32QE = Y). Test procedures are also included for testing the 32D (32V and/or 32I) element.

Method: Program the desired programmable output (A1 - A4) to follow the 67N2 bit in Relay Word row 2. Use the SET command to disable the LOP scheme. This prevents test-condition voltages from setting the loss-of-potential condition and defeating the directional sensing ability of the relay. This step is unnecessary when testing the current polarized method alone (32IE=Y, 32QE=N, and 32VE=N).

32Q and 32V Tests

1. The negative-sequence element and voltage polarized part of the zero-sequence element can be checked identically. With 32QE=Y, 32VE=N, and 32IE=N, check the negative-sequence element first.

   Apply the following voltages to the relay:

Table 7.8: 32Q and 32V Test Voltages

VA	VB	VC	
30.00	0.00	0.00	Volts
0.0°	0.0°	0.0°	Degrees

   For the voltages shown in Table 7.8, the resulting negative- and zero-sequence voltages are ten volts. The following equations illustrate the equations you should use to calculate magnitudes and angles for V2 and V0.

$$\begin{aligned} V0 &= \tfrac{1}{3}[VA + VB + VC] \\ &= \tfrac{1}{3}[30V \angle 0^\circ + 0V \angle 0^\circ + 0V \angle 0^\circ] \\ &= 10V \angle 0^\circ \end{aligned}$$

$$V2 = \tfrac{1}{3}[VA + a^2(VB) + a(VC)]$$

   Where: $a \equiv 1 \angle 120^\circ$ and $a^2 \equiv 1 \angle 240^\circ$

$$\begin{aligned} V2 &= \tfrac{1}{3}[30V \angle 0^\circ + 0V \angle(0^\circ + 240^\circ) + 0V \angle(0+120^\circ)] \\ &= \tfrac{1}{3}[30V \angle 0^\circ + 0V \angle -120^\circ + 0V \angle 120^\circ] \\ &= 10V \angle 0^\circ \end{aligned}$$

   To calculate I2 and I0, substitute currents for voltages in the equations above.

Please note that the angular relationship of V2 and I2 (or V0 and I0) using a single voltage and current differs by 180° from using three voltages and a single current. Figure 7.11 illustrates the difference between using a single voltage and current and using three voltages and a single current. For the sake of simplicity, this test uses the single voltage and current method. The relay declares ground faults in the forward direction when I2 (I0) leads ±90° from the MTA.

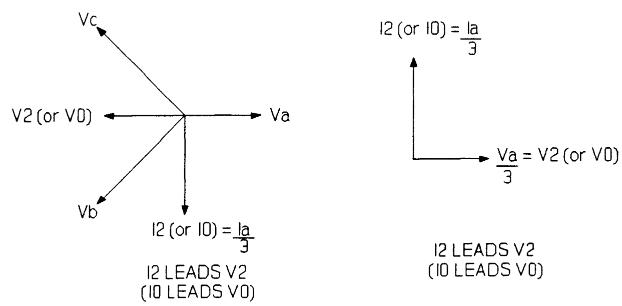


Figure 7.11: Three Voltage vs. One Voltage for Directional Tests (current vector shown in the operate region for MTA = 90°)

2. Apply IA = 3 amperes, corresponding to negative- and zero-sequence currents of one ampere. IB and IC are zero for this test.

3. Move the phase angle of the current with respect to the voltage and observe the boundary of the directional element at MTA ±90°.

4. Repeat the previous steps with only 32VE enabled to check the zero-sequence voltage polarization directional element.

32I Tests

5. Verify the current polarization directional element boundaries by turning off the voltage and applying a second current source to the polarizing current input (IP).

   Enable only the 32IE element in the relay setting procedure. Apply the currents shown in Table 7.9 to the IA and IP current inputs with the test connection in Figure 7.12.

Table 7.9: 32I Test Currents

IA	Ipol	
3.00	3.00	Amperes
0.0°	0.0°	Degrees

The 67N2 bit should set and close the output contact when both currents are applied.

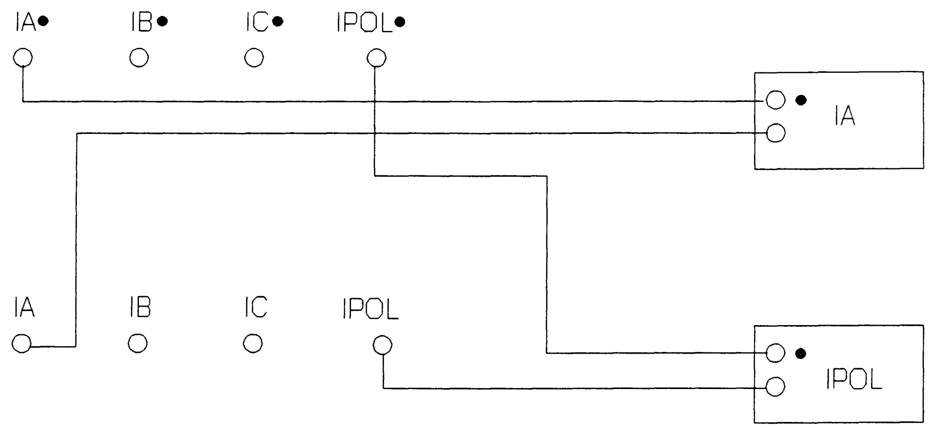


Figure 7.12: Current Polarized Directional Element Test Connection

6. Move the phase angle of IA with respect to the angle of IP to determine the zero torque axis. The maximum torque angle of the current polarized directional element is 0° (e.g., the A-phase current angle in phase with the IPOL current). The boundary of the characteristic should be at ±90°.

RESIDUAL OVERCURRENT ELEMENT TESTS

Purpose: Verify the pickup thresholds of the 67N1, 67N2, 67N3, and 51NP residual overcurrent elements.

Method:

1. Using the LOGIC command, set the desired programmable output (A1 - A4) to follow the appropriate overcurrent element. Select one of the overcurrent elements from the Relay Word as indicated below:

   67N1 = Zone 1 Instantaneous Residual Element (pickup set by 50N1P setting)
   67N2 = Zone 2 Instantaneous Residual Element (pickup set by 50N2P setting)
   67N3 = Zone 3 Instantaneous Residual Element (pickup set by 50N3P setting)
   51NP = Residual Time-Overcurrent Pickup Element

   Please note that the 67N2 element includes any delay set by the Z2SG timer.

