SEL-221C
SEL-121C

PHASE DISTANCE/TIME-OVERCURRENT RELAY
GROUND DIRECTIONAL OVERCURRENT RELAY
AND FAULT LOCATOR

INSTRUCTION MANUAL

MARCH 10, 1995

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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.

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 accidental 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 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.

SEL RELAY INSTRUCTION MANUAL ADDENDUM

Kilometer Option

The SEL relay instruction manuals are written for fault locations in terms of miles. If your 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 as follows:

> 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 length in radians at 60 Hz. One wavelength at **60 Hz is 4989 kilometers**. For example, the line length of a 100-kilomerter line in radians is:
>
> $(100/4989) \cdot 2 \cdot 3.14159 = 0.1260$ 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.

SECTION 1: SEL-200 SERIES RELAY ADDENDUM

The SEL-200 series relays with 125 Vdc optical isolator inputs now have level-sensitive inputs. These inputs compare to the original SEL-200 series relays as follows:

ORIGINAL SEL-200 SERIES OPTICAL ISOLATOR LOGIC INPUT RATING

125 Vdc: 80 - 150 Vdc; 4 milliamps at nominal voltage

NEW SEL-200 SERIES OPTICAL ISOLATOR LOGIC INPUT RATING

125 Vdc: 100 - 150 Vdc; 6 milliamps at nominal voltage

The optical isolator input does not assert for applied voltages less than 75 Vdc. The firmware remains unchanged.

SEL-200 SERIES (SHALLOW) RELAY HARDWARE ADDENDUM

The shallow SEL-200 series hardware brings a reduction in unit depth and weight. It compares to the original SEL-200 series relay hardware as follows:

ORIGINAL SEL-200 SERIES RELAY HARDWARE SPECIFICATIONS

3.47" x 19.00" x 11.66" (8.81 cm x 48.26 cm x 29.62 cm) (H x W x D)

16 pounds (7.3 kg)

SEL-200 SERIES (SHALLOW) RELAY HARDWARE SPECIFICATIONS

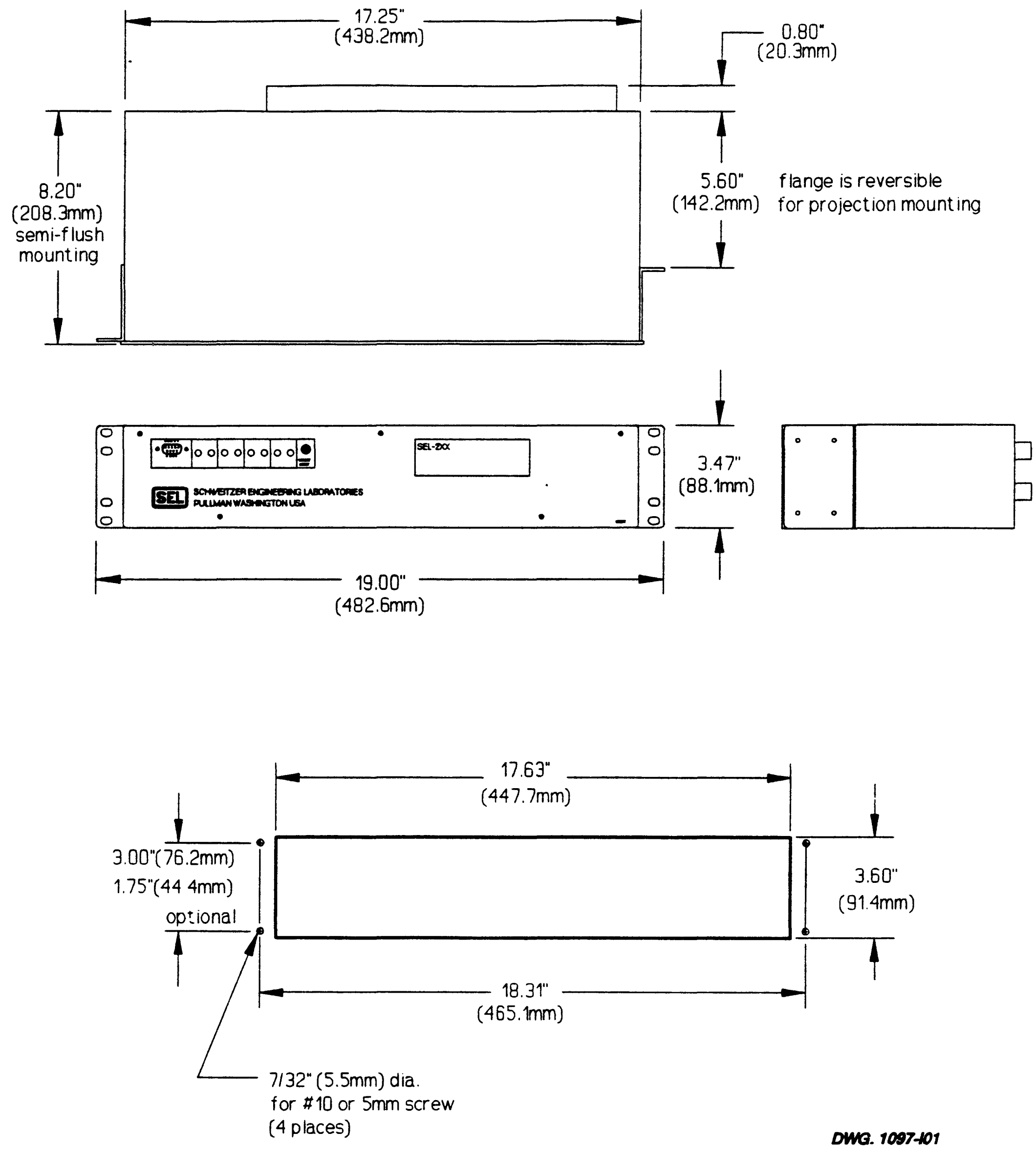
3.47" x 19.00" x 9.00" (8.81 cm x 48.26 cm x 22.86 cm) (H x W x D)

12 pounds (5.5 kg)

Depth (dimension D) is to the end of the rear panel terminal blocks.

This hardware is also equipped for low-level testing. The firmware remains unchanged.

All other specifications remain the same. The shallow SEL-200 series relay dimensions, panel cutout, and drill diagrams are on the following page.



SEL-200 Series (Shallow) Relay Dimensions, Panel Cutout, and Drill Diagrams

JUMPER INSTALLATION INSTRUCTIONS FOR ALL 200-SERIES RELAYS EXCEPT SEL-279 AND SEL-279H

The power available from these ports is limited and should be used only for SEL-RDs, SEL-DTAs, dc-powered modems, or other low-wattage devices approved by SEL.

The power is available on either Port 1 or Port 2R. Port 2F, located on the front of the relay, does NOT have power available.

To install jumpers for supplying power through the rear EIA RS-232-C ports on all SEL-200 series relays (except SEL-279 and SEL-279H Relays), perform the following steps:

1. Remove the relay top cover or withdraw the main circuit board.
2. Locate jumpers JMP12 (+5 Vdc), JMP13 (+12 Vdc) and JMP14 (-12 Vdc) near the AUX INPUT connector.
3. Remove and install the needed jumpers in the "on" position.
4. Replace the top cover or re-insert the main circuit board. (Ensure that the board is correctly seated and the cables to the power supply and input transformers are reconnected.)

TABLE OF CONTENTS

INTRODUCTION

Getting Started 1-1
Overview 1-1
General Description 1-2

SPECIFICATIONS

Relay Standards and Input Parameters 2-1
Functional Specifications 2-2
- Expanded Mho Characteristics for Phase-Phase and Three-Phase Faults 2-2
- Phase Time-Overcurrent Protection for Phase Faults 2-3
- Residual Overcurrent Protection for Ground Faults 2-3
- Residual Overcurrent Directional Elements 2-3
- Reclosing 2-4
- Loss-of-Potential (LOP) Detection 2-4
- Nondirectional Phase Overcurrent Elements 2-4
- Switch-Onto-Fault Protection 2-4
- IRIG-B Input 2-5
- Relay Word 2-5
- Logic Inputs 2-5
- Output Contacts 2-5
- Event Reporting 2-6
- Fault Location 2-6
- Metering 2-6
- Targeting 2-7
- Self-Testing 2-7

Detailed Specifications 2-7
- Distance Elements 2-7
  - Phase-Phase Distance 2-7
  - Three-Phase Distance 2-8
  - Maximum Torque Angle (MTA) 2-8
  - Zone 2 and 3 settings are limited 2-8
  - Accuracy 2-8
  - Operating Speed 2-8
  - Memory Polarization 2-8
  - Zone 3 Distance Element Timer 2-8
- Overcurrent Elements 2-9
  - Nondirectional Phase Overcurrent Elements 2-9
  - Phase Time-Overcurrent Element 2-9
  - Ground Overcurrent Elements 2-9
  - Ground Overcurrent Element Timers 2-10

Ground Directional Elements . . . 2-10
Negative-Sequence Directional Element . . . 2-10
Zero-Sequence Directional Element . . . 2-11
Sequence-Component Elements . . . 2-12
Miscellaneous Timers . . . 2-13
Potential Inputs . . . 2-13
Current Inputs . . . 2-13
Logic Inputs . . . 2-14
Direct Trip (DT) . . . 2-14
Permissive Trip (PT) . . . 2-14
Block Trip (BT) . . . 2-14
Direct Close (DC) . . . 2-15
Circuit Breaker Status (52A) . . . 2-15
External Trigger for Event Report (ET) . . . 2-15
Output Contacts . . . 2-15
TRIP Output . . . 2-15
CLOSE Output . . . 2-16
ALARM Output . . . 2-16
Programmable Outputs (A1, A2, A3, A4) . . . 2-16
Logic Description . . . 2-16
Relay Elements . . . 2-16
Optically Coupled Contact Inputs . . . 2-17
Contact Outputs . . . 2-17
Timers . . . 2-18
Enables from Setting Procedure . . . 2-18
Intermediate Logic . . . 2-18
Loss-of-Potential (LOP) Logic . . . 2-19
Phase Overcurrent Conditions . . . 2-19
Distance Relay Logic . . . 2-19
Ground Overcurrent Conditions . . . 2-19
Output Equations and Logic . . . 2-20
Trip Suspicion Logic . . . 2-21
Scenario 1 - Actual Transmission Line Fault . . . 2-21
Scenario 2 - Potential Transfer Operation . . . 2-22
Relay Word . . . 2-22
Targets . . . 2-24
Reclosing Relay . . . 2-25
No Voltage Checking LLC = N, DLC = N . . . 2-26
Live Voltage Checking, LLC = Y, DLC = N . . . 2-26
Dead Voltage Checking, LLC = N, DLC = Y . . . 2-27
Reclose Cancellation . . . 2-28
Recloser Reset Time, 79RS . . . 2-28
Signal Processing . . . 2-28
Event Reporting . . . 2-29
Fault Locator . . . 2-29
Metering . . . 2-30
Serial Interfaces . . . 2-30
IRIG-B Input Description . . . 2-31
Self-Tests . . . 2-31

Offset . . . 2-31
Power Supply . . . 2-32
Random-Access Memory . . . 2-32
Read-Only Memory . . . 2-32
Analog-to-Digital Converter . . . 2-32
Master Offset . . . 2-33
Settings . . . 2-33
Functional Description . . . 2-34
Mho Elements . . . 2-34
Mho Element Expansion . . . 2-35
Three-Phase Elements . . . 2-36
Time-Overcurrent Elements and Curves . . . 2-36
Directional Elements . . . 2-37
Programmable Logic Mask Concept . . . 2-38
Relay Element Operating Time Curves . . . 2-39
Time-Overcurrent Curve Equations . . . 2-41
Logic Diagrams . . . 2-43

COMMUNICATIONS

Introduction . . . 3-1
Serial Port Connections and Configurations . . . 3-1
Communications Protocol . . . 3-4
Command Characteristics . . . 3-5
Startup . . . 3-6
Command Format . . . 3-7
Command Descriptions . . . 3-7
Access Level 0 Command . . . 3-7
Access Level 1 Commands . . . 3-8
Access Level 2 Commands . . . 3-19
SEL-221C/121C Relay Command Summary . . . 3-27

EVENT REPORTING

Event Report Generation . . . 4-1
Summary Event Report . . . 4-2
Relay Identifier . . . 4-2
Event Time and Date . . . 4-3
Event Type . . . 4-3
Fault Location . . . 4-4
Secondary Ohms . . . 4-5
Fault Duration . . . 4-5
Maximum Phase Current . . . 4-5
Shot Counter . . . 4-5
Long Event Report . . . 4-6
Interpretation of Voltage and Current Data . . . 4-6

Relays . . . 4-7
Contact Outputs and Inputs . . . 4-8
Event Summary . . . 4-8
Relay Settings . . . 4-8
Example Event Reports . . . 4-9
Externally Triggered Event Report . . . 4-9
Zone 1 BC Fault . . . 4-11
Zone 2 BC Fault . . . 4-15
Switch-onto-Fault Event . . . 4-21
Firmware Identification . . . 4-24

APPLICATIONS

Relay Application Overview . . . 5-1
Coordinate Phase Protection with Downstream Devices . . . 5-1
Time-Step Relaying . . . 5-1
Backup Relaying . . . 5-1
Schemes Involving Communications . . . 5-2
Replacement of Outdated Protective Relays . . . 5-2
Other Applications . . . 5-2
69 kV Setting Example . . . 5-2
Purpose . . . 5-2
System Data . . . 5-3
Protection Scheme Overview . . . 5-3
Coordination at Breaker 3 . . . 5-3
Coordination at Breaker 4 . . . 5-4
Relay Settings . . . 5-4
Identifier . . . 5-5
R1, X1, R0, X0, and Line Length (LL) . . . 5-5
Current and Potential Transformer Ratio Selection . . . 5-6
Maximum Torque Angle (MTA) . . . 5-7
Fault Locator Enable (LOCAT) . . . 5-8
Reclosing Relay Voltage Supervision Settings (47PXD, 47PXL, 59N) . . . 5-8
Reclosing Relay Voltage Condition Time Delay (VCT) . . . 5-9
Reclosing Relay Voltage Condition Checking Settings (LLC, DLC, CVC, and VSA) . . . 5-10
Reclosing Open Intervals and Reset Time (79OI1, 79OI2, 79OI3, and 79RS) . . . 5-11
Low-Set Phase Overcurrent Setting (50L) . . . 5-12
Medium-Set Phase Overcurrent Setting (50M) . . . 5-13
High-Set Phase Overcurrent Setting . . . 5-14
Zone 1 Reach Setting (Z1%) . . . 5-15
Zone 2 Reach Setting (Z2%) . . . 5-16
Zone 3 Reach Setting (Z3%) . . . 5-18
Zone 3 Phase Time Delay (Z3DP) . . . 5-19
Phase Time-Overcurrent Settings (51PP, 51PC, 51PTD) . . . 5-20
Residual Time-Overcurrent Settings (51NP, 51NC, 51NTD, 51NTC) . . . 5-21
Trip Duration Timer (TDUR) . . . 5-22
50N1P Residual Overcurrent Setting (50N1P) . . . 5-22

50N2P Residual Overcurrent Setting (50N2P) 5-23
50N3P Residual Overcurrent Setting (50N3P) 5-24
Zone 2 Residual Overcurrent Time Delay (Z2DG) 5-25
Zone 3 Residual Overcurrent Time Delay (Z3DG) 5-25
52BT Setting (52BT) and Switch-Onto-Fault Protection 5-26
Zone 3 Direction Setting 5-28
Residual Overcurrent Polarization Method Selection (32QE, 32VE, 32IE) 5-28
Negative-Sequence Polarization 5-28
Zero-Sequence Voltage Polarization 5-28
Zero-Sequence Current Polarization 5-29
Loss-of-Potential (LOP) Enable Setting, (LOPE) 5-29
Serial Port(s) Timeout Settings (TIME1, TIME2) 5-30
Autoport Designation Setting (AUTO) 5-31
Modem Answer Ring Setting (RINGS) 5-31
Full Example Setting Group 5-31
Programmable Output Contact Mask Settings 5-32
Communication Scheme Use of Logic Masks 5-32
MTU: Mask for Trip Unconditional 5-33
Mask for Trip Unconditional (MTU) 5-33
MPT: Mask for Trip with Permissive Trip Input Asserted 5-34
Mask for Permissive Trip (MPT) 5-34
MTB: Mask for Trip with Block Trip Input Deasserted 5-34
Mask for Trip Block (MTB) 5-35
MTO: Mask for Trip with the 52BT Element Asserted 5-35
Mask for Trip Breaker Open (MTO) 5-35
MA1, MA2, MA3, and MA4 Programmable Output Contact Masks 5-36
Mask for the A1 Output Contact (MA1) 5-36
Mask for the A2 Output Contact (MA2) 5-36
Mask for the A3 Output Contact (MA3) 5-37
Mask for the A4 Output Contact (MA4) 5-37
MRI: Mask for Reclose Initiation 5-37
Mask for Reclose Initiation (MRI) 5-37
MRC: Mask for Reclose Cancellation 5-38
Mask for Reclose Cancel (MRC) 5-38
Relay Word Bits Intended for Relay Testing 5-38
Reclosing Relay Operation Examples 5-38
Overview 5-38
Example 1: DLC = N, LLC = N, Two Shot Reclose Sequence 5-39
Example 2: DLC = N, LLC = N, Reclosing Cancelled Due to RC Assertion 5-41
Example 3: DLC = Y, LLC = N, Dead-line Supervised Reclose Sequence 5-42
Example 4: DLC = Y, LLC = N, Reclosing Sequence Cancelled Due to VCT Expiration 5-44
Example 5: DLC = N, LLC = Y, Live-line Supervised Reclose Sequence 5-45
Example 6: DLC = N, LLC = Y, Second Shot Cancelled Due to CVC Failure 5-47
Settings Sheet 5-49

INSTALLATION

Installation 6-1
- Mounting 6-1
- Frame Ground Connection 6-1
- Power Connections 6-1
- Secondary Circuits 6-1
- Control Circuits 6-1
- Communications Circuits 6-2
- Jumper Selection 6-2
  - EIA-232 Jumpers 6-2
  - Password Protection Jumper 6-2
  - OPEN/CLOSE Command Enable Jumper 6-2
  - A4 Output Contact Jumper 6-3
  - Output Contact Soldered Wire Jumpers 6-3
  - Communication Port External Power Jumpers 6-3
- EIA-232 and IRIG-B Installation 6-3
  - EIA-232 Cables 6-4
- IRIG-B Input Description 6-4

Installation Checkout 6-5

SEL Direction and Polarity Check Form 6-12

SEL Direction and Polarity Check Form 6-13

MAINTENANCE & TESTING

Test Procedures 7-1
- Test Aids Provided by the Relay 7-1
  - METER Command 7-1
  - TARGET Command 7-1
  - Event Reporting 7-1
  - Programmable Logic 7-2
- Low-Level Test Interface (patents pending) (Available only in SEL-200 series relays) . . 7-2
- Test Methods 7-3
  - Testing Via Target LED Illumination 7-3
  - Testing Via Output Contact Assertion 7-3
  - Using a Breaker Simulator 7-4

Initial Checkout 7-4
- Minimum Equipment Required 7-4
- Checkout Procedure 7-4
  - Output Contact Explanation 7-12
  - Target LED Explanation 7-12

Full Functional Test 7-13
- Equipment Required 7-13
- What Should Be Tested 7-14

Setting Test 7-14

Meter Test 7-15

Mho Element Testing 7-17

A. Determining Fault Simulation Values - Phase-Phase and Phase-Ground Faults . . . 7-17
B. Onebus Input Description 7-18
C. Determining Fault Simulation Values - Three-Phase Faults 7-19
D. Three-Phase Mho Relay Test 7-20
E. Phase-Phase Mho Element Tests 7-24
Directional Element Tests 7-27
32Q and 32V Tests 7-27
32I Tests 7-29
Residual Overcurrent Element Tests 7-30
Residual Time-Overcurrent Element Timing Tests 7-30
Phase Overcurrent Element Tests 7-31
Phase Time-Overcurrent Element Test 7-32
Memory Voltage Polarization Test 7-33
Loss-Of-Potential Test 7-34
50MF, 50MFD Test 7-34
Z2DG and Z3DG Timer Tests 7-35
Z3DP Timer Test 7-36
Switch-Onto-Fault Tests 7-37
Recloser Test, LLC = N, DLC = N 7-38
Recloser Test, LLC = N, DLC = Y 7-39
Recloser Test, LLC = Y, DLC = N 7-40
Input Circuits Test 7-41
Serial Ports Test 7-42
IRIG-B Time Code Input Test 7-42
Power Supply Voltages Test 7-42
Relay Calibration 7-43
Troubleshooting 7-44
Inspection Procedure 7-44
Troubleshooting Table 7-44
All Front Panel LEDs Dark 7-44
System Does Not Respond to Commands 7-44
Tripping Output Relay Remains Closed Following Fault 7-45
No Prompting Message Issued to Terminal upon Power-Up 7-45
System Does Not Respond to Faults 7-45
Terminal Displays Meaningless Characters 7-46
Self-Test Failure: +5 Volts 7-46
Self-Test Failure: +15 Volts 7-46
Self-Test Failure: -15 Volts 7-46
Self-Test Failure: Offset 7-46
Self-Test Failure: ROM Checksum 7-46
Self-Test Failure: RAM 7-46
Self-Test Failure: A/D Converter 7-47
Alarm Contact Closed 7-47
Firmware Upgrade Instructions 7-47
Firmware Upgrade Instructions, SEL-121C Relay 7-47
Firmware Upgrade Instructions, SEL-221C Relay 7-49
Factory Assistance 7-49

APPENDICES

Appendix A - Firmware Versions . . . . Appendix A-1

Appendix B - Internal Diagrams . . . . Appendix B-1

Appendix C - Onebus: Program to Compute Test Set Settings for Testing Distance Relays . . . . Appendix C-1

TABLES

Table 2.1: Relay Word 2-5
Table 2.2: Directional Element Sensitivities at Maximum Torque Angle (MTA) 2-11
Table 2.3: Logic Input Functions 2-14
Table 2.4: Relay Word Bit Summary 2-23
Table 2.5: Power Supply Self-Test Limits 2-32
Table 2.6: Self-Test Summary 2-33
Table 2.7: Directional Element Torque Equations 2-37
Table 3.1: SEL-221C Relay Serial Port Connector Pin Assignments 3-3
Table 3.2: SEL-121C Serial Port Connector Pin Assignments 3-4
Table 3.3: Hexadecimal/Binary Conversion 3-15
Table 3.4: Target LED Assignment 3-17
Table 4.1: Event Report Triggering Actions 4-1
Table 4.2: Non-Event Report Triggering Actions 4-1
Table 5.1: Settings for: Bus B, 69 kV, Line 2 5-32
Table 5.2: Reclosing Relay Timing Examples 5-39
Table 5.3: Recloser Settings for Examples 1 and 2 5-40
Table 5.4: Recloser Settings for Examples 3 and 4 5-42
Table 5.5: Recloser Settings for Examples 5 and 6 5-45
Table 6.1: AUX INPUT Pin Definition 6-5
Table 7.1: Fault Locator Test Values 7-11
Table 7.2: Target LED Results 7-11
Table 7.3: Three-Phase Fault Voltages and Currents at MTA 7-20
Table 7.4: Zone 1 Three-Phase Element Test Quantities at MTA 7-22
Table 7.5: Zone 1 Three-Phase Test Quantities at MTA ±45° 7-23
Table 7.6: Zone 1 Phase-Phase Test Voltages and Currents, BC Fault 7-26
Table 7.7: Zone 1 Phase-Phase Test Quantities at MTA ±45° 7-27
Table 7.8: 32Q and 32V Test Voltages 7-28
Table 7.9: 32I Test Currents 7-29
Table 7.10: Current Quantities for 51N Timing Test Example 7-31
Table 7.11: Zone 2 Phase-Phase Test Voltages and Currents, 51P Test 7-32
Table 7.12: Three-Phase Close-In Fault 7-33
Table 7.13: Conditions for the SET LOP and CLEAR LOP Logic Equations 7-34
Table 7.14: Standard Zone 2 AG Fault Using Factory Relay Settings 7-35
Table 7.15: Standard Zone 3 AG Fault Using Factory Relay Settings 7-35

Table 7.16: Standard Zone 3 BC Fault Using Factory Relay Settings 7-36
Table 7.17: Zone 2 AG Fault Quantities 7-37
Table 7.18: Zone 1 AG Fault Quantities 7-38
Table 7.19: Contact Inputs 7-42

FIGURES

Figure 2.1: Phase-Phase and Three-Phase Mho Element Characteristics 2-3
Figure 2.2: Residual Overcurrent Zones of Protection 2-4
Figure 2.3: 32Q and 32V Polarization Criteria 2-12
Figure 2.4: 32I Polarization Criteria 2-12
Figure 2.5: Trip Suspicion (TS) Logic 2-21
Figure 2.6: Relay Targets 2-24
Figure 2.7: Mho Element Reach at Maximum Torque Angle 2-34
Figure 2.8: Expanded Two-Phase Mho Characteristics 2-35
Figure 2.9: Expanded Three-Phase Mho Characteristics 2-36
Figure 2.10: Programmable Logic Mask Analogy 2-39
Figure 2.11: Phase Distance Speed Curves and 50H Phase Overcurrent Speed Curve 2-40
Figure 2.12: Moderately Inverse Curves 2-42
Figure 2.13: Inverse Curves 2-42
Figure 2.14: Very Inverse Curves 2-42
Figure 2.15: Extremely Inverse Curves 2-42
Logic Diagrams 2-43
Figure 3.1: SEL-221C 9-Pin Connector Pin Number Convention 3-2
Figure 3.2: SEL-121C 9-Pin Connector Pin Number Convention 3-2
Figure 4.1: Example System Single-Line Diagram 4-11
Figure 5.1: 69 kV Setting Example System Single-Line Diagram 5-3
Figure 5.2: 52A Input and 52BT Timing Diagram 5-26
Figure 5.3: Faulted Line with All Sources In 5-27
Figure 5.4: DLC = N, LLC = N, Two Shot Reclose Sequence 5-40
Figure 5.5: DLC = N, LLC = N, Reclosing Cancelled Due to RC Assertion 5-42
Figure 5.6: DLC = Y, LLC = N, Dead-line Supervised Reclose Sequence 5-43
Figure 5.7: DLC = Y, LLC = N, Reclosing Sequence Cancelled Due to VCT Expiration . . 5-44
Figure 5.8: DLC = N, LLC = Y, Live-line Supervised Reclose Sequence 5-46
Figure 5.9: DLC = N, LLC = Y, Second Shot Cancelled Due to CVC Failure 5-47
Figure 6.1: 9-Pin Connector Pin Number Convention 6-3
Figure 6.2: Horizontal Front and Rear Panel Drawings 6-7
Figure 6.3: Panel Cutout and Drill Patterns for SEL (Shallow) Low-Profile Instruments 6-8
Figure 6.4: Communications and Clock Connections - One Unit at One Location 6-9
Figure 6.5: Communications and Clock Connections - Multiple Units at One Location 6-9
Figure 6.6: SEL Relay Communications Diagram for Connection to the SEL-DTA 6-10
Figure 6.7: External AC Current and Voltage Connections 6-10
Figure 6.8: External DC Connection Diagram (Typical) 6-11
SEL Direction and Polarity Check Form 6-12
SEL Direction and Polarity Check Form 6-13
Figure 7.1: Low-Level Test Interface 7-2

Figure 7.2: Relay Part Number and Hardware Identification Sticker 7-5
Figure 7.3: Communication Interface Setup 7-6
Figure 7.4: METER Test Connections 7-16
Figure 7.5: Example ONEBUS Input Data for Phase-Phase and Ground Faults 7-17
Figure 7.6: Example ONEBUS Result Screen for Phase-Phase and Ground Faults 7-18
Figure 7.7: Example ONEBUS Input Data for Three-Phase Faults 7-19
Figure 7.8: Example ONEBUS Result Screen for Three-Phase Faults 7-19
Figure 7.9a: Three-Phase Voltage and Current Source Test Connections for Three-Phase Mho Test 7-21
Figure 7.9b: Three-Phase Voltage and Two-Phase Current Source Test Connections for Three-Phase Mho Test 7-22
Figure 7.10a: Three-Phase Voltage and Two-Phase Current Source Test Connections for Phase-Phase Mho Test 7-25
Figure 7.10b: Three-Phase Voltage and One-Phase Current Source Test Connections for Phase-Phase Mho Test 7-25
Figure 7.11: Three Voltage vs. One Voltage for Directional Tests 7-28
Figure 7.12: Current Polarized Directional Element Test Connection 7-29
Figure 7.13: SEL-221C Relay 9-Pin Connector Pin Number Convention 7-43
Figure 7.14: SEL-121C Relay 9-Pin Connector Pin Number Convention 7-43
SEL-121C Module Interconnections Diagram . . . . Appendix B-1
SEL-200 Series (Shallow) Main Board Troubleshooting Test Points and Jumper Locations . . . . Appendix B-3

INTRODUCTION
TABLE OF CONTENTS

Getting Started 1-1
Overview 1-1
General Description 1-2

INTRODUCTION

GETTING STARTED

This instruction manual applies to SEL-121C and SEL-221C Relays. The SEL-221C and SEL-121C 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-221C 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-221C Relay to your installations.

- Three zones of phase distance protection
- Phase time-overcurrent element is torque controlled by a phase distance element for improved coordination
- Residual time-overcurrent element with selectable curves
- Three instantaneous/definite time residual overcurrent elements
- Voltage-supervised three shot reclosing relay
- Negative- or zero-sequence polarization of ground directional elements
- Versatile user programmable logic for outputs and tripping
- Loss-of-potential detection logic
- Programmable switch-onto-fault logic
- Fault locating
- Metering
- EIA-232 communication ports for local and remote access
- Automatic self-testing
- Demodulated IRIG-B time code input
- Target indicators for faults and testing
- Compact and economical

GENERAL DESCRIPTION

The SEL-221C phase distance/time-overcurrent and ground directional overcurrent relay with fault locator provides high-speed and time-delayed protection for transmission, subtransmission, and distribution lines. A 30-bit Relay Word combines mho distance elements, overcurrent elements, directional element, timers, and data and control bits. The applications engineer can program the logic through bit combinations to control tripping, reclosing, and four general purpose programmable outputs.

Because of its many relay elements, large setting ranges, programmability, and low cost, the SEL-221C 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 loss-of-potential, alarm, and trip.

The SEL-221C Relay simplifies relay coordination with downstream phase time-overcurrent protection by torque controlling the phase time-overcurrent element with the Zone 2 phase distance element. The phase time-overcurrent element only requires coordination with time-graded protection within the Zone 2 phase distance element reach. This provides greater flexibility in selecting pickup, time-dial, and operating characteristic settings. The relay has four time curves to increase relay versatility: moderately inverse, inverse, very inverse, and extremely inverse.

The SEL-221C Relay also supports communication-based relaying schemes, including:

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

Analog inputs from current and voltage transformers are analog filtered, sampled, digitized, digital filtered and delivered to the protective relaying elements. They are saved for additional features such as metering and fault locating.

Relay elements process the digital data. Intermediate logic includes overcurrent supervision of the mho elements, directional supervision of the residual-overcurrent elements, and grouping of certain elements into zones.

The relay includes a three-shot reclosing relay capable of using live- or dead-line voltage conditions to supervise start of the reclosing interval and issuing the close.

The SEL-221C 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 (external 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
- Reclosing relay shot counter state
- 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-221C 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 "a" type contacts.

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

SPECIFICATIONS
TABLE OF CONTENTS

Relay Standards and Input Parameters 2-1
Functional Specifications 2-2
- Expanded Mho Characteristics for Phase-Phase and Three-Phase Faults 2-2
- Phase Time-Overcurrent Protection for Phase Faults 2-3
- Residual Overcurrent Protection for Ground Faults 2-3
- Residual Overcurrent Directional Elements 2-3
- Reclosing 2-4
- Loss-of-Potential (LOP) Detection 2-4
- Nondirectional Phase Overcurrent Elements 2-4
- Switch-Onto-Fault Protection 2-4
- IRIG-B Input 2-5
- Relay Word 2-5
- Logic Inputs 2-5
- Output Contacts 2-5
- Event Reporting 2-6
- Fault Location 2-6
- Metering 2-6
- Targeting 2-7
- Self-Testing 2-7

Detailed Specifications 2-7
- Distance Elements 2-7
  - Phase-Phase Distance 2-7
  - Three-Phase Distance 2-8
  - Maximum Torque Angle (MTA) 2-8
  - Zone 2 and 3 settings are limited 2-8
  - Accuracy 2-8
  - Operating Speed 2-8
  - Memory Polarization 2-8
  - Zone 3 Distance Element Timer 2-8
- Overcurrent Elements 2-9
  - Nondirectional Phase Overcurrent Elements 2-9
  - Phase Time-Overcurrent Element 2-9
  - Ground Overcurrent Elements 2-9
  - Ground Overcurrent Element Timers 2-10
  - Ground Directional Elements 2-10
  - Negative-Sequence Directional Element 2-10
  - Zero-Sequence Directional Element 2-11
- Sequence-Component Elements 2-12
- Miscellaneous Timers 2-13
- Potential Inputs 2-13
- Current Inputs 2-13
- Logic Inputs 2-14
  - Direct Trip (DT) 2-14
  - Permissive Trip (PT) 2-14

Block Trip (BT) 2-14
Direct Close (DC) 2-15
Circuit Breaker Status (52A) 2-15
External Trigger for Event Report (ET) 2-15
Output Contacts 2-15
TRIP Output 2-15
CLOSE Output 2-16
ALARM Output 2-16
Programmable Outputs (A1, A2, A3, A4) 2-16
Logic Description 2-16
Relay Elements 2-16
Optically Coupled Contact Inputs 2-17
Contact Outputs 2-17
Timers 2-18
Enables from Setting Procedure 2-18
Intermediate Logic 2-18
Loss-of-Potential (LOP) Logic 2-19
Phase Overcurrent Conditions 2-19
Distance Relay Logic 2-19
Ground Overcurrent Conditions 2-19
Output Equations and Logic 2-20
Trip Suspicion Logic 2-21
Scenario 1 - Actual Transmission Line Fault 2-21
Scenario 2 - Potential Transfer Operation 2-22
Relay Word 2-22
Targets 2-24
Reclosing Relay 2-25
No Voltage Checking LLC = N, DLC = N 2-26
Live Voltage Checking, LLC = Y, DLC = N 2-26
Dead Voltage Checking, LLC = N, DLC = Y 2-27
Reclose Cancellation 2-28
Recloser Reset Time, 79RS 2-28
Signal Processing 2-28
Event Reporting 2-29
Fault Locator 2-29
Metering 2-30
Serial Interfaces 2-30
IRIG-B Input Description 2-31
Self-Tests 2-31
Offset 2-31
Power Supply 2-32
Random-Access Memory 2-32
Read-Only Memory 2-32
Analog-to-Digital Converter 2-32
Master Offset 2-33
Settings 2-33
Functional Description 2-34
Mho Elements 2-34
Mho Element Expansion 2-35

Three-Phase Elements 2-36
Time-Overcurrent Elements and Curves 2-36
Directional Elements 2-37
Programmable Logic Mask Concept 2-38
Relay Element Operating Time Curves 2-39
Time-Overcurrent Curve Equations 2-41
Logic Diagrams 2-43

TABLES

Table 2.1: Relay Word 2-5
Table 2.2: Directional Element Sensitivities at Maximum Torque Angle (MTA) 2-11
Table 2.3: Logic Input Functions 2-14
Table 2.4: Relay Word Bit Summary 2-23
Table 2.5: Power Supply Self-Test Limits 2-32
Table 2.6: Self-Test Summary 2-33
Table 2.7: Directional Element Torque Equations 2-37

FIGURES

Figure 2.1: Phase-Phase and Three-Phase Mho Element Characteristics 2-3
Figure 2.2: Residual Overcurrent Zones of Protection 2-4
Figure 2.3: 32Q and 32V Polarization Criteria 2-12
Figure 2.4: 32I Polarization Criteria 2-12
Figure 2.5: Trip Suspicion (TS) Logic 2-21
Figure 2.6: Relay Targets 2-24
Figure 2.7: Mho Element Reach at Maximum Torque Angle 2-34
Figure 2.8: Expanded Two-Phase Mho Characteristics 2-35
Figure 2.9: Expanded Three-Phase Mho Characteristics 2-36
Figure 2.10: Programmable Logic Mask Analogy 2-39
Figure 2.11: Phase Distance Speed Curves and 50H Phase Overcurrent Speed Curve 2-40
Figure 2.12: Moderately Inverse Curves 2-42
Figure 2.13: Inverse Curves 2-42
Figure 2.14: Very Inverse Curves 2-42
Figure 2.15: Extremely Inverse Curves 2-42
Logic Diagrams 2-43

SPECIFICATIONS

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

RELAY STANDARDS AND INPUT PARAMETERS

Rated AC Input Voltage	115 volt nominal phase-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
Time-Code Input	Relay accepts demodulated IRIG-B time code.
Communications	Two EIA-232 serial communications ports, SEL-221C Relay includes a front panel connector for Port 2.
Power Supply Ratings	24/48 Volt: 20 - 60 Vdc; 12 watts 125/250 Volt: 85 - 350 Vdc or 85 - 264 Vac; 12 watts
Relay Dimensions	3.47" x 19" x 9" (8.81 cm x 48.26 cm x 22.86 cm) (H x W x D), SEL-221C 5.25" x 19" x 13" (13.34 cm x 48.26 cm x 33.02 cm) (H x W x D), SEL-121C
Mounting	Mounts in standard EIA 19" (48.26 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-232)

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	12 pounds (5.5 kg), SEL-221C 21 pounds (9.5 kg), SEL-121C
Shipping Weight	17 pounds (7.7 kg) including one instruction manuals, SEL-221C 26 pounds (11.8 kg), including one instruction manuals, SEL-121C
Burn-in Temperature	140°F (60°C) for 96 hours.
Environmental Test	IEC 68-2-30 Temp/Humidity Cycle Test - six day (type tested)

FUNCTIONAL SPECIFICATIONS

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

- Three zones of phase-phase distance protection
- Zones 1, 2, and 3 three-phase distance elements memory polarized
- Zone 2 distance element torque controls phase time-overcurrent element
- Independent timer for Zone 3 distance element (time-step backup protection)
- Fault detector elements supervise all distance elements
- Loss-of-potential logic supervises all distance elements when enabled
- Zone 3 reversible with a simple setting (all Zone 3 elements are reversed when ZONE3 = R in the relay settings)

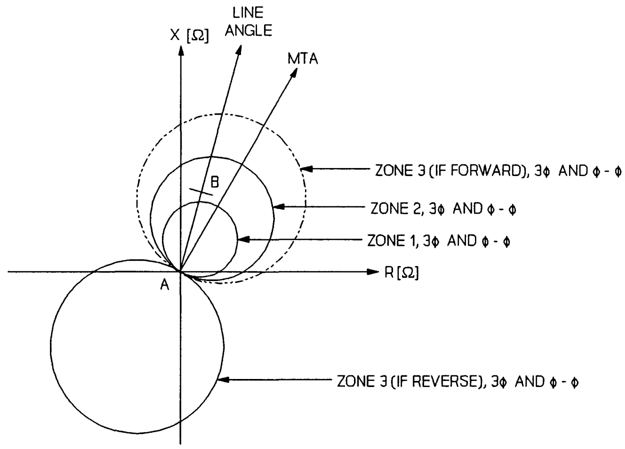


Figure 2.1: Phase-Phase and Three-Phase Mho Element Characteristics

Phase Time-Overcurrent Protection for Phase Faults

- Time-overcurrent element
  - Four curve families (moderate, inverse, very inverse, and extremely inverse)
  - Torque controlled by Zone 2 phase distance element to limit coordination region

Residual Overcurrent Protection for Ground Faults

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

Residual Overcurrent Directional Elements

- Four methods of residual overcurrent directional polarization:
  - Negative-sequence voltage and current
  - Zero-sequence voltage and residual current
  - External zero-sequence current and residual current
  - Dual zero-sequence polarization

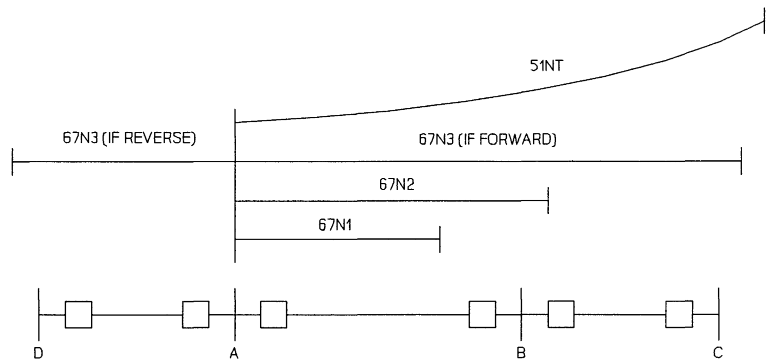


Figure 2.2: Residual Overcurrent Zones of Protection

Reclosing

- Three separate shots of reclosing with settable open interval timers
- Selectable reclose initiate and cancel conditions
- Settable reclose reset timer
- Selectable live/dead line voltage checking can supervise reclosing

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 in conjunction with the low-set residual overcurrent element
- Low-set phase overcurrent elements used in loss-of-potential logic to help detect blown potential fuses
- High-set phase overcurrent element provides switch-onto-fault protection for close-in three-phase faults

Switch-Onto-Fault Protection

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

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 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 then controls the relay output contacts. Each TRIP, programmable output relay, and reclose initiate and cancel condition has a corresponding logic mask (see Programmable Logic Masks). These masks determine the state of the output relay and reclosing sequence, depending on which elements are asserted in the Relay Word.

Table 2.1 shows the SEL-221C Relay Word.

Table 2.1: Relay Word

51PT	1ABC	2ABC	3ABC	51PP	50H	50L	LOP
51NT	67N1	67N2	67N3	51NP	Z1P	Z2P	Z3P
DF	DR	Z2GT	Z3GT	50MF	RC	RI	Z3PT
50M	TRIP	TC	DT	52BT	59N		

Logic Inputs

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

Output Contacts

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

Event Reporting

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

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

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

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

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

Fault Location

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

Metering

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

Targeting

Under normal operating conditions, the enable (EN) LED is illuminated. If the relay trips, it illuminates the LED(s) for the highest priority zone and fault type at the time of trip. Target LEDs are latching, so the targets remain illuminated until you press the Target Reset button, execute the TARGET R command, or a trip with a different zone and fault type occurs. When a new trip occurs, targets clear and display the new 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 Relay Word elements. See the TARGET command in Section 3: COMMUNICATIONS for more details.

Self-Testing

The relay runs exhaustive self-tests which ensure reliable operation. If a test fails, the relay enters a warning or failure state, closes the ALARM output relay, and issues a status report to the port 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)
- Analog-to-Digital Conversion Time
- Master Offset
- Settings

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

DETAILED SPECIFICATIONS

Distance Elements

Phase-Phase Distance (Secondary Quantities)

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

Three-Phase Distance (Secondary Quantities)

21ABC1: 0.125 to 64 ohms
21ABC2: 0.125 to 64 ohms
21ABC3: 0.125 to 64 ohms

Maximum Torque Angle (MTA)

Adjustable from 47° - 90°.

Zone 2 and 3 settings are limited as follows:

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 2.11 for operating time curves.

Memory Polarization

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

Zone 3 Distance Element Timer

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)

- 50AL, 50BL, 50CL (low-set phase fault detectors)
- 50AM, 50BM, 50CM (medium-set phase fault detectors)
- 50AH, 50BH, 50CH (high-set phase overcurrent elements)
  Pickup: 0.5 to 40 A, ± 0.1 A ± 2% of setting
  Transient overreach: ± 5% of set pickup

Phase Time-Overcurrent Element (Secondary Quantities)

51P phase 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: 1 - 12 A
  ±0.05 A ±2% of settings above 3 A
  ±0.2 A ±5% of settings below 3 A
- Timing: ±4% and ±1 cycle for phase current magnitude between 2 and 20 multiples of pickup
- Torque controlled by 21ABC2, 21P2

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 outputs of the ground overcurrent elements are separate in the Relay Word, permitting access to both. This allows use of a time delay for time-stepped backup functions while maintaining the required instantaneous outputs for communication-based schemes.

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

The relay does not allow you to select negative-sequence and zero-sequence polarization at the same time.

Negative-Sequence Directional Element

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

Zero-Sequence Directional Element

Voltage Polarization

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

Current Polarization

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

Note: If you want current polarization of the ground directional elements, 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: 32V and 32I sensitivities depend on the pickup setting of the residual time-overcurrent element 51NP.

