SEL-221H
SEL-121H

Phase Distance Relay
Ground Directional
Overcurrent Relay
Fault Locator

Instruction Manual

19970304

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.

PM121H-01

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.

SEL-121H INSTRUCTION MANUAL ADDENDUM

KILOMETER OPTION

The SEL-121H relay instruction manual is written for fault locations in terms of miles. If your SEL-121H 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 60Hz. 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.

SEL RELAY INSTRUCTION MANUAL ADDENDUM

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 or ACB rotation.

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

SECTION 1: SEL-100 SERIES ADDENDUM

The SEL-100 series relay logic inputs have been improved to prevent operation of the logic input due to the conditions described in SELUPDATE 94.10. If you would like a copy of SELUPDATE 94.10, please contact the SEL factory.

The new interface board also provides field selectable input voltage selection. The operating voltages and jumper selection for each logic input are shown in the table below.

Control Voltage	Relay Terminals											
	39/40		41/42		43/44		45/46		47/48		49/50	
	JMP11	JMP12	JMP9	JMP10	JMP7	JMP8	JMP5	JMP6	JMP3	JMP4	JMP1	JMP2
250 V												
125 V		•—•		•—•		•—•		•—•		•—•		•—•
48 V	•—•	•—•	•—•	•—•	•—•	•—•	•—•	•—•	•—•	•—•	•—•	•—•

CONTROL INPUT OPERATING RANGES

Control Voltage	Operating Range
250 Vdc	150 - 300 Vdc
125 Vdc	80 - 150 Vdc
48 Vdc	30 - 60 Vdc

Changing the input voltage jumpers requires that you disassemble the relay. The following information describes the procedure for changing the input voltage selection jumpers:

1. Remove power from relay.
2. Place relay in a static-safe work area.
3. Remove top and bottom chassis covers (eight screws total).
4. Remove the four screws securing the front panel.
5. Carefully allow the top edge of the front panel to come forward and down (exposing relay main board/power supply/interface tray assembly).
6. From the bottom of the relay, locate and remove the two 4-40 hex jack screws that secure the tray assembly to the chassis. These jack screws are located at the front corners of the draw-out tray and require a long 3/16-inch nut driver or extended socket.

7. Carefully remove the ribbon cable from the front panel LED display. The power switch/fuse assembly will remain attached to the relay and front panel.

8. Carefully remove the ribbon cable from the main board P104 connector.

9. Pull forward on the draw-out tray using the two standoffs located on the bottom of the tray. Removing the draw-out tray will require a good amount of force.

10. With the main board facing up, rotate the draw-out tray so that the back is facing you. The input jumpers are now exposed on the inside of the interface board (board below draw-out tray).

11. Make the correct jumper selection for the desired input voltages per the jumper selection table.

12. Turn board so that the main board is facing up and reinstall into relay chassis. Note guide hole alignment at the back of the draw-out tray and make sure interface pins located on the back plane board are aligned with the draw-out tray before "seating" the draw-out assembly. Inserting the draw-out tray will require a good amount of force.

13. Reattach ribbon cable to main board P104 connector.

14. Reattach ribbon cable to front panel LED assembly.

15. Replace the 4-40 hex jack screws (two only) so that the draw-out tray is secure.

16. Lift the edge of the front panel up into normal position and replace the four front panel screws. (Make sure switch/fuse cable and ribbon cables are free from any "pinch" points.)

17. Make sure power switch/fuse cable assembly is seated on the back panel connector. (During the normal removal process, it is possible to have partially or completely disconnected this cable.)

18. Carefully replace top and bottom chassis covers and screws (eight screws total).

TABLE OF CONTENTS

INTRODUCTION

SPECIFICATIONS

COMMUNICATIONS

EVENT REPORTING

APPLICATIONS

INSTALLATION

MAINTENANCE & TESTING

APPENDICES

TABLES

FIGURES

INTRODUCTION
TABLE OF CONTENTS

INTRODUCTION

GETTING STARTED

This instruction manual applies to SEL-121H and SEL-221H relays. The SEL-221H and SEL-121H relays have identical protection features, but use different hardware designs. Where there are differences between the two relay models, both relays are described.

If you are not familiar with this relay, we suggest that you read this introduction, then perform the Initial Checkout Procedure in Section 7: MAINTENANCE & TESTING.

OVERVIEW

The SEL-221H relay is designed to protect transmission, subtransmission, and distribution lines for all fault types. The following list outlines protective features, performance, and versatility gained when applying the SEL-221H relay to your installations.

- Special logic for permissive overreaching transfer trip schemes.
- Weak- and zero-infeed logic.
- 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.
- Fault locating.
- Metering.
- EIA RS-232-C communication ports for local and remote access.
- Automatic self testing.
- IRIG-B time code input.
- Target indicators for faults and testing.
- Compact and economical.

GENERAL DESCRIPTION

The SEL-221H Phase Distance Relay 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 its seven mho distance elements, seven overcurrent elements, directional element, eight timers, and data and control bits. The applications engineer can program the logic through bit combinations to control tripping, communication channel keying, and four general purpose programmable outputs.

Because of its many relay elements, large setting ranges, programmability, and low cost, the SEL-221H relay meets the requirements of a broad spectrum of applications. The flexible yet simple programmability provides access to relay elements (before and after time delays) and logic results, including Zone 3 reverse block, permissive overreach transfer trip keying, echo keying, loss-of-potential, alarm, and trip.

The SEL-221H relay is particularly well-suited for permissive overreaching transfer trip applications because it provides:

- Current reversal logic with coordinating timers
- Permissive trip signal echo logic with coordinating timers
- Weak- and zero-infeed logic for weak source terminal applications
- Dedicated programmable mask for the permissive signal qualifying elements

Without the need for an external initiating contact input, the SEL-221H relay provides time-stepped protection in parallel with the communication based scheme logic if the communication channel fails or is out-of-service. The SEL-221H relay also supports:

- Directional Comparison Unblocking (DCUB) schemes
- Permissive Underreaching Transfer Trip (PUTT) schemes
- Direct Underreaching Transfer Trip (DUTT) schemes
- Directional Comparison Blocking (DCB) 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 SEL-221H relay generates an eleven-cycle event report which contains information captured starting four cycles before the fault until seven cycles after fault detection. 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
- Status of the relay elements
- External inputs (breaker status, permissive trip, etc.)
- Relay contact outputs

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

The relay stores the last 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 SEL-221H 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 SEL-221H relay is compatible with the SEL-PRTU™ Protective Relay Terminal Unit, the SEL-DTA™ Display Transducer Adapter, and the SEL-PROFILE® Transmission Line Fault Analysis Program.

SPECIFICATIONS
TABLE OF CONTENTS

TABLES

FIGURES

SPECIFICATIONS

Section 2: SPECIFICATIONS 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 Contact Current Ratings	30 amp make per IEEE C37.90 para 6.7.2 6 amp carry continuously MOV protection provided
Optical Isolator Logic Input Ratings	24 Vdc: 10 - 30 Vdc 48 Vdc: 25 - 60 Vdc 125 Vdc: 60 - 200 Vdc 250 Vdc: 200 - 280 Vdc Current = 4 mA at nominal voltage
Power Supply Ratings	24/48 Volt: 20 - 60 Vdc; 12 watts 125/250 Volt: 85 - 280 Vdc or 85 - 200 Vac; 12 watts
Relay Dimensions	3.5" x 19" x 10.5" (8.89 cm x 48.2 cm x 26.7 cm) (H x W x D), SEL-221H 5.25" x 19" x 13" (13.3 cm x 48.2 cm x 33.0 cm) (H x W x D), SEL-121H
Mounting	Mounts in standard EIA 19" (48.2 cm) relay rack or panel cutout. Available in horizontal or vertical mounting configurations.
Operating Temperature	-40° F to 158° F (-40° C to 70° C)
Dielectric Strength Routine Tested	V, I inputs: 2500 Vac for 10 seconds Other: 3000 Vdc for 10 seconds (excludes EIA RS-232-C)
Interference Tests	IEEE C37.90 SWC test (type tested) IEC 255-6 interference test (type tested)

Impulse Tests	IEC 255-5 0.5 joule 5000 volt test (type tested)
RFI Tests	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.
Electrostatic Discharge Tests	IEC 801-2 (type tested)
Unit Weight	16 pounds (7.3 kg), SEL-221H 21 pounds (9.1 kg), SEL-121H
Shipping Weight	26 pounds (11.8 kg) including two instruction manuals, SEL-221H 32 pounds (14.5 kg), including two instruction manuals, SEL-121H
Burn-in Temperature	140°F (60°C) for 100 hours.
Environmental Tested	IEC 68-2-30 (type tested)

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 switch-onto-fault tripping
  - Zone 4 concentric to Zone 3 and includes the origin. Zone 3 reversible, but Zone 4 always remains forward.
- Zones 1, 2, and 3 three-phase distance elements memory polarized
  - Zone 4 does not require memory polarization due to its offset
- Independent timers for Zone 2 and 3 distance elements
- Fault detector elements supervise all distance elements
- Loss-of-potential logic supervises all distance elements
- Zone 3 reversible with a simple setting (all Zone 3 elements are reversed when ZONE3 = R in the relay settings)
- Zone 3 must be reversed when weak-infeed conditional is enabled, or when current reversal logic is desired.

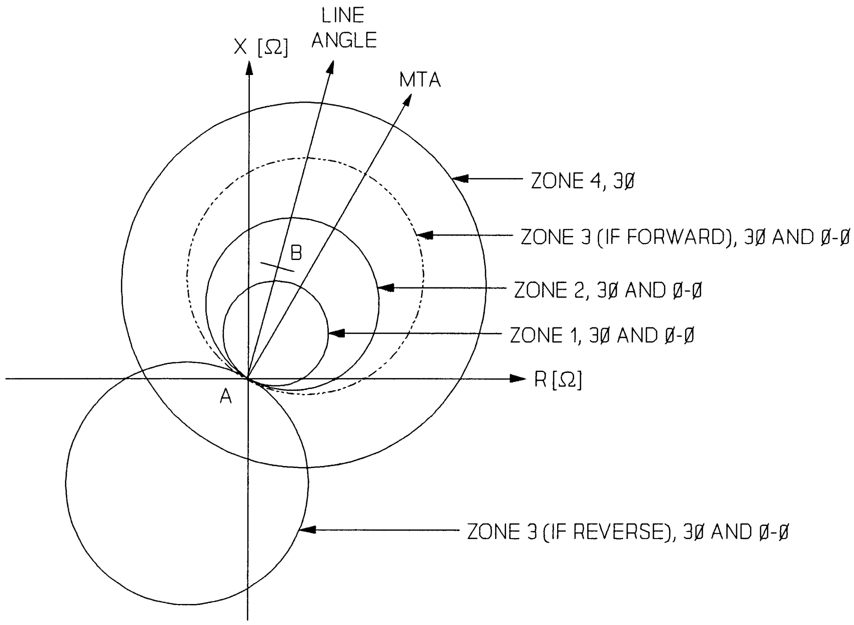


Figure 2.1: Phase-Phase and Three-Phase Mho Element Characteristics

Residual Overcurrent Protection for Ground Faults

- Time-overcurrent element
  - Four families of curves (moderate, inverse, very inverse, and extremely inverse)
  - Directional or nondirectional as enabled in relay settings
- Three residual overcurrent elements
  - Independent timers for Zone 2 and 3 elements
  - Zone 3 reversible with a simple setting
  - Zone 3 must be reversed when weak-infeed conditional is enabled or current reversal logic is desired.
- 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

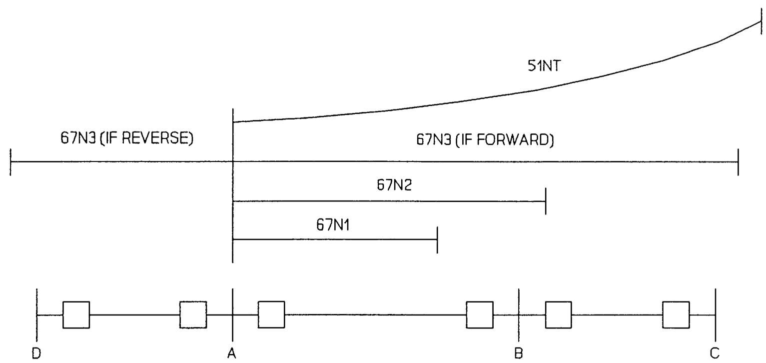


Figure 2.2: Residual Overcurrent Zones of Protection

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

- Low-set phase overcurrent elements supervise mho distance elements and release the TRIP output contacts
- Medium-set phase overcurrent element for loss-of-potential (LOP) logic and non-directional phase overcurrent protection during LOP conditions (or nondirectional 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
- Independent of communications channel equipment

Open Breaker Echo Keying

- Echoes the received permissive trip signal to the remote terminal when the local line breaker is judged open by the 52A input to the relay
- Echo duration is settable
- Received permissive trip signal must be present for a settable time before echoing is permitted

Weak-Infeed Conditional Logic

- Conditions a received permissive trip signal to allow tripping of a weak-infeed terminal if no reverse elements are asserted and the breaker is closed (Echo-Conversion-To-Trip or ECTT)
- Phase-phase and residual voltage elements monitor line-line undervoltage and residual overvoltage magnitudes
- Zone 3 elements must be reversed when weak-infeed conditional is enabled

Current Reversal Logic

- Reverse phase distance, ground overcurrent elements, and breaker status serve as enables for the current reversal logic
- Settable current reversal timer (Z3RBT)
- Settable timer for breaker status to defeat current reversal logic (BZ3RB) during a line test

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 logical "AND" process. This process in turn controls the relay output contacts. Each TRIP and programmable output relay has a corresponding logic mask (see Programmable Logic Masks). These masks determine the state of the output relay, depending on which asserted elements in the Relay Word can close that output contact.

The Relay Word for the SEL-221H relay appears in Table 2.1.

Table 2.1: Relay Word

1ABC	2ABC	3ABC	4ABC	LOP	50H	50M	50L
51NT	67N1	67N2	67N3	51NP	Z1P	Z2P	Z3P
Z2PT	Z3PT	Z3RB	KEY	50MF	PTEE	ECTT	DF
ALRM	TRIP	TC	DT	52BT	WFC	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 form a or form b.

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 the 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 or External Trigger input contacts assert, or by execution of the TRIGGER or OPEN commands.

When tripping occurs after the end of the event report, the trip triggers a second report. For details on the contents and analysis of SEL-221H relay event reports, see Section 4: EVENT REPORTING.

Fault Location

The relay computes fault location from event report data stored for each fault or disturbance. The primary fault locating algorithm compensates for prefault current to improve fault locating accuracy for high-resistance faults. The relay uses two fault locating methods: the Takagi method where sound prefault data are available, or a simple reactance method when sound prefault 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 different zone and fault type occurs. When a new trip occurs, the targets clear and display the latest tripping target.

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

You may clear front panel targets locally by pressing the front panel TARGET RESET button or remotely with the TARGET RESET (TAR R) command. The TARGET RESET button also unlatches the 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 rear panel port 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 for a thorough description of the 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: 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:

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

Transient Overreach:

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

Operating Speed:

- See Figure 2.10 for operating time curves.

Memory Polarization

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

Distance Element Timers

Zone 2 timer (Z2DP) range: (0 - 2000 cycles in quarter-cycle steps)
Zone 3 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.

Overcurrent Elements

Nondirectional Phase Overcurrent Elements (Secondary Quantities)

- The 50 elements are nondirectional phase magnitude measuring elements.

  - 50AL, 50BL, 50CL (low-set phase fault detectors)
  - 50AM, 50BM, 50CM (medium-set phase fault detectors, used in loss-of-potential logic)

- Pickup: 0.5 to 40 A, ±0.1 A ±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 ±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)

Ground Overcurrent Element Timers

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

Note: The instantaneous and time delayed output from the residual overcurrent elements are separate in the Relay Word, permitting access to both.

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
- Enabled with 32QE setting in the relay setting procedure
- 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 the measured residual current and the 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, you must 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: 51NP is the pickup setting of the 51N element in secondary amps.

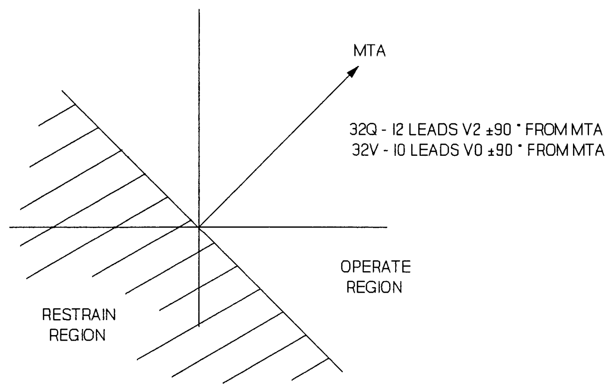


Figure 2.3: 32Q and 32V Polarization Criteria

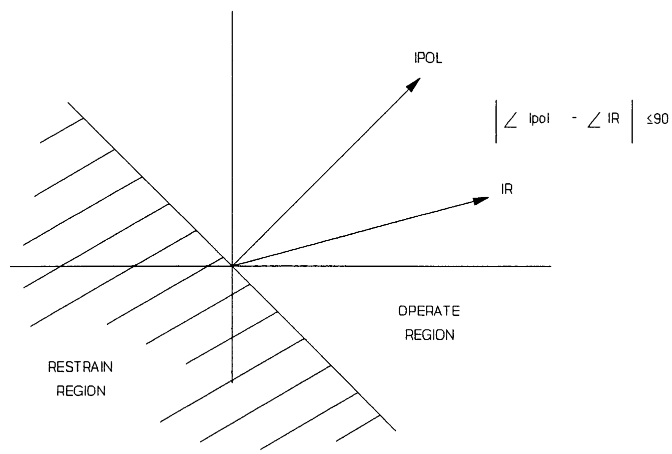


Figure 2.4: 32I Polarization Criteria

Please refer to the Functional Description portion of this section for equations to determine the 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

Voltage-Checking Elements (Weak-Infeed Conditional Logic)

- 27AB, 27BC, 27CA elements monitor the magnitude of phase-to-phase phasor difference voltage calculated from the phase-to-neutral voltages.
- 59N monitors the magnitude of the resultant voltage from the phasor addition of the voltages presented to the VA, VB, and VC inputs divided by three.
- Voltage setting ranges:
  - 27PP elements: 0 - 260 $V_{l\text{-}l}$ secondary, ±5%, ±1 V
  - 59N element: 0 - 150 $V_{l\text{-}n}$ secondary, ±5%, ±1 V

Miscellaneous Timers

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

• 50MFD	- Loss-of-potential enabled O/C, TDPU	: 0.0 - 60
• 52BT	- Switch-onto-fault timer, TDPU/TDDO	: 0.5 - 10,000
• ETDPU	- Echo time delay pickup timer, TDPU	: 0.0 - 8000
• EDUR	- Echo pulse duration timer	: 0.0 - 8000
• Z3RBT	- Zone 3 reverse block timer, TDDO	: 0.0 - 8000
• BZ3RB	- Block-the-reverse-block timer, TDDO (-1 disables this timer)	: -1.0 - 8000
• TDUR	- Trip duration timer	: 0.0 - 8000 (0.0 Disables OPEN Command)
• A1TP	- A1 output contact pickup timer, TDPU	: 0.0 - 8000
• A1TD	- A1 output contact dropout timer, TDDO	: 0.0 - 8000

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 is deasserted, dropping out about one-half cycle after DT deasserts. DT input assertion generates an event report. Applications include test trip and Direct Underreaching Transfer Trip (DUTT) schemes. 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 and the 52A input is not asserted. The CLOSE command has the same effect as the DC input. 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). This input does not trigger 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.

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 breaker is open. The closing functions, Switch-Onto-Fault, Echo, and Echo-Conversion-To-Trip (ECTT) logic use the status of this input. 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 form a or form b contacts.

All relay contacts are rated for circuit breaker tripping duty.

TRIP Output

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 open (MTO logic mask). The TRIP output never closes for less than the fault condition duration or the TRIP Duration timer interval. After this, it opens when the fault condition vanishes, as judged by the dropout of both the low-set phase (50L) and low-set residual overcurrent (50NL) elements.

CLOSE Output

This output closes for assertion of the DC input and in response to the CLOSE command. The CLOSE output remains closed until the 52A input asserts or the fixed 255 quarter-cycle timer (79RS) expires, whichever occurs first. The 79RS timer is decremented at the assertion of the CLOSE output relay. 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 attempt: 1 second pulse
- Self test failures: permanent contact closure or 1 second pulse depending on which test fails
- 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 the 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 overcurrent relays	50AL 50BL 50CL	(phase 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	(SOTF tripping)
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**	T.C. or nondirectional
Residual time-overcurrent trip	**51NT**	T.C. or nondirectional
Residual instantaneous 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	loss-of-potential detection
Zero-sequence overcurrent	50NL	loss-of-potential detection
Positive-sequence overvoltage	47P	loss-of-potential detection

Weak-Infeed Conditionals

Phase-phase undervoltage conditional	27PP
Residual overvoltage conditional	59N

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	Phase fault current supervision
3P50	= 50AL * 50BL * 50CL	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 * 3P50 * NOT (**LOP** * LOPE)	**4ABC** in Relay Word
Z3ABC	= 21ABC3 * 3P50 * NOT (**LOP** * LOPE)	**3ABC** in Relay Word
Z2ABC	= 21ABC2 * 3P50 * NOT (**LOP** * LOPE)	**2ABC** in Relay Word
Z1ABC	= 21ABC1 * 3P50 * NOT (**LOP** * LOPE)	**1ABC** in Relay Word
Z3P	= 21P3 * **50L** * NOT (**LOP** * LOPE)	
Z2P	= 21P2 * **50L** * NOT (**LOP** * LOPE)	
Z1P	= 21P1 * **50L** * NOT (**LOP** * LOPE)	
Z3PT	= (**Z3P** + Z3ABC) * Z3PD	Zone 3 timeout-phase
Z2PT	= (**Z2P** + Z2ABC) * Z2PD	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 + 32D * (32IE + 32VE)	Direction Reverse
D3	= **DF**	If Zone 3 is forward
D3	= DR	If Zone 3 is reverse
67N1	= 50N1 * **DF**	
67N2	= 50N2 * **DF**	
67N3	= 50N3 * D3	(Reversible)

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 will not operate when Zone 3 is reversed.

Z3GT	= **67N3** * Z3GD	Zone 3 timeout-ground
Z2GT	= **67N2** * Z2GD	Zone 2 timeout-ground

KEY and Echo-Conversion-To-Trip (ECTT) Logic

BZ3RB	= NOT(52A) * BZ3RBT	Instantaneous pickup and TDDO
Z3RB	= NOT(BZ3RB) * (**3ABC** + **Z3P** + **67N3**) * Z3RBT	Instantaneous pickup and TDDO
PTEE	= (PT * ETDPU) * NOT(EDUR)	TDPU, limited duration echo pulse
KEY	= (R * MPT) * NOT(**Z3RB**) + NOT(**Z3RB**) * **PTEE**	
WFC	= ((27AB + 27BC + 27CA) + 59N) * WFCE	Weak Feed Conditional
ECTT	= (NOT(**Z3RB**) * **PTEE**) * 52A * **WFC**	Echo Conversion To Trip

The logic diagram in Figure 2.5 illustrates the **KEY** and **ECTT** logic.

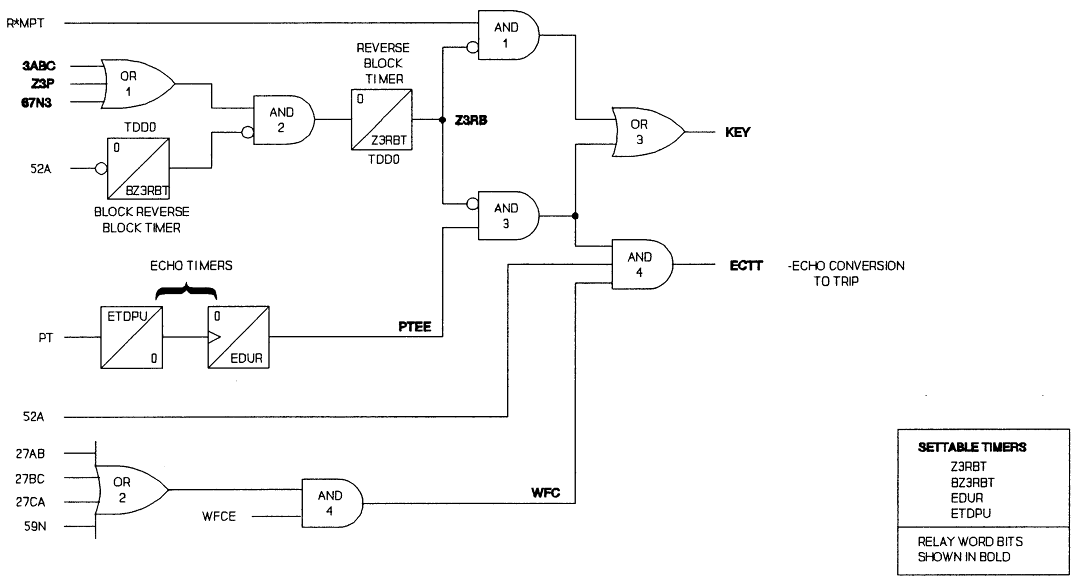


Figure 2.5: Key and ECTT Logic

Output Equations and Logic

The relay has programmable logic for controlling the **TRIP**, A1, A2, A3 and A4 output relays for flexibility and testing. 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 open)

Then:

TRIP =	R * MTU	(unconditional tripping)
	+ R * MPT * PT * NOT(**Z3RB**)	(permissive tripping with PT input asserted and no reverse block)
	+ R * MTB * NOT (BT)	(tripping with BT input deasserted)
	+ R * MTO * **52BT**	(breaker open/just closed tripping)

Close TRIP contact	=	**TRIP**
Open TRIP contact	=	NOT (**TRIP**) * [(NOT(**50L** + 50NL)) + TARGET RESET button pushed] * (trip duration timer expires)
Close CLOSE contact	=	(DC + CLOSE COMMAND) * NOT (52A) * NOT (**TRIP**)
Open CLOSE contact	=	NOT (CLOSE) + 63.75 cycle CLOSE reset timer

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 Intermediate Logic Description defines the 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	Z3RB	KEY	50MF	PTEE	ECTT	DF
ALRM	TRIP	TC	DT	52BT	WFC	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%)
3ABC	-	Zone 3 three-phase instantaneous element (set by Z3%)
4ABC	-	Zone 4 three-phase instantaneous element (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	-	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]
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%)
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)
Z3RB	-	Zone 3 reverse block timer output (TDDO time set by Z3RBT)
KEY	-	Communication channel keying bit (see KEY Logic)
50MF	-	Asserts a settable delay after LOP and 50M pickup (delay set by 50MFD)
PTEE	-	Permissive Trip Echo Enable (limited duration pulse set by echo timers, ETDPU and EDUR)
ECTT	-	Echo-Conversion-To-Trip
DF	-	Direction forward for ground faults
ALRM	-	System alarm
TRIP	-	Trip contact closure
TC	-	Trip (OPEN) Command
DT	-	Direct Trip (or other user defined external purposes)
52BT	-	Inverted time delayed 52A follower (delay set by 52BT setting)
WFC	-	Weak-infeed conditional (set by 27PP and 59N)
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. 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 (see LOGIC command). 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-221H relay is equipped with two EIA RS-232-C 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.

The baud rate of 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.

The SEL-121H relay does not include a front panel connector for PORT 2.

The serial data format is:

Eight data bits
Two stop bits
No parity

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

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 status 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. The offset levels of 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 deenergizes 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. While 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.

The following table 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, ∅1	:	For 67N1 + Z1P + Z1ABC + 50H + 50MF, but no 51NT
G2, ∅2	:	For 67N2 + Z2P + Z2ABC, but no Zone 1 or 51NT
G3, ∅3	:	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. All eight indicators illuminate for a one second lamp test. Afterward, the fault targets clear and the enable light shows that the relay is operational again. Pressing TARGET RESET also unlatches the TRIP output. This feature is useful during testing and reduces the possibility of relay installation while the TRIP output is asserted.

IRIG-B Input Description

The port labelled 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 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.

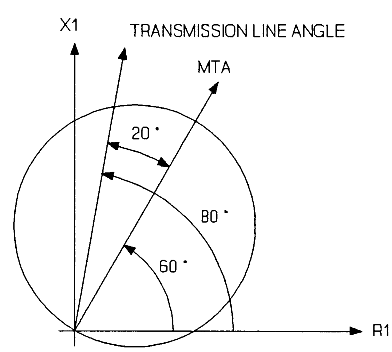


Figure 2.6: Mho Element Reach at Maximum Torque Angle

The 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 one-quarter to give a diameter of the offset circle which equals 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 the mho characteristics experience, the 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:

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

Where:

ZS $\equiv$ Positive-sequence source impedance behind the relay location
ZR $\equiv$ 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 2.7 and 2.8 illustrate this example and compares the expanded mho characteristic with the self-polarized mho characteristics.

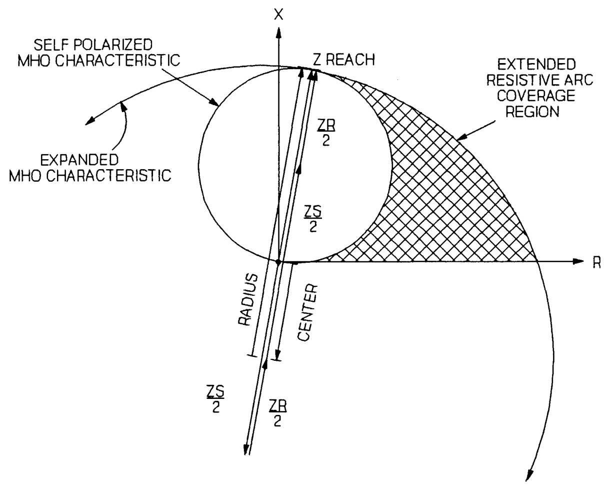


Figure 2.7: Expanded Two-Phase Mho Characteristics

Three-Phase Elements:

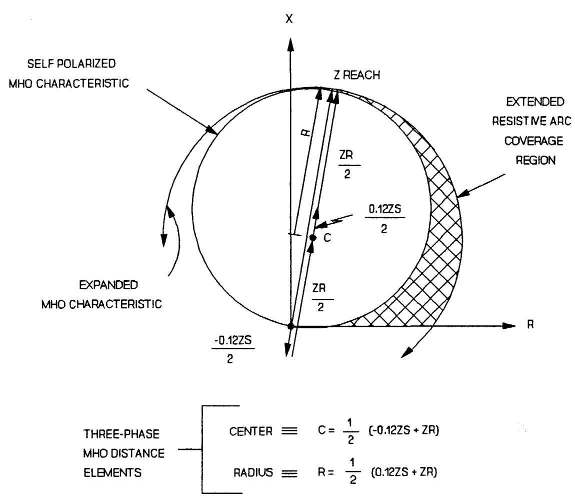


Figure 2.8: Expanded Three-Phase Mho Characteristics

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 the 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 50N3 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

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

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

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, 3, or 4
- 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)

(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 determines 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 prefault 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 by the "TRIGGER" command
or		
	"TRIP"	for reports triggered by the assertion of the "TRIP" output contact.

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 prefault 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 midfault currents and "If" values are midfault 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 prefault and fault data, it compensates for errors introduced by fault resistance in the presence of load flow. If the event record contains no sound prefault data, the relay gives 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. The 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 2 miles short for a fault at the far end of a 100 mile line.

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

Using series capacitor compensation, the relay sustains accurate performance for faults between itself and the capacitors, and beyond the capacitors if the capacitor protective gaps flash. If the gaps do not flash, measured impedance includes line and capacitance impedance, and errors can be substantial. This problem is aggravated by high speed clearing and the excitation of eigenmodes or resonances of the line capacitor system approaching 60 Hz. In cases where series capacitor gaps do not flash, you can recompute the fault location from the event report data using a voltage equal to the measured voltage minus the capacitor voltage drop. Compute the latter using the capacitance value and 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	Zone 4 pickup
Direct trip	51N pickup	External trigger	50H pickup
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 eleven 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. Direct close asserts the DIRECT CLOSE input and 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 for a summary report of 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 labelled 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. 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.

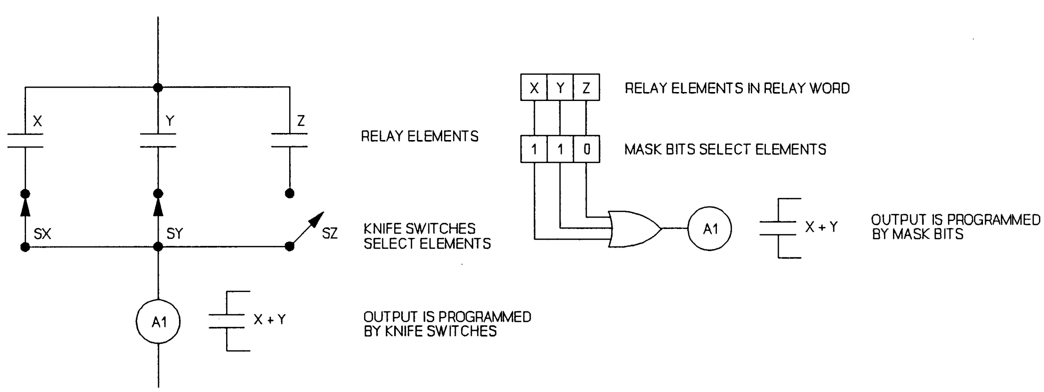


Figure 2.9: Programmable Logic Mask Analogy

RELAY ELEMENT OPERATING TIME CURVES

Figure 2.10 shows operating times for the SEL-221H 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 prefault 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 three-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 prefault load current was included. System frequency is 60 Hz.