2. Disable all directional and LOP functions for this test. Set 51NTC, 32QE, 32VE, 32IE, and LOP = N.

3. Apply current to one phase and observe the pickup and dropout of each element. Record the results.

RESIDUAL TIME-OVERCURRENT ELEMENT TIMING TESTS

Purpose: Verify the 51NT residual time-overcurrent element operating time.

Method:

1. Disable all directional functions for this test. Set 51NTC, 32QE, 32VE, and 32IE = N.

2. Set a programmable output (A1-A4) to follow the 51NP time-overcurrent pickup element. Use the assertion of this output (open to close) to start an external timer.

3. Set another programmable output to follow the timeout of the time-overcurrent element timeout via the 51NT bit in the Relay Word. Use the assertion of this output to stop the external timer.

4. Calculate the expected operating time of the 51NT element using the appropriate equation for the curve number. This is dictated by the relay 51NC setting. TD is the relay 51ND time dial setting. M is the multiple of pickup current to be applied to the relay. Using example relay settings and a current multiple of pickup equal to three, the equation for the very inverse curve (3) is:

   $$t_M = TD \left(0.0963 + \frac{3.88}{M^2 - 1} \right)$$

   Where M = Multiples of Pickup = 3
   TD = Time Dial =4

   $$t_M = 2.33 \text{ seconds}$$

   For example, if the relay measures 3.45 amperes of residual current, the 51NT bit in the Relay Word asserts 2.33 seconds after the 51NP bit in the Relay Word asserts. Table 7.10 shows the current quantities of the previous example.

   Table 7.10: Current Quantities for 51N Timing Test Example

IA	IB	IC	
3.45	0.00	0.00	Amperes
0.0°	0.0°	0.0°	Degrees

5. Apply a multiple of pickup current to one phase. Record the operating time of the 51NT element and compare to the calculated time.

6. Repeat the test for various multiples of pickup current (e.g., M = 3, 5, and 7) and various time dial settings (e.g., TD = 1, 5, and 10) for each of the four curve indexes.

PHASE OVERCURRENT ELEMENT TESTS

Purpose: Verify the pickup thresholds of the 50L, 50L3, 50M, and 50H phase overcurrent elements.

Method:

1. Using the LOGIC command, set the desired programmable output (A1 - A4) to follow the appropriate non-directional instantaneous phase overcurrent element. Select one of the phase overcurrent elements from the Relay Word as indicated below:

   50L = Zones 1 and 2 low-set instantaneous phase overcurrent element
   50L3 = Zones 3 and 4 low-set instantaneous phase overcurrent element
   50M = Medium-set instantaneous phase overcurrent element
   50H = High-set instantaneous phase overcurrent element

2. Apply current to one phase and observe the pickup and dropout of each element. Record the results. Pickup of the 50H element generates an event report.

MEMORY VOLTAGE POLARIZATION TEST

Purpose: Test the memory polarization duration for zero voltage close-in three-phase faults in front of the relay.

Method:

1. Using the factory relay settings, apply a zero voltage three-phase fault at the bus in front of the relay. Pre-fault and fault voltages and currents appear in Table 7.11. Pre-fault voltages are needed to charge the memory polarization filters.

Table 7.11: Three-Phase Close-In Fault

Pre-fault Quantities:

VA	VB	VC	IA	IB	IC	
67.00	67.00	67.00	0.00	0.00	0.00	Volts/Amps
0.0°	-120.0°	120.0°	0.0°	0.0°	0.0°	Degrees

Fault Quantities:

VA	VB	VC	IA	IB	IC	
0.00	0.00	0.00	11.00	11.00	11.00	Volts/Amps
0.0°	0.0°	0.0°	-83.7°	156.3°	36.3°	Degrees

2. In the generated event report, count the number of quarter-cycles between the time voltages collapse to zero and when the Zone 1 three-phase mho element drops out. The Zone 1 three-phase element should be asserted for a minimum of 16 quarter-cycles. The 4ABC element should still be asserted, as it does not require memory polarization.

LOSS-OF-POTENTIAL TEST

Purpose: Verify the SET LOP and CLEAR LOP conditions. The following equations show the SET LOP and CLEAR LOP logic equations.

SET LOP = 47NL * NOT(50NL)
+ NOT(47P) * NOT(50M)

CLEAR LOP = NOT(47NL) * 47P

Where: 47NL = 14 V of V0
50NL = 0.083 A of I0 for 51NP < 3.15 A and
(0.083 A)*(51NP/3.15), 51NP ≥ 3.15 A
47P = 14 V of V1
50M = Current in any phase over the 50M setting

Method: Table 7.12 provides the voltage and current sets required to create SET LOP and CLEAR LOP conditions.

Table 7.12: Conditions for the SET LOP and CLEAR LOP Logic Equations

SET LOP:

VA	VB	VC	IA	IB	IC	
0.00	67.00	67.00	0.00	0.00	0.00	Volts/Amps
0.0°	-120.0°	120.0°	0.0°	0.0°	0.0°	Degrees

CLEAR LOP:

VA	VB	VC	IA	IB	IC	
67.00	67.00	67.00	0.00	0.00	0.00	Volts/Amps
0.0°	-120.0°	120.0°	0.0°	0.0°	0.0°	Degrees

50MF, 50MFD TEST

Purpose: Verify that the 50MF bit in the Relay Word asserts 50MFD cycles after the current in any phase rises above the 50M setting following an LOP condition.

Method:

1. Program the desired programmable output (A1-A4) to follow the 50MF bit in the Relay Word.
2. Program another programmable output to follow the 50M bit in the Relay Word.
3. Start a timer when the 50M programmable output asserts (open to close).
4. Stop the timer when the 50MF bit asserts the output relay (open to close) and verify the accuracy of the 50MFD timer.

Z2DG AND Z3DG TIMER TESTS

Purpose: Verify the Z2DG and Z3DG timer accuracy.