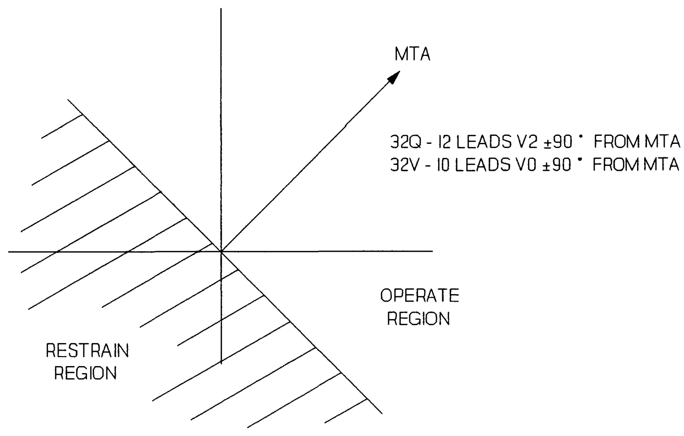


Figure 2.3: 32Q and 32V Polarization Criteria

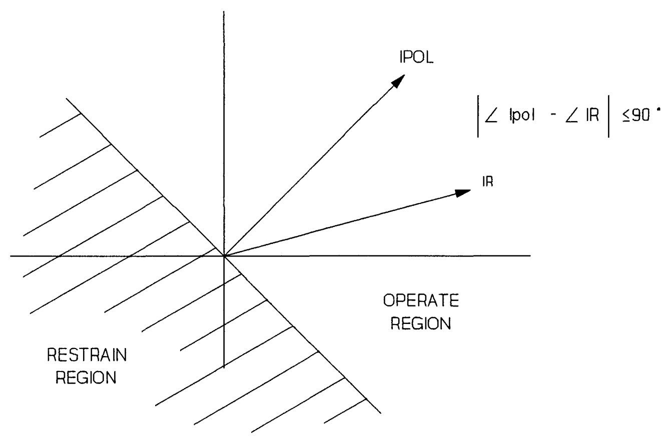


Figure 2.4: 32I Polarization Criteria

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

Sequence-Component Elements

The following elements are used in the recloser supervision logic and loss-of-potential detection logic. All thresholds are in secondary quantities.

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

- Positive-sequence overvoltage element (47P)
  Pickup: 14 volts of V1 (fixed)
- Positive-sequence dead line threshold (47PD)
  Pickup: User settable ($0 \leq$ 47PXD $\leq$ 129 V_{l-l}), ± 5 V
- Positive-sequence live line threshold (47XL)
  Pickup: User settable ($0 \leq$ 47PXL $\leq$ 129 V_{l-l}), ± 5 V
- Zero-sequence overvoltage element (59N)
  Pickup: User settable ($0 <$ 59N $<$ 75 V_{l-n}), ± 5 V

Miscellaneous Timers

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

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

TDPU ≡ Time-Delayed Pickup
TDDO ≡ Time-Delayed Dropout

Potential Inputs

Potential inputs should be driven from a set of three line potential transformers with their primaries connected in a grounded-wye configuration and secondaries connected in a four-wire wye. The relay is equipped with three input transformers connected in a four-wire wye.

The relay determines the zero-sequence voltage from the three voltage inputs VA, VB, and VC, so a separate V0 input is not needed.

The nominal input voltage rating is 115 volts line-to-line or 67 volts line-to-neutral.

Current Inputs

Each current input is independent; the current transformers are not interconnected inside the relay. The rating of the input transformers in the relay is 5 amperes nominal, 15 amperes continuous, and 500 amperes for one second.

Logic Inputs

The relay has six opto-isolator inputs to control relay functions and 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. Control voltage polarity is not important.

Table 2.3 lists the inputs and their functions.

Table 2.3: Logic Input Functions

Input	Function
DT	Direct Trip Input
PT	Permissive Trip Input
BT	Block Trip Input
DC	Direct Close Input
52A	52 Auxiliary Contact Input
ET	External Trigger Input

Direct Trip (DT)

Asserting the DT input, immediately and unconditionally sets Relay Word bit DT. The DT bit remains set until the DT input deasserts, dropping out about one-half cycle after DT deasserts. DT input assertion generates an event report. You can use the DT input to trip the relay, initiate or cancel reclosing, or as a programmable input.

Permissive Trip (PT)

The PT input is normally used in Permissive Overreaching Transfer Tripping (POTT) schemes. When the PT input is asserted, elements set in the MPT logic mask are enabled for tripping (see the LOGIC MPT command). Asserting this input triggers an event report.

Block Trip (BT)

The BT input is normally used in Directional Comparison Blocking (DCB) schemes. Assert the BT input to block tripping by elements set in the MTB logic mask. Assertions of this input trigger event report generation.

Direct Close (DC)

When you assert the DC input, the relay shuts the CLOSE output if no fault is detected, a trip condition is not present, and the 52A input is not asserted. This input does not trigger an event report.

Circuit Breaker Status (52A)

Connect the 52A input such that when the line circuit breaker is closed, the 52A input is asserted. The CLOSE command, recloser, and switch-onto-fault logic use the status of this input. Assertions of this input do not trigger event reports.

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 external protective relays, backup protection, breaker failure relaying, bus differential relaying, etc.

Output Contacts

The relay has seven output contacts: TRIP, CLOSE, ALARM, and four programmable outputs (A1, A2, A3, and A4). You can program all outputs except the CLOSE and ALARM outputs using the LOGIC command. Any output contacts except TRIP may be factory configured as "a" or "b" type.

All relay contacts are rated for circuit breaker tripping duty.

TRIP Output

This output closes for a 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 or just closed (MTO logic mask).

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

CLOSE Output

This output closes for reclose operations, DC input assertion, and CLOSE command execution. The CLOSE output remains closed until the 52A input asserts, the 79RS timer expires, or a TRIP occurs. The 79RS timer starts when the CLOSE output relay asserts. Operation of this contact does not trigger an event report.

ALARM Output

The ALARM output closes for the following conditions:

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

Programmable Outputs (A1, A2, A3, A4)

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

Logic Description

Relay logic includes relay elements, timers, and combinations of conditions. Many of these are recorded in the Relay Word (R), which is the basis of 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 3 three-phase mho distance	21ABC3	(reversible)
Zone 3 phase-phase mho distance	21P3	(reversible)
Zone 2 three-phase mho distance	21ABC2	torque controls 51P
Zone 2 phase-phase mho distance	21P2	torque controls 51P
Zone 1 three-phase mho distance	21ABC	
Zone 1 phase-phase mho distance	21P1	
Phase time-overcurrent pickup	**51PP**	t.c. by 21ABC2, 21P2
Phase time-overcurrent trip	**51PT**	t.c. by 21ABC2, 21P2

Residual time-overcurrent pickup	**51NP**	directional as enabled
Residual time-overcurrent trip	**51NT**	directional as enabled
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	LOP detection
Zero-sequence overcurrent	50NL	LOP detection and TRIP unlatch
Positive-sequence overvoltage	47P	LOP detection
Positive-sequence undervoltage	47XD	Dead-line voltage detector, asserts if $V1_{l-l}$ < 47PXD setting
Positive-sequence overvoltage	47XL	Live-line voltage detector, asserts if $V1_{l-l}$ > 47PXL setting
Zero-sequence overvoltage	**59N**	Asserts if zero-sequence voltage is above 59N setting.

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	ET

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

Timers

Z2DG	Zone 2 ground timer operated by **67N2**	
Z3DG	Zone 3 ground timer operated by **67N3**	
Z3DP	Zone 3 phase timer operated by **Z3P** and **3ABC**	
52AT	Time-delayed 52A (pickup and dropout)	(52BT timer setting)
52BT	Inverse of 52AT	(52BT timer setting)
79OI1	Reclosing relay first open interval timer	
79OI2	Reclosing relay second open interval timer	
79OI3	Reclosing relay third open interval timer	
79RS	Reclosing relay reset interval timer	
50MFD	Loss-of-potential enabled 50MF time-delayed pickup (50MFD timer setting)	
VCT	Reclosing voltage condition timer	

Enables from Setting Procedure

ZONE3	Zone 3 reach (F = Forward, R = Reverse)
32VE	Enables zero-sequence voltage polarization of 32D
32IE	Enables zero-sequence current polarization of 32D
32QE	Enables negative-sequence polarization, 32Q
51NTC	Selects torque control for 51N
LLC	Live voltage supervision enable
DLC	Dead voltage supervision enable
CVC	Reclosing check voltage condition at close enable
VSA	Voltage supervise all reclose shots
LOPE	Loss-of-potential enable

Intermediate Logic

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

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	

The different set and clear conditions ensure that LOP stays latched during subsequent faults, but is cleared when balanced voltages 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

3ABC	= 21ABC3 * **3P50** * NOT (**LOP** * LOPE)	
2ABC	= 21ABC2 * **3P50** * NOT (**LOP** * LOPE)	
1ABC	= 21ABC1 * **3P50** * NOT (**LOP** * LOPE)	
Z3P	= 21P3 * **50L** * NOT (**LOP** * LOPE)	
Z2P	= 21P2 * **50L** * NOT (**LOP** * LOPE)	
Z1P	= 21P1 * **50L** * NOT (**LOP** * LOPE)	
Z3PT	= (**Z3P** + **3ABC**) * Z3DP	Zone 3 timeout-phase

Ground Overcurrent Conditions

DF	= (32QF + [**LOP** * LOPE]) * 32QE + 32DF * 32IE + (32DF + [**LOP** * LOPE]) * 32VE + NOT(32QE + 32VE + 32IE)	Forward direction
DR	= 32QR * 32QE + 32DR * (32IE + 32VE)	Reverse direction
D3	= **DF** if Zone 3 is forward	
D3	= **DR** if Zone 3 is reverse	
67N1	= 50N1 * **DF**	Torque Controlled
67N2	= 50N2 * **DF**	Torque Controlled
67N3	= 50N3 * D3	Torque Controlled (reversible)

Note: When all directional elements are disabled (32QE = 32VE = 32IE = N), the DF (directional forward) bit defaults forward. The Zone 3 ground element will not operate under this condition if Zone 3 = R.

Z2GT	= **67N2** * Z2DG	Zone 2 timeout-ground
Z3GT	= **67N3** * Z3DG	Zone 3 timeout-ground

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 relay has two separate masks for reclose initiation and cancellation. Program logic by setting masks for various conditions. These masks are applied to the general Relay Word. The form for each output equation follows:

Let R = Relay Word

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

Then:

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

Close TRIP contact	=	**TRIP**
Open TRIP contact	=	NOT (**TRIP**) * [NOT(50NL + **50L**) + TARGET RESET button pushed] * (Minimum Trip Duration timer (TDUR) expired)
Close CLOSE contact	=	(DC + [(79OI1 + 79OI2 + 79OI3) * (CVC Condition Satisfied)] + CLOSE COMMAND) * NOT (52A) * NOT (**TRIP**)
Open CLOSE contact	=	NOT (CLOSE) + 79RS + **TRIP**

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

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

Trip Suspicion Logic

In substations where two independent buses may be connected to the protected line at different times, relay potentials may be obtained from two separate potential transformer banks. It is not desirable to parallel the secondary windings of potential transformers attached to separate sources, thus a break-before-make potential transfer switch is used to transfer the relay potential source from one bus to the other.

When the potential transfer switch is operated, the break-before-make action removes all polarizing voltages from the relay momentarily. If load currents are above the 50L fault detector setting, this temporary removal of polarizing voltages may cause a race between the three-phase loss-of-potential logic pickup and operation of the three-phase distance element. Three-phase LOP logic is included to address the loss of three secondary potential fuses, not potential transfer switch applications.

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

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

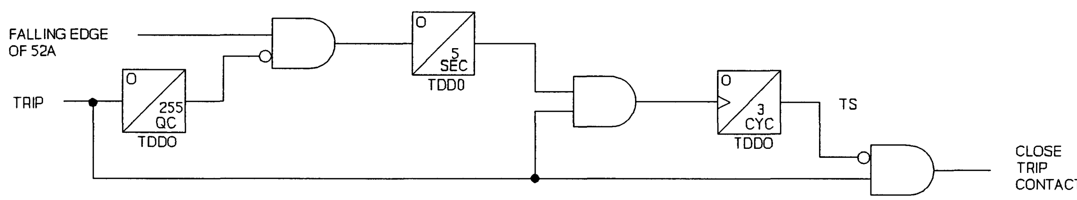


Figure 2.5: Trip Suspicion (TS) Logic

The following two scenarios illustrate Trip Suspicion logic operation:

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

Scenario 1 - Actual Transmission Line Fault

When the relay issues a trip with the 52A input energized, the relay does not start the five second timer (T1) because it issued the trip. Thus, this logic does not interfere with the normal relay trip operation.

Scenario 2 - Potential Transfer Operation

If the relay senses the falling edge of a 52A input and it did not issue a trip in the previous 255 quarter-cycles, the T1 timer starts. The T1 timer allows the operator five seconds to transfer the relay potentials from one bus to another. If the relay issues a trip during this five second window, tripping is restrained for three cycles. This three-cycle time period is greater than the time required for the three-phase LOP logic to assert or for the polarizing potential magnitude of the second bus to stabilize. Remember that the loss-of-potential condition only occurs when the potential transfer switch is twisted left or right while the switch is fully depressed.

This logic does not depend upon the speed of the actual potential transfer operation. It does require that the procedure last less than five seconds and that the relay 52A input circuit be interrupted when the potential transfer switch is depressed.

This potential transfer switch logic presents an additional benefit if an operator inadvertently transfers potentials to a de-energized or dead bus. If the LOP bit is set in a programmable output contact logic mask when the relay is transferred to a dead bus, the LOP bit asserts, causing the programmable output contact to assert. Output contact closure can alert the operator to the dead bus condition.

Loss of relaying potentials due to potential fuse or potential transfer switch operation may cause the relay to trip if phase current is above the 50L setting.

Relay Word

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

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

The Logic Description defines logic conditions in the Relay Word.

RELAY WORD

51PT	1ABC	2ABC	3ABC	51PP	50H	50L	LOP
51NT	67N1	67N2	67N3	51NP	Z1P	Z2P	Z3P
DF	DR	Z2GT	Z3GT	50MF	RC	RI	Z3PT
50M	TRIP	TC	DT	52BT	59N		

The meaning of each bit of the Relay Word is explained in the Relay Word Bit Summary Table.

Table 2.4: Relay Word Bit Summary

51PT	-	Phase time-overcurrent time out (set by 51PP, 51PTD, and 51PC)
1ABC	-	Zone 1 three-phase mho distance element (instantaneous)(set by Z1%)
2ABC	-	Zone 2 three-phase mho distance element (instantaneous)(set by Z2%)
3ABC	-	Zone 3 three-phase mho distance element (instantaneous)(set by Z3%)
51PP	-	Phase time-overcurrent pickup (set by 51PP)
50H	-	High-set instantaneous overcurrent element (set by 50H)
50L	-	Low-set instantaneous overcurrent element (set by 50L)
LOP	-	Loss-of-potential element
51NT	-	Ground time-overcurrent time out (set by 51NP, 51NTD, and 51NC)
67N1	-	Zone 1 ground directional overcurrent element (instantaneous)(set by 50N1P)
67N2	-	Zone 2 ground directional overcurrent element (instantaneous)(set by 50N2P)
67N3	-	Zone 3 ground directional overcurrent element (instantaneous)(set by 50N3P)
51NP	-	Ground time-overcurrent pickup (set by 51NP)
Z1P	-	Zone 1 phase-phase mho element (instantaneous)(set by Z1%)
Z2P	-	Zone 2 phase-phase mho element (instantaneous)(set by Z2%)
Z3P	-	Zone 3 phase-phase mho element (instantaneous)(set by Z3%)
DF	-	Direction forward (ground faults)
DR	-	Direction reverse (ground faults)
Z2GT	-	Zone 2 timeout-ground (set by Z2DG)
Z3GT	-	Zone 3 timeout-ground (set by Z3DG)
50MF	-	Asserts a settable delay after LOP and 50M pickup (delay set by 50MFD)
RC	-	Reclose cancellation
RI	-	Reclose initiation
Z3PT	-	Zone 3 timeout-phase (set by Z3DP)
50M	-	Medium-set instantaneous overcurrent element (set by 50M)
TRIP	-	Circuit breaker trip
TC	-	Trip (OPEN) command
DT	-	Direct trip from DT input
52BT	-	Time-delayed inverse of 52A (delay set by 52BT setting)
59N	-	Zero-Sequence Overvoltage Element (set by 59N setting)

The use of the Relay Word and programmable masks provides the user great flexibility in applying the SEL-221C Relay without the need for rewiring panels or changing jumpers on circuit boards.

Targets

Figure 2.6 shows the front panel targets.

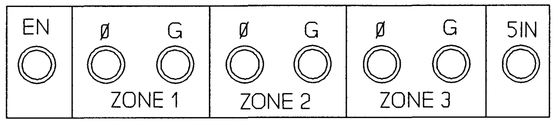


Figure 2.6: Relay Targets

The enable light (EN) indicates normal operation.

The next six indicators show the phase and ground element status for all three zones. The last light shows the status of the residual time-overcurrent element. The targets illuminate to indicate which elements caused the relay to initiate a trip.

Front panel targets illuminate for the following conditions:

Target LED	Conditions for Illumination
EN	Normal Operation
$\phi 1$	Z1P + 1ABC + 50H
G1	67N1
$\phi 2$	Z2P + 2ABC
G2	67N2
$\phi 3$	Z3P + 3ABC
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, $\phi 1$	:	For 67N1 + Z1P + 1ABC + 50H, but no 51NT
G2, $\phi 2$	:	For 67N2 + Z2P + 2ABC, but no Zone 1 or 51NT
G3, $\phi 3$	:	For 67N3 + Z3P + 3ABC, but no Zone 2, Zone 1, or 51NT

The relay normally displays the targets identified on the front panel. Under normal operating conditions, the enable (EN) target lamp is lit. If the relay trips, it illuminates the LED corresponding to the element asserted at the time of trip. The target LEDs latch. The target LEDs which illuminated during the last trip remain lit until one of the following occurs:

- Next trip
- Operator presses front panel TARGET RESET button
- Operator executes TARGET R command

When a new trip occurs, the targets clear and the LEDs display the most recent tripping target.

When you press the TARGET RESET button, all eight indicators illuminate for a one-second lamp test. If no trip condition is present, the relay targets clear and the Enable light (EN) illuminates to indicate that the relay is operational.

Use the TARGET command and display to examine the state of the relay inputs, outputs, and Relay Word elements.

Pressing TARGET RESET also unlatches the TRIP output if no trip condition is present. This feature is useful during testing and reduces the possibility of relay installation with the TRIP output asserted.

Reclosing Relay

The SEL-221C reclosing relay provides up to three shots of automatic reclosing for selectable fault types. The open intervals and reset timer are individually programmable. You may use voltage conditions to supervise the reclosing function.

The SEL-221C Relay voltage supervision logic assumes line side PTs for live voltage/dead voltage reclosing supervision. This relay does not compare line and bus side voltages or perform synchronism checking.

The voltage supervision and recloser timing functions are discussed below. Setting selection is discussed and several examples are provided in Section 5: APPLICATIONS.

The recloser voltage supervision function is configured using the LLC, DLC, CVC, and VSA settings. Available voltage condition checking settings are:

- Live-voltage checking enabled (LLC = Y).
- Dead-voltage checking enabled (DLC = Y).
- Check voltage at close enabled (CVC = Y).
- Voltage supervise all shots (VSA = Y).

If CVC = N, the relay does not supervise issue of the close with voltage conditions. If VSA = N, only the first open interval timer start is supervised by voltage conditions.

A Voltage Condition Timer (VCT) defines a fixed interval during which voltage conditions must be satisfied in order for the open interval timer to start. This is explained in detail below.

In order for the SEL-221C Relay reclosing unit to operate, four conditions must be met:

- The relay must trip.
- The 52A signal must deassert, indicating that the line breaker opened.
- Reclosure must be initiated by operation of an element set in the MRI logic mask.
- Reclosure must not be cancelled by operation of an element set in the MRC logic mask.

The following discussions assume that the above conditions have been fulfilled, initializing the reclosing sequence.

No Voltage Checking LLC = N, DLC = N

With LLC = DLC = N, the reclosing relay is not supervised by voltage conditions.

Following a trip, the 79OI1 timer starts when the TRIP condition has dropped out and the 52A input is deasserted. When the 79OI1 timer expires, the relay closes the CLOSE output contacts.

If the relay trips following the first reclosure, the relay begins timing for the second shot using the 79OI2 timer. The second open interval time starts when the trip drops out and the 52A input is deasserted. The third open interval operates in the same manner.

When LLC = DLC = N, the VCT timer does not operate and the relay ignores the CVC and VSA settings.

Live Voltage Checking, LLC = Y, DLC = N

When you set LLC = Y, the 79OI1 timer starts when live voltage conditions are met. If CVC = Y, the relay checks voltage at close using the 47XL and 59N elements. The 47XL element indicates that line voltage is high enough to permit reclosing.

Following a trip, the VCT timer starts when the TRIP condition has dropped out and the 52A input is deasserted. If the live-line condition (47XL is asserted, 59N is deasserted) is fulfilled for one full cycle before the VCT timer expires, the 79OI1 timer starts. If the live-line condition does not assert for at least one cycle before the VCT timer expires, the 790I1 timer does not start and the reclosing cycle is cancelled.

If CVC = N, when the 79OI1 timer expires the relay issues a CLOSE. If CVC = Y (check voltage at close enabled), the relay checks the 47XL and 59N elements to determine if the line is still live. If the line is live when 79OI1 expires, the relay closes the CLOSE output contacts. If the line is not live within one cycle of 79OI1 timer expiration, the reclosing cycle is cancelled.

If the first reclosing shot is not cancelled by voltage conditions, the relay trips following the first reclosure, and no reclose cancel condition occurs during the second trip, then the reclose sequence continues.

If VSA = N, the 79OI2 timer starts when the second trip drops out and the 52A input is deasserted. If VSA = Y, the VCT timer starts when the TRIP condition drops out and the 52A input is deasserted. Live voltage conditions must be fulfilled for one full cycle before VCT expires, or the reclosing sequence is cancelled. If live voltage conditions are fulfilled for one cycle before the VCT timer expires, the 79OI2 timer starts.

When the 79OI2 timer expires, if CVC = Y, the relay does not issue a close unless live voltage conditions are fulfilled. If CVC = N, the relay issues a close when the 79OI2 timer expires.

The third shot operates in the same manner as the second, when 79OI3 is greater than zero.

Dead Voltage Checking, LLC = N, DLC = Y

When you set DLC = Y, the 79OI1 timer starts when dead voltage conditions are met. If CVC = Y, the relay checks voltage at close using the 47XD and 59N elements. The 47XD element indicates that line voltage is low enough to permit reclosing.

Following a trip, the VCT timer starts when the TRIP condition has dropped out and the 52A input is deasserted. If the dead-line condition (47XD is asserted, 59N is deasserted) is fulfilled for one full cycle before the VCT timer expires, the 79OI1 timer starts. If the dead-line condition does not assert for at least one cycle before the VCT timer expires, the 790I1 timer does not start and the reclosing cycle is cancelled.

If CVC = N, when the 79OI1 timer expires the relay issues a CLOSE. If CVC = Y (check voltage at close enabled), the relay checks the 47XD and 59N elements to determine if the line is still dead. If the line is dead when 79OI1 expires, the relay closes the CLOSE output contacts. If the line is not dead within one cycle of 79OI1 timer expiration, the reclosing cycle is cancelled.

If the first reclosing shot is not cancelled by voltage conditions, the relay trips following the first reclosure, and no reclose cancel condition occurs during the second trip, then the reclose sequence continues.

If VSA = N, the 79OI2 timer starts when the second trip drops out and the 52A input is deasserted. If VSA = Y, the VCT timer starts when the TRIP condition drops out and the 52A input is deasserted. Dead voltage conditions must be fulfilled for one full cycle before VCT expires, or the reclosing sequence is cancelled. If dead voltage conditions are fulfilled for one cycle before the VCT timer expires, the 79OI2 timer starts.

When the 79OI2 timer expires, if CVC = Y, the relay does not issue a close unless dead voltage conditions are fulfilled. If CVC = N, the relay issues a close when the 79OI2 timer expires.

The third shot operates in the same manner as the second, when 79OI3 is greater than zero.

Note: The relay does not permit you to set LLC = DLC = Y.

Reclose Cancellation

While the TRIP output is asserted, any remaining reclosing shots are cancelled if a bit set in the MRC logic mask asserts in the Relay Word. Once the TRIP contacts open, assertion of Relay Word bits set in the MRC logic mask does not cancel reclosing.

Reclosing is cancelled when the relay trips during the open interval of any shot.

Recloser Reset Time, 79RS

The relay includes a 79RS reclosing reset timer setting. The relay uses this timer in several ways:

- To limit the CLOSE contact operation time.
- To reset the recloser after a successful closing sequence.
- To block the recloser after the breaker is closed manually.

The relay operates the CLOSE output in response to command execution, Direct Close input assertions, and reclosing relay operations. The relay CLOSE contacts remain closed until the 52A input asserts (indicating that the breaker has closed), the 79RS timer expires, or a trip condition occurs. This prevents a standing CLOSE signal.

After each close operation during a reclosing sequence, the 79RS timer runs. If a fault occurs before the 79RS timer expires, the reclosing relay advances to the next shot or goes to lockout if no shots remain. If the 79RS timer expires, the reclosing relay is reset and the full reclosing sequence is enabled.

When the breaker has been open for some time, the reclosing relay is not reenabled until the 52A input has been asserted for 79RS time or 30 seconds, which ever is longer. This prevents the recloser from operating when an operator closes into a fault.

Signal Processing

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. The CAL filter eliminates dc offset and reduces the decaying exponential offset that may be present on the input signal following a fault.

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.

Event Reporting

The relay retains an eleven-cycle data record for each of the last twelve events. The record includes input currents and voltages, element states, input contacts, and output contacts. The relay saves a report when any of the following occur:

- The relay trips.
- Certain protective elements, inputs, or outputs assert.
- User executes the TRIGGER command.

Protective elements which trigger event reports when they pick up are:

- Zones 1, 2, and 3 phase distance and ground directional overcurrent elements.
- Ground time-overcurrent element.
- High-set nondirectional phase overcurrent element.

The relay stores the last twelve event reports in a buffer. You can examine any full length report stored in the relay using the EVENT command. The relay clears the event buffer when relay power is interrupted or when you make a setting or logic change.

The relay stores event summaries corresponding to each of the twelve events. Summaries contain operation data such as event type, event date and time, fault type and location, maximum phase current near the middle of the fault, and fault duration. Use the HISTORY command to view summaries for events reports stored in the relay history buffer.

Section 4: EVENT REPORTING has further information regarding the generation, content, and analysis of event reports and summaries saved by the relay.

Fault Locator

The SEL-221C Relay calculates a fault location from data stored in the event report. The fault locator can be enabled or disabled with LOCAT setting in the setting procedure.

The fault location is determined for event records in which any triggering relay elements listed above are picked up, unless they are picked up in the first seven rows of pre-fault data or picked up only in the last five rows of the event report.

The actual fault location algorithm is composed of two steps. First the fault type must be determined, then the location can be calculated.

For the event reports, the fault type is determined independently from the relay element operations. The involved phases are determined by fault current comparison.

Once fault type is determined, the fault locator employs the Takagi algorithm to locate the fault. Using pre-fault and fault data, it compensates for errors introduced by fault resistance or the presence of load flow. If the event record does not provide pre-fault data, the relay gives a location based on a simple reactance measurement.

Although the fault location computation takes several seconds, the relay can handle faults in quick succession, such as those occurring in a reclosing sequence. This is because the fault data are stored, then processed later. For example, suppose three faults occur within a few seconds. The data from each is stored as it occurs. Fault location computations begin with the first (oldest) fault and proceed until all three faults are processed.

Metering

The meter function shows the values of ac current, voltage, and real and reactive power measured by the relay (see Section 3: COMMUNICATIONS, METER command). You can execute the METER command locally or remotely to check breaker conditions.

Serial Interfaces

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

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

Serial communications Port 1 and the Auxiliary Input for demodulated IRIG-B time-code input 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 Port 2, remove the relay front panel. The jumpers are visible near the center of the relay drawout assembly, to the right of the target LEDs. Carefully move the jumpers using needle-nosed pliers. Available rates are 300, 600, 1200, 2400, 4800, and 9600 baud.

The SEL-121C Relay does not include a front panel connector for Port 2.

The serial data format is:

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

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

IRIG-B Input Description

The port labeled J201/AUX INPUT accepts demodulated IRIG-B input.

The IRIG-B serial format consists of a one second long, 100 pulse code divided into fields. The relay decodes the second, minute, hour, and day fields.

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, then the frames are compared. If the frames do not agree, the data are considered erroneous and discarded.

Automatic execution is invoked about once every five minutes. The relay stops IRIG-B data acquisition ten minutes before midnight on New Year's Eve and restarts acquisition twenty minutes later. IRIG-B data acquisition is halted so the system clock may implement the year change without interference from the IRIG-B clock.

Self-Tests

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

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

Offset

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

Power Supply

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

Table 2.5: Power Supply Self-Test Limits

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

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

Random-Access Memory

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

Read-Only Memory

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

Analog-to-Digital Converter

The analog-to-digital converter (A/D) changes voltage signals derived from power system voltages and currents into numbers for processing by the microcomputer. The A/D test verifies converter function by checking conversion time. The test fails if conversion time is excessive or a conversion starts and never finishes. There is no warning state for this test.

Though an A/D failure disables protective functions, control functions remain intact. The relay transmits a STATUS command response and closes the ALARM relay contacts.

Master Offset

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

Settings

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

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

Table 2.6: Self-Test Summary

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

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 self-polarized circles pass through the impedance-plane origin. 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 relay 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.

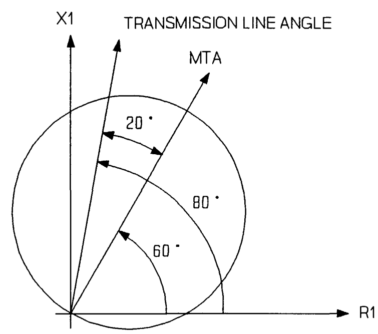


Figure 2.7: Mho Element Reach at Maximum Torque Angle

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)

The constant Z1 is the reach of the relay element in positive-sequence ohms.

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 2.11 illustrates the expanded mho characteristics for phase-phase faults in front of the relay. Figure 2.12 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 impedance of the source relative to the impedance of the protected line section. To determine the amount of expansion mho characteristics experience, relay reach and positive-sequence source impedance must be known. With these quantities known, use the following equations for the circle center and radius to plot the mho characteristics:

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

Where:

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

For example, consider an application where the source impedance is twice as great as the relay set reach. Plot the characteristics. Figures 2.11 and 2.12 illustrate this example and compare the expanded mho characteristic with the self-polarized mho characteristics.

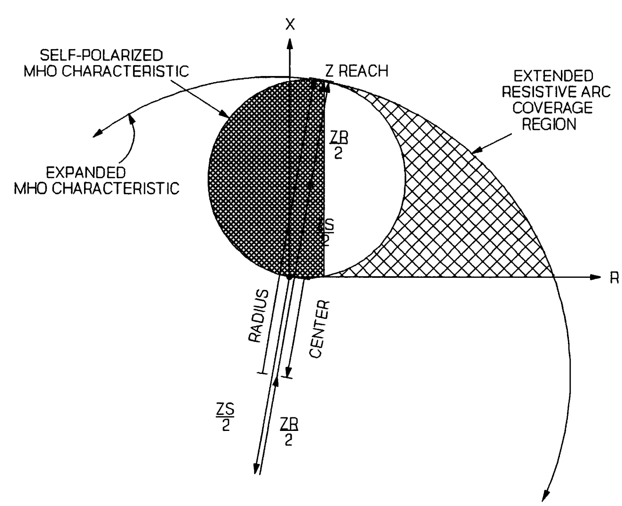


Figure 2.8: Expanded Two-Phase Mho Characteristics

Three-Phase Elements:

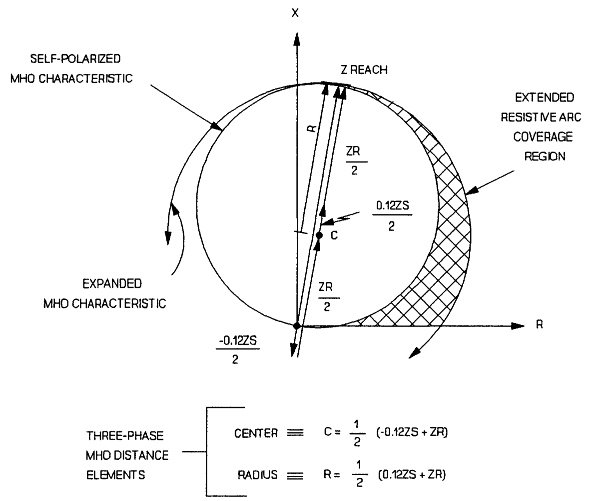


Figure 2.9: Expanded Three-Phase Mho Characteristics

Time-Overcurrent Elements and Curves

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

The 51P time-overcurrent element provides forward-reaching phase fault protection. The element is torque controlled by the Zone 2 phase distance element. This allows you to coordinate the element with downstream protective devices, while using an element pickup setting that does not compromise line protection.

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 are shown near the end of this section.

The relay forms the time-overcurrent characteristics by calculating a recursive sum of the magnitude or magnitude-squared of the phase or residual current adjusted by the appropriate 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 $\pm 90°$ 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 $\pm 90°$ 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 $\pm 90°$ 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

$$32Q:\ T \equiv |V2| \text{x} |I2| \text{x}[\cos(\angle\text{-}V2 - (\angle I2 + MTA))]$$

$$32V:\ T \equiv |V0| \text{x} |IR| \text{x}[\cos(\angle\text{-}V0 - (\angle IR + MTA))]$$

$$32I:\ T \equiv |Ipol| \text{x} |IR| \text{x}[\cos(\angle Ipol - \angle IR)]$$

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

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

Programmable Logic Mask Concept

Figure 2.10 illustrates the concept of the programmable logic mask by comparing it to the connections of discrete relay elements. At the top, the figure shows relay element contacts X, Y, and Z connected to a common reference, such as the positive pole of the battery. The other ends of these contacts pass through knife switches, while the other side of the switches are connected to drive an auxiliary relay labeled A1. The knife switch positions select relay elements which can pick up the auxiliary relay.

In the figure, switches SX and SY are closed, so closure of either contact X or Y causes A1 to pick up. 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 group 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 2.10 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 Logic Command in Section 3: COMMUNICATIONS). 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 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.

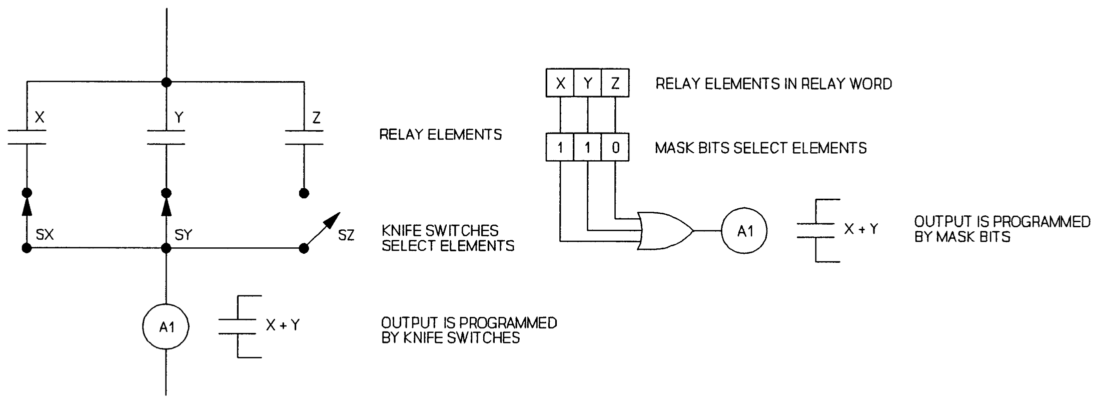


Figure 2.10: Programmable Logic Mask Analogy

RELAY ELEMENT OPERATING TIME CURVES

Figure 2.11 shows operating times for the relay phase-phase mho distance elements and the 50H instantaneous phase overcurrent element. At each reach percentage or current multiple, ten tests were run. The diagrams show maximum, average, and minimum operating times at each test point. Operating times include output contact closure time.

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

Balanced three-phase currents and no voltages were applied to the relay for the 50H overcurrent element tests. This test simulates a bolted 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 pre-fault load current was included. System frequency is 60 Hz.

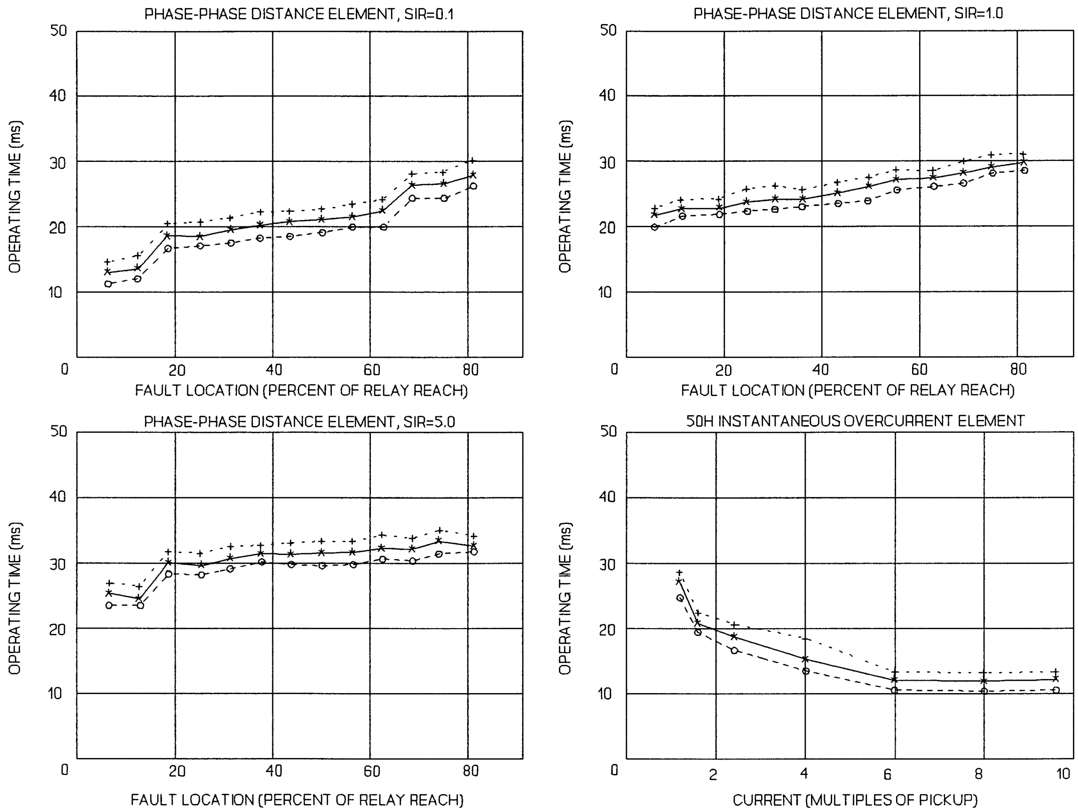


Figure 2.11: Phase Distance Speed Curves and 50H Phase Overcurrent Speed Curve

TIME-OVERCURRENT CURVE EQUATIONS

These time curve equations are valid for the phase and residual time-overcurrent elements. Plots showing operating time versus multiples of pickup current are shown on the following pages.