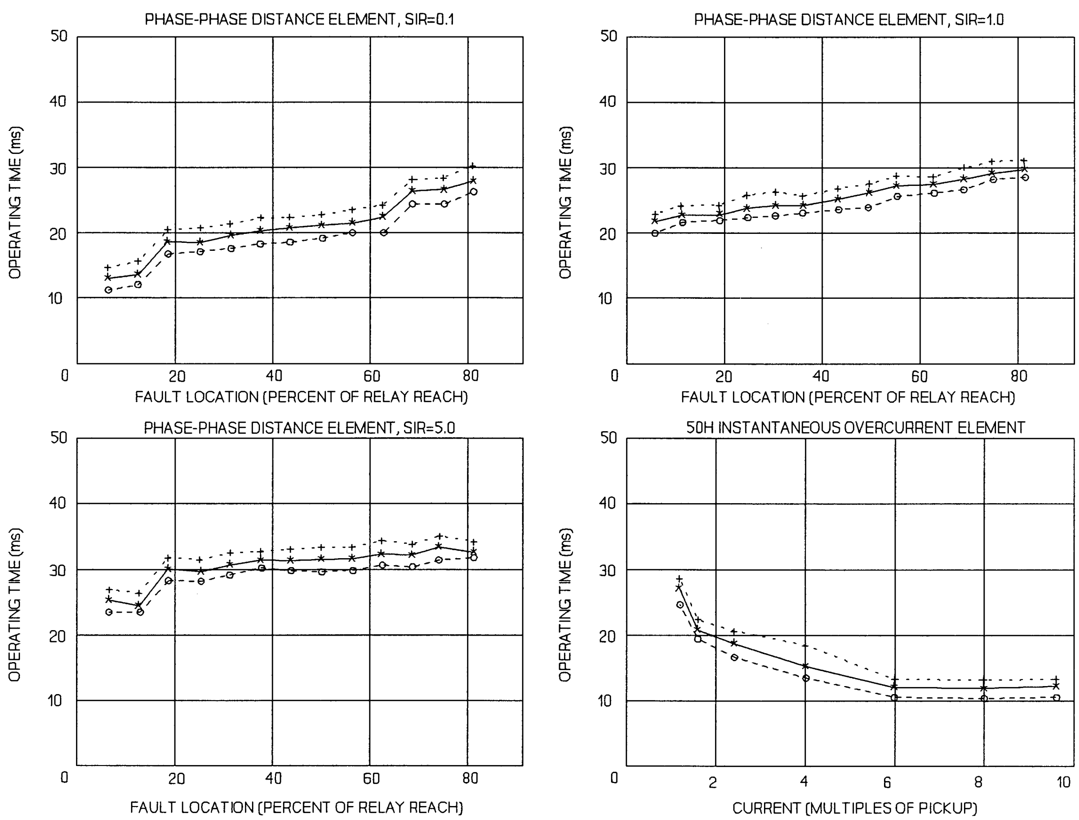


Figure 2.10: Phase Distance Speed Curves and Phase Overcurrent Speed Curve

TIME-OVERCURRENT CURVE EQUATIONS

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

Curve 1 -- Moderately Inverse

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

Curve 2 -- Inverse

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

Curve 3 -- Very Inverse

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

Curve 4 -- Extremely Inverse

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

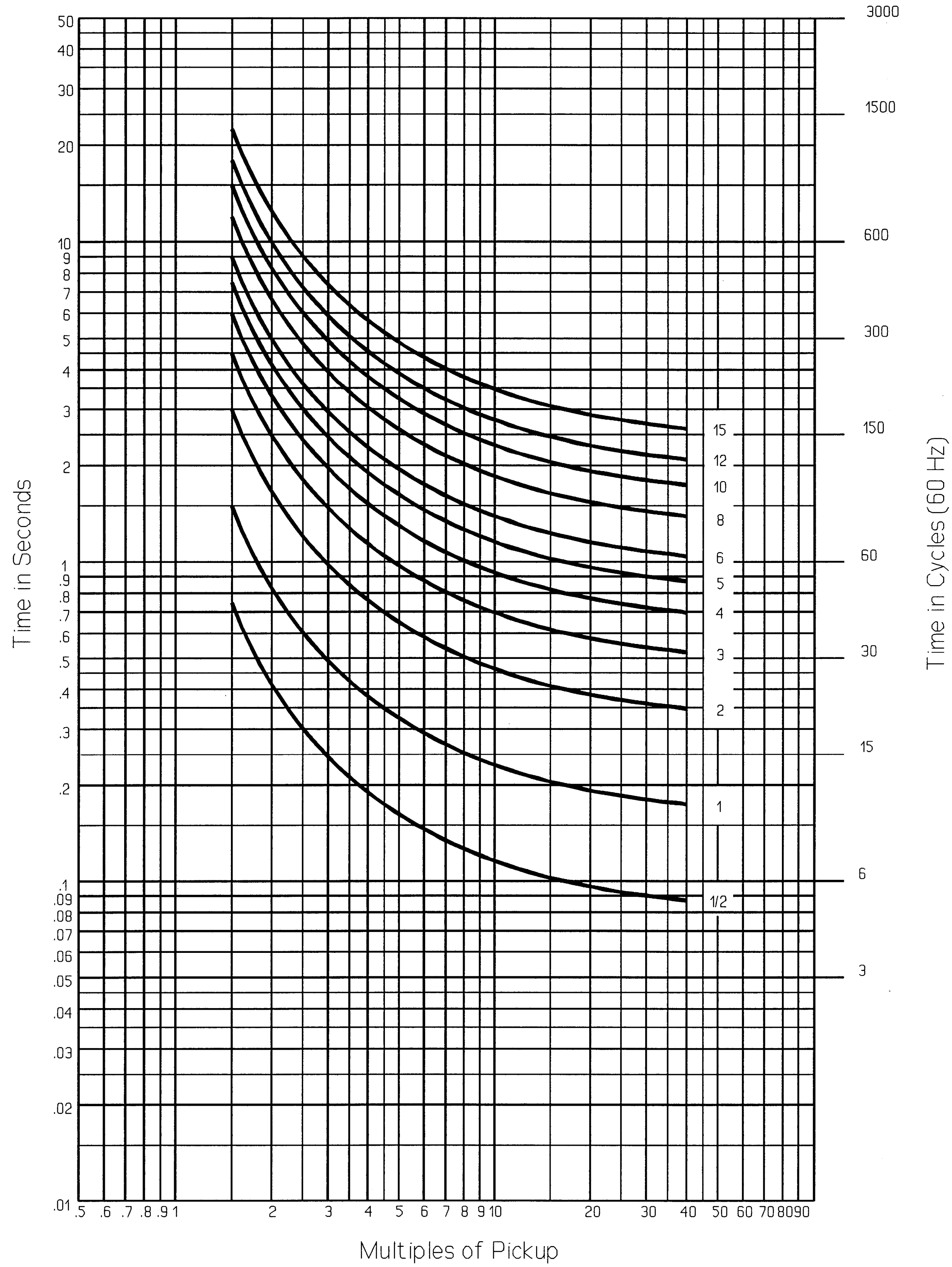


Figure 2.11: Residual Time-Overcurrent Element Moderately Inverse Time Characteristic (Curve 1)

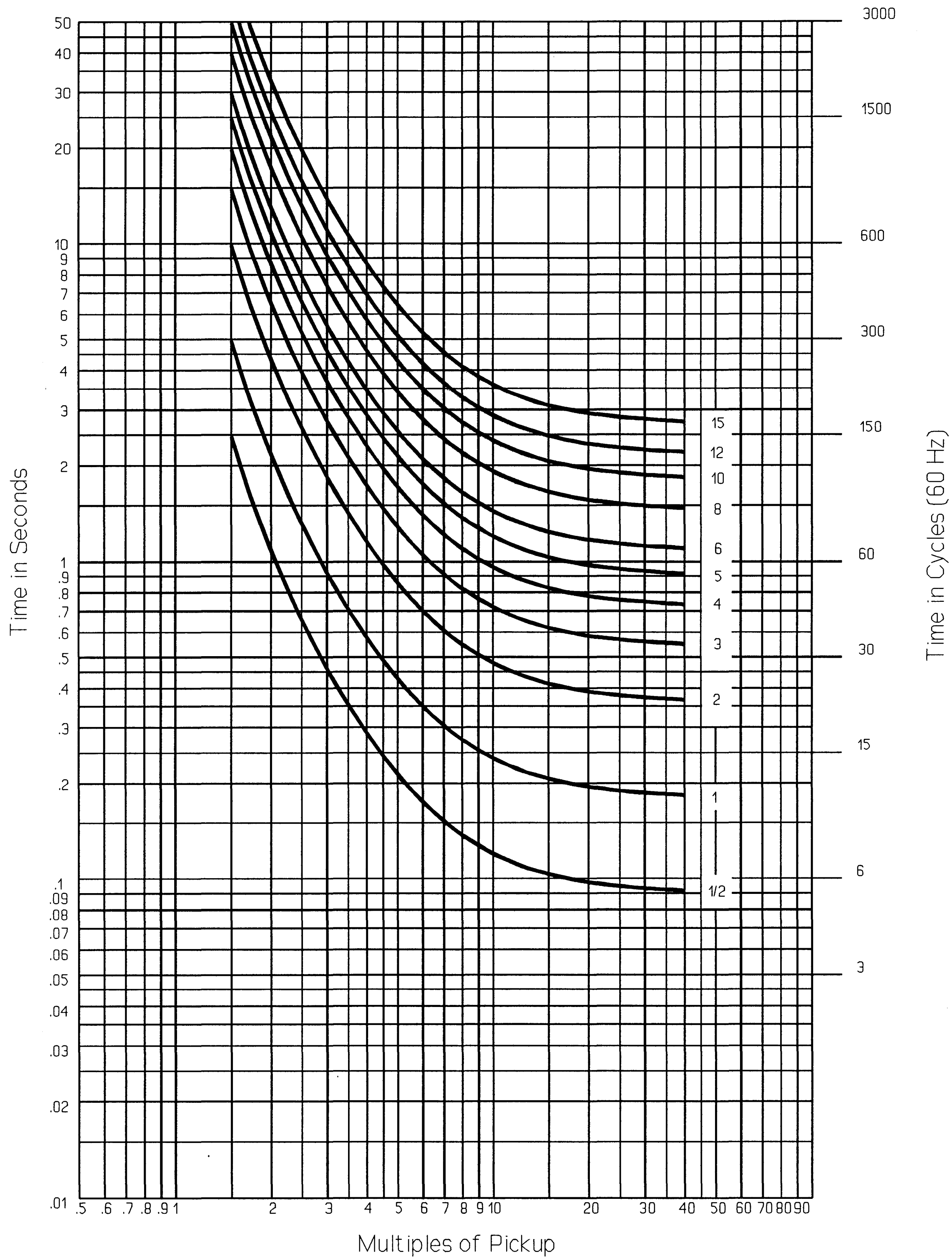


Figure 2.12: Residual Time-Overcurrent Element Inverse Time Characteristic (Curve 2)

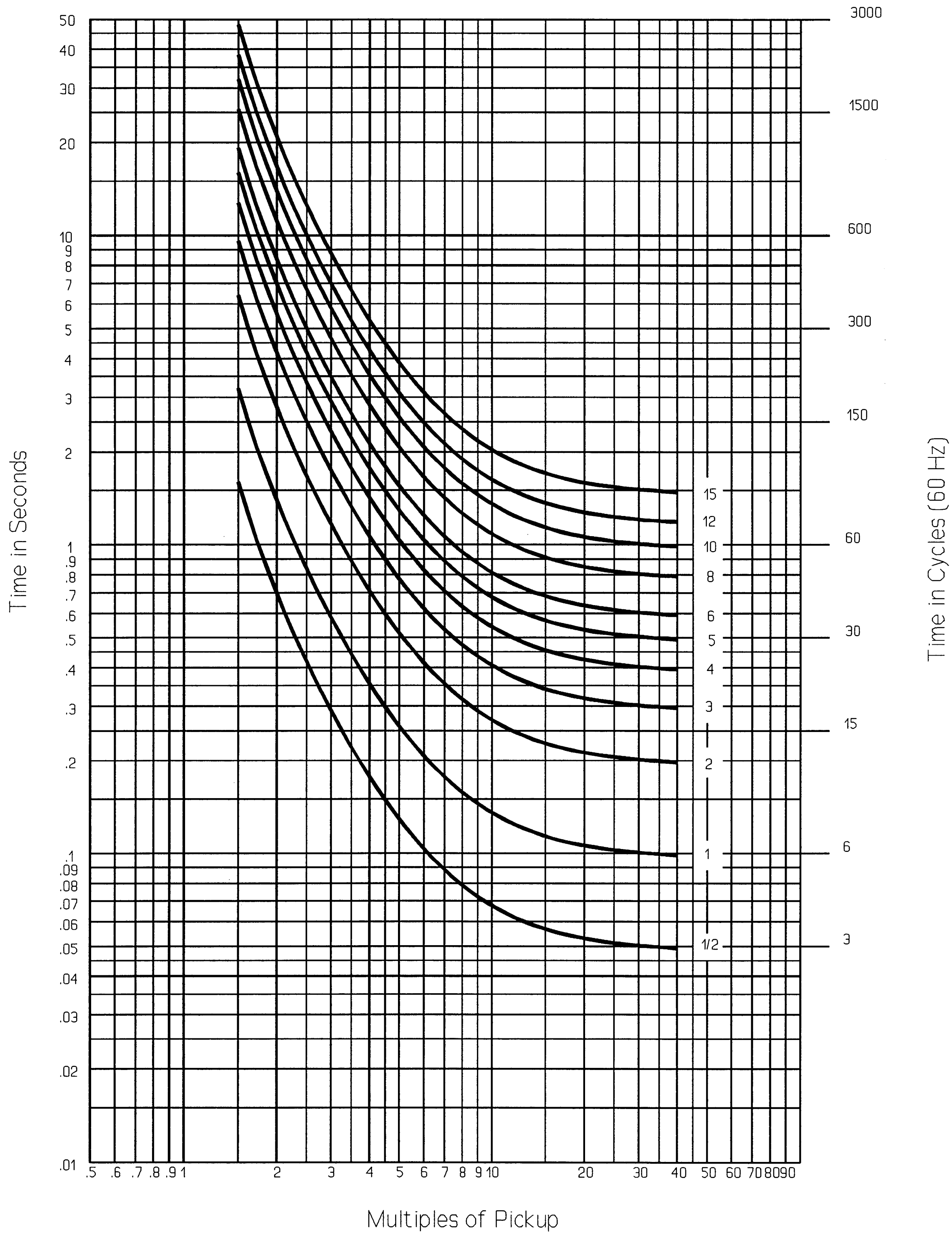


Figure 2.13: Residual Time-Overcurrent Element Very Inverse Time Characteristic (Curve 3)

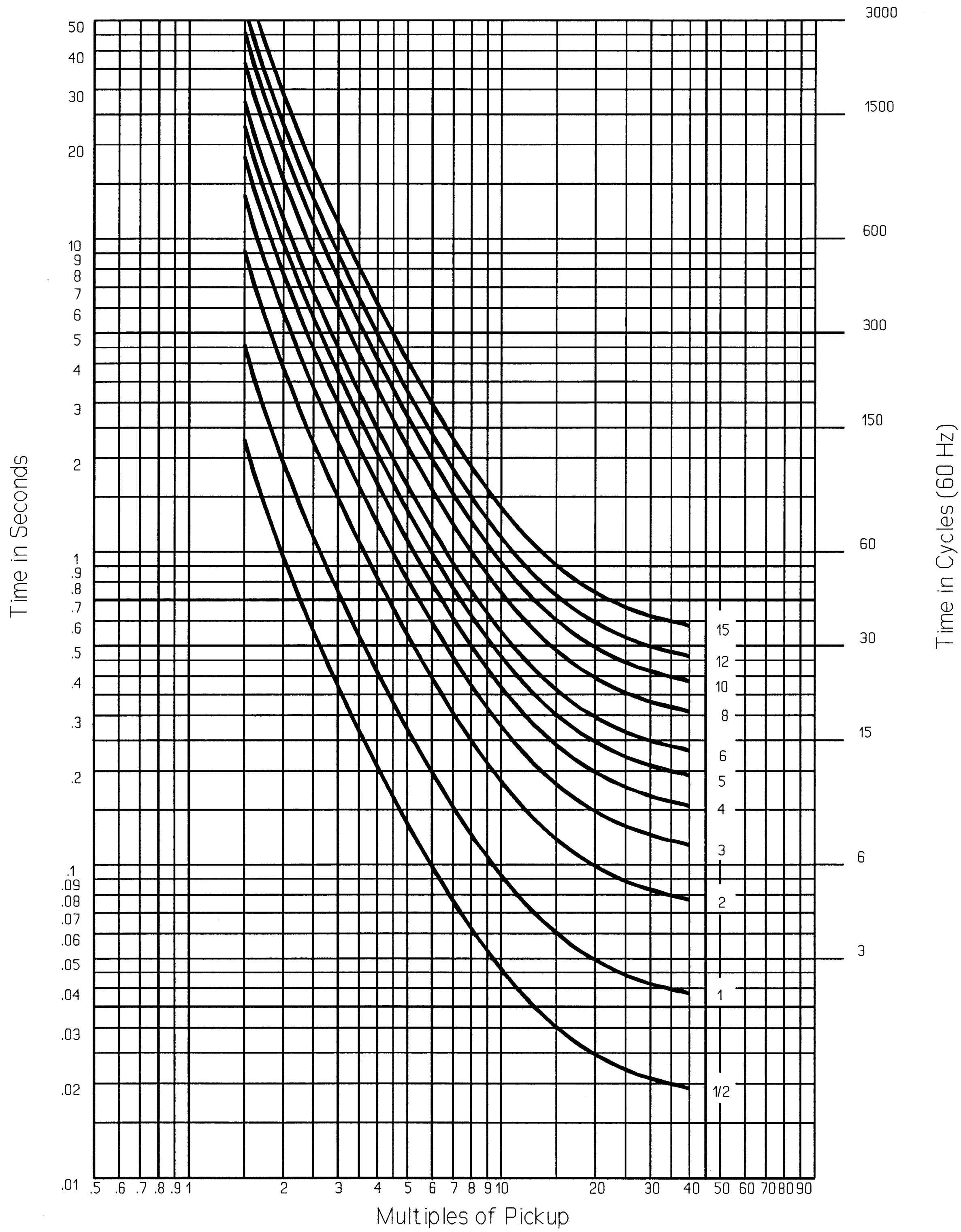
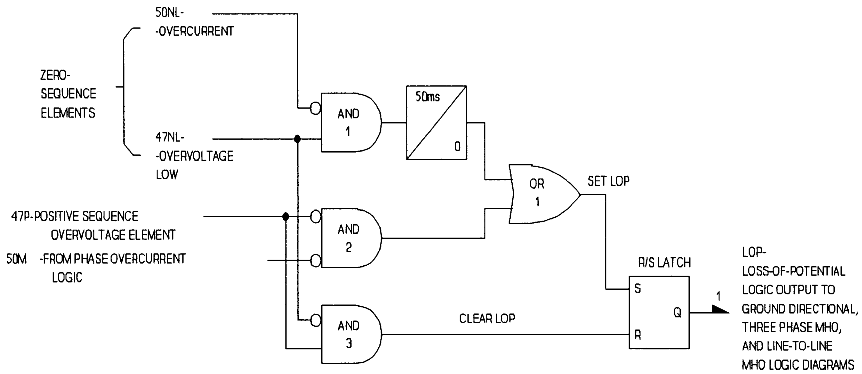
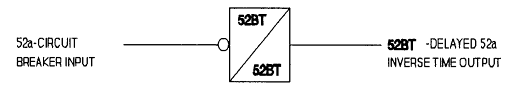


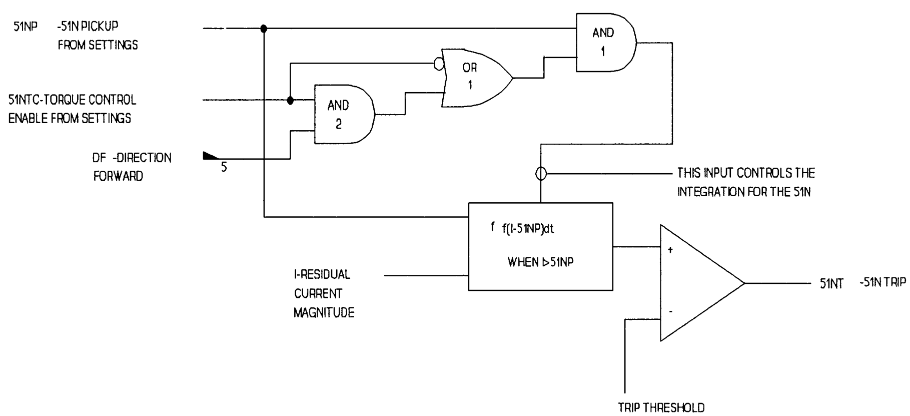
Figure 2.14: Residual Time-Overcurrent Element Extremely Inverse Time Characteristic (Curve 4)



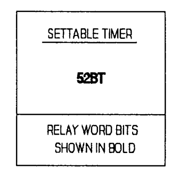
SEL-221 H/121 H LOSS-OF-POTENTIAL LOGIC DIAGRAM

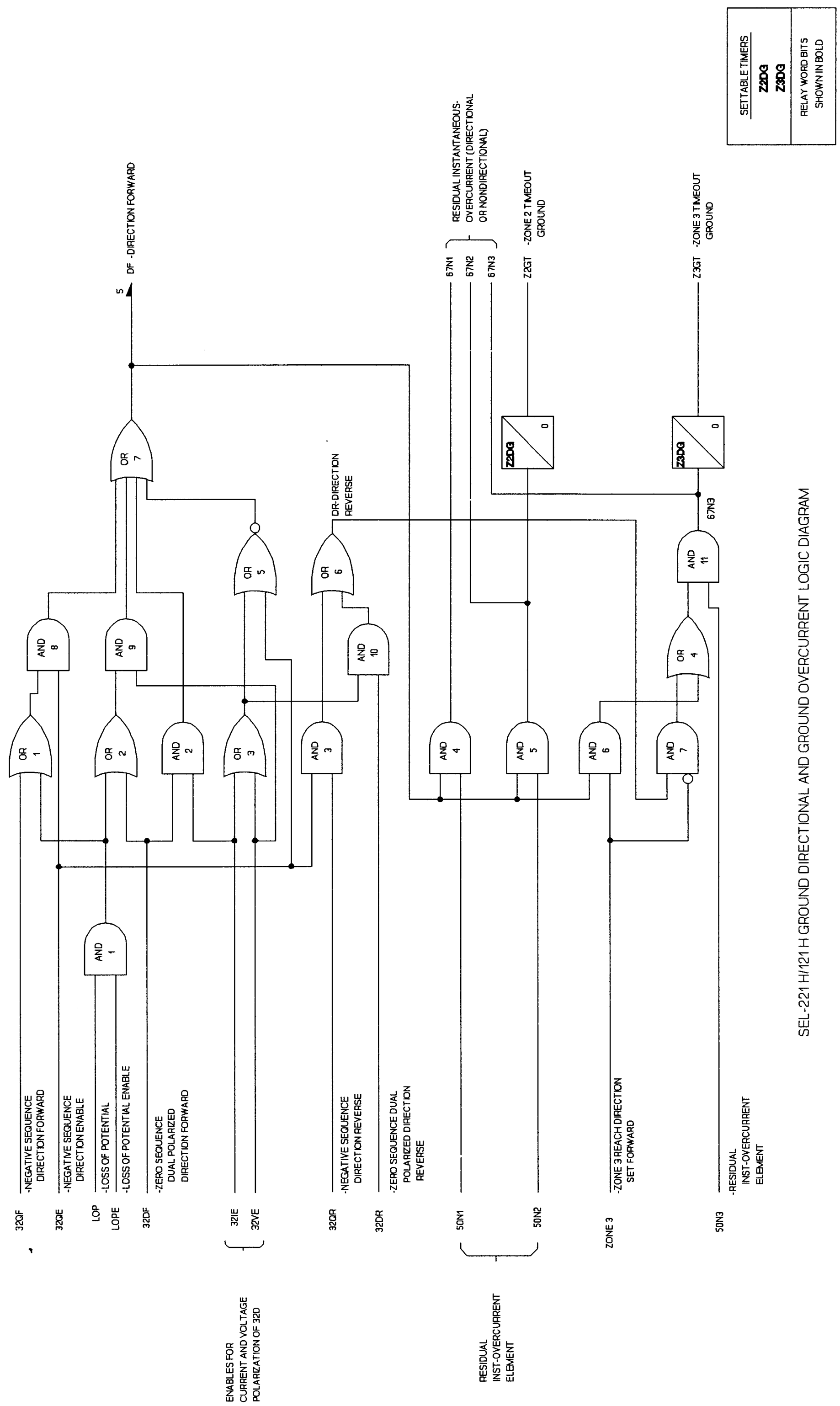


SEL-221 H/121 H CIRCUIT BREAKER CONTACT DELAY
LOGIC DIAGRAM

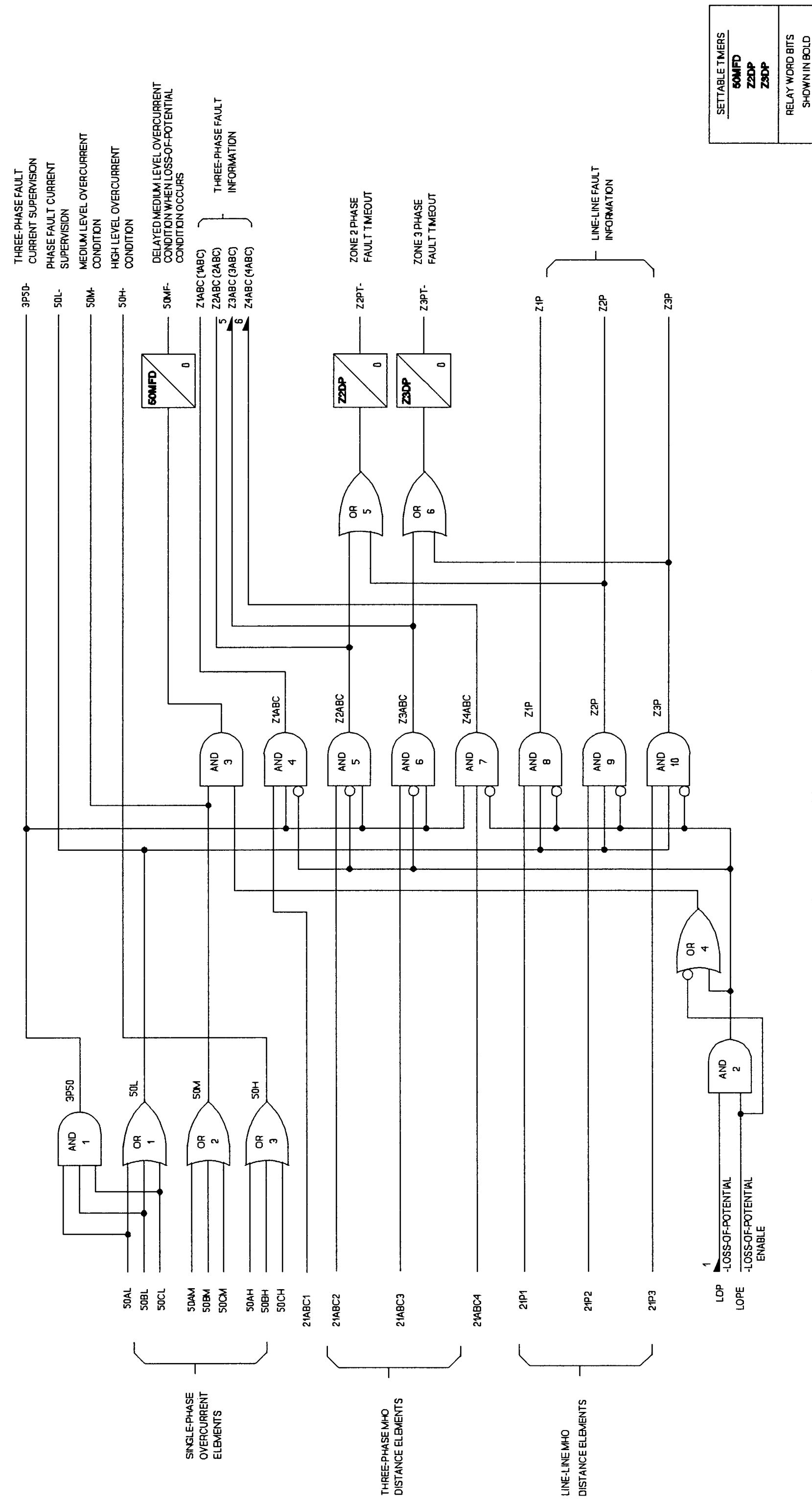


SEL-221 H/121 H RESIDUAL TIME-OVERCURRENT (51N) LOGIC DIAGRAM

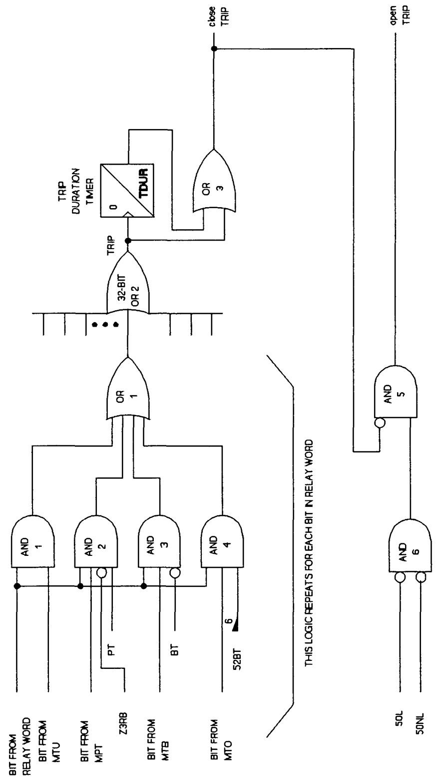




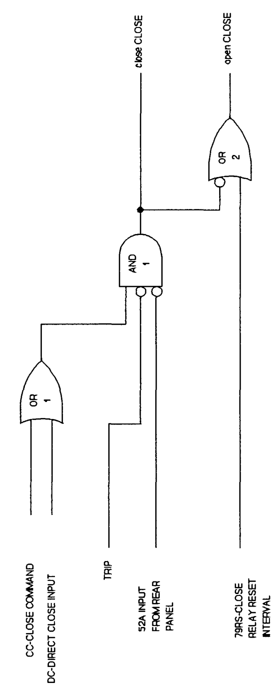
SEL-221H/121H GROUND DIRECTIONAL AND GROUND OVERCURRENT LOGIC DIAGRAM



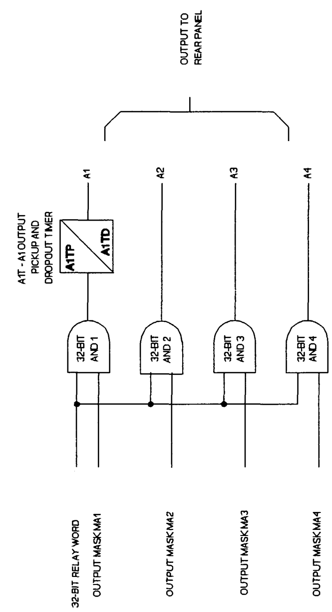
SEL-221H/121H THREE-PHASE MHO, LINE-LINE MHO, AND PHASE OVERCURRENT LOGIC DIAGRAM



SEL-221H/121H PROGRAMMABLE TRIP LOGIC DIAGRAM



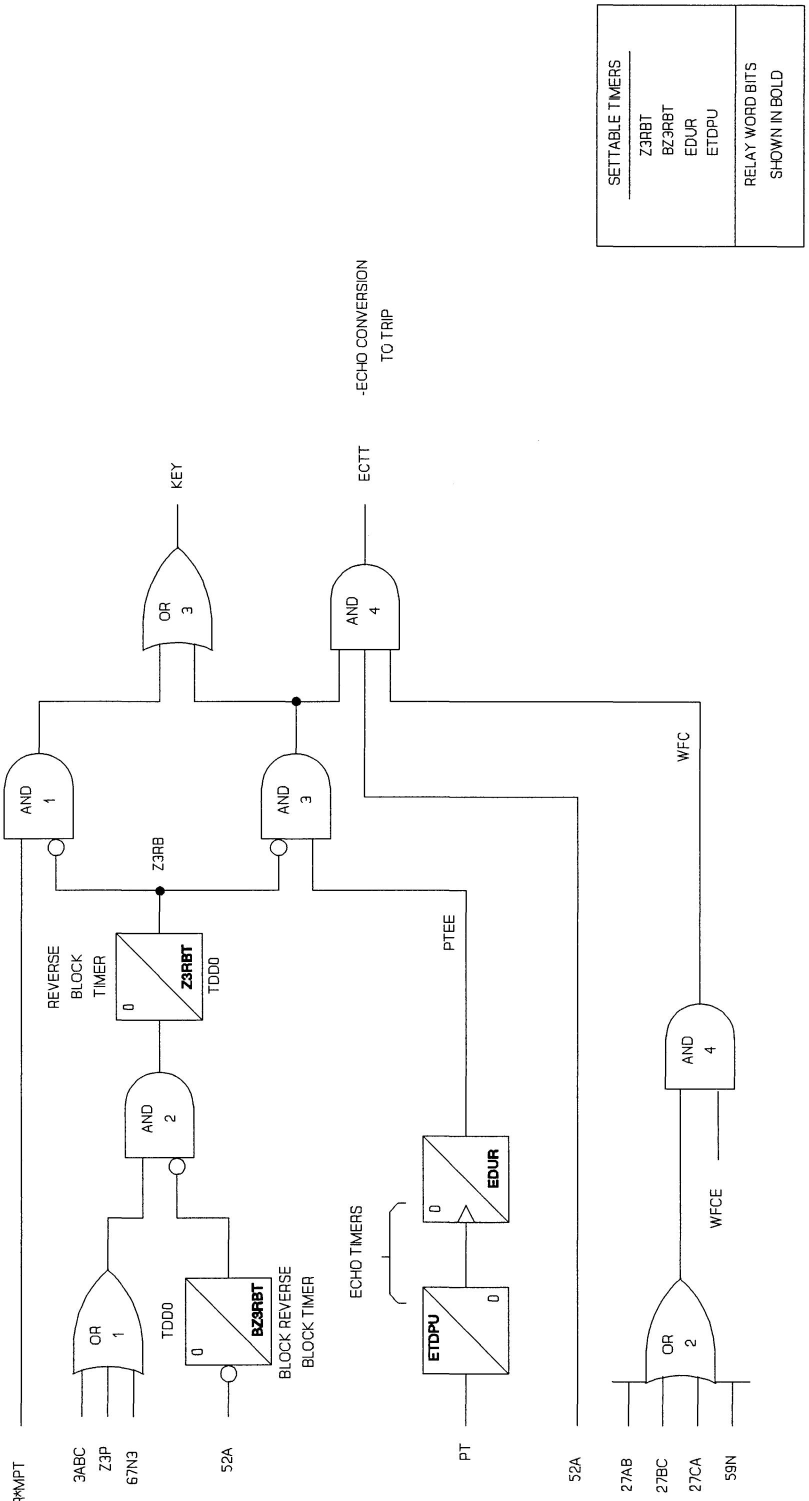
SEL-221H/121H CLOSE LOGIC DIAGRAM



SEL-221H/121H PROGRAMMABLE OUTPUT LOGIC DIAGRAM

SETTABLE TIMERS
A1TP
A1TD
TDUR

RELAY WORD BITS SHOWN IN BOLD



SEL-221H/121H CURRENT REVERSAL, ECHO, AND WEAK INFEED LOGIC

COMMUNICATIONS
TABLE OF CONTENTS

TABLES

FIGURES

COMMUNICATIONS

INTRODUCTION

The relay is set and operated via serial communications interfaces connected to a computer terminal and/or modem, or the SEL Protective Relay Terminal Unit. 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 assertions of the TRIP output, for an event triggering command, or for the 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: 1/1/92     Time: 01:01:01
```

SERIAL PORT CONNECTIONS AND CONFIGURATIONS

The SEL-221H relay is equipped with two EIA RS-232-C 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 are located 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 PORTs 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. Available rates are 300, 600, 1200, 2400, 4800, and 9600 baud.

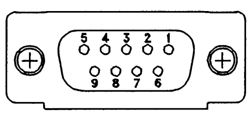
Caution: Do not select two baud rates for the same port as this can damage the relay baud rate generator. The relay is shipped with PORT 1 set to 300 baud and PORT 2F/2R set to 2400 baud.

The SEL-121H relay does not include a front panel connector for PORT 2.

The serial data format is:

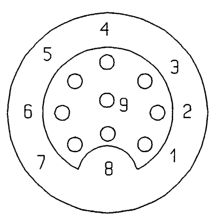
eight data bits
two stop bits
no parity bit

This format cannot be altered.



(female chassis connector, as viewed from outside panel)

Figure 3.1: SEL-221H Nine-Pin Connector Pin Number Convention



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

Figure 3.2: SEL-121H Nine-Pin Connector Pin Number Convention

Table 3.1 lists port pin assignments and signal definitions.

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

Pin	PORT 1, PORT 2R	PORT 2F	Description
1	+5 Vdc	N/C	
2	RXD	RXD	Receive data input.
3	TXD	TXD	Transmit data output.
4	+12 Vdc	N/C	
5	GND	GND	
6	-12 Vdc	N/C	
7	RTS	RTS	The 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 relay monitors CTS, and transmits characters only if CTS is asserted.
9	GND	GND	Ground for ground wires and shields

Table 3.2 lists port pin assignments and signal definitions.

Table 3.2: SEL-121H 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

The 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 one-quarter full.

The relay transmits XOFF (ASCII hex 13) when the buffer is over three-fourths 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: 1/1/92      Time: 01:01:01

SEL-121H
=
```

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: 1/1/92       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: 1/1/92       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:  1/1/92    Time: 14:03:57

Level 1
=>
```

The => prompt indicates Access Level 1.

If you enter wrong 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: 1/1/92     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, successful or otherwise (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 June 20, 1991, enter:

```
=>DATE 6/20/91 <ENTER>
6/20/91
=>
```

The relay sets the date, pulses the ALARM relay closed as the year is stored in EEPROM (if the year input differs from the stored year), 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 are shown in the History readout.