Method:

1. Program the 67N2 bit in the Relay Word into one of the available outputs (A1 - A4) to start an external timer. Set the Z2SG timer setting equal to zero to remove the delay introduced by this timer on the instantaneous pickup of the 67N2 element.
2. Program the Z2GT bit into a different output to stop the timer.
3. Apply a Zone 2 AG fault as in Table 7.13 for a duration which exceeds the Z2DG setting.

Table 7.13: Standard Zone 2 AG Fault Using Factory Relay Settings

2AG Fault

VA	VB	VC	IA	IB	IC	
54.24	69.60	69.89	4.83	0.00	0.00	Volts/Amps
0.0°	-123.8°	123.6°	-82.4°	0.0°	0.0°	Degrees

4. Repeat steps 1 to 3, substituting 67N3 for 67N2 and Z3GT for Z2GT into the appropriate programmable output. Table 7.14 shows a standard Zone 3 AG fault. Apply this 3AG fault for a duration which exceeds the Z3DG setting.

Table 7.14: Standard Reverse Zone 3 AG Fault Using Factory Relay Settings

3AG Fault

VA	VB	VC	IA	IB	IC	
54.24	69.60	69.89	4.83	0.00	0.00	Volts/Amps
0.0°	-123.8°	123.6°	97.6°	0.0°	0.0°	Degrees

Note: If an external timer is not available, use event report time tags to calculate Z2DG and Z3DG time delays with the following steps.

1. Mask only the Z2GT bit of the Relay Word into the MTU mask. Zero the MTO mask out so no other condition can assert the TRIP output.

2. Apply the Zone 2 AG fault as given in Table 7.13.

3. For Z2DG settings greater than approximately 6 cycles, the relay generates two event reports: one for the 67N2 element pickup, the other for TRIP output assertion (and the Z2GT bit of the Relay Word).

4. Calculate the Z2DG time delay using the difference between the 67N2 element pickup in the first event report and the TRIP (and Z2GT bit) assertion in the second event report.

5. The Z3DG timer can be tested with the same method using the Zone 3 AG fault in Table 7.14.

Z2DP AND Z3DP TIMER TESTS

Purpose: Verify the Z2DP and Z3DP timer accuracy.

Method:

1. Program the Z2P bit in the Relay Word into one of the available outputs (A1 - A4) to start an external timer. Set the Z2SP timer setting equal to zero to remove the delay introduced by this timer on the instantaneous pickup of the Z2P element.

2. Program the Z2PT bit into a different programmable output to stop the timer.

3. Apply the Zone 2 BC fault shown in Table 7.15 for a duration which exceeds the Z2PT setting.

Table 7.15: Standard Zone 2 BC Fault Using Factory Relay Settings

2BC Fault

VA	VB	VC	IA	IB	IC	
67.00	57.69	57.69	0.00	7.06	7.06	Volts/Amps
0.0°	-125.5°	125.5°	0.0°	-173.7°	6.3°	Degrees

4. Repeat steps 1 to 3, substituting 67N3 for 67N2 and Z3GT for Z2GT using the fault in Table 7.16.

Table 7.16: Standard Reverse Zone 3 BC Fault Using Factory Relay Settings

3BC Fault:

VA	VB	VC	IA	IB	IC	
67.00	57.69	57.69	0.00	7.06	7.06	Volts/Amps
0.0°	-125.5°	125.5°	0.0°	6.3°	-173.7°	Degrees

Note: If an external timer is not available, use event report time tags to calculate the Z2DP and Z3DP time delays with the following steps.

1. Mask only the Z2PT bit of the Relay Word into the MTU mask. Zero the MTO mask out so no other condition can assert the TRIP output.

2. Apply the Zone 2 BC fault as given in Table 7.15.

2. Apply the Zone 2 BC fault as given in Table 7.15.

3. For Z2DP settings exceeding approximately 6 cycles, the relay generates two event reports: one for the 21P2 element pickup, the other for the TRIP output assertion (and the Z2PT bit of the Relay Word).

4. Calculate the Z2DP time delay using the difference from the 21P2 element pickup in the first event report to TRIP (and Z2PT bit) assertion in the second event report.

5. The Z3DP timer can be tested with the same method using the Zone 3 BC fault in Table 7.16.

SWITCH-ONTO-FAULT TESTS

Purpose:

1. Verify 52BT timer accuracy and MTO (Switch-Onto-Fault) Logic Mask.

2. Verify that elements enabled to trip via the MTO logic mask are only enabled when the breaker is open for a duration exceeding the 52BT setting (52BT bit in Relay Word is asserted).

Method:

1. Program one of the available output contacts (A1 - A4) to follow the 52BT bit in the Relay Word.

2. Use the 52A contact input deassertion (control voltage on to off) to start an external timer.

3. Use the 52BT programmed contact output assertion (open to close) to stop the timer.

4. Compare the timer value to the 52BT setting.

5. To make sure the elements in the MTO logic mask are only enabled when 52BT = 1, apply a fault to pick up an element masked into the MTO logic mask but not the MTU mask.

6. Table 7.17 contains pre-fault and fault voltage and current quantities for a Zone 2 AG fault.

Table 7.17: Zone 2 AG Fault Quantities

Pre-fault:

VA	VB	VC	IA	IB	IC	
67.00	67.00	67.00	0.00	0.00	0.00	Volts/Amps
0.0°	-120.0°	120.0°	0.0°	0.0°	0.0°	Degrees

2AG Fault:

VA	VB	VC	IA	IB	IC	
54.24	69.60	69.89	4.83	0.00	0.00	Volts/Amps
0.0°	-123.8°	123.6°	-82.4°	0.0°	0.0°	Degrees

7. Apply the Zone 2 AG fault with the breaker closed (52A = 1 and 52BT = 0). The relay should not trip.

8. Open the breaker to deassert the 52A input which asserts the 52BT bit in the Relay Word. Use the TARGET 4 command to verify that 52BT is set.

9. Apply the same Zone 2 AG fault and verify that the relay trips instantaneously when the Z2AG element asserts.

RECLOSER TEST

Purpose: Verify that the reclosing relay functions properly.