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

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

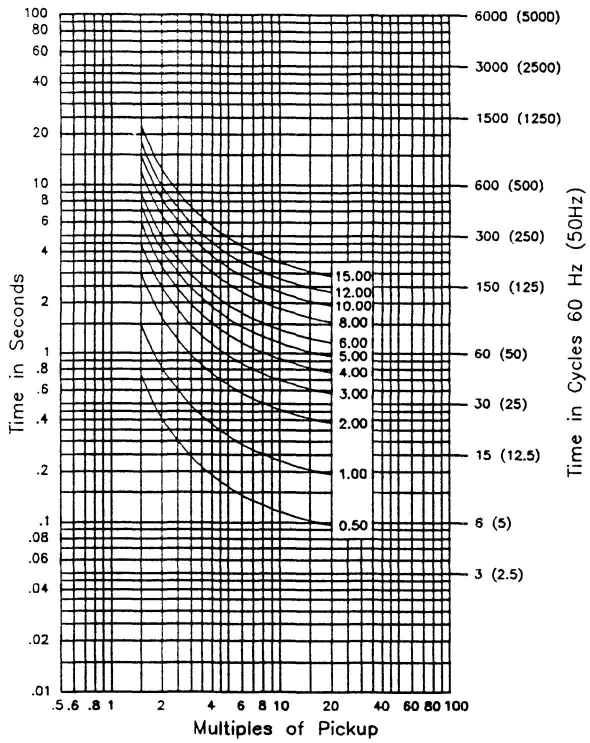


Figure 2.12: Moderately Inverse Curves

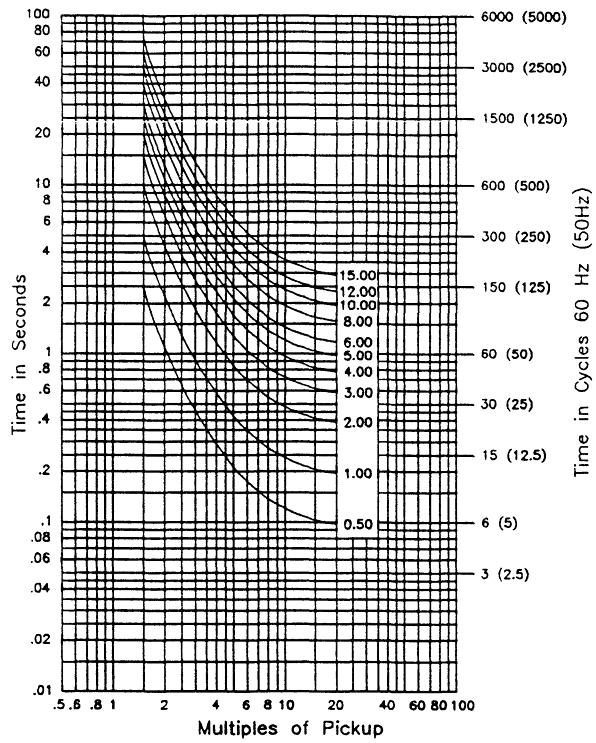


Figure 2.13: Inverse Curves

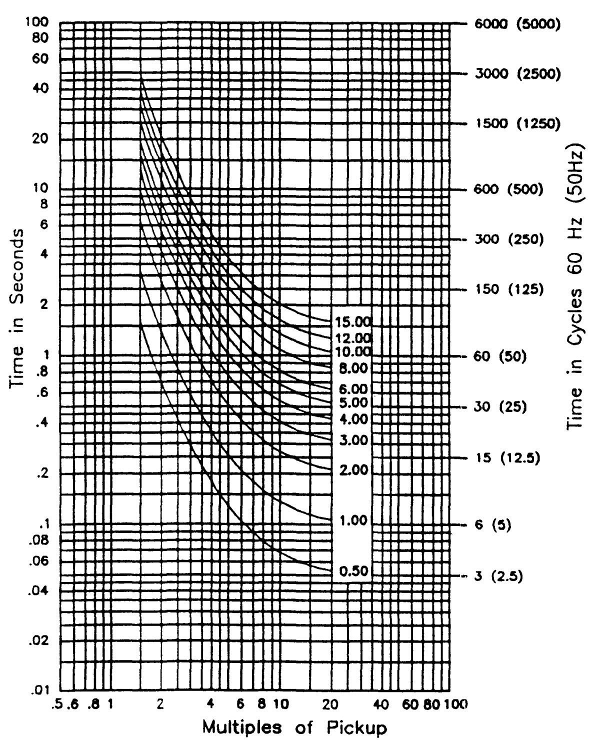


Figure 2.14: Very Inverse Curves

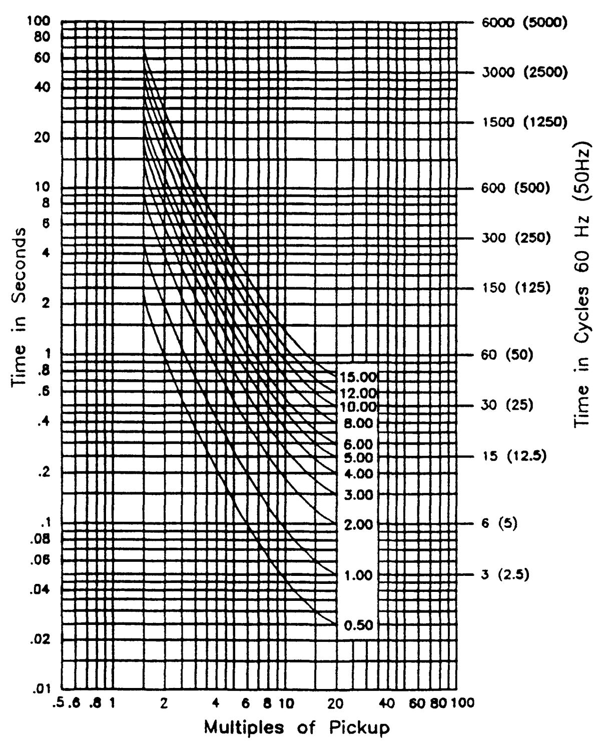
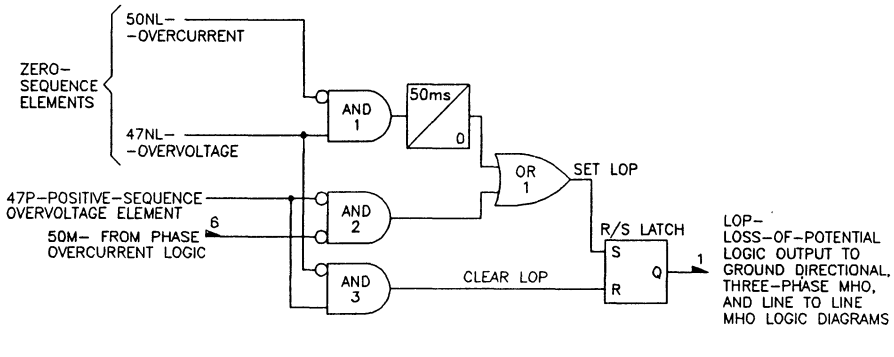
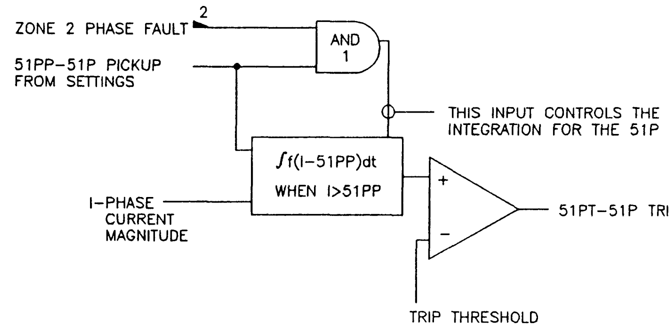


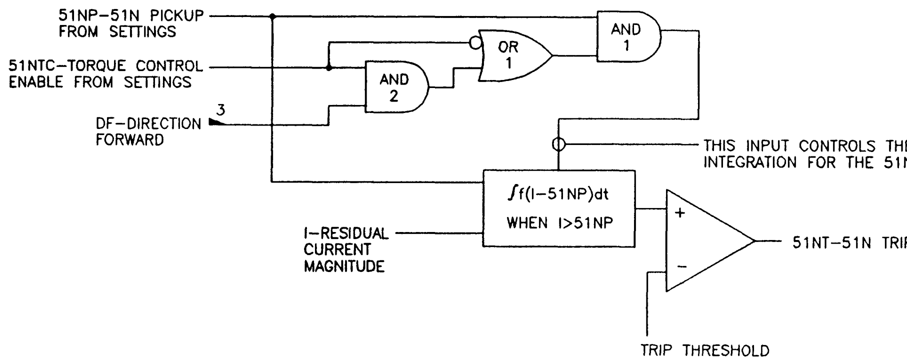
Figure 2.15: Extremely Inverse Curves



RELAY LOSS-OF-POTENTIAL LOGIC DIAGRAM



PHASE TIME-OVERCURRENT (51P) LOGIC DIAGRAM

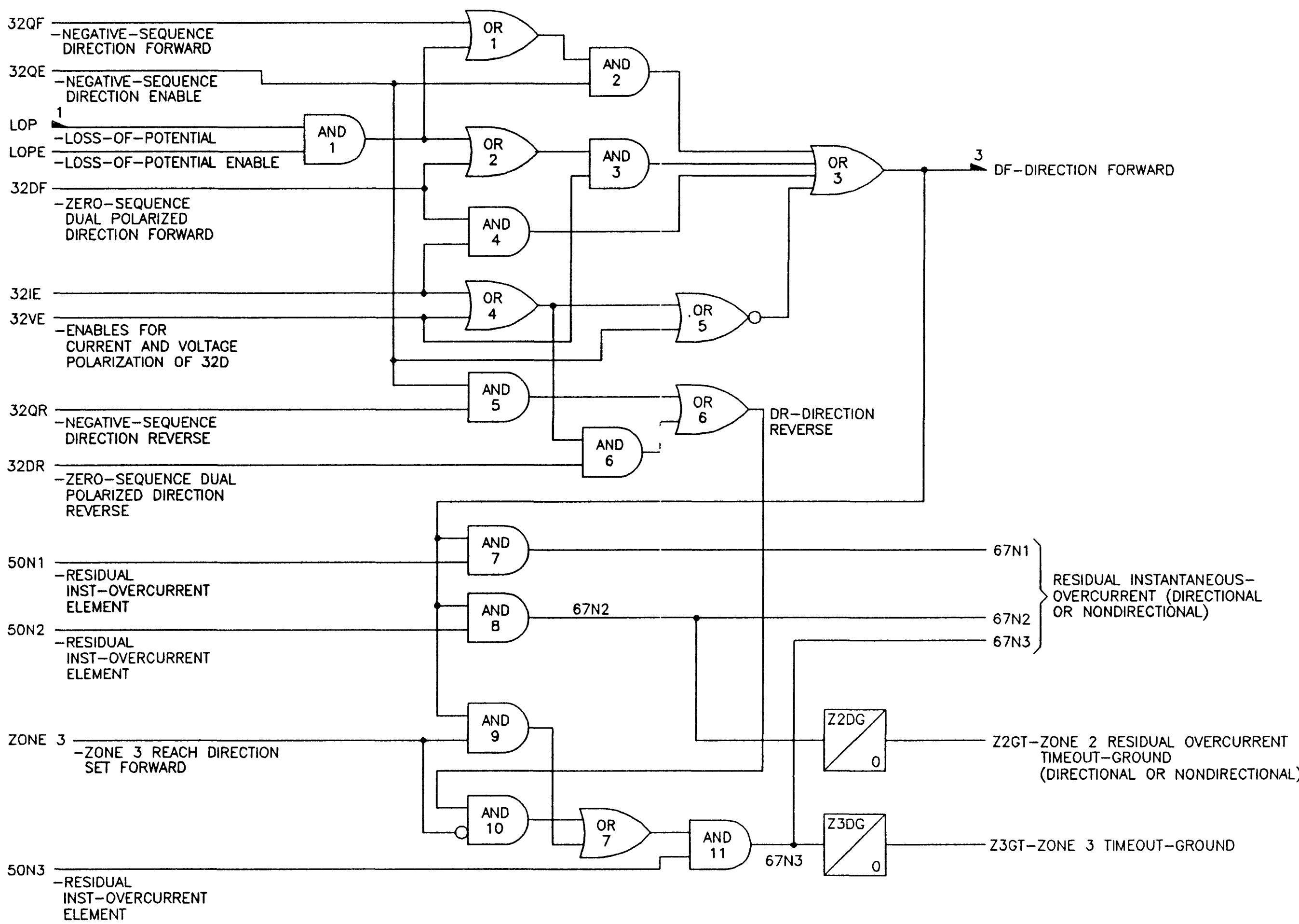


RELAY RESIDUAL TIME-OVERCURRENT (51N) LOGIC DIAGRAM

USED ON

SEL-121C
SEL-221C

DWG. A7-0907A

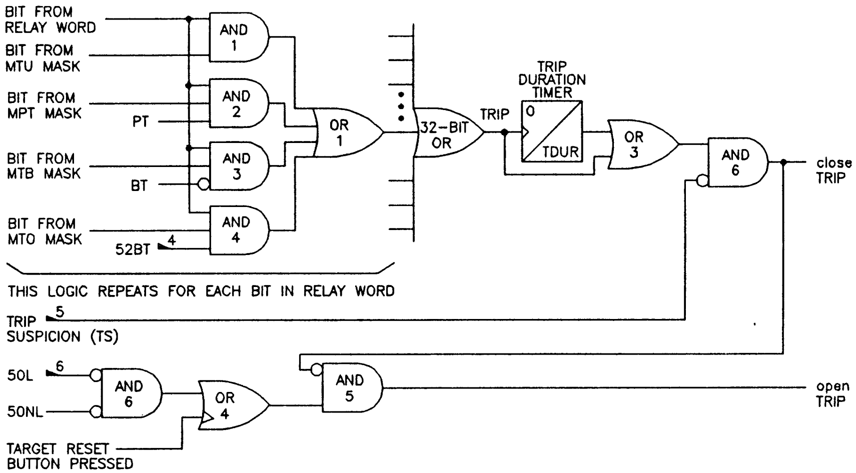


RELAY GROUND DIRECTIONAL AND GROUND OVERCURRENT LOGIC DIAGRAM

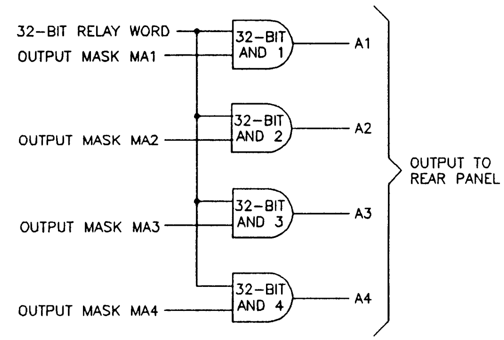
USED ON
SEL-121C
SEL-221C

SETTABLE TIMERS
Z2DG Z3DG

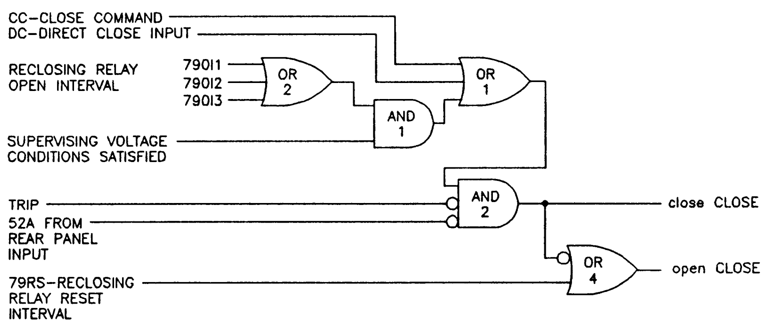
DWG. A7-0907B



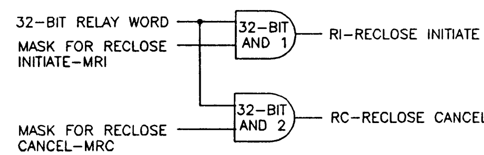
PROGRAMMABLE TRIP LOGIC DIAGRAM



PROGRAMMABLE OUTPUT LOGIC DIAGRAM



CLOSE LOGIC DIAGRAM



PROGRAMMABLE RECLOSE INITIATE AND CANCEL LOGIC DIAGRAM

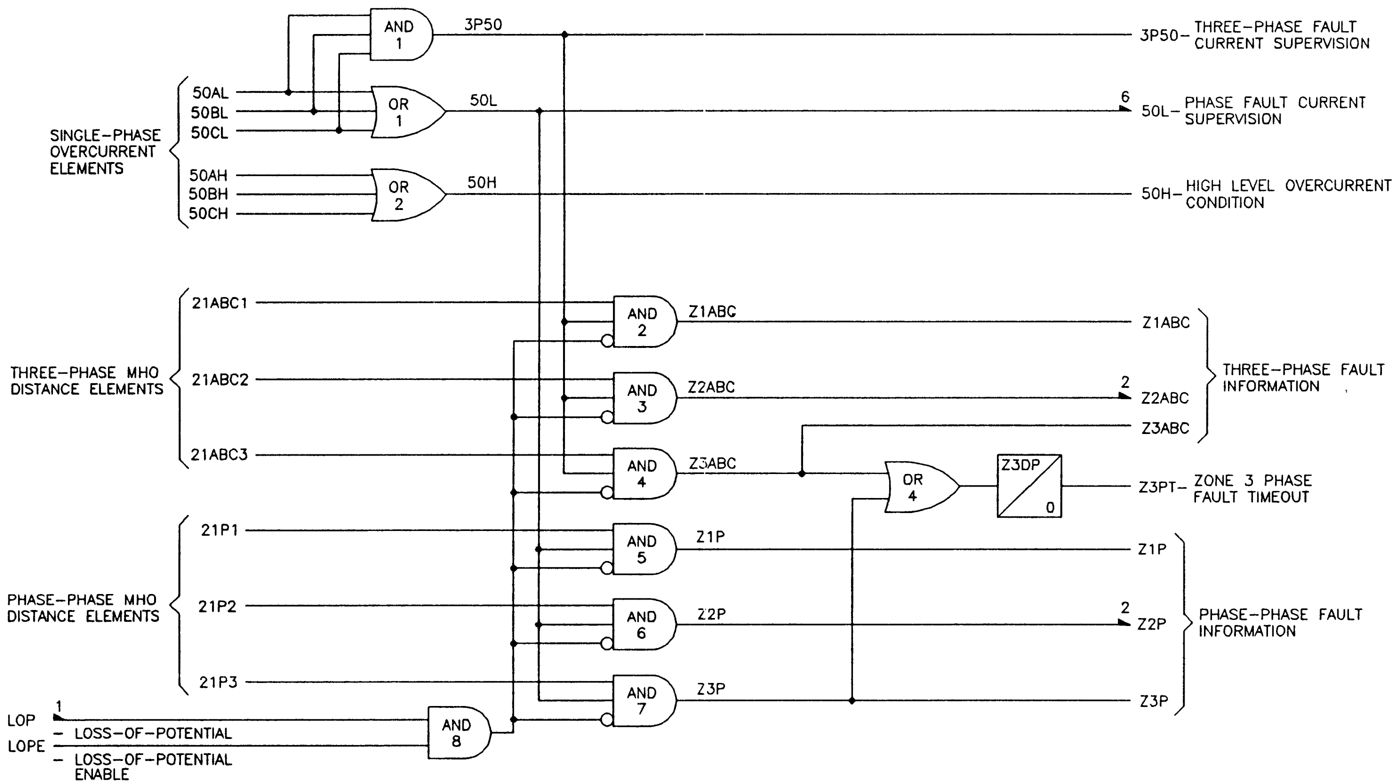
MTU-MASK FOR UNCONDITIONAL TRIP
MPT-MASK FOR TRIP WITH PERMISSIVE-TRIP ASSERTED
MTB-MASK FOR TRIP WITH BLOCK-TRIP UNASSERTED
MTO-MASK FOR TRIP WITH BREAKER OPEN
PT-PERMISSIVE TRANSFER TRIP
BT-BLOCK TRIP
52BT-52A INPUT TIMER INVERTED OUTPUT

USED ON

SEL-121C
SEL-221C

SETTABLE TIMER
TDUR

DWG. A7-0907C



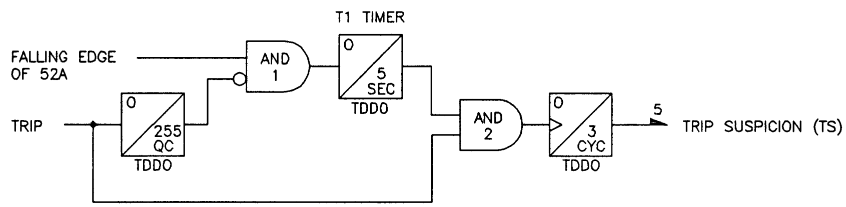
THREE-PHASE MHO, PHASE-PHASE MHO, AND PHASE OVERCURRENT LOGIC DIAGRAM

USED ON

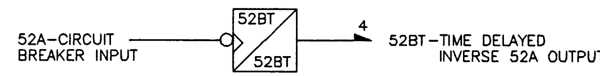
SEL-121C
SEL-221C

SETTABLE TIMER
Z3DP

DWG. A7-0907D



RELAY TRIP SUSPICION LOGIC DIAGRAM



RELAY CIRCUIT BREAKER CONTACT DELAY LOGIC DIAGRAM

USED ON

SEL–121C
SEL–221C

SETTABLE TIMER
52BT

DWG. A7–0907E

COMMUNICATIONS
TABLE OF CONTENTS

Introduction 3-1
Serial Port Connections and Configurations 3-1
Communications Protocol 3-4
Command Characteristics 3-5
Startup 3-6
Command Format 3-7
Command Descriptions 3-7
Access Level 0 Command 3-7
Access Level 1 Commands 3-8
Access Level 2 Commands 3-19
SEL-221C/121C Relay Command Summary 3-27

TABLES

Table 3.1: SEL-221C Relay Serial Port Connector Pin Assignments 3-3
Table 3.2: SEL-121C Serial Port Connector Pin Assignments 3-4
Table 3.3: Hexadecimal/Binary Conversion 3-15
Table 3.4: Target LED Assignment 3-17

FIGURES

Figure 3.1: SEL-221C 9-Pin Connector Pin Number Convention 3-2
Figure 3.2: SEL-121C 9-Pin Connector Pin Number Convention 3-2

COMMUNICATIONS

INTRODUCTION

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

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

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

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

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

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

Relay output appears boxed and in the following format:

```
Example 69 kV Line                    Date: 1/1/92     Time: 01:01:01
```

SERIAL PORT CONNECTIONS AND CONFIGURATIONS

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

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

Serial communications Port 1 and the Auxiliary Input for demodulated IRIG-B time-code input 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 Port 2, remove the relay front panel. The jumpers are visible near the center of the relay drawout assembly, to the right of the target LEDs. Carefully move the jumpers using needle-nosed pliers. Available rates are 300, 600, 1200, 2400, 4800, and 9600 baud.

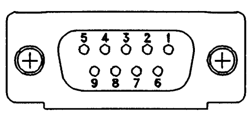
Caution: Do not select two baud rates for the same port as this can damage the relay baud rate generator. The relay is shipped with Port 1 set to 300 baud and Port 2F/2R set to 2400 baud.

The SEL-121C Relay does not include a front panel connector for Port 2.

The serial data format is:

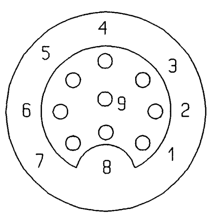
eight data bits
two stop bits (-E2 model) or one stop bit (-E1 model)
no parity bit

This format cannot be altered.



(female chassis connector, as viewed from outside panel)

Figure 3.1: SEL-221C 9-Pin Connector Pin Number Convention



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

Figure 3.2: SEL-121C 9-Pin Connector Pin Number Convention

Table 3.1 lists port pin assignments and signal definitions.

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

Pin	Port 1, Port 2R	Port 2F	Description
1	+5 Vdc	N/C	+5 Vdc available if JMP12 installed
2	RXD	RXD	Receive data input.
3	TXD	TXD	Transmit data output.
4	+12 Vdc	N/C	+12 Vdc available if JMP13 installed
5	GND	GND	
6	-12 Vdc	N/C	-12 Vdc available if JMP14 installed
7	RTS	RTS	The SEL-221C Relay asserts this line under normal conditions. When its received-data buffer is full, the line is deasserted, and asserts again when the buffer has sufficient room to receive more data. Connected devices should monitor RTS (usually with their CTS input) and stop transmission whenever the line deasserts. If transmission continues, data may be lost.
8	CTS	CTS	The SEL-221C 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-121C Relay Serial Port Connector Pin Assignments

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

COMMUNICATIONS PROTOCOL

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

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

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

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

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

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

<MESSAGE LINE 1> <CRLF>
<MESSAGE LINE 2> <CRLF>
.
.
<LAST MESSAGE LINE> <CRLF>

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

4. You can use an XON/XOFF procedure to control the relay during data transmission. When the relay receives XOFF during transmission, it pauses until it receives an XON character. If there is no message in progress when the relay receives XOFF, it blocks transmission of any message presented to its buffer. Messages are 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 69 kV Line                    Date: 1/1/92     Time: 01:01:01

SEL-121C
=
```

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 69 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 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 69 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 69 kV Line                    Date:  1/1/92      Time:
14:03:57

Level 1
=>
```

The => prompt indicates Access Level 1.

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

Access Level 1 Commands

2ACCESS

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

The following display indicates successful access.

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


Example 69 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 (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 it stores the year in EEPROM (if the year input differs from the year stored), and displays the new date.

EVENT n

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

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

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

The following incidents clear the event buffers:

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

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

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

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

HISTORY

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

```
=>HISTORY <ENTER>


Example 69 kV Line                    Date: 1/1/92       Time:
07:38:12

#   DATE          TIME        TYPE   DIST   DUR   CURR   SHOT

1  6/19/91   11:03:06.087  EXT                             0
2  5/15/91   09:32:48.125  2BCT   25.60  7.50  392.5     0
3  5/15/91   09:11:54.800  2BC    25.57  7.25  390.1     0
4
5
6
7
8
9
10
11
12

=>
```

Note that only three events has occurred since the relay was set or powered on.

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

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

For faults, the indication includes zone and phase involvement information. The zone is determined from the relay elements asserted at the middle of the first contiguous sequence of relay elements picked up in the report. For example, if relay elements are continuously 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
- 5 : For 51N pickup, but not Zone 3, 2, or 1
- H : For 50H pickup, but not 51N or Zone 3, 2, or 1
- ? : For none of the above picked up at mid-fault

Phase involvement is shown by the characters following the zone indication and is determined independently from relay elements. Phase involvement is determined solely from uncompensated and load compensated current magnitudes. These magnitudes are measured at the midpoint of the first continuous relay element pickup sequence in the event report. The phase involvement is indicated as one of the list below.

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

Zone and phase involvement data are joined into a single string, completing the TYPE designation, as in "3BG" for a Zone 3 B-phase-to-ground fault. For event reports triggered by TRIP output assertion, the TYPE designation is appended with a "T." This aids in determining clearing times for faults continuing after completion of the first event report. For example, if the relay trips for a 3BG fault after completing 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 shows "TRIP" when the relay generates an event report in response to TRIP output assertion. This could occur after OPEN command execution during no-fault conditions. For all other events, TYPE is "EXT," indicating that the report was generated in response to some external stimulus, such as ET (External Trigger), PT (Permissive Trip), BT (Block Trip), or DT (Direct Trip) input assertion, or TRIGGER command execution.

The DIST column presents the equivalent distance to a fault in miles. This is calculated using either the Takagi algorithm or a reactance measurement, depending on whether sound prefault data are available in the event report. For some boundary faults of long duration when relay operation is sporadic, the fault locator may not be able to locate the fault for every report generated. The DIST column may display "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. This is calculated using the first pickup of a Zone 1, 2, 3, 51N, 51P, 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 CURR column shows the magnitude of the maximum phase current measured at the middle of the fault in primary amperes.

The SHOT column indicates the status of the recloser shot counter when an event is triggered. A zero in this column indicates the recloser is reset, a one indicates first recloser shot, a two indicates second recloser shot or recloser locked out.

As an example, if two shot reclosing is enabled and all voltage conditions are met, the following scenario would occur for a permanent fault:

Trip -> Event Report with Shot Counter = 0 -> Reclose and Increment Shot Counter
Trip -> Event Report with Shot Counter = 1 -> Reclose and Increment Shot Counter
Trip -> Event Report with Shot Counter = 2 -> Reclose and Increment Shot Counter
Trip -> Event Report with Shot Counter = 3 -> No Reclose (Recloser Locked Out)

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 69 kV Line                    Date: 1/1/92     Time: 01:01:01

=>
```

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 69 kV Line                    Date: 1/1/92     Time: 07:56:36

                A       B       C       AB      BC      CA
I (A)           52      50      50      86      87      87
V (kV)        39.8    39.6    39.8    69.0    68.8    69.2

P (MW)        5.87
Q (MVAR)      1.03

=>
```

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.

The example above shows 40 kilovolts in positive sequence with 50 amperes of load current lagging the voltages by 10°.

$$S = (39{,}800)(52) + (39{,}600)(50) + (39{,}800)(50) = 6.04 \text{ MVA}$$

$$P = (S)(\cos(10°)) = 5.95 \text{ MW}$$

$$Q = (S)(\sin(10°)) = 1.05 \text{ MVAR}$$

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

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

QUIT

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

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

```
=>QUIT <ENTER>

Example 69 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 69 kV Line

R1   =24.92    X1   =28.16    R0   =28.04    X0   =71.54    LL   =30.00
CTR  =60.00    PTR  =600.00   MTA  =48.50    LOCAT=Y
47PXD=13.80    47PXL=55.20    59N  =4.00     VCT  =10.00
LLC  =N        DLC  =Y        CVC  =Y        VSA  =Y
79OI1=40.00    79OI2=100.00   79OI3=200.00   79RS =240.00
50L  =280.00   50M  =500.00   50MF =20.00    50H  =975.00
Z1%  =70.00    Z2%  =120.00   Z3%  =120.00   Z3DP =60.00
51PP =330.00   51PTD=4.00     51PC =4
51NP =280.00   51NTD=3.00     51NC =4        51NTC=Y        TDUR =9.00
50N1P=660.00   50N2P=335.00   50N3P=266.00   Z2DG =30.00    Z3DG =60.00
52BT =20.00    ZONE3=R        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  MRI  MRC
C0   00   00   F4   20   80   00   00   00   F4
C4   00   00   F7   22   80   00   00   44   80
31   00   00   00   00   00   02   04   00   31
30   00   00   30   00   00   00   00   00   30

=>
```

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

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

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

Row 1, of any column:	51PT	1ABC	2ABC	3ABC	51PP	50H	50L	LOP
Row 2, of any column:	51NT	67N1	67N2	67N3	51NP	Z1P	Z2P	Z3P
Row 3, of any column:	DF	DR	Z2GT	Z3GT	50MF	RC	RI	Z3PT
Row 4, of any column:	50M	TRIP	TC	DT	52BT	59N		

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

Table 3.3: Hexadecimal/Binary Conversion

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

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

C4 -> 1100 0100.

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

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

STATUS

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

The STATUS report format appears below.

```
=>STATUS <ENTER>

Example 69 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    -2   0    0    0    0    0
PS     5.03      15.08    -15.22
RAM    ROM    A/D    MOF    SET
OK     OK     OK     OK     OK

=>
```

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

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

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

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

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

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

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

TARGET n k

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

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 as seen in Table 3.4.

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

Table 3.4: Target LED Assignment

LED: n	1	2	3	4	5	6	7	8	
0	EN	$\phi 1$	G1	$\phi 2$	G2	$\phi 3$	G3	51N	RELAY TARGETS
1	51PT	1ABC	2ABC	3ABC	51PP	50H	50L	LOP	RELAY WORD row 1
2	51NT	67N1	67N2	67N3	51NP	Z1P	Z2P	Z3P	RELAY WORD row 2
3	DF	DR	Z2GT	Z3GT	50MF	RC	RI	Z3PT	RELAY WORD row 3
4	50M	TRIP	TC	DT	52BT	59N			RELAY WORD row 4
5	52AT		ET	52A	DC	BT	PT	DT	CONTACT INPUTS
6		TRIP	CLOS	A1	A2	A3	A4	ALRM	CONTACT OUTPUTS

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

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

```
=>TARGET 3 10 <ENTER>

 DF   DR   Z2GT Z3GT 50MF  RC    RI    Z3PT
 0    0    0    0    0     0     0     0
 0    0    0    0    0     0     0     0
 0    0    0    0    0     0     0     0
 0    0    0    0    0     0     0     0
 0    0    0    0    0     0     0     0
 0    0    0    0    0     0     0     0
 0    0    0    0    0     0     0     0
 0    0    0    0    0     0     0     0

 DF   DR   Z2GT Z3GT 50MF  RC    RI    Z3PT
 0    0    0    0    0     0     0     0
 0    0    0    0    0     0     0     0

=>
```

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

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

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

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

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

=>
```

When a serial port times out (see TIME1, TIME2 settings) and an automatic message is sent to that port, the relay automatically clears the target display and displays the TAR 0 data. While this feature prevents confusion among station operators and readers, it can be inconvenient if the relay tester requires targets to remain on another level. Targets remain in the specified level if you assign the AUTO setting to a port with zero timeout or set both TIME1 and TIME2 to zero. This halts automatic message transmission to a port which may be timed out.

TIME hh:mm:ss

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

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

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

TRIGGER

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

```
=>TRIGGER <ENTER>
Triggered

=>

Example 69 kV Line                   Date: 1/1/92  Time: 10:25:08.841

Event   : EXT    Location    :        mi          ohms sec
Duration:        Flt Current:         Shot Counter: 0

=>
```

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

Access Level 2 Commands

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

CLOSE

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

To close the circuit breaker with this command, type **CLOSE <ENTER>**. The prompting message "Close BREAKER (Y/N) ?" is displayed. **Y <ENTER>** yields a second prompting string: "Are you sure (Y/N) ?" Type **Y <ENTER>** to assert the CLOSE output relay, as long as the TRIP output and 52A input are not asserted. The relay transmits the message "Breaker CLOSED" when 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
=>>
```

If the relay response is "Breaker OPEN," the 52A input indicates that the breaker did not close.

LOGIC n

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

The parameter n specifies a mask to program.

MTU	-	Mask for unconditional trip
MPT	-	Mask for trip with permissive-trip input asserted
MTB	-	Mask for trip with block-trip input deasserted
MTO	-	Mask for trip with breaker open (switch-onto-fault mask)
MA1	-	Mask for A1 relay control
MA2	-	Mask for A2 relay control
MA3	-	Mask for A3 relay control
MA4	-	Mask for A4 relay control
MRI	-	Mask for reclose initiate
MRC	-	Mask for reclose cancel

The logic programming procedure requires entry of changes for the mask or typing **<ENTER>** to indicate no change. Each of the masks listed above is split into sections corresponding to the four rows of the Relay Word as follows:

RELAY WORD

Row 1	51PT	1ABC	2ABC	3ABC	51PP	50H	50L	L0P
Row 2	51NT	67N1	67N2	67N3	51NP	Z1P	Z2P	Z3P
Row 3	DF	DR	Z2GT	Z3GT	50MF	RC	RI	Z3PT
Row 4	50M	TRIP	TC	DT	52BT	59N		

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

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

LOGIC command example for the MTU mask:

```
=>>LOGIC MTU <ENTER>

1 selects, 0 deselects.

Example 69 kV Line                    Date: 1/1/92     Time: 11:05:40

51PT 1ABC 2ABC 3ABC 51PP 50H  50L  LOP
 1    1    0    0    0    0    0    0
 ?  <ENTER>
51NT 67N1 67N2 67N3 51NP Z1P  Z2P  Z3P
 1    1    0    0    0    1    0    0
 ?  <ENTER>
DF   DR   Z2GT Z3GT 50MF RC   RI   Z3PT
 0    0    1    1    0    0    0    1
 ?  <ENTER>
50M  TRIP TC   DT   52BT 59N
 0    0    1    1    0    0    0    0
 ? 00010000 <ENTER>
 0    0    0    1    0    0    0    0
 ? <ENTER>

New MTU :

51PT 1ABC 2ABC 3ABC 51PP 50H  50L  LOP
 1    1    0    0    0    0    0    0
51NT 67N1 67N2 67N3 51NP Z1P  Z2P  Z3P
 1    1    0    0    0    1    0    0
DF   DR   Z2GT Z3GT 50MF RC   RI   Z3PT
 0    0    1    1    0    0    0    1
50M  TRIP TC   DT   52BT 59N
 0    0    0    1    0    0    0    0

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

Example 69 kV Line                    Date: 1/1/92     Time: 11:06:01


=>>
```

The previous example selects unconditional tripping for assertion of the Zone 1 three-phase, phase-phase, and ground elements, timeout of the 51N and 51P elements, time out of Zones 2 and 3 ground timers and Zone 3 phase timer and assertion of the DT input.

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

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

OPEN

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

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

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

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

If the relay response is "Breaker Closed," the 52A input did not indicate that the breaker opened.

PASSWORD (1 or 2) [password]

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

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

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

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

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

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

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

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

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

SET n

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

The relay checks new settings against established limits twice. The first check ensures that settings fall within setting limits shown on the next page. The relay also checks settings to ensure they fall within the secondary limits shown in Section 2: SPECIFICATIONS.

The SET command prompts you for each setting. If the setting is within primary setting 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 new settings. Error messages notify you when entries result in out-of-range settings. If all settings are acceptable, the relay enables them, closes the ALARM contact momentarily, and clears the event buffer.

Primary setting ranges appear to the right of each numerical entry below. Setting limits and units appear in brackets. The relay does not display these ranges during the actual set procedure. Check element specifications in Section 2: SPECIFICATIONS to determine secondary setting limits.

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

ID	39-character string to identify relay in event reports and SEL-DTA LCD display
R1, X1	Positive-sequence primary impedance of line (0 - 9999 ohms)
R0, X0	Zero-sequence primary impedance of line (0 - 9999 ohms)
LL	Line length (0.1 - 999 miles)
CTR	CT ratio (e.g., for 600:5, enter 120) (1 - 5000)
PTR	PT ratio (e.g., 1200:1, enter 1200) (1 - 10,000)
MTA	Maximum torque angle for mho elements (47° - 90°)
LOCAT	Do you want fault locator enabled? (Y or N)
47PXD	Positive-sequence phase-phase voltage threshold for dead voltage (0 - 2000 kV)
47PXL	Positive-sequence phase-phase voltage threshold for live voltage (0 - 2000 kV)
59N	Zero-sequence voltage threshold for reclosing supervision (0 - 2000 kV)
VCT	Voltage condition timer defines maximum time to meet supervising voltage conditions (0 - 10,000 cycles)
LLC	Live-line voltage check enable (Y or N)
DLC	Dead-line voltage check enable (Y or N)
CVC	Check voltage at close? (Y or N)
VSA	Voltage supervise all reclosing shots? (Y or N)
79OI1	Reclosing relay open interval 1 (0.25 to 10,000 cycles; 0 disables reclosing)
79OI2	Reclosing relay open interval 2 (0.25 to 10,000 cycles; 0 disables reclosing)
79OI3	Reclosing relay open interval 3 (0.25 to 10,000 cycles; 0 disables reclosing)
79RS	Reclosing relay reset time (60 to 8,000 cycles)
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)
Z1%	Zone 1 reach (percent of line length: 0 to 2000%)
Z2%	Zone 2 reach (percent of line length: 0 to 3200%)
Z3%	Zone 3 reach (percent of line length: 0 to 3200%)
Z3DP	Zone 3 delay for phase-phase and three-phase faults (0 - 2000 cycles in quarter-cycle steps)

51PP	Phase time-overcurrent pickup (0.25 - 50,000 primary amperes)
51PTD	Phase time-overcurrent time dial (0.5 - 15)
51PC	Phase time-overcurrent curve index Choices are as follows: 1 selects a moderately inverse curve 2 selects an inverse curve 3 selects a very inverse curve 4 selects an extremely inverse curve
51NP	Residual time-overcurrent pickup (0.25-50,000 primary amperes)
51NTD	Residual time-overcurrent time dial (0.5-15)
51NC	Residual time-overcurrent curve index. Choices are as follows: 1 selects a moderately inverse curve 2 selects an inverse curve 3 selects a very inverse curve 4 selects an extremely inverse curve
51NTC	Do you want residual time-overcurrent torque control? (Y or N)
TDUR	Trip duration timer (0-2000 cycles)(0.0 setting disables OPEN command)
50N1P	Zone 1 residual instantaneous overcurrent (0.25-50,000 primary amperes)
50N2P	Zone 2 residual instantaneous overcurrent (0.25-50,000 primary amperes)
50N3P	Zone 3 residual instantaneous overcurrent (0.25-50,000 primary amperes)
Z2DG	Zone 2 delay for ground faults (0-2000 cycles in quarter-cycle steps)
Z3DG	Zone 3 delay for ground faults (0-2000 cycles in quarter-cycle steps)
52BT	52B time delay (0.5 - 10,000 cycles)
ZONE3	Zone 3 direction (F = forward or R = reverse)
32QE	Do you want negative-sequence directional supervision of 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 loss-of-potential detection block distance elements? (Y or N)
TIME1	Timeout for Port 1 (0-30 minutes)
TIME2	Timeout for Port 2 (0-30 minutes)
AUTO	Autoport (Port 1, 2, or 3 (for both))
RINGS	Number of rings after which the modem answers (1-30 rings)

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

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

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

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

SEL-221C/121C RELAY COMMAND SUMMARY

Access Level 0

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

Access Level 2

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

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EVENT REPORTING
TABLE OF CONTENTS

Event Report Generation 4-1
Summary Event Report 4-2
  Relay Identifier 4-2
  Event Time and Date 4-3
  Event Type 4-3
  Fault Location 4-4
  Secondary Ohms 4-5
  Fault Duration 4-5
  Maximum Phase Current 4-5
  Shot Counter 4-5
Long Event Report 4-6
  Interpretation of Voltage and Current Data 4-6
  Relays 4-7
  Contact Outputs and Inputs 4-8
  Event Summary 4-8
  Relay Settings 4-8
Example Event Reports 4-9
  Externally Triggered Event Report 4-9
  Zone 1 BC Fault 4-11
  Zone 2 BC Fault 4-15
  Switch-onto-Fault Event 4-21
Firmware Identification 4-24

TABLES

Table 4.1: Event Report Triggering Actions 4-1
Table 4.2: Non-Event Report Triggering Actions 4-1

FIGURES

Figure 4.1: Example System Single-Line Diagram 4-11

EVENT REPORTING

EVENT REPORT GENERATION

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

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

Table 4.1: Event Report Triggering Actions

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

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

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

Table 4.2: Non-Event Report Triggering Actions

- CLOSE command execution
- DIRECT CLOSE input assertion
- 52A input status changes
- Pickup of the 50L overcurrent element

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

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

SUMMARY EVENT REPORT

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

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

The summary event report includes:

- Relay 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
- Reclosing relay shot counter

The following shows an example summary event report.

```
Bus B, 69 kV, Line 2           Date: 1/1/92     Time: 10:25:08.841

Event   : 1BC    Location   : 15.07  mi  1.89   ohms sec
Duration: 3.75   Flt Current: 715.9  Shot Counter: 0


=>
```

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

Relay Identifier

The relay identifier is the information entered in the 39 character Relay ID setting. This information can include the identification of the protected line, serial number of the relay, date of last relay maintenance, etc.

Event Time and Date

The event summary date and time are taken from the relay internal clock. The time corresponds to the data in the sixteenth row of the event report.

Event Type

The event type indicates zone and phase involvement of the fault.

The zone is determined from the relay elements picked up at the middle of the first contiguous sequence of picked-up relay elements in the report. For example, if relay elements are continuously picked up from the 16th to the 24th rows, the zone will be determined using 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
5	:	For 51N pickup, but not Zone 3, 2, or 1
H	:	For 50H pickup, but not 51N or Zone 3, 2, or 1
?	:	For none of the above picked up at mid-fault

The relay determines phase involvement independently of the relay element operations based upon a phase current magnitude comparison.

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

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

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

Where:

Imax	=	Highest uncompensated phase current
Imed	=	Second highest uncompensated phase current
Imin	=	Lowest uncompensated phase current
Ifmax	=	Highest load compensated phase current
Ifmed	=	Second highest load compensated phase current
Ifmin	=	Lowest load compensated phase current

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

The phase involvement is indicated as one of the following:

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 joined into a single string, completing the TYPE designation, as in "3BG" for a Zone 3 B-phase-to-ground fault.

For event reports triggered by TRIP output assertion, TYPE designation is appended with a "T." This aids in determining clearing times for faults that continue after the first event report ends. For example, if the relay trips for a 3BG fault after completing the initial report, the second report shows "3BGT" for TYPE.

Event records taken with no triggering relay elements picked up are labeled as follows:

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

or

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

Fault Location

The relay fault locating function is separate from the protective functions. The relay calculates fault location from data stored in the 44-cycle event report. It calculates a fault location for every event report which has fault detecting elements asserted between the 8th and 39th event report rows.

The relay uses the fault type selected above and performs a fault locating calculation based on the Takagi algorithm, if pre-fault data is available. The Takagi algorithm uses pre-fault current values to compensate for the effects of fault resistance, load current, and remote infeed. When valid pre-fault data is not available, the relay uses the simple reactance method calculation for fault locating.

Secondary Ohms

The relay also displays the fault location in secondary ohms. This value corresponds to the distance value calculated above when the protected line has a constant impedance per unit distance characteristic.

Fault Duration

The event summary contains a fault duration calculated from the first pickup of a fault detecting element until the last fault detecting element drops out or the event report ends.

Maximum Phase Current

The relay displays the maximum phase current magnitude calculated in the same event report row where fault data was gathered for the fault locating calculation. This data helps show the severity of the fault.

Shot Counter

The shot counter shows the state of the reclosing relay when the relay tripped. If the first reclosing shot is not cancelled, the shot counter advances when the first close is issued. Then the shot counter advances again when the second close is issued.

If the first shot is cancelled due to voltage conditions, the shot counter advances when the first shot is cancelled. If the shot counter is at 3, the reclosing relay is locked out.

The shot counter resets when the 79RS timer expires.

LONG EVENT REPORT

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

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

Interpretation of Voltage and Current Data

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

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

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

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

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

   The filter has the property of a double differentiator smoother.

4. The latest four samples are processed through the digital filter every quarter-cycle. Successive outputs of the filter arrive every 90°. 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.

The following example may clarify why we refer to the older data as the leading component of the phasor.

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 Report 1 shows the process of converting the rectangular format voltages and currents displayed in the event report to polar format.

Relays

The states of all relay elements are indicated in the six columns headed "Relays." Active states of the various relay elements are indicated by designator symbols which correspond with relay element names. The contents of the columns for active relay elements appear below. Assertion of the 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
21P	:	Two-phase distance units	:	1	=	Z1	Zone 1 picked up
				2	=	Z2	Zone 2 picked up
				3	=	Z3	Zone 3 picked up
67N	:	Residual overcurrent units	:	1	=	67N1	High-set picked up
				2	=	67N2	Medium-set picked up
				3	=	67N3	Low-set picked up
51N	:	Residual time-overcurrent	:	P	=	51NP	51N element picked up
				T	=	TRIP	51N trip threshold reached
51P	:	Phase time-overcurrent	:	P	=	51PP	51P element picked up
				T	=	TRIP	51P trip threshold reached

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

Event Summary

Following the 44 quarter-cycles of fault data, the relay displays the short form event summary. Event summary contents are described in the Summary Event Report Section.

Relay Settings

After the event summary, the relay displays the relay settings and logic mask settings installed when the event occurred.

EXAMPLE EVENT REPORTS

Externally Triggered Event Report

Recall from Section 3: COMMUNICATIONS that the relay records an eleven-cycle 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 3 in the system shown in Figure 4.1. The event report was generated with the TRIGGER command. From this excerpt, you can immediately see that load currents are balanced by the lack of current in the IR column. Also, note that the line breaker is closed, as signified by the asterisk in the 52A column.

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

Using the voltage and current phasor diagrams at the end of the SEL Direction and Polarity Check Form, note that the current and voltage phase rotation is ABC in the clockwise direction. This phase rotation must match the rotation of your system. In addition, note that the load is flowing out from Breaker 3 as indicated by each phase current lagging the respective phase voltage by the load flow angle.