```
=>HISTORY <ENTER>


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

#   DATE         TIME       TYPE  DIST   DUR   CURR

1  8/31/90   07:36:52.150  1AG   74.93  5.00  1070.1
2  8/31/90   07:36:18.400  1BC   74.53  4.75  1567.2
3  8/31/90   07:35:42.970  2BC   84.68  4.25  1411.8
4  8/31/90   07:35:23.783  EXT
5  8/31/90   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 in the event report. 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 midfault

The 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 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

The 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 the assertion of the TRIP output, 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, the TYPE indication is either "TRIP" or "EXT." The TYPE is "TRIP" when the relay generates an event report in response to the assertion of the TRIP output. This can occur after execution of the OPEN command during a no-fault condition. For all other events, TYPE shows "EXT," indicating a report was generated in response to assertion of the ET (External Trigger) input 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 prefault 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: 1/1/92     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: 1/1/92     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°.

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

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

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

P and Q are positive when the power flows in the direction of the reach of the relay, e.g., 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 Levels 1 or 2 and resets the front panel target indicators 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: 1/1/92      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
Z1%  =80.00   Z2%  =120.00  Z3%  =120.00
Z2DP =20.00   Z3DP =60.00   A1TP =0.00    A1TD =0.00
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
Z2DG =30.00   Z3DG =60.00
TDUR =9.00    52BT =20.00   ZONE3=R       Z3RBT=4.50    BZ3RB=1.50
ETDPU=2.00    EDUR =3.5     WFCE =Y       27PP =160.00  59N  =6.00
32QE =Y       32VE =N       32IE =N       LOPE =Y
TIME1=5.00    TIME2=0.00    AUTO =2       RINGS=7.00

Logic settings:

MTU  MPT  MTB  MTO  MA1  MA2  MA3  MA4
80   40   00   D4   00   08   00   80
C4   22   00   E6   00   00   00   00
CA   00   00   00   10   00   00   00
33   10   00   00   00   00   04   00

=>
```

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

Line 4: Zones 2 and 3 time delay settings for phase faults and A1 contact output pickup and dropout delay settings.

Line 5: 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 6: Residual time-overcurrent pickup setting, time dial, curve, and torque control enable.

Line 7: Zones 1, 2, and 3 instantaneous residual overcurrent element pickup settings.

Line 8: Zones 2 and 3 time delay settings for ground faults detected by the Zone 2 and Zone 3 instantaneous overcurrent residual elements.

Line 9: Trip duration timer, 52B time delay, Zone 3 direction, Zone 3 reverse block timer delay setting, and block the reverse block time delay setting.

Line 10: Echo time delayed pickup time delay setting, echo duration time delay setting, weak-infeed conditional enable, phase-to-phase undervoltage and residual overvoltage settings.

Line 11: Enables for the negative-sequence directional, voltage polarized zero-sequence directional and current polarized zero-sequence directional elements, and loss-of-potential enable.

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

The SET command description includes a complete description of the settings.

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	Z3RB	KEY	50MF	PTEE	ECTT	DF
Row 4, of any column:	ALRM	TRIP	TC	DT	52BT	WFC	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 3 of mask MTU, which is set to CA hex format. Using the table, convert CA to binary:

CA -> 1100 1010.

Now, build row 3 of the Relay Word for the MTU mask as follows:

Z2PT	Z3PT	Z3RB	KEY	50MF	PTEE	ECTT	DF
1	1	0	0	1	0	1	0
C				A			

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: 1/1/92     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 appears in place of OK.

The A/D self test checks the analog-to-digital conversion time.

The MOF test checks the dc offset in the MUX-PGA-A/D circuit when a grounded input is selected.

The SET self test calculates the checksum of the settings stored in nonvolatile memory and compares it to the checksum calculated when the 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 front panel 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	Z3RB	KEY	50MF	PTEE	ECTT	DF	Relay Word Row 3
4	ALRM	TRIP	TC	DT	52BT	WFC	Z2GT	Z3GT	Relay Word Row 4
5	.	.	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 remotely reading the targets. A "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 Z3RB KEY  50MF PTEE ECTT DF
 0    0    0    0    0    0    0    1
 0    0    0    0    0    0    0    1
 0    0    0    0    0    0    0    1
 0    0    0    0    0    0    0    1
 0    0    0    0    0    0    0    1
 0    0    0    0    0    0    0    1
 0    0    0    0    0    0    0    1
 0    0    0    0    0    0    0    1

 Z2PT Z3PT Z3RB KEY  50MF PTEE ECTT DF
 0    0    0    0    0    0    0    1
 0    0    0    0    0    0    0    1

=>
```

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

When a serial port times out (see TIME1, TIME2 settings), the relay automatically clears the target display and displays the TAR 0 data.

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

You can reset the 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 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.

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: 1/1/92     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 explains 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 is deasserted and the 52A input is 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 and no reverse block condition
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

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:

SEL-221H 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	Z3RB	KEY	50MF	PTEE	ECTT	DF
Row 4	ALRM	TRIP	TC	DT	52BT	WFC	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 displays existing settings and the question mark prompt after entry 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 Z3RB KEY  50MF PTEE ECTT DF
 0    0    0    0    0    0    0    0
 ? 11001000 <ENTER>
 1    1    0    0    1    0    0    0
 ? <ENTER>
ALRM TRIP TC   DT   52BT WFC  Z2GT Z3GT
 0    0    0    0    0    0    0    0
 ? 00110000 <ENTER>
 0    0    1    1    0    0    0    0
 ? <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 KEY  50MF PTEE ECTT DF
 1    1    0    0    1    0    0    0
ALRM TRIP TC   DT   52BT WFC  Z2GT Z3GT
 0    0    1    1    0    0    0    0

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

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


=>>
```

The previous example selects unconditional tripping for assertion of the Zone 1 three-phase, phase-to-phase and ground elements, timeout of the 51N element, timeout of the Zone 2 and Zone 3 phase and ground timers, trip command (OPEN), and assertion of the Direct Trip (DT) input.

The MPT, MTB, MTO, MA1, MA2, MA3, and MA4 masks are set in a similar manner.

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

OPEN

The TRIP output relay closes in response to the OPEN command, as long as the TC (TRIP 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) and no zero-sequence overcurrent condition (50NL) or if you push the TARGET RESET button on the front panel.

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>** 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. Also, if TDUR = 0.0, the OPEN command is disabled.

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

Example 230 kV Line                  Date: 1/1/92  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 the 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. If the setting is within range, the relay prompts you for the next setting. Press **<ENTER>** to retain an existing setting.

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 combinations of entries result in a secondary out-of-range 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 be within the secondary setting limit of the relay.

ID	39-character string to identify relay in event reports.
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).
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%).
Z2DP	Zone 2 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).
A1TP	A1 contact output pickup delay (0 - 8,000 cycles in quarter-cycle steps).
A1TD	A1 contact output dropout delay (0 - 8,000 cycles in quarter-cycle steps).
50L	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: Use 1 to select a moderately inverse curve Use 2 to select an inverse curve Use 3 to select a very inverse curve Use 4 to select an extremely inverse curve
51NTC	Do you want residual time-overcurrent torque control? (Y or N).

50N1P	Zone 1 instantaneous residual overcurrent pickup setting (0.25 - 50,000 primary amperes).
50N2P	Zone 2 instantaneous residual overcurrent pickup setting (0.25 - 50,000 primary amperes).
50N3P	Zone 3 instantaneous residual overcurrent pickup setting (0.25 - 50,000 primary amperes).
Z2DG	Zone 2 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	Trip duration timer setting (0 - 2,000 cycles in quarter-cycle steps; 0.0 setting disables OPEN command).
52BT	52B time delay setting (0.5 - 10,000 cycles in quarter-cycle steps).
ZONE3	Zone 3 direction setting (F = forward or R = reverse).
Z3RBT	Reverse block timer setting (0 - 8,000 cycles in quarter-cycle steps).
BZ3RB	Block the reverse block timer setting (-1, 0 - 8,000 cycles in quarter-cycle steps, -1 disables).
ETDPU	Echo time delay pickup timer setting (0 - 8,000 cycles in quarter-cycle steps).
EDUR	Echo duration timer setting (0 - 8,000 cycles in quarter-cycle steps).
WFCE	Do you want weak-infeed conditional enabled? (Y or N).
27PP	Phase undervoltage setting (0 - 2,000 primary kilovolts).
59N	Ground overvoltage setting (0 - 2,000 primary kilovolts).
32QE	Do you want negative-sequence directional supervision of the ground overcurrent elements? (Y or N).
32VE	Do you want voltage polarization for the zero-sequence directional element enabled? (Y or N).
32IE	Do you want current polarization for the zero-sequence directional element enabled? (Y or N).
LOPE	Should mho element tripping be blocked when loss-of-potential is detected? (Y or N).
TIME1	Timeout for PORT 1 communications (0 - 30 minutes).
TIME2	Timeout for PORT 2 communications (0 - 30 minutes).
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, the auto setting must be set to send 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-221H 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	Show or set date. DAT 2/3/90 sets date to Feb. 3, 1990. IRIG-B time code input overrides existing month and day settings. DATE pulses ALARM contacts when year entered differs from year stored.
EVENT	Show event record. EVE 1 shows newest event; EVE 12 shows oldest.
HISTORY	Show DATE, TIME, TYPE, DIST (distance), DUR (duration), and CURR (maximum fault current) for the last twelve events.
IRIG	Force immediate attempt to synchronize internal relay clock to time code input.
METER n	Display primary phase-to-neutral and phase-to-phase voltages and currents, and real and reactive power. Option n displays meter data n times.
QUIT	Return control to Access Level 0; return target display to Relay Targets.
SHOWSET	Display settings without affecting them.
STATUS	Show self test status.
TARGET n k	Show data and set 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	Show or set time. TIM 13/32/00 sets clock to 1:32:00 PM. IRIG-B synchronization overrides this setting.
TRIGGER	Trigger and save an event record (event type is EXT).

Access Level 2

CLOSE	Close circuit breaker, if allowed by jumper setting.
LOGIC n	Show or set logic masks MTU, MPT, MTB, MTO, MA1-MA4. Command pulses ALARM contacts closed for one second and clears event buffers when new settings are stored.
OPEN	Open circuit breaker, if allowed by jumper setting.
PASSWORD	Show or set 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	Initiate set procedure. Optional n directs relay to begin setting procedure at that setting. SET EDUR initiates setting procedure at EDUR setting. SET initiates setting procedure at beginning. Command pulses ALARM contacts closed and clears event buffers when new settings are stored.

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EVENT REPORTING
TABLE OF CONTENTS

TABLES

FIGURES

EVENT REPORTING

EVENT REPORT GENERATION

The relay generates a summary and long event report in response to the 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.

Table 4.1: Event Report Triggering Actions

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

A second summary and long event report are generated for the same fault if the trip occurs after the end of the first report.

Event reports are not triggered by any action listed in Table 4.2.

Table 4.2: Non-Event Report Triggering Actions

- CLOSE command execution
- DIRECT CLOSE input assertion
- PERMISSIVE TRIP input assertion
- BLOCK TRIP input assertion
- 52A input status changes
- Pickup of the 50L overcurrent element
- 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 zero for the timeout setting of 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 location to fault
- 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: 1/1/92    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 prefault, 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, 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°. 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°.

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° 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° are 1 and 0; its phasor representation is (0,1). The phasor (0,1) leads the phasor (1,0) by 90°. This coincides with a 90° 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°. 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 state 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. The 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	low set picked up
213	:	Three-phase distance units	:	1=1ABC	Zone 1 picked up
				2=2ABC	Zone 2 picked up
				3=3ABC	Zone 3 picked up
				4=4ABC	Zone 4 picked up
21P	:	Two-phase distance units	:	1=Z1P	Zone 1 picked up
				2=Z2P	Zone 2 picked up
				3=Z3P	Zone 3 picked up
67N	:	Instantaneous overcurrent	:	1=67N1	Zone 1 picked up
				2=67N2	Zone 2 picked up
				3=67N3	Zone 3 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 SEL-221H relay application is a Permissive Overreaching Transfer Trip (POTT) scheme as shown in Figure 4.1. This figure shows two parallel transmission lines, each line protected by two SEL-221H relays connected with a communication channel to transmit the guard and permissive trip signals.

Zone 3 elements on each relay are reversed for use in the current reversal, echo, and weak-infeed logic in the POTT scheme. Each relay is set to trip instantaneously from its Mask for Unconditional Trip (MTU) if Zone 1 elements pick up, the Zone 2 or Zone 3 ground and phase timers expire, or the directional ground time-overcurrent element times out. This logic provides the time graded backup protective functions in case the communications channel fails. Each relay can also trip from its Mask for Permissive Trip (MPT) if forward Zone 2 elements pick up, the relay receives a Permissive Trip (PT) from the remote terminal, and no reverse block (Z3RB) condition is detected.

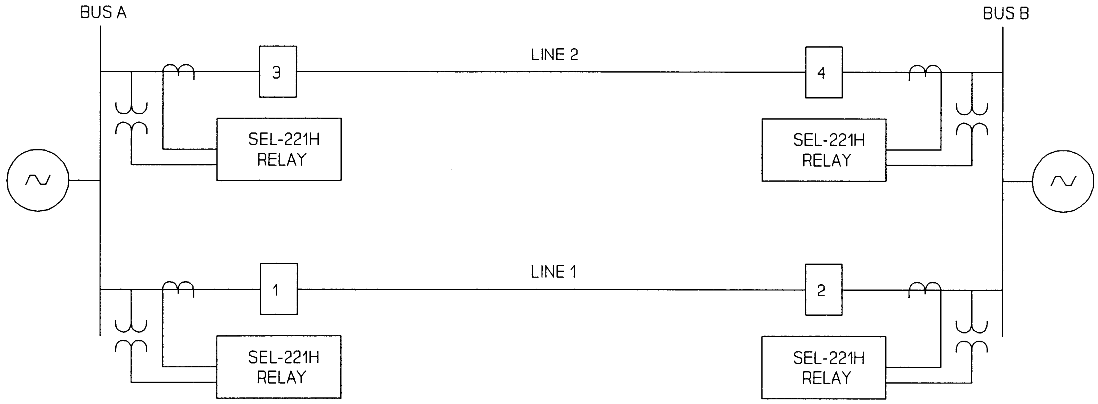


Figure 4.1: Example Transmission Line Protection Using the SEL-221H Relay

Externally Triggered Event Report

Recall from Section 3: Communications that the relay records an eleven cycle "snap-shot" 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 shows the first cycle of normal operating conditions for Breaker 1. The event report was generated with the TRIGGER command. From this excerpt of the event report, you can immediately see that load currents are balanced by the lack of current in the residual current column IR. Also, note that the line breaker is closed, as signified by the asterisk in the column labelled 52A.

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 appears on the following page.

Example Event Report 1

```
Example 230 kV Line                           Date: 1/1/92       Time: 09:43:06.395
FID=SEL-121H-R400-V656mptr1s-D900823
                  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:
```

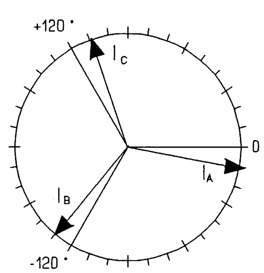
SEL DIRECTION AND POLARITY CHECK FORM

STATION SEL DATE: 1 / 20/ 92 TESTED BY ______
SWITCH NO. ______ EQUIPMENT SEL-221H Relay
INSTALLATION ______ ROUTINE X OTHER ______

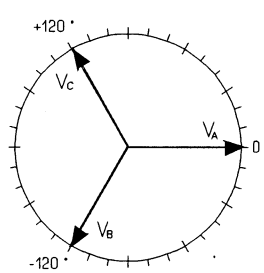
LOAD CONDITIONS:
STATION READINGS: ______ MW (OUT)(IN) ______ MVAR (OUT)(IN) ______ VOLTS ______ AMPS
SEL READINGS: 155 MW (+)(-) 27 MVAR (+)(-)

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

Using the voltage and current phasor diagrams on the bottom of the SEL Direction and Polarity Check Form, note that the current and voltage phase rotation is ABC in the counter-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 was generated by 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. The date and time tags at the top of the event report are referenced to this row of data. The relay labelled the event a Zone 2 BC fault and calculated a fault location 85 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, while the qualifying condition is a permissive trip signal from Breaker 2 at Bus B. Figure 4.2 shows the fault placement on Line 1.

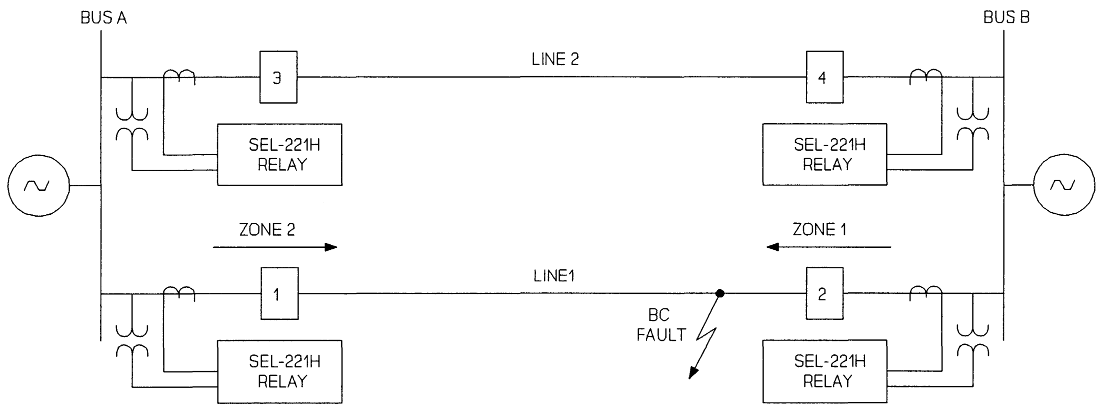


Figure 4.2: Zone 2 BC Fault 85 Miles from Breaker 1

Example Event Report 2

Example 230 kV Line   Date: 1/1/92   Time: 09:20:59.241

FID=SEL-121H-R400-V656mptr1s-D900823

		Currents (amps)				Voltages (kV)		Relays	Outputs	Inputs
IPOL	IR	IA	IB	IC	VA	VB	VC	52265L 011710 P3PNNP	TCAAAAA PL1234L	DPBD5E TTTC2T A
3	-2	-66	94	-31	-115.0	-0.9	116.5	......	....	....*.
-3	0	-72	-19	94	67.6	-133.7	65.7	......	....	....*.
-3	4	66	-91	31	115.0	1.0	-116.5	......	....	....*.
6	0	72	16	-94	-67.6	133.6	-65.7	......	....	....*.
-3	-4	-66	91	-31	-115.0	-1.0	116.5	......	....	....*.
-3	2	-72	-16	94	67.6	-133.6	65.6	......	....	....*.
3	2	66	-91	31	115.0	1.0	-116.5	......	....	....*.
0	-2	72	16	-94	-67.6	133.7	-65.6	......	....	....*.
0	-2	-66	91	-31	-115.0	-1.1	116.6	......	....	....*.
0	2	-72	-16	94	67.8	-133.6	65.6	......	....	....*.
0	2	66	-94	31	114.9	1.7	-117.2	......	....	....*.
0	7	72	107	-173	-67.8	129.7	-61.6	......	....	....*.
0	-13	-66	409	-356	-114.9	-0.1	115.5	L.....	....	....*.
0	-38	-72	-481	513	67.8	-121.0	52.9	M.....	....	.*..*.
3	49	66	-893	878	114.9	-5.5	-109.8	M.....	....	.*..*.
-3	60	72	799	-809	-67.8	115.5	-47.4	M.2...	*.*....	.*..*.
-3	-71	-66	1092	-1101	-114.8	9.4	105.9	M.2...	*.*....	.*..*.
3	-64	-72	-840	849	67.8	-114.8	46.6	M.2...	*.*....	.*..*.
0	73	66	-1120	1129	114.8	-9.9	-105.4	M.2...	*.*....	.*..*.
0	64	72	846	-859	-67.8	114.7	-46.4	M.2...	*.*....	.*..*.
0	-73	-66	1123	-1129	-114.8	9.9	105.3	M.2...	*.*....	.*..*.
0	-64	-72	-846	859	67.8	-114.7	46.5	M.2...	*.*....	.*..*.
0	73	66	-1123	1126	114.8	-10.4	-104.8	M.2...	*.*....	.*..*.
0	53	60	755	-761	-67.8	118.5	-50.3	M.2...	*.*....	.*..*.
0	-60	-53	790	-793	-114.9	8.9	106.4	M.2...	*.*....	.*....
0	-24	-31	-378	381	67.9	-127.2	59.1	M.....	*.*....	.*....
0	27	25	-255	255	114.8	-3.2	-112.1	L.....	*.*....	.*....
0	4	9	50	-50	-67.9	132.8	-64.6	......	*.*....	.*....
0	-7	-6	31	-31	-114.8	-0.7	116.1	......	*.*....	.*....
0	2	-3	-6	6	67.9	-133.5	65.3	......	*......	.*....
0	2	3	-3	6	114.8	1.2	-116.7	......	*......	......
3	-2	0	-3	-3	-68.0	133.5	-65.3	......	*......	......
-3	-2	0	0	0	-114.8	-1.3	116.7	......	*......	......
-3	2	3	6	0	68.0	-133.6	65.3	......	*......	......
3	2	-3	0	0	114.8	1.4	-116.7	......	*......	......
0	-2	0	-3	0	-68.0	133.6	-65.4	......	*......	......
0	-2	3	-3	0	-114.8	-1.4	116.7	......	*......	......
0	2	-6	3	0	68.0	-133.6	65.3	......	*......	......
0	2	0	3	0	114.8	1.4	-116.7	......	*......	......
0	-2	6	-3	0	-68.0	133.6	-65.3	......	*......	......
0	0	0	-3	0	-114.8	-1.4	116.7	......	*......	......
0	0	-6	3	0	68.0	-133.6	65.3	......	*......	......
0	0	0	3	0	114.7	1.4	-116.7	......	*......	......
0	0	6	-6	0	-68.0	133.6	-65.3	......	*......	......

Event   : 2BC   Location   : 84.70 mi 6.63   ohms sec
Duration: 2.50   Flt Current: 1418.9

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	
Z1% =80.00	Z2% =120.00	Z3% =120.00		
Z2DP =20.00	Z3DP =60.00	A1TP =0.00	A1TD =0.00	
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		
Z2DG =30.00	Z3DG =60.00			
TDUR =9.00	52BT =20.00	ZONE3=R	Z3RBT=4.50	BZ3RB=1.50
ETDPU=2.00	EDUR =3.50	WFCE =Y	27PP =160.00	59N =6.00
32QE =Y	32VE =N	32IE =N	LOPE =Y	
TIME1=5.00	TIME2=0.00	AUTO =2	RINGS=7.00	

Logic settings:

MTU	MPT	MTB	MTO	MA1	MA2	MA3	MA4
80	40	00	D4	00	00	00	80
C4	22	00	E6	00	00	00	00
CA	00	00	00	10	20	00	00
33	10	00	00	00	00	04	00

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

	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	-2	-66	94	-31	-115.0	-0.9	116.5	......	....	....*.	1
-3	0	-72	-19	94	67.6	-133.7	65.7	......	....	....*.	2
-3	4	66	-91	31	115.0	1.0	-116.5	......	....	....*.	3
6	0	72	16	-94	-67.6	133.6	-65.7	......	....	....*.	4
-3	-4	-66	91	-31	-115.0	-1.0	116.5	......	....	....*.	5
-3	2	-72	-16	94	67.6	-133.6	65.6	......	....	....*.	6
3	2	66	-91	31	115.0	1.0	-116.5	......	....	....*.	7
0	-2	72	16	-94	-67.6	133.7	-65.6	......	....	....*.	8
0	-2	-66	91	-31	-115.0	-1.1	116.6	......	....	....*.	9
0	2	-72	-16	94	67.8	-133.6	65.6	......	....	....*.	10
0	2	66	-94	31	114.9	1.7	-117.2	......	....	....*.	11
0	7	72	107	-173	-67.8	129.7	-61.6	......	....	....*.	12
0	-13	-66	409	-356	-114.9	-0.1	115.5	L.....	....	....*.	13
0	-38	-72	-481	513	67.8	-121.0	52.9	M.....	....	.*..*.	14
3	49	66	-893	878	114.9	-5.5	-109.8	M.....	....	.*..*.	15
-3	60	72	799	-809	-67.8	115.5	-47.4	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 prefault 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 permissive trip signal arrival.

The following outline lists observed incidents shown in Example Event Report 2 by quarter-cycle.

Quarter Cycle	Event Report Shows:
1-12	Prefault conditions:
	• No residual current in IR column indicates balanced load currents.
	• No protective relay elements are picked up.
	• * in 52A Inputs column verifies that breaker was closed (as does load current flow).
13-14	Fault Inception:
	• Fault current reached 50L element pickup threshold as shown by L in 50P column.
14	• Fault current reached 50M element pickup threshold as shown by M in 50P column.
	• * in PT Inputs column indicates that communication equipment at Breaker 1 detected a permissive trip signal arrived from Breaker 2.
16	• A 2 in 21P column shows when Zone 2 phase-phase element picked up.
	• * in A1 Outputs column reveals A1 output contact closure. Logic settings below relay settings show that relay keyed permissive trip to remote breaker via KEY bit in Relay Word.
	• * in TP Outputs column indicates assertion of TRIP output contact.

The relay closed the TRIP output in row 16 because a Zone 2 element was picked up, the PT input was asserted, and no reverse block (Z3RB) condition existed. The remaining quarter-cycles of the report show the external tripping scheme clearing the fault after instructing the breaker to trip.

The following excerpt from Example Event Report 2 shows cycles five through seven (quarter-cycles 17 - 28). These cycles represent the midfault 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

   -3    -71    -66   1092  -1101 -114.8    9.4  105.9   M.2... *.*.... .*..*.             17
    3    -64    -72   -840    849   67.8 -114.8   46.6   M.2... *.*.... .*..*.             18
    0     73     66  -1120   1129  114.8   -9.9 -105.4   M.2... *.*.... .*..*.             19
    0     64     72    846   -859  -67.8  114.7  -46.4   M.2... *.*.... .*..*.             20

    0    -73    -66   1123  -1129 -114.8    9.9  105.3   M.2... *.*.... .*..*.             21
    0    -64    -72   -846    859   67.8 -114.7   46.5   M.2... *.*.... .*..*.             22
    0     73     66  -1123   1126  114.8  -10.4 -104.8   M.2... *.*.... .*..*.             23
    0     53     60    755   -761  -67.8  118.5  -50.3   M.2... *.*.... .*..*.             24

    0    -60    -53    790   -793 -114.9    8.9  106.4   M.2... *.*.... .*....             25
    0    -24    -31   -378    381   67.9 -127.2   59.1   M..... *.*.... .*....             26
    0     27     25   -255    255  114.8   -3.2 -112.1   L..... *.*.... .*....             27
    0      4      9     50    -50  -67.9  132.8  -64.6   ...... *.*.... .*....             28
```

Quarter Cycle	Event Report Shows:
	Midfault conditions:
25	• Period in 52A Inputs column indicates opening of breaker auxiliary contacts.
	• 2 in 21P column indicates Zone 2 phase-phase element is picked up.
	• * in PT Inputs column indicates permissive trip receive signal is present. This input remains asserted until 30th quarter-cycle.
	• * in A1 Outputs column indicates that relay is keying permissive trip. This output remains asserted until 36th quarter-cycle.
	• * in TP Outputs column indicates closure of TRIP output. TRIP output remains closed for at least TDUR duration. In this example, TDUR setting is nine cycles.
26	• Period in 21P column indicates that Zone 2 phase-phase element is dropped out.
27	• L in 50P column indicates that 50M element is dropped out (50L is now the only overcurrent element picked up).
28	• Period in 50P column indicates current in each phase is below 50L setting threshold.

Current Reversal in Line 1

Example Event Report 3 shows an out-of-section fault which results in a current reversal after Breaker 3 opens. Referring to Figures 4.3a and 4.3b, 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 reverse Zone 3 67N3 ground overcurrent element. The relay at Breaker 3 trips instantaneously via its Zone 1 ground elements. However, the protection at Breaker 4 must wait to receive a permissive signal from the protection at Breaker 3. This results in a short duration sequential clearance for the fault on Line 2 shown in Figure 4.3. After Breaker 3 opens, the fault current redistributes and the relay at Breaker 1 sees the fault as a forward Zone 2 ground fault. This creates a potential hazard: if the permissive trip signal at Breaker 1 has not reset before the Zone 2 element asserts, the relay at Breaker 1 has permission to trip from Breaker 2. If unique logic is not included in the protection scheme, Breaker 1 of the healthy line may open. The SEL-221H relay current reversal logic easily handles this potential hazard (please refer to Section 2: SPECIFICATIONS and Section 5: APPLICATIONS, Current Reversals and Timers).

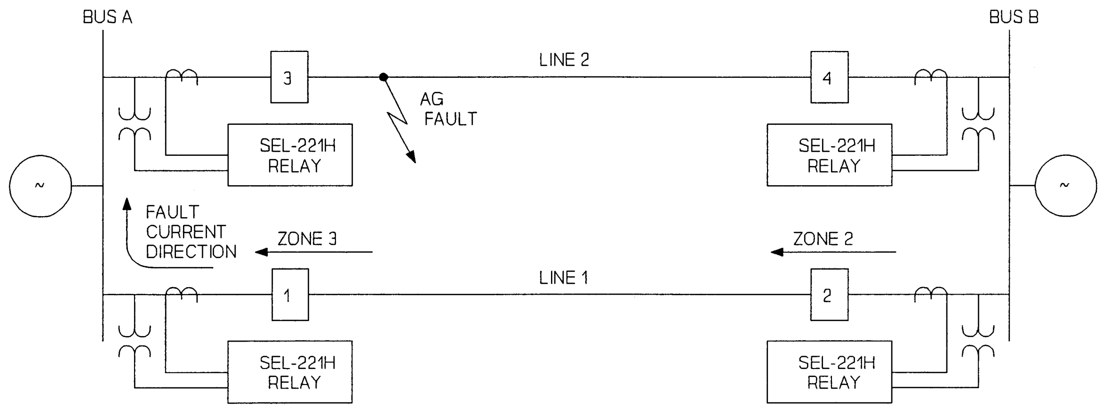


Figure 4.3a: Zone 3 Out-of-Section Reverse Fault when Breakers 3 and 4 are Closed

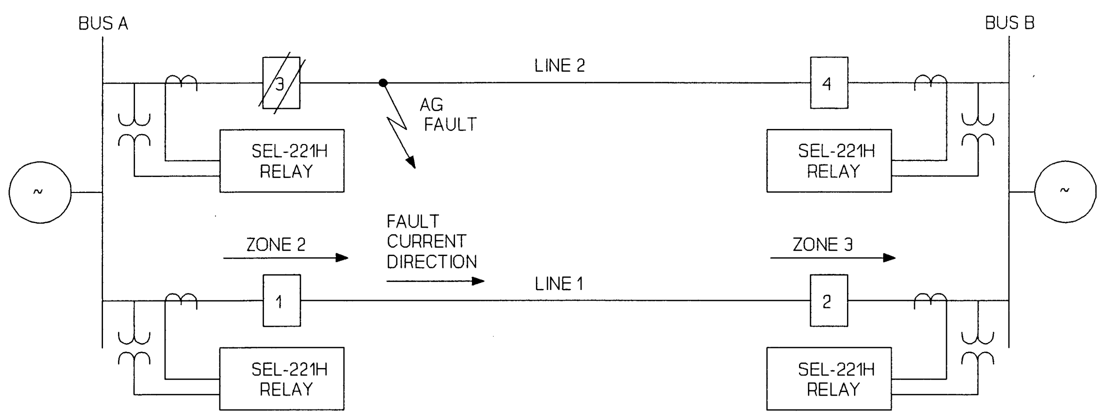


Figure 4.3b: Current Reversal at Breaker 1 when Breaker 3 Opens

The Z3RB element picks up with the assertion of any reverse Zone 3 element and drops out a settable time after the Zone 3 elements. This prevents the relay from tripping via the permissive logic when the current reverses and the Zone 2 elements pick up.