Note: This test should be performed using a breaker simulator to simulate the action of the breaker 52A auxiliary contacts. A simple latching relay works well as a breaker simulator.

Method:

1. Program the MRI (Mask for Reclose Initiate) with the 67N1 bit in the Relay Word. Make certain this same bit is not masked into the MRC (Mask for Reclose Cancel).

2. Program the MTU (Mask for Unconditional Trip) with the 67N1 bit also.

3. Apply a Zone 1 AG fault as shown in Table 7.18. Make certain the 52A input is energized for 79RS cycles prior to applying the fault. The TRIP output contact closure should result in the circuit breaker simulator de-energizing the 52A input and removal of current inputs to the relay.

Table 7.18: 1AG Fault

Pre-fault:

VA	VB	VC	IA	IB	IC
52.89	70.12	70.06	0.00	0.00	0.00
0.0°	-124.0°	124.0°	0.0°	0.0°	0.0°

1AG Fault

VA	VB	VC	IA	IB	IC
52.89	70.12	70.06	5.11	0.00	0.00
0.0°	-124.0°	124.0°	-80.0°	0.0°	0.0°

4. Immediately following the closure of the TRIP outputs, remove the A Phase fault current. This allows the first open interval timer (790I1) to time out. Record the duration between opening of the TRIP output contacts or 52A input deassertion (whichever occurs later) and CLOSE output contact closure.

5. Record this time and compare against 790I1 setting.

INPUT CIRCUITS TEST

Purpose: Verify that logic inputs assert when control voltage is applied across the respective terminal pair.

Method:

1. Set target LEDs to display the contact inputs by typing TAR 5 <ENTER>. The front panel LEDs should now follow the contact inputs.

2. Apply control voltage to each input and make sure the corresponding target LED turns on. Energizing the DT and ET inputs should trigger an event report. Table 7.19 lists the contact inputs.

Table 7.19: Contact Inputs

Direct Trip	(DT)
Permissive Trip	(PT)
Block Trip	(BT)
Direct Close	(DC)
52A	
External Trigger	(ET)

SERIAL PORTS TEST

Purpose: Verify operation of serial PORT 1.

Method: The initial checkout procedure assumes you connected a terminal to PORT 2. Set the baud rate of PORT 1 to match that of PORT 2 and switch your terminal from PORT 2 to PORT 1. Be sure you can communicate through this port. If the relay is an SEL-221G, be sure you can communicate through PORT 2 on the front and rear panels. If the relay is an SEL-221G, be sure you can communicate through PORT 2 on the front and rear panels.

IRIG-B TIME CODE INPUT TEST

Purpose: Verify operation of the IRIG-B clock input port.

Method:

1. Connect a source of demodulated IRIG-B time code to the relay Auxiliary Port in series with a resistor to monitor the current. Adjust the source to obtain an "ON" current of about 10 mA.
2. Execute the IRIG command. Make sure the relay clock displays the correct date and time.

Note: A recording of the IRIG-B signal passed through a simple demodulator provides a convenient, inexpensive test of the IRIG-B port. Please contact the factory for further details.

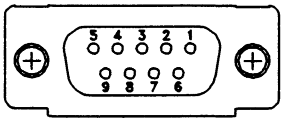
POWER SUPPLY VOLTAGES TEST

Purpose: Verify that correct output voltages are presented to PORT 1, PORT 2, and the auxiliary port. These voltages are required by external devices including a dc powered modem or the SEL-DTA unit.

Method:

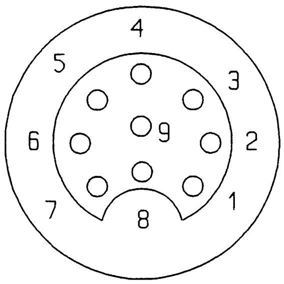
1. Execute the STATUS command and inspect the voltage readings for the +5 and ±15 volt supplies.
2. At the Auxiliary Port, use a voltmeter to read the +5 and ±12 volt outputs. The 12 volt outputs are derived from the 15 volt supplies using three-terminal regulators. The following pins are the read points:

SEL-221G	SEL-121G
Pin 1: +5 Vdc	Pin 6: +5 Vdc
Pin 4: +12 Vdc	Pin 7: +12 Vdc
Pin 6: -12 Vdc	Pin 8: -12 Vdc



(female chassis connector, as viewed from outside panel)

Figure 7.13: SEL-221G Relay 9-Pin Connector Pin Number Convention



(female chassis connector, as viewed from outside panel)

Figure 7.14: SEL-121G Relay 9-Pin Connector Pin Number Convention

3. Compare the +5 volt readings from the status report and voltmeter. The voltage difference should be less than 50 mV, and both readings should be within 0.15 volts of five volts.

   The 12 volt supplies should be within 0.5 volts of their nominal values.

RELAY CALIBRATION

Each SEL relay is factory calibrated. If you suspect that the relay if out of calibration, please contact the factory.

TROUBLESHOOTING

Inspection Procedure

Complete the following procedure before disturbing the system. After you finish the inspection, proceed to the Troubleshooting Table.

1. Measure and record control power voltage at the power input terminals.

2. Check to see that the power is on, but do not turn system off if it is on.

3. Measure and record the voltage at all control inputs.

4. Measure and record the state of all output relays.

5. Inspect the cabling to the serial communications ports and be sure a communications device is connected to at least one communications port.

Troubleshooting Table

All Front Panel LEDs Dark

1. Power is off.

2. Blown fuse.

3. Input power not present.

4. Self-test failure.

5. Target command improperly set.

   Note: For 1, 2, 3, and 4 the ALARM relay contacts should be closed.

System Does Not Respond to Commands

1. Communications device not connected to system.

2. Relay or communications device at incorrect baud rate or other communication parameter incompatibility, including cabling error.

3. Internal ribbon cable connector loose or disconnected.

4. System is processing event record. Wait several seconds.

5. System is attempting to transmit information, but cannot due to handshake line conflict. Check communications cabling.