Example Event Report 1

```
Bus B, 69 kV, Line 2                          Date: 1/1/92      Time: 01:15:09.995
FID=SEL-121C-R401-V656mptrc2-D900912
                Currents                   Voltages        Relays Outputs Inputs
                 (amps)                      (kV)
                                                           522655 TCAAAAA DPBD5E
  IPOL      IR      IA      IB      IC      VA      VB      VC  011711 PL1234L TTTC2T
                                                           P3PNNP               A

     0       0      58      60    -120    16.4    23.6   -40.1  ...... ....... ....*.
     0       0    -103     102       3   -36.8    32.5     4.2  ...... ....... ....*.
    -1       0     -58     -60     120   -16.4   -23.6    40.1  ...... ....... ....*.
     1       0     103    -102      -3    36.8   -32.5    -4.2  ...... ....... ....*.

Event    : EXT     Location    :        mi        ohms sec
Duration:          Flt Current:         Shot Counter: 0
```

SEL DIRECTION AND POLARITY CHECK FORM

STATION SEL DATE: 11/17/91 TESTED BY

SWITCH NO. EQUIPMENT SEL-121C Relay

INSTALLATION ROUTINE X OTHER

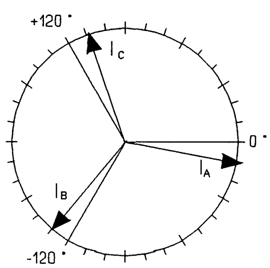
LOAD CONDITIONS:

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

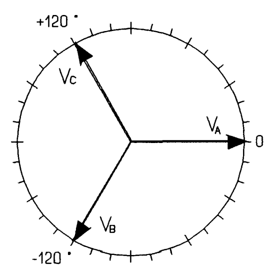
SEL READINGS: 14.28 MW (+)(-) 1.2 MVAR (+)(-)

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)	58	60	-120	16.4	23.6	-40.1	
2nd LINE CHOSEN (X COMPONENT)	-103	102	3	-36.8	32.5	4.2	
CALCULATED MAGNITUDE $\sqrt{X^2 + Y^2}$	118	118	120	40.3	40.2	40.3	ROW 1
ANGLE IN DEGREES ARCTAN Y/X	150.6	30.5	-88.6	155.9	35.9	-84.0	
VALUE OF Va DEGREES TO SUBTRACT TO OBTAIN Va DEGREES = 0	155.9	155.9	155.9	155.9	155.9	155.9	
@ Va DEGREES = 0, ANGLE USED TO DRAW PHASOR DIAGRAM	-5.3	-125.4 °	116.3	0.0	-120.0	120.1	ROW 2

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



CURRENTS



VOLTAGES

Zone 1 BC Fault

Example Event Report 2 shows an in-section fault as viewed from Breaker 3 at Bus B. This report was triggered 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 labeled the event a Zone 1 BC fault and calculated a fault location 15.07 miles from the relay terminal. The relay is expected to trip for this fault. The fault detecting element is the Zone 1 phase-phase element set in the MTU logic mask.

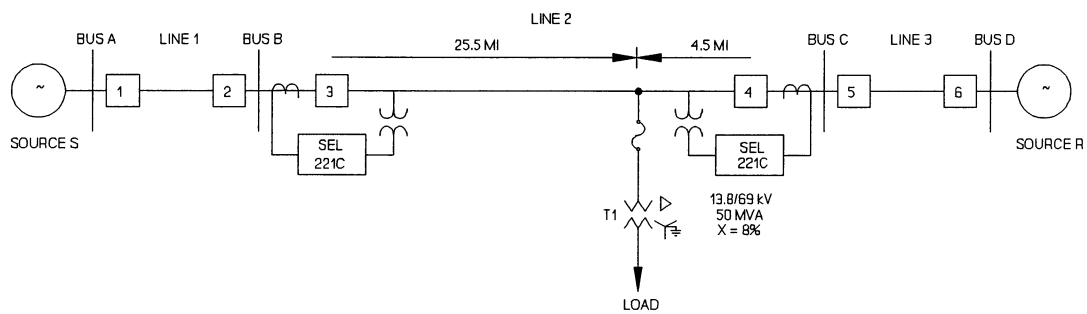


Figure 4.1: Example System Single-Line Diagram

Example Event Report 2

```
Bus B, 69 kV, Line 2                         Date: 1/1/92     Time: 10:25:08.841
FID=SEL-121C-R401-V656mptrs2-D920102-E2

                  Currents                     Voltages        Relays Outputs Inputs
                   (amps)                        (kV)
                                                               522655 TCAAAAA DPBD5E
  IPOL      IR      IA      IB      IC     VA      VB      VC  011711 PL1234L TTTC2T
                                                               P3PNNP              A

    -1       0     -52      47       4  -37.4    31.5     5.7  ...... ....... ....*.
     2       0     -27     -32      59  -14.9   -24.9    39.9  ...... ....... ....*.
    -1       0      52     -47      -4   37.4   -31.5    -5.8  ...... ....... ....*.
    -1       0      27      32     -59   14.9    24.9   -39.9  ...... ....... ....*.

     1       0     -52      47       4  -37.4    31.5     5.8  ...... ....... ....*.
     0       0     -27     -32      59  -14.9   -24.9    39.9  ...... ....... ....*.
     0       0      52     -47      -4   37.4   -31.5    -5.8  ...... ....... ....*.
     0       0      27      32     -59   14.9    24.9   -39.9  ...... ....... ....*.

     0       0     -52      47       4  -37.4    31.5     5.8  ...... ....... ....*.
     0       0     -27     -32      59  -14.9   -24.9    39.9  ...... ....... ....*.
     0       0      52     -47      -4   37.5   -30.0    -7.2  ...... ....... ....*.
     0       0      27      33     -59   14.9    23.4   -38.3  ...... ....... ....*.

     0      -8     -52     212    -170  -37.4    24.3    13.0  ...... ....... ....*.
     0      -8     -27    -110     128  -14.9   -14.9    29.8  ...... ....... ....*.
     0      33      52    -505     486   37.5   -21.6   -15.7  L..... ....... ....*.
     0      19      27     211    -215   14.9     6.7   -21.5  L.2..P ....... ....*.

     1     -52     -52     648    -648  -37.4    23.4    14.0  L.1..P *...*.. ....*.
    -1     -25     -27    -238     237  -14.9    -5.3    20.1  L.1..P *...*.. ....*.
    -1      58      52    -667     671   37.4   -23.5   -13.8  L.1..P *...*.. ....*.
     1      25      27     241    -241   14.9     5.1   -19.9  L.1..P *...*.. ....*.

     0     -58     -52     670    -674  -37.5    23.6    13.8  L.1..P *...*.. ....*.
     0     -25     -27    -242     242  -14.9    -5.1    19.9  L.1..P *...*.. ....*.
     0      58      52    -670     674   37.5   -23.6   -13.8  L.1..P *...*.. ....*.
     0      25      27     242    -242   14.9     5.1   -19.9  L.1..P *...*.. ....*.

     0     -58     -52     670    -674  -37.5    23.5    13.8  L.1..P *...*.. ....*.
     0     -25     -27    -242     242  -14.9    -5.1    19.9  L.1..P *...*.. ....*.
     0      58      52    -670     674   36.6   -22.2   -14.3  L.1..P *...*.. ....*.
     0      25      27     241    -241    9.1     6.9   -16.0  L.1..P *...*.. ....*.

     0     -49     -43     490    -495  -24.7    12.7    11.9  L.1..P *...*.. ....*.
     0     -14     -19    -152     153   -2.1    -5.1     7.2  L.1..P *...*.. ....*.
     0      22      19    -174     177    7.7    -2.6    -5.1  ...... *...... ....*.
     0       3       6      35     -36    0.5     0.8    -1.3  ...... *...... ....*.

     0      -3      -1      22     -24   -0.9     0.3     0.6  ...... *...... ....*.
     0       0      -1      -4       4   -0.1    -0.1     0.2  ...... *...... ......
     0       0       0      -3       4    0.1    -0.0    -0.1  ...... *...... ......
     0       0       0       1      -1    0.0     0.0    -0.0  ...... *...... ......

     0       0       0       0       0    0.0     0.0     0.0  ...... *...... ......
     1       0       0       0       0    0.0     0.0     0.0  ...... *...... ......
    -1       0       0       0       0    0.0     0.0     0.0  ...... *...... ......
    -1       0       0       0       0    0.0     0.0     0.0  ...... *...... ......

     1       0       0       0       0    0.0     0.0    -0.0  ...... *...... ......
     0       0       0       0       0    0.0     0.0     0.0  ...... *...... ......
     0       0       0       0       0    0.0     0.0     0.0  ...... *...... ......
     0       0       0       0       0    0.0     0.0     0.0  ...... *...... .....

Event   : 1BC      Location   : 15.07  mi  1.89   ohms sec
Duration: 3.75     Flt Current: 715.9  Shot Counter: 0

R1    =24.92     X1    =28.16     R0    =28.04     X0    =71.54     LL    =30.00
CTR   =60.00     PTR   =600.00    MTA   =48.50     LOCAT=Y
47PXD=13.80      47PXL=55.20      59N   =4.00     VCT   =10.00
LLC   =N         DLC   =Y         CVC   =Y        VSA   =Y
79OI1=40.00      79OI2=100.00     79OI3=200.00     79RS  =240.00
50L   =280.00    50M   =500.00    50MFD=20.00      50H   =975.00
Z1%   =70.00     Z2%   =120.00    Z3%   =120.00    Z3DP  =60.00
51PP  =330.00    51PTD=4.00       51PC  =4
51NP  =280.00    51NTD=3.00       51NC  =4         51NTC=Y          TDUR  =9.00
50N1P=660.00     50N2P=335.00     50N3P=266.00     Z2DG  =30.00     Z3DG  =60.00
52BT  =20.00     ZONE3=R          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  MRI  MRC
C0   00   00   44   00   00   00   00   C0   04
C4   00   00   44   00   00   00   00   C4   00
31   00   00   00   00   00   02   04   20   11
30   00   00   10   08   04   00   00   10   20
```

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

	Currents (amps)				Voltages (kV)			Relays	Outputs	Inputs	
								522655	TCAAAAA	DPBD5E	
IPOL	IR	IA	IB	IC	VA	VB	VC	011711	PL1234L	TTTC2T	
								P3PNNP		A	Quarter-Cycles
-1	0	-52	47	4	-37.4	31.5	5.7	......	....	....*.	1
2	0	-27	-32	59	-14.9	-24.9	39.9	......	....	....*.	2
-1	0	52	-47	-4	37.4	-31.5	-5.8	......	....	....*.	3
-1	0	27	32	-59	14.9	24.9	-39.9	......	....	....*.	4
1	0	-52	47	4	-37.4	31.5	5.8	......	....	....*.	5
0	0	-27	-32	59	-14.9	-24.9	39.9	......	....	....*.	6
0	0	52	-47	-4	37.4	-31.5	-5.8	......	....	....*.	7
0	0	27	32	-59	14.9	24.9	-39.9	......	....	....*.	8
0	0	-52	47	4	-37.4	31.5	5.8	......	....	....*.	9
0	0	-27	-32	59	-14.9	-24.9	39.9	......	....	....*.	10
0	0	52	-47	-4	37.5	-30.0	-7.2	......	....	....*.	11
0	0	27	33	-59	14.9	23.4	-38.3	......	....	....*.	12
0	-8	-52	212	-170	-37.4	24.3	13.0	......	....	....*.	13
0	-8	-27	-110	128	-14.9	-14.9	29.8	......	....	....*.	14
0	33	52	-505	486	37.5	-21.6	-15.7	L.....	....	....*.	15
0	19	27	211	-215	14.9	6.7	-21.5	L.2..P	....	....*.	16

The event report uses a sequence of events format which allows performance analysis of the system by quarter-cycles. Through this analysis, you can observe the pre-fault voltage and current conditions, determine whether or not the breaker was closed by the 52A Inputs column and line current magnitudes, and learn when the protective elements assert. The following outline lists observed incidents shown in Example Event Report 2 by quarter-cycle.

Quarter-Cycle	Event Report Shows:
1-14	Pre-fault conditions:
	• No residual current in IR column indicates balanced load currents.
	• No protective relay elements are picked up.
	• An asterisk (*) in 52A Inputs column verifies breaker closure (as does load current flow).
15	Fault Inception:
	• L in 50P column shows fault current reached 50L element pickup threshold.
16	• 2 in 21P column shows when Zone 2 phase-phase element picked up.
	• P in 51P column shows that the phase time-overcurrent element picked up.

The phase time-overcurrent element picked up in row 16 because the current in at least one phase was above the 51PP setting and the Zone 2 phase distance element was asserted.

Quarter-cycles 17 through 32 are shown below.

```
               Currents                        Voltages       Relays Outputs Inputs
                (amps)                           (kV)
                                                              522655 TCAAAAA DPBD5E
 IPOL     IR      IA      IB      IC      VA      VB      VC  011711 PL1234L TTTC2T
                                                              P3PNNP             A        Quarter-Cycles

    1    -52     -52     648    -648   -37.4    23.4    14.0  L.1..P *...*.. ....*.             17
   -1    -25     -27    -238     237   -14.9    -5.3    20.1  L.1..P *...*.. ....*.             18
   -1     58      52    -667     671    37.4   -23.5   -13.8  L.1..P *...*.. ....*.             19
    1     25      27     241    -241    14.9     5.1   -19.9  L.1..P *...*.. ....*.             20

    0    -58     -52     670    -674   -37.5    23.6    13.8  L.1..P *...*.. ....*.             21
    0    -25     -27    -242     242   -14.9    -5.1    19.9  L.1..P *...*.. ....*.             22
    0     58      52    -670     674    37.5   -23.6   -13.8  L.1..P *...*.. ....*.             23
    0     25      27     242    -242    14.9     5.1   -19.9  L.1..P *...*.. ....*.             24

    0    -58     -52     670    -674   -37.5    23.5    13.8  L.1..P *...*.. ....*.             25
    0    -25     -27    -242     242   -14.9    -5.1    19.9  L.1..P *...*.. ....*.             26
    0     58      52    -670     674    36.6   -22.2   -14.3  L.1..P *...*.. ....*.             27
    0     25      27     241    -241     9.1     6.9   -16.0  L.1..P *...*.. ....*.             28

    0    -49     -43     490    -495   -24.7    12.7    11.9  L.1..P *...*.. ....*.             29
    0    -14     -19    -152     153    -2.1    -5.1     7.2  L.1..P *...*.. ....*.             30
    0     22      19    -174     177     7.7    -2.6    -5.1  ...... *...... ....*.             31
    0      3       6      35     -36     0.5     0.8    -1.3  ...... *...... ....*.             32
```

Quarter-Cycle	Event Report Shows:
17	Tripping conditions: • 1 in the 21P column shows that the Zone 1 phase distance element is asserted. • An asterisk (*) in TP Outputs column shows that the relay closed the TRIP output contacts. • An asterisk (*) in A3 Outputs column shows that the relay closed the A3 output contact to indicate assertion of the Reclose Initiate bit.
18-30	Mid-fault Data: • Fault detecting elements and output contacts remain asserted. • Fault locating, event type, and fault current information is calculated from data in this area of the event report.
31-32	• Current and voltage magnitudes decrease as the breaker opens. Fault detecting elements drop out.

The relay tripped in event report row 17 due to assertion of the Zone 1 phase distance element. The A3 contact asserted to indicate the initiation of reclose (RI set in the MA3 logic mask).

The last three cycles of event data are shown below.

	Currents (amps)				Voltages (kV)			Relays	Outputs	Inputs	
IPOL	IR	IA	IB	IC	VA	VB	VC	522655 011711 P3PNNP	TCAAAAA PL1234L	DPBD5E TTTC2T A	Quarter-Cycles
0	-3	-1	22	-24	-0.9	0.3	0.6	......	*......	....*.	33
0	0	-1	-4	4	-0.1	-0.1	0.2	......	*......	......	34
0	0	0	-3	4	0.1	-0.0	-0.1	......	*......	......	35
0	0	0	1	-1	0.0	0.0	-0.0	......	*......	......	36
0	0	0	0	0	0.0	0.0	0.0	......	*......	......	37
1	0	0	0	0	0.0	0.0	0.0	......	*......	......	38
-1	0	0	0	0	0.0	0.0	0.0	......	*......	......	39
-1	0	0	0	0	0.0	0.0	0.0	......	*......	......	40
1	0	0	0	0	0.0	0.0	-0.0	......	*......	......	41
0	0	0	0	0	0.0	0.0	0.0	......	*......	......	42
0	0	0	0	0	0.0	0.0	0.0	......	*......	......	43
0	0	0	0	0	0.0	0.0	0.0	......	*......	......	44

Quarter-Cycle	Event Report Shows:
33-44	Post-fault conditions: • Voltage and current samples go to zero, indicating that the breaker is open and line de-energized. Potentials in this example are drawn from line-side PTs. • No protective relay elements are picked up. • An asterisk (*) in 52A Inputs column deasserts to show the breaker has opened. • An asterisk (*) in TP Outputs column shows that trip is still asserted. The 9.0 cycle TDUR setting ensures that the trip contacts remain closed for at least nine cycles.

The event summary shows that the fault was a B-C fault in Zone 1, at approximately 15 miles from the relay location. The fault duration was 3.75 cycles and maximum phase current magnitude at the midpoint of the fault was 715.9 amps primary.

Zone 2 BC Fault

Example Event Reports 3 and 4 show an in-section, Zone 2 fault as viewed from Breaker 3 at Bus B. The first report was triggered 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 second report was triggered by assertion of the TRIP outputs. The relay tripped due to operation of the phase time-overcurrent element 51PT.

The relay labeled the event a Zone 2 BC fault and calculated a fault location 25.57 miles from the relay terminal (Event Report 3) and 25.60 miles (Event Report 4). The relay is expected to trip for this fault. The fault detecting element is the 51P phase time-overcurrent element torque controlled by the Zone 2 phase-phase element. The 51PT bit is set in the MTU logic mask, allowing the relay to trip when the time-overcurrent element trips.

Example Event Report 3

```
Bus B, 69 kV, Line 2                  Date: 1/1/92          Time: 09:11:54.800
FID=SEL-121C-R401-V656mptrs2-D920102-E2

                  Currents                        Voltages        Relays Outputs Inputs
                   (amps)                           (kV)
                                                                  522655 TCAAAAA DPBD5E
  IPOL     IR      IA      IB      IC      VA      VB      VC     011711 PL1234L TTTC2T
                                                                  P3PNNP              A

     0      0     -55       9      45   -34.4    -0.7    35.1     ...... ....... ....*.
     0      0      23     -57      36    20.6   -40.2    19.3     ...... ....... ....*.
     0      0      55      -9     -45    34.4     0.7   -35.1     ...... ....... ....*.
     0      0     -23      57     -37   -20.6    40.2   -19.3     ...... ....... ....*.

     0      0     -55       9      45   -34.4    -0.7    35.1     ...... ....... ....*.
     0      0      23     -57      38    20.6   -40.2    19.3     ...... ....... ....*.
     0      0      55      -9     -45    34.4     0.7   -35.1     ...... ....... ....*.
     0      0     -23      57     -37   -20.6    40.2   -19.3     ...... ....... ....*.

     0      0     -55       9      45   -34.4    -0.7    35.1     ...... ....... ....*.
     0      0      23     -58      37    20.6   -40.2    19.3     ...... ....... ....*.
     0      0      55      -8     -46    34.3     4.8   -39.2     ...... ....... ....*.
     0      0     -23      70     -49   -20.6    29.2    -8.4     ...... ....... ....*.

     0     -5     -55     108     -71   -34.3     0.1    34.2     ...... ....... ....*.
     0      3      23    -233     223    20.6   -19.6    -1.2     ...... ....... ....*.
     0     14      55    -162     152    34.3    -9.9   -24.4     L..... ....... ....*.
     0     -5     -23     379    -379   -20.6    21.1    -0.3     L.2..P ....... ....*.

     0    -16     -55     118    -117   -34.3    10.7    23.6     L.2..P ....... ....*.
     0      5      23    -374     375    20.6   -21.2     0.3     L.2..P ....... ....*.
     0     16      55    -119     118    34.3   -10.7   -23.7     L.2..P ....... ....*.
     0     -5     -23     374    -375   -20.6    21.1    -0.3     L.2..P ....... ....*.

     0    -16     -55     119    -117   -34.3    10.7    23.7     L.2..P ....... ....*.
     0      5      23    -374     374    20.7   -21.1     0.3     L.2..P ....... ....*.
     0     16      55    -119     117    34.3   -10.7   -23.7     L.2..P ....... ....*.
     0     -5     -23     374    -374   -20.7    21.1    -0.3     L.2..P ....... ....*.

     0    -16     -55     119    -117   -34.3    10.7    23.7     L.2..P ....... ....*.
     0      5      23    -375     374    20.7   -21.1     0.3     L.2..P ....... ....*.
     0     16      55    -118     117    34.3   -10.7   -23.7     L.2..P ....... ....*.
     0     -5     -23     375    -375   -20.7    21.1    -0.3     L.2..P ....... ....*.

     0    -16     -55     118    -116   -34.3    10.7    23.7     L.2..P ....... ....*.
     0      5      23    -374     375    20.7   -21.2     0.3     L.2..P ....... ....*.
     0     16      55    -119     116    34.3   -10.7   -23.7     L.2..P ....... ....*.
     0     -5     -23     374    -375   -20.7    21.2    -0.3     L.2..P ....... ....*.

     0    -16     -54     119    -116   -34.3    10.6    23.7     L.2..P ....... ....*.
     0      5      22    -375     375    20.7   -21.2     0.3     L.2..P ....... ....*.
     0     16      54    -118     116    34.3   -10.6   -23.7     L.2..P ....... ....*.
     0     -5     -22     375    -375   -20.7    21.2    -0.3     L.2..P ....... ....*.

     0    -16     -55     118    -116   -34.3    10.6    23.7     L.2..P ....... ....*.
     0      5      23    -375     375    20.7   -21.2     0.3     L.2..P ....... ....*.
     0     16      55    -118     116    34.3   -10.6   -23.7     L.2..P ....... ....*.
     0     -5     -23     375    -375   -20.7    21.2    -0.3     L.2..P ....... ....*.

     0    -16     -55     118    -116   -34.3    10.6    23.6     L.2..P ....... ....*.
     0      5      23    -375     375    20.7   -21.2     0.3     L.2..P ....... ....*.
     0     16      55    -118     116    34.3   -10.6   -23.6     L.2..P ....... ....*.
     0     -5     -23     375    -375   -20.7    21.2    -0.3     L.2..P ....... ....*.

Event   : 2BC    Location   : 25.57  mi  3.21   ohms sec
Duration: 7.25   Flt Current: 392.2  Shot Counter: 0

R1   =24.92     X1   =28.16     R0   =28.04     X0   =71.54     LL   =30.00
CTR  =60.00     PTR  =600.00    MTA  =48.50     LOCAT=Y
47PXD=13.80     47PXL=55.20     59N  =4.00      VCT  =10.00
LLC  =N         DLC  =Y         CVC  =Y         VSA  =Y
79OI1=40.00     79OI2=100.00    79OI3=200.00    79RS =240.00
50L  =280.00    50M  =500.00    50MFD=20.00     50H  =975.00
Z1%  =70.00     Z2%  =120.00    Z3%  =120.00    Z3DP =60.00
51PP =330.00    51PTD=4.00      51PC =4
51NP =280.00    51NTD=3.00      51NC =4         51NTC=Y         TDUR =9.00
50N1P=660.00    50N2P=335.00    50N3P=266.00    Z2DG =30.00     Z3DG =60.00
52BT =20.00     ZONE3=R         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  MRI  MRC
C0   00   00   44   00   00   00   00   C0   04
C4   00   00   44   00   00   00   00   C4   00
31   00   00   00   00   00   02   04   20   11
30   00   00   10   08   04   00   00   10   20
```

Example Event Report 4

```
Bus B, 69 kV, Line 2                           Date: 1/1/92     Time: 09:12:48.125
FID=SEL-121C-R401-V656mptrs2-D920102-E2

                  Currents                       Voltages        Relays Outputs Inputs
                   (amps)                         (kV)
                                                                 522655 TCAAAAA DPBD5E
  IPOL     IR      IA      IB      IC      VA      VB      VC    011711 PL1234L TTTC2T
                                                                 P3PNNP              A

     0      3       3     294    -294    -4.9    15.0    -9.9    L.2..P ....... ....*.
     0    -16     -58     260    -259   -39.7    18.3    21.5    L.2..P ....... ....*.
     0      0      -3    -293     294     4.9   -15.0     9.9    L.2..P ....... ....*.
     0     16      58    -261     259    39.7   -18.3   -21.5    L.2..P ....... ....*.

     0      0       4     294    -294    -5.0    15.0    -9.9    L.2..P ....... ....*.
     0    -14     -59     261    -259   -39.7    18.3    21.5    L.2..P ....... ....*.
     0     -3      -4    -294     294     5.0   -15.0     9.9    L.2..P ....... ....*.
     0     14      59    -260     259    39.7   -18.3   -21.5    L.2..P ....... ....*.

     0      3       4     294    -294    -5.0    15.0    -9.9    L.2..P ....... ....*.
     0    -14     -59     260    -259   -39.7    18.3    21.5    L.2..P ....... ....*.
     0     -3      -4    -294     294     5.0   -15.0     9.9    L.2..P ....... ....*.
     0     14      59    -260     259    39.7   -18.3   -21.5    L.2..P ....... ....*.

     0      3       3     294    -294    -5.0    15.0    -9.9    L.2..P ....... ....*.
     0    -14     -58     260    -259   -39.7    18.3    21.5    L.2..P ....... ....*.
     0     -3      -3    -294     294     5.0   -15.0     9.9    L.2..P ....... ....*.
     0     14      58    -260     259    39.7   -18.3   -21.5    L.2..T *...*.. ....*.

     0      3       3     294    -294    -5.0    15.0    -9.8    L.2..T *...*.. ....*.
     0    -14     -58     260    -259   -39.7    18.3    21.5    L.2..T *...*.. ....*.
     0      0      -3    -294     294     5.0   -15.0     9.8    L.2..T *...*.. ....*.
     0     11      58    -260     259    39.7   -18.3   -21.5    L.2..T *...*.. ....*.

     0      0       4     294    -294    -5.0    15.1    -9.8    L.2..T *...*.. ....*.
     0    -11     -59     260    -259   -39.7    18.3    21.5    L.2..T *...*.. ....*.
     0     -3      -3    -294     294     5.0   -15.1     9.8    L.2..T *...*.. ....*.
     0     14      59    -260     259    39.7   -18.3   -21.5    L.2..T *...*.. ....*.

     0      3       2     294    -294    -5.0    15.1    -9.8    L.2..T *...*.. ....*.
     0    -14     -58     260    -259   -39.7    18.3    21.5    L.2..T *...*.. ....*.
     0      0      -3    -294     294     5.0   -15.1     9.8    L.2..T *...*.. ....*.
     0     11      58    -260     259    38.7   -16.4   -22.4    L.2..T *...*.. ....*.

     0      0       3     294    -294   -12.2    15.6    -3.3    L.2..T *...*.. ....*.
     0     -8     -45     122    -120   -19.5     5.4    14.1    L.2..T *...*.. ....*.
     0      0       1    -147     145     9.7    -7.9    -1.9    ...... *...... ....*.
     0      3      16       8      -8     0.6     1.8    -2.4    ...... *...... ....*.

     0      0      -2       0       2    -0.1    -0.2     0.3    ...... *...... ....*.
     0      0       0       0      -1     0.0     0.0    -0.0    ...... *...... ....*.
     0      0       0       0       0     0.0    -0.0     0.0    ...... *...... ....*.
     0      0       0       0       0    -0.0     0.0    -0.0    ...... *...... ......

     0      0       0       0       0     0.0     0.0     0.0    ...... *...... ......
     0      0       0       0       0     0.0     0.0     0.0    ...... *...... ......
     0      0       0       0       0     0.0     0.0     0.0    ...... *...... ......
     0      0       0       0       0    -0.0    -0.0    -0.0    ...... *...... ......

     0      0       0       0       0     0.0     0.0     0.0    ...... *...... ......
     0      0       0       0       0     0.0     0.0     0.0    ...... *...... ......
     0      0       0       0       0    -0.0     0.0     0.0    ...... *...... ......
     0      0       0       0       0    -0.0     0.0    -0.0    ...... *...... ......

Event   : 2BCT   Location   : 25.60  mi 3.21   ohms sec
Duration: 7.50   Flt Current: 392.5  Shot Counter: 0

R1   =24.92    X1   =28.16     R0   =28.04     X0   =71.54     LL   =30.00
CTR  =60.00    PTR  =600.00    MTA  =48.50     LOCAT=Y
47PXD=13.80    47PXL=55.20     59N  =4.00      VCT  =10.00
LLC  =N        DLC  =Y         CVC  =Y         VSA  =Y
79OI1=40.00    79OI2=100.00    79OI3=200.00    79RS =240.00
50L  =280.00   50M  =500.00    50MFD=20.00     50H  =975.00
Z1%  =70.00    Z2%  =120.00    Z3%  =120.00    Z3DP =60.00
51PP =330.00   51PTD=4.00      51PC =4
51NP =280.00   51NTD=3.00      51NC =4         51NTC=Y        TDUR =9.00
50N1P=660.00   50N2P=335.00    50N3P=266.00    Z2DG =30.00    Z3DG =60.00
52BT =20.00    ZONE3=R         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  MRI  MRC
C0   00   00   44   00   00   00   00   C0   04
C4   00   00   44   00   00   00   00   C4   00
31   00   00   00   00   00   02   04   20   11
30   00   00   10   08   04   00   00   10   20
```

The following is the first four cycles (quarter-cycles 1 - 16) of Example Event Report 3, showing pre-fault and fault inception conditions.

		Currents (amps)				Voltages (kV)		Relays	Outputs	Inputs	
IPOL	IR	IA	IB	IC	VA	VB	VC	522655 011711 P3PNNP	TCAAAAA PL1234L	DPBD5E TTTC2T A	Quarter-Cycles
0	0	-55	9	45	-34.4	-0.7	35.1	......	....	....*.	1
0	0	23	-57	36	20.6	-40.2	19.3	......	....	....*.	2
0	0	55	-9	-45	34.4	0.7	-35.1	......	....	....*.	3
0	0	-23	57	-37	-20.6	40.2	-19.3	......	....	....*.	4
0	0	-55	9	45	-34.4	-0.7	35.1	......	....	....*.	5
0	0	23	-57	38	20.6	-40.2	19.3	......	....	....*.	6
0	0	55	-9	-45	34.4	0.7	-35.1	......	....	....*.	7
0	0	-23	57	-37	-20.6	40.2	-19.3	......	....	....*.	8
0	0	-55	9	45	-34.4	-0.7	35.1	......	....	....*.	9
0	0	23	-58	37	20.6	-40.2	19.3	......	....	....*.	10
0	0	55	-8	-46	34.3	4.8	-39.2	......	....	....*.	11
0	0	-23	70	-49	-20.6	29.2	-8.4	......	....	....*.	12
0	-5	-55	108	-71	-34.3	0.1	34.2	......	....	....*.	13
0	3	23	-233	223	20.6	-19.6	-1.2	......	....	....*.	14
0	14	55	-162	152	34.3	-9.9	-24.4	L.....	....	....*.	15
0	-5	-23	379	-379	-20.6	21.1	-0.3	L.2..P	....	....*.	16

The following outline lists observed incidents shown in Example Event Report 3 by quarter-cycle.

Quarter-Cycle	Event Report Shows:
1-14	Pre-fault conditions: • No residual current in IR column indicates balanced load currents. • No protective relay elements are picked up. • An asterisk (*) in 52A Inputs column verifies breaker closure (as does load current flow).
15	Fault Inception: • L in 50P column shows fault current reached 50L element pickup threshold.
16	• 2 in 21P column shows when Zone 2 phase-phase element picked up. • P in 51P column shows that the phase time-overcurrent element picked up.

The phase time-overcurrent element picked up in row 16 because the current in at least one phase was above the 51PP setting and the Zone 2 phase distance element was asserted.

The remaining quarter-cycles of the report show fault current flowing. During this time, the 51P element is accumulating energy, moving toward assertion of the 51PT bit.

Because no fault detecting elements were asserted in the first five event report quarter-cycles, the relay uses the Takagi Algorithm to calculate the 25.57 mile fault location.

The following is the first four cycles (quarter-cycles 1 - 16) of Example Event Report 4, showing timeout of the 51P element and assertion of the relay TRIP outputs.

	Currents (amps)				Voltages (kV)			Relays	Outputs	Inputs	
								522655	TCAAAAA	DPBD5E	
IPOL	IR	IA	IB	IC	VA	VB	VC	011711	PL1234L	TTTC2T	
								P3PNNP		A	Quarter-Cycles
0	3	3	294	-294	-4.9	15.0	-9.9	L.2..P	....	....*.	1
0	-16	-58	260	-259	-39.7	18.3	21.5	L.2..P	....	....*.	2
0	0	-3	-293	294	4.9	-15.0	9.9	L.2..P	....	....*.	3
0	16	58	-261	259	39.7	-18.3	-21.5	L.2..P	....	....*.	4
0	0	4	294	-294	-5.0	15.0	-9.9	L.2..P	....	....*.	5
0	-14	-59	261	-259	-39.7	18.3	21.5	L.2..P	....	....*.	6
0	-3	-4	-294	294	5.0	-15.0	9.9	L.2..P	....	....*.	7
0	14	59	-260	259	39.7	-18.3	-21.5	L.2..P	....	....*.	8
0	3	4	294	-294	-5.0	15.0	-9.9	L.2..P	....	....*.	9
0	-14	-59	260	-259	-39.7	18.3	21.5	L.2..P	....	....*.	10
0	-3	-4	-294	294	5.0	-15.0	9.9	L.2..P	....	....*.	11
0	14	59	-260	259	39.7	-18.3	-21.5	L.2..P	....	....*.	12
0	3	3	294	-294	-5.0	15.0	-9.9	L.2..P	....	....*.	13
0	-14	-58	260	-259	-39.7	18.3	21.5	L.2..P	....	....*.	14
0	-3	-3	-294	294	5.0	-15.0	9.9	L.2..P	....	....*.	15
0	14	58	-260	259	39.7	-18.3	-21.5	L.2..T	*...*..	....*.	16

The following outline lists observed incidents shown in Example Event Report 4 by quarter-cycle.

Quarter-Cycle	Event Report Shows:
1-15	Fault conditions: • An asterisk (*) in 52A Inputs column verifies breaker closure. • L in 50P column shows fault current reached 50L element pickup threshold. • 2 in 21P column shows when Zone 2 phase-phase element picked up. • P in 51P column shows that the phase time-overcurrent element picked up.
16	Trip assertion: • T in 51P column indicates that the phase time-overcurrent element has timed out. • An asterisk (*) in TP column indicates that the Trip outputs have asserted due to assertion of the 51PT bit. • An asterisk (*) in A3 column shows that a Reclose Initiate condition has been fulfilled, causing the RI bit to assert.

The relay tripped because the phase time-overcurrent element timed out in event report row 16. We can calculate the duration of the fault by subtracting the time tag of Event Report 3 from the time tag of Event Report 4.

Trip time = 09:12:48.125 - 09:11:54.800
Trip time = 53.325 seconds

This is the time from pickup of the 51P element to assertion of the TRIP outputs.

Quarter-cycles 17 through 28 of the report show fault current flowing before the circuit breaker operates to clear the fault.

The following is the final four cycles (quarter-cycles 29 - 44) of Example Event Report 4, showing the breaker clearing the fault.

	Currents (amps)				Voltages (kV)			Relays	Outputs	Inputs	
								522655	TCAAAAA	DPBD5E	
IPOL	IR	IA	IB	IC	VA	VB	VC	011711	PL1234L	TTTC2T	
								P3PNNP		A	Quarter-Cycles
0	0	3	294	-294	-12.2	15.6	-3.3	L.2..T	*...*..	....*.	29
0	-8	-45	122	-120	-19.5	5.4	14.1	L.2..T	*...*..	....*.	30
0	0	1	-147	145	9.7	-7.9	-1.9	......	*......	....*.	31
0	3	16	8	-8	0.6	1.8	-2.4	......	*......	....*.	32
0	0	-2	0	2	-0.1	-0.2	0.3	......	*......	....*.	33
0	0	0	0	-1	0.0	0.0	-0.0	......	*......	....*.	34
0	0	0	0	0	0.0	-0.0	0.0	......	*......	....*.	35
0	0	0	0	0	-0.0	0.0	-0.0	......	*......	......	36
0	0	0	0	0	0.0	0.0	0.0	......	*......	......	37
0	0	0	0	0	0.0	0.0	0.0	......	*......	......	38
0	0	0	0	0	0.0	0.0	0.0	......	*......	......	39
0	0	0	0	0	-0.0	-0.0	-0.0	......	*......	......	40
0	0	0	0	0	0.0	0.0	0.0	......	*......	......	41
0	0	0	0	0	0.0	0.0	0.0	......	*......	......	42
0	0	0	0	0	-0.0	0.0	0.0	......	*......	......	43
0	0	0	0	0	-0.0	0.0	-0.0	......	*......	......	44

The following outline lists observed incidents shown in Example Event Report 4, quarter-cycles 29-44.

Quarter-Cycle	Event Report Shows:
29-30	Fault clearing: • An asterisk (*) in 52A Inputs column verifies breaker closure. • L in 50P column shows fault current reached 50L element pickup threshold. • 2 in 21P column shows when Zone 2 phase-phase element picked up. • T in 51P column indicates that the phase time-overcurrent element has timed out. • An asterisk (*) in TP column indicates that the Trip outputs have asserted. • An asterisk (*) in A3 column shows that a Reclose Initiate condition has been fulfilled.
31-34	Breaker opening: • An asterisk (*) in 52A Inputs column verifies breaker closure. • An asterisk (*) in TP column indicates that the Trip outputs have asserted. • Current and voltage samples decreasing in magnitude, showing that the breaker poles are opening. Voltage drops out because the relay potentials are drawn from line-side PTs.
35-44	• An asterisk (*) in TP column indicates that the Trip outputs have asserted. They remain asserted until the TDUR timer expires (9.00 cycle setting), the fault condition vanishes, and current drops below the 50L and 50NL element pickup levels.

Because fault detecting elements were asserted in the first five event report quarter-cycles, the relay uses the Reactance Method to calculate the 25.60 mile fault location.

Switch-onto-Fault Event

Example Event Report 5 was triggered in response to a simulated line test into a bolted three-phase fault immediately in front of the relay location. Because the relay voltage inputs are drawn from line-side potential transformers, no polarizing potential is available for the relay distance elements before or during the fault. The relay trips due to assertion of the 50H element enabled to trip through the MTO logic mask.

The full event report is shown on the following page. The following is the first four cycles (quarter-cycles 1 - 16) of Example Event Report 5, showing pre-fault and fault inception conditions.

```
                 Currents                        Voltages       Relays Outputs Inputs
                  (amps)                           (kV)
                                                                522655 TCAAAAA DPBD5E
 IPOL     IR      IA      IB      IC     VA      VB      VC     011711 PL1234L TTTC2T
                                                                P3PNNP              A       Quarter-Cycles

  0       0       0       0      -1     0.0    -0.0    -0.0     ...... ..*.... ......              1
  0       0       0       0       1     0.0     0.0     0.0     ...... ..*.... ......              2
  0       0       0       0       0     0.0     0.0     0.0     ...... ..*.... ......              3
  0       0       0       0       0     0.0    -0.0     0.0     ...... ..*.... ......              4

  0       0       0       0       0     0.0    -0.0    -0.0     ...... ..*.... ......              5
  0       0       0       0       0     0.0     0.0     0.0     ...... ..*.... ......              6
  0       0       0       0       0     0.0     0.0     0.0     ...... ..*.... ......              7
  0       0       0       0       0     0.0     0.0    -0.0     ...... ..*.... ......              8

  0       0       0       0       0    -0.0    -0.0    -0.0     ...... ..*.... ......              9
  0       0       0       0       0     0.0     0.0     0.0     ...... ..*.... ......             10
  0       0       0       0       0     0.0     0.0     0.0     ...... ..*.... ......             11
  0       0      -1       0       0     0.0    -0.0     0.0     ...... ..*.... ......             12

  0       0      69      34    -102    -0.0    -0.0    -0.0     ...... ..*.... ......             13
  0       0    -275     423    -146     0.0     0.0     0.0     L..... ..*.... ......             14
  0       3    -253    -507     762     0.0     0.0     0.0     L..... ..*.... ......             15
  0      -3     913    -866     -51     0.0     0.0    -0.0     H..... *.*..*. ......             16
```

The following outline lists observed incidents shown in the first four cycles of Example Event Report 5 by quarter-cycle.

Quarter-Cycle	Event Report Shows:
1-13	Pre-fault conditions: • No current flowing and no voltage indicates that the breaker is open. • No protective relay elements are picked up. • No asterisk (*) in 52A Inputs column verifies that the breaker is open. • An asterisk (*) in the A1 column indicates that the 52BT bit is asserted, enabling elements set in the MTO logic mask for tripping.
14-15	Fault Inception: • L in 50P column shows fault current reached 50L element pickup threshold. • Because the fault is bolted and PTs are on the line side of the breaker, voltages are not measured during this fault.
16	• H in 50P column shows fault current reached 50H element pickup threshold. • An asterisk (*) in the TP output column indicates that the relay asserted the TRIP output in response to assertion of the 50H element while MTO tripping is enabled. • An asterisk (*) in the A4 output column indicates that a Reclose Cancel condition has asserted. In this case, 50H element assertion cancels reclosing.

Example Event Report 5

```
Bus B, 69 kV, Line 2                        Date: 1/1/92     Time: 09:38:40.554
FID=SEL-121C-R401-V656mptrs2-D920102-E2

                  Currents                       Voltages         Relays Outputs Inputs
                  (amps)                          (kV)
                                                                  522655 TCAAAAA DPBD5E
  IPOL      IR      IA      IB      IC      VA      VB      VC    011711 PL1234L TTTC2T
                                                                  P3PNNP              A

     0       0       0       0      -1     0.0    -0.0    -0.0    ...... ..*.... ......
     0       0       0       0       1     0.0     0.0     0.0    ...... ..*.... ......
     0       0       0       0       0     0.0     0.0     0.0    ...... ..*.... ......
     0       0       0       0       0     0.0    -0.0     0.0    ...... ..*.... ......

     0       0       0       0       0     0.0    -0.0    -0.0    ...... ..*.... ......
     0       0       0       0       0     0.0     0.0     0.0    ...... ..*.... ......
     0       0       0       0       0     0.0     0.0     0.0    ...... ..*.... ......
     0       0       0       0       0     0.0     0.0    -0.0    ...... ..*.... ......

     0       0       0       0       0    -0.0    -0.0    -0.0    ...... ..*.... ......
     0       0       0       0       0     0.0     0.0     0.0    ...... ..*.... ......
     0       0       0       0       0     0.0     0.0     0.0    ...... ..*.... ......
     0       0      -1       0       0     0.0    -0.0     0.0    ...... ..*.... ......

     0       0      69      34    -102    -0.0    -0.0    -0.0    ...... ..*.... ......
     0       0    -275     423    -146     0.0     0.0     0.0    L..... ..*.... ......
     0       3    -253    -507     762     0.0     0.0     0.0    L..... ..*.... ......
     0      -3     913    -866     -51     0.0     0.0    -0.0    H..... *.*..*. ......

     0      -3     328     947   -1279     0.0    -0.0    -0.0    H..... *.*..*. ....*.
     0       3   -1270     888     389     0.0     0.0     0.0    H..... *.*..*. ....*.
     0       3    -286    -949    1240     0.0     0.0     0.0    H..... *.*..*. ....*.
     0      -3    1266    -888    -385     0.0    -0.0     0.0    H..... *.*..*. ....*.

     0      -3     286     949   -1241    -0.0    -0.0    -0.0    H..... *.*..*. ....*.
     0       5   -1266     888     387     0.0     0.0     0.0    H..... *.*..*. ....*.
     0       0    -286    -949    1240     0.0     0.0     0.0    H..... *.*..*. ....*.
     0      -5    1266    -887    -387    -0.0    -0.0    -0.0    H..... *.*..*. ....*.

     0       0     285     950   -1240     0.0    -0.0    -0.0    H..... *.*..*. ....*.
     0       3   -1265     886     387     0.0     0.0     0.0    H..... *.*..*. ....*.
     0       3    -285    -950    1240     0.0     0.0     0.0    H..... *.*..*. ....*.
     0      -3    1265    -886    -387     0.0     0.0     0.0    H..... *.*..*. ....*.

     0      -3     215     916   -1136    -0.0    -0.0    -0.0    H..... *.*..*. ....*.
     0       3    -988     463     531     0.0     0.0     0.0    H..... *.*..*. ....*.
     0       0     -32    -443     478     0.0     0.0     0.0    H..... *.*..*. ....*.
     0       0     352     -21    -334     0.0    -0.0    -0.0    L..... *.*.... ....*.

     0       0     -41       2      38    -0.0    -0.0    -0.0    L..... *.*.... ....*.
     0       0       4       0      -4     0.0     0.0     0.0    ...... *.*.... ....*.
     0       0       1       0       1     0.0     0.0     0.0    ...... *.*.... ....*.
     0       0      -1       0       0     0.0     0.0    -0.0    ...... *.*.... ......

     0       0      -1       0       0    -0.0    -0.0    -0.0    ...... *.*.... ......
     0       0       1       0       0     0.0     0.0     0.0    ...... *.*.... ......
     0       0       1       1       0     0.0     0.0     0.0    ...... *.*.... ......
     0       0      -1      -1       0     0.0    -0.0     0.0    ...... *.*.... ......

     0       0      -1      -1       0     0.0    -0.0    -0.0    ...... *.*.... ......
     0       0       1       1       0     0.0     0.0     0.0    ...... *.*.... ......
     0       0       1       0       1     0.0     0.0     0.0    ...... *.*.... ......
     0       0      -1       0      -1    -0.0     0.0     0.0    ...... *.*.... ......

Event   : HABC   Location   : -0.00  mi  -0.00  ohms sec
Duration: 4.00   Flt Current: 1299.5 Shot Counter: 0

R1   =24.92    X1   =28.16    R0   =28.04    X0   =71.54    LL   =30.00
CTR  =60.00    PTR  =600.00   MTA  =48.50    LOCAT=Y
47PXD=13.80    47PXL=55.20    59N  =4.00     VCT  =10.00
LLC  =N        DLC  =Y        CVC  =Y        VSA  =Y
79OI1=40.00    79OI2=100.00   79OI3=200.00   79RS =240.00
50L  =280.00   50M  =500.00   50MFD=20.00    50H  =975.00
Z1%  =70.00    Z2%  =120.00   Z3%  =120.00   Z3DP =60.00
51PP =330.00   51PTD=4.00     51PC =4
51NP =280.00   51NTD=3.00     51NC =4        51NTC=Y        TDUR =9.00
50N1P=660.00   50N2P=335.00   50N3P=266.00   Z2DG =30.00    Z3DG =60.00
52BT =20.00    ZONE3=R        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  MRI  MRC
C0   00   00   44   00   00   00   00   C0   04
C4   00   00   44   00   00   00   00   C4   00
31   00   00   00   00   00   02   04   20   11
30   00   00   10   08   04   00   00   10   20
```

The following outline lists observed incidents shown in cycles five through nine of Example Event Report 5 by quarter-cycle.

```
                 Currents                       Voltages        Relays Outputs Inputs
                  (amps)                          (kV)
                                                                522655 TCAAAAA DPBD5E
IPOL     IR      IA      IB      IC      VA      VB      VC     011711 PL1234L TTTC2T
                                                                P3PNNP              A      Quarter-Cycles

   0     -3     328     947   -1279     0.0    -0.0    -0.0     H..... *.*..*. ....*.            17
   0      3   -1270     888     389     0.0     0.0     0.0     H..... *.*..*. ....*.            18
   0      3    -286    -949    1240     0.0     0.0     0.0     H..... *.*..*. ....*.            19
   0     -3    1266    -888    -385     0.0    -0.0     0.0     H..... *.*..*. ....*.            20

   0     -3     286     949   -1241    -0.0    -0.0    -0.0     H..... *.*..*. ....*.            21
   0      5   -1266     888     387     0.0     0.0     0.0     H..... *.*..*. ....*.            22
   0      0    -286    -949    1240     0.0     0.0     0.0     H..... *.*..*. ....*.            23
   0     -5    1266    -887    -387    -0.0    -0.0    -0.0     H..... *.*..*. ....*.            24

   0      0     285     950   -1240     0.0    -0.0    -0.0     H..... *.*..*. ....*.            25
   0      3   -1265     886     387     0.0     0.0     0.0     H..... *.*..*. ....*.            26
   0      3    -285    -950    1240     0.0     0.0     0.0     H..... *.*..*. ....*.            27
   0     -3    1265    -886    -387     0.0     0.0     0.0     H..... *.*..*. ....*.            28

   0     -3     215     916   -1136    -0.0    -0.0    -0.0     H..... *.*..*. ....*.            29
   0      3    -988     463     531     0.0     0.0     0.0     H..... *.*..*. ....*.            30
   0      0     -32    -443     478     0.0     0.0     0.0     H..... *.*..*. ....*.            31
   0      0     352     -21    -334     0.0    -0.0    -0.0     L..... *.*.... ....*.            32

   0      0     -41       2      38    -0.0    -0.0    -0.0     L..... *.*.... ....*.            33
   0      0       4       0      -4     0.0     0.0     0.0     ...... *.*.... ....*.            34
   0      0       1       0       1     0.0     0.0     0.0     ...... *.*.... ....*.            35
   0      0      -1       0       0     0.0     0.0    -0.0     ...... *.*.... ......            36
```

Quarter-Cycle	Event Report Shows:
17-31	Fault conditions: • An asterisk (*) in 52A Inputs column verifies breaker closure. • An asterisk (*) in TP column indicates that the Trip outputs are asserted. • An asterisk (*) in the A1 column indicates that the 52BT bit is asserted. • H in 50P column shows fault current is above the 50H element pickup threshold.
32-33	Fault clearing: • L in 50P column indicates that the 50H element has dropped out, but 50L is still asserted. • An asterisk (*) in TP column indicates that the Trip outputs are asserted.
34-36	• An asterisk (*) in 52A input column deasserts, showing that the breaker auxiliary contact opened. • Current samples go to zero, indicating that the breaker opened. • An asterisk (*) in the A1 column indicates that the 52BT bit is asserted. • An asterisk (*) in TP Outputs column shows that trip is still asserted. The 9.0 cycle TDUR setting ensures that the trip contacts remain closed for at least nine cycles.