Example Event Report 3

```
Example 230 kV Line                        Date: 1/1/92      Time: 09:33:50.620

FID=SEL-121H-R400-V656mptr1s-D900823

                 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      82       0     -88   -43.4   131.1   -87.6   ...... ....... ....*.
     0      0     -50      98     -50  -126.2    25.6   101.2   ...... ....... ....*.
     0      0     -82      -3      88    43.4  -131.2    87.6   ...... ....... ....*.
     3      0      50     -98      50   126.1   -25.5  -101.2   ...... ....... ....*.

    -3     -2      82       3     -88   -43.4   131.2   -87.6   ...... ....... ....*.
    -3      2     -50      94     -50  -126.1    25.5   101.2   ...... ....... ....*.
     3      2     -82       0      88    43.4  -131.2    87.6   ...... ....... ....*.
     0     -2      50     -94      50   126.2   -25.5  -101.2   ...... ....... ....*.

     0      0      82       0     -88   -43.5   131.1   -87.5   ...... ....... ....*.
     0      0     -47      94     -50  -126.2    25.5   101.2   ...... ....... ....*.
     0      0     -85       0      88    43.5  -131.1    87.5   ...... ....... ....*.
     0      0      47     -94      50   125.8   -25.5  -101.3   ...... ....... ....*.

     0   -102     -16       0     -85   -43.3   131.1   -87.5   ...... ....... ....*.
     0     22     -28      94     -53  -118.4    28.6   104.3   ...... ....... ....*.
     0    520     437       3      85    39.5  -132.6    86.1   L..... ....*.. ....*.
     0   -246    -195     -98      53   106.6   -33.5  -109.2   L..3.. ...**.. .*..*.

     0   -905    -821      -3     -88   -35.4   134.2   -84.5   M..3.. ...**.. .*..*.
     0    473     422      98     -50  -101.6    35.5   111.4   M..3.. ...**.. .*..*.
     0    980     897       0      88    34.9  -134.4    84.2   M..3.. ...**.. .*..*.
     0   -500    -453     -94      50   100.9   -35.8  -111.7   M..3.. ...**.. .*..*.

     0   -989    -903       0     -88   -34.9   134.5   -84.1   M..3.. ...**.. .*..*.
     0    502     456      94     -50  -100.9    35.8   111.6   M..3.. ...**.. .*..*.
     3    989     903       0      88    34.9  -134.5    84.1   M..3.. ...**.. .*..*.
    -3   -502    -456     -94      50   100.9   -35.8  -111.6   M..3.. ...**.. .*..*.

    -3   -823    -736       0     -88   -34.9   134.5   -84.1   M..3.. ...**.. .*..*.
     3    469     422      94     -50  -100.9    35.8   111.7   M..3.. ...**.. .*..*.
     0    142      50       0      88    34.9  -134.5    84.1   L..3.. ...**.. .*..*.
     0   -113     -57     -94      50   100.9   -35.8  -111.7   ...... ...**.. .*..*.

     0    484     573       0     -88   -35.0   134.5   -84.1   M..... ...**.. .*..*.
     0   -254    -311      94     -50  -100.9    35.8   111.7   M..2P. ...**.. .*..*.
     0   -608    -692       0      88    35.0  -134.5    84.1   M..2P. ...**.. .*..*.
     3    303     356     -94      50   100.7   -35.7  -111.9   M..2P. ...**.. .*..*.

    -3    624     708       0     -88   -35.0   134.4   -84.1   M..2P. ...**.. .*..*.
    -3   -310    -359      94     -50  -100.7    35.7   111.9   M..2P. ...**.. .*..*.
     3   -622    -711       0      88    35.0  -134.4    84.1   M..2P. ...**.. .*..*.
     0    310     359     -94      50   101.0   -35.7  -111.7   M..2P. ...**.. .*..*.

     0    546     636       0     -88   -35.1   134.5   -84.0   M..2P. ...**.. .*..*.
     0   -294    -343      94     -50  -108.6    32.5   108.7   M..2P. ...**.. .*..*.
     0   -248    -333       0      88    39.0  -133.1    85.4   L..2P. ...**.. .*..*.
     0    137     182     -94      50   120.3   -27.6  -103.8   L..2P. ...*... .*..*.

     0    -27      60       0     -88   -43.2   131.5   -87.0   ...... ...*... .*..*.
     0     24     -19      94     -50  -125.3    25.4   101.7   ...... ...*... .*..*.
     0     80      -9       0      88    43.7  -131.3    87.2   ...... ...*... .*..*.
     0    -46       0     -94      50   126.0   -25.2  -101.5   ...... ...*... ....*.

Event   : 3AG    Location   : -77.14 mi -6.04  ohms sec
Duration: 3.00   Flt Current: 1011.6

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
Z1%  =80.00      Z2%  =120.00    Z3%  =120.00
Z2DP =20.00      Z3DP =60.00     A1TP =0.00      A1TD =0.00
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
Z2DG =30.00      Z3DG =60.00
TDUR =9.00       52BT =20.00     ZONE3=R         Z3RBT=4.50      BZ3RB=1.50
ETDPU=2.00       EDUR =3.50      WFCE =Y         27PP =160.00    59N  =6.00
32QE =Y          32VE =N         32IE =N         LOPE =Y
TIME1=5.00       TIME2=0.00      AUTO =2         RINGS=7.00

Logic settings:

MTU  MPT  MTB  MTO  MA1  MA2  MA3  MA4
80   40   00   D4   00   00   00   80
C4   22   00   E6   00   00   00   00
CA   00   00   00   10   20   00   00
33   10   00   00   00   00   04   00
```

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

	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	0	82	0	-88	-43.4	131.1	-87.6	......	....	....*.	1
0	0	-50	98	-50	-126.2	25.6	101.2	......	....	....*.	2
0	0	-82	-3	88	43.4	-131.2	87.6	......	....	....*.	3
3	0	50	-98	50	126.1	-25.5	-101.2	......	....	....*.	4
-3	-2	82	3	-88	-43.4	131.2	-87.6	......	....	....*.	5
-3	2	-50	94	-50	-126.1	25.5	101.2	......	....	....*.	6
3	2	-82	0	88	43.4	-131.2	87.6	......	....	....*.	7
0	-2	50	-94	50	126.2	-25.5	-101.2	......	....	....*.	8
0	0	82	0	-88	-43.5	131.1	-87.5	......	....	....*.	9
0	0	-47	94	-50	-126.2	25.5	101.2	......	....	....*.	10
0	0	-85	0	88	43.5	-131.1	87.5	......	....	....*.	11
0	0	47	-94	50	125.8	-25.5	-101.3	......	....	....*.	12
0	-102	-16	0	-85	-43.3	131.1	-87.5	......	....	....*.	13
0	22	-28	94	-53	-118.4	28.6	104.3	......	....	....*.	14
0	520	437	3	85	39.5	-132.6	86.1	L.....	....*..	....*.	15
0	-246	-195	-98	53	106.6	-33.5	-109.2	L..3..	...**..	.*..*.	16

In Example Event Report 3, quarter-cycle 15, the A3 contact output asserts, revealing a Weak-infeed Condition, WFC. (In this example, programmable output A3 is masked with the WFC bit in the Relay Word). Residual voltage over the 59N setting generates the WFC. You can verify this by calculating the ground voltage from event report rows 14 and 15.

$$
\begin{aligned}
V0 &= 1/3[V_a + V_b + V_c] \\
&= 1/3[(-118.4 + 28.6 + 104.3) + j(-43.3 + 131.1 - 87.5)] \\
&= 5.37 \angle -169.0^\circ \text{ kV} \\
&= 2.68 \text{ V secondary}
\end{aligned}
$$

The 59N element is expected to assert at three volts of zero-sequence volts secondary, ± 1 V. Thus, the WFC bit masked into the A3 programmable output contact asserted correctly.

Quarter Cycle	Event Report Shows:
1-14	Prefault conditions: • No residual current in IR column indicates balanced load currents. • No protective relay elements are picked up. • * in 52A column verifies closed breaker (as does load current flow).
15	Fault Inception: • L in 50P column shows fault current above 50L element pickup. • * in A3 output column indicates a WFC condition.
16	• 3 in 67N column indicates pickup assertion of 67N3 element. • * in A2 output column indicates a Zone 3 reverse block condition. • * in PT input column indicates that communication equipment at Breaker 1 received a permissive trip signal from Breaker 2.

The event report shows how assertion of the Zone 3 Reverse Block (Z3RB) element with the breaker closed follows reverse looking Zone 3 element assertion. The following extract from Example Event Report 3 shows assertion of the forward looking Zone 2 directional ground overcurrent element with the PT input asserted. Note that the Z3RB element prevents a misoperation at Breaker 1 caused by the current reversal.

Starting at quarter-cycle 27 of the same event report, the current reverses after Breaker 3 opens. The fault is now viewed as a Zone 2 forward AG fault from Breaker 1. Quarter-cycles 29 through 44 show the pickup of the 67N2 element.

	Currents (amps)					Voltages (kV)		Relays	Outputs	Inputs	
								52265L	TCAAAAA	DPBD5E	
IPOL	IR	IA	IB	IC	VA	VB	VC	011710	PL1234L	TTTC2T	
								P3PNNP		A	Quarter-cycle
0	484	573	0	-88	-35.0	134.5	-84.1	M.....	...**..	.*..*.	29
0	-254	-311	94	-50	-100.9	35.8	111.7	M..2P.	...**..	.*..*.	30
0	-608	-692	0	88	35.0	-134.5	84.1	M..2P.	...**..	.*..*.	31
3	303	356	-94	50	100.7	-35.7	-111.9	M..2P.	...**..	.*..*.	32
-3	624	708	0	-88	-35.0	134.4	-84.1	M..2P.	...**..	.*..*.	33
-3	-310	-359	94	-50	-100.7	35.7	111.9	M..2P.	...**..	.*..*.	34
3	-622	-711	0	88	35.0	-134.4	84.1	M..2P.	...**..	.*..*.	35
0	310	359	-94	50	101.0	-35.7	-111.7	M..2P.	...**..	.*..*.	36
0	546	636	0	-88	-35.1	134.5	-84.0	M..2P.	...**..	.*..*.	37
0	-294	-343	94	-50	-108.6	32.5	108.7	M..2P.	...**..	.*..*.	38
0	-248	-333	0	88	39.0	-133.1	85.4	L..2P.	...**..	.*..*.	39
0	137	182	-94	50	120.3	-27.6	-103.8	L..2P.	...*...	.*..*.	40

Quarter Cycle	Event Report Shows:
	Fault conditions after current reversal:
30-39	• * in 52A input column indicates that breaker remains closed.
	• 2 in 67N column indicates Zone 2 directional ground overcurrent element is picked up. Since Zone 2 is forward reaching, the fault is now in the forward direction for Breaker 1.
	• P in 51N column indicates that ground time-overcurrent element has picked up and is timing toward trip.
	• * in PT input column indicates that permissive trip receive signal is present. This input remains asserted until 42nd quarter-cycle.
	• * in A2 output column indicates Z3RB element is asserted and blocking relay from keying permissive trip via 67N2 element or tripping via permissive logic. This output remains asserted for the duration of the event report.
40	• Period in A3 output column indicates WFC condition is no longer present because system voltages are restoring after Breaker 4 opened.

No trip occurred at Breaker 1 following the current reversal because the Z3RB element blocked the permissive trip and key logic. Recall that:

TRIP = R * [MTU + PT*MPT*NOT(Z3RB) + 52BT*MTO + NOT(BT)*MTB]

Where:

MTU	=	Mask for Unconditional TRIP
MPT	=	Mask for Permissive TRIP
MTO	=	Mask for TRIP when breaker is Open
MTB	=	Mask for TRIP when Block Trip is not asserted
R	=	Relay Word
Z3RB	=	Zone 3 Reverse Block

ECHO Conversion to Trip (ECTT)

Example Event Report 4 shows a scenario where the source behind Breaker 1 has grown very weak because Line 2 is removed from service while generation is reduced behind Bus A. The event report for this example shows a three-phase fault on Line 1. The protection at Breaker 2 has sufficient fault current to pick up its Zone 1 distance elements. Due to the weak source behind the relay at Breaker 1, the fault current is insufficient to pick up any relay elements at this terminal. No fault detecting elements are asserted at the time of trip, the fault type in the event report is designated as TRIP.

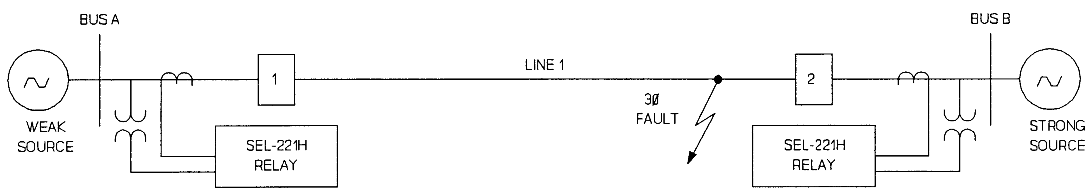


Figure 4.4: Weak Source Behind Terminal 1

Example Event Report 4

```
Example 230 kV Line                             Date: 1/1/92      Time: 09:41:43.083

FID=SEL-121H-R400-V656mptr1s-D900823

                    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      -94       76       25   -59.5   -73.9   133.6 ...... ....... ....*.
     0       0      -25      -69      101   119.4  -111.4    -8.7 ...... ....... ....*.
     0       0       94      -72      -25    56.6    77.5  -134.3 ...... ....... ....*.
     0       0       41       76     -123  -104.3    84.4    20.4 ...... ....... ....*.

     0       0     -123       91       31   -41.1   -60.3   101.9 ...... ....... ....*.
     0      -2      -57     -107      167    65.9   -46.8   -19.4 ...... ....... ....*.
     0       2      167     -126      -41    23.8    32.0   -56.1 ...... ....*.. ....*.
     0       2       57      135     -192   -39.6    34.9     5.0 ...... ....*.. .*..*.

     0      -2     -186      142       44   -18.4   -23.3    41.9 ...... ....*.. .*..*.
     0       0      -57     -138      195    36.2   -33.4    -3.0 ...... ....*.. .*..*.
     0       0      189     -145      -47    17.6    22.2   -40.1 ...... ....*.. .*..*.
     0      -2       57      138     -192   -35.7    33.3     2.7 ...... ....*.. .*..*.

     0       2     -189      145       50   -17.6   -22.1    40.0 ...... ....*.. .*..*.
     0       4      -53     -138      189    35.7   -33.2    -2.6 ...... ....*.. .*..*.
     0      -4      189     -145      -50    17.5    22.1   -40.0 ...... ....*.. .*..*.
     3      -4       50      138     -189   -35.7    33.2     2.6 ...... *.*.*.. .*..*.

    -3       4     -189      145       50   -17.5   -22.1    40.0 ...... *.*.*.. .*..*.
    -3       2      -53     -138      189    35.7   -33.2    -2.6 ...... *.*.*.. .*..*.
     3      -2      189     -145      -50    17.5    22.1   -40.0 ...... *.*.*.. .*..*.
     0      -2       57      138     -189   -35.7    33.2     2.6 ...... *.*.*.. .*..*.

     0       0     -189      145       50   -17.5   -22.1    40.0 ...... *.*.*.. .*..*.
     0       4      -57     -138      189    35.7   -33.2    -2.8 ...... *.*.*.. .*..*.
     0       0      189     -145      -50    16.4    23.7   -40.1 ...... *.*.*.. .*..*.
     0      -2       25      126     -142   -29.3    21.6     7.8 ...... *.*.*.. .*..*.

     0       0     -129       94       31   -59.5   -73.9   133.6 ...... *.*.... ......
     0       0        3      -63       53   119.4  -111.4    -8.7 .....* *.*.... ......
     0       0       38      -25       -6    56.6    77.5  -134.3 .....* *.*.... ......
     0       0        3        6       -6  -104.3    84.4    20.4 .....* *.*.... ......

     0       0       -6        3        0   -59.5   -73.9   133.6 .....* *.*.... ......
     0       0        0        0        0   119.4  -111.4    -8.7 .....* *...... ......
     0       0        3        0        0    56.6    77.5  -134.3 .....* *...... ......
     0       0       -6        3        0  -104.3    84.4    20.4 .....* *...... ......

     0       0        0        0        0   -59.5   -73.9   133.6 .....* *...... ......
     0       0        6       -3        0   119.4  -111.4    -8.7 .....* *...... ......
     0       0        0       -3        0    56.5    77.5  -134.3 .....* *...... ......
     0       0       -6        3        0  -104.3    84.4    20.4 .....* *...... ......

     3       0        0        0        0   -59.5   -73.9   133.6 .....* *...... ......
    -3       0        3       -3        0   119.4  -111.4    -8.7 .....* *...... ......
    -3       0        0        3        0    56.5    77.5  -134.3 .....* *...... ......
     3       0        0        3        0  -104.3    84.4    20.4 .....* *...... ......

     0       0        0       -3        0   -59.5   -73.9   133.6 .....* *...... ......
     0       0        0       -3        0   119.4  -111.4    -8.7 .....* *...... ......
     0       0        3        3        0    56.5    77.5  -134.3 .....* *...... ......
     0       0        0        3        0  -104.3    84.4    20.4 .....* *...... ......

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

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
Z1%  =80.00      Z2%  =120.00    Z3%  =120.00
Z2DP =20.00      Z3DP =60.00     A1TP =0.00      A1TD =0.00
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
Z2DG =30.00      Z3DG =60.00
TDUR =9.00       52BT =20.00     ZONE3=R         Z3RBT=4.50     BZ3RB=1.50
ETDPU=2.00       EDUR =3.50      WFCE =Y         27PP =160.00   59N   =6.00
32QE =Y          32VE =N         32IE =N         LOPE =Y
TIME1=5.00       TIME2=0.00      AUTO =2         RINGS=7.00

Logic settings:

MTU  MPT  MTB  MTO  MA1  MA2  MA3  MA4
80   40   00   D4   00   00   00   80
C4   22   00   E6   00   00   00   00
CA   00   00   00   10   20   00   00
33   10   00   00   00   00   04   00
```

The following is an excerpt from Example Event Report 4; it shows the first 16 quarter-cycles of data recorded by the relay.

		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	0	-94	76	25	-59.5	-73.9	133.6	......	....	....*.	1
0	0	-25	-69	101	119.4	-111.4	-8.7	......	....	....*.	2
0	0	94	-72	-25	56.6	77.5	-134.3	......	....	....*.	3
0	0	41	76	-123	-104.3	84.4	20.4	......	....	....*.	4
0	0	-123	91	31	-41.1	-60.3	101.9	......	....	....*.	5
0	-2	-57	-107	167	65.9	-46.8	-19.4	......	....	....*.	6
0	2	167	-126	-41	23.8	32.0	-56.1	......	....*..	....*.	7
0	2	57	135	-192	-39.6	34.9	5.0	......	....*..	.*..*.	8
0	-2	-186	142	44	-18.4	-23.3	41.9	......	....*..	.*..*.	9
0	0	-57	-138	195	36.2	-33.4	-3.0	......	....*..	.*..*.	10
0	0	189	-145	-47	17.6	22.2	-40.1	......	....*..	.*..*.	11
0	-2	57	138	-192	-35.7	33.3	2.7	......	....*..	.*..*.	12
0	2	-189	145	50	-17.6	-22.1	40.0	......	....*..	.*..*.	13
0	4	-53	-138	189	35.7	-33.2	-2.6	......	....*..	.*..*.	14
0	-4	189	-145	-50	17.5	22.1	-40.0	......	....*..	.*..*.	15
3	-4	50	138	-189	-35.7	33.2	2.6	......	*.*.*..	.*..*.	16

The outline below lists observed incidents in Example Event Report 4 on a quarter-cycle basis.

Quarter Cycle	Event Report Shows:
1-6	Prefault conditions: • No residual current in IR column indicates balanced load currents. • No protective relay elements are picked up. • * in 52A column verifies breaker closure (as does load current flow).
7	Weak-infeed condition detected: • * in A3 output column indicates detection of a WFC condition at Breaker 1. See following WFC calculations for 27PP element pickup. WFC bit in Relay Word remains asserted until row 24.
8-15	• * in PT input column indicates arrival of permissive trip signal from Breaker 2. PT input remains asserted until row 24.
16	• * in TP output column indicates Echo-Conversion-To-Trip conditions are satisfied and the TRIP output closes. Note that ECTT required four conditions: 1. Breaker closed as judged by 52A input assertion. 2. No Z3RB condition. 3. A WFC condition. 4. PT input asserted for ETDPU time.

Quarter-cycle 7 of this event report shows a weak-infeed condition (WFC bit in the Relay Word). This WFC results from the phase-to-phase voltage level dropping below the 27PP setting threshold. Because this is a three-phase fault, the residual overvoltage element (59N) never asserts. For instance, the phase-to-phase voltage V_{ab} in rows 6 and 7 is:

$$\begin{aligned} V_{ab} &= V_a - V_b \\ &= (23.8 - 32.0) + j(65.9 + 46.8) \\ &= 113.0 \angle 94.2^\circ \text{ kV} \end{aligned}$$

Since 113 kV is lower than the 27PP setting of 160 kV and the WFC setting is Y, the WFC bit set in row 7 of the event report.

FIRMWARE IDENTIFICATION

The SEL-221H relay provides a means of interpreting Firmware Identification Data (FID). The FID string is included near the top of each long event report. The string format is as follows:

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

Where:

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

[RN] = Revision Number (e.g., 400)

[VS] = Version Specifications (e.g., 656mptr1s)

[RD] = Release Date (e.g., YYMMDD=901016)

For the SEL-221H 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 LED's
G	c, r	cumulative, recent	Target LED Update Logic
H	1, 2	1.5, 2.0	Zone 4 size = [H] * Zone 3
I	s, m	standard, modified	Command Access Level

Please contact Schweitzer Engineering Laboratories, Inc. for information concerning available versions of the SEL-221H relay. Version specifications provided above are not intended for ordering purposes but as an identification of the software installed in a relay.

APPLICATIONS
TABLE OF CONTENTS

TABLES

FIGURES

APPLICATIONS

SCHEMES INVOLVING COMMUNICATIONS

The SEL-221H relay is the ideal relay for use in communications based schemes. 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 SEL-221H relay provides time-stepped backup protection without the need for external wiring modifications or dedicated input contacts.

In Permissive Overreaching Transfer Tripping (POTT) schemes, special logic is included in the SEL-221H relay to overcome the typical deficiencies. Typical POTT schemes are vulnerable to the following conditions and may result in an incorrect trip if special logic and provisions are not provided to account for these:

- Current reversals.
- Weak-infeed conditions at one terminal.
- Breaker open at one terminal.
- Switch-onto-fault conditions.

While communications equipment circuitry may account for these shortcomings, it may not be available for applications where only the protective relaying is being upgraded, or when dependence on this external circuitry is neither economical nor desirable.

The SEL-221H relay logic accounts for the deficiencies listed above. If the communication channel is lost or out of service, time-step backup protection is provided without special switching or detection schemes. The SEL-221H relay is also capable of supporting direct and permissive underreaching transfer tripping schemes, direct transfer trip schemes, and unblocking schemes.

Event reporting and fault-locating features provide an important system performance analysis tool. The event report shows the voltages, currents, relay elements, inputs (including the arrival of the permissive signal) and outputs (including the permissive keying signal), which simplify the process of evaluating scheme performance.

Replacement of Outdated Protective Relays

The SEL-221H 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 SEL-221H relay meets this requirement by utilizing the widely used compensator distance measuring principles for the 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 replacement of electromechanical relays with SEL-221H relays especially convenient in crowded substations. Both horizontal and vertical mounting configurations are available. The required panel cutout dimensions are equivalent to that of a single electromechanical distance relay, which eliminates panel cutting where relays already exist. 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-221H relay an attractive alternative for overburdened current and potential transformers.

Time-Step Relaying

The SEL-221H relay provides three zones of time-step protection with separate timers for phase and ground faults in Zones 2 and 3; Zone 1 is always instantaneous. In such applications, the SEL-221H relay is the only instrument needed for primary relaying. 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. Nominal secondary currents for normal load flow should be approximately 5 amperes.

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

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.

SELECTION OF DISTANCE ELEMENT REACHES

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

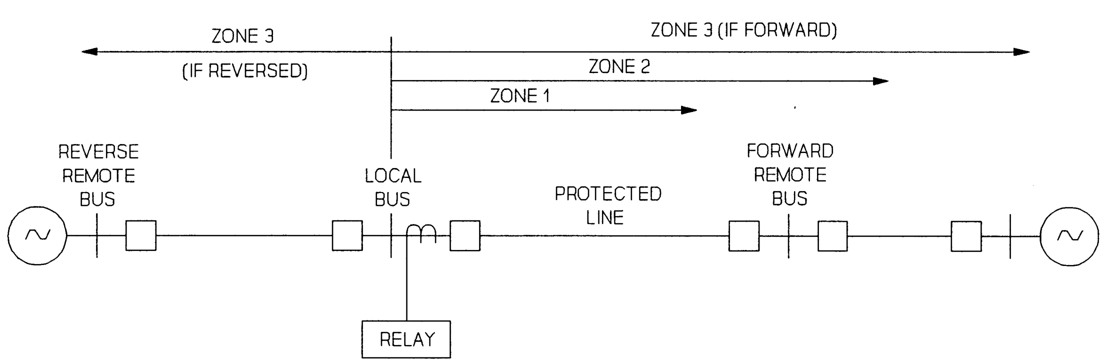


Figure 5.1: System Single Line Diagram

CHOICE OF ZONE 1 DISTANCE ELEMENT REACH

Typically, the Zone 1 reach is 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, independent 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 five percent, errors in the CT and PT ratios, modeled transmission line data, and fault study data do not permit Zone 1 element settings for 100% of the transmission line.

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 Permissive Overreaching Transfer Trip (POTT) applications, the Zone 2 elements at both terminals must detect internal faults and key permissive trip. To assure detection of end-of-line faults where parallel source infeeds may increase 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 requirement avoids race conditions between the 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 are used in the current reversal guard, echo, and weak-infeed logic for Permissive Overreaching Transfer Trip (POTT) schemes. In Directional Comparison Blocking (DCB) schemes, these same reverse looking Zone 3 elements act as carrier start elements. In both applications, the Zone 3 elements are reversed and must detect all out-of-section faults the remote Zone 2 elements sense. The time delayed outputs of the Zone 3 elements can also serve as remote backup for faults behind the relay location.

In the POTT and 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 act as remote backup for faults at remote buses two line sections from the local terminal.

CHOICE OF ZONE 2 AND ZONE 3 TIME DELAY SETTINGS

The time delayed Zone 2 and Zone 3 elements coordinate time-step protection. Time delay selections must coordinate with the protection at the remote terminal and local bus. Both the 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 Zone 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 delay allows time for the remote Zone 1 elements to pick up plus breaker operating time. Settings for the Zone 2 residual overcurrent element depend on the strength of the 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 as well as the remote Zone 2 elements when Zone 3 is forward reaching. A typical phase distance time delay setting for Zone 3 is 60 cycles.

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

The 50L element provides fault detector supervision of the mho distance elements and must pick up for all fault conditions where a distance element is expected to operate. The ideal setting for the 50L element is above load but below minimum fault duty. For instance, when Zone 3 is reversed, the 50L element must pick up for minimum fault duty on either side of the relay. While 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 can operate. For three-phase faults, the current magnitude in all three phases must exceed the 50L pickup threshold before the three-phase distance elements operate.

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.

50M, Medium-Set Phase Overcurrent Element

The 50M element is a conditional in the loss-of-potential (LOP) logic for three blown PT fuses and provides non-directional phase overcurrent protection after an LOP condition is declared. When enabled, an LOP condition blocks the mho distance elements from operating due to the loss of a sound voltage reference for these elements. As a means of protecting the transmission line locally until the blown potential fuse condition can be remedied, non-directional 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 not exceed the 50M pickup threshold under maximum load conditions. This assures 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 potential 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 measures the positive-sequence voltage magnitude.

The 50M element setting must be above load, but below the minimum phase-phase or three-phase fault duty for the 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, the pickup of the 50M element after a loss-of-potential condition starts a definite-timer labeled 50MFD. Once the 50MFD timer 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 employed, the level of polarizing voltage required by the three-phase distance elements is never established. In this situation, the elements are blocked from operating. The 50H element is provided to prevent such a failure to trip the line breaker. The 50H element measures the magnitude of current in each phase with no dependence on polarizing voltages. This element is non-directional 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 the fault duty in front of the line terminal is much greater than behind the line terminal, the 50H element can also be used in the unconditional trip logic mask (MTU) to provide rapid clearance of close-in faults.

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

CHOICE OF RESIDUAL TIME-OVERCURRENT PICKUP SETTING

Select the pickup setting of the residual time-overcurrent element by consulting a fault study. 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. As the measure of residual current varies with system switching configuration, fault location, and fault resistance, a complete fault study must be performed to determine the minimum pickup setting and appropriate time dial. When enabled as directional, only consider 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. These overcurrent elements are made directional by selecting a residual polarizing method: 32QE, 32VE, or 32IE. Zones 2 and 3 each have an associated timer to provide time-stepped protection.

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). 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 Zone 3 setting. When reversed, the relay uses status of the instantaneous 67N3 element in the current reversal, weak-infeed, and echo logic for POTT schemes.

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.

SWITCH-ONTO-FAULT LOGIC (MTO LOGIC MASK)

The relay has switch-onto-fault logic which allows very sensitive overreaching elements to be enabled for a short duration after the line breaker is closed to test the line. This logic permits instantaneous tripping of the line breaker for end-of-line faults which would normally be cleared in Zone 2 time. In POTT schemes, the time required to echo the permissive signal to the remote terminal and back is greater than the time required to issue a trip via the switch-onto-fault logic. The following list illustrates the four tripping masks and the differences in their qualifying logic:

MTU	≡	Mask for trip unconditional (no logic qualifiers),
MPT	≡	Mask for trip with the permissive trip input asserted and no reverse block,
MTB	≡	Mask for trip with the block trip input not asserted,
MTO	≡	Mask for trip while the 52BT element is asserted.

The 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. This 52BT element may be thought of as an inverted time delayed follower of the 52A input. When the 52A input to the relay changes from an asserted (breaker closed) to a deasserted state (breaker open), the 52BT element remains low for the 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, the 52BT remains high for 52BT time. Thus, for 52BT time after the breaker is closed, the assertion of any element selected in the MTO logic mask closes the TRIP output contacts. This logic provides Switch-On-To-Fault (SOTF) protection.

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

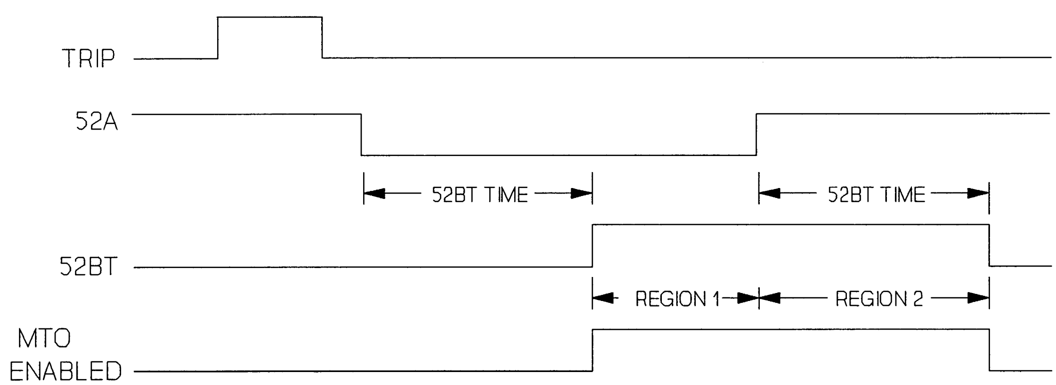


Figure 5.2: 52A Input and 52BT Timing Diagram

During the time period shown for Regions 1 and 2, the MTO logic is enabled. During Region 1, the MTO logic is enabled to protect the open line breaker. Thus, for line breaker tank faults the relay can issue a trip signal required for breaker failure schemes. Any time delay associated with the circuit breaker auxiliary contact opening is accounted for during the time shown in Region 1.

Region 2 shows the time period where the MTO logic is performing true switch-on-to-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 after the line breaker is closed. Normally, these sensitive elements are only used for tripping in conjunction with a qualifying permissive signal from the remote end of the line (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. Further 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. By employing the MTO logic of the relay, the non-time delayed Zone 2 phase elements detect the fault and instantly issues a trip signal. This reduces the amount of time the transmission line is exposed to the fault energy. The possibility of overreaching the remote terminal with the instantaneous Zone 2 element is nonexistent because Breaker 2 is open while the MTO logic of Breaker 1 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 when the elements of the MTO mask can trip the breaker: 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. Typical settings for the 52BT setting are 15 - 20 cycles.