6. System is in the XOFF state, halting communications. Type <CTRL>Q to put system in XON state.

Tripping Output Relay Remains Closed Following Fault

1. Auxiliary contact inputs improperly wired.

2. Output relay contacts burned closed.

3. Interface board failure.

No Prompting Message Issued to Terminal upon Power-Up

1. Terminal not connected to system.

2. Wrong baud rate.

3. Terminal improperly connected to system.

4. Other port designated AUTO in the relay settings.

5. Port timeout interval set to a value other than zero.

6. Main board or interface board failure.

System Does Not Respond to Faults

1. Relay improperly set. Review your settings with the SHOWSET command.

2. Improper test settings.

3. PT or CT input cable wiring error.

4. Analog input cable between transformer-termination and main board loose or defective.

5. Check self-test status with STATUS command.

6. Check input voltages and currents with METER command and TRIGGER and EVENT sequence.

Terminal Displays Meaningless Characters

1. Baud rate set incorrectly. Check terminal configuration. See Section 3: COMMUNICATIONS.

Self-test Failure: +5 Volts

1. Power supply +5 volt output out of tolerance. See STATUS command.

2. A/D converter failure.

Self-test Failure: +15 Volts

1. Power supply +15 volt output out of tolerance. See STATUS command.

2. A/D converter failure.

Self-test Failure: -15 Volts

1. Power supply -15 volt output out of tolerance. See STATUS command.

2. A/D converter failure.

Self-test Failure: Offset

1. Offset drift. Adjust offsets.

2. A/D converter drift.

3. Loose ribbon cable between transformers and main board.

Self-test Failure: ROM Checksum

1. EPROM failure. Replace EPROM(s).

Self-test Failure: RAM

1. Static RAM IC failure. Replace RAM(s).

Self-test Failure: A/D Converter

1. A/D converter failure.

2. RAM error not detected by RAM test.

Alarm Contact Closed

1. Power is off.

2. Blown fuse.

3. Power supply failure.

4. Improper EPROMs or EPROM failure.

5. Main board or interface board failure.

Firmware Upgrade Instructions, SEL-121G Relay

SEL may occasionally offer firmware upgrades to improve the performance of your relay. These instructions explain how to install new firmware.

The modifications require that you power down the relay, remove its front panel, pull out the drawout unit, exchange several integrated circuit chips, and reassemble the relay. If you do not wish to perform the modifications yourself, we can assist you. Simply return the relay and integrated circuit chips to us. We will install the new chips and return the unit to you within a few days.

Warning: This procedure requires that you handle electrostatic discharge sensitive components. If your facility is not equipped to work with these components, we recommend that you return the relay to SEL for firmware installation.

Upgrade Instructions

1. If the relay is in service, disable its control functions.

2. Turn off control power to the relay.

3. Remove the front panel by unscrewing the four front panel screws (one in each corner).

4. With the front panel leaning forward, you can see the aluminum drawout chassis. The main board is attached to the top of the drawout chassis. The power supply and interface board are attached to the bottom of the drawout chassis. Several ribbon cables connect the boards to each other and to other portions of the relay.

5. Disconnect the analog input ribbon cable (the right-most cable) from the main board.

6. The front panel display cable connects the relay interface board to the front panel display board. It is located on the left side of the front panel. Disconnect this cable from the display board.

7. Two hex head screws hold the drawout chassis in place. These screws are on the bottom of the chassis in each front corner. Remove both screws.

8. Remove the drawout assembly by pulling the spacers on the bottom of the drawout chassis. You should be able to remove the assembly with your fingers.

9. Because steps 10 through 12 involve handling electrostatic discharge (ESD) sensitive devices and assemblies, perform these steps at an ESD safe work station. This will help prevent possible damage by electrostatic discharge.

10. Note the orientation of the ICs to be replaced. Use a small screwdriver to pry the indicated ICs free from their sockets. Be careful not to bend the IC pins or damage adjacent components.

11. Carefully place the new ICs in the appropriate sockets.

12. Check the orientation of the ICs. Be sure that each IC is in its corresponding socket. Look for IC pins that are bent under or did not enter a socket hole.

13. Slide the drawout assembly back into the relay chassis. Using your fingers, push the assembly in until the retaining screw holes in the drawout assembly align with corresponding holes in the relay chassis.

14. Install the retaining screws and reconnect the two ribbon cables.

15. With breaker control disabled, turn relay power back on and enter your settings. Execute the STATUS, METER, and TRIGGER commands to ensure that all functions are operational. Set and record your Access Level 1 and 2 passwords and the date and time. The relay is now ready to resume protective functions.

16. Please return the old ICs to Schweitzer Engineering Laboratories, Inc. in the same packing materials. New chips are shipped with a mailing label to simplify this process. When we receive the old parts, we will record a firmware upgrade for each of your relays.

Firmware Upgrade Instructions, SEL-221G Relay

SEL may occasionally offer firmware upgrades to improve the performance of your relay. These instructions explain how to remove the relay drawout assembly to install new firmware.

The modifications require that you power down the relay, remove the relay front panel, pull out the drawout unit, exchange several integrated circuit chips, and reassemble the relay. If you do not wish to perform the modifications yourself, we can assist you. Simply return the relay and integrated circuit chips to us. We will install the new chips and return the unit to you within a few days.

Warning: This procedure requires that you handle electrostatic discharge sensitive components. If your facility is not equipped to work with these components, we recommend that you return the relay to SEL for firmware installation.

Upgrade Instructions

1. If the relay is in service, disable its control functions. Turn off control power to the relay. Short the relaying CT secondary inputs to the relay using appropriate shorting switches.

2. Remove the relay front panel by unscrewing the five front panel screws. With the front panel removed, you can see the aluminum drawout chassis. The main board is attached to the top of the drawout chassis. The power supply and transformer assembly are attached to the bottom of the relay chassis.

3. Disconnect the power supply and transformer secondary cables from the underside of the drawout assembly.

4. Remove the drawout assembly by pulling the spacers on the bottom of the drawout chassis. You should be able to remove the assembly with your fingers. Because steps 5 and 6 involve handling electrostatic discharge (ESD) sensitive devices and assemblies, perform these steps at an ESD safe work station. This will help prevent possible damage by electrostatic discharge.

5. Note the orientation of the ICs to be replaced. Use a small screwdriver to pry the indicated ICs free from their sockets. Be careful not to bend the IC pins or damage adjacent components.