Event type shown is HABC. The H indication is due to assertion of only the 50H element at the instant the TRIP output was asserted. The three-phase fault indication is due to the presence of balanced currents during the fault. The location of a zero voltage fault is always zero miles.

FIRMWARE IDENTIFICATION

The relay provides a Firmware Identification Data (FID) string to identify the relay software version installed. The FID string is included near the top of each full length event report. The string format is as follows:

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

Where:

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

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

[VS] = Version Specifications (e.g., 656mptrc2)

[RD] = Release Date (e.g., YYMMDD=900912)

[ER] = Version Specification: EEROM

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

V[VS] = V[ABCDEFGHI]

Option	Specifier	Specifier Meaning	Option Description
A	5, 6	50 Hz, 60 Hz	Power System Frequency
B	1, 5	1 amp, 5 amps	Nominal Amps per Phase
C	1, 6	120 volts, 67 volts	Nominal Volts per Phase
D	m, k	miles, kilometers	Fault Locator Distance Units
E	p, n	positive, negative	Phase-Sequence of Power System
F	a, t	all, trip only	Zones Reported on Target LEDs
G	c, r	cumulative, recent	Target LED Update Logic
H	s, c	std., cancel shot	Recloser Logic
I	1, 2	Rev.1, Rev. 4	Main Board Configuration

EEROM version specifications are interpreted as follows:

E[ER] = E[Z]

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

Please contact Schweitzer Engineering Laboratories, Inc. for more information concerning available versions of the relay. Version specifications provided above are not intended for ordering purposes but to help users identify software installed in a relay.

APPLICATIONS
TABLE OF CONTENTS

Relay Application Overview 5-1
  Coordinate Phase Protection with Downstream Devices 5-1
  Time-Step Relaying 5-1
  Backup Relaying 5-1
  Schemes Involving Communications 5-2
  Replacement of Outdated Protective Relays 5-2
  Other Applications 5-2
69 kV Setting Example 5-2
  Purpose 5-2
  System Data 5-3
  Protection Scheme Overview 5-3
    Coordination at Breaker 3 5-3
    Coordination at Breaker 4 5-4
  Relay Settings 5-4
    Identifier 5-5
    R1, X1, R0, X0, and Line Length (LL) 5-5
    Current and Potential Transformer Ratio Selection 5-6
    Maximum Torque Angle (MTA) 5-7
    Fault Locator Enable (LOCAT) 5-8
    Reclosing Relay Voltage Supervision Settings (47PXD, 47PXL, 59N) 5-8
    Reclosing Relay Voltage Condition Time Delay (VCT) 5-9
    Reclosing Relay Voltage Condition Checking Settings (LLC, DLC, CVC, and VSA) . 5-10
    Reclosing Open Intervals and Reset Time (79OI1, 79OI2, 79OI3, and 79RS) 5-11
    Low-Set Phase Overcurrent Setting (50L) 5-12
    Medium-Set Phase Overcurrent Setting (50M) 5-13
    High-Set Phase Overcurrent Setting 5-14
    Zone 1 Reach Setting (Z1%) 5-15
    Zone 2 Reach Setting (Z2%) 5-16
    Zone 3 Reach Setting (Z3%) 5-18
    Zone 3 Phase Time Delay (Z3DP) 5-19
    Phase Time-Overcurrent Settings (51PP, 51PC, 51PTD) 5-20
    Residual Time-Overcurrent Settings (51NP, 51NC, 51NTD, 51NTC) 5-21
    Trip Duration Timer (TDUR) 5-22
    50N1P Residual Overcurrent Setting (50N1P) 5-22
    50N2P Residual Overcurrent Setting (50N2P) 5-23
    50N3P Residual Overcurrent Setting (50N3P) 5-24
    Zone 2 Residual Overcurrent Time Delay (Z2DG) 5-25
    Zone 3 Residual Overcurrent Time Delay (Z3DG) 5-25
    52BT Setting (52BT) and Switch-Onto-Fault Protection 5-26
    Zone 3 Direction Setting 5-28
    Residual Overcurrent Polarization Method Selection (32QE, 32VE, 32IE) 5-28
      Negative-Sequence Polarization 5-28
      Zero-Sequence Voltage Polarization 5-28
      Zero-Sequence Current Polarization 5-29

Loss-of-Potential (LOP) Enable Setting, (LOPE) . . . 5-29
Serial Port(s) Timeout Settings (TIME1, TIME2) . . . 5-30
Autoport Designation Setting (AUTO) . . . 5-31
Modem Answer Ring Setting (RINGS) . . . 5-31
Full Example Setting Group . . . 5-31
Programmable Output Contact Mask Settings . . . 5-32
Communication Scheme Use of Logic Masks . . . 5-32
MTU: Mask for Trip Unconditional . . . 5-33
Mask for Trip Unconditional (MTU) . . . 5-33
MPT: Mask for Trip with Permissive Trip Input Asserted . . . 5-34
Mask for Permissive Trip (MPT) . . . 5-34
MTB: Mask for Trip with Block Trip Input Deasserted . . . 5-34
Mask for Trip Block (MTB) . . . 5-35
MTO: Mask for Trip with the 52BT Element Asserted . . . 5-35
Mask for Trip Breaker Open (MTO) . . . 5-35
MA1, MA2, MA3, and MA4 Programmable Output Contact Masks . . . 5-36
Mask for the A1 Output Contact (MA1) . . . 5-36
Mask for the A2 Output Contact (MA2) . . . 5-36
Mask for the A3 Output Contact (MA3) . . . 5-37
Mask for the A4 Output Contact (MA4) . . . 5-37
MRI: Mask for Reclose Initiation . . . 5-37
Mask for Reclose Initiation (MRI) . . . 5-37
MRC: Mask for Reclose Cancellation . . . 5-38
Mask for Reclose Cancel (MRC) . . . 5-38
Relay Word Bits Intended for Relay Testing . . . 5-38
Reclosing Relay Operation Examples . . . 5-38
Overview . . . 5-38
Example 1: DLC = N, LLC = N, Two Shot Reclose Sequence . . . 5-39
Example 2: DLC = N, LLC = N, Reclosing Cancelled Due to RC Assertion . . . 5-41
Example 3: DLC = Y, LLC = N, Dead-line Supervised Reclose Sequence . . . 5-42
Example 4: DLC = Y, LLC = N, Reclosing Sequence Cancelled Due to VCT Expiration 5-44
Example 5: DLC = N, LLC = Y, Live-line Supervised Reclose Sequence . . . 5-45
Example 6: DLC = N, LLC = Y, Second Shot Cancelled Due to CVC Failure . . . 5-47
Settings Sheet . . . 5-49

TABLES

Table 5.1: Settings for: Bus B, 69 kV, Line 2 . . . 5-32
Table 5.2: Reclosing Relay Timing Examples . . . 5-39
Table 5.3: Recloser Settings for Examples 1 and 2 . . . 5-40
Table 5.4: Recloser Settings for Examples 3 and 4 . . . 5-42
Table 5.5: Recloser Settings for Examples 5 and 6 . . . 5-45

FIGURES

Figure 5.1: 69 kV Setting Example System Single-Line Diagram 5-3
Figure 5.2: 52A Input and 52BT Timing Diagram 5-26
Figure 5.3: Faulted Line with All Sources In 5-27
Figure 5.4: DLC = N, LLC = N, Two Shot Reclose Sequence 5-40
Figure 5.5: DLC = N, LLC = N, Reclosing Cancelled Due to RC Assertion 5-42
Figure 5.6: DLC = Y, LLC = N, Dead-line Supervised Reclose Sequence 5-43
Figure 5.7: DLC = Y, LLC = N, Reclosing Sequence Cancelled Due to VCT Expiration . . 5-44
Figure 5.8: DLC = N, LLC = Y, Live-line Supervised Reclose Sequence 5-46
Figure 5.9: DLC = N, LLC = Y, Second Shot Cancelled Due to CVC Failure 5-47

APPLICATIONS

RELAY APPLICATION OVERVIEW

Coordinate Phase Protection with Downstream Devices

The SEL-221C Relay is ideal when line protection must coordinate with downstream apparatus, taps, or buses equipped with time-current protection for phase and ground faults while offering high-speed phase protection over as much of the line as possible.

The relay includes instantaneous and definite-time phase distance protection. Close-in phase faults can be cleared with no intentional time delay using an instantaneous Zone 1 phase-distance element. Use the 51P phase time-overcurrent element to clear phase faults beyond the reach of the Zone 1 distance element.

The 51P element has four selectable curve shapes and a wide time dial setting range to simplify coordination with downstream relays, fuses, or line reclosers. The phase time-overcurrent element is torque-controlled by the Zone 2 phase distance element. You can set the Zone 2 distance element reach to prevent the 51P element from overreaching the downstream protection while using a low 51P pickup setting. The scheme is selective, secure, and sensitive. It is also compact and easy to apply, test, and maintain because the SEL-221C Relay includes all necessary elements and timers.

Time-Step Relaying

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

Backup Relaying

Where adequate high-speed primary protection already exists, the SEL-221C Relay can be applied as backup protection. Its programmability and remote-access capabilities allow remote adjustment of relay settings to meet virtually any contingency.

Its application also offers the benefits of event reporting and fault locating.

Schemes Involving Communications

Although the SEL-221C Relay was designed for applications at subtransmission voltages where communications are not usually applied, the relay supports direct and permissive underreaching transfer tripping, permissive overreaching transfer tripping, and blocking schemes. Since the event report shows the voltages, currents, relay elements, inputs and outputs, it is easy to evaluate scheme performance.

Replacement of Outdated Protective Relays

The relay is an ideal replacement for aging or obsolete electromechanical relays. If protective relays are to be upgraded at one terminal only, it is important that relays have measuring principles compatible with surrounding terminals. The relay meets this requirement by using compensator distance measuring principles for phase distance elements. It also includes residual instantaneous and time-overcurrent elements. The residual time-overcurrent element curve shape is selectable from four curve families to permit the best possible coordination with residual time-overcurrent protection at other line terminals. The relay also provides four means of polarizing the residual overcurrent elements to match the polarizing method with the rest of the system.

Compact size and simple field wiring make replacing electromechanical relays with this relay especially convenient in crowded substations. Both horizontal and vertical mounting configurations are available.

Event reporting and fault locating features economically provide valuable engineering and operating information, eliminating the need for event recorders and oscillographs in most applications. A negligible instrument transformer burden makes the relay an attractive alternative for overburdened current and potential transformers.

Other Applications

The SEL-221C Relay is cost-effective in applications requiring fault locating, temporary installations, bus-tie breaker relaying (where frequent setting changes may be required), and remote control and monitoring.

69 kV SETTING EXAMPLE

Purpose

This example shows the steps for setting the relay at Breaker 3 to protect Line 2 in Figure 5.1 and includes comments on settings for the relay at Breaker 4. System impedance data appears in following table.

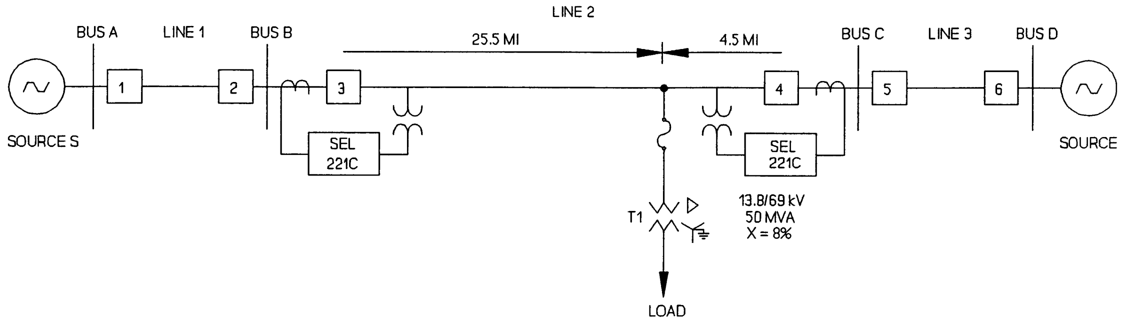


Figure 5.1: 69 kV Setting Example System Single-Line Diagram

System Data

Nominal System Voltage	: 69 kV (39.8 kV line-neutral)	
Line Length	: 30 miles	
Line Impedances:		
Positive-sequence	: Z1 = 37.60 ∠48.5°	(primary Ω)
	= 24.92 + j28.16	(primary Ω)
Zero-sequence	: Z0 = 76.84 ∠68.6°	(primary Ω)
	= 28.04 + j71.54	(primary Ω)
Source Impedances:		
Source S = Source R	: Z1S = Z1R = 15.04 ∠48.5°	(primary Ω)
	: Z0S = Z0R = 3 x Z1S	
Current Transformer Ratio	: 300:5 (60:1)	
Potential Transformer Ratio	: 600:1	

Protection Scheme Overview

The line section under consideration is the section from Bus B to Bus C. The relays at Breakers 3 and 4 are the primary protection for faults on the line. The tap fuse should operate to clear high-side transformer faults and act as backup for faults on the 13.8 kV distribution line(s).

Coordination at Breaker 3

As shown in Figure 5.1, the load tap is 25.5 miles from Breaker 3. Phase and ground faults between Breaker 3 and the load tap should be cleared using instantaneous elements. The instantaneous elements should not reach beyond the tap fuse when Line 3 is out.

End section phase faults on Line 2 should be cleared by the 51P phase time-overcurrent element at Breaker 3. The 51P element is torque controlled by the Zone 2 phase distance element. The Zone 2 element should be set to cover faults beyond Bus C. The 51P element must coordinate with protection at Bus C and the tap fuse. When Breaker 4 is open, the Zone 2 element reaches through the tap transformer onto the 13.8 kV system. For that reason, the 51P element must also coordinate with downstream load tap fuses within the Zone 2 reach when Breaker 4 is open. When Breaker 4 is closed, remote infeed reduces the effective reach of the Zone 2 phase distance element.

End section ground faults on Line 2 should be cleared by the definite-time directional ground overcurrent element, Z2GT. High-impedance end section faults should be cleared by the directional ground time-overcurrent element 51NT.

Reverse Zone 3 elements at Breaker 3 should provide backup protection for Bus B and Line 1.

Three reclosing shots are provided at Breaker 3. Dead-line voltage supervision of the reclosing shots is provided. Switch-onto-fault protection shall be provided using the 50H high-set nondirectional instantaneous overcurrent element.

Coordination at Breaker 4

A detailed study of relay settings at Breaker 4 is not provided. Some setting items are listed below, and expanded upon in the text.

The relay at Breaker 4 should operate instantaneously for faults on most of Line 2, load tap transformer faults, and some faults on the 13.8 kV system.

Time delayed directional ground overcurrent protection should coordinate with protective relays at Bus B and on the 13.8 kV system. The 51P phase-time overcurrent element should coordinate with downstream protection on the 69 kV and 13.8 kV systems.

Reverse Zone 3 elements provide time delayed bus protection and backup protection for faults on Line 3.

A single reclosing shot should be provided. Reclosing should occur after the line-test by Breaker 3. Line voltage should be above the live-line voltage setting when the open interval timer starts and at the close. This ensures that the fault has been cleared and Breaker 3 has reclosed successfully.

Relay Settings

The following information presents considerations for selecting each relay setting value. Use this information to help improve your understanding of the relay functions. Select relay settings appropriate to your applications.

Fault voltages and currents in this example were derived from a fault study of the system in Figure 5.1.

Values entered 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. The date of the last functional test may also be included for maintenance purposes.

Where an SEL-DTA is used with the relay, the identifier string is displayed on the SEL-DTA display screen. This feature helps in recognizing the associated line terminal when multiple SEL-DTA's are separated from their respective relays.

For the relay at Breaker 3:

```
ID = BUS B, 69 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)

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 to establish phase distance element reaches and calculate fault locations. Similarly, the relay uses zero-sequence impedances with positive-sequence impedances to calculate line-ground fault locations.

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 are the positive-sequence resistance and reactance for the protected transmission line section. The R0 value is transmission line zero-sequence resistance; the X0 value is transmission line zero-sequence reactance.

The relay fault locator uses the line length setting to scale the calculated fault location in terms of miles or kilometers. Set the LL setting equal to the transmission line length which corresponds to the value of positive-sequence impedance entered for R1 and X1. Typically, this is the length of the protected transmission line section.

For the relay at Breaker 3:

```
R1 = 24.92
X1 = 28.16
R0 = 28.04
X0 = 71.54
LL = 30.00
```

- Setting Limit Check

The relay allows impedance settings in the range 0 - 9999 ohms and line length settings 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 distance element reach setting of 0.125 Ω secondary or above the maximum setting limit of 32 Ω secondary for Zone 1, 128 Ω secondary for Zones 2 and 3.

- Other Settings Affected

Z1%, Z2%, Z3%

■ Current and Potential Transformer Ratio Selection

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.

Select a current transformer ratio which reduces the likelihood of CT saturation and allows the current transformer to deliver a reliable secondary representation of the primary current during a fault condition.

The potential transformer ratio (PTR) setting should be selected to match the primary voltage ratio (l-n) to approximately 67 $V_{l\text{-}n}$.

The ratio selected for this example is 300:5 or 60:1. This ratio allows 300 A of load to flow without exceeding five amperes of secondary current, while limiting the secondary current to well below 50 A for the maximum available fault duty.

```
CTR = 60.00
```

The system voltage is 69 kV line-line or 39.8 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 600:1.

$$PTR = \frac{(69\ kV)}{(115\ V)} = 600:1$$

```
PTR =  600.00
```

- 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
PTR - All voltage element pickup settings

Ratio of PTR:CTR: Z1%, Z2%, Z3%

■ 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. This extends the amount of resistive coverage provided by the mho elements. MTA selected for this example is 48.5°. Note that this value matches the positive-sequence line impedance angle of 48.5°.

```
MTA = 48.5
```

- Setting Limit Check

The primary setting range check allows MTA settings from 47° - 90°. There is no secondary check for this setting.

- Other Settings Affected

Zone 1, Zone 2, and Zone 3 distance element reach at MTA degrees if MTA does not equal the positive-sequence transmission line impedance angle.

■ Fault Locator Enable (LOCAT)

This setting allows you to enable or disable the relay fault locating function. In this example, as with most applications, fault locating is desired.

```
LOCAT = Y
```

- Setting Limit Check

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

- Other Settings Affected

None.

■ Reclosing Relay Voltage Supervision Settings (47PXD, 47PXL, 59N)

The 47PXD and 47PXL settings fix the positive-sequence line-line dead- and live-line voltage values. The 59N setting fixes the zero-sequence voltage check level.

The 47XD condition asserts when positive-sequence line-line voltage drops below the 47PXD setting, declaring the line dead for reclosing purposes. The 47XL condition asserts when positive-sequence line-line voltage rises above the 47PXL setting, declaring the line live for reclosing purposes. The 59N element measures zero-sequence voltage. If zero-sequence line-neutral voltage is above the 59N setting, the Relay Word 59N bit asserts.

The reclosing relay uses the 47XL, 47XD, and 59N bits in different ways, depending on what type of recloser voltage checking is enabled (see Section 2: SPECIFICATIONS, Reclosing Relay).

Set the 47PXL setting just below the positive-sequence live-line voltage specified by your reclosing philosophy. A setting of 50% to 80% of nominal line-line voltage should be suitable for many applications. Please note your company policies may dictate a live-line threshold different than 50-80% of nominal line-line voltage.

Set the 47PXD setting just above the positive-sequence dead-line voltage specified by your reclosing philosophy. A setting of 20% to 50% of nominal line-line voltage should be suitable for many applications.

The relay at Breaker 3 is specified to perform reclosing using dead-line voltage supervision. We select the 47PXD setting to indicate when positive-sequence line-line voltage is below 20% of the nominal line voltage. Please note that your company policies may dictate a dead-line threshold greater than 20%.

$$47PXD = (0.20)x(69\ kV) = 13.8\ kV$$

If you use dead- or live-line voltage checking in your reclosing scheme, 59N element assertion may delay or cancel one or both reclosing shots. Assertion of the 59N element may indicate that a remote terminal has not cleared (or has reclosed into) a ground fault. You may wish to delay or cancel reclosing in either event. Set the 59N element to pick up at a level below the zero-sequence voltage present at the local relay when the remote breaker is energizing a ground fault. We select a sensitive 59N setting to help prevent Breaker 3 from reclosing when Breaker 4 has not operated to clear a ground fault.

$$59N = (0.10)x(39.8\ kV) = 4.0\ kV$$

The relay at Breaker 4 is required to perform live-voltage checking during the reclosing function. The setting recommendations above would be used for the 47PXL and 59N settings.

For the relay at Breaker 3:

```
47PXD = 13.8
47PXL = 55.2
59N   =  4.0
```

- Setting Limit Check

The primary setting range check allows voltage settings from 0 - 2,000 kV primary. The 47PXD and 47PXL secondary setting range is from 0 - 129.0 $V_{l\text{-}l}$ secondary, 59N element setting range is 0 - 75 $V_{l\text{-}n}$ secondary.

$$\frac{47PXD}{PTR} = \frac{13.8\ kV}{600} = 23\ V_{l\text{-}l}\ \text{secondary}$$

$$\frac{47PXL}{PTR} = \frac{55.2\ kV}{600} = 92\ V_{l\text{-}l}\ \text{secondary}$$

$$\frac{59N}{PTR} = \frac{3.9\ kV}{600} = 6.5\ V_{l\text{-}n}\ \text{secondary}$$

- Relay Word Bits and Other Settings Affected

Relay Word bit 59N. DLC, LLC, VSA, and CVC reclosing relay settings, and the VCT reclosing relay timer, when used.

■ Reclosing Relay Voltage Condition Time Delay (VCT)

The VCT timer defines the time allowed for reclosing voltage conditions to be met before the open interval timer starts. If LLC = Y or DLC = Y and voltage conditions are not met before the VCT timer expires, the open interval timer does not start and the reclosing sequence is cancelled.

If LLC = DLC = N, the VCT timer is not used.

For this example, the relay at Breaker 3 performs reclosing supervised by dead-line voltage conditions. The VCT timer defines the time allowed to fulfill the dead-line conditions before the first reclosing shot is cancelled. VCT time should be longer than the maximum expected clearing time for all sources on the system. For Breaker 3, we select a VCT timer setting of 10.0 cycles. The DLTMR timer is only used when VC = B, thus we set DLTMR = 0.

The relay at Breaker 4 performs live-line voltage checking to start the first reclosing interval timer, 79OI1. Issue of the CLOSE signal at Breaker 4 is also supervised by the live-line conditions. After a fault, Breaker 3 closes to test the line. If the fault was not permanent or if it was cleared by the load tap fuse, the Breaker 4 relay 47XL asserts and 59N remains deasserted. The Breaker 4 79OI1 timer starts. Assuming that voltage conditions are still valid when 79OI1 expires, the Breaker 4 relay issues a CLOSE signal. If the fault was permanent, live-voltage conditions may not be fulfilled at Breaker 4, delaying the start of the 79OI1 timer.

In order to assure that Breaker 4 recloses any time Breaker 3 successfully recloses, the VCT timer setting at Breaker 4 should be longer than the total reclose sequence time at Breaker 3.

If the two sides of the system are strongly linked, Breaker 4 may be safely closed without checking synchronism at the breaker. If the two systems are not strongly linked, consider supervising the CLOSE function at Breaker 4 with an external synchronism checking relay.

For the relay at Breaker 3:

```
VCT    = 10.00
```

- Setting Limit Check

VCT timer setting has a primary range limit of 0 - 10,000 cycles. There is no secondary limit check for this setting.

- Other Settings Affected

79OI1, 79OI2, and 79OI3 timer settings.

■ Reclosing Relay Voltage Condition Checking Settings (LLC, DLC, CVC, and VSA)

Please see Section 2: SPECIFICATIONS, Reclosing Relay for a full description of the way the reclosing relay uses these settings. Several timing diagrams showing successful and unsuccessful reclosing sequences are shown at the end of Section 5.

For this example, Breaker 3 performs reclosing using dead-line voltage supervision. We select LLC = N, DLC = Y to enable this reclosing method. The line must be declared dead before the open interval timer can start.

The reclosing relay uses the Check Voltage at Close CVC setting to select whether shots are supervised by dead-line conditions at the issue of the CLOSE signal. We select CVC = Y.

With the setting VSA = Y, the relay voltage supervises all reclosing shots. Thus, the line must be dead before the relay can start each open interval timer or issue a close signal at the end of each open interval.

Breaker 4 uses a single reclosing shot. Open interval timer starting is supervised by the 47XL and 59N elements. The live-line conditions supervise CLOSE signal issue when the 79OI1 timer expires. To enable this reclosing sequence, set LLC = Y, DLC = N, CVC = Y, and VSA = Y.

For the relay at Breaker 3:

```
LLC  = N
DLC  = Y
CVC  = Y
VSA  = Y
```

- Setting Limit Check

The relay allows each of the settings, LLC, DLC, CVC, and VSA to be set Y or N. The relay does not allow LLC = DLC = Y.

- Other Settings Affected

79OI1, 79OI2, and 79OI3 open interval timers; VCT voltage condition timer.

■ Reclosing Open Intervals and Reset Time (79OI1, 79OI2, 79OI3, and 79RS)

Open interval timers control each of the reclosing shots. The recloser must coordinate with remote reclosing schemes.

For this example, the first reclose attempt at Breaker 3 is 40 cycles after the TRIP condition is gone. The second reclose open interval should be 100 cycles long. If the reclose sequence goes to a third shot, the open interval should be 200 cycles long.

Because 79RS limits the duration of CLOSE output operation, the reset time (79RS) must be at least as long as it takes the breaker to completely close. The 79RS timer also serves to block automatic reclosing for 79RS time period after an operator (or SCADA) closes the line breaker. This feature allows the local operator to retain control of the line breaker. For this example, the 79RS timer is set for 240 cycles or four seconds.

For the reclosing relay at Breaker 4, the 79OI1 timer setting should be longer than the length of the second open interval at Breaker 3, 60 cycles (in this case). This setting allows Breaker 3 to complete the reclosing sequence before Breaker 4 attempts to parallel. At Breaker 4, we select 79OI1 = 70 cycles, 79OI2 = 0 to disable the second and third reclosing shots.

For the relay at Breaker 3:

```
79OI1 =  40
79OI2 = 100
79OI3 = 200
79RS  = 240
```

- Setting Limit Check

79OI1, 79OI2, and 79OI3 have primary limit checks of 0 to 10,000 cycles. 79RS has a primary limit check of 60 to 8,000 cycles. There is no secondary limit check for 79OI1, 79OI2, 79OI3 or 79RS. For this example, each open interval and 79RS reset timer setting lies within the relay setting limits.

- Other Settings Affected

Please note that the 52BT timer should be set less than the shortest open interval timer if you need the switch-onto-fault logic enabled for each shot (see 52BT Setting for details).

■ Low-Set Phase Overcurrent Setting (50L)

The 50L element provides fault detector supervision of the phase distance elements and must pick up for all fault conditions where a phase 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. Although it is not ideal, you can set 50L below load to permit distance element operation for end-of-line faults with magnitudes below load. When 50L is below load current and a potential fuse operates, the relay LOP function may not operate quickly enough to prevent the relay from tripping upon assertion of the distance elements. When 50L is below load current and all three potential fuse operate, the relay three-phase LOP function cannot operate.

For phase-phase faults, at least one current magnitude must exceed the 50L pickup threshold before the phase-phase distance elements are allowed to 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 open until current has stopped flowing in the breaker.

For the relay at Breaker 3 in the system shown in Figure 5.1, the governing fault condition is a phase-phase fault at Bus D. The fault study revealed that the lowest phase fault current equals 465 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 465 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 280 A (approximately 60% of the minimum fault current).

```
50L = 280.00
```

- 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 = 60:1

$$\text{50L secondary amps} = \frac{280 \text{ A primary}}{60} = 4.67 \text{ A secondary}$$

The 50L setting of 280 A for this example lies within the relay setting limits.

- Relay Word Bits and Other Settings Affected

50L bit in the Relay Word and all phase distance elements: Relay Word bits 1ABC, 2ABC, 3ABC, Z1P, Z2P, and Z3P.

■ Medium-Set Phase Overcurrent Setting (50M)

The setting for the 50M pickup value requires that the element must never be picked up for load current conditions. The setting must also be below the minimum fault current level for which the relay is required to trip following an LOP condition. In this example, the application should detect a fault at Bus C after an LOP condition is detected. It is important to remember that the 50M element is nondirectional and requires a coordinating time delay setting for the 50MF bit to use in tripping. The maximum expected load for this circuit is 450 A. The minimum fault current level for a fault at Bus C is 535 A. Faults at Bus C do not drop the positive-sequence voltage at Bus B below 14 V. With a small margin for fault study and CT performance error, the 50M setting for this example is 500 A.

```
50M = 500.00
```

- Setting Limit Check

The primary limit check allows for 50M settings of 0.25 - 50,000 A. The secondary check allows for a secondary amp setting of 0.5 - 40 A.

Calculations: CTR = 60:1

$$50M \text{ secondary amps} = \frac{280 \text{ A primary}}{60} = 4.67 \text{ A secondary}$$

The 50M setting of 500 A for this example lies within the relay setting limits.

- Relay Word Bits and Other Settings Affected

50M and 50MF bits in the Relay Word.

■ High-Set Phase Overcurrent Setting

The 50H element is intended for use as a high-set nondirectional phase overcurrent detector in the switch-onto-fault logic. If a line breaker is closed into a close-in three-phase bolted fault where line-side potential transformers are used, polarizing voltage for the three-phase distance elements is never established. In this situation, the distance elements do not operate. The 50H element is provided to help prevent a failure to trip the line breaker in this instance. The 50H element measures current magnitude in each phase with no dependence on polarizing voltages. This element is nondirectional and should be used only in the switch-onto-fault logic mask (MTO) when the line breaker is closed to test the line on a radial basis. If fault duty in front of the line terminal is much greater than behind it, the 50H element can also be used in the unconditional trip logic mask (MTU) to provide rapid clearance of close-in faults.

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

The three-phase fault duty for a fault at Bus B is 1300 A. To assure rapid clearance of this fault, a 50H setting of 975 A is selected for this example.

```
50H = 975.00
```

- 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 - 40 A.

Calculations: CTR = 60:1

$$50H \text{ secondary amps} = \frac{975 \text{ A primary}}{60} = 16.25 \text{ A secondary}$$

The 50H setting of 975 A for this example lies within the setting limits of the relay.

- Relay Word Bits and Other Settings Affected

50H bit in the Relay Word.

■ Zone 1 Reach Setting (Z1%)

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

In this example, the Zone 1 phase distance element at Breaker 3 must not reach past the load tap. The tap lies at 25.5 miles from Breaker 3, and the positive-sequence line impedance between Breaker 3 and the tap accounts for 85% of the total line section impedance. Thus, to prevent overreaching due to the sources of error listed above, the required reach for the Zone 1 three-phase and phase-phase elements is 70% of the positive-sequence impedance of Line 2.

$$\text{Z1 Reach} = 0.70 \times 37.60\ \Omega \text{ primary @ } 48.5° = 26.32\ \Omega \text{ primary @ } 48.5°$$

The reach settings for the phase 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:

$$\text{Diameter} = \frac{26.32\ \Omega}{\cos(48.5° - 48.5°)}$$

$$= 26.32\ \Omega \text{ primary along the MTA}$$

The Zone 1 reach setting for the relay at Breaker 4 will not be limited by the location of the load tap. Breaker 4 may be set to operate without time delay for faults on the majority of Line 2. This setting causes the relay to trip for some faults on the load tap. This is assumed to be acceptable for this example.

For the relay at Breaker 3:

```
Z1% = 70.00
```

- 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 - 32 ohms secondary along the MTA.

Calculations: PTR = 600:1 PTR:CTR = 10
CTR = 60:1

$$\text{Secondary Ohms} = \frac{26.32\ \Omega\ \text{primary}}{10} = 2.632\ \Omega\ \text{secondary along the MTA}$$

The Z1% setting of 70 for this example lies within primary and secondary setting limits of the relay.

- Relay Word Bits and 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 phase distance element torque controls the 51P phase time-overcurrent element. These 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. The time-overcurrent function allows simple coordination with downstream time-current protection.

Use the Zone 2 element to limit the response of the 51P element. Typically, the pickup setting of the phase time-overcurrent element would be dictated by the available fault current and the pickup settings of the downstream time-current protective devices. Because the 51P element only operates when the Zone 2 phase distance element picks up, the 51P pickup may be set more sensitively without fear of overreaching and miscoordination. The 51P element must still coordinate with protective devices that fall within the Zone 2 reach.

Zone 2 elements should never extend past the Zone 1 reach of the next line terminal. This prevents race conditions between Zone 2 time delayed elements of the two line terminals. Typical settings for the Zone 2 phase distance elements are 120 - 130% of the protected line.

The Zone 2 elements must have adequate reach to detect all phase faults along Line 2, but cannot overreach the Breaker 5 Zone 1 elements for faults on Line 3. In this example, the impedances for Lines 2 and 3 are identical.

ZL for Line 2 = ZL for Line 3 = 37.60 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 phase faults on Line 2 are detectable, even with infeed from the remote terminals.

Assuming Breaker 5 Zone 1 reach is set for 80% of the line impedance of Line 3, verify that a Zone 2 reach of 115% for Breaker 3 does not overreach the Zone 1 elements at Breaker 5.

$$\text{Line 2 Impedance} + [0.8 \times \text{Line 3 Impedance}] = 37.6\ \Omega + [0.8 \times 37.6\ \Omega]$$
$$= 67.68\ \Omega \text{ primary}$$

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

$$\text{Zone 2 @ Bkr. 3} = 1.20 \times 37.6\ \Omega = 45.12\ \Omega \text{ along the line angle}$$

Since $45.12\ \Omega < 67.68\ \Omega$, the Zone 2 setting of 120% at Breaker 3 does not overreach the Zone 1 protection of Line 3. Any effect of infeed tends to increase the apparent ohms seen at Breaker 3 for faults on Line 3.

At Breaker 3, the minimum apparent impedance of faults on the 13.8 kV system occurs when Line 3 is out. From the fault study, a phase-phase fault on the low-side of transformer bank T1 has an apparent impedance of 38.00 Ω primary. This impedance is within the Zone 2 reach of the relay at Breaker 3. During reclosing sequences we expect to test the line using Breaker 3 while Breaker 4 is open. Thus the 51P element must coordinate with any time-current protection on the 13.8 kV system that is also within the Breaker 3 Zone 2 element reach while Breaker 4 is open.

At Breaker 4, in order for the Zone 2 distance element to overreach Bus B, it will reach far onto the 13.8 kV system. This increases the complexity of coordinating the 51P element at Breaker 4.

The MTA setting applies to all of the phase distance elements and is the same as the positive-sequence line angle. Calculate the diameter of the Zone 2 mho circle with the following equation:

$$\text{Diameter} = \frac{\text{Set Reach}}{\cos(\text{Angle of Z1} - \text{MTA})}$$

For this example, the Zone 2 mho circle diameter along the MTA becomes:

$$\text{Diameter} = \frac{45.12\ \Omega}{\cos(48.5° - 48.5°)}$$
$$= 45.12\ \Omega \text{ along the MTA}$$

For the relay at Breaker 3:

```
Z2% = 120.00
```

- Setting Limit Check

The primary limit check allows Zone 2 percent reach settings of 0 - 3200% with the requirement that the Zone 2 reach be equal to or greater than the Zone 1 reach. The secondary check allows secondary reach settings of 0.125 - 128 ohms secondary along the MTA.

Calculations:	PTR = 600:1	PTR:CTR = 10
	CTR = 60:1	

$$\text{Secondary Ohms} = \frac{45.12\ \Omega\ \text{primary}}{10} = 4.512\ \Omega\ \text{secondary along the MTA}$$

The Z2% setting of 120 for this example lies within the secondary setting limits of the relay.

- Relay Word Bits and 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. Because the Zone 2 element torque controls the phase time-overcurrent element, the Z2% also affects Relay Word bits 51PP and 51PT and settings 51PP, 51PTD, and 51PC.

■ Zone 3 Reach Setting (Z3%)

The Zone 3 elements can be set reverse for use as local bus backup protection or in communication-based protection schemes. If you set the Zone 3 elements forward-reaching, their time delayed outputs can serve as remote backup for faults beyond the far bus.

For the example, we use reverse looking Zone 3 elements as time delayed backup protection for faults on Line 1. Therefore, reverse looking Zone 3 elements must see faults along the entire length of Line 1. Considering this requirement, the Zone 3 elements should be set for 120% of the apparent impedance for faults at Bus A. The impedance of Line 1 equals the impedance of Line 2, thus:

```
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 forward reaching, the Zone 3 distance element reach must exceed that of Zone 2. The secondary check allows secondary reach settings of 0.125 - 128 ohms secondary along the MTA.

Calculations: PTR = 600:1 PTR:CTR = 10
CTR = 60:1

$$\text{Secondary Ohms} = \frac{43.24\ \Omega \text{ primary}}{10} = 4.324\ \Omega \text{ secondary along the MTA}$$

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

- Relay Word Bits and Other Settings Affected

The 3ABC, Z3P, and Z3PT bits in the Relay Word depend on the Z3% setting.

■ Zone 3 Phase Time Delay (Z3DP)

The Z3DP timer adds a settable delay to the instantaneous outputs of the Zone 3 phase-phase (Z3P) and three-phase (3ABC) elements. The time delayed output of the Zone 3 phase-phase and three-phase distance elements are represented by the Z3PT bit in the Relay Word. Time delayed Zone 3 elements provide time-step protection. Time delay selections must coordinate with protection at the remote terminal and local bus. You can include the time delayed output of the Zone 3 element in the Mask for Trip Unconditional (MTU).

When Zone 3 is forward-reaching, the Zone 3 phase time delay should coordinate with the Zone 2 operating time of the relay and breaker at the remote bus. This allows the remote Zone 1 and Zone 2 elements to pick up and clear the fault.

When Zone 3 is reversed, the Zone 3 time delay must coordinate with the Zone 2 protection at the local bus. A typical Zone 3 phase distance time delay setting is 60 cycles.

In the example at Breaker 3, the time selection should coordinate with the Breaker 2 Zone 2 protection to provide time-step backup protection for Line 1. 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. A Z3DP of 60 cycles lies within the relay setting limits. There is no secondary limit check for this setting.

- Relay Word Bits and Other Settings Affected

Z3PT bit in the Relay Word.

■ Phase Time-Overcurrent Settings (51PP, 51PC, 51PTD)

Consult a fault study to select the phase time-overcurrent element pickup setting. The phase time-overcurrent element provides current dependent time delayed clearance of phase faults within the Zone 2 phase distance element reach. It can serve as backup protection for remote terminals. Because the apparent impedance of phase faults varies with system switching configuration, fault location, and fault resistance, a complete fault study is necessary to determine the minimum pickup setting, appropriate time dial, and curve characteristic. Consider only downstream protective devices within the Zone 2 distance element reach for coordinating purposes.

For the relay at Breaker 3, a phase fault at Bus C dictates the sensitivity required for the phase time-overcurrent element. The phase current magnitude for this fault is 659 A primary. To allow for fault resistance, a value of 50% of 659 A is selected as the phase time-overcurrent element pickup. The pickup (51PP), time dial (51PTD), and family of curves (51PC) selections are assumed to coordinate with the downstream protective devices on the example system.

```
51PP  = 330.00
51PTD = 4.00
51PC  = 4
```

- Setting Limit Check

The primary limit check for the phase time-overcurrent element allows 51PP settings of 0.25 - 50,000 A. The secondary check allows for secondary amp settings of 1.0 - 12.0 A. The 51PC setting check allows settings of 1, 2, 3, or 4 for the family of curves. The 51PTD setting check allows settings from 0.5 to 15 in increments of 0.01.

Calculations: CTR = 60:1

$$\text{51PP secondary amps} = \frac{330 \text{ A primary}}{60} = 5.5 \text{ A secondary}$$

The 51PP, 51PTD, and 51PC settings are all within the setting limits of the relay.

- Relay Word Bits and Other Settings Affected

Relay Word bits 51PP and 51PT depend on the 51PP, 51PTD, and 51PC settings.