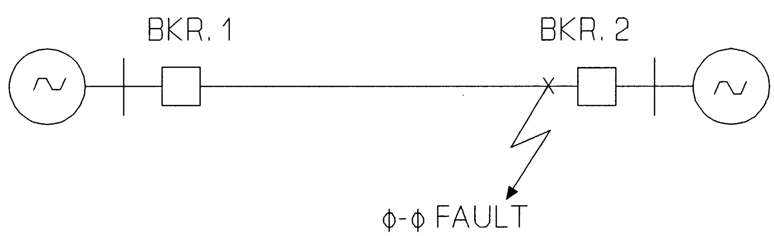


Figure 5.3: Faulted Line with All Sources In

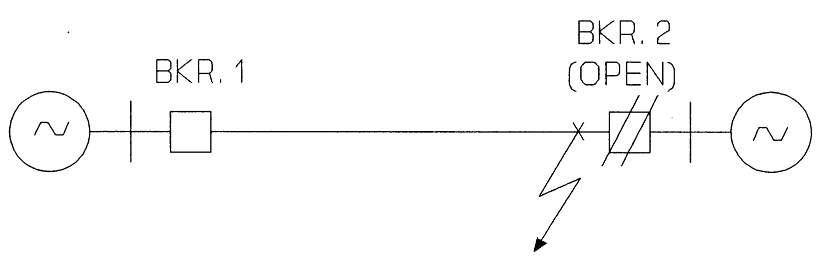


Figure 5.4: Faulted Line with Breaker 2 Open

CURRENT REVERSAL LOGIC AND TIMERS

In double circuit line applications, faults near one end of the line may result in a sequential trip operation. This happens when the breaker nearest the fault is tripped by instantaneous protection independent from the communication scheme. This sequential fault current clearance creates a current reversal in the healthy parallel line. Figure 5.5 shows a double circuit line configuration at the inception of the fault; Figure 5.6 shows the configuration after one breaker has opened.

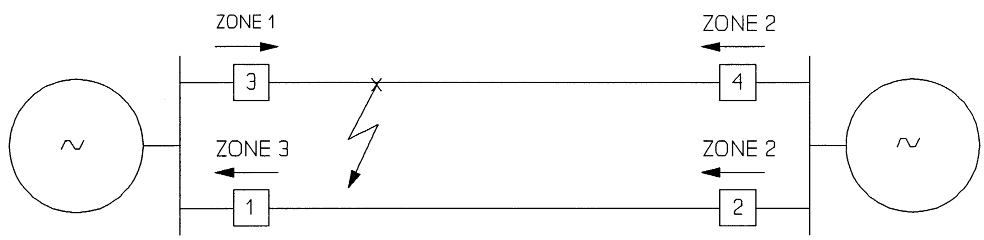


Figure 5.5: Fault Inception with All Sources In

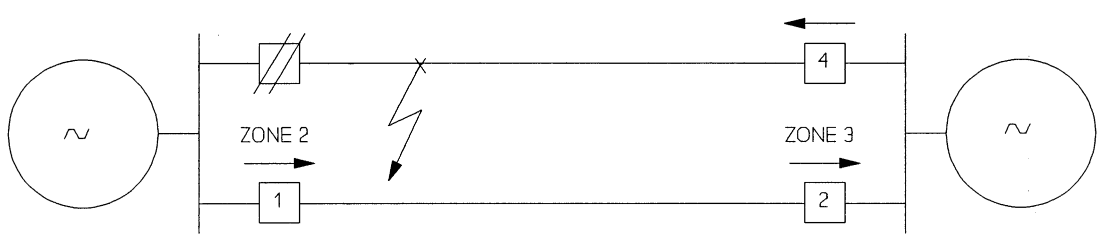


Figure 5.6: Faulted System with Breaker 1 Open

In Figure 5.5, the relay at Breaker 3 detects the fault within Zone 1 and issues a trip signal independent from the communication scheme. When the Zone 1 element at Breaker 3 detects the fault, the Zone 2 elements simultaneously pick up and issue a permissive signal to the protection at Breaker 4. The protection at Breaker 4 detects the fault within Zone 2, but must wait for the permissive signal from Breaker 3 before issuing a permissive qualified trip output.

Notice in Figure 5.5 that the Zone 2 element at Breaker 2 of the healthy line also picked up at the initial fault inception. It issues a permissive signal to the protection scheme at Breaker 1. While the Zone 2 elements are picked up at Breaker 2, the Zone 3 elements are picked up at Breaker 1, indicating that the fault is reverse to its location.

After Breaker 3 opens, the fault currents redistribute so the Zone 2 element at Breaker 2 and Zone 3 element at Breaker 1 begin to drop out. If the Zone 2 element at Breaker 1 picks up before the received permissive signal has reset, Breaker 1 trips due to the current reversal.

To preserve the security of the healthy line, the relay uses internal logic to detect the potential current reversal in the healthy line after a fault on a parallel line. Notice in Figure 5.5 that the Zone 3 elements at Breaker 1 were initially picked up. This is a critical indicator that an out-of-section fault is present: a current reversal may soon take place in the healthy line.

The following steps and the timing sequence in Figure 5.7 outline the logic process which safeguards Breaker 1 against a misoperation during the current reversal condition described above:

<u>Time Reference</u>	<u>Logic Performed</u>
Fault Inception	● At Breaker 1: - Zone 3 element picks up - Breaker is in the closed state - Reverse Block Timer initiated to block permissive logic, Z3RB is a logic state "1" - Permissive Signal is received from Breaker 2. In actual practice the Zone 3 element at Breaker 1 should assert before the Zone 2 elements at Breaker 2 pickup. Communication channel time is assumed to be near zero for this example. ● At Breaker 2 - Zone 2 element picks up - Breaker is in the closed state
Breaker 3 Opens	● At Breaker 1: - Zone 3 element drops out - Zone 2 element picks up - Permissive Signal is still present from Breaker 2 - Reverse Block Timer begins timing to drop out, Z3RB is still in logic state "1" - Z3RB blocks sending a permissive signal to Breaker 2 ● At Breaker 2: - Zone 2 element drops out - Zone 3 element picks up - Breaker is in the closed state - Reverse Block Timer initiated to block permissive logic, Z3RB is a logic state "1"
Breaker 4 Opens	● At Breaker 1: - Zone 2 element drops out ● At Breaker 2: - Zone 3 element drops out - Reverse Block Timer completes timing out

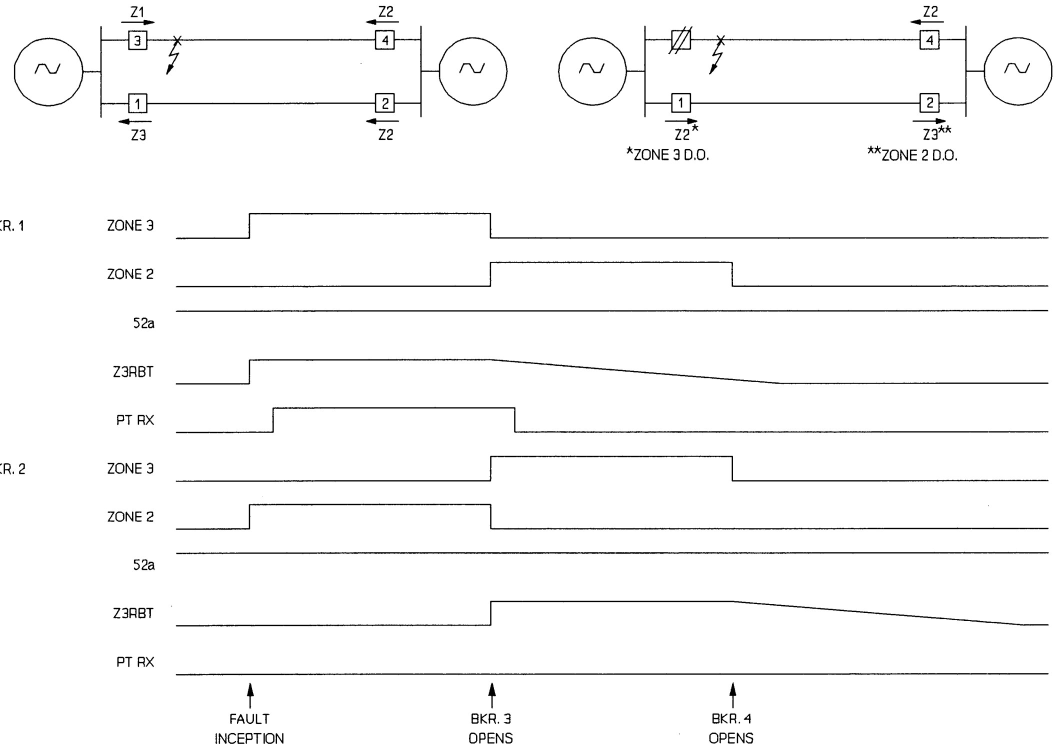


Figure 5.7: Current Reversal Timing Sequence

As shown in the timing sequence in Figure 5.1, the key factors in the current reversal logic are pickup of the reverse looking Zone 3 elements and time delayed dropout of the Zone 3 Reverse Block Timer (Z3RB).

Factors which influence the Z3RB timer setting are channel pickup delay, channel reset delay, and the maximum expected clearing time of the parallel faulted line. For instance, given the following for the circuit shown in Figure 5.6:

Channel operate and reset delay = ½ cycle each
Breaker operate time = 3 cycles
Relay time = 1 cycle (operate and reset)

A fault near one terminal on the parallel line would be totally cleared in eight and one-half cycles (four cycles near end, four and one-half cycles remote end). The Z3RB timer must be set so that after the current reverses in the healthy line, the near terminal neither issues a permissive signal, nor allows a permissive signal assisted trip. Given that the Z3RB timer does not begin to decrement until the Zone 3 elements drop out, a conservative Z3RB setting would be the sum of breaker operate time, channel reset time, and remote element reset time.

The current reversal logic described above may create a problem when the line breaker first energizes the transmission line or recloses into a fault. This problem stems from possible line breaker pole closing disymmetry and the time required to charge line potential transformers. Figure 5.8 illustrates this hazard. If the first pole of the line breaker to close belongs to the faulted phase, the directional element for the residual overcurrent relay declares the fault direction as reverse until the remaining breaker poles close. If logic does not account for this possible pole closing disymmetry, the Zone 3 reverse block timer is enabled and permissive trip logic is blocked for a period equal to the Z3RB timer setting. As a result, the fault clearance is greatly delayed when MTO logic is not employed.

To avoid this potential problem, the relay includes logic to block the reverse block signal issued by the reverse elements for a settable time delay after the breaker has closed. The 52A contact of the line breaker and/or line disconnect switches key this block-the-block action. Typical BZ3RB settings are one to two cycles.

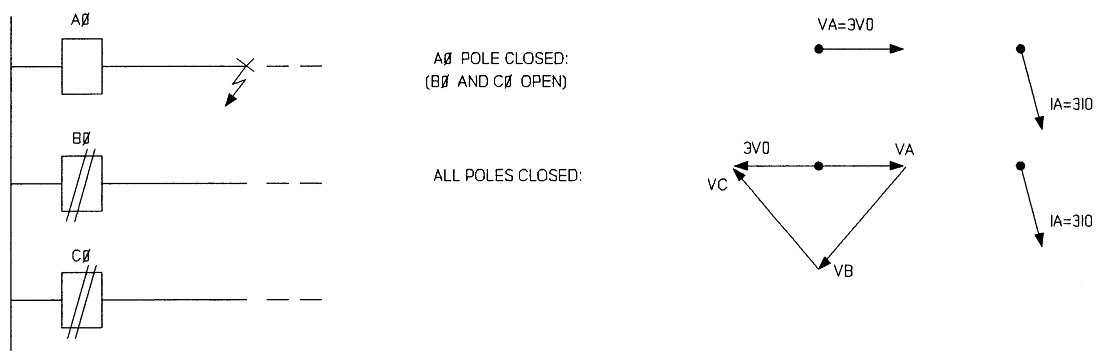


Figure 5.8: Pole Closing Disymmetry Example

ECHO KEYING

Permissive overreaching transfer trip schemes require permission from both terminals to achieve accelerated trip times for internal faults along the entire line. When one line terminal is open, its protective relays are unable to detect an internal fault and cannot issue permission to the remote terminal. This usually requires that end-of-line faults be cleared by Zone 2 time delayed elements. The SEL-221H relay permits rapid clearance of end-of-line faults via the permissive scheme. The permissive scheme includes logic to "echo" the received permissive signal to the remote terminal from the open terminal breaker. This echoed signal permits rapid clearance of internal faults when one line terminal is open.

The simplest means of echoing the permissive signal from the remote terminal is a 52b contact of the open breaker. However, this solution is undesirable because it can result in constant keying of the permissive signal from both terminals after they open to clear an internal fault.

In the SEL-221H relay logic, the following conditions must be met before a received permissive signal is repeated or echoed to the initiating terminal:

1. A reverse fault must not have been detected by the reverse looking elements.
2. The permissive signal must be received for a settable length of time.

The first requirement assures that the fault is not behind the relay location before transmitting permission to the remote terminal (assuming the Zone 2 elements at the remote breaker detected a fault and sent a permissive signal). The second requirement prevents the relay from issuing a permissive signal to the remote terminal for communication channel noise. This noise, detected at the local breaker, is caused by an out-of-section fault. The second requirement also allows time for the reverse looking elements to assert. This permissive trip signal qualifying time is determined by the Echo Time Delay Pickup (ETDPU) timer setting.

Once the echoed permissive signal is issued to the remote terminal, its duration must be limited to prevent a situation where both terminals maintain the permissive signal channel in a continuous "trip keyed" or constantly "on" state. The relay logic prevents this condition by limiting the echoed permissive trip signal to a settable duration. This duration is determined by the Echo Duration Timer (EDUR) setting.

Typical PT signal qualifying timer settings (ETDPU) are one to two cycles. This setting is influenced by communication channel operation times plus the operation speed of the remote line breaker.

It is desirable to maintain the echoed permissive trip signal to the remote breaker until the fault is cleared. Assuming a three cycle breaker and one-half cycle channel operation time, a typical EDUR setting would be three and one-half cycles.

WEAK-INFEED LOGIC AND SETTINGS

In some applications, with all sources in, one terminal may not contribute enough fault current to operate the protective elements. If the fault lies within the Zone 1 reach of the strong terminal, the fault currents may redistribute after the strong terminal line breaker opens to permit sequential tripping of the weak-infeed terminal line breaker. If currents do not redistribute sufficiently to operate the protective elements at the weak-infeed terminal, it is still desirable to open the local breaker. This prevents the low level currents from maintaining the fault arc and allows successful autoreclosure from the strong terminal. When the fault location is near the weak terminal, the Zone 1 elements of the strong terminal do not pick up and the fault does not clear rapidly. This is because the weak terminal protective elements do not operate. Note that while the weak-infeed terminal contributes little fault current, the phase voltage(s) are depressed.

The SEL-221H relay provides additional logic for weak-infeed terminals to permit rapid tripping of both line terminals for internal faults near the weak terminal. The strong terminal is permitted to trip via the permissive signal echoed back from the weak terminal. The weak terminal is tripped by converting the echoed permissive signal to a trip signal after the following conditions are met:

1. No reverse looking elements have picked up.
   For faults behind the relay location, the reverse elements operate to inhibit the operation of the weak-infeed and echo logic.
2. At least one phase-phase undervoltage or the residual overvoltage element operates.
3. The line terminal breaker is closed.
4. A permissive trip signal is received for ETDPU time period. The received PT signal is initiated by the overreaching remote terminal Zone 2 Elements.

After these four conditions are met, the weak-infeed logic sets the Echo Conversion To Trip (ECTT) bit in the Relay Word. This bit may be masked in the MTU logic mask to permit tripping the local breaker under the conditions described above.

Typical phase-phase undervoltage settings (27PP) are 70-80% of the lowest expected system operating voltage. The residual overvoltage setting should be set to approximately twice the expected standing V0 voltage. With the 59N element set at twice the nominal standing V0 voltage, the instrument measures only fault induced zero-sequence voltage.

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 while the other end of the same line is connected to a strong generation source. When a parallel circuit has a double-line-to ground fault in a double circuit line configuration, it can cause the strong positive- and negative-sequence source end of the healthy line to issue a permissive signal from its phase distance relaying. Meanwhile, the other end of the healthy line can issue 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 the 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 is to remain zero-sequence for at least one terminal, zero-sequence should be retained. This assumes adequate levels of polarizing quantities exist at all terminals.

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 voltage polarization is a viable method.

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 breakers results in a loss-of-potential of polarizing inputs to the relay. Loss of one or more phase voltages disable the relay; 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 falls 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.

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

Purpose

This example shows the steps for setting the relay at Breaker 3 to protect Line 2 in Figure 5.9 between Buses B and C. The basic criteria for protecting this line appear below:

- The communications scheme is Permissive Overreaching Transfer Trip (POTT)
- Zone 2 and Zone 3 serve as time-step backup
- Breaker 3 may be a weak-infeed terminal
- Current reversals may occur at the Breaker 3 location
- The minimum expected running system voltage is 87% of nominal
- The maximum expected load is less than 450 A

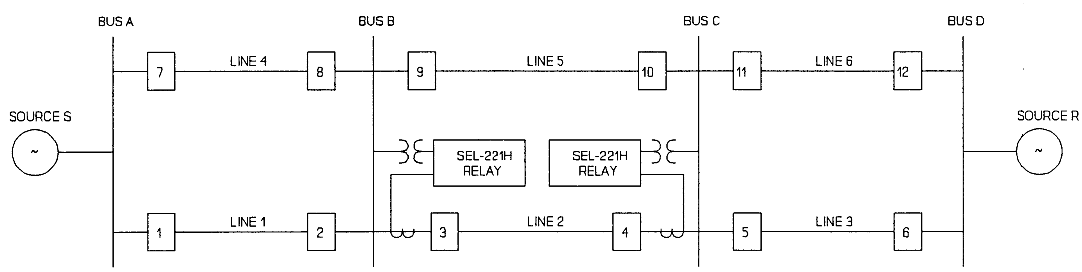


Figure 5.9: 230 kV Setting Example System Single-Line Diagram

System Data

Nominal System Voltage	:	230 kV (132.8 kV line-neutral)	
Line Length	:	100 miles	
Line 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)
Source Impedances:			
Source S = Source R	:	Z1S = Z1R = 29.34 $\angle$83.72°	(primary Ω)
	:	Z0S = Z0R = 3 x 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 5.9.

The values you 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.

```
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%
PTR - 27PP, 59N

■ 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°. Notice this value matches the positive-sequence line of 83.72°.

```
MTA = 83.72
```

- Setting Limit Check

The primary setting range check allows MTA settings from 47° - 90°. There is no secondary setting range 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, the fault locating capability of the relay is desired.

```
LOCAT = Y
```

- Setting Limit Check

There is no setting limit check for this setting. The fault locator is either enabled (Y) or disabled (N).

- Other Settings Affected

None.

■ 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.

$$Z1 \text{ Reach} = 0.80 \times 78.24\ \Omega \text{ primary} @ 83.72° = 62.59\ \Omega \text{ primary} @ 83.72°$$

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

$$\text{Secondary Ohms} = \left[\frac{62.59\ \Omega \text{ primary}}{10}\right] = 6.259\ \Omega \text{ secondary along the MTA}$$

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 either 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
Z1L for Line 3 = Z1L 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 the 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.

$$\text{Line 2 Impedance} + [0.8 \times \text{Line 3 Impedance}] = 78.24\ \Omega + [0.8 \times 39.12\ \Omega] = 109.54\ \Omega \text{ primary}$$

When Zone 2 at Breaker 3 has a set reach of 120%, the effective reach is:

Zone 2 @ Bkr. 3 = $1.20 \times 78.24\ \Omega = 93.89\ \Omega$ along the line angle

Since $93.89\ \Omega < 109.54\ \Omega$, 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 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

$$\text{Secondary Ohms} = \left[\frac{93.89\ \Omega \text{ primary}}{10}\right] = 9.389\ \Omega \text{ secondary along the MTA}$$

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 and Z2P bits of the Relay Word depend on the Z2% setting.

■ Zone 3 Reach Setting (Z3%)

This example uses a Permissive Overreaching Transfer Trip (POTT) communication scheme. The current reversal echo and weak-infeed logic require reversal of the Zone 3 elements. This is accomplished by selecting ZONE 3 = R later in the setting procedure. The Zone 3 element reach at Breaker 3 must be selected to detect all out-of-section faults also detected by the overreaching elements at Breaker 4. At a minimum, the Zone 3 reach setting must equal the impedance the overreaching element at Breaker 4 sees behind Breaker 3.

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, the 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

$$\text{Secondary Ohms} = \left[\frac{93.89\ \Omega\ \text{primary}}{10}\right] = 9.389\ \Omega\ \text{secondary along the MTA}$$

The Z3% setting of 120 for this example is within the primary and secondary setting limits of the relay.

- Other Settings Affected

Zone 4 reach. Zone 4 is internally set to 1.5 x Zone 3. The 3ABC, 4ABC, and Z3P bits in the Relay Word depend on the Z3% setting.

■ **Zone 2 Phase Time Delay (Z2DP)**

The Z2DP timer adds a settable delay to the instantaneous outputs of the Zone 2 phase-phase (Z2P) and three-phase (2ABC) elements. 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 setting limits of the relay. 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 2 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 setting limits of the relay. There is no secondary limit check for this setting.

- Other Settings Affected

Z3PT bit in the Relay Word.

■ A1 Output Contact Time Delay Pickup (A1TP)

The A1 output contact setting can include a time delay pickup. In this example, the A1 contact is connected to the permissive keying contact of the communications equipment. By including the "KEY" bit in the MA1 mask, the communications channel is keyed from guard to trip frequency when the A1 output contacts close. In this example, no intentional delay on pickup is desired for this contact.

```
A1TP = 0.00
```

- Setting Limit Check

The limit check allows A1TP time delays of 0 - 8000 cycles. The A1TP timer setting of zero cycles lies within the setting limits of the relay.

- Other Settings Affected

None.

■ A1 Output Contact Time Delay Dropout (A1TD)

The A1 output contact programming can include a time delay dropout as well as a time delay pickup. In this example, no intentional delay on dropout is desired for this contact.

```
A1TD = 0.00
```

- Setting Limit Check

The limit check allows A1TD time settings of 0 - 8000 cycles. The A1TD timer setting of zero cycles lies within the setting limits of the relay.

- Other Settings Affected

None.

■ Low-Set Phase Overcurrent Setting (50L)

The primary function of the 50L element is to supervise the phase distance elements. For three-phase faults, the current in each phase must exceed the 50L setting. Recall from the intermediate logic for the mho distance elements that the three-phase distance elements are logically ANDed with the 3P50 element (the 3P50 element is asserted when the magnitude of the current 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 5.9, 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 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 accounts for arc resistance and errors in fault study calculations. 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 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

$$\text{50L secondary amps} = \frac{275 \text{ A primary}}{200} = 1.38 \text{ A secondary}$$

The 50L setting of 275 A for this example lies within the setting limits of the relay.

- Other Settings Affected

50L bit in the Relay Word.

■ 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. 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 non-directional 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 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 setting limits of the relay.

- 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 5.9, 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. 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

$$\text{50H secondary amps} = \frac{3420}{200} = \text{17.10 A secondary}$$

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 (51N) 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 1, 2, 3, or 4 for the family of curves selection. 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 non-directional).

Calculations: CTR = 200:1

51NP secondary amps $= \frac{230}{200} = 1.15$ 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, and 50N3P 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

50N1P secondary amps = $\frac{835}{200}$ = 4.18 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 initiates keying of the permissive channel and qualifies the received permissive trip signal. Based on fault study, the minimum residual current measured at Breaker 3 for a fault at Bus C equals 460 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 secondary amps = $\frac{276}{200}$ = 1.38 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. The instantaneous output of this element initiates the current reversal logic. The non-assertion of this element is used as one of the qualifying conditions for echoing the received permissive signal during weak-infeed 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 secondary amps = $\frac{282}{200}$ = 1.41 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 Residual Overcurrent Time Delay (Z2DG)

This Zone 2 timer adds a settable definite delay to the overreaching Zone 2 instantaneous residual overcurrent element (67N2). 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 setting limits of the relay. 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 setting limits of the relay. 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 lesser 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 setting limits of the relay. There is no secondary limit check for this setting. When TDUR = 0, the OPEN command is disabled.

- Other Settings Affected

TRIP bit in the Relay Word.

■ **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 the closure of the line breaker 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 is to be high speed at 25 cycles. To ensure that the 52BT element is asserted before reclosure of the line breaker, 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 setting limits of the relay. There is no secondary limit check for this setting.

- Other Settings Affected

52BT bit in the Relay Word.

■ 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 current reversal, echo, and weak-infeed logic. The reverse Zone 3 elements provide time-step backup protection for Bus A.

```
ZONE3 = R
```

- Setting Limit Check

The Zone 3 setting must be set for either F (forward) or R (reverse). When the weak-infeed enable setting (WFCE) is set to Y (yes), the Zone 3 setting must be R. Otherwise, an error message results.

- Other Settings Affected

WFCE, Z2%, and Z3% reach limitations.

■ Zone 3 Reverse Block Timer Setting (Z3RBT)

The Zone 3 reverse block timer extends the block signal issued by reverse looking elements after a current reversal occurs and Zone 3 elements drop out. The Zone 3 relay elements do not encompass the origin. Therefore, no special timing considerations are needed to avoid a block for an initial internal fault on the protected line when the line breaker has been closed for BZ3RB time. The recommended time setting for the Z3RBT timer is the remote faulted terminal breaker time, communication channel reset time, and remote Zone 2 relay reset time. Assume a typical breaker operation time of three cycles, communication channel reset time of one-half cycle, and remote Zone 2 relay reset time of one cycle. The sum of these times gives a conservative Z3RBT timer setting of 4.5 cycles.

```
Z3RBT = 4.50
```

- Setting Limit Check

The primary limit check allows Z3RBT time delay settings of 0.0 - 8,000 cycles. The Z3RBT setting of 4.50 cycles lies within the setting limits of the relay. There is no secondary limit check for this setting.

- Other Settings Affected

KEY, TRIP, and ECTT bits in the Relay Word.

■ **Block Zone 3 Reverse Block Timer Setting (BZ3RB)**

The BZ3RB timer blocks the reverse block function of the current reversal logic for a settable time period immediately after the breaker closes. This function accounts for dissimilar line breaker pole closing, which can create a polarizing voltage polarity opposite that of the fault-derived polarity (see Current Reversal Logic and Timers information in this section). The BZ3RB timer setting should be set slightly longer than the maximum expected line breaker pole disymmetry during a closing operation. For this example, Breaker 3 is assumed to have a maximum pole scatter of 1.25 cycles.

```
BZ3RB = 1.50
```

- Setting Limit Check

The primary limit check allows BZ3RB time delay settings of -1.0 - 8,000 cycles (-1.0 disables the BZ3RB timer). The BZ3RB setting of 1.50 cycles lies within the setting limits of the relay. There is no secondary limit check for this setting.

- Other Settings Affected

KEY and ECTT bits in the Relay Word.

■ **Echo Time Delay Pickup Timer Setting (ETDPU)**

An echo delay ensures that the reverse elements at the receiving end have sufficient time to operate and block the echo repeat for faults behind that terminal. It also insulates the echo and weak-infeed logic against noise bursts which can occur on the communication channel mediums during close-in external faults. Typically, these noise bursts coincide with faults external to the line section.

Since the pickup time of the reverse elements and duration of these noise bursts are very short, the system requires a received permissive signal to be present for a short time before the permissive signal can be echoed back to the remote terminal or used in the Echo-Conversion-To-Trip (ECTT) logic. This timer specifies the duration of time a permissive trip signal must be present. The Echo Duration (EDUR) timer setting determines the length of time a permissive signal is echoed. The ETDPU setting depends upon your communications equipment, but a typical setting for this timer is approximately two cycles.

```
ETDPU = 2.00
```

- Setting Limit Check

The limit check allows for ETDPU time delay settings of 0.0 - 8,000 cycles. The ETDPU setting of 2.00 cycles lies within the setting limits of the relay. There is no secondary limit check for this setting.

- Other Settings Affected

PTEE bit in the Relay Word

■ Echo Duration Timer Setting (EDUR)

The Echo Duration Timer (EDUR) limits the duration of the echoed permissive signal. Once the echo signal is initiated, it should be maintained for a minimum period. The echo signal should be cut off after some time, even if the permissive signal is continuously received. This prevents permissive trip signal lockup between the two line ends. A typical EDUR timer setting is 3.50 cycles. Assume a three cycle breaker at the remote terminal and one-half cycle channel delay. The summation of remote breaker operation time plus channel delay gives an EDUR setting of 3.5 cycles.

```
EDUR = 3.50
```

- Setting Limit Check

The primary limit check allows EDUR time delay settings of 0.0 - 8,000 cycles. The EDUR setting of 3.50 cycles lies within the setting limits of the relay. There is no secondary limit check for this setting.

- Other Settings Affected

PTEE bit in the Relay Word.

■ Phase-Phase Undervoltage Setting (27PP)

The phase-phase undervoltage elements are one of two voltage conditionals for weak-infeed conditions at the local breaker. The pickup settings of these elements should be sensitive enough to detect end-of-line faults during special switching conditions (line out or a generation outage). Typical settings for the 27PP elements are 80% of the minimum system line-line voltage.

Minimum system voltage for this example is 200 kV:

$$
\begin{aligned}
27PP &= (200\ \text{kV})(0.8) \\
&= 160\ \text{kV}
\end{aligned}
$$

```
27PP = 160.00
```

- Setting Limit Check

The primary limit check allows 27PP settings of 0.00 - 2000 kV. The secondary limit check allows secondary voltage settings of 0 - 260 V_{l-l}.

Calculations: PTR = 2000:1

27PP secondary volts = $\frac{160 \text{ kV primary}}{2000}$ = 80.0 V_{l-l} secondary

The 27PP setting of 160 kV for this example lies between the 0.00 V and 260 V_{l-l} secondary setting limits.

- Other Settings Affected

WFC bit in the Relay Word.

■ Residual Overvoltage Setting (59N)

The residual overvoltage element is the second voltage conditional for weak-infeed conditions at the local breaker. The pickup setting of this element should be sensitive enough to detect single-line-to-ground faults at the remote end of the transmission line. Typical settings for this element are two to three times the standing zero-sequence voltage (V0) measured at the local line breaker. The standing voltage results from imperfectly matched PT ratios for each phase. To ensure that the measured V0 voltage for a fault is not that of the standing voltage, set the 59N pickup to twice the expected standing voltage. This rule of thumb gives adequate sensitivity for end-of-line faults.

Expected standing voltage for this example equals 1.5 V secondary. Therefore, the 59N element requires a secondary setting of 3 V or 6 kV primary.

```
59N = 6.00
```

-Setting Limit Check

The primary limit check allows 59N settings of 0.0 - 2000 kV. The secondary limit check allows secondary voltage settings of 0 - 150 V_{l-n}.

Calculations: PTR = 2000:1

59N secondary volts = $\frac{6 \text{ kV primary}}{2000}$ = 3 V secondary

The 59N setting of 6 kV for this example lies between the 0 V and 150 $V_{l\text{-}n}$ secondary setting limits.

- Other Settings Affected

WFC bit in the Relay Word.

■ Residual Overcurrent Polarization Method Selection (32QE, 32VE, and 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, the zero-sequence methods may not be selected. When you select zero-sequence polarization, one or both of the zero-sequence voltage and current polarizations methods may be selected.

- Other Settings Affected

None.

■ Loss-of-Potential Enable Setting (LOPE)

The loss-of-potential logic detects blown PT 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.

■ Weak-Infeed Conditional Enable (WFCE)

The WFCE setting enables or disables the weak-infeed feature of the relay. When the WFCE setting is Y, the Echo-Conversion-To-Trip (ECTT) logic is enabled. When the setting is N, ECTT logic is disabled. In applications where WFCE = N, your setting calculation procedure may be greatly simplified because the 27PP and 59N settings can both be set to zero. In the sample application, Breaker 3 becomes a weak terminal for various switching conditions, which requires that the WFCE setting be Y.