6. Carefully place the new ICs in the appropriate sockets. Check the orientation of the ICs. Be sure that each IC is in its corresponding socket. Look for IC pins that are bent under or did not enter a socket hole.

7. Slide the drawout assembly into the relay chassis. Using your fingers, push the assembly in until the front of the assembly is flush with the front of the relay chassis. Reconnect the power supply and transformer secondary cables to the receivers on the underside of the drawout assembly. Replace the relay front panel.

8. With breaker control disabled, turn relay power on and enter your settings. Execute the STATUS, METER, and TRIGGER commands to ensure that all functions are operational. Set and record your Access Level 1 and 2 passwords and the date and time. The relay is now ready to resume protective functions.

Factory Assistance

If you have any questions regarding the performance, application, or repair of this or any other SEL product, do not hesitate to contact the factory. Our staff is happy to assist you.

Schweitzer Engineering Laboratories, Inc.
2350 NE Hopkins Court
Pullman, WA 99163-5603
Tel: (509)332-1890
FAX: (509)332-7990

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APPENDIX A - FIRMWARE VERSIONS

This manual covers SEL relays that contain firmware bearing the following part numbers and revision numbers:

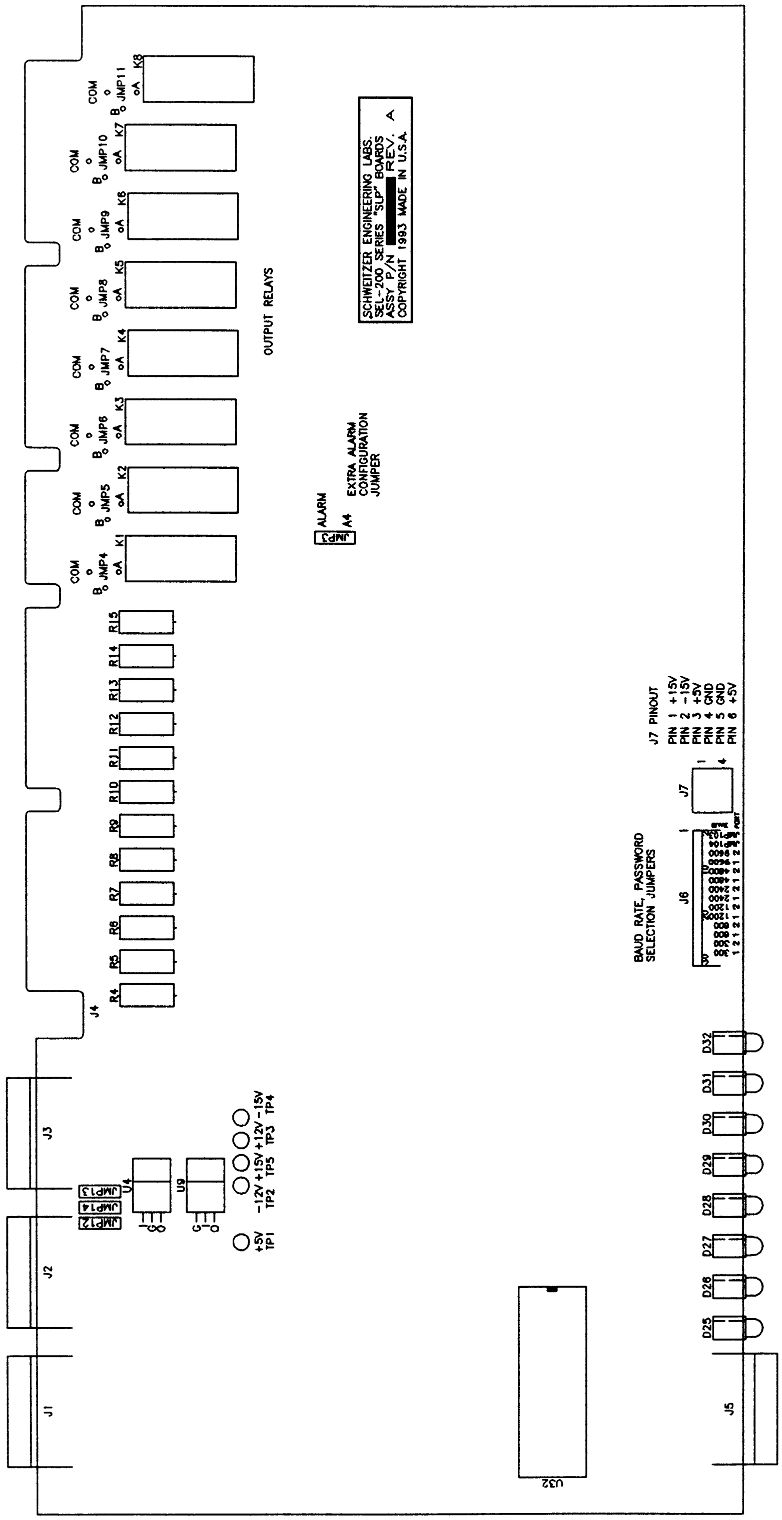
Firmware Part/Revision No.	Description of Firmware
	This firmware differs from previous versions as follows: – ACB Fast Meter type addition – Fast Meter time drift correction
SEL-121G6-R406 SEL-121G7-R601	No OOSB, Zone 4 always reverse No OOSB, Zone 4 always reverse, Trip duration tddo only
SEL-121G6-R405 SEL-121G7-R600	No OOSB, Zone 4 always reverse No OOSB, Zone 4 always reverse, Trip duration tddo only
SEL-121G6-R404	No OOSB, Zone 4 always reverse
SEL-121G6-R403	No OOSB, Zone 4 always reverse
SEL-121G6-R402	No OOSB, Zone 4 always reverse
SEL-121G6-R401	No OOSB, Zone 4 always reverse
SEL-121G6-R400	No OOSB, Zone 4 always reverse

To find the firmware revision number in your relay, obtain an event report (which identifies the firmware) using the EVENT command. This is an FID number with the Part/Revision number in bold:

FID=**SEL-121G6-R405**-V656mptr12syzrs2-D940301-E2

For a detailed explanation of the Firmware Identification Number (FID) refer to Section 4: EVENT REPORTING.