■ Residual Time-Overcurrent Settings (51NP, 51NC, 51NTD, 51NTC)

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

For the relay at Breaker 3, 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 560 A primary. To allow for ground fault resistance, a value of 50% of 560 A is selected as the residual time-overcurrent element pickup. The pickup (51NP), time dial (51NTD), and family of curves (51NC) selections are assumed to coordinate with the remaining residual time-overcurrent elements of the example system.

```
51NP = 280.00
51NTD= 3.00
51NC = 4
51NTC= Y
```

- Setting Limit Check

The primary limit check for the residual time-overcurrent element allows 51NP settings of 0.25 - 50,000 A. The secondary check allows for secondary amp settings of 0.25 - 6.3 A. The 51NC setting check allows settings of 1, 2, 3, or 4 for the family of curves. The 51NTD setting check allows settings from 0.5 to 15 in increments of 0.01. The 51NTC setting allows the residual time-overcurrent element to be torque controlled (Y for forward reaching directional) or non-torque controlled (N for nondirectional).

Calculations: CTR = 60:1

$$\text{51NP secondary amps} = \frac{280 \text{ A primary}}{60} = 4.67 \text{ A secondary}$$

The 51NP, 51NTD, 51NC, and 51NTC settings are all within the setting limits of the relay.

- Relay Word Bits and Other Settings Affected

The 51NP setting affects the 50N1P, 50N2P, and 50N3P pickup setting ranges. The 51NP setting dictates the sensitivity of the ground directional element when 32Q, 32V or 32I is selected. Relay Word bits 51NT and 51NP depend on the 51NP, 51NTD, 51NC and 51NTC settings.

■ Trip Duration Timer (TDUR)

The trip duration timer setting determines the minimum length of time the TRIP output contacts close when the relay trips. The TRIP output contacts close for the greater of the TDUR time or the duration of the trip condition. A typical setting for this timer is 150 msec or 9 cycles.

```
TDUR = 9.00
```

- Setting Limit Check

The primary limit check allows TDUR time delay settings of 0 - 2000 cycles. The TDUR setting of 9.00 cycles lies within the relay setting limits. There is no secondary limit check for this setting.

- Relay Word Bits and Other Settings Affected

TRIP bit in the Relay Word.

■ 50N1P Residual Overcurrent Setting (50N1P)

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

The Zone 1 residual overcurrent element is always instantaneous. If a polarization method is selected, the element is always 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. This prevents the instantaneous element from overreaching the forward bus.

The 50N1P ground instantaneous residual overcurrent element should not overreach Bus C under the maximum single line to ground fault conditions. The maximum residual current measured at Breaker 3 for a fault at Bus C equals 552 A. To ensure that the instantaneous element does not overreach Bus C, the 50N1P setting should be 120% of 552 A. This 120% factor accounts for differences between the modeled and actual system, CT ratio errors, etc.

For the relay at Breaker 3, the 50N1P element should not pick up for SLG faults between the load tap fuse and the high-side of transformer T1. Maximum single line to ground fault duty at the load tap is 590 A primary, below the 50N1P pickup setting.

```
50N1P = 660.00
```

- 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 = 60:1

$$\text{50N1P secondary amps} = \frac{\text{660 A primary}}{60} = \text{11.0 A secondary}$$

The 50N1P setting of 660 A for this example is greater than 0.5 A secondary (51NP > 3.15 A secondary) and less than 48 times the 51NP setting.

- Relay Word Bits and Other Settings Affected

67N1 bit in the Relay Word.

■ 50N2P Residual Overcurrent Setting (50N2P)

The Zone 2 residual overcurrent element is always nondirectional or 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 50N2P element should overreach Bus C under minimum duty single line to ground fault conditions. Based on fault study, the minimum residual current measured at Breaker 3 for a fault at Bus C equals 559 A with all sources in. To ensure that this element overreaches Bus C, the 50N2P setting should be 60% of 559 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 Line 3 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 = 335.00
```

- 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 = 60:1

$$50N2P \text{ secondary amps} = \frac{335 \text{ A primary}}{60} = 5.59 \text{ A secondary}$$

The 50N2P setting of 335 A for this example is greater than 0.5 A secondary (51NP > 3.15 A secondary) and less than 48 times the 51NP setting.

- Relay Word Bits and Other Settings Affected

67N2 bit in the Relay Word.

■ 50N3P Residual Overcurrent Setting (50N3P)

When the ground overcurrent elements are enabled for directional operation, the Zone 3 residual overcurrent element may be either forward or reverse looking as enabled by the ZONE3 setting. Whether Zone 3 is forward or reverse, the time delayed output of the 67N3 element can provide backup protection for local or remote buses. The pickup setting requirement for the 50N3P element depends on the direction of Zone 3.

If Zone 3 is reversed, the 67N3 element must (at a minimum) pick up for all SLG faults detected by the Breaker 2 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.

In the example, the Zone 3 elements are reversed. The 50N3P element should detect all faults sensed by the overreaching Zone 2 ground fault protection at Breaker 2 under minimum duty single line to ground fault conditions. Based on fault study, the minimum residual current measured at Breaker 3 for a fault at Bus A equals 443 A with all sources in. To assure this element overreaches Bus A, the 50N3P setting should be 60% of 443 A. This 60% factor accounts for differences between the modeled and actual system, CT ratio errors, fault resistance, etc.

```
50N3P = 266.00
```

- 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 = 60:1

$$\text{50N3P secondary amps} = \frac{\text{266 A primary}}{60} = \text{4.43 A secondary}$$

The 50N3P setting of 266 A for this example is greater than 0.5 A secondary (51NP > 3.15 A secondary) and less than 48 times the 51NP setting. Therefore, the 266 A setting for the 50N3P element lies within the secondary setting limits of the relay.

- Relay Word Bits and 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 relay setting limits. There is no secondary limit check for this setting.

- Relay Word Bits and Other Settings Affected

Z2GT bit in the Relay Word.

■ Zone 3 Residual Overcurrent Time Delay (Z3DG)

This Zone 3 timer adds a settable definite-time delay to the Zone 3 instantaneous residual overcurrent element (67N3). The timer must coordinate with the local residual overcurrent protection at Bus B to provide time delay backup protection for faults at Bus A (Zone 3 reversed for this example). For this example, a time delay of 60 cycles is selected and assumed to coordinate.

```
Z3DG = 60.00
```

- Setting Limit Check

The primary limit check allows Zone 3 time delays of 0 - 2000 cycles. The Z3DG of 60 cycles lies within the relay setting limits. There is no secondary limit check for this setting.

- Relay Word Bits and Other Settings Affected

Z3GT bit in the Relay Word.

■ 52BT Setting (52BT) and Switch-Onto-Fault Protection

The relay includes switch-onto-fault logic for use during line testing. This logic allows you to enable selected elements for a short duration after line breaker closure. Switch-onto-fault logic permits instantaneous line breaker tripping for end-of-section faults which would normally be cleared in Zone 2 time.

Switch-onto-fault protection is provided through elements selected in the MTO logic mask, typically non-time delay overreaching elements. The 52BT time delay setting dictates the interval during which these elements are enabled for tripping.

The 52BT bit is an inverted time delayed follower of the 52A input. When the 52A input changes from the asserted (breaker closed) to deasserted state (breaker open), the 52BT bit remains low for 52BT time. After the 52BT timer expires, the 52BT bit changes from logic state "0" to "1." When the breaker is closed (from an open state), 52BT remains high for 52BT time, then deasserts. While the 52BT bit is high, elements selected in the MTO logic mask are enabled to trip. Thus, for 52BT time after breaker closure, assertion of any element selected in the MTO logic mask causes the relay to close the TRIP output contacts. This logic provides Switch-Onto-Fault (SOTF) protection.

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

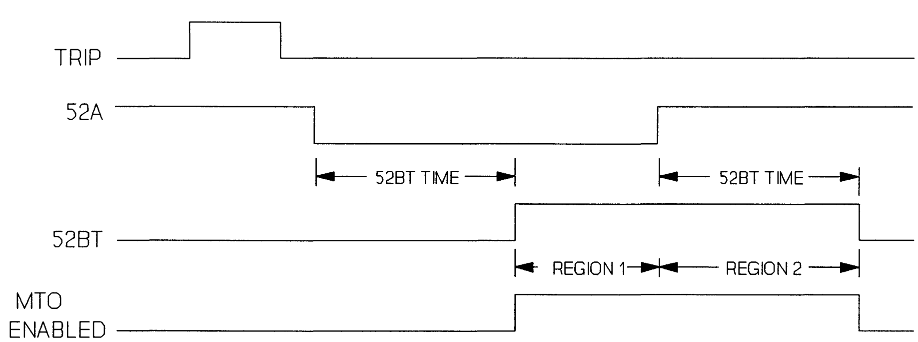


Figure 5.2: 52A Input and 52BT Timing Diagram

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

Region 2 shows the time period where MTO logic is performing true switch-onto-fault transmission line protection. The 52BT element serves as a permissive signal for elements set in the MTO mask.

For example, the circuit shown in Figure 5.3 has a phase-phase fault close to Breaker 2. Suppose that Breaker 1 is the preferred source for testing the line (Breaker 2 is to remain open until Breaker 1 energizes the line). If standard time-stepped distance protection is employed without SOTF protection, the fault would have to be cleared in Zone 2 time. Using the relay MTO logic, the instantaneous Zone 2 phase elements detect the fault and issue a trip signal without intentional time delay. This reduces the amount of time the system is exposed to the fault energy.

There is no possibility of overreaching the remote terminal with the instantaneous Zone 2 element because Breaker 2 is open while the Breaker 1 MTO logic is enabled. If the fault is not present when Breaker 1 tests the line, the MTO logic of Breaker 1 resets after 52BT time. Then Breaker 2 can synchronize and close. This emphasizes the need to limit the time during which MTO mask elements can trip the breaker. Remember: the 52BT time setting must be long enough for the sensitive elements in the MTO logic mask to assert, yet shorter than the time allowed for Breaker 2 to parallel.

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

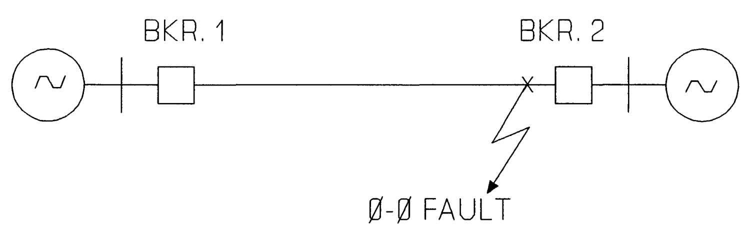


Figure 5.3: Faulted Line with All Sources In

For the relay at Breaker 3 in Figure 5.1, we expect the load tap fuse to clear transformer faults and faults on the 13.8 kV system. For that reason, we do not set the instantaneous Zone 2 elements in the MTO logic mask. However, because Breaker 3 is equipped with line-side PTs, we use the 50H element in the MTO logic mask to provide switch-onto-fault protection for close-in bolted faults.

In this example, the first reclose will occur at 40 cycles. A 52BT time of 20 cycles ensures that the 52BT element is asserted before the line breaker recloses. Switch-onto-fault protection is provided for each reclosing shot with this setting.

```
52BT = 20.00
```

- Setting Limit Check

The limit check allows 52BT time delay settings of 0.5 - 10,000 cycles. The 52BT setting of 20.00 cycles lies within the relay setting limits. There is no secondary limit check for this setting.

- Relay Word Bits and Other Settings Affected

52BT bit in the Relay Word, the lesser of 79OI1, 79OI2, and 79OI3 settings.

■ Zone 3 Direction Setting

The reverse Zone 3 elements provide time-step backup protection for Bus A.

```
ZONE3 = R
```

- Setting Limit Check

The ZONE3 setting must be set for either F (forward) or R (reverse).

- Other Settings Affected

Z2% and Z3% reach limitations.

■ Residual Overcurrent Polarization Method Selection (32QE, 32VE, 32IE)

Negative-Sequence Polarization Where strong zero-sequence mutual coupling exists between adjacent transmission lines, consider negative-sequence ground directional polarization if sufficient polarizing quantities exist. 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, consider negative-sequence again.

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

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

Zero-Sequence 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.

If no polarization method is enabled, the ground directional overcurrent elements are nondirectional.

This example uses negative-sequence polarization. For all single-line-to-ground faults, the negative-sequence polarizing volt-amperes are sufficient to polarize the ground directional element. It is assumed that the residual overcurrent protection of the surrounding system is negative-sequence polarized.

```
32QE = Y
32VE = N
32IE = N
```

- Setting Limit Check

When you select negative-sequence polarization, you cannot use zero-sequence methods. When you select zero-sequence polarization, you can use one or both of the zero-sequence voltage and current polarization methods.

- Relay Word Bits and Other Settings Affected

67N1, 67N2, 67N3, Z2GT, Z3GT, DF and DR.

■ Loss-of-Potential (LOP) Enable Setting, (LOPE)

The loss-of-potential logic detects blown potential transformer PT secondary fuse conditions. If an LOP condition is detected, the mho distance elements are blocked from operating and the ground directional element defaults forward. Loss-of-potential is enabled with the setting LOPE = Y. With LOP enabled, the 50MF bit in the Relay Word is set after the following conditions are met:

1. A loss-of-potential condition is detected
2. Current exceeds the 50M pickup
3. 50MFD timer expires (requires conditions 1 and 2 to start timing; only condition 2 is required if LOPE=N)

When LOP is not enabled, LOPE = N. The 50MFD timer is initiated when the current exceeds the 50M pickup. For this example, both LOP detection and nondirectional 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.

■ Serial Port(s) Timeout Settings (TIME1, TIME2)

The TIME1 and TIME2 settings allow their respective ports to time out after the relay detects a period of inactivity for that port. After timing out, access for the port returns to Level 0 and no automatic messages are transmitted to it. In this example, a modem is connected to Port 1. This requires a definite-time setting for the port to prevent accumulation of toll charges if an operator does not hang up. Port 2 is to be connected to an SEL-DTA and should never time out. This allows the SEL-DTA to receive any automatic message transmitted by the relay.

```
TIME1= 5   TIME2 = 0
```

- Setting Limit Check

The TIME1 and TIME2 limit check allows settings of 0 - 30 minutes. A zero setting signifies that the port never times out. There is no secondary limit check for this setting.

- Other Settings Affected

None.

■ Autoport Designation Setting (AUTO)

The AUTO setting specifies the port to which the relay directs automatically generated messages. The example has a modem connected to Port 1 and an SEL-DTA connected to Port 2. Since only the SEL-DTA is required to receive automatic messages, the AUTO setting is 2.

```
AUTO = 2
```

- Setting Limit Check

The limit check allows messages to be sent to Port 1 only, (AUTO = 1), Port 2 only (AUTO = 2), or both ports (AUTO = 3).

- Other Settings Affected

None.

■ Modem Answer Ring Setting (RINGS)

The RINGS setting specifies the number of rings a modem connected to Port 1 waits to answer. This permits use of a single substation telephone line by both substation personnel and the relay. In this example, personnel have seven rings to answer the phone before the modem answers.

```
RINGS = 7
```

- Setting Limit Check

The limit check allows for the modem to answer between 1 and 30 rings.

- Other Settings Affected

None.

■ Full Example Setting Group

The following table shows all relay settings calculated above. Please note that many of these settings differ from the settings installed in each new relay during factory testing and calibration. Factory settings were selected to simplify production tests and the initial checkout procedure.

Table 5.1: Settings for: Bus B, 69 kV, Line 2

R1 =24.92	X1 =28.16	R0 =28.04	X0 =71.54	LL =30.00
CTR =60.00	PTR =600.00	MTA =48.50	LOCAT=Y	
47PXD=13.80	47PXL=55.20	59N =4.0	VCT =10.00	
LLC =N	DLC =Y	CVC =Y	VSA =Y	
79OI1=40.00	79OI2=100.00	79OI3=200.00	79RS =240.00	
50L =280.00	50M =500.00	50MF =20.00	50H =975.00	
Z1% =70.00	Z2% =120.00	Z3% =120.00	Z3DP =60.00	
51PP =330.00	51PTD=4.00	51PC =4		
51NP =280.00	51NTD=3.00	51NC =4	51NTC=Y	TDUR =9.00
50N1P=660.00	50N2P=335.00	50N3P=266.00	Z2DG =30.00	Z3DG =60.00
52BT =20.00	ZONE3=R	32QE =Y	32VE =N	32IE =N
LOPE =Y	TIME1=5	TIME2=0	AUTO =2	RINGS=7

■ Programmable Output Contact Mask Settings

The relay uses ten separate logic masks. Four of these masks control the TRIP output contacts (MTU, MPT, MTB, and MTO). The masks labeled MA1, MA2, MA3, and MA4 control the four programmable output contacts. The masks for reclose initiation (MRI) and reclose cancel (MRC) are used as inputs for controlling the reclosing relay.

Communication Scheme Use of Logic Masks

The relay supports a wide variety of protective schemes, some of which are shown below:

- Time-Stepped distance
- Directional Comparison Blocking (DCB) schemes
- Permissive-Overreaching Transfer Trip (POTT) schemes
- Directional Comparison Unblocking (DCUB) schemes
- Direct Underreaching Transfer Trip (DUTT) schemes
- Permissive Underreaching Transfer Trip (PUTT) schemes
- Direct Transfer Trip (DTT) schemes

The Relay Word and programmable masks provide great flexibility in applying the relay without rewiring panels or changing jumpers on circuit boards.

Operating the relay in each of the various schemes involves three simple steps: 1) connecting the communications equipment to the appropriate rear panel logic input (DT, PT, or BT), 2) selecting the appropriate mask and bits for the tripping scheme (MTU, MPT, MTB, or MTO), and 3) depending on which scheme is selected, determining the number of programmable output contacts required to interface with the communications equipment. Each mask is independent from the other masks. This allows multiple schemes to function simultaneously.

The following guideline shows typical usage of bits in each mask.

Please note that each application requires a careful study of bits used in each mask. This guideline is included as a reference of typical Relay Word bit uses.

MTU: Mask for Trip Unconditional

Elements selected in this mask do not require that external conditions be met to initiate a trip. If an element masked in the MTU logic mask picks up, the TRIP output contacts close. You must be certain that elements used in this mask coordinate with other system protective devices. Unless your application permits, it is not advisable to set nondirectional overcurrent elements in the MTU logic mask.

Typical bits masked in the MTU logic mask include Zone 1 instantaneous elements (1ABC, Z1P, and 67N1) if they underreach the remote terminal, the phase and ground time-overcurrent elements (51PT and 51NT), time delayed Zone 2 ground directional overcurrent element (Z2GT), time delayed Zone 3 elements (Z3PT and Z3GT), the TC bit to close TRIP output contacts upon OPEN command execution, and the Direct Trip (DT) bit if an external tripping source energizes the DT input. The external tripping source is often a backup protective relay, breaker failure relaying, or a direct trip signal from communications equipment. In each example listed (except breaker failure), energizing the DT input allows you to utilize the reclosing functions by forcing the relay to trip.

Note: Never mask the TRIP bit into the MTU logic mask. This causes an undesirable seal-in of TRIP output contacts.

■ **Mask for Trip Unconditional (MTU)**

								Event Report Hexadecimal Code
51PT	1ABC	2ABC	3ABC	51PP	50H	50L	LOP	
1	1	0	0	0	0	0	0	C0
51NT	67N1	67N2	67N3	51NP	Z1P	Z2P	Z3P	
1	1	0	0	0	1	0	0	C4
DF	DR	Z2GT	Z3GT	50MF	RC	RI	Z3PT	
0	0	1	1	0	0	0	1	31
50M	TRIP	TC	DT	52BT	59N			
0	0	1	1	0	0	0	0	30

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), 51P element (51PT) timeout, 51N element (51NT) timeout, Zone 3 phase distance (Z3DP) timeout, residual overcurrent element (Z2DG and Z3DG) timeout, the OPEN command (TC ≡ Trip Command), and Direct Trip input (DT) assertion.

Where primary and secondary protection trip output contacts are routed to separate trip coils of the line breaker, you can cross trip the relays by routing the trip output of each set of protection to trip the other. When you need to cross trip the SEL-221C Relay, route the trip output from the secondary line protection relays to the DT input.

MPT: Mask for Trip with Permissive Trip Input Asserted

The relay closes the TRIP output when the Permissive Trip (PT) input is asserted and elements selected in the MPT mask pick up. PT input assertion is an external qualifying condition. As with the MTU logic mask, it is not advisable to mask nondirectional elements in the MPT logic mask unless your application permits.

Typical bits masked in the MPT logic mask include Zone 2 instantaneous elements (2ABC, Z2P, and 67N2).

Note: Never mask the TRIP bit into the MPT logic mask. This causes an undesirable seal-in of TRIP output contacts during PT input assertion.

■ **Mask for Permissive Trip (MPT)**

								Event Report Hexadecimal Code
51PT	1ABC	2ABC	3ABC	51PP	50H	50L	LOP	
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
DF	DR	Z2GT	Z3GT	50MF	RC	RI	Z3PT	
0	0	0	0	0	0	0	0	00
50M	TRIP	TC	DT	52BT	59N			
0	0	0	0	0	0	0	0	00

The example mask for permissive tripping contains all zeros because the relay is not being used in a permissive overreaching transfer tripping scheme.

MTB: Mask for Trip with Block Trip Input Deasserted

The relay closes the TRIP output when the Block Trip (BT) input is not asserted and elements selected in this mask pick up. BT input assertion serves as an external qualifying condition. As with the MTU logic mask, it is not advisable to mask nondirectional elements in the MTB logic mask unless your application permits.

Typical bits masked in the MTB logic mask include Zone 2 instantaneous elements (2ABC, Z2P, and 67N2).

Note: Never mask the TRIP bit into the MTB logic mask. This causes an undesirable seal-in of the TRIP output contacts when the BT input is not asserted.

■ **Mask for Trip Block (MTB)**

								Event Report Hexadecimal Code
51PT	1ABC	2ABC	3ABC	51PP	50H	50L	LOP	
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
DF	DR	Z2GT	Z3GT	50MF	RC	RI	Z3PT	
0	0	0	0	0	0	0	0	00
50M	TRIP	TC	DT	52BT	59N			
0	0	0	0	0	0	0	0	00

The example mask for block tripping contains all zeros because the relay is not being used in a directional comparison blocking scheme.

MTO: Mask for Trip with the 52BT Element Asserted

The relay closes the TRIP output when the 52BT bit is asserted and elements selected in this mask pick up. The 52BT bit is a time delayed, inverted follower of the 52A input (see switch-onto-fault logic explanation for a detailed timing explanation of the 52BT bit). This tripping mask differs from the MTU, MPT, and MTB tripping masks because it is acceptable to mask sensitive nondirectional elements into MTO in certain applications. Such masking is advisable except in applications where the line breaker is closed into a line energized from the remote terminal (i.e., synchronized closures).

Typical bits set in the MTO logic mask include Zone 1 instantaneous elements (1ABC, Z1P, and 67N1), the nondirectional high-set element (50H), Zone 2 instantaneous elements (2ABC, Z2P, and 67N2), and the Direct Trip (DT) bit if an external tripping source energizes the DT input of the relay.

For example Breaker 3 in Figure 5.1, the instantaneous Zone 2 elements are not set in the MTO logic mask for reasons discussed above.

Note: Never mask the TRIP or 52BT bits into the MTO logic mask. This causes an undesirable seal-in of TRIP output contacts when the 52BT bit is asserted.

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

								Event Report Hexadecimal Code
51PT	1ABC	2ABC	3ABC	51PP	50H	50L	LOP	
0	1	0	0	0	1	0	0	44
51NT	67N1	67N2	67N3	51NP	Z1P	Z2P	Z3P	
0	1	0	0	0	1	0	0	44
DF	DR	Z2GT	Z3GT	50MF	RC	RI	Z3PT	
0	0	0	0	0	0	0	0	00
50M	TRIP	TC	DT	52BT	59N			
0	0	0	1	0	0	0	0	10

Zone 2 instantaneous elements are not enabled in this example. This prevents the relay from tripping for faults beyond the tap fuse on line test.

MA1, MA2, MA3, and MA4 Programmable Output Contact Masks

Any element listed in the Relay Word may be masked into these programmable output contacts. Guidelines to follow when masking elements into each mask depends on equipment connected to the contact outputs. If external equipment is not connected to the contact outputs, you may set elements in these masks to enhance event report analysis. For example, masking the DF bit (ground overcurrent direction forward declaration) into one of the programmable output contacts informs you when the relay declares a ground fault to be in the forward direction.

For commissioning purposes, you may mask the TC bit into an individual output contact and use the OPEN command to verify contact closure.

■ **Mask for the A1 Output Contact (MA1)**

								Event Report Hexadecimal Code
51PT	1ABC	2ABC	3ABC	51PP	50H	50L	LOP	
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
DF	DR	Z2GT	Z3GT	50MF	RC	RI	Z3PT	
0	0	0	0	0	0	0	0	00
50M	TRIP	TC	DT	52BT	59N			
0	0	0	0	1	0	0	0	08

For the example, the A1 output contact closes when the 52BT bit asserts. Examination of event reports following a reclosing sequence will show whether the 52BT bit was asserted when the relay tripped, indicating whether the trip could have been initiated by the relay switch-onto-fault protection.

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

								Event Report Hexadecimal Code
51PT	1ABC	2ABC	3ABC	51PP	50H	50L	LOP	
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
DF	DR	Z2GT	Z3GT	50MF	RC	RI	Z3PT	
0	0	0	0	0	0	0	0	00
50M	TRIP	TC	DT	52BT	59N			
0	0	0	0	0	1	0	0	04

The A2 output contact asserts when zero-sequence voltage rises above the 59N element setting.

■ **Mask for the A3 Output Contact (MA3)**

								Event Report Hexadecimal Code
51PT	1ABC	2ABC	3ABC	51PP	50H	50L	LOP	
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
DF	DR	Z2GT	Z3GT	50MF	RC	RI	Z3PT	
0	0	0	0	0	0	1	0	02
50M	TRIP	TC	DT	52BT	59N			
0	0	0	0	0	0	0	0	00

The A3 output contact asserts when any reclose initiate condition set in the MRI logic mask is fulfilled.

■ **Mask for the A4 Output Contact (MA4)**

								Event Report Hexadecimal Code
51PT	1ABC	2ABC	3ABC	51PP	50H	50L	LOP	
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
DF	DR	Z2GT	Z3GT	50MF	RC	RI	Z3PT	
0	0	0	0	0	1	0	0	04
50M	TRIP	TC	DT	52BT	59N			
0	0	0	0	0	0	0	0	00

The A4 output contact asserts when any reclose cancel condition set in the MRC logic mask is fulfilled.

MRI: Mask for Reclose Initiation

If an element masked in the MRI mask is asserted when the TRIP output contacts close, reclosing is initiated unless a reclose cancel condition occurs. Reclose initiation is subordinate to reclose cancel. See the Specification and Application Reclosing Relay descriptions for more details.

■ **Mask for Reclose Initiation (MRI)**

								Event Report Hexadecimal Code
51PT	1ABC	2ABC	3ABC	51PP	50H	50L	LOP	
1	1	0	0	0	0	0	0	C0
51NT	67N1	67N2	67N3	51NP	Z1P	Z2P	Z3P	
1	1	0	0	0	1	0	0	C4
DF	DR	Z2GT	Z3GT	50MF	RC	RI	Z3PT	
0	0	1	0	0	0	0	0	20
50M	TRIP	TC	DT	52BT	59N			
0	0	0	1	0	0	0	0	10

The example mask for reclose initiation selects the Zone 1 instantaneous elements (67N1, Z1P, 1ABC), the time delayed Zone 2 ground overcurrent element (Z2GT), time-overcurrent elements (51PT and 51NT), and assertion of the Direct Trip (DT) input for reclose initiation. Do not set the RI bit in the mask for reclose initiate.

MRC: Mask for Reclose Cancellation

If an element masked in the MRC mask is asserted when the TRIP output contacts close, reclosing is cancelled even if a reclose initiate condition occurs. Reclose initiation is subordinate to reclose cancellation.

■ **Mask for Reclose Cancel (MRC)**

								Event Report Hexadecimal Code
51PT	1ABC	2ABC	3ABC	51PP	50H	50L	LOP	
0	0	0	0	0	1	0	0	04
51NT	67N1	67N2	67N3	51NP	Z1P	Z2P	Z3P	
0	0	0	0	0	0	0	0	00
DF	DR	Z2GT	Z3GT	50MF	RC	RI	Z3PT	
0	0	0	1	0	0	0	1	11
50M	TRIP	TC	DT	52BT	59N			
0	0	1	0	0	0	0	0	20

The example mask for reclose cancel stops reclosing for a 50H high-set overcurrent condition, timeout of the Zone 3 phase timer Z3PT, the Trip Command (TC), or time out of the Zone 3 ground timer (Z3GT).

Relay Word Bits Intended for Relay Testing

Each bit in the Relay Word has a designated purpose. The following bits are included to assist in relay testing: 50L, 51NP, 51PP, 50MF, TC, DF, and DR. This does not exclude the use of these bits in one of four trip or programmable output contacts if required by your application.

Note: Each mask must be properly configured for your application.

RECLOSING RELAY OPERATION EXAMPLES

Overview

The SEL-221C Relay includes two voltage supervised reclosing schemes and one unsupervised scheme. The following timing diagrams and text explain how each reclosing scheme operates successfully. Also, there is one example of a cancelled reclosing shot for each scheme. Section 2: SPECIFICATIONS provides detailed reclosing logic descriptions.

Table 5.2 outlines the reclosing examples in this section.

Table 5.2: Reclosing Relay Timing Examples

Example 1.	DLC = LLC = N, Two Shot Reclose Sequence
Example 2.	DLC = LLC = N, Reclosing Cancelled Due to RC Assertion
Example 3.	DLC = Y, LLC = N, Dead-line Supervised Reclose Sequence
Example 4.	DLC = Y, LLC = N, First Shot Cancelled Due to VCT Expiration
Example 5.	DLC = N, LLC = Y, Live-line Supervised Reclose Sequence
Example 6.	DLC = N, LLC = Y, Second Shot Cancelled Due to CVC Failure

Examples 1 and 2 provide information on the basic reclosing function, and describe recloser action when DLC = LLC = N. The remaining examples describe the reclosing options in greater detail. Timing diagrams, example settings, and an explanation of the events are provided in each example.