```
WFCE = Y
```

- Setting Limit Check

The primary limit check allows WFCE settings of Y (enabled) or N (not enabled). Remember, if WFCE = Y, the Zone 3 elements must be reversed.

- Other Settings Affected

The ECTT and WFC bits in the Relay Word. Zone 3 must be reversed when WFCE=Y.

■ Serial Port(s) Timeout Settings (TIME1 and 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 substation personnel as well as 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 - 30 rings.

- Other Settings Affected

None.

■ Programmable Output Contact Mask Settings

The relay elements and intermediate logic results are represented in a 32-bit Relay Word grouped into four 8-bit words. Selected bits are stored in masks for each output contact and recorded in hexadecimal format at the bottom of each event report. Hexadecimal formatting is used to reduce the printed report length.

The Relay Word Bit Summary Table at the end of this section explains the meaning of each bit.

The SEL-221H relay has eight logic masks. Four masks control the TRIP output contacts, while four control the four programmable output relay contacts (A1, A2, A3, and A4). The following masking samples use the same setting example as above.

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	Z3RB	KEY	50MF	PTEE	ECTT	DF	
1	1	0	0	1	0	1	0	CA
ALRM	TRIP	TC	DT	52BT	WFC	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), timeout of the 51N element (51NT), timeout of Zone 2 and 3 phase distance (Z2DP and Z3DP), timeout of the residual overcurrent elements (Z2DG and Z3DG), the 50MF element, Echo-Conversion-To-Trip (ECTT), the OPEN command (TC ≡ Trip Command), and assertion of the Direct Trip input (DT).

In this example, the DT input will be energized by the trip output of the local breaker failure protection for event report generation. The A1 output will transmit a permissive signal to the remote breaker. Where primary and secondary protection trip output contacts are routed to separate trip coils of the line breaker, cross tripping is accomplished by routing the trip output of each set of protection to trip the other. When cross tripping is desirable, the trip output from the secondary line protection relays would be routed to the DT input of the relay.

■ Mask Permissive Trip (MPT)

								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	Z3RB	KEY	50MF	PTEE	ECTT	DF	
0	0	0	0	0	0	0	0	00
ALRM	TRIP	TC	DT	52BT	WFC	Z2GT	Z3GT	
0	0	0	1	0	0	0	0	10

The example mask for permissive tripping (MPT) selects tripping by the Zone 2 three-phase (2ABC), Zone 2 phase-phase (Z2P), Zone 2 residual instantaneous overcurrent element (67N2), and assertion of the Direct Trip input (DT).

The scheme specified for the example case is permissive overreaching transfer trip. This requires masking of the forward overreaching elements and DT bit in the MPT mask. This masking closes the TRIP output contacts when the PT input is asserted and the current reversal logic is not issuing a block signal. Including these elements in the MPT mask also keys permissive trip via the KEY bit in the Relay Word.

■ Mask for Trip Block (MTB)

								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	Z3RB	KEY	50MF	PTEE	ECTT	DF	
0	0	0	0	0	0	0	0	00
ALRM	TRIP	TC	DT	52BT	WFC	Z2GT	Z3GT	
0	0	0	0	0	0	0	0	00

The example mask for block tripping contains all zeros because the selected scheme is POTT.

■ **Mask for Trip Breaker Open (MTO)**

								Event Report Hexadecimal Code
1ABC	2ABC	3ABC	4ABC	LOP	50H	50M	50L	
1	1	0	1	0	1	0	0	D4
51NT	67N1	67N2	67N3	51NP	Z1P	Z2P	Z3P	
1	1	1	0	0	1	1	0	E6
Z2PT	Z3PT	Z3RB	KEY	50MF	PTEE	ECTT	DF	
0	0	0	0	0	0	0	0	00
ALRM	TRIP	TC	DT	52BT	WFC	Z2GT	Z3GT	
0	0	0	0	0	0	0	0	00

The MTO mask selects elements to trip when 52BT asserts. The example mask for trip while breaker open (MTO) selects tripping by Zone 1, 2, and 4 instantaneous three-phase elements (1ABC, 2ABC, and 4ABC), 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	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	Z3RB	KEY	50MF	PTEE	ECTT	DF	
0	0	0	1	0	0	0	0	10
ALRM	TRIP	TC	DT	52BT	WFC	Z2GT	Z3GT	
0	0	0	0	0	0	0	0	00

The A1 output contact connects to the permissive keying input of the communications equipment. Where slow or stuck breakers are a concern, the A1 contact may be programmed with a set time delay dropout. The example mask setting for the A1 contact permits closure of the A1 output contact when the KEY bit is set.

■ **Mask for the A2 Output Contact (MA2)**

								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	Z3RB	KEY	50MF	PTEE	ECTT	DF	
0	0	0	0	0	0	0	0	00
ALRM	TRIP	TC	DT	52BT	WFC	Z2GT	Z3GT	
0	0	0	0	0	0	0	0	00

The A2 output contact connects to the local annunciator panel to alarm for loss-of-potential conditions. The example mask setting for the A2 contact permits closure of the A2 output contact when the LOP bit is set.

■ 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	Z3RB	KEY	50MF	PTEE	ECTT	DF	
0	0	0	0	0	0	0	0	00
ALRM	TRIP	TC	DT	52BT	WFC	Z2GT	Z3GT	
0	0	0	0	0	1	0	0	04

The A3 output contact is masked to show weak-infeed conditions in the event report. The example mask setting for the A3 contact permits closure of the A3 output contact when the WFC bit is set.

■ Mask for the A4 Output Contact (MA4)

								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	
0	0	0	0	0	0	0	0	00
Z2PT	Z3PT	Z3RB	KEY	50MF	PTEE	ECTT	DF	
0	0	0	0	0	0	0	0	00
ALRM	TRIP	TC	DT	52BT	WFC	Z2GT	Z3GT	
0	0	0	0	0	0	0	0	00

The A4 output contact is wired to the reclose cancel input of an external recloser. The condition selected for cancelling reclose is a Zone 1 three-phase fault. The example mask setting for the A4 contact permits closure of the A4 output contact when the 1ABC bit is set.

Table 5.1: Relay Word Bit Summary

1ABC	-	Zone 1 three-phase instantaneous element (set by Z1%)
2ABC	-	Zone 2 three-phase instantaneous element (set by Z2%)
3ABC	-	Zone 3 three-phase instantaneous element (set by Z3%)
4ABC	-	Zone 4 three-phase instantaneous element (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	-	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]
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%)
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)
Z3RB	-	Zone 3 Reverse Block timer output (TDDO time set by Z3RBT)
KEY	-	Communication channel keying bit (see KEY Logic)
50MF	-	Asserts a settable delay after LOP and 50M pickup (delay set by 50MFD)
PTEE	-	Permissive Trip Echo Enable (limited duration pulse set by echo timers, ETDPU and EDUR)
ECTT	-	Echo-Conversion-To-Trip
DF	-	Direction forward for ground faults
ALRM	-	System alarm
TRIP	-	Trip contact closure
TC	-	Trip (OPEN) Command
DT	-	Direct Trip (or other user defined external purposes)
52BT	-	Inverted time delayed 52A follower (delay set by 52BT setting)
WFC	-	Weak-infeed conditional (set by 27PP and 59N)
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.

SETTINGS SHEET
FOR SEL-221H RELAY

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

HEXADECIMAL REPRESENTATION

MASK: MTU (UNCONDITIONAL 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	Z3RB	KEY	50MF	PTEE	ECTT	DF	
ROW #4: RELAY WORD BINARY REPRESENTATION	ALRM	TRIP	TC	DT	52BT	WFC	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	Z3RB	KEY	50MF	PTEE	ECTT	DF	
ROW #4: RELAY WORD BINARY REPRESENTATION	ALRM	TRIP	TC	DT	52BT	WFC	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	Z3RB	KEY	50MF	PTEE	ECTT	DF	
ROW #4: RELAY WORD BINARY REPRESENTATION	ALRM	TRIP	TC	DT	52BT	WFC	Z2GT	Z3GT	

SETTINGS SHEET
FOR SEL-221H RELAY

SUBSTATION ____________

HEXADECIMAL REPRESENTATION

MASK: MTO (SWITCH-ONTO-FAULT)

									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	Z3RB	KEY	50MF	PTEE	ECTT	DF	
ROW #4: RELAY WORD BINARY REPRESENTATION	ALRM	TRIP	TC	DT	52BT	WFC	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	Z3RB	KEY	50MF	PTEE	ECTT	DF	
ROW #4: RELAY WORD BINARY REPRESENTATION	ALRM	TRIP	TC	DT	52BT	WFC	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	Z3RB	KEY	50MF	PTEE	ECTT	DF	
ROW #4: RELAY WORD BINARY REPRESENTATION	ALRM	TRIP	TC	DT	52BT	WFC	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	Z3RB	KEY	50MF	PTEE	ECTT	DF	
ROW #4: RELAY WORD BINARY REPRESENTATION	ALRM	TRIP	TC	DT	52BT	WFC	Z2GT	Z3GT	

SETTINGS SHEET
FOR SEL-221H RELAY

SUBSTATION ___________

HEXADECIMAL REPRESENTATION

MASK: MA4 (A4 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	Z3RB	KEY	50MF	PTEE	ECTT	DF	
ROW #4: RELAY WORD BINARY REPRESENTATION	ALRM	TRIP	TC	DT	52BT	WFC	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 & 2 COMMANDS.

SEL-221H RELAY SETTING TABLE

DATE ______
SUBSTATION ______

DESCR. / RANGE					
DESCR. RANGE	POS SEQ. IMPEDANCE 0-9999 (PRI. OHMS)		ZERO SEQ. IMPEDANCE 0-9999 (PRI. OHMS)		LINE LENGTH* 0.1-999 MILES
ABBREV. **SETTING**	**R1**	**X1**	**R0**	**X0**	**LL**
DESCR. RANGE	C.T. RATIO 1-5000:1	P.T. RATIO 1-10,000:1	MAX. TORQ. ANGLE 47°-90°	ENABLE FAULT LOCATOR (Y OR N)	
ABBREV. **SETTING**	**CTR**	**PTR**	**MTA**	**LOCAT**	
DESCR. RANGE	ZONE 1 REACH (0.125-64Ω SEC.) 0-2000% OF LL	ZONE 2 REACH** (0.125-64Ω SEC.) 0-3200% OF LL	ZONE 3 REACH** (0.125-64Ω SEC.) 0-3200% OF LL		
ABBREV. **SETTING**	**Z1%**	**Z2%**	**Z3%**		
DESCR. RANGE	ZONE 2 $\phi\phi$ & 3ϕ TIME-STEP BACKUP TIMER 0-2000 CYCLES (¼ CYCLE STEPS)	ZONE 3 $\phi\phi$ & 3ϕ TIME-STEP BACKUP TIMER 0-2000 CYCLES (¼ CYCLE STEPS)	A1 CONTACT TIME DELAY PICKUP 0-8000 CYCLES (¼ CYCLE STEPS)	A1 CONTACT TIME DELAY DROPOUT 0-8000 CYCLES (¼ CYCLE STEPS)	
ABBREV. **SETTING**	**Z2DP**	**Z3DP**	**A1TP**	**A1TD**	
DESCR. RANGE	ϕ O/C LOW-SET PICKUP (0.5-40A SEC.) 0.25-50,000 AMP PRI.	ϕ O/C MEDIUM-SET PICKUP (0.5-40A SEC.) 0.25-50,000 AMP PRI.	ϕ O/C LOP DELAY (LOSS-OF-POTENTIAL) 0-60 CYCLES (¼ CYCLES STEPS)	ϕ O/C HIGH-SET PICKUP (0.5-80A SEC.) 0.25-50,000. AMPS PRI.	
ABBREV. **SETTING**	**50L**	**50M**	**50MFD**	**50H**	
DESCR. RANGE	GND TIME O/C PICKUP (0.25-6.3A SEC.) 0.25-50,000 AMP PRI.	GND TIME O/C TIME DIAL 0.5-15 (0.01 STEPS)	GND TIME O/C CURVE SHAPE (1, 2, 3, OR 4)	GND TIME O/C TORQUE CONTROL (Y OR N)	
ABBREV. **SETTING**	**51NP**	**51NTD**	**51NC**	**51NTC**	

SEL-221H RELAY SETTING TABLE

DATE ______
SUBSTATION ______

DESCR. RANGE	ZONE 1 GND INST O/C *** (0.25A-48x51NP) 0.25-50,000 AMP PRI.	ZONE 2 GND INST O/C *** (0.25A-48x51NP) 0.25-50,000 AMP PRI.	ZONE 3 GND INST O/C *** (0.25A-48x51NP) 0.25-50,000 AMP PRI.		
ABBREV. **SETTING**	**50N1P**	**50N2P**	**50N3P**		
DESCR. RANGE	ZONE 2 GND TIMER 0-2000 CYCLES (¼ CYCLE STEPS)	ZONE 3 GND TIMER 0-2000 CYCLES (¼ CYCLE STEPS)			
ABBREV. **SETTING**	**Z2DG**	**Z3DG**			
DESCR. RANGE	TRIP DURATION TIMER 0-2000 CYCLES (¼ CYCLE STEPS)	52b TIME DELAY 0.5-10,000 CYCLES (¼ CYCLE STEPS)	ZONE 3 DIRECTION (F OR R)	ZONE 3 REV. BLK. TIMER 0-8000 CYCLES (¼ CYCLE STEPS)	BLOCK ZONE 3 REV. BLK. TIMER -1-8000 CYCLES (¼ CYCLE STEPS)
ABBREV. **SETTING**	**TDUR**	**52BT**	**ZONE 3**	**Z3RBT**	**BZ3RB**
DESCR. RANGE	ECHO TIME DELAY PICKUP TIMER 0-8000 CYCLES (¼ CYCLE STEPS)	ECHO DURATION TIMER 0-8000 CYCLES (¼ CYCLE STEPS)	WEAK-INFEED CONDITIONAL ENABLE (Y OR N)	PHASE-PHASE UNDERVOLTAGE 0-2000kV PRI (0-260V_{l-l} SEC.)	GROUND OVERVOLTAGE 0-2000kV PRI (0-150V_{l-m} SEC.)
ABBREV. **SETTING**	**ETDPU**	**EDUR**	**WFCE**	**27PP**	**59N**
DESCR. RANGE	GND O/C NEGATIVE SEQ. POLAR. (Y OR N)	GND O/C ZERO SEQ. VOLTAGE POLAR. (Y OR N)	GND O/C ZERO SEQ. CURRENT POLAR. (Y OR N)	LOSS-OF-POT. ENABLE (Y OR N)	
ABBREV. **SETTING**	**32QE**	**32VE**	**32IE**	**LOPE**	
DESCR. RANGE	SEL-221H PORT #1 TIMEOUT 0-30 MINUTES	SEL-221H PORT #2 TIMEOUT 0-30 MINUTES	AUTOMATIC MESSAGE TRANSMIT AUTOPORT SELECTION PORT 1, 2, OR 3(BOTH)	# RINGS AFTER WHICH MODEM ANSWERS 1-30	
ABBREV. **SETTING**	**TIME1**	**TIME 2**	**AUTO**	**RINGS**	

SEL-221H RELAY SETTING TABLE

DATE ______
SUBSTATION ______

* Line Length = Station #1 (relay location) to Station #2, full distance in "miles" between the stations.

Note: Length may also be represented in metric units, primary or secondary ohms, etc., but conversion to miles would be required.

** Zone 2 and 3 are limited as follows: ohmic range 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

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 ET input, you must apply control voltage to the ET 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 RS-232-C serial communications ports are made via the two nine-pin connectors labelled 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 RS-232-C 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 the front panel.

EIA RS-232-C Jumpers

JMP105 provides EIA RS-232-C 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.

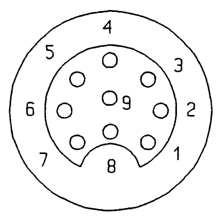
OPEN/CLOSE Command Enable Jumper

With jumper JMP104 in place, the OPEN and CLOSE commands are enabled. If you remove jumper JMP104, OPEN and CLOSE command execution results in the message: "Aborted."

EIA RS-232-C And IRIG-B Installation

This section contains specific information concerning pinouts of the communications ports.

A pin definition of the nine-pin port connectors and cabling information for the EIA RS-232-C ports appears below in Figure 6.1. The following cable listings show several types of EIA RS-232-C 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: Nine-Pin Connector Pin Number Convention

EIA RS-232-C Cables

```
SEL Relay              25-Pin *DTE DEVICE

GND  1 ------------------ 7   GND
TXD  2 ------------------ 3   RXD
RTS  3 ------------------ 5   CTS
RXD  4 ------------------ 2   TXD          (SEL  CABLE 123)
CTS  5 ------------------ 4   RTS
+5   6
+12  7
-12  8
GND  9 ------------------ 1   GND
                          6-┐ DSR
                          8-┤ DCD
                         20-┘ DTR
```

```
SEL Relay              25-Pin **DCE DEVICE

GND   1 ----------------- 7   GND
TXD   2 ----------------- 2   RXD
RTS   3 ----------------- 20  DTR          (SEL  CABLE 422)
RXD   4 ----------------- 3   TXD
CTS   5 ----------------- 8   CD
GND   9 ----------------- 1   GND
```

```
SEL Relay                          9-Pin *DTE DEVICE

GND  1 ─────────────────────────── 5  GND
TXD  2 ─────────────────────────── 2  RXD
RTS  3 ─────────────────────────── 8  CTS
RXD  4 ─────────────────────────── 3  TXD        (SEL  CABLE 134)
CTS  5 ─────────────────────────── 7  RTS
                                   1┐ DCD
                                   4┤ DIR
                                   6┘ DSR
                                   9  RI
```

```
SEL Relay                            PRTU

GND   1 ────────────────────────── 1  GND
TXD   2 ────────────────────────── 4  RXD
RXD   4 ────────────────────────── 2  TXD        (SEL  CABLE 331A - 338A)
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 labelled 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 opto-coupler 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 later, the relay restarts IRIG-B Data Acquisition.

INSTALLATION CHECKOUT

You may follow the suggestions below or combine them with your normal practice. 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 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. 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° 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.

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 the 2ACCESS command. 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, assuming 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 output should last at least as long as the TDUR setting and will not deassert until the 50L phase overcurrent and 50NL ground overcurrent elements drop out or you press the front panel TARGET RESET button.

7. The circuit breaker may be closed two ways; by CLOSE command execution or DIRECT CLOSE input assertion. The CLOSE output relay closes for either 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 (PT) and block trip (BT) inputs are used, check them for proper operation (see the LOGIC MPT and LOGIC MTB settings in Section 3: COMMUNICATIONS). An event record should not be generated for assertion of either the PT or BT inputs.

9. Assert the External Trigger input. This should trigger an event record. It 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.

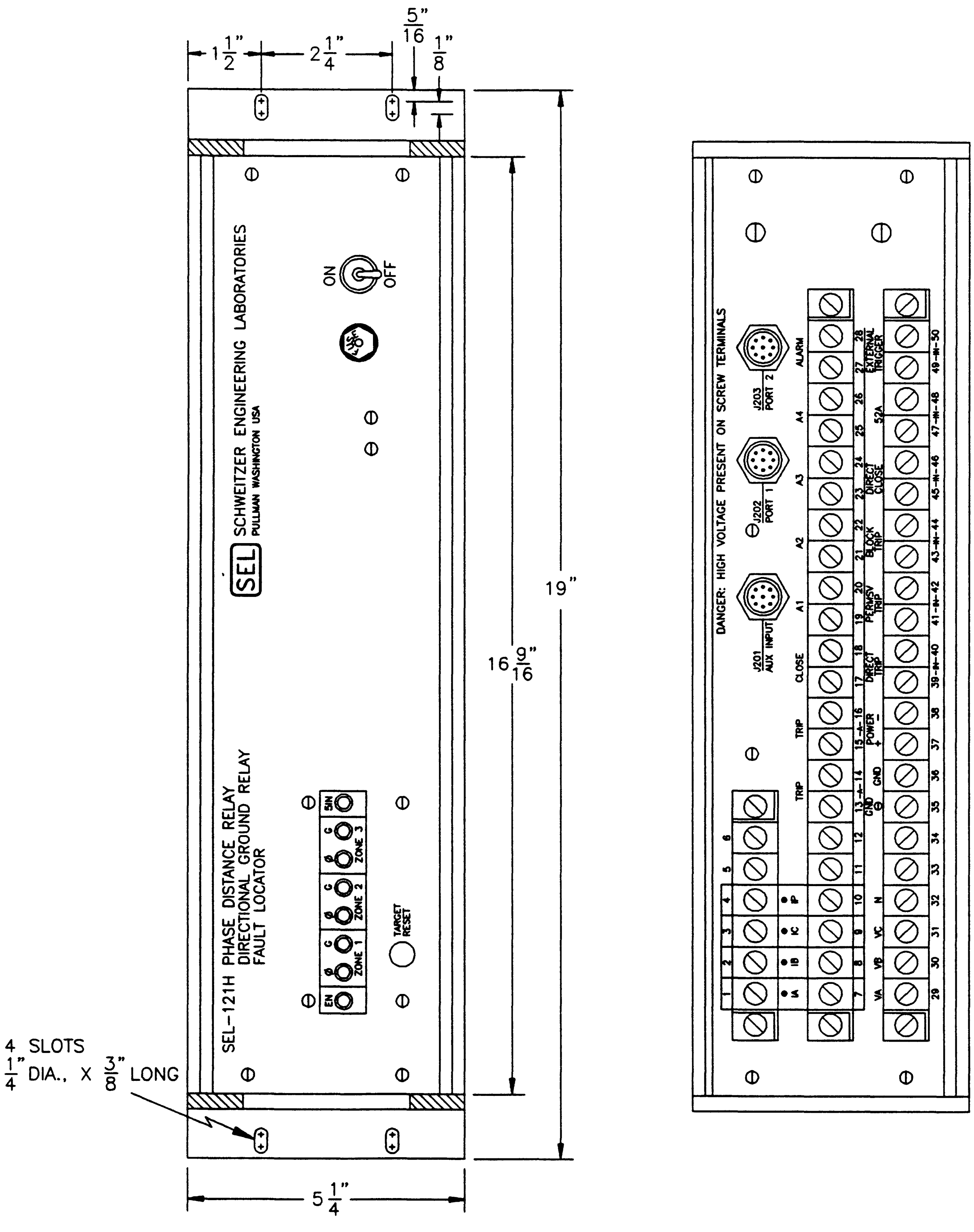


Figure 6.2: SEL-121H Relay Horizontal Front and Rear Panel Drawings

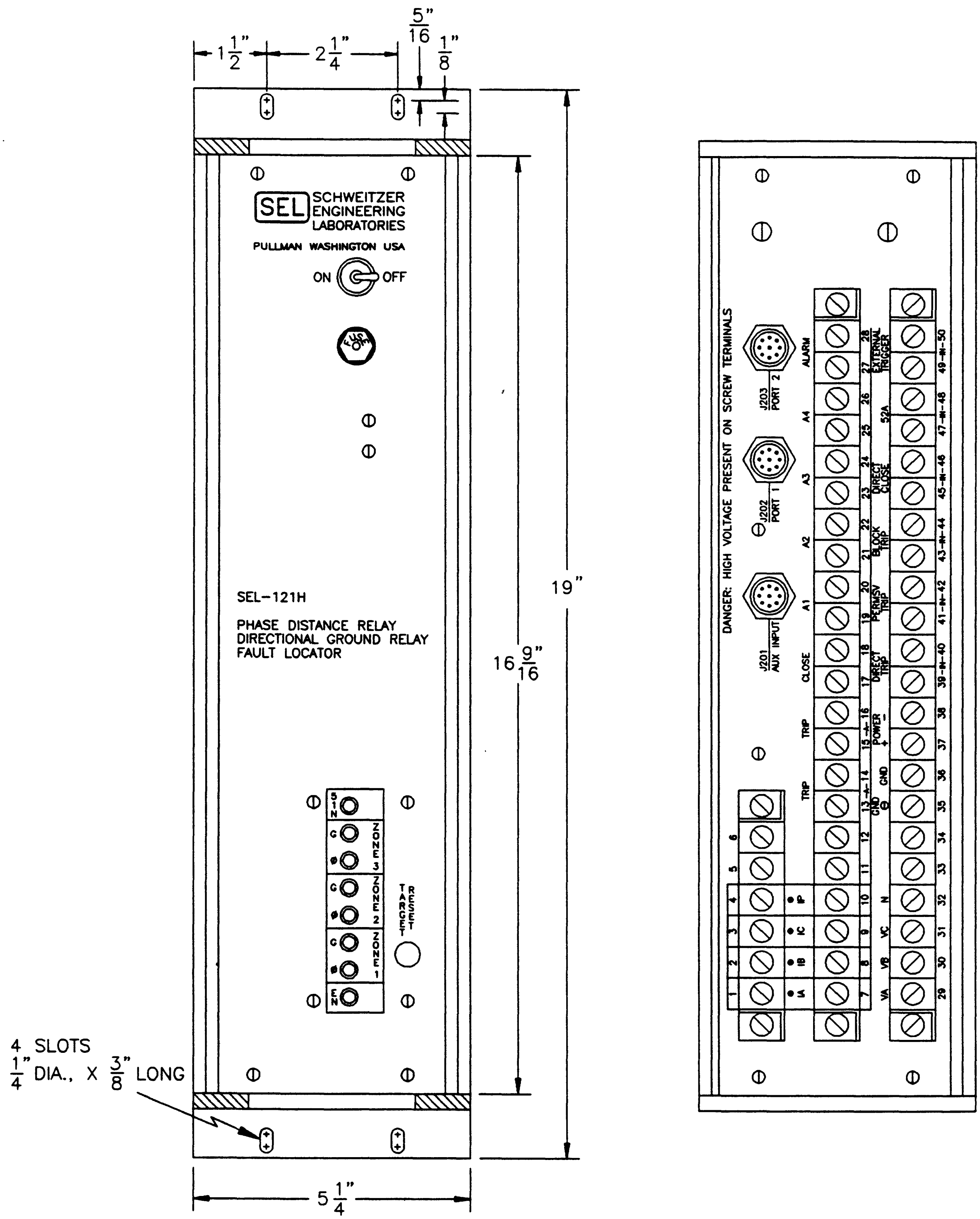
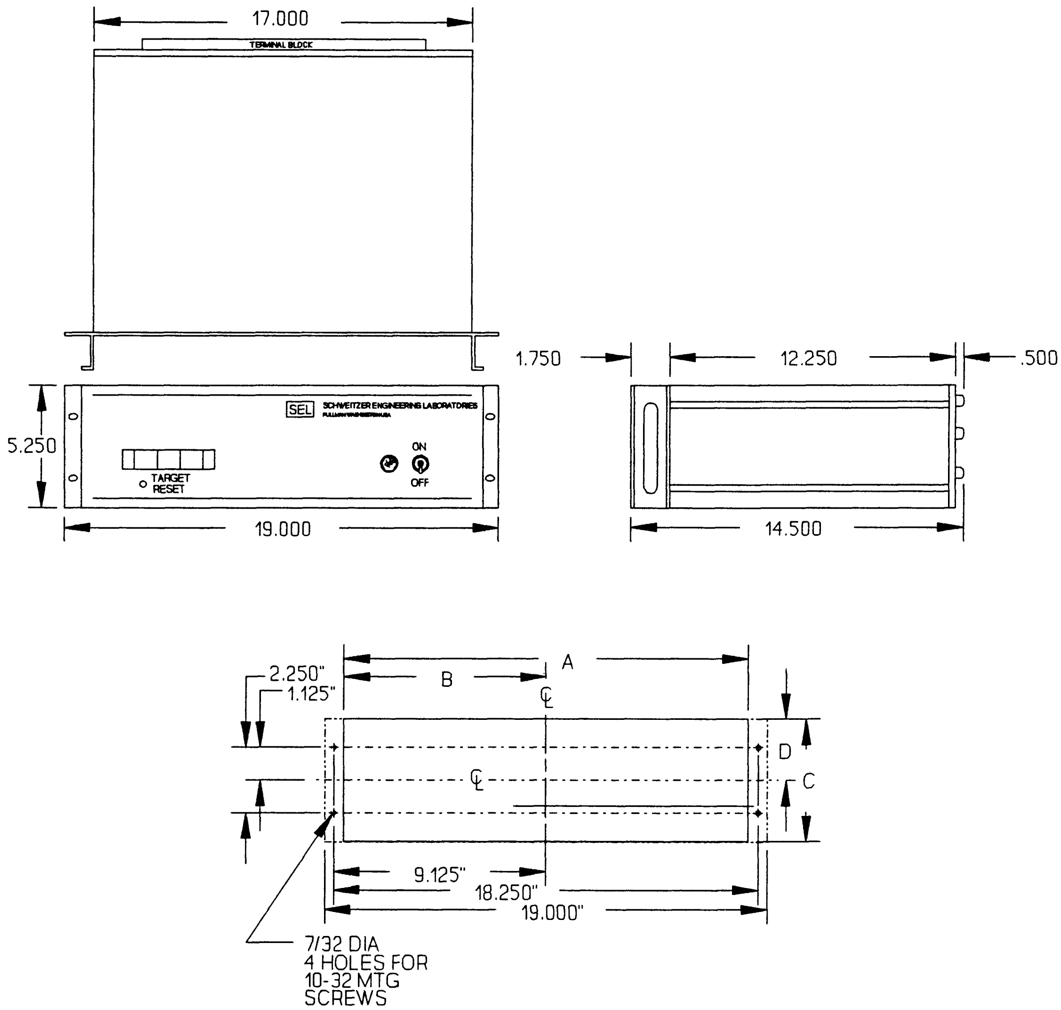


Figure 6.3: SEL-121H Relay Vertical Front and Rear Panel Drawings



DIMENSION A:
CUT OUT: 17.250" - 17.875"
17.375" PREFERRED

DIMENSION B:
CUT OUT: 8.625" - 8.9375"
8.688" PREFERRED

DIMENSION C:
CUT OUT: 5.350" - 5.450"

DIMENSION D:
CUT OUT: 2.675" - 2.725"

<u>NOTE</u>: ALL INSTRUMENTS MAY BE MOUNTED HORIZONTALLY (AS SHOWN) OR VERTICALLY.

PANEL CUTOUT AND DRILL FOR SEMI-FLUSH MOUNTING OF 5.250 INCH HIGH CASE.

Figure 6.4: Relay Dimensions, Panel Cutout, and Drill Plan

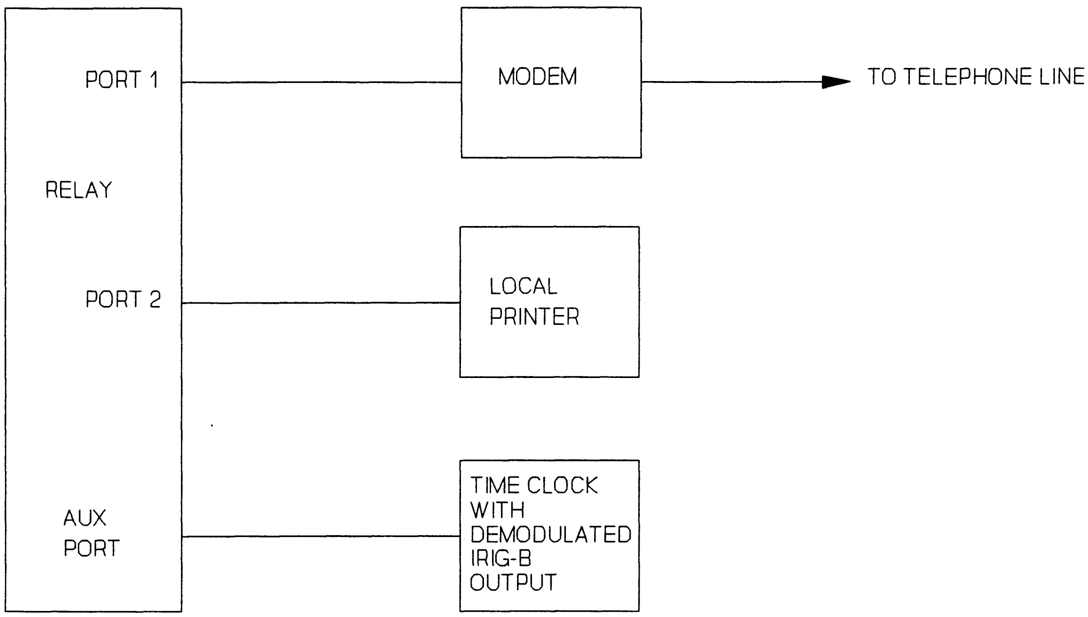


Figure 6.5: Communications and Clock Connections - One Unit at One Location

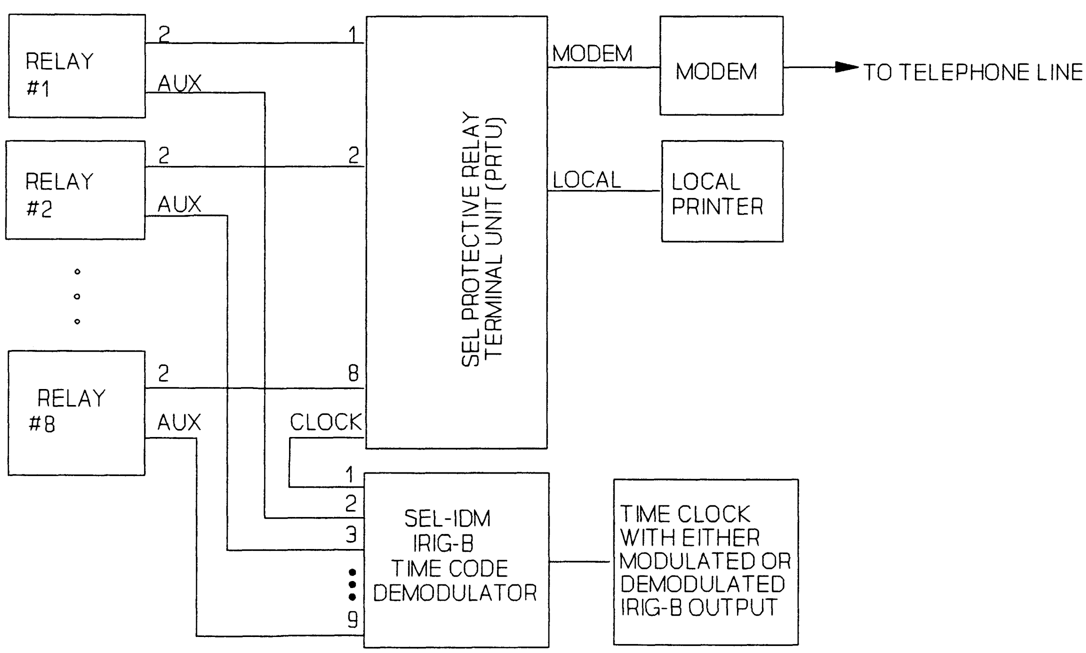


Figure 6.6: Communications and Clock Connections - Multiple Units at One Location

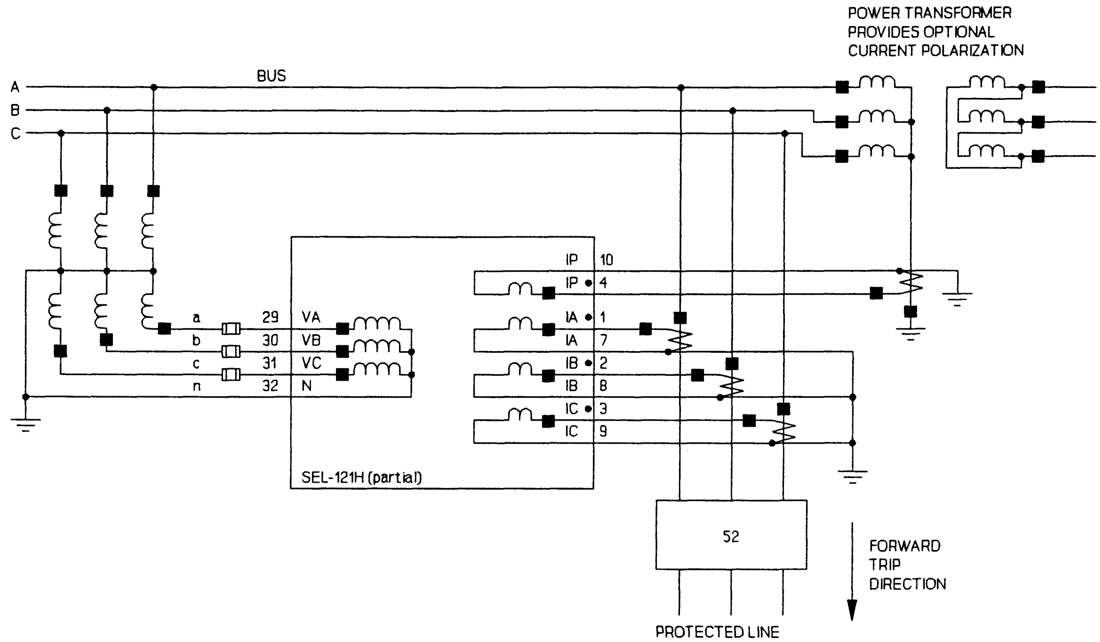


Figure 6.7: SEL-121H Relay External Ac Current and Voltage Connections

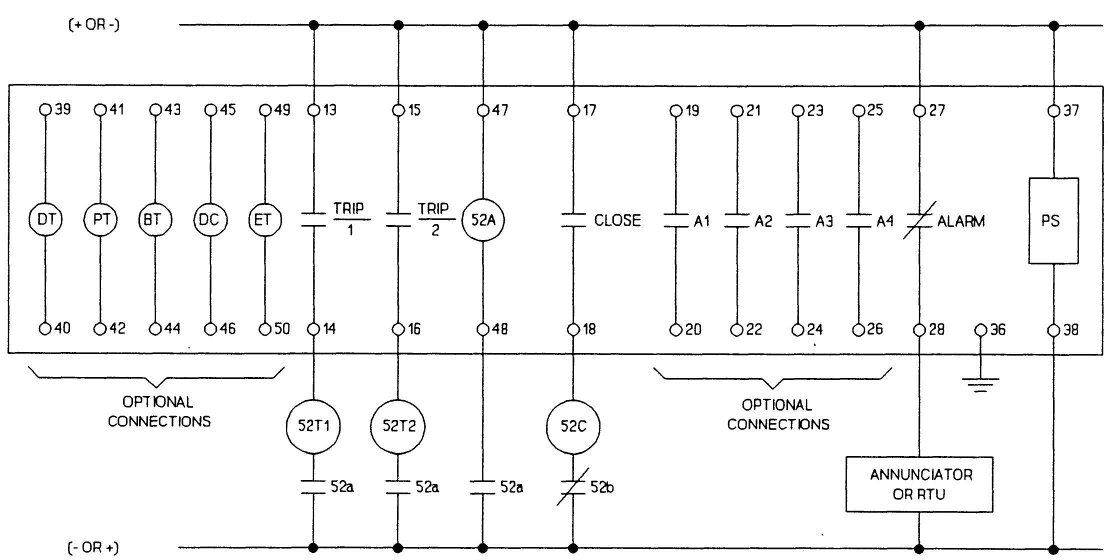


Figure 6.8: SEL-121H Relay External Dc Connection Diagram (Typical)