APPENDIX B - PARTS PLACEMENT DIAGRAM



1099–z01

Figure B.1: SEL-200 Series Main Board Troubleshooting Test Points and Jumper Locations

APPENDIX C - ONEBUS: PROGRAM TO COMPUTE TEST SET SETTINGS FOR TESTING DISTANCE RELAYS

The BASIC program in this note determines voltages and currents which would appear on distance relay terminals for ground and phase faults on a radial system with source impedance at the same angle as line impedance. It is useful in determining test voltage and current settings for SEL distance relays and fault locating equipment.

The program was initially designed to run on a TRS-80 Model 100 briefcase computer but may be installed on virtually any personal computer or laptop.

The program first prompts you for the positive- and zero-sequence impedances of the transmission line. Enter the data in secondary ohms for the entire length of the protected line.

Next, you may enter fault resistance, which is used in the ground-fault computations.

Enter source impedance as a per-unit value with a base of the previously-entered transmission line data. For example, if the radial system has a source impedance of about ten percent of the entered line impedance, enter 0.1 for the per-unit distance from the source to the bus.

Specify the distance from the bus to the fault as a fraction of the total line length. To obtain the voltages and currents for a fault one-half the way down the line from the bus, enter 0.5 for the distance from the bus to the fault.

After you enter this data, the program begins computations. The display then shows voltages and currents for both an AG and BC fault. These data can be entered into any active test source.

The bottom line of the display offers you a choice of entering new impedance data (I), changing the distance from the source to the bus (B), specifying a new fault location (F), or quitting (Q).

```
1       REM SCHWEITZER ENGINEERING
LABORATORIES, INC.
2       REM 2350 NE Hopkins Court
3       REM Pullman, WA  99163-5603
4       REM
10      REM COMPUTE DOBLE SETTINGS FOR A ONE-
BUS SYSTEM
20      REM HOMOGENEOUS SYSTEM
30      REM SOURCE VOLTS= 67 L-N
40      REM
50      REM ENTER IMPEDANCES FOR 100% OF LINE
60      INPUT "ENTER Z1: R,X";R1,S1
70      INPUT "ENTER Z0: R,X";R0,S0
75      INPUT "ENTER RF FOR GND FLTS";RF
80      REM
90      REM ENTER BUS LOC. FROM SOURCE
100     INPUT "DIST SOURCE TO BUS (PU OF
LINE)";S
120     INPUT "DIST BUS TO FAULT (PU OF
LINE)";F
130     REM
140     REM  PHASE A TO GROUND
150     REM COMPUTE POS SEQ CURRENT
160     X = R0+2*R1: Y = S0+2*S1
170     R3 = R1-R0:   S3 = S1-S0
180     AR=1/(S+F):  AI=0
190     BR=X      :  BI=Y
195     BR=BR+3*RF/(S+F)
200     GOSUB 2000
210     I = RR    :   J = RI
220     IA = 3*67*I:  JA=3*67*J
225     IB=0:JB=0:IC=0:JC=0
230     AR=X:AI=Y:BR=I:BI=J
232     GOSUB 1000
234     UA=67*(1-S*RR):VA=67*(-S*RI)
240     AR=R3      :AI=S3
250     BR=I       :BI=J
260     GOSUB 1000
270     TR=S*RR    :TS=S*RI
280     UB=67*(-0.5+TR)
290     VB=67*(-SQR(3)/2+TS)
300     UC=67*(-0.5+TR)
310     VC=67*(SQR(3)/2+TS)
315     FF$="A-G"
320     GOSUB 4041
500     REM  B-C FAULT
510     AR=1: AI=0
520     BR=2*R1*(S+F):BI=2*S1*(S+F)
530     GOSUB 2000
540     I=RR:J=RI
550     IA=0:JA=0
560     AR=I:AI=J:BR=0:BI=-67*SQR(3)
570     GOSUB 1000
580     IB=RR:JB=RI:IC=-IB:JC=-JB
590     UA=67:VA=0
600     AR=I:AI=J:BR=S*RI:BI=S*S1
610     GOSUB 1000
620     AR=RR:AI=RI:BR=0:BI=SQR(3)
630     GOSUB 1000
635     TR=RR:TS=RI
640     UB=67*(-0.5+TR)
650     VB=67*(-SQR(3)/2+TS)
660     UC=67*(-0.5-TR)
670     VC=67*(0.5*SQR(3)-TS)
675     FF$="B-C"
680     GOSUB 4041
900     INPUT "IMP BUS FAULT OR QUIT
(I,B,F,Q)";A$
910     IF A$ = "I" THEN GOTO 50
920     IF A$ = "B" THEN GOTO  75
930     IF A$ = "F" THEN GOTO 120 ELSE GOTO
999
999     END
1000    REM MULT SUBROUTINE
1010    REM AR,AI * BR,BI = RR,RI
1020    RR=AR*BR-AI*BI
1030    RI=AI*BR+AR*BI
1040    RETURN
2000    REM DIVISION SUBROUTINE
2010    REM AR,AI / BR,BI = RR,RI
2020    D = BR*BR + BI*BI
2030    RR = AR*BR + AI*BI
2040    RR = RR/D
2050    RI = BR*AI - AR*BI
2060    RI = RI/D
2070    RETURN
3000    REM RECT TO POLAR CONV
3010    REM AR,AI, TO RH, TH
3020    PI = 3.14159265358
3030    IF (AR=0 AND AI=0) THEN    RH=0: TH=0:
RETURN
3040    IF (AR=0 AND AI>0) THEN    RH=AI:
TH=90:RETURN
3050    IF (AR=0 AND AI<0) THEN RH=-AI: TH=-
90: RETURN
3060    IF (AR>0) THEN TH=(180/PI)*ATN(AI/AR)
3070    IF (AR<0) THEN
TH=(180/PI)*ATN(AI/AR)+180
3080    IF TH>180 THEN TH = TH-360
3090    RH=SQR(AR*AR+AI*AI)
3100    RETURN
4041    AR=UA:AI=VA:GOSUB 3000
4042    UA=RH:VA=TH
4043    AR=UB:AI=VB:GOSUB 3000
4044    UB=RH:VB=TH-VA
4045    AR=UC:AI=VC:GOSUB 3000
4046    UC=RH:VC=TH-VA
4047    AR=IA:AI=JA:GOSUB 3000
4048    IA=RH:JA=TH-VA
4049    AR=IB:AI=JB:GOSUB 3000
4050    IB=RH:JB=TH-VA
4055    AR=IC:AI=JC:GOSUB 3000
4060    IC=RH:JC=TH-VA
4061    VA=0
4100    PRINT " VA    VB    VC    IA    IB    IC"
4130    PRINT USING"##.# ";UA;UB;UC;IA;IB;IC,
4132    PRINT FF$
4140    PRINT USING"#### ";VA;VB;VC;JA;JB;JC
4150    RETURN
```