In each of the cases, the 79RS timer starts when the 52A input asserts. If the 79RS timer expires before the next trip, the relay resets the recloser and all available shots are reenabled. Refer to Section 2: SPECIFICATIONS, 79RS Timer for more details.

Example 1: DLC = N, LLC = N, Two Shot Reclose Sequence

This example shows a successful two shot reclosing sequence. Regardless of other recloser settings, four requirements must be fulfilled before the relay can initiate the reclosing sequence. The four requirements are listed below.

- The relay must trip.
- The 52A input must deassert.
- At least one reclose initiate condition must occur.
- No reclose cancel condition can occur.

Table 5.3 shows the recloser settings used for Examples 1 and 2. Settings not shown in Table 5.3 are identical to the example settings calculated earlier in this section. Figure 5.4 shows the timing of Example 1. Settings marked N/A are not applicable to the example.

Table 5.3: Recloser Settings for Examples 1 and 2

47PXD	N/A
47PXL	N/A
59N	N/A
DLC	N
LLC	N
CVC	N/A
VSA	N/A
VCT	N/A
79OI1	**40** cycles
79OI2	**100** cycles
79OI3	**0** cycles
79RS	**240** cycles
TDUR	**9** cycles

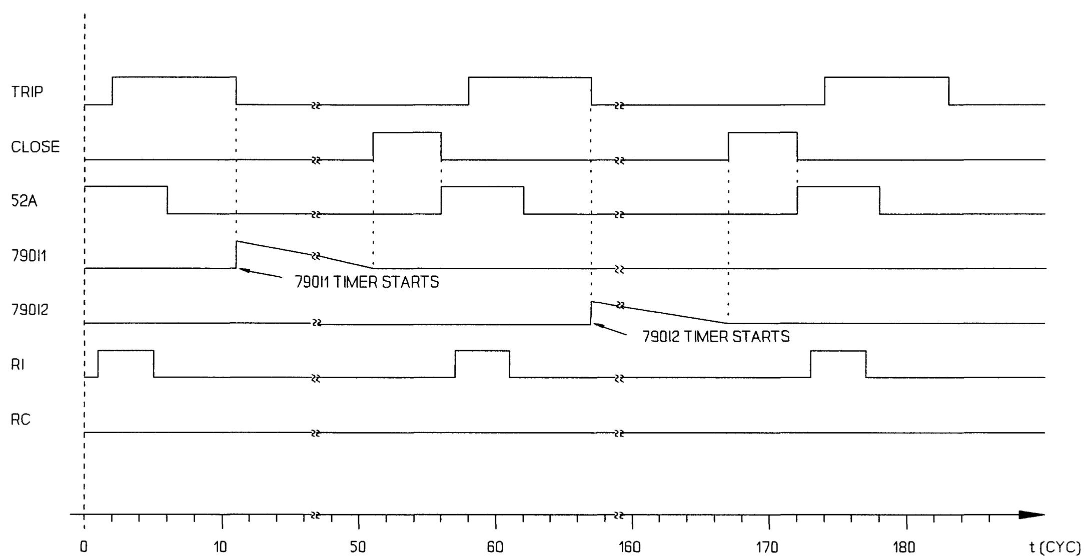


Figure 5.4: DLC = N, LLC = N, Two Shot Reclose Sequence

Referring to Figure 5.4 at t = 0, a permanent phase-phase fault occurs within the relay Zone 1 reach. The relay detects the fault and asserts the TRIP outputs, fulfilling the first requirement to initiate the reclosing sequence. Because the Z1P Zone 1 phase distance element is set in the Mask for Reclose Initiate, the RI bit asserts.

In response to the relay TRIP signal, the line breaker opens. This causes the RI bit to deassert because the Z1P element drops out. When the breaker opens, the breaker auxiliary contact also opens, deasserting the relay 52A input.

The relay TDUR setting of 9 cycles causes the TRIP to remain asserted until cycle 11. No reclose cancel condition occurred, and the other three initiating conditions were fulfilled, so the 79OI1 timer starts when TRIP drops out.

Forty cycles later, the 79OI1 timer expires. The relay issues the CLOSE signal, the relay shot counter (not shown) advances to 1, the breaker recloses, and the 52A input is asserted by closure of the breaker auxiliary contact.

When the breaker closes, the phase-phase fault is re-energized. The relay Z1P element picks up causing the relay to TRIP and the RI bit to assert. Again, the breaker opens and the 52A input deasserts. No reclose cancel conditions occur, so when the TRIP contacts open, the relay starts the 79OI2 timer.

When the 79OI2 timer expires, the shot counter advances, the relay issues a CLOSE signal, the breaker closes, and the 52A input asserts.

With the 79OI3 timer set equal to zero, the third reclosing shot is disabled. Because the two available reclosing shots have operated, when the relay trips a third time, the recloser is locked out and the breaker remains open.

Example 2: DLC = N, LLC = N, Reclosing Cancelled Due to RC Assertion

In this example, the fault is a reverse Zone 3 phase-phase fault. The fault was not cleared by the primary protection, so this relay tripped due to assertion of the time delayed Zone 3 phase distance element, Z3PT. Because the Z3PT bit is set in the Mask for Reclose Cancel, the RC bit asserts when Z3PT asserts, cancelling both reclosing shots.

Because Reclose Cancel has precedence over Reclose Initiate, the reclosing sequence is cancelled any time RC asserts while the TRIP is asserted, regardless of the presence of Reclose Initiating conditions.

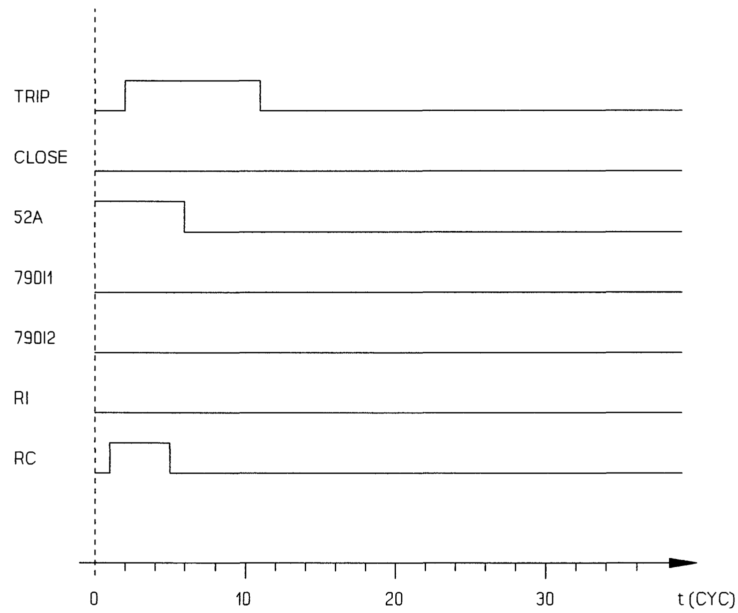


Figure 5.5: DLC = N, LLC = N, Reclosing Cancelled Due to RC Assertion

<u>Example 3: DLC = Y, LLC = N, Dead-line Supervised Reclose Sequence</u>

This example shows a successful two shot reclosing sequence. Reclosing is supervised by dead-line conditions. To simplify the example, we assume that the four requirements listed in Example 1 are met, allowing reclosing to proceed.

Table 5.4 shows the recloser settings used for Examples 3 and 4. Settings not shown in Table 5.4 are identical to the example settings calculated earlier in this section. Figure 5.6 shows the timing of Example 3.

Table 5.4: Recloser Settings for Examples 3 and 4

47PXD	**13.8 kV**
47PXL	N/A
59N	**3.9 kV**
DLC	**Y**
LLC	**N**
CVC	**Y**
VSA	**N**
VCT	**10** cycles
79OI1	**40** cycles
79OI2	**100** cycles
79OI3	**0** cycles
79RS	**240** cycles
TDUR	**9** cycles

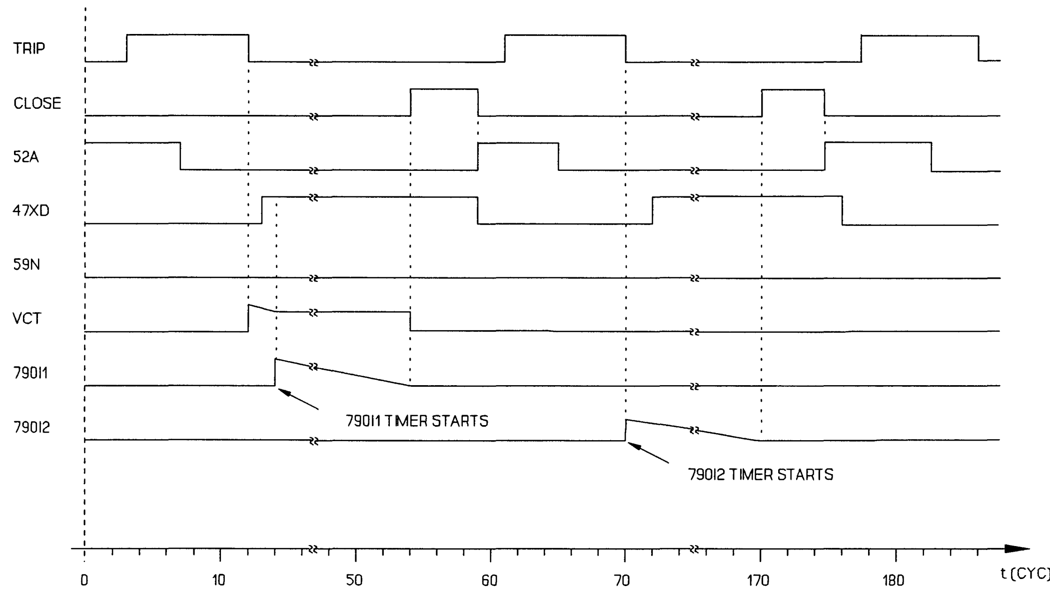


Figure 5.6: DLC = Y, LLC = N, Dead-line Supervised Reclose Sequence

Referring to Figure 5.6 at t = 1, a permanent phase-phase fault occurs within the relay Zone 1 reach. The relay detects the fault and asserts the TRIP outputs, fulfilling the first requirement to initiate the reclosing sequence. Because the Z1P Zone 1 phase distance element is set in the Mask for Reclose Initiate, the reclose initiate bit asserts.

In response to the relay TRIP signal, the line breaker opens. When the breaker opens, the breaker auxiliary contact also opens, deasserting the relay 52A input.

The relay TDUR setting of 9 cycles causes the TRIP to remain asserted until cycle 12. No reclose cancel condition occurred, and the other three initiating conditions were fulfilled, so the VCT timer starts when TRIP drops out.

Dead-line conditions (47XD asserted, 59N deasserted) must be fulfilled for one full cycle before the VCT timer expires or the first shot is cancelled. In cycle 13, the 47XD condition asserts to indicate that the line is dead for reclosing purposes. The 59N bit is deasserted. One cycle later, the VCT timer has not expired and the voltage conditions are still valid. Thus, the 79OI1 timer starts.

Forty cycles later, the 79OI1 timer expires. The CVC setting equals Y, so issue of the first CLOSE is supervised by the dead-line conditions. The 47XD condition is still asserted and 59N is still deasserted fulfilling the dead-line conditions. The relay issues the CLOSE signal, the shot counter (not shown) advances to 1, the breaker recloses, and the 52A input is asserted by closure of the breaker auxiliary contact.

When the breaker closes, the phase-phase fault is re-energized. The relay Z1P element picks up causing the relay to TRIP and the RI bit to assert. Again, the breaker opens and the 52A input deasserts. No reclose cancel conditions occur, so when the TRIP contacts open, the relay starts the 79OI2 timer. Because the VSA setting equals N, the relay does not supervise start of the second open interval timer with voltage conditions.

When the 79OI2 timer expires, the shot counter advances, the relay issues a CLOSE signal, the breaker closes, and the 52A input asserts.

With the 79OI3 timer set equal to zero, the third reclosing shot is disabled. Because the two available reclosing shots have operated, when the relay trips a third time, the recloser is locked out and the breaker remains open.

Example 4: DLC = Y, LLC = N, Reclosing Sequence Cancelled Due to VCT Expiration

This example shows the reclosing sequence cancelled due to expiration of the VCT timer.

Figure 5.7 shows the timing of Example 4.

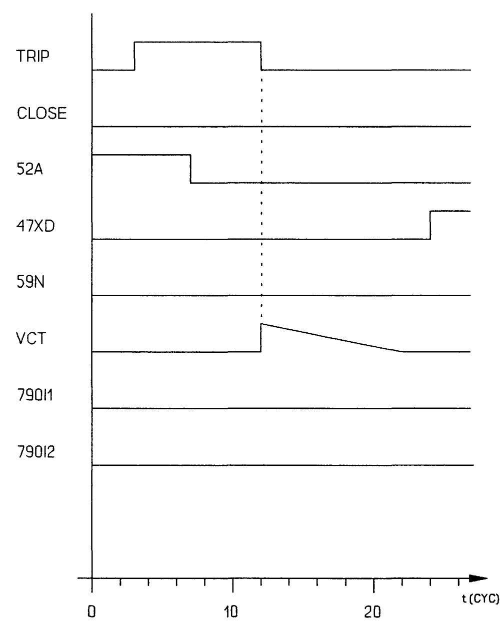


Figure 5.7: DLC = Y, LLC = N, Reclosing Sequence Cancelled Due to VCT Expiration

Referring to Figure 5.7 at t = 1, a permanent phase-phase fault occurs within the relay Zone 1 reach. The relay detects the fault and asserts the TRIP outputs, fulfilling the first requirement to initiate the reclosing sequence. Because the Z1P Zone 1 phase distance element is set in the Mask for Reclose Initiate, the reclose initiate bit asserts.

In response to the relay TRIP signal, the line breaker opens. When the breaker opens, the breaker auxiliary contact also opens, deasserting the relay 52A input.

The relay TDUR setting of 9 cycles causes the TRIP to remain asserted until cycle 12. No reclose cancel condition occurred, and the other three initiating conditions were fulfilled, so the VCT timer starts when TRIP drops out.

Dead-line conditions (47XD asserted, 59N deasserted) must be fulfilled for one full cycle before the VCT timer expires or the 79OI1 timer never starts. When the VCT timer expires in cycle 22, the 47XD bit has not asserted. The line is not dead so the 79OI1 timer never starts and the first reclosing shot is cancelled. The recloser is locked out and the breaker remains open.

Example 5: DLC = N, LLC = Y, Live-line Supervised Reclose Sequence

This example shows a successful two shot reclosing sequence. Reclosing is supervised by live-line conditions. To simplify the example, we assume that the four requirements listed in Example 1 are met, allowing reclosing to proceed.

Table 5.5 shows the recloser settings used for Examples 5 and 6. Settings not shown in Table 5.5 are identical to the example settings calculated earlier in this section. Figure 5.8 shows the timing of Example 5.

Table 5.5: Recloser Settings for Examples 5 and 6

47PXD	N/A
47PXL	55.2 kV
59N	3.9 kV
DLC	N
LLC	Y
CVC	Y
VSA	Y
VCT	10 cycles
79OI1	40 cycles
79OI2	100 cycles
79OI3	0 cycles
79RS	240 cycles
TDUR	9 cycles

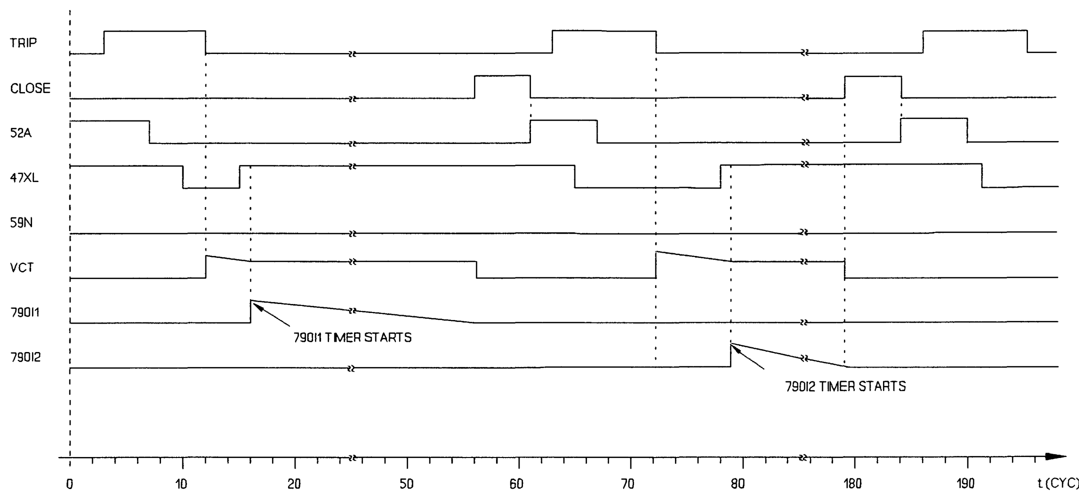


Figure 5.8: DLC = N, LLC = Y, Live-line Supervised Reclose Sequence

Referring to Figure 5.8 at t = 1, a permanent phase-phase fault occurs within the relay Zone 1 reach. The relay detects the fault and asserts the TRIP outputs, fulfilling the first requirement to initiate the reclosing sequence. Because the Z1P Zone 1 phase distance element is set in the Mask for Reclose Initiate, the reclose initiate bit asserts.

In response to the relay TRIP signal, the line breaker opens. When the breaker opens, the breaker auxiliary contact also opens, deasserting the relay 52A input.

The relay TDUR setting of 9 cycles causes the TRIP to remain asserted until cycle 12. No reclose cancel condition occurred, and the other three initiating conditions were fulfilled, so the VCT timer starts when TRIP drops out.

Live-line conditions (47XL asserted, 59N deasserted) must be fulfilled for one full cycle before the VCT timer expires or the reclosing sequence is cancelled. In cycle 15, the 47XL bit asserts to indicate that the line is live for reclosing purposes. The 59N bit is deasserted. One cycle later, the VCT timer has not expired and the voltage conditions are still valid. Thus the 79OI1 timer starts.

Forty cycles later, the 79OI1 timer expires. The CVC setting is Y and VSA equals Y, so the first and second reclose shots are voltage supervised. LLC = Y so supervision is performed by the live-line conditions. The 47XL condition is still asserted and 59N is still deasserted so the relay issues the CLOSE signal. The relay shot counter (not shown) advances to 1, the breaker recloses, and the 52A input is asserted by closure of the breaker auxiliary contact.

When the breaker closes, the phase-phase fault is re-energized. The relay Z1P element picks up causing the relay to TRIP and the RI bit to assert. Again, the breaker opens and the 52A input deasserts. No reclose cancel conditions occur, so when the TRIP contacts open, the relay starts the VCT timer.

Recall that VSA = Y. The relay voltage supervises the start of all reclosing open intervals. LLC = Y so supervision is performed with the live-line conditions. In cycle 78 the 47XL condition asserts. The 59N bit is deasserted. One cycle later, the VCT timer has not expired and the voltage conditions are still valid. The relay starts the 79OI2 timer.

Because CVC = Y and VSA = Y, the relay supervises the reclosing shots at the time of close. When the 79OI2 timer expires, the relay checks the 47XL and 59N elements. The 47XL bit is asserted and the 59N bit is deasserted. The relay issues a CLOSE signal, the shot counter advances, the breaker closes, and the 52A input asserts.

With the 79OI3 timer set equal to zero, the third reclosing shot is disabled. Because the two available reclosing shots have operated, when the relay trips a third time, the recloser is locked out and the breaker remains open.

Example 6: DLC = N, LLC = Y, Second Shot Cancelled Due to CVC Failure

This example shows a two shot reclosing sequence where the second shot is cancelled due to voltage conditions. Reclosing is supervised by live-line conditions. To simplify the example, we assume that the four requirements listed in Example 1 are met, allowing reclosing to proceed.

Table 5.5 shows the recloser settings used for Examples 5 and 6. Settings not shown in Table 5.5 are identical to the example settings calculated earlier in this section. Figure 5.9 shows the timing of Example 6.

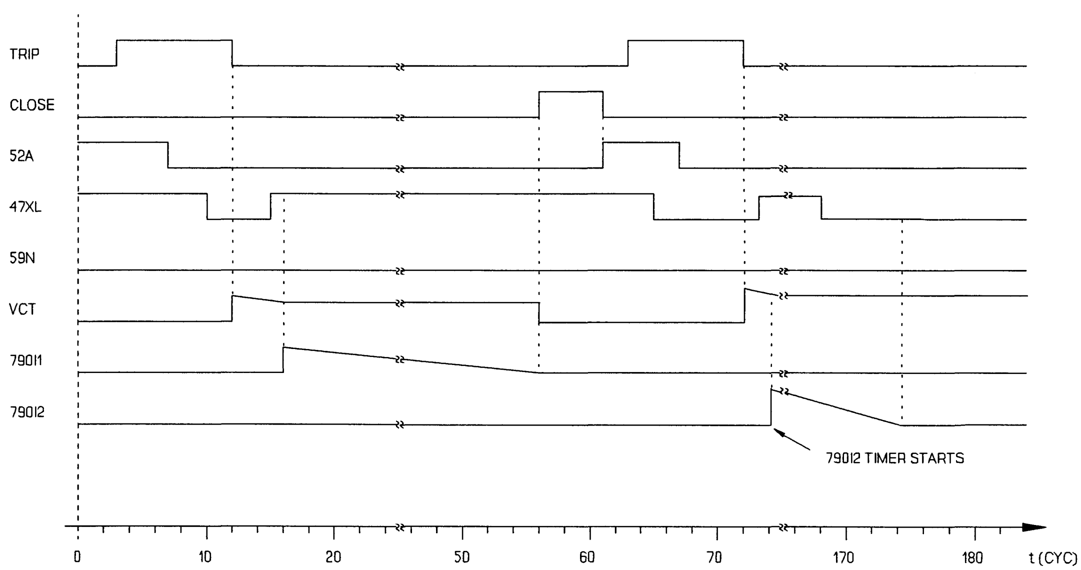


Figure 5.9: DLC = N, LLC = Y, Second Shot Cancelled Due to CVC Failure

Referring to Figure 5.9 at t = 1, a permanent phase-phase fault occurs within the relay Zone 1 reach. The relay detects the fault and asserts the TRIP outputs, fulfilling the first requirement to initiate the reclosing sequence. Because the Z1P Zone 1 phase distance element is set in the Mask for Reclose Initiate, the reclose initiate bit asserts.

In response to the relay TRIP signal, the line breaker opens. When the breaker opens, the breaker auxiliary contact also opens, deasserting the relay 52A input.

The relay TDUR setting of 9 cycles causes the TRIP to remain asserted until cycle 12. No reclose cancel condition occurred, and the other three initiating conditions were fulfilled, so the VCT timer starts when TRIP drops out.

Live-line conditions (47XL asserted, 59N deasserted) must be fulfilled for one full cycle before the VCT timer expires or the reclosing sequence is cancelled. In cycle 15, the 47XL condition asserts to indicate that the line is live for reclosing purposes. The 59N bit is deasserted. One cycle later, the VCT timer has not expired and the voltage conditions are still valid so the 79OI1 timer starts.

Forty cycles later, the 79OI1 timer expires. The CVC setting is Y and VSA = Y, so issue of the first and second CLOSEs are supervised. LLC = Y so supervision is performed by the live-line conditions. The 47XL condition is still asserted and 59N is still deasserted so the relay issues the CLOSE signal. The relay shot counter (not shown) advances to 1, the breaker recloses, and the 52A input is asserted by closure of the breaker auxiliary contact.

When the breaker closes, the phase-phase fault is re-energized. The relay Z1P element picks up causing the relay to TRIP and the RI bit to assert. Again, the breaker opens and the 52A input deasserts. No reclose cancel conditions occur, so when the TRIP contacts open, the relay starts the VCT timer. When voltage conditions are fulfilled in cycle 74 the relay starts the 79OI2 timer.

Recall that CVC = Y and VSA = Y. These settings cause the relay to supervise the first and second reclosing shots at the time of close. LLC = Y so supervision is performed with the live-line conditions. When the 79OI2 timer expires, the relay checks the 47XL and 59N elements. The 47XL bit is deasserted. The relay cancels the second reclose shot and the breaker remains open.

SETTINGS SHEET
FOR SEL-221C RELAY

DATE ____________

SUBSTATION ________________ CIRCUIT ____

BREAKER ________________ DEVICE NO. ____

FUNCTION ____

MAKE _________________ C.T. SETTING ____

MODEL/STYLE NO. _____ P.T. SETTING ____

PART # ___________ SOFTWARE VERSION ____

SERIAL #_________ POWER SUPPLY_________ VOLTS ac/dc LOGIC INPUT_____ Vdc

SECONDARY INPUTS: V/ϕ = 67L-N, NOMINAL AMPS = 5, Hz = 60

MASK: MTU (UNCONDITIONAL TRIP)

									HEXADECIMAL REPRESENTATION SETTING
ROW #1: RELAY WORD BINARY REPRESENTATION	51PT	1ABC	2ABC	3ABC	51PP	50H	50L	LOP	
ROW #2: RELAY WORD BINARY REPRESENTATION	51NT	67N1	67N2	67N3	51NP	Z1P	Z2P	Z3P	
ROW #3: RELAY WORD BINARY REPRESENTATION	DF	DR	Z2GT	Z3GT	50MF	RC	RI	Z3PT	
ROW #4: RELAY WORD BINARY REPRESENTATION	50M	TRIP	TC	DT	52BT	59N			

MASK: MPT (PERMISSIVE TRIP)

									SETTING
ROW #1: RELAY WORD BINARY REPRESENTATION	51PT	1ABC	2ABC	3ABC	51PP	50H	50L	LOP	
ROW #2: RELAY WORD BINARY REPRESENTATION	51NT	67N1	67N2	67N3	51NP	Z1P	Z2P	Z3P	
ROW #3: RELAY WORD BINARY REPRESENTATION	DF	DR	Z2GT	Z3GT	50MF	RC	RI	Z3PT	
ROW #4: RELAY WORD BINARY REPRESENTATION	50M	TRIP	TC	DT	52BT	59N			

MASK: MTB (BLOCK TRIP)

									SETTING
ROW #1: RELAY WORD BINARY REPRESENTATION	51PT	1ABC	2ABC	3ABC	51PP	50H	50L	LOP	
ROW #2: RELAY WORD BINARY REPRESENTATION	51NT	67N1	67N2	67N3	51NP	Z1P	Z2P	Z3P	
ROW #3: RELAY WORD BINARY REPRESENTATION	DF	DR	Z2GT	Z3GT	50MF	RC	RI	Z3PT	
ROW #4: RELAY WORD BINARY REPRESENTATION	50M	TRIP	TC	DT	52BT	59N			

SETTINGS SHEET
FOR SEL-221C RELAY

DATE ________

HEXADECIMAL REPRESENTATION

MASK: MTO (SWITCH ONTO FAULT)

									SETTING
ROW #1: RELAY WORD BINARY REPRESENTATION	51PT	1ABC	2ABC	3ABC	51PP	50H	50L	LOP	
ROW #2: RELAY WORD BINARY REPRESENTATION	51NT	67N1	67N2	67N3	51NP	Z1P	Z2P	Z3P	
ROW #3: RELAY WORD BINARY REPRESENTATION	DF	DR	Z2GT	Z3GT	50MF	RC	RI	Z3PT	
ROW #4: RELAY WORD BINARY REPRESENTATION	50M	TRIP	TC	DT	52BT	59N			

MASK: MA1 (A1 CONTACT)

									SETTING
ROW #1: RELAY WORD BINARY REPRESENTATION	51PT	1ABC	2ABC	3ABC	51PP	50H	50L	LOP	
ROW #2: RELAY WORD BINARY REPRESENTATION	51NT	67N1	67N2	67N3	51NP	Z1P	Z2P	Z3P	
ROW #3: RELAY WORD BINARY REPRESENTATION	DF	DR	Z2GT	Z3GT	50MF	RC	RI	Z3PT	
ROW #4: RELAY WORD BINARY REPRESENTATION	50M	TRIP	TC	DT	52BT	59N			

MASK: MA2 (A2 CONTACT)

									SETTING
ROW #1: RELAY WORD BINARY REPRESENTATION	51PT	1ABC	2ABC	3ABC	51PP	50H	50L	LOP	
ROW #2: RELAY WORD BINARY REPRESENTATION	51NT	67N1	67N2	67N3	51NP	Z1P	Z2P	Z3P	
ROW #3: RELAY WORD BINARY REPRESENTATION	DF	DR	Z2GT	Z3GT	50MF	RC	RI	Z3PT	
ROW #4: RELAY WORD BINARY REPRESENTATION	50M	TRIP	TC	DT	52BT	59N			

MASK: MA3 (A3 CONTACT)

									SETTING
ROW #1: RELAY WORD BINARY REPRESENTATION	51PT	1ABC	2ABC	3ABC	51PP	50H	50L	LOP	
ROW #2: RELAY WORD BINARY REPRESENTATION	51NT	67N1	67N2	67N3	51NP	Z1P	Z2P	Z3P	
ROW #3: RELAY WORD BINARY REPRESENTATION	DF	DR	Z2GT	Z3GT	50MF	RC	RI	Z3PT	
ROW #4: RELAY WORD BINARY REPRESENTATION	50M	TRIP	TC	DT	52BT	59N			

SETTINGS SHEET
FOR SEL-221C RELAY

DATE ____________

MASK: MA4 (A4 CONTACT)

									HEXADECIMAL REPRESENTATION SETTING
ROW #1: RELAY WORD BINARY REPRESENTATION	51PT	1ABC	2ABC	3ABC	51PP	50H	50L	LOP	
ROW #2: RELAY WORD BINARY REPRESENTATION	51NT	67N1	67N2	67N3	51NP	Z1P	Z2P	Z3P	
ROW #3: RELAY WORD BINARY REPRESENTATION	DF	DR	Z2GT	Z3GT	50MF	RC	RI	Z3PT	
ROW #4: RELAY WORD BINARY REPRESENTATION	50M	TRIP	TC	DT	52BT	59N			

MASK: MRI (RECLOSE INITIATE)

									SETTING
ROW #1: RELAY WORD BINARY REPRESENTATION	51PT	1ABC	2ABC	3ABC	51PP	50H	50L	LOP	
ROW #2: RELAY WORD BINARY REPRESENTATION	51NT	67N1	67N2	67N3	51NP	Z1P	Z2P	Z3P	
ROW #3: RELAY WORD BINARY REPRESENTATION	DF	DR	Z2GT	Z3GT	50MF	RC	RI	Z3PT	
ROW #4: RELAY WORD BINARY REPRESENTATION	50M	TRIP	TC	DT	52BT	59N			

MASK: MRC (RECLOSE CANCEL)

									SETTING
ROW #1: RELAY WORD BINARY REPRESENTATION	51PT	1ABC	2ABC	3ABC	51PP	50H	50L	LOP	
ROW #2: RELAY WORD BINARY REPRESENTATION	51NT	67N1	67N2	67N3	51NP	Z1P	Z2P	Z3P	
ROW #3: RELAY WORD BINARY REPRESENTATION	DF	DR	Z2GT	Z3GT	50MF	RC	RI	Z3PT	
ROW #4: RELAY WORD BINARY REPRESENTATION	50M	TRIP	TC	DT	52BT	59N			

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

ACCESS Command passwords: (6 Characters excluding "SPACE, COMMA, SEMI-COLON and SLASH")

LEVEL 0: "=" **ACCESS <ENTER>**
PASSWORD: ______________________

LEVEL 1: "=>" **2ACCESS <ENTER>**
PASSWORD: ______________________

LEVEL 2: "=>>" ENTER SETTINGS PER MATRIX TABLE

NOTE: FOR NEW RELAYS BEGIN WITH LEVEL 1 PASSWORD = OTTER AND LEVEL 2 PASSWORD = TAIL. WHEN IN LEVEL 2 MODIFY PASSWORDS VIA PASSWORD 1 AND 2 COMMANDS.

SETTINGS SHEET
FOR SEL-221C RELAY

DATE ____________

DESCRIP.	POS-SEQ. IMPEDANCE		ZERO-SEQ. IMPEDANCE		LINE LENGTH*
RANGE	0-9999 (PRI. OHMS)		0-9999 (PRI. OHMS)		0.1-999 MILES
ABBREV. SETTING	**R1**	**X1**	**R0**	**X0**	**LL**
DESCRIP.	C. T. RATIO	P. T. RATIO	MAX. TORQUE ANGLE	ENABLE FAULT LOCATOR	
RANGE	1-5000:1	1-10,000:1	47°-90°	(Y OR N)	
ABBREV. SETTING	**CTR**	**PTR**	**MTA**	**LOCAT**	
DESCRIP.	POS.-SEQ DEAD-LINE DETECTOR	POS.-SEQ. LIVE-LINE DETECTOR	ZERO-SEQ. VOLTAGE DETECTOR	VOLTAGE CONDITION TIMER	
RANGE	(0-129V L-L, SEC) 0-2000 KV PRI.	(0-129V L-L, SEC) 0-2000 KV PRI.	(0-75V L-N, SEC) 0-2000 KV PRI.	0-10,000 CYCLES	
ABBREV. SETTING	**47PXD**	**47PXL**	**59N**	**VCT**	
DESCRIP.	LIVE-LINE VOLTAGE CHECK ENABLE	DEAD-LINE VOLTAGE CHECK ENABLE	CHECK VOLTAGE AT CLOSE ENABLE	VOLTAGE SUPERVISE ALL SHOTS	
RANGE	(Y OR N)	(Y OR N)	(Y OR N)	(Y OR N)	
ABBREV. SETTING	**LLC**	**DLC**	**CVC**	**VSA**	
DESCRIP.	RECL. OPEN INT. 1	RECL. OPEN INT. 2	RECL. OPEN INT. 3	RECL. RESET TIME	
RANGE	0-10,000 CYCLES (¼ CYCLE STEPS)	0-10,000 CYCLES (¼ CYCLE STEPS)	0-10,000 CYCLES (¼ CYCLE STEPS)	60-8,000 CYCLES (¼ CYCLE STEPS)	
ABBREV. SETTING	**79OI1**	**79OI2**	**79OI3**	**79RS**	
DESCRIP.	ϕ O/C LOW-SET PICKUP	ϕ O/C MEDIUM-SET PICKUP	ϕ O/C LOP DELAY (LOSS-OF-POTENTIAL)	ϕ O/C HIGH-SET PICKUP	
RANGE	(0.5-40A SEC.) 0.25-50,000 AMP PRI.	(0.5-40A SEC.) 0.25-50,000 AMP PRI.	0-60 CYCLES (¼ CYCLE STEPS)	(0.5-40A SEC.) 0.25-50,000 AMP PRI.	
ABBREV. SETTING	**50L**	**50M**	**50MFD**	**50H**	
DESCRIP.	ZONE 1 REACH	ZONE 2 REACH**	ZONE 3 REACH**	ZONE 3 $\phi\phi$ & 3ϕ TIME-STEP BACKUP TIMER	
RANGE	(0.125-32Ω SEC) 0-2000% OF R1+JX1	(0.125-128Ω SEC) 0-3200% OF R1+JX1	(0.125-128Ω SEC) 0-3200% OF R1+JX1	0-2000 CYCLES (¼ CYCLE STEPS)	
ABBREV. SETTING	**Z1%**	**Z2%**	**Z3%**	**Z3DP**	

SETTINGS SHEET
FOR SEL-221C RELAY

DATE ____________

DESCRIP.	PHS TIME OC/O PICKUP	PHS TIME O/C TIME DIAL	PHS TIME O/C CURVE SHAPE		
RANGE	(1-12A SEC.) 0.25-50,000 AMP PRI.	0.5-15 (0.01 STEP)	1, 2, 3, OR 4		
ABBREV. SETTING	**51PP**	**51PTD**	**51PC**		
DESCRIP.	GND TIME O/C PICKUP	GND TIME O/C TIME DIAL	GND TIME O/C CURVE SHAPE	GND TIME O/C TORQUE CONTROL	MINIMUM TRIP DURATION TIMER
RANGE	(0.25-6.3A SEC) 0.25-50,000 AMP PRI.	0.5-15 (0.01 STEPS)	1, 2, 3, OR 4	(Y OR N)	0-2000 CYCLES (¼ CYCLE STEPS)
ABBREV. SETTING	**51NP**	**51NTD**	**51NC**	**51NTC**	**TDUR**
DESCRIP.	ZONE 1 GND INST. O/C ***	ZONE 2 GND INST. O/C ***	ZONE 3 GND INST. O/C ***	ZONE 2 GND TIME-STEP BACKUP TIMER	ZONE 3 GND TIME-STEP BACKUP TIMER
RANGE	(0.25A-48x51NP 0.25-50,000 AMP PRI.	(0.25A-48x51NP 0.25-50,000 AMP PRI.	(0.25A-48x51NP 0.25-50,000 AMP PRI.	0-2000 CYCLES (¼ CYCLE STEPS)	0-2000 CYCLES (¼ CYCLE STEPS)
ABBREV. SETTING	**50N1P**	**50N2P**	**50N3P**	**Z2DG**	**Z3DG**
DESCRIP.	52BT TIME DELAY	ZONE 3 DIRECTION	GND O/C NEGATIVE-SEQ. POLAR.	GND O/C ZERO-SEQ. VOLTAGE POLAR.	GND O/C ZERO-SEQ. CURRENT POLAR.
RANGE	0.5-10,000 CYCLES	(F OR R)	(Y OR N)	(Y OR N)	(Y OR N)
ABBREV. SETTING	**52BT**	**ZONE 3**	**32QE**	**32VE**	**32IE**
DESCRIP.	LOSS-OF-POT. ENABLE	SEL-121C-1 PORT #1 TIMEOUT	SEL-121C-1 PORT #2 TIMEOUT	AUTOMATIC MESSAGE TRANSMIT AUTOPORT SELECTION	# RINGS AFTER WHICH MODEM ANSWERS
RANGE	(Y OR N)	0-30 MINUTES	0-30 MINUTES	PORT 1, 2, OR 3(BOTH)	1-30
ABBREV. SETTING	**LOPE**	**TIME1**	**TIME2**	**AUTO**	**RINGS**

SETTINGS SHEET
FOR SEL-221C RELAY

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

NOTE: Length may also be represented in metric units.

** Zones 2 and 3 are limited as follows: ohmic range is 0.125 to 64 ohms secondary.

Zone 1 < Zone 2, 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 req'd. Yes______ No______

Substation ________________________

INSTALLATION
TABLE OF CONTENTS

Installation 6-1
- Mounting 6-1
- Frame Ground Connection 6-1
- Power Connections 6-1
- Secondary Circuits 6-1
- Control Circuits 6-1
- Communications Circuits 6-2
- Jumper Selection 6-2
  - EIA-232 Jumpers 6-2
  - Password Protection Jumper 6-2
  - OPEN/CLOSE Command Enable Jumper 6-2
  - A4 Output Contact Jumper 6-3
  - Output Contact Soldered Wire Jumpers 6-3
  - Communication Port External Power Jumpers 6-3
- EIA-232 And IRIG-B Installation 6-3
  - EIA-232 Cables 6-4
- IRIG-B Input Description 6-4

Installation Checkout 6-5

SEL Direction and Polarity Check Form 6-12

SEL Direction and Polarity Check Form 6-13

TABLES

Table 6.1: AUX INPUT Pin Definition 6-5

FIGURES

Figure 6.1: 9-Pin Connector Pin Number Convention 6-3

Figure 6.2: Horizontal Front and Rear Panel Drawings 6-7

Figure 6.3: Panel Cutout and Drill Patterns for SEL (Shallow) Low-Profile Instruments 6-8

Figure 6.4: Communications and Clock Connections - One Unit at One Location 6-9

Figure 6.5: Communications and Clock Connections - Multiple Units at One Location 6-9

Figure 6.6: SEL Relay Communications Diagram for Connection to the SEL-DTA 6-10

Figure 6.7: External Ac Current and Voltage Connections 6-10

Figure 6.8: External Dc Connection Diagram (Typical) 6-11

SEL Direction and Polarity Check Form 6-12

SEL Direction and Polarity Check Form 6-13

INSTALLATION

Mounting

The relay is designed for mounting by its front vertical flanges in a 19" vertical relay rack. It can also be mounted semi-flush in a switchboard panel. Use four #10 screws for mounting. Figure 6.2 shows front and rear panel drawings.

Frame Ground Connection

Terminal 46 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 44 and 45 on the rear panel must be connected to a source of control voltage. Control power passes through these terminals to the fuse(s) and a toggle switch, if installed. The power continues through a surge filter and connects to the switching power supply. The control power circuitry is isolated from the frame ground.

Secondary Circuits

The relay presents a very low burden to the secondary potential and current circuits. It requires four-wire wye potentials and three currents from the power system current transformer secondaries.

Control Circuits

The control inputs are dry. For example, to assert the 52A input, you must apply control voltage to the 52A input terminals. Each input is individually isolated, and a terminal pair is brought out for each input. There are no internal connections between control inputs.

Control outputs are dry relay contacts rated for tripping duty. A metal-oxide varistor protects each contact.

Communications Circuits

Connections to the two EIA-232 serial communications ports are made via the two 9-pin connectors labeled Port 1 and Port 2R on the rear panel and Port 2F on the front panel. Pins 5 and 9 connect directly to frame (chassis) ground.

Warning: Do not rely upon pins 5 and 9 for safety grounding, since their current-carrying capacity is less than control-power short circuit current and protection levels.

The communications circuits are protected by low-energy, low-voltage MOVs and passive RC filters. You can minimize communications-circuit difficulties by keeping the length of the EIA-232 cables as short as possible. Lengths of twelve feet or less are recommended, and the cable length should never exceed 100 feet. Use shielded communications cable for lengths greater than ten feet. Modems are required for communications over long distances.

Route the communications cables well away from the secondary and control circuits. Do not bundle the communications wiring with secondary or control circuit wiring. If these wires are bundled, switching spikes and surges can cause noise in the communications wiring. This noise may exceed the communications logic thresholds and introduce errors. Always route the IRIG-B clock cable away from control wiring and secondary circuits.

Jumper Selection

All jumpers are on the front edge of the main board. They are easily accessed by removing the top cover or front panel.

EIA-232 Jumpers

JMP105 provides EIA-232 baud rate selection. Available baud rates are 300, 600, 1200, 2400, 4800, and 9600. To select a baud rate for a particular port, place the jumper so it connects a pin labeled with the desired port to a pin labeled with the desired baud rate.

Caution: Do not select two baud rates for the same port. This can damage the baud rate generator.

Password Protection Jumper

Put JMP103 in place to disable password protection. This feature is useful if passwords are not required or when passwords are forgotten.

OPEN/CLOSE Command Enable Jumper

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

A4 Output Contact Jumper

With jumper JMP3 in the A4 position, the A4 output contact operates per logic mask MA4. With jumper JMP3 in the ALARM position, the A4 output contact operates with the ALARM output contact.

Output Contact Soldered Wire Jumpers

All the output contacts can be configured as "a" or "b" contacts with soldered wire jumpers JMP4 through JMP11 (each jumper has positions A and B). The output contact/soldered wire jumper correspondence is as follows:

Output Contact	Jumper
TRIP (terminals 1,2)	JMP11
TRIP (terminals 3,4)	JMP10
CLOSE	JMP9
A1	JMP8
A2	JMP7
A3	JMP6
A4	JMP5
ALARM	JMP4

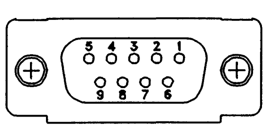
Communication Port External Power Jumpers

DC power is available from Port 1 and Port 2R to power external devices. Jumpers must be selected to route dc power to the rear panel connectors. The internal jumpers are near Port 1 and are labeled as follows: JMP12 = +5 V; JMP13 = +12 V; JMP14 = -12 V. Use caution to ensure the dc current requirement of the external equipment does not exceed the relay power supply specifications. Only route dc power to the rear ports if required for your application.

EIA-232 and IRIG-B Installation

The following information contains specific details regarding communications port pinouts.

A pin definition of the 9-pin port connectors and cabling information for the EIA-232 ports appears in Figure 6.1. The following cable listings show several types of EIA-232 cables. These and other cables are available from SEL. Cable configuration sheets are also available at no charge for a large number of devices. Contact the factory for more information.



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

Figure 6.1: 9-Pin Connector Pin Number Convention

EIA-232 Cables