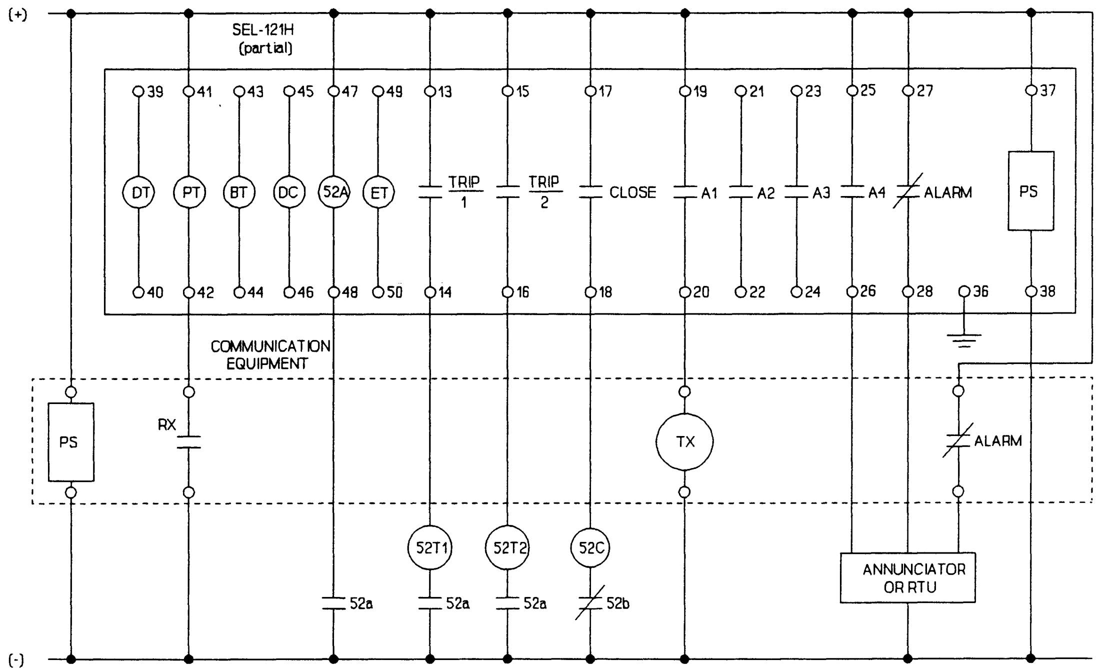


Figure 6.9: SEL-121H Relay External Dc Connections to Communication Equipment

SEL DIRECTION AND POLARITY CHECK FORM

STATION ________________ DATE: ___/___/___ TESTED BY ________________

SWITCH NO. ________________ EQUIPMENT ________________

INSTALLATION ________ROUTINE ________OTHER ________________

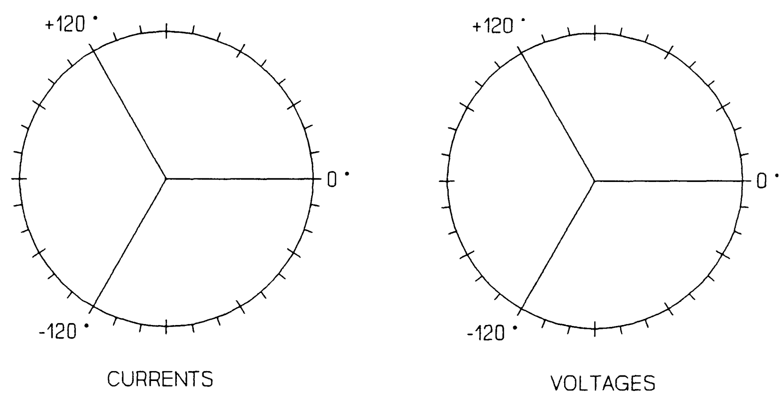
LOAD CONDITIONS:

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



SEL DIRECTION AND POLARITY CHECK FORM

STATION ________________________ DATE: ___/___/___ TESTED BY ______________

SWITCH NO. ______________ EQUIPMENT ______________________________

INSTALLATION ________ ROUTINE _______ OTHER ____________________________

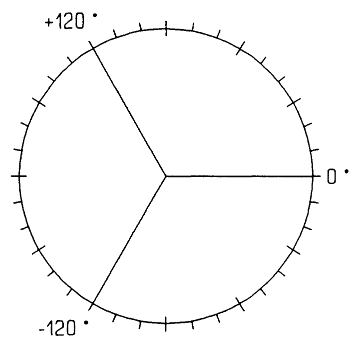
LOAD CONDITIONS:

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

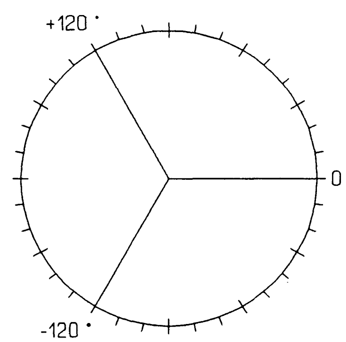
SEL READINGS: ________ MW (+)(-) ________ MVAR (+)(-)

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
TABLE OF CONTENTS

TABLES

FIGURES

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 Calibration in 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 further details of the TARGET command. By employing the target LEDs for testing, you need not change the relay settings for testing purposes.
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 assistance.

Each event report is date and time tagged relative to the sixteenth quarter-cycle of the event report. Each report is triggered upon assertion of designated relay elements and/or contact inputs and outputs. If the time-out 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.

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 to 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 a Form a contact, when the condition asserts, the output contact closes; when the condition deasserts, the output contact opens.

For a Form 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 Form 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 a form a output contact.

Using a Breaker Simulator

Because much of the relay logic depends on whether the breaker is open (52A deenergized) or closed (52A energized), it is important to use a breaker simulator. The following logic depends on the state of the 52A contact input:

- Switch-onto-Fault Logic
- Current Reversal Logic
- Echo Conversion To Trip (ECTT) Logic
- Close Function Logic

We recommend testing the SEL-221H 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.

INITIAL CHECKOUT

The initial checkout procedure should familiarize you with the relay and ensure that all functions are operational. Study Functional Specification and Description in Section 2: SPECIFICATIONS, command descriptions in Section 3: COMMUNICATIONS, and Section 4: EVENT REPORTING for a complete understanding of the relay capabilities.

Equipment Required

The following equipment is necessary for initial checkout.

1. Terminal with EIA RS-232-C 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: 1/1/92    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 7.1 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.

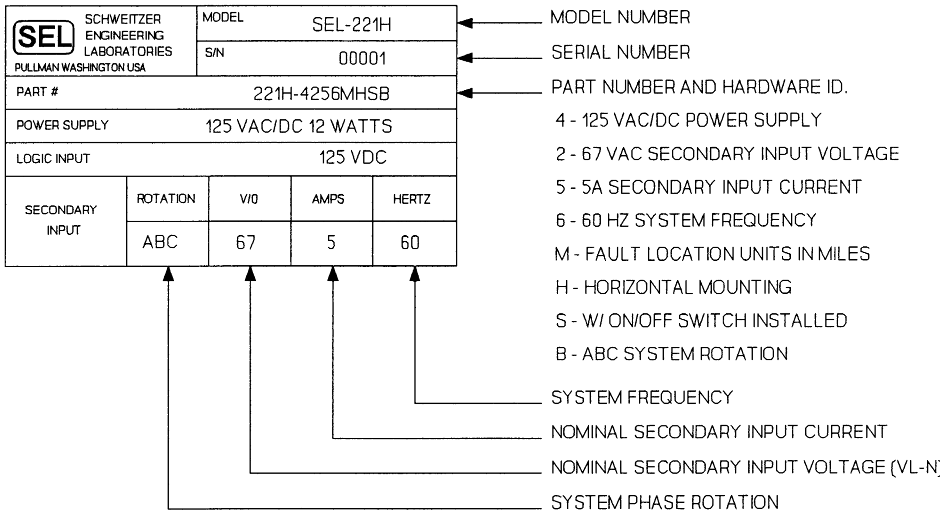


Figure 7.1: Relay Part Number and Hardware Identification Sticker

- **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, two stop bits, and no parity. 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 details on port configurations. Baud rate selection is described under Jumper Selection in Section 6: INSTALLATION. Figure 7.2 shows the typical communication interface setup for testing purposes.

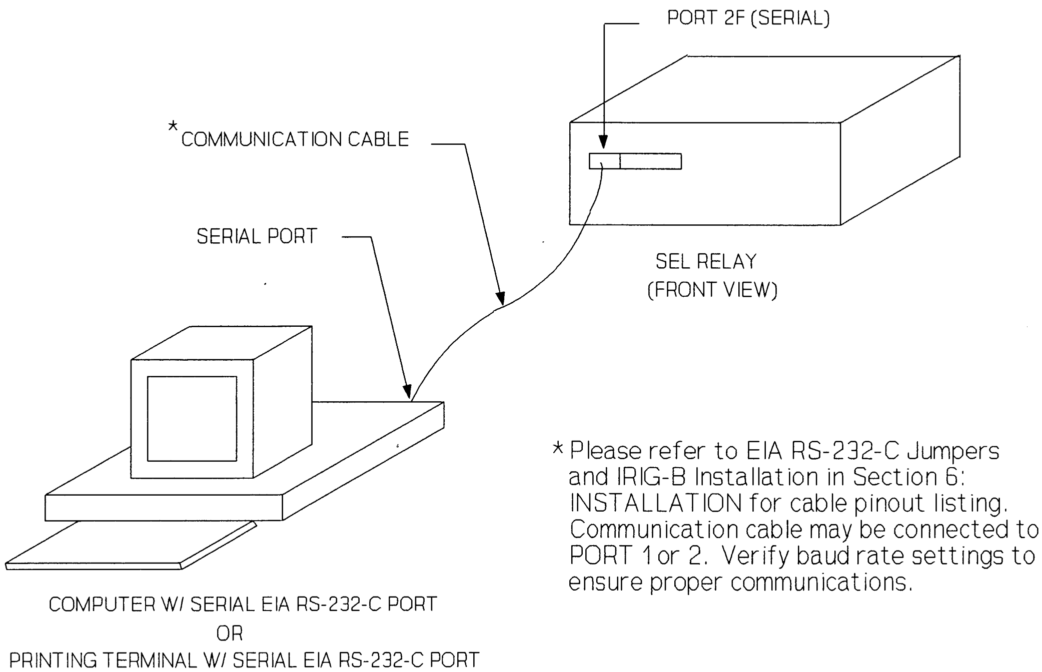


Figure 7.2: Communication Interface Setup

- **Step 4**

Purpose: Establish control power connections.

Method: Connect a frame ground to terminal marked GND on the rear panel and connect rated control power to terminals marked + and -. Polarity is unimportant. Relays supplied with 125 or 250 V power supplies may be powered from a 115 V ac 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: 1/1/92      Time: 01:01:01

SEL-121H
=
```

The ALARM relay should pull in, holding its "b" contacts open. Since the LOP bit of the MA2 mask is set, output relay A2 (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: 1/1/92 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:

```
Settings for:  Example 230 kV Line

R1    =8.56     X1    =77.77     R0    =35.12    X0    =236.96    LL    =100.0
CTR   =200.00   PTR   =2000.00   MTA   =83.72    LOCAT=Y
Z1%   =80.00    Z2%   =120.00    Z3%   =120.00
Z2DP  =20.00    Z3DP  =60.00     A1TP  =0.00     A1TD  =0.00
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
Z2DG  =30.00    Z3DG  =60.00
TEX   =9.00     52BT  =20.00     ZONE3=R         Z3RBT=4.5        BZ3RB=1.5
ETDPU=2.00      EDUR  =3.5       WFCE  =Y        27PP  =160.00    59N   =6.00
32QE  =Y        32VE  =N         32IE  =N        LOPE  =Y
TIME1=5         TIME2=0          AUTO  =2        RINGS=7

Logic settings:

MTU   MPT   MTB   MTO   MA1   MA2   MA3   MA4
80    40    00    D4    00    08    00    80
C4    22    00    E6    00    00    00    00
CA    00    00    00    10    00    00    00
33    10    00    00    00    00    04    00

=>
```

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	Z3RB	KEY	50MF	PTEE	ECTT	DF
Relay Word Row 4:	ALRM	TRIP	TC	DT	52BT	WFC	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 relay at terminals marked VA, VB, VC, and VN (See Figure 7.8b). Apply 67 volts per phase (line-to-neutral) in positive-sequence rotation. Wye-connect the two current sources as shown in Figure 7.8b 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 potentials applied to the relay, the A2 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 9. 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 230 kV Line       Date: 01/01/92  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 zero. It is important to remember this when commissioning the relay using system voltages and currents.

■ **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 0.2 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 terminal pair prior to applying each fault. The 52A input should remain energized for the duration of this step to block the switch-onto-fault 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	52.89	69.89	70.21	5.34	0.00	0.00	V or A
		0.00	-124.2	124.0	-82.4	0.00	0.00	Degrees
	BC	67.00	56.75	56.75	0.00	7.81	7.81	V or A
		0.00	-126.2	126.2	0.00	-173.7	6.3	Degrees
85 miles (forward direction fault)	AG	54.24	69.60	69.89	4.83	0.00	0.00	V or A
		0.00	-123.8	123.6	-82.4	0.00	0.00	Degrees
	BC	67.00	57.69	57.69	0.00	7.06	7.06	V or A
		0.	-125.5	125.5	0.00	-173.7	6.3	Degrees
-85 miles (reverse direction fault)	AG	54.24	69.60	69.89	4.83	0.00	0.00	V or A
		0.00	-122.8	122.7	97.6	0.00	0.00	Degrees
	BC	67.00	57.69	57.69	0.00	7.06	7.06	V or A
		0.00	-125.5	125.5	0.00	6.3	-173.7	Degrees

Faults at 75 miles are within Zone 1, since the Zone 1 reach setting is 80.0% of the 100 mile positive-sequence line impedance (see Z1% in the settings). 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, A1, A3	G1
75 mi	BC	TRIP, A1	Ø1
85 mi	AG	TRIP, A1, A3	G2
85 mi	BC	TRIP, A1	Ø2
-85 mi	AG	TRIP, A3	G3
-85 mi	BC	TRIP	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. Any Echo-Conversion-To-Trip (ECTT) condition.
9. The assertion of the DT input.
10. The OPEN command.

The A1 output relay is set to key permissive trip for any condition which asserts the KEY bit in the Relay Word. From the table, output relay A1 should close for all forward faults listed (i.e., positive fault location).

The A3 output relay asserts when there is a weak-infeed condition (WFC). Each ground fault used results in V0 greater than the 59N setting of 6 kV primary. This condition sets the WFC bit in the Relay Word.

The programming of the 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 ∅2 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 closing the A2 output relay. The A2 output relay is programmed to follow LOP in the example settings.

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 RS-232-C 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 KEY  50MF PTEE ECTT DF
 1    1    0    0    1    0    1    0
? <ENTER>
ALRM TRIP TC   DT   52BT WFC  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 KEY  50MF PTEE ECTT DF
 1    1    0    0    1    0    1    0
ALRM TRIP TC   DT   52BT WFC  Z2GT 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 marked VA, VB, and VC with a jumper. See Figure 7.3 for the test connections.

2. Series all current inputs as shown in Figure 7.3.

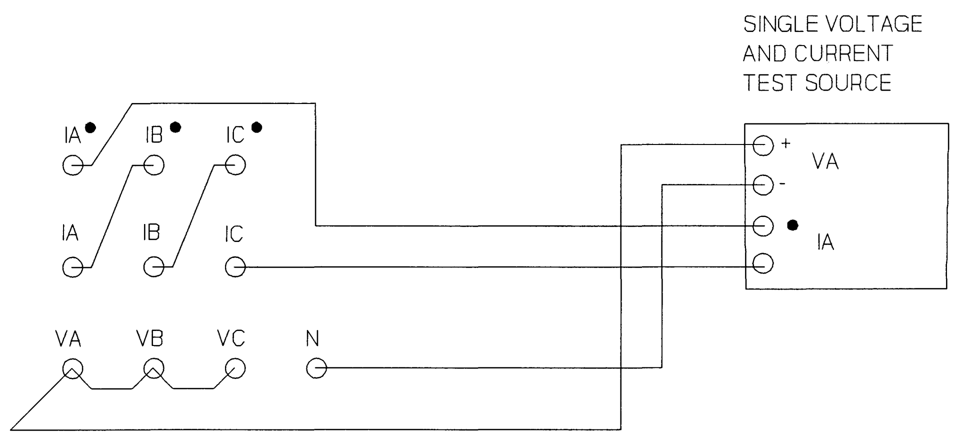


Figure 7.3: METER Test Connections

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:

$$VA = VB = VC = (50\ V)(2000)$$
$$= 100\ kV\ (\pm 0.5\%).$$

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:

$$IA = IB = IC = (5\ A)(200)$$
$$= 1000\ A\ (\pm 1\%).$$

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 for 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 7.4 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 7.4: 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

6IMP BUS FAULT OR QUIT (I,B,F,Q)?
```

Figure 7.5: 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 for 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 7.6: 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 7.7: 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

   The Zone 4 offset mho circle diameter is 1.5 times the Zone 3 mho circle diameter. Therefore, the forward reach of Zone 4 is 1.25 times that of Zone 3, while the reverse reach is 0.25 times the Zone 3 setting. Zone 3 may be reversed but Zone 4 always remains forward.

   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 7.8a or Figure 7.8b. Figure 7.8a uses three current sources, while Figure 7.8b uses only two.

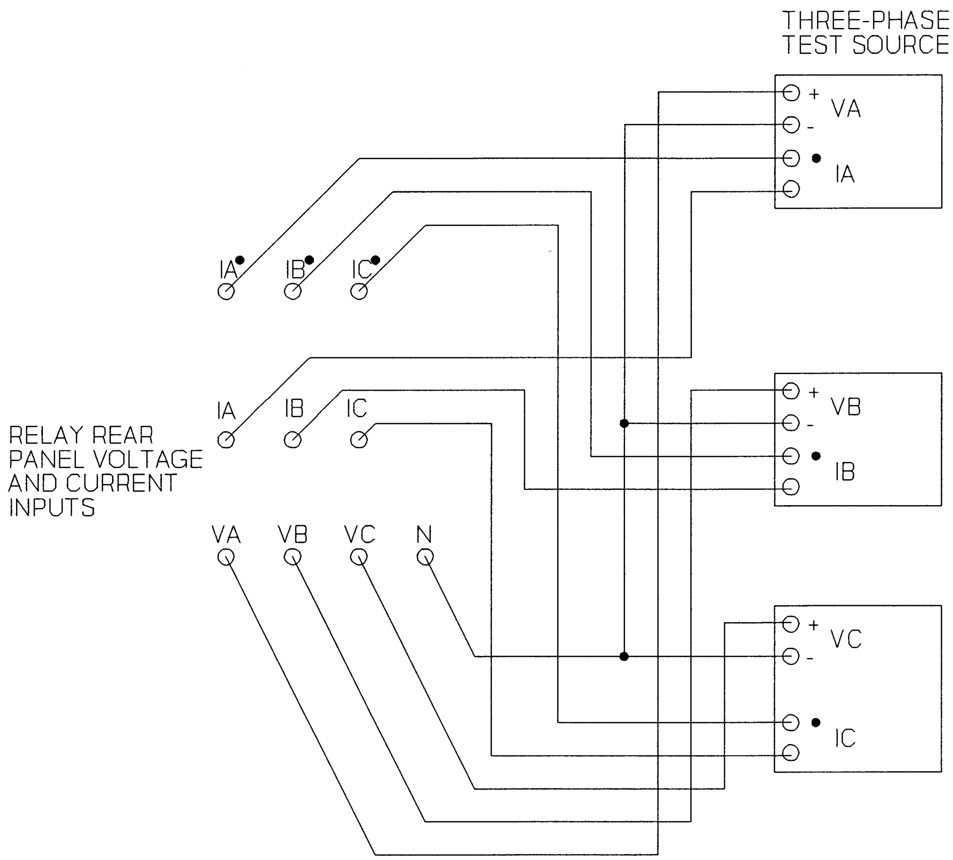


Figure 7.8a: Three-Phase Voltage and Current Source Test Connections for Three-Phase Mho Test

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.

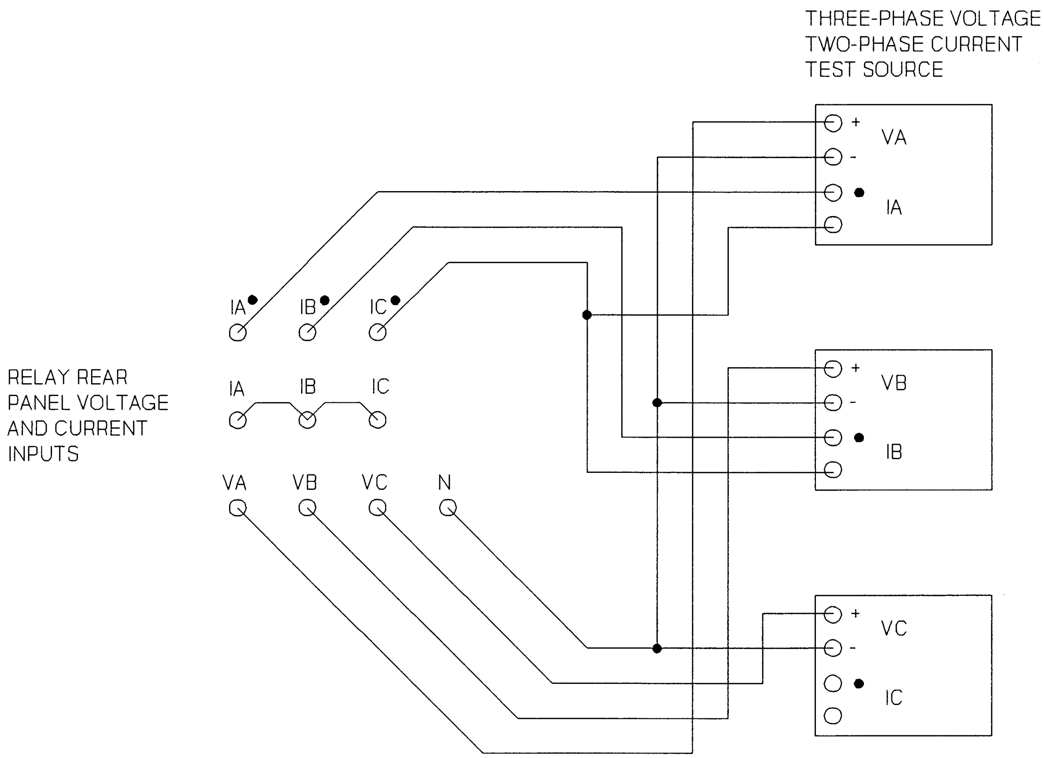


Figure 7.8b: Three-Phase Voltage and Two-Phase Current Source Test Connections for Three-Phase Mho Test

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 an 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

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 7.9a or Figure 7.9b). Note that two current sources are employed in Figure 7.9a, while only one current source is used in Figure 7.9b.

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.

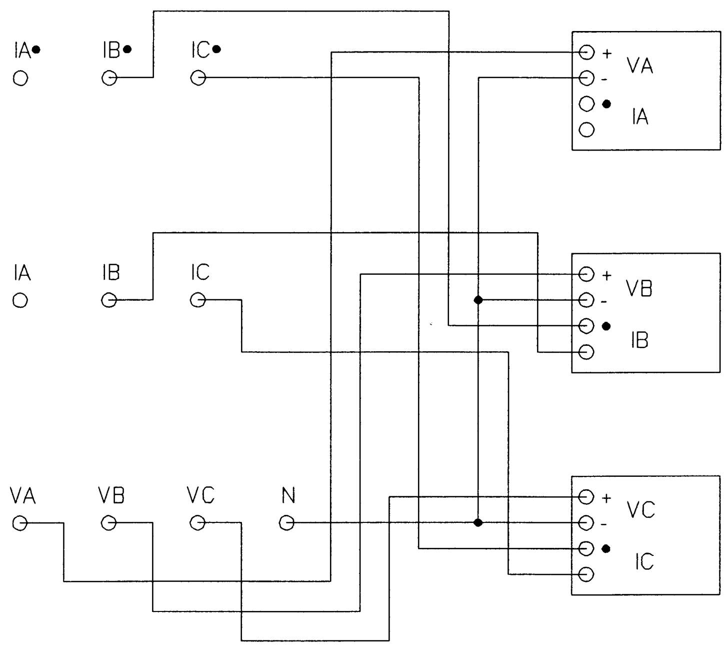


Figure 7.9a: **Three-Phase Voltage and Two-Phase Current Source Test Connections for Phase-Phase Mho Test**

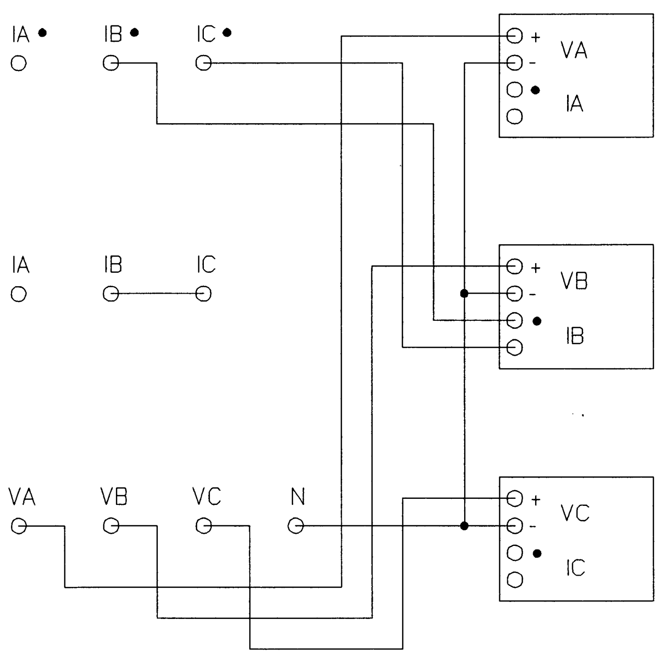


Figure 7.9b: **Three-Phase Voltage and One-Phase Current Source Test Connections for Phase-Phase Mho Test**

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 an 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 BASIC 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 DF bit in Relay Word row 3. 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.

$$
\begin{aligned}
V0 &= \tfrac{1}{3}\,[VA + VB + VC] \\
&= \tfrac{1}{3}\,[30V \angle 0° + 0V \angle 0° + 0V \angle 0°] \\
&= 10V \angle 0°
\end{aligned}
$$

$$V2 = \tfrac{1}{3}\,[VA + a^2(VB) + a(VC)]$$

Where: $a \equiv 1 \angle 120°$ and $a^2 \equiv 1 \angle 240°$

$$
\begin{aligned}
V2 &= \tfrac{1}{3}\,[30V \angle 0° + 0V \angle (0° + 240°) + 0V \angle (0+120°)] \\
&= \tfrac{1}{3}\,[30V \angle 0° + 0V \angle -120° + 0V \angle 120°] \\
&= 10V \angle 0°
\end{aligned}
$$

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 7.10 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.

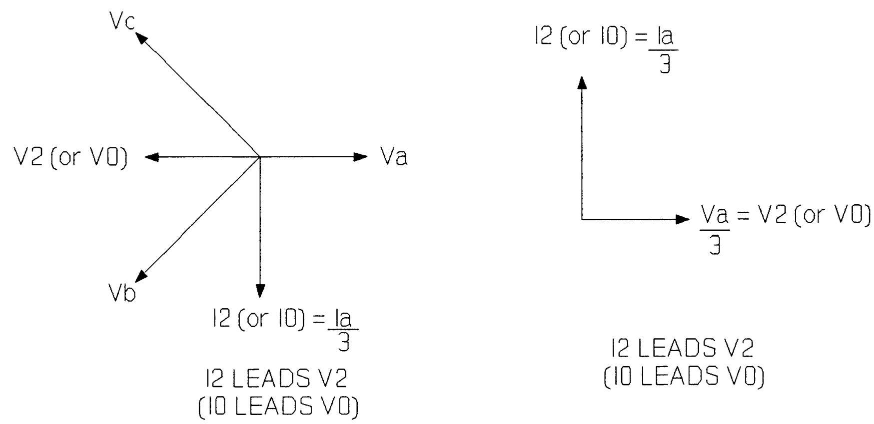


Figure 7.10: Three Voltage vs. One Voltage for Directional Tests (current vector shown in the operate region for MTA = 90°)

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 7.11.

Table 7.9: 32I Test Currents

IA	Ipol	
3.00	3.00	Amperes
0.0°	0.0°	Degrees

The DF bit should set and close the output contact when both currents are applied.

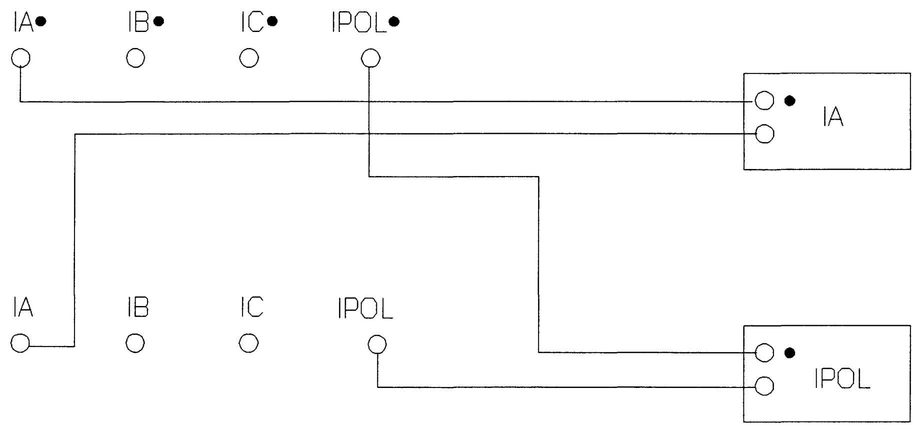


Figure 7.11: Current Polarized Directional Element Test Connection

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 $\pm 90°$.

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

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 3.45 amperes of residual current is measured by the relay, 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, 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 = 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.

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. Prefault and fault voltages and currents are given in Table 7.11. Prefault voltages are needed to charge the memory polarization filters. Prefault voltages should be applied for a minimum of 10 cycles.

Table 7.11: Three-Phase Close-In Fault

Prefault 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. From the generated event report, count the number of quarter-cycles from when the voltages collapse to zero 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 voltage 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.
5. Mask only the 50MF bit of the Relay Word into the MTU mask. Zero the MTO mask out so no other condition can assert the TRIP output.
6. Apply current in any phase over the 50M setting. The time shown on the timer should match the 50MFD time delay setting. Record the results.

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.
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 reverse 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 reverse 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.

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 Z3P for Z2P and Z3PT for Z2PT 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.

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.

PT LOGIC TEST

Purpose: Verify the following logic:

KEY = (R * MPT) * NOT(Z3RB)

and

TRIP = R * MPT * PT * NOT(Z3RB)

Where:
R = Relay Word,
MPT = Mask for Permissive Trip
PT = Permissive Trip contact input
Z3RB = Zone 3 Reverse Block

Method:

1. Program the KEY bit of the Relay Word into one of the four programmable output contacts (A1-A4).

2. Set ZONE3 = R and WFCE = N.

   The Z3RB condition must not exist (no Zone 3 elements picked up) to assure that the NOT(Z3RB) condition is met. The KEY bit asserts when any element in the MPT mask picks up and no Z3RB condition is present. With the factory relay settings, the Zone 2 elements 2ABC, Z2P, and 67N2 are selected in the MPT mask.

3. Test that KEY asserts when elements selected in the MPT mask are picked up and there is no Z3RB condition. Note that this does not require PT input assertion. Table 7.17 shows a Zone 2 AG fault that will pick up the 67N2 element selected in the MPT mask.

4. Make sure that when elements selected in the MPT mask are picked up and the PT input is asserted during a Z3RB condition (Zone 3 elements up), there will not be a TRIP (TRIP = R * MPT * PT * NOT(Z3RB). Make sure that no other conditions can cause a TRIP (e.g., zero out the other trip logic masks MTU, MTO, and MTB).

   Use the LOGIC command to select only the 67N3 bit of the Relay Word in the MPT mask.

5. Apply a reverse Zone 3 AG fault as shown in Table 7.18 while asserting the PT input. The 67N3 and Z3RB elements in the Relay Word will assert and no TRIP should occur.