SEL-221G/121G RELAY COMMAND SUMMARY

Access Level 0

ACCESS — Answer password prompt (if password protection is enabled) to enter Access Level 1. Three unsuccessful attempts pulse ALARM contacts closed for one second.

Access Level 1

2ACCESS — Answer password prompt (if password protection is enabled) to enter Access Level 2. This command always pulses the ALARM contacts closed for one second.

DATE m/d/y — Shows or set date. DAT 2/3/91 sets date to Feb. 3, 1991. IRIG-B time code input overrides existing month and day settings. DATE pulses ALARM contacts when year entered differs from year stored.

EVENT — Shows event record. EVE 1 shows newest event; EVE 12 shows oldest.

HISTORY — Shows DATE, TIME, TYPE, DIST (distance), DUR (duration), and CURR (maximum fault current) for the last twelve events.

IRIG — Forces immediate attempt to synchronize internal relay clock to time code input.

METER n — Displays primary phase-to-neutral and phase-to-phase voltages and currents and real and reactive power. Option n displays meter data n times.

QUIT — Returns control to Access Level 0; returns target display to Relay Targets.

SHOWSET — Displays settings without affecting them.

STATUS — Shows self-test status.

TARGET n k — Shows data and sets target LEDs as follows:

TAR 0: Relay Targets	TAR 1: Relay Word row #1
TAR 2: Relay Word row #2	TAR 3: Relay Word row #3
TAR 4: Relay Word row #4	TAR 5: Contact Input States
TAR 6: Contact Output States	TAR R: Clears Targets and returns to TAR 0

Option k displays target data k times.

TIME h/m/s — Shows or sets time. TIM 13/32/00 sets clock to 1:32:00 PM. IRIG-B synchronization overrides this setting.

TRIGGER — Triggers and saves an event record (event type is EXT).

Access Level 2

CLOSE — Closes circuit breaker, if allowed by jumper setting.

LOGIC n — Shows or sets logic masks MTU, MPT, MTB, MTO, MA1-MA4, MRI, and MRC. Command pulses ALARM contacts closed for one second and clears event buffers when new settings are stored.

OPEN — Opens circuit breaker, if allowed by jumper setting. TDUR=0 also disables the OPEN command.

PASSWORD — Shows or sets passwords. Command pulses ALARM contacts closed momentarily after password entry. PAS 1 OTTER sets Level 1 password to OTTER. PAS 2 TAIL sets Level 2 password to TAIL.

SET n — Initiates set procedure. Optional n directs relay to begin setting procedure at that setting. SET TDUR initiates setting procedure at TDUR setting. SET initiates setting procedure at beginning. Command pulses ALARM contacts closed and clears event buffers when new settings are stored.

SEL-221G/121G RELAY COMMAND SUMMARY

Access Level 0

ACCESS	Answer password prompt (if password protection is enabled) to enter Access Level 1. Three unsuccessful attempts pulse ALARM contacts closed for one second.

Access Level 1

2ACCESS	Answer password prompt (if password protection is enabled) to enter Access Level 2. This command always pulses the ALARM contacts closed for one second.
DATE m/d/y	Shows or set date. DAT 2/3/91 sets date to Feb. 3, 1991. IRIG-B time code input overrides existing month and day settings. DATE pulses ALARM contacts when year entered differs from year stored.
EVENT	Shows event record. EVE 1 shows newest event; EVE 12 shows oldest.
HISTORY	Shows DATE, TIME, TYPE, DIST (distance), DUR (duration), and CURR (maximum fault current) for the last twelve events.
IRIG	Forces immediate attempt to synchronize internal relay clock to time code input.
METER n	Displays primary phase-to-neutral and phase-to-phase voltages and currents and real and reactive power. Option n displays meter data n times.
QUIT	Returns control to Access Level 0; returns target display to Relay Targets.
SHOWSET	Displays settings without affecting them.
STATUS	Shows self-test status.
TARGET n k	Shows data and sets target LEDs as follows: TAR 0: Relay Targets — TAR 1: Relay Word row #1 TAR 2: Relay Word row #2 — TAR 3: Relay Word row #3 TAR 4: Relay Word row #4 — TAR 5: Contact Input States TAR 6: Contact Output States — TAR R: Clears Targets and returns to TAR 0 Option k displays target data k times.
TIME h/m/s	Shows or sets time. TIM 13/32/00 sets clock to 1:32:00 PM. IRIG-B synchronization overrides this setting.
TRIGGER	Triggers and saves an event record (event type is EXT).

Access Level 2

CLOSE	Closes circuit breaker, if allowed by jumper setting.
LOGIC n	Shows or sets logic masks MTU, MPT, MTB, MTO, MA1-MA4, MRI, and MRC. Command pulses ALARM contacts closed for one second and clears event buffers when new settings are stored.
OPEN	Opens circuit breaker, if allowed by jumper setting. TDUR=0 also disables the OPEN command.
PASSWORD	Shows or sets passwords. Command pulses ALARM contacts closed momentarily after password entry. PAS 1 OTTER sets Level 1 password to OTTER. PAS 2 TAIL sets Level 2 password to TAIL.
SET n	Initiates set procedure. Optional n directs relay to begin setting procedure at that setting. SET TDUR initiates setting procedure at TDUR setting. SET initiates setting procedure at beginning. Command pulses ALARM contacts closed and clears event buffers when new settings are stored.