Table 7.17: Zone 2 AG Fault Quantities

Prefault:

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

Table 7.18: Reverse Zone 3 AG Fault Quantities

Prefault:

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

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

Z3RBT TEST

Purpose: Verify the accuracy of the Zone 3 Reverse Block Timer (Z3RBT).

Method:

1. Set the BZ3RB timer equal to -1 to disable the Block the Zone 3 Reverse Block logic.
2. Program the Zone 3 element 3ABC into one of the four available outputs (A1-A4).
3. Set ZONE3 = R.
4. Program a different output with Z3RB.
5. Apply the Zone 3 3ABC fault to the relay and start a timer with the 3ABC element contact dropout (close to open). Stop the timer with the Z3RB element contact dropout (close to open). Table 7.19 shows a reverse Zone 3 three-phase fault.

Table 7.19: Reverse Zone 3 ABC Fault Quantities

Prefault:

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

3ABC Fault:

VA	VB	VC	IA	IB	IC	
67.00	67.00	67.00	10.07	10.07	10.07	Volts/Amps
0.0°	-120.0°	120.0°	96.3°	-23.7°	-143.7°	Degrees

6. Verify the Z3RBT timer accuracy by comparing the timer reading to the Z3RBT setting.

BZ3RB TEST

Purpose: Verify the Block the Zone 3 Reverse Block logic and the BZ3RB timer accuracy.

Method:

1. Program an available output (A1-A4) with only the Z3RB bit from the Relay Word.

   Set ZONE3 = R in the relay settings. With the breaker open (52A input deasserted), apply a reverse fault (in Zone 3) to the relay. Table 7.20 shows 3AG, Z3P, and 3ABC reverse fault quantities. The output programmed with the Z3RB bit should not assert.

2. Connect a timer to start with the 52A input assertion (control voltage applied to the contact input).

3. Connect this same timer to stop with the (open to close) Z3RB programmable output assertion.

4. Assert the 52A input to start the timer and allow the relay to decrement the BZ3RB timer.

5. Make sure the BZ3RB setting matches the timer result.

Table 7.20: Reverse Zone 3 Fault Quantities

Prefault:

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

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

Z3P 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

3ABC Fault:

VA	VB	VC	IA	IB	IC	
67.00	67.00	67.00	10.07	10.07	10.07	Volts/Amps
0.0°	-120.0°	120.0°	96.3°	-23.7°	-143.7°	Degrees

WFC TEST

Purpose: Verify the weak-infeed logic. With the weak-infeed conditional enable setting (WFCE) equal to Y, the WFC bit in the Relay Word asserts when either the phase-to-phase voltage drops below the 27PP setting or the zero-sequence voltage (V0) rises above the 59N setting.

Method: 1. Set the 27PP element setting to zero volts so the WFC does not assert when the phase-to-phase voltages drop below the 27PP setting. Set the 59N to 6 kV primary (3 V secondary).

2. Apply three-phase voltages in an unbalanced condition to generate zero-sequence voltage. For example:

   $VA = 58 \angle 0°$ volts
   $VB = 67 \angle -120°$ volts
   $VC = 67 \angle 120°$ volts

   $$V0 = \frac{1}{3}(VA + VB + VC)$$

   $$= 3 \angle -180° \text{ volts secondary}$$

   This set of voltages is on the boundary of the 59N element picking up and dropping out.

3. Find the 59N element pickup and dropout by monitoring the WFC bit in TARGET 4 while increasing or decreasing the A-phase voltage magnitude while keeping voltage phase angles constant. Record the result.

4. Restore the 27PP setting and test the 27PP pickup. Apply positive-sequence voltages and vary their magnitudes but not their phase angles to find the pickup and dropout of the 27PP elements. For example:

   $VA = 46.15 \angle 0°$
   $VB = 46.15 \angle -120°$
   $VC = 46.15 \angle 120°$

   $$V_{ab} = VA - VB = 80.0 \angle 30° \text{ secondary}$$

   For a 27PP setting of 80(PTR) = 160 kV (PTR = 2,000), the 27PP elements for V_{ab}, V_{bc}, and V_{ca} should be on the border of pickup/dropout with the 46.15 V per phase secondary presented to the relay voltage inputs.

5. Find the pickup and dropout of the 27PP elements by monitoring WFC in TARGET 4 and varying the magnitude of each phase to neutral voltage in unison while keeping their phase angles constant.

ECHO TIMER TESTS

Purpose: Verify the Echo Time Delay Pickup (ETDPU) timer and the Echo DURation (EDUR) timer accuracy:

1. Make sure the EDUR timer is not loaded when the PT input asserts for less than the ETDPU timer setting.

2. Make sure the PTEE bit of the Relay Word asserts for EDUR cycles when PT input assertion exceeds the ETDPU setting.

Method:

1. Program the PTEE bit in the Relay Word into one of the four programmable outputs (A1-A4). Use this contact output to start an external timer when the contact asserts (open to close) and stop when the contact deasserts (close to open). This timer measures the EDUR timer. Record the results.

2. Start another timer upon the PT input assertion. Stop the timer when the PTEE programmable output asserts (close to open). This timer measures the ETDPU time delay. Record the results.

3. Assert the PT input for less time than the ETDPU setting and verify that PTEE never asserts. One possible way to drive the PT input is from another programmable output with the 50L masked into this output. Using one current test source, you can control the length of 50L element (and PT input) assertion. Figure 7.12 shows the connections to make a programmable output drive the PT input.

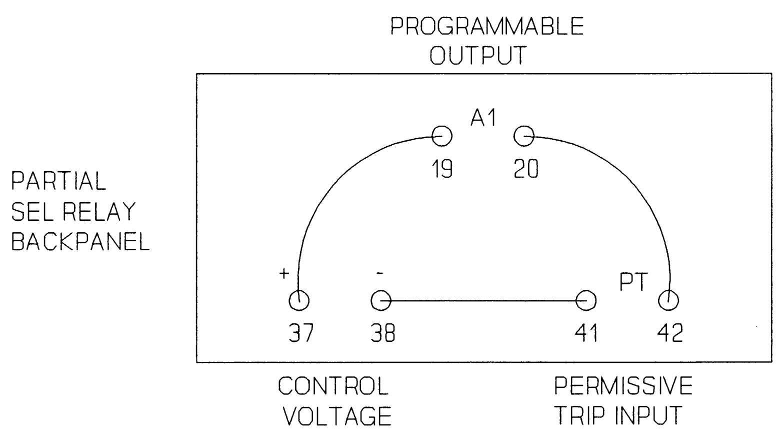


Figure 7.12: Connections for Wiring a Programmable Output to Drive the PT Input

4. Assert the PT input for longer than the ETDPU setting and make sure the ETDPU timer matches the ETDPU setting and the EDUR timer matches the EDUR setting.

ECTT TEST

Purpose: Verify the ECTT logic:

ECTT = NOT(Z3RB) * PTEE * 52A * WFC

Method: Satisfy the following conditions to test the ECTT logic:

NOT(Z3RB) ==> No Zone 3 elements (3ABC, Z3P, or 67N3) picked up.

PTEE ==> PT input asserted for at least ETDPU cycles.

52A ==> 52A input asserted (breaker closed).

WFC ==> Weak-infeed condition (V0 > 59N or Vac, Vbc, or Vca < 27PP).

The ECTT bit in the Relay Word asserts when all the above conditions are met. Table 7.21 gives voltage and current quantities with no Z3RB condition and a WFC condition. The test assumes use of factory relay settings: 6 kV for 59N and 160 kV for 27PP.

Table 7.21: Voltage and Current Quantities for a NOT(Z3RB) * WFC Condition

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

SWITCH-ONTO-FAULT TESTS

Purpose:

1. Verify 52BT timer accuracy and MTO logic (Switch-On-To-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 52A = 0, apply a fault to pick up an element masked into the MTO logic mask but not the MTU mask.

6. Table 7.22 contains prefault and fault voltage and current quantities for a Zone 2 AG fault.

Table 7.22: Zone 2 AG Fault Quantities

Prefault:

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 instantaneously.

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.

INPUT CIRCUITS TEST

Purpose: Verify that logic inputs assert when control voltage is applied across the respective terminal pair.

Method :
1. Set the 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 7.23 lists the contact inputs.

Table 7.23: 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 your relay is equipped with front and rear panel serial ports, verify that both operate correctly.

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

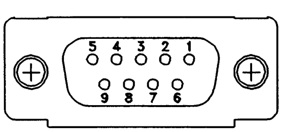
Purpose: Verify that correct output voltages are presented to PORT 1, PORT 2, and the auxiliary port. These voltages are required by external devices including a dc powered modem or the SEL-DTA unit.

Method:

1. Execute the STATUS command and inspect the voltage readings for the +5 and ±15 volt supplies.

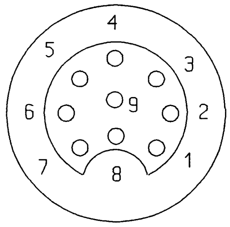
2. At the Auxiliary Port, use a voltmeter to read the +5 and ±12 volt outputs. The 12 volt outputs are derived from the 15 volt supplies using three-terminal regulators. The following pins are the read points:

SEL-221H	SEL-121H
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-221H Relay Nine-Pin Connector Pin Number Convention



(female chassis connector, as viewed from outside panel)

Figure 7.14: SEL-121H Relay Nine-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.

CALIBRATION

The SEL-221H Relay is factory calibrated. If you suspect that the relay is 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 terminals marked + and -.
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-121H 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 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-221H Relay

1. If the relay is in service, disable its control functions. Turn off control power to the relay.

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 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

SEL SCHWEITZER ENGINEERING LABORATORIES, INC.
2350 NE HOPKINS COURT • PULLMAN, WA 99163-5603 • TEL: (509) 332-1890

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 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.

It 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 a new impedance data (I), changing the distance from the source to the bus (B), specifying a new fault location (F), or quitting (Q).

TWX: 5106012265 (SCHWEITZER SEL) FACSIMILE: (509) 332-7990

```
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
```

APPENDICES
TABLE OF CONTENTS

APPENDIX A - FIRMWARE VERSIONS

This manual covers SEL-221H and SEL-121H Relays that contain firmware bearing the following part numbers and revision numbers (most recent firmware listed at top):

Firmware Part/Revision No.	Description of Firmware
SEL-121H-R602	Negative-Sequence Version
SEL-121H-R406	Base Product Fast Meter Cmd
SEL-121H3-R506	Kilometric Fault Locator Fast Meter Cmd
SEL-121H-R601	Negative-Sequence Version
SEL-121H-R441	40 Hertz Version
SEL-121H-R405	Base Product Fast Meter Cmd
SEL-121H3-R505	Kilometric Fault Locator Fast Meter Cmd
SEL-121H-R600	Negative-Sequence Version
SEL-121H-R440	40 Hertz Version
SEL-121H-R404	Base Product Fast Meter Cmd
SEL-121H3-R504	Kilometric Fault Locator Fast Meter Cmd

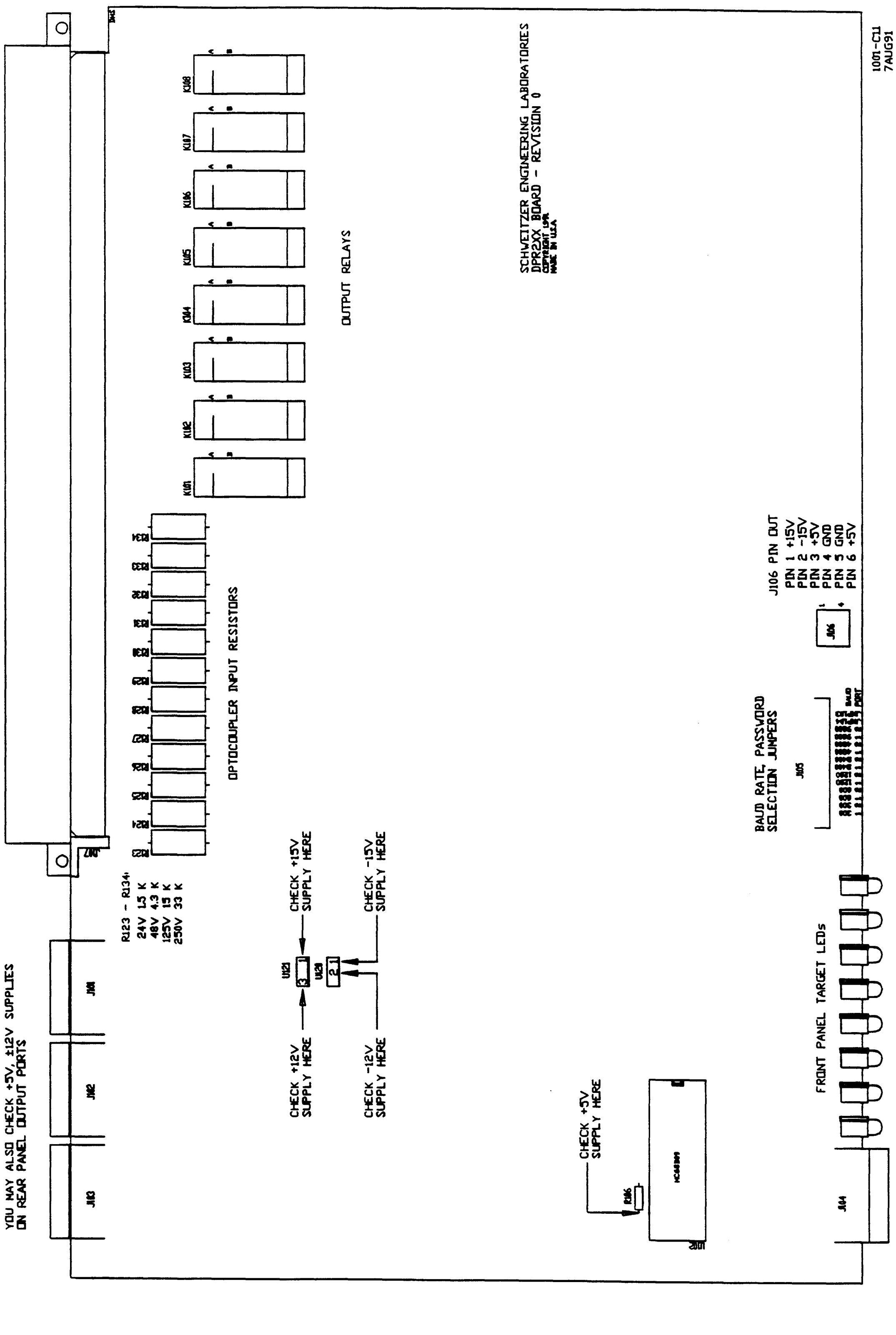
To find the firmware revision number in your relay, obtain an event report (which identifies the firmware) using the EVENT command. This is an FID number with the Part/Revision number in bold:

FID=**SEL-121H-R403**-V656mptr1s-D910422

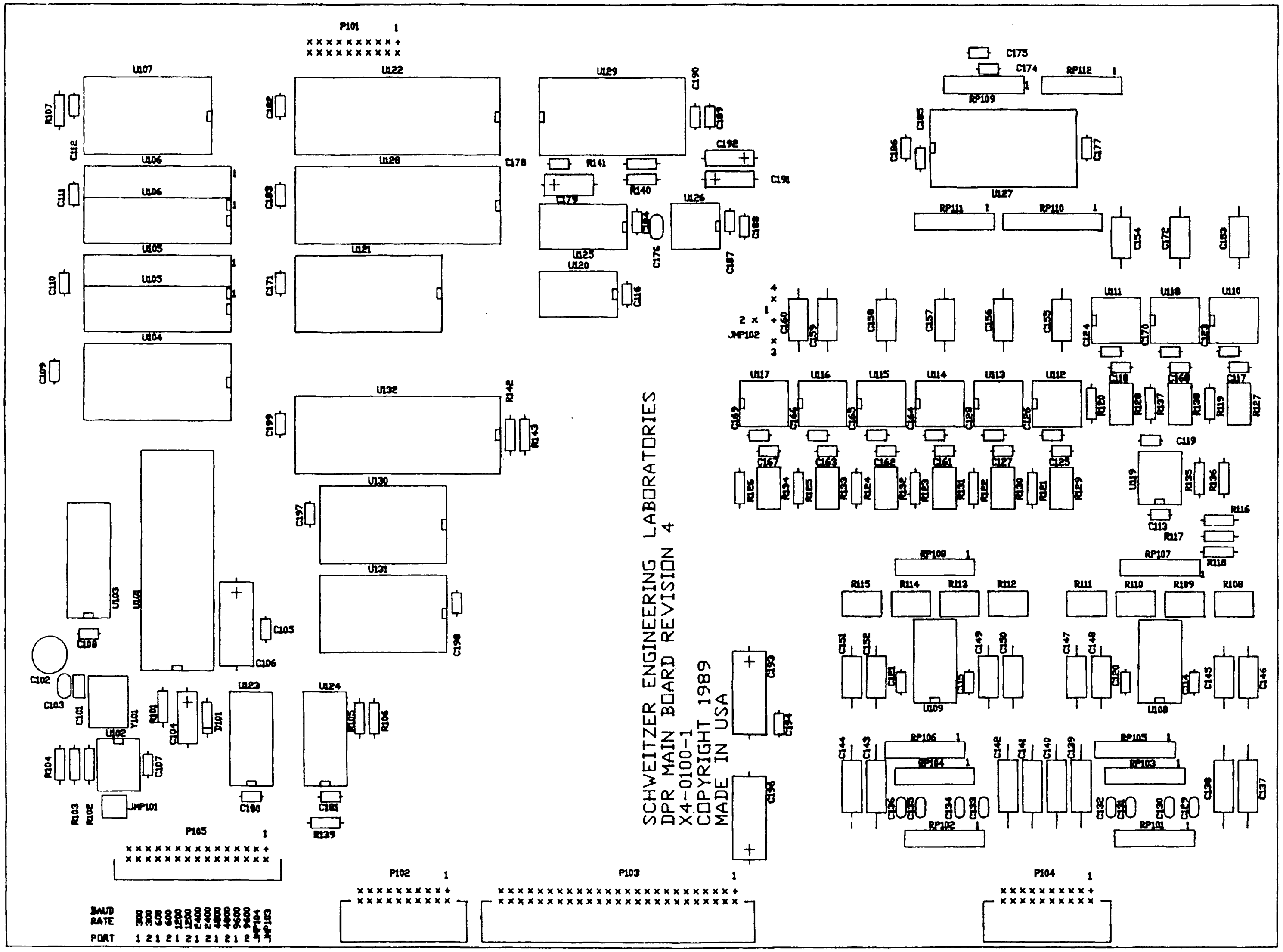
For a detailed explanation of the FID refer to Section 4: EVENT REPORTING.

The following table shows firmware that does not precisely match this manual.

Firmware Part/Revision No.	Description of Firmware
SEL-121H-R403	Base Product Fast Meter Cmd
SEL-121H3-R503	Kilometric Fault Locator Fast Meter Cmd
SEL-121H-R402	Base Product Fast Meter Cmd
SEL-121H3-R502	Kilometric Fault Locator Fast Meter Cmd
SEL-121H-R400	Base Product Fast Meter Cmd
SEL-121H3-R500	Kilometric Fault Locator Fast Meter Cmd



SEL-200 Series Relay Main Board Troubleshooting Test Points and Jumper Locations



UNLESS OTHERWISE NOTED ALL DIMENSIONS ARE IN INCHES

.XXX DIMENSIONS NOT TO SCALE

USED ON

RELEASED

APP.

CH.

DR.

TOL. EXCEPT AS NOTED

HOLE DIA.

XX ± .01"
XXX ± .005"
ANG. ± 1°

ITEM	PART NO.	DESCRIPTION	QTY.

SCALE NONE

TITLE DPR MAIN BOARD REVISION 4
PARTS PLACEMENT DIAGRAM

SEL SCHWEITZER ENGINEERING LABORATORIES
PULLMAN WASHINGTON USA

DWG. NO. B1-0100 REV. 4

SHEET 1 OF 1

SEL-221H 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	Show or set date. DAT 2/3/90 sets date to Feb. 3, 1990. IRIG-B time code input overrides existing month and day settings. DATE pulses ALARM contacts when year entered differs from year stored.
EVENT	Show event record. EVE 1 shows newest event; EVE 12 shows oldest.
HISTORY	Show DATE, TIME, TYPE, DIST (distance), DUR (duration), and CURR (maximum fault current) for the last twelve events.
IRIG	Force immediate attempt to synchronize internal relay clock to time code input.
METER n	Display primary phase-to-neutral and phase-to-phase voltages and currents, and real and reactive power. Option n displays meter data n times.
QUIT	Return control to Access Level 0; return target display to Relay Targets.
SHOWSET	Display settings without affecting them.
STATUS	Show self test status.
TARGET n k	Show data and set 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	Show or set time. TIM 13/32/00 sets clock to 1:32:00 PM. IRIG-B synchronization overrides this setting.
TRIGGER	Trigger and save an event record (event type is EXT).

Access Level 2

CLOSE	Close circuit breaker, if allowed by jumper setting.
LOGIC n	Show or set logic masks MTU, MPT, MTB, MTO, MA1-MA4. Command pulses ALARM contacts closed for one second and clears event buffers when new settings are stored.
OPEN	Open circuit breaker, if allowed by jumper setting.
PASSWORD	Show or set 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	Initiate set procedure. Optional n directs relay to begin setting procedure at that setting. SET EDUR initiates setting procedure at EDUR setting. SET initiates setting procedure at beginning. Command pulses ALARM contacts closed and clears event buffers when new settings are stored.

SCHWEITZER ENGINEERING LABORATORIES, INC.
2350 NE Hopkins Court
Pullman, WA 99163-5603
TEL: (509) 332-1890 FAX: (509) 332-7990

EXPLANATION OF EVENT REPORT

```
Example 230 kV Line                         Date: 9/18/90     Time: 09:20:59.241

FID=SEL-121H-R400-V656mptr1s-D900823

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

     0     -13     -66     409    -356  -114.9    -0.1   115.5     L..... ....... ....*.
     0     -38     -72    -481     513    67.8  -121.0    52.9     M..... ....... .*..*.
     3      49      66    -893     878   114.9    -5.5  -109.8     M..... ....... .*..*.
    -3      60      72     799    -809   -67.8   115.5   -47.4     M.2... *.*.... .*..*.

    -3     -71     -66    1092   -1101  -114.8     9.4   105.9     M.2... *.*.... .*..*.
     3     -64     -72    -840     849    67.8  -114.8    46.6     M.2... *.*.... .*..*.

Event   : 2BC     Location   : 84.70  mi  6.63   ohms sec
Duration: 2.50    Flt Current: 1418.9

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
Z1%  =80.00     Z2%  =120.00    Z3%  =120.00
Z2DP =20.00     Z3DP =60.00     A1TP =0.00      A1TD =0.00
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
Z2DG =30.00     Z3DG =60.00
TDUR =9.00      52BT =20.00     ZONE3=R         Z3RBT=4.50      BZ3RB=1.50
ETDPU=2.00      EDUR =3.50      WFCE =Y         27PP =160.00    59N  =6.00
32QE =Y         32VE =N         32IE =N         LOPE =Y
TIME1=5.00      TIME2=0.00      AUTO =2         RINGS=7.00
```

Currents and voltages are in primary amps and kV. Rows are ¼ cycle apart. Time runs down page. Obtain phasor RMS value and angle using any entry as Y-component and the entry immediately underneath as the X-component. For example, from bottom rows, IBY = 1092, IBX = -840. Therefore, IB = 1378 amps primary at an angle of ATAN (1092/-840) = 128°, with respect to the sampling clock.

```
<FID>              Firmware Identification Data
<Relays>           columns show states of internal relay elements     ---> Designators
                   50P : phase overcurrent ..... : 50H, 50M, 50L      ---> H,M,L
                   213 : 3-phase distance ...... : Z1, Z2, Z3, Z4     ---> 1,2,3,4
                   21P : 2-phase distance ...... : Z1, Z2, Z3         ---> 1,2,3
                   67N : inst ground overcurrent : 67N1, 67N2, 67N3   ---> 1,2,3
                   51N : ground time-overcurrent                      ---> P,T
                   LOP : loss-of-potential logic                      ---> *
<Outputs>          columns show states of output contacts: ON = "*", OFF = "."
                       TP=TRIP, CL=CLOSE, A1-A4=PROGRAMMABLE, AL=ALARM
<Inputs>           columns show states of input contacts:
                       DT=DIRECT TRIP, PT=PERMISSIVE TRIP, BT=BLOCK TRIP, DC=DIRECT CLOSE, 52A=AUX A-CONTACT,
                       ET=EXTERNAL TRIGGER (event report)
<Event>            Fault indications are "ZT" where Z indicates zone and T type
                       Z is one of 1=Zone 1, 2=Zone 2, 3=Zone3, 4=Zone4, 5=51N, H=50H, "?" = indeterminate
                       T is one of AG,BG,CG = single-phase to ground, AB,BC,CA = 2-phase,
                           ABG,BCG,CAG = 2-phase to ground, ABC = 3-phase.
                       Followed by a "T" if a TRIP triggered the report
                       Other indications are TRIP = triggered by TRIP output and EXT = externally or otherwise
                           triggered
<Location>         Distance to fault in miles.  999999 is indeterminate distance
<ohms sec>         Distance to fault in secondary ohms. 999999 is indeterminate
<Duration>         Fault duration determined from relay element(s) pickup time (cyc.)
<Flt Current>      Maximum phase current (primary amps) taken near middle of fault
R1,X1,R0,X0        Primary series impedance settings for transmission line (ohms)
LL                 Line length corresponding to specified line impedances
CTR, PTR           Current and potential transformer ratios (XTR:1)
MTA,LOCAT          Maximum torque angle (degrees) and fault locator enable (Y/N)
Z1%,Z2%,Z3%        Reaches of 3- and 2-phase mhos, percent of positive sequence line impedances
Z2DP,Z3DP          Zones 2 and 3 timer settings for 3- and 2-phase faults (cyc.)
A1TP,A1TD          A1 programmable output pickup and dropout delays (cyc.)
50L,M,H,MFD        Overcurrent settings and coordinating delay for 50M & LOP Trip
51NP,TD, C,TC      GND time-overcurrent Pickup, Time Dial, Curve, Torque Control
50N1P,2,3          Ground inst-overcurrent pickup settings Zones 1, 2 and 3
Z2DG, Z3DG         Zone 2 and 3 ground timer settings (cyc.)
TDUR,52BT          Trip output duration timer, 52B delay setting (for switch-onto-fault coordination) (cyc.)
ZONE3              Direction of all zone 3 elements (Fwd/Rvs)
Z3RBT,BZ3RB        Reverse block and block-the-reverse-block timer settings (cyc.)
ETDPU,EDUR         Echo Time Delay Pickup timer and Echo Duration timer (cyc.)
WFCE,27PP,59N      Weak Feed enable (Y/N), phase-phase voltage level detector (kV), and residual overvoltage
                       level detector (kV).
32QE,VE,IE         Ground fault directionality from (V2,I2) or (V0/IP,I0)
LOPE               Loss-of-potential enable (Y/N)
TIME1,2            Communications port timeout intervals (automatic log-off) (minutes)
AUTO               Port assignment for automatic message transmissions (1, 2, or 3)
RINGS              Number of rings to wait before modem answers telephone
<Logic settings>       See LOGIC command for a description of mask settings
```

SEL-221H 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	Show or set date. DAT 2/3/90 sets date to Feb. 3, 1990. IRIG-B time code input overrides existing month and day settings. DATE pulses ALARM contacts when year entered differs from year stored.
EVENT	Show event record. EVE 1 shows newest event; EVE 12 shows oldest.
HISTORY	Show DATE, TIME, TYPE, DIST (distance), DUR (duration), and CURR (maximum fault current) for the last twelve events.
IRIG	Force immediate attempt to synchronize internal relay clock to time code input.
METER n	Display primary phase-to-neutral and phase-to-phase voltages and currents, and real and reactive power. Option n displays meter data n times.
QUIT	Return control to Access Level 0; return target display to Relay Targets.
SHOWSET	Display settings without affecting them.
STATUS	Show self test status.
TARGET n k	Show data and set 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	Show or set time. TIM 13/32/00 sets clock to 1:32:00 PM. IRIG-B synchronization overrides this setting.
TRIGGER	Trigger and save an event record (event type is EXT).

Access Level 2

CLOSE	Close circuit breaker, if allowed by jumper setting.
LOGIC n	Show or set logic masks MTU, MPT, MTB, MTO, MA1-MA4. Command pulses ALARM contacts closed for one second and clears event buffers when new settings are stored.
OPEN	Open circuit breaker, if allowed by jumper setting.
PASSWORD	Show or set 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	Initiate set procedure. Optional n directs relay to begin setting procedure at that setting. SET EDUR initiates setting procedure at EDUR setting. SET initiates setting procedure at beginning. Command pulses ALARM contacts closed and clears event buffers when new settings are stored.

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EXPLANATION OF EVENT REPORT

```
Example 230 kV Line                          Date: 9/18/90     Time: 09:20:59.241

FID=SEL-121H-R400-V656mptr1s-D900823

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

     0    -13     -66     409    -356 -114.9    -0.1   115.5  L..... ....... ....*.
     0    -38     -72    -481     513   67.8 -121.0    52.9   M..... ....... .*..*.
     3     49      66    -893     878  114.9    -5.5 -109.8   M..... ....... .*..*.
    -3     60      72     799    -809  -67.8   115.5   -47.4  M.2... *.*.... .*..*.

    -3    -71     -66    1092   -1101 -114.8     9.4   105.9  M.2... *.*.... .*..*.
     3    -64     -72    -840     849   67.8 -114.8    46.6   M.2... *.*.... .*..*.

Event   : 2BC    Location   : 84.70  mi  6.63    ohms sec
Duration: 2.50   Flt Current: 1418.9

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
Z1%   =80.00     Z2%   =120.00   Z3%   =120.00
Z2DP  =20.00     Z3DP  =60.00    A1TP  =0.00     A1TD  =0.00
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
Z2DG  =30.00     Z3DG  =60.00
TDUR  =9.00      52BT  =20.00    ZONE3=R         Z3RBT=4.50      BZ3RB=1.50
ETDPU=2.00       EDUR  =3.50     WFCE  =Y        27PP  =160.00   59N   =6.00
32QE  =Y         32VE  =N        32IE  =N        LOPE  =Y
TIME1=5.00       TIME2=0.00      AUTO  =2        RINGS=7.00
```

Currents and voltages are in primary amps and kV. Rows are ¼ cycle apart. Time runs down page. Obtain phasor RMS value and angle using any entry as Y-component and the entry immediately underneath as the X-component. For example, from bottom rows, IBY = 1092, IBX = -840. Therefore, IB = 1378 amps primary at an angle of ATAN (1092/-840) = 128°, with respect to the sampling clock.

```
<FID>               Firmware Identification Data
<Relays>            columns show states of internal relay elements     ---> Designators
                    50P : phase overcurrent ..... : 50H, 50M, 50L      ---> H,M,L
                    213 : 3-phase distance ...... : Z1, Z2, Z3, Z4     ---> 1,2,3,4
                    21P : 2-phase distance ...... : Z1, Z2, Z3         ---> 1,2,3
                    67N : inst ground overcurrent : 67N1, 67N2, 67N3 ---> 1,2,3
                    51N : ground time-overcurrent                      ---> P,T
                    LOP : loss-of-potential logic                      ---> *
<Outputs>           columns show states of output contacts: ON = "*", OFF = "."
                        TP=TRIP, CL=CLOSE, A1-A4=PROGRAMMABLE, AL=ALARM
<Inputs>            columns show states of input contacts:
                        DT=DIRECT TRIP, PT=PERMISSIVE TRIP, BT=BLOCK TRIP, DC=DIRECT CLOSE, 52A=AUX A-CONTACT,
                        ET=EXTERNAL TRIGGER (event report)
<Event>             Fault indications are "ZT" where Z indicates zone and T type
                        Z is one of 1=Zone 1, 2=Zone 2, 3=Zone3, 4=Zone4, 5=51N, H=50H, "?" = indeterminate
                        T is one of AG,BG,CG = single-phase to ground, AB,BC,CA = 2-phase,
                            ABG,BCG,CAG = 2-phase to ground, ABC = 3-phase.
                        Followed by a "T" if a TRIP triggered the report
                        Other indications are TRIP = triggered by TRIP output and EXT = externally or otherwise
                            triggered
<Location>          Distance to fault in miles.  999999 is indeterminate distance
<ohms sec>          Distance to fault in secondary ohms. 999999 is indeterminate
<Duration>          Fault duration determined from relay element(s) pickup time (cyc.)
<Flt Current>       Maximum phase current (primary amps) taken near middle of fault
R1,X1,R0,X0         Primary series impedance settings for transmission line (ohms)
LL                  Line length corresponding to specified line impedances
CTR, PTR            Current and potential transformer ratios (XTR:1)
MTA,LOCAT           Maximum torque angle (degrees) and fault locator enable (Y/N)
Z1%,Z2%,Z3%         Reaches of 3- and 2-phase mhos, percent of positive sequence line impedances
Z2DP,Z3DP           Zones 2 and 3 timer settings for 3- and 2-phase faults (cyc.)
A1TP,A1TD           A1 programmable output pickup and dropout delays (cyc.)
50L,M,H,MFD         Overcurrent settings and coordinating delay for 50M & LOP Trip
51NP,TD, C,TC       GND time-overcurrent Pickup, Time Dial, Curve, Torque Control
50N1P,2,3           Ground inst-overcurrent pickup settings Zones 1, 2 and 3
Z2DG, Z3DG          Zone 2 and 3 ground timer settings (cyc.)
TDUR,52BT           Trip output duration timer, 52B delay setting (for switch-onto-fault coordination) (cyc.)
ZONE3               Direction of all zone 3 elements (Fwd/Rvs)
Z3RBT,BZ3RB         Reverse block and block-the-reverse-block timer settings (cyc.)
ETDPU,EDUR          Echo Time Delay Pickup timer and Echo Duration timer (cyc.)
WFCE,27PP,59N       Weak Feed enable (Y/N), phase-phase voltage level detector (kV), and residual overvoltage
                        level detector (kV).
32QE,VE,IE          Ground fault directionality from (V2,I2) or (V0/IP,I0)
LOPE                Loss-of-potential enable (Y/N)
TIME1,2             Communications port timeout intervals (automatic log-off) (minutes)
AUTO                Port assignment for automatic message transmissions (1, 2, or 3)
RINGS               Number of rings to wait before modem answers telephone
<Logic settings>        See LOGIC command for a description of mask settings
```