```
SEL-221C                     9-Pin *DTE DEVICE

GND  5 ----------------- 5   GND
TXD  3 ----------------- 2   RXD
RXD  2 ----------------- 3   TXD          (SEL  CABLE 234)
RTS  7 --+
         | Jumper
CTS  8 --+
                      +- 1   DCD
                      |- 4   DTR
              Jumper  |- 6   DSR
                      +- 8   CTS
                         9   RI
```

```
SEL-221C                     **DCE DEVICE

GND   5 ---------------- 7   GND
TXD   3 ---------------- 2   RXD
RTS   7 ---------------- 20  DTR          (SEL  CABLE 222)
RXD   2 ---------------- 3   TXD
CTS   8 ---------------- 8   CD
GND   9 ---------------- 1   GND
```

```
PRTU                         SEL-221C

GND   1 ---------------- 5   GND
TXD   2 ---------------- 2   RXD
RXD   4 ---------------- 3   TXD          (SEL  CABLE 231)
CTS   5 ---------------- 7   RTS
+12   7 ---------------- 8   CTS
GND   9 ---------------- 9   GND
```

* DTE = Data Terminal Equipment (terminals, printers, computers, etc.)
** DCE = Data Communications Equipment (modems, etc.)

IRIG-B Input Description

The port labeled J201/AUX INPUT receives demodulated IRIG-B input. Pin definitions appear in Table 6.1.

Table 6.1: AUX INPUT Pin Definition

Pin	Name	Description
2	IRIGIN HI	Positive IRIG-B input
3	IRIGIN LOW	Negative IRIG-B input
6	+5 *	
7	+12 *	
8	-12 *	
1,5,9	GND	Ground

* Consult the factory before using these power supply outputs

The actual IRIG-B input circuit is a 56 ohm resistor in series with a optocoupler input diode. The input diode has a forward drop of about 1.5 volts. Driver circuits should put approximately 10 mA through the diode when "on."

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

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

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

INSTALLATION CHECKOUT

You may follow the suggestions below or combine them with your standard procedures. Never implement recommendations prohibited by the rules of your normal practice.

The following equipment is required for initial checkout:

- Portable terminal or computer
- Control power to the relay power connections
- Source of three-phase voltages and at least one current source
- Ohmmeter or contact opening/closing sensing device

1. Apply control power and make sure the terminal displays the startup message. If not, set AUTO = 2 with the SET command in Access Level 2. Check the settings with the ACCESS and SHOWSET commands. Use the TIME command to set the clock.

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. See the SEL Direction and Polarity Check Form at the end of this section for this purpose.

4. Use the TARGET command to check the state of all contact inputs and outputs.

5. Proceed to Access Level 2 with the 2ACCESS command and second password. Be sure the ALARM relay contacts close and open when the relay executes 2ACCESS. The ALARM pulse will not be detectable if the ALARM contacts are closed due to an alarm condition.

6. Test the tripping function in three ways. First, be sure the circuit breaker can be tripped by OPEN command execution. Verify that the TC bit is set in the MTU mask. Second, the circuit breaker may be tripped by DIRECT TRIP input assertion if the DT bit is selected in the MTU mask. Third, the circuit breaker may be tripped by applying voltages and currents representing a fault condition for which the relay should respond. Here, the TRIP relay closes regardless of the 52A contact state, and opens when there are no currents above the 50L condition, zero-sequence current is below the 50NL threshold, and fault conditions no longer exist. The TRIP output always remains closed for at least the TDUR setting.

7. There are three ways the circuit breaker is closed: by CLOSE command execution, a reclose attempt by the reclosing relay, or DIRECT CLOSE input assertion. The CLOSE output relay closes for all of these conditions if 52A 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, the 79RS timer expires, or a trip condition occurs whichever occurs first.

8. If the Permissive Trip and Block Trip inputs are used, check them for proper operation (see the LOGIC MPT and LOGIC MTB settings in Section 3: COMMUNICATIONS). An event record should be generated after PT input assertion.

9. Assert the External Trigger input. This should trigger an event record, but does not affect the protective relaying functions in any way.

10. Use the STATUS command to inspect the self-test status. You may wish to save the reading as part of an "as-left" record.

When local checkout is complete, check communications with the instrument via a remote interface (if used). Make sure the automatic port is properly assigned and that desired timeout intervals are selected for each port. Also, be sure to record password settings.

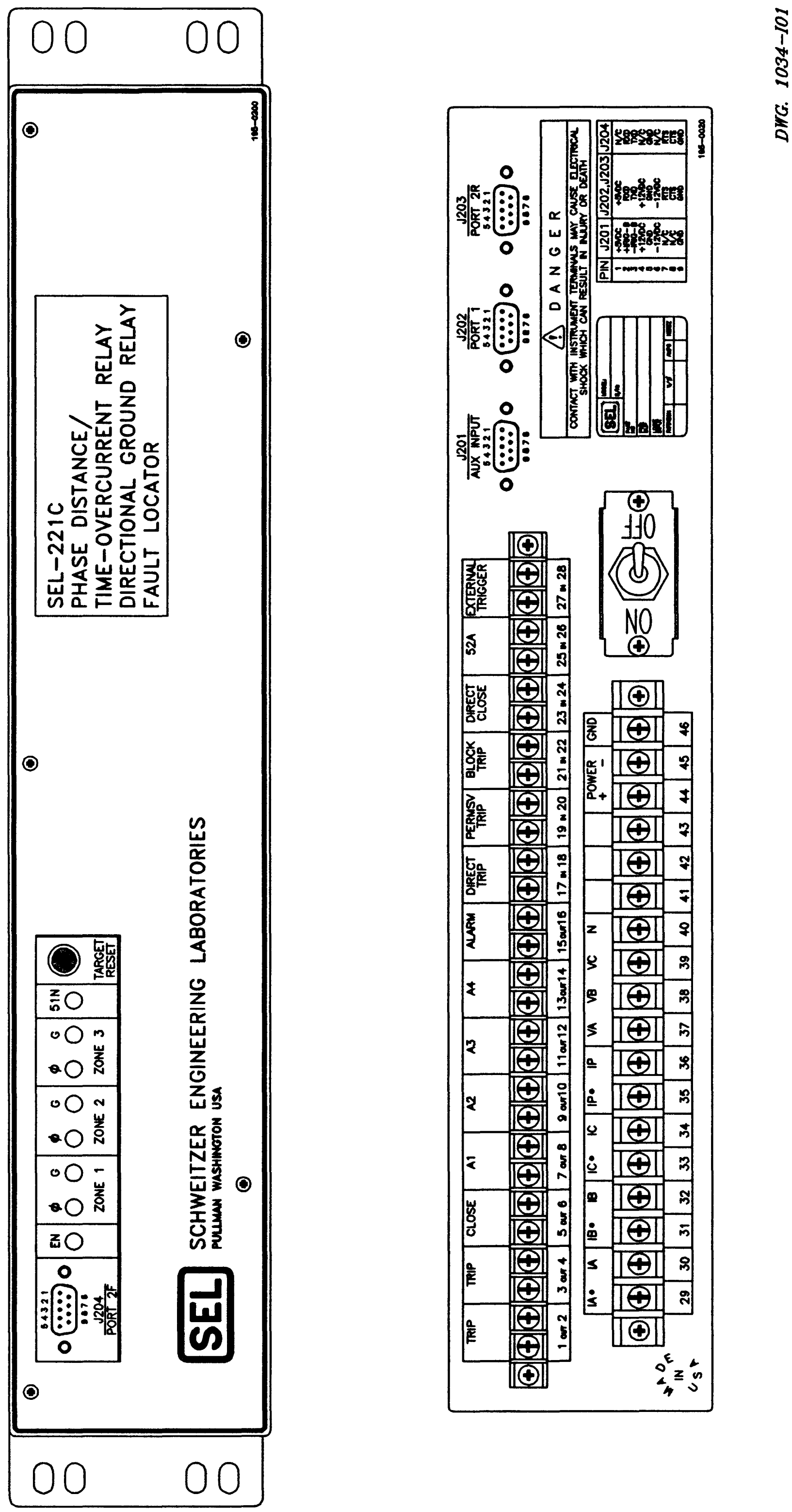


Figure 6.2: Horizontal Front and Rear Panel Drawings

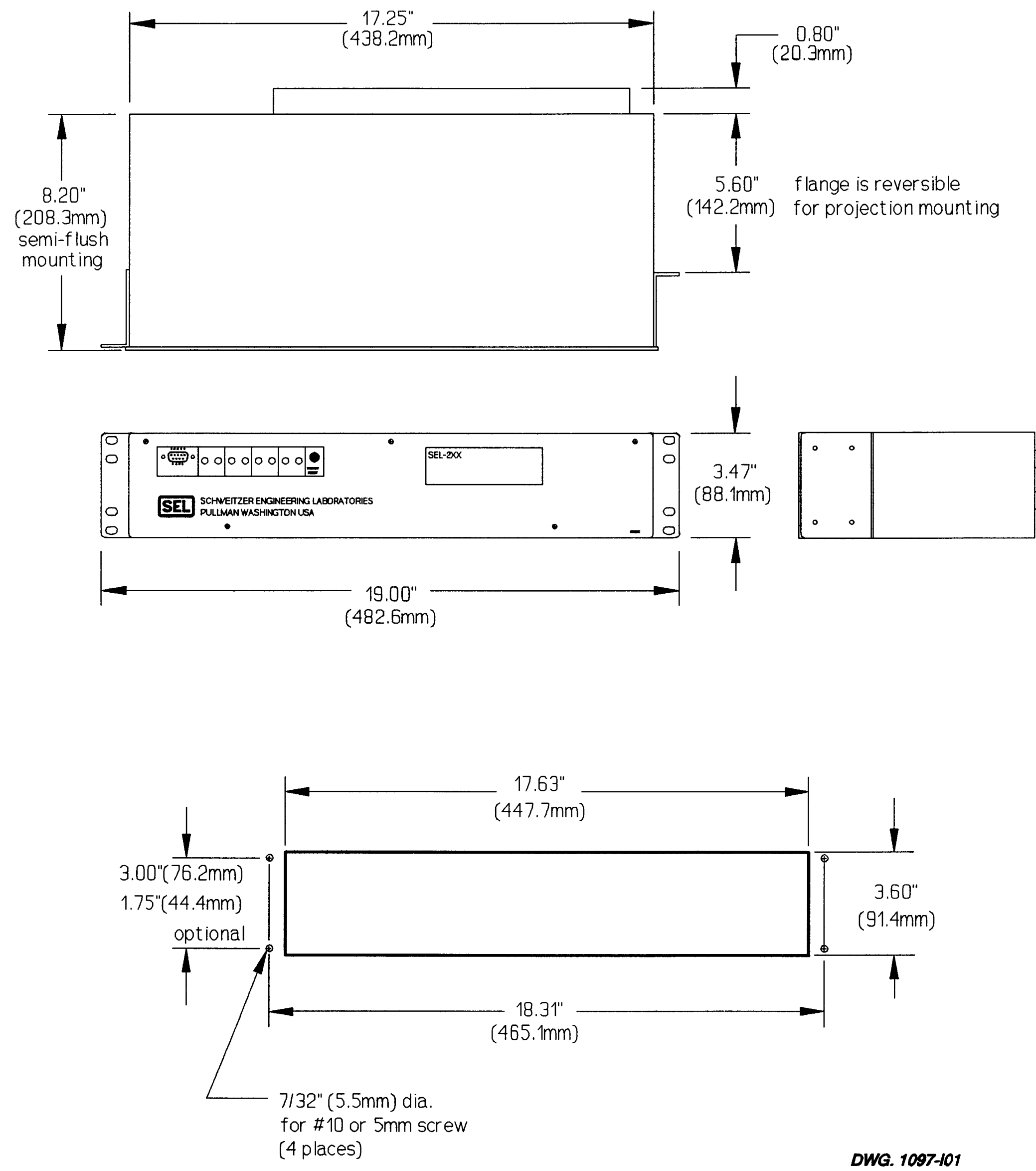


Figure 6.3: Panel Cutout and Drill Patterns for SEL (Shallow) Low-Profile Instruments

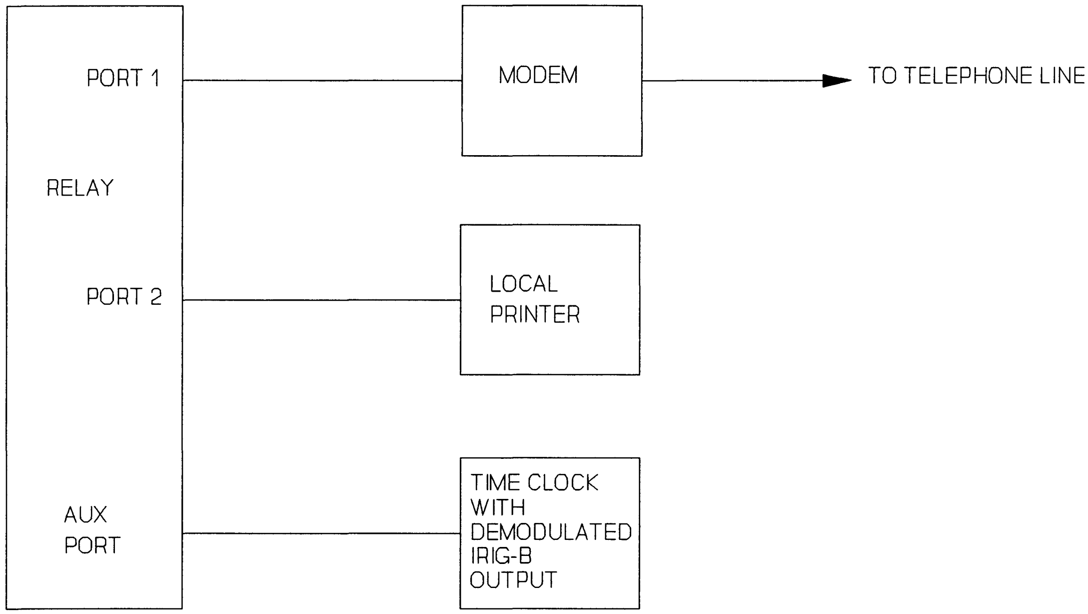


Figure 6.4: Communications and Clock Connections - One Unit at One Location

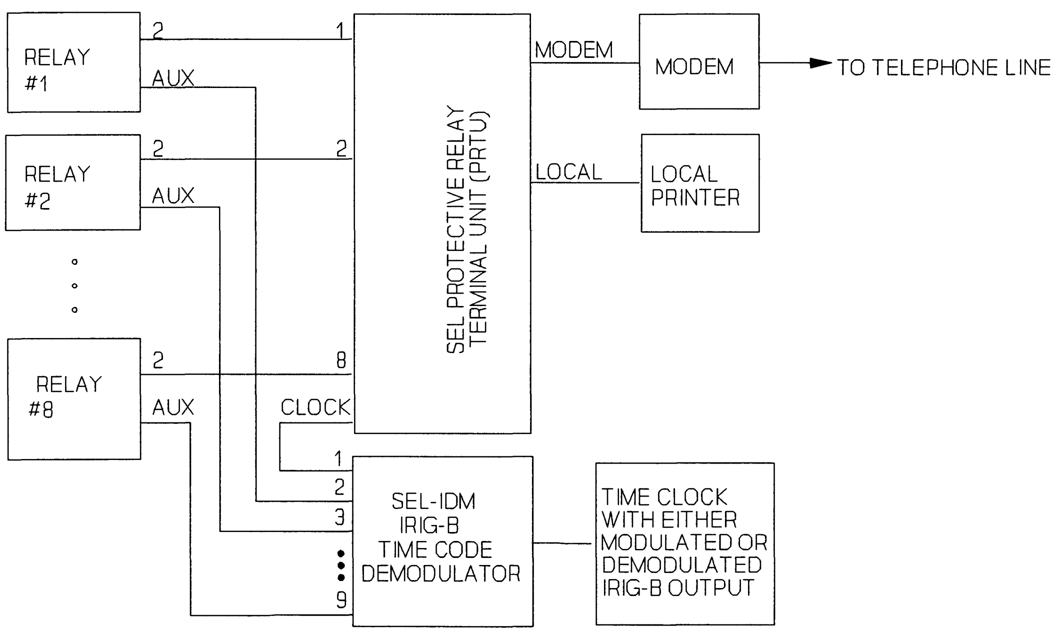


Figure 6.5: Communications and Clock Connections - Multiple Units at One Location

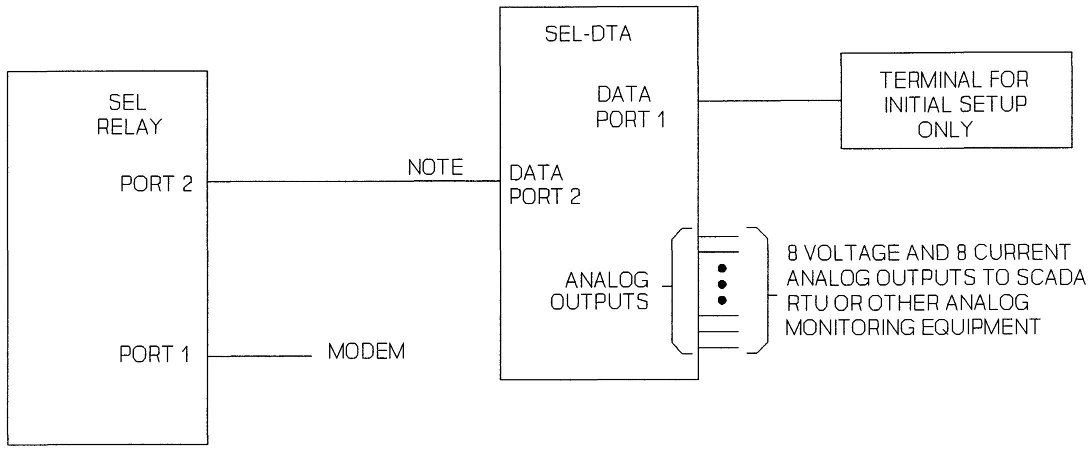


Figure 6.6: SEL Relay Communications Diagram for Connection to the SEL-DTA

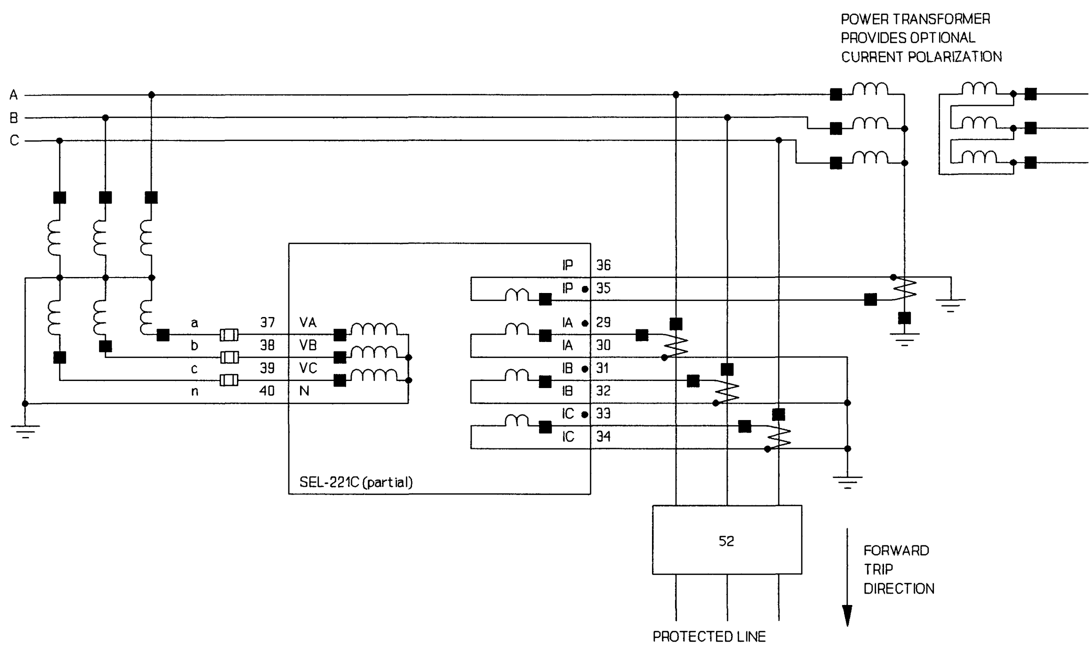


Figure 6.7: External AC Current and Voltage Connections

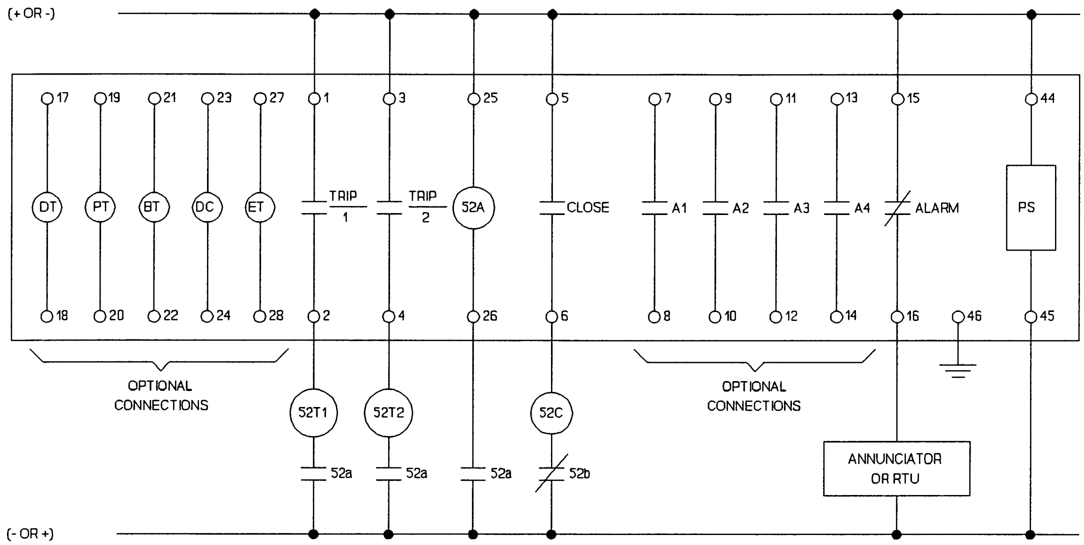


Figure 6.8: External DC Connection Diagram (Typical)

SEL DIRECTION AND POLARITY CHECK FORM

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

SWITCH NO.: ______________ EQUIPMENT: ______________________

INSTALLATION: ________ ROUTINE: ________ OTHER: ______________________

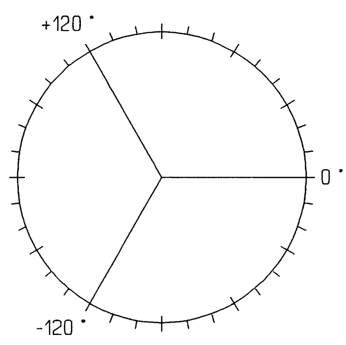
LOAD CONDITIONS

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

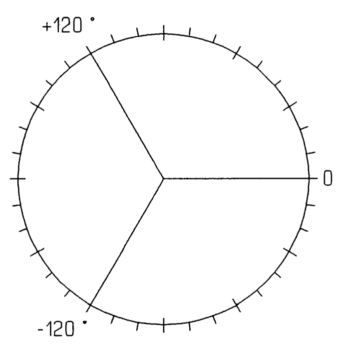
SEL READINGS: ________ MW (+)(-) ________ MVAR (+)(-)

AS SEEN ON SCREEN	**Ia**	**Ib**	**Ic**	**Va**	**Vb**	**Vc**	
COMPANY NOTATION	I( )	I( )	I( )	V( )	V( )	V( )	
1st LINE CHOSEN (Y COMPONENT)							
2nd LINE CHOSEN (X COMPONENT)							
CALCULATED MAGNITUDE $\sqrt{X^2 + Y^2}$							ROW 1
ANGLE IN DEGREES ARCTAN Y/X							
VALUE OF Va DEGREES TO 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

DWG: A7-0446

SEL DIRECTION AND POLARITY CHECK FORM

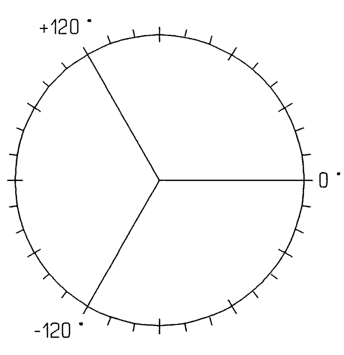
STATION: ______________________ DATE: ___/___/___ TESTED BY: ______________
SWITCH NO.: ______________ EQUIPMENT: ______________________________
INSTALLATION: ______ ROUTINE: ______ OTHER: ______________________________

LOAD CONDITIONS

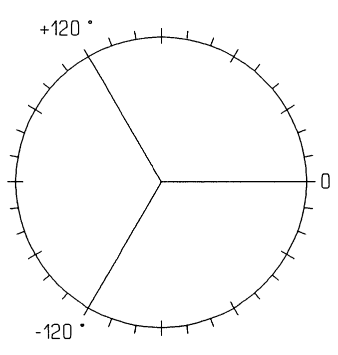
STATION READINGS: ______ MW (OUT)(IN) ______ MVAR (OUT)(IN) ______ VOLTS ______ AMPS
SEL READINGS: ______ MW (+)(-) ______ MVAR (+)(-)

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 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

DWG: A7-0446

MAINTENANCE & TESTING
TABLE OF CONTENTS

Test Procedures 7-1
Test Aids Provided by the Relay 7-1
METER Command 7-1
TARGET Command 7-1
Event Reporting 7-1
Programmable Logic 7-2
Low-Level Test Interface (patents pending) (Available only in SEL-200 series relays) 7-2
Test Methods 7-3
Testing Via Target LED Illumination 7-3
Testing Via Output Contact Assertion 7-3
Using a Breaker Simulator 7-4
Initial Checkout 7-4
Minimum Equipment Required 7-4
Checkout Procedure 7-4
Output Contact Explanation 7-12
Target LED Explanation 7-12
Full Functional Test 7-13
Equipment Required 7-13
What Should Be Tested 7-14
Setting Test 7-14
Meter Test 7-15
Mho Element Testing 7-17
A. Determining Fault Simulation Values - Phase-Phase and Phase-Ground Faults 7-17
B. Onebus Input Description 7-18
C. Determining Fault Simulation Values - Three-Phase Faults 7-19
D. Three-Phase Mho Relay Test 7-20
E. Phase-Phase Mho Element Tests 7-24
Directional Element Tests 7-27
32Q and 32V Tests 7-27
32I Tests 7-29
Residual Overcurrent Element Tests 7-30
Residual Time-Overcurrent Element Timing Tests 7-30
Phase Overcurrent Element Tests 7-31
Phase Time-Overcurrent Element Test 7-32
Memory Voltage Polarization Test 7-33
Loss-Of-Potential Test 7-34
50MF, 50MFD Test 7-34
Z2DG and Z3DG Timer Tests 7-35
Z3DP Timer Test 7-36
Switch-Onto-Fault Tests 7-37
Recloser Test, LLC = N, DLC = N 7-38
Recloser Test, LLC = N, DLC = Y 7-39
Recloser Test, LLC = Y, DLC = N 7-40
Input Circuits Test 7-41

Serial Ports Test 7-42
IRIG-B Time Code Input Test 7-42
Power Supply Voltages Test 7-42
Relay Calibration 7-43
Troubleshooting 7-44
    Inspection Procedure 7-44
    Troubleshooting Table 7-44
        All Front Panel LEDs Dark 7-44
        System Does Not Respond to Commands 7-44
        Tripping Output Relay Remains Closed Following Fault 7-45
        No Prompting Message Issued to Terminal upon Power-Up 7-45
        System Does Not Respond to Faults 7-45
        Terminal Displays Meaningless Characters 7-46
        Self-Test Failure: +5 Volts 7-46
        Self-Test Failure: +15 Volts 7-46
        Self-Test Failure: -15 Volts 7-46
        Self-Test Failure: Offset 7-46
        Self-Test Failure: ROM Checksum 7-46
        Self-Test Failure: RAM 7-46
        Self-Test Failure: A/D Converter 7-47
        Alarm Contact Closed 7-47
Firmware Upgrade Instructions 7-47
    Firmware Upgrade Instructions, SEL-121C Relay 7-47
    Firmware Upgrade Instructions, SEL-221C Relay 7-49
    Factory Assistance 7-49

TABLES

Table 7.1:	Fault Locator Test Values	7-11
Table 7.2:	Target LED Results	7-11
Table 7.3:	Three-Phase Fault Voltages and Currents at MTA	7-20
Table 7.4:	Zone 1 Three-Phase Element Test Quantities at MTA	7-22
Table 7.5:	Zone 1 Three-Phase Test Quantities at MTA $\pm 45°$	7-23
Table 7.6:	Zone 1 Phase-Phase Test Voltages and Currents, BC Fault	7-26
Table 7.7:	Zone 1 Phase-Phase Test Quantities at MTA $\pm 45°$	7-27
Table 7.8:	32Q and 32V Test Voltages	7-28
Table 7.9:	32I Test Currents	7-29
Table 7.10:	Current Quantities for 51N Timing Test Example	7-31
Table 7.11:	Zone 2 Phase-Phase Test Voltages and Currents, 51P Test	7-32
Table 7.12:	Three-Phase Close-In Fault	7-33
Table 7.13:	Conditions for the SET LOP and CLEAR LOP Logic Equations	7-34
Table 7.14:	Standard Zone 2 AG Fault Using Factory Relay Settings	7-35
Table 7.15:	Standard Zone 3 AG Fault Using Factory Relay Settings	7-35
Table 7.16:	Standard Zone 3 BC Fault Using Factory Relay Settings	7-36
Table 7.17:	Zone 2 AG Fault Quantities	7-37
Table 7.18:	Zone 1 AG Fault Quantities	7-38
Table 7.19:	Contact Inputs	7-42

FIGURES

Figure 7.1:	Low-Level Test Interface	7-2
Figure 7.2:	Relay Part Number and Hardware Identification Sticker	7-5
Figure 7.3:	Communication Interface Setup	7-6
Figure 7.4:	METER Test Connections	7-16
Figure 7.5:	Example ONEBUS Input Data for Phase-Phase and Ground Faults	7-17
Figure 7.6:	Example ONEBUS Result Screen for Phase-Phase and Ground Faults	7-18
Figure 7.7:	Example ONEBUS Input Data for Three-Phase Faults	7-19
Figure 7.8:	Example ONEBUS Result Screen for Three-Phase Faults	7-19
Figure 7.9a:	Three-Phase Voltage and Current Source Test Connections for Three-Phase Mho Test	7-21
Figure 7.9b:	Three-Phase Voltage and Two-Phase Current Source Test Connections for Three-Phase Mho Test	7-22
Figure 7.10a:	Three-Phase Voltage and Two-Phase Current Source Test Connections for Phase-Phase Mho Test	7-25
Figure 7.10b:	Three-Phase Voltage and One-Phase Current Source Test Connections for Phase-Phase Mho Test	7-25
Figure 7.11:	Three Voltage vs. One Voltage for Directional Tests	7-28
Figure 7.12:	Current Polarized Directional Element Test Connection	7-29
Figure 7.13:	SEL-221C Relay 9-Pin Connector Pin Number Convention	7-43
Figure 7.14:	SEL-121C Relay 9-Pin Connector Pin Number Convention	7-43

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 scaled 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.

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 of elements in much the same manner as an output contact. See Section 3: COMMUNICATIONS for more information about the TARGET command.

By using the target LEDs for testing, you need not change the relay settings during testing.

Event Reporting

The relay generates an eleven-cycle event report in response to faults or disturbances. Each event report contains voltage and current information, relay element states, and input/output contact information in quarter-cycle resolution. If you question the relay response or your test method, use the event report for more information.

Each event report is date and time tagged. The time corresponds to data taken in the sixteenth quarter-cycle. Each report is triggered upon assertion of designated relay elements and/or contact inputs and outputs. If the timeout of a protective element results in TRIP output contact closure, the trip triggers a second event report. Thus, the relay can generate two event reports: the first when the instantaneous element asserted, the second when the TRIP output contact closes. Where time delayed pickup (TDPU) timers are concerned, the time tag in the event reports may be used to determine the validity of a TDPU timer setting. Simply subtract the latest event report time tag from the previous event report time tag. Section 2: SPECIFICATIONS has further details concerning event report generation.

Programmable Logic

Programmable logic allows you to isolate individual relay elements. See the LOGIC command description in Section 3: COMMUNICATIONS for further details.

Low-Level Test Interface (patents pending) (Available only in SEL-200 series relays)

The relay has low-level test interface between the calibrated input module and the separately-calibrated processing module. You may test the relay in either of two ways: conventionally, by applying ac current signals to the relay inputs; or by applying low magnitude ac voltage signals to the low-level test interface. Access the test interface by removing the relay front panel.

Figure 7.1 shows the interface connections. This drawing also appears on the inside of the relay front panel. Remove the ribbon cable between the two modules to access the outputs of the input module and the inputs to the processing module (relay main board).

You can test the relay processing module using signals from the SEL-RTS Low-Level Relay Test System. Never apply voltage signals greater than 20 volts peak-peak to the low-level test interface. Figure 7.1 shows the signal scaling factors.

You can test the input module two different ways:

- Measure the outputs from the input module with an accurate voltmeter, and compare the readings to accurate instruments in the relay input circuits, or

- replace the ribbon cable, execute the METER command, and compare the relay readings to accurate instruments in the relay input circuits.

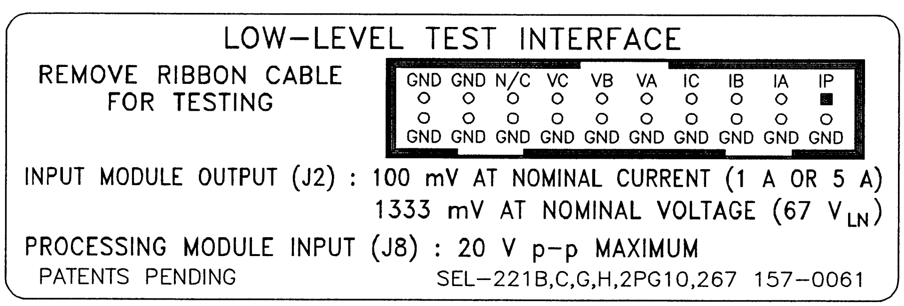


Figure 7.1: Low-Level Test Interface

Test Methods

There are two means of determining the pickup and dropout of relay elements: target lamp illumination and output contact closure.

Testing Via Target LED Illumination

During testing you can use target lamp illumination to monitor relay element status. Using the TARGET command, set the front panel targets to display the element under test. For example, the Zone 1 three-phase distance element appears in Relay Word row 1. When you type the command **TARGET 1 <ENTER>**, the LEDs display the status of the elements in Relay Word row 1. Thus, with Target 1 displayed, if the Zone 1 three-phase distance element (1ABC) asserts, the left most LED illuminates. Using LED illumination as an indicator, you can measure the element operating characteristics.

When the TARGET command sets the target LED output to a level other than 0 (Relay Targets), the front panel target markings no longer correspond 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 the relay transmits an automatic message to a timed out port. While this feature helps prevent confusion among station operators and readers, it can be inconvenient if the relay tester does not want targets to revert to Level 0.

To simplify testing using targets, set the relay AUTO setting equal to the port which you intend to use. Also, set that port TIME setting equal to zero. This prevents automatic message transmission to a port which may be timed out. Remember to reset these settings and the target level before returning the relay to service following tests.

Testing Via Output Contact Assertion

To test using this method, set one programmable output contact to assert when the element under test picks up. With the LOGIC n command, set a 1 in the mask for the element under test. Set all other elements in that mask to 0.

For an "a" contact, when the condition asserts, the output contact closes. When the condition deasserts, the output contact opens.

For a "b" contact, when the condition asserts, the output contact opens. When the condition deasserts, the output contact closes. Programmable contacts can be specified at the factory as either "a" or "b." Using contact operation as an indicator, you can measure element operating characteristics, start or stop timers, etc.

Tests in this section use the output contact method and assume an "a" output contact.

Using a Breaker Simulator

Because the switch-onto-fault and recloser logic depend on whether the breaker is open (52A input de-energized) or closed (52A input energized), it is important to use a breaker simulator for these tests. We recommend testing the relay with a latching relay to simulate line breaker auxiliary contact action. This ensures proper assertion and deassertion of the 52A input contact on the back panel. If you do not have a means of simulating breaker action and status, zero out the MTO logic mask and omit the recloser tests.

INITIAL CHECKOUT

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

Minimum Equipment Required

The following equipment is necessary for initial checkout.

1. Terminal with EIA-232 serial interface
2. Interconnecting cable between terminal and relay
3. Source of control power
4. Source of three-phase voltages and at least two currents
5. Ohmmeter or contact opening/closing sensing device

Checkout Procedure

In the procedure below, you will use several relay commands. Section 3: COMMUNICATIONS provides a full explanation of all commands. The following information should allow you to complete the checkout without referring to the detailed descriptions in Section 3.

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

Relay output appears in the following format:

```
Example 69 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 7.2 provides an example. Information on this sticker is important to note before applying power to the relay or starting tests. Be sure your dc supply is correctly adjusted for the control and logic input requirements.

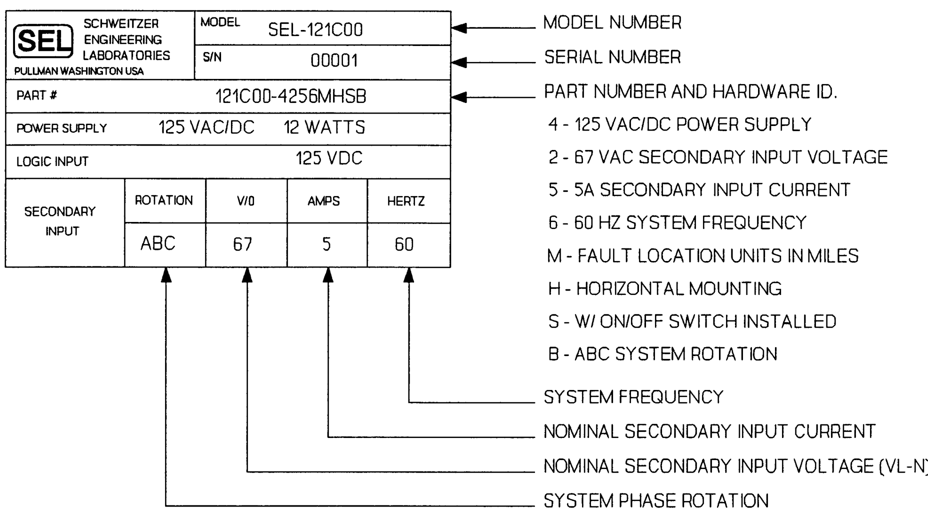


Figure 7.2: Relay Part Number and Hardware Identification Sticker

- **Step 3**

Purpose: Verify the communications interface setup.

Method: Connect a computer terminal to Port 2 on the relay front or rear panel. The terminal should be configured to 2400 baud, eight data bits, 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 information about port configurations. Baud rate selection is described under Jumper Selection in Section 6: INSTALLATION. Figure 7.3 shows the typical communication interface setup for testing purposes.

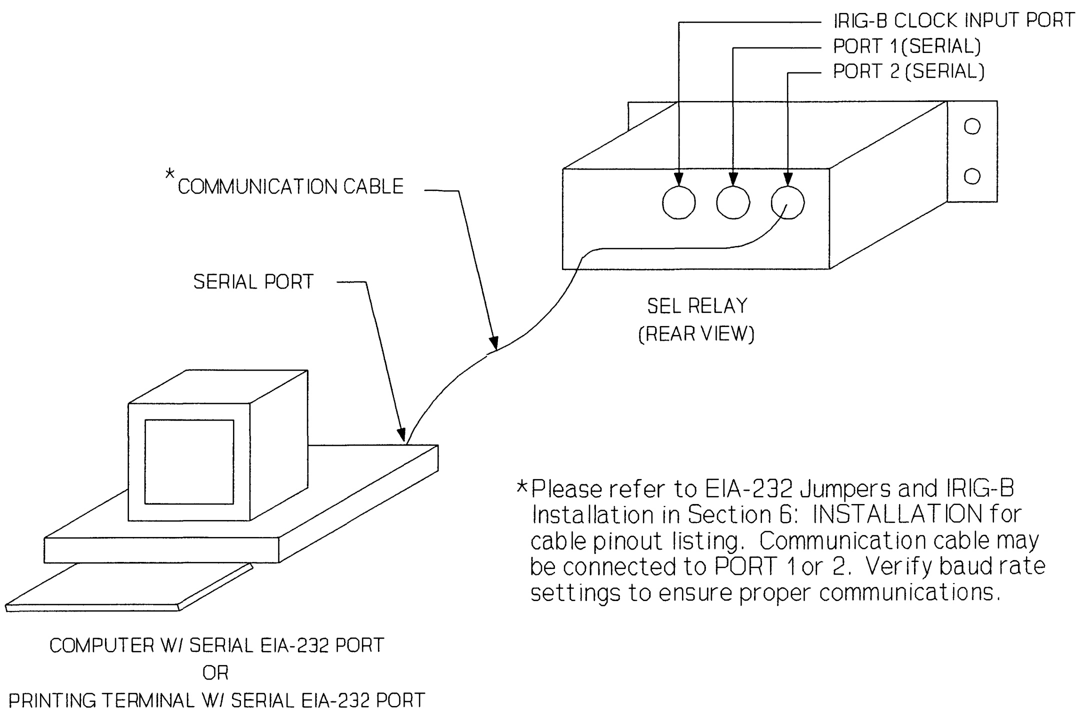


Figure 7.3: Communication Interface Setup

- **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 Vac wall receptacle for testing. In the final installation, we recommend that the relay receive control power from the station dc battery to avoid losing events stored in volatile memory if 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 69 kV Line              Date: 1/1/92  Time: 01:01:01

SEL-121C
=
```

The ALARM relay should pull in, holding its "b" contacts open. 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.

- **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 relay self-test status.

Method: Type **STATUS** and press **<ENTER>**. The following display should appear on the terminal:

```
=>STATUS <ENTER>


Example 69 kV Line                        Date: 1/1/92        Time: 11:04:01
SELF-TESTS

W=Warn F=Fail
      IP   IR   IA   IB   IC   VA   VB   VC
OS    0    0    -2   0    0    0    0    0
PS     5.03     15.08    -15.22
RAM    ROM    A/D    MOF    SET
OK     OK     OK     OK     OK
```

- **Step 8**

Purpose: View the demonstration settings entered before shipment.

Method: The relay is shipped with demonstration settings; type **SHOWSET <ENTER>** to view the settings. The terminal should display the following:

```
=>SHOWSET <ENTER>

Settings for: Example 69 kV Line

R1   =49.83    X1   =56.32    R0   =56.07    X0   =143.07   LL   =60.00
CTR  =60.00    PTR  =600.00   MTA  =48.50    LOCAT=Y
47PXD=10.00    47PXL=25.00    59N  =10.00    VCT  =100.00
LLC  =N        DLC  =Y        CVC  =Y        VSA  =N
79OI1=40.00    79OI2=60.00    79OI3=80.00    79RS =240.00
50L  =50.00    50M  =100.00   50MF =20.00    50H  =1500.00
Z1%  =80.00    Z2%  =120.00   Z3%  =150.00   Z3DP =60.00
51PP =120.00   51PTD=3.00     51PC =2
51NP =100.00   51NTD=2.00     51NC =3        51NTC=Y        TDUR =9.00
50N1P=403.00   50N2P=288.00   50N3P=237.00   Z2DG =20.00    Z3DG =40.00
52BT =30.00    ZONE3=F        32QE =Y        32VE =N        32IE =N
LOPE =Y        TIME1=5        TIME2=0        AUTO =2        RINGS=3

Logic settings:

MTU  MPT  MTB  MTO  MA1  MA2  MA3  MA4  MRI  MRC
C0   00   00   F4   20   80   00   00   00   F4
C4   00   00   F7   22   80   00   00   44   80
31   00   00   00   00   00   02   04   00   31
30   00   00   30   00   00   00   00   00   30

=>
```

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:

51PT	1ABC	2ABC	3ABC	51PP	50H	50L	LOP
51NT	67N1	67N2	67N3	51NP	Z1P	Z2P	Z3P
DF	DR	Z2GT	Z3GT	50MF	RC	RI	Z3PT
50M	TRIP	TC	DT	52BT	59N		

Logic settings appear in hexadecimal format. A table and example of hexadecimal to binary conversion appears with the SHOWSET command description in Section 3: COMMUNICATIONS.

- **Step 9**

Purpose: Connect voltage and current sources to the relay.

Method: Turn power off and connect a source of three-phase voltages to the relay at terminals marked VA, VB, VC, and VN (See Figure 7.9b). Apply 67 volts per phase (line-to-neutral) in ABC Phase Rotation. Wye-connect the two current sources as shown in Figure 7.9b to generate balanced positive-sequence currents:

9a. Connect the Aϕ and Bϕ 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 correct voltage and current connections and levels.

Method: Turn the relay on and enter Access Level 1. Turn on voltage and current sources. Use the METER command to measure the voltages and currents applied. With applied voltages of 67 volts per phase and a potential transformer ratio of 600:1, the displayed line-to-neutral voltages should be 40.2 kV. With applied currents of 2.0 amperes per phase and a current transformer ratio of 60:1, the displayed line-to-neutral currents should be 120 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 14.47 MW; reactive power Q should be approximately 0 MVAR.

```
=> METER <ENTER>

Example 69 kV Line                   Date: 01/01/92        Time: 00:01:00

              A        B        C        AB       BC      CA
I (A)        121      120      121      207      208     208
V (kV)       40.2     40.0     40.0     69.6     69.4    69.6

P (MW)       14.45
Q (MVAR)      0.32

=>
```

If you inadvertently switched a pair of voltages or currents, the MW reading should be incorrect.

■ Step 11

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 60 mile line impedance. A listing of this BASIC program is included in this manual (see Appendix C).

Note: To simplify this step, apply rated logic voltage across the 52A input prior to applying each fault. This 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
36 miles	AG	50.25	71.14	67.41	8.39	0.00	0.00	V or A
		0.00	-122.0	124.0	-59.0	0.00	0.00	Degrees
	BC	67.00	54.92	54.92	0.00	9.64	9.64	V or A
		0.00	-128.0	128.0	0.00	-139.0	41.0	Degrees
51 miles	AG	54.24	70.15	67.28	6.39	0.00	0.00	V or A
		0.00	-122.0	122.0	-59.0	0.00	0.00	Degrees
	BC	67.00	57.69	57.69	0.00	7.35	7.35	V or A
		0.00	-126.0	126.0	0.00	-139.0	41.0	Degrees
75 miles	AG	57.76	69.27	69.27	4.63	0.00	0.00	V or A
		0.00	-121.0	121.0	-59.0	0.00	0.00	Degrees
	BC	67.00	60.20	60.20	0.00	5.32	5.32	V or A
		0.00	-124.0	124.0	0.00	-139.0	41.0	Degrees

The phase fault at 36 miles is within Zone 1, since the Zone 1 reach setting is 80.0% of the 60 mile positive-sequence line impedance (see Z1% in the settings). The ground fault at 36 miles is a Zone 1 fault because the residual current is above the 50N1P pickup setting. The phase fault at 51 miles is beyond Zone 1, but within the 120% setting of Zone 2 phase distance element (see Z2% in the settings). This fault is cleared by 51P element operation. The ground fault at 51 miles is a Zone 2 fault because residual current is above the 50N2P setting, but below the 50N1P setting. The phase fault at 75 miles is within Zone 3, set to 150% (see Z3% in the settings). The ground fault at 75 miles is a Zone 3 fault because residual current is above the 50N3P setting but below the 50N2P setting.

Faults listed in Table 7.1 cause certain combinations of front panel LEDs to illuminate. Table 7.2 shows the results. Note that these tests assume you are using a breaker simulator. If you are not using a breaker simulator, remember to zero out the MTO logic mask.

Table 7.2: Target LED Results

LOCATION	TYPE	TARGET LED
36 mi	AG	**G1**
36 mi	BC	**ϕ1**
51 mi	AG	**G2**
51 mi	BC	**ϕ2**
75 mi	AG	**G3**
75 mi	BC	**ϕ3**

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 resulting in expiration of the 51P phase time-overcurrent element
3. Any Zone 2 line-to-ground fault which persists for 20 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 40 cycles
6. Any forward line-to-ground fault resulting in expiration of the residual time-overcurrent element (51NT)
7. DT input assertion
8. The OPEN command

The output relay A1 is set to permissive trip for any Zone 2 fault. Output relay A1 should close for all faults except the Zone 3 ground and phase faults.

The phase and residual time-overcurrent trips are monitored with the A2 output. The output relay A2 operates on any of the phase and ground faults in the first table if the fault condition persists longer than the time delays specified by the settings. The 51N fault target does not illuminate if the 51N is not the element which caused the trip. If the fault clears before the 51N time is elapsed, the 51N should not trip.

Reclose initiate and cancel are monitored with the output relays A3 and A4 respectively. The output relay A3 should close for Zone 1 faults only, since the logic mask MRI is set to reclose initiate for Zone 1 ground and phase-to-phase faults.

If any of the faults listed in the first table persist, relay A4 should close to show that reclose is cancelled. The reclose cancel (A4) closes only if the reclosure is cancelled due to assertion of a bit set in the MRC logic mask.

The output relays A1 - A4 and four trip logic mask settings are explained in detail in the LOGIC command description, Section 3: COMMUNICATIONS.

Target LED Explanation

G1: The AG ground fault at 36 miles should illuminate the Zone 1 ground fault target (G1).

G2: The AG ground fault at 51 miles should illuminate the G2 target.

G3: The AG ground fault at 75 miles should illuminate the G3 target.

ϕ1: The Zone 1 BC fault at 36 miles should illuminate the ϕ1 Target.

$\phi 2$: The Zone 2 BC fault at 51 miles should illuminate the $\phi 2$ Target.

$\phi 3$: The Zone 3 BC fault at 75 miles should illuminate the $\phi 3$ Target.

Note: The target level must be at Level 0 to display the fault targets. See the TARGET command description in Section 3: COMMUNICATIONS for more details.

Each fault generates a short event report. To see the full event report for the last fault, type **EVENT 1** and press **<ENTER>**. Each event report provides an eleven-cycle record of the currents, voltages, relay element states, and all contact input and output states. The twelve newest reports are saved.

- **Step 12**

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 asserting the LOP bit in Relay Word row 1 (TAR 1 command).

This checkout procedure demonstrates only a few relay features. For a complete understanding of relay capabilities, study Functional Description in Section 2: SPECIFICATIONS, the command descriptions in Section 3: COMMUNICATIONS, and Section 4: EVENT REPORTING. For more test procedures, see the Full Functional Test portion of this section.

FULL FUNCTIONAL TEST

This procedure allows you to test the protective and control functions of the relay more fully than the initial checkout procedure does.

Equipment Required

The following equipment is necessary to complete a full functional test:

1. Communications terminal with EIA-232 serial interface
2. Data cable to connect terminal and relay
3. Source of relay control power
4. Source of synchronized three-phase voltages and at least two currents
5. Ohmmeter or contact opening/closing sensing device
6. Timer with contact inputs for start and stop

What Should Be Tested

A full functional test includes the initial checkout procedure and the additional steps described below. In general, these tests assure that the relay settings match your application rather than checking relay performance. For commissioning purposes, your company policy may require you to perform the full functional test. For maintenance purposes, a quick test of selected fault types and zones should suffice. For example, test a Zone 1 AG fault, Zone 2 BC fault, and a Zone 3 ABC fault.

SETTING TEST

Purpose: Ensure that the relay accepts settings.

Method:

1. Gain Level 2 Access (see ACCESS and 2ACCESS commands in Section 2: COMMUNICATIONS).

2. Change one setting. For example, change the Zone 1 reach from 80 to 82%.

   Type **SET Z1%** and press **<ENTER>**.

   Following the Z1% prompt, type **82** and press **<ENTER>**.

3. To complete the setting procedure, type **END** and press **<ENTER>**. Type **Y <ENTER>** at the prompt: "OK (Y or N) ?" The relay computes internal settings and compares them against fixed limits. If all settings are within acceptable ranges, the ALARM contact closes momentarily as the new settings are enabled, unless an alarm condition already exists (e.g., self-test failure).

4. Use the SHOWSET command to inspect settings. Make sure your change was accepted.

   Type **SHOWSET** and press **<ENTER>**.

5. Use SET and SHOWSET again to restore the initial values and check the settings.

6. Type **LOG MTU** and press **<ENTER>**.

7. Change one bit in the MTU logic mask. For example, remove the TC bit from the fourth row of the Relay Word as shown in the following example.

```
=>>LOGIC MTU <ENTER>

1 selects, 0 deselects.

51PT 1ABC 2ABC 3ABC 51PP 50H  50L  LOP
 1    1    0    0    0    0    0    0
 ? <ENTER>
51NT 67N1 67N2 67N3 51NP Z1P  Z2P  Z3P
 1    1    0    0    0    1    0    0
 ? <ENTER>
DF   DR   Z2GT Z3GT 50MF RC   RI   Z3PT
 0    0    1    1    0    0    0    1
 ? <ENTER>
50M  TRIP TC   DT   52BT 59N
 0    0    1    1    0    0    0    0
 ? 00010000 <ENTER>
 0    0    0    1    0    0    0    0
 ? <ENTER>

New MTU :

51PT 1ABC 2ABC 3ABC 51PP 50H  50L  LOP
 1    1    0    0    0    0    0    0
51NT 67N1 67N2 67N3 51NP Z1P  Z2P  Z3P
 1    1    0    0    0    1    0    0
DF   DR   Z2GT Z3GT 50MF RC   RI   Z3PT
 0    0    1    1    0    0    0    1
50M  TRIP TC   DT   52BT 59N
 0    0    0    1    0    0    0    0

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

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 7.4 for the test connections.

2. Series all current inputs as shown in Figure 7.4.

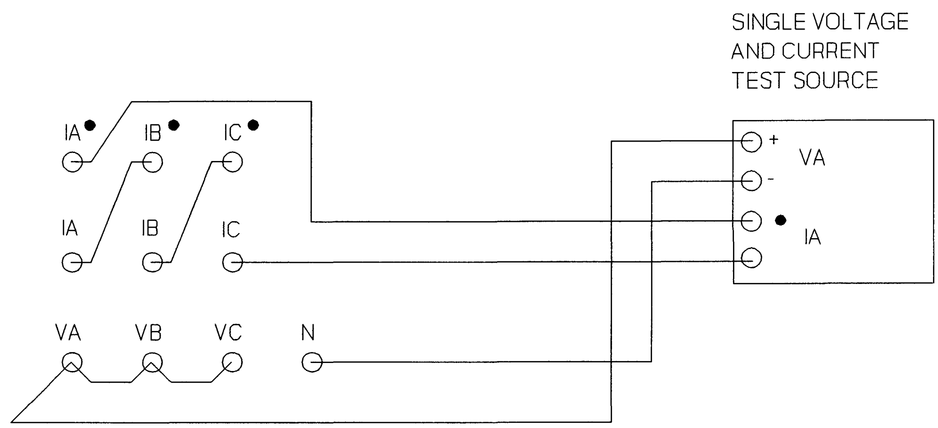


Figure 7.4: METER Test Connections

3. Apply a voltage of 50 Vac between the paralleled voltage inputs to the neutral point and a current of five amperes through the three inputs. The phase angle of the voltage and current source should be set to 0°.

4. Use the METER command to inspect measured voltages, currents, and power. Voltages VA, VB, and VC should equal the applied voltage times the potential transformer ratio setting. With the Example 69 kV Line settings, you should obtain:

$$VA = VB = VC = (50\ V)(600) = 30\ kV\ (\pm 0.5\%).$$

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 69 kV Line settings, you should obtain:

$$IA = IB = IC = (5\ A)(60) = 300\ A\ (\pm 1\%).$$

Difference currents IAB, IBC, and ICA should be less than 20 amperes.
The power reading, P (MW), should read:

$$(VA)(IA) + (VB)(IB) + (VC)(IC) = 27\ MW.$$

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 Appendix C for a simple program (ONEBUS) to calculate the voltages and currents required to simulate a power system fault at the line angle.

Note: ONEBUS is included as a test aide; it is not required to test the relay.

During mho element tests, we recommend disabling the loss-of-potential (LOP) logic by setting LOPE = N in the relay set procedure. This prevents an LOP condition from blocking mho distance elements. You must enable the LOP feature during LOP testing.

A. Determining Fault Simulation Values - Phase-Phase and Phase-Ground Faults

All line impedance entries for the ONEBUS program must be entered in secondary values. Convert the primary impedance settings from your relay setting sheet or SHOWSET printout to secondary values with the following formula:

$$\text{R1 secondary} = \text{R1}\left(\frac{\text{Current Transformer Ratio}}{\text{Potential Transformer Ratio}}\right)$$

$$\text{X1 secondary} = \text{X1}\left(\frac{\text{Current Transformer Ratio}}{\text{Potential Transformer Ratio}}\right)$$

$$\text{R0 secondary} = \text{R0}\left(\frac{\text{Current Transformer Ratio}}{\text{Potential Transformer Ratio}}\right)$$

$$\text{X0 secondary} = \text{X0}\left(\frac{\text{Current Transformer Ratio}}{\text{Potential Transformer Ratio}}\right)$$

Next, calculate required voltages and currents for a single-line-to-ground and phase-phase fault at the boundary of the Zone 1 reach using the example settings provided with the relay. Enter the bold face data in Figure 7.5 into the ONEBUS program:

```
ENTER Z1: R,X? 4.983,5.632
ENTER Z0: R,X? 5.607,14.307
ENTER RF FOR GND FLTS? 0
DIST SOURCE TO BUS (PU OF LINE)? 0.2
DIST BUS TO FAULT (PU OF LINE)? 0.8
```

Figure 7.5: Example ONEBUS Input Data for Phase-Phase and Ground Faults

ONEBUS should produce the following output:

```
    VA       VB       VC       IA       IB      IC
  53.60    70.30    67.30     6.71     0.00    0.00      A-G
   0.0    -121.7    123.3    -58.7     0.0     0.0

    VA       VB       VC       IA       IB      IC
  67.00    57.24    57.24     0.00     7.72    7.72      B-C
   0.0    -125.8    125.8     0.0    -138.5   41.5

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

Figure 7.6: Example ONEBUS Result Screen for Phase-Phase and Ground Faults

B. Onebus Input Description

Line 1: On the first line, enter the real and reactive values of the secondary positive-sequence impedance for the entire transmission line. Separate each value with a comma.

Line 2: On the second line, enter the real and reactive values of the secondary zero-sequence impedance for the entire transmission line.

Line 3: The "RF FOR GROUND FAULTS" input allows you to introduce ground fault resistance into the line-ground fault cases. In most instances RF will be zero.

Line 4: The "DIST SOURCE TO BUS" input models the source strength behind the relay location as a source to line impedance ratio. Enter this setting 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 proportionally a lower voltage.

If the source impedance ratio is unknown, enter a source impedance ratio of one to determine whether calculated currents are within the range of the current source. It is desirable to keep the source impedance ratio as realistic as possible.

Line 5: The final input is the "DIST BUS TO FAULT." This is the distance from the relay terminal to the fault location. To obtain the voltages and currents for a fault at 80% of the line, enter 0.8 for the per unit distance from the bus to fault.

C. Determining Fault Simulation Values - Three-Phase Faults

Three-phase fault voltages and currents can be calculated with the ONEBUS program. Enter the positive-sequence line impedance values at the prompt for zero-sequence values and set the source impedance ratio to zero. The following uses the example relay settings:

```
ENTER Z1: R,X? 4.983,5.632
ENTER Z0: R,X? 4.983,5.632
ENTER RF FOR GND FLTS? 0
DIST SOURCE TO BUS (PU OF LINE)? 0.0
DIST BUS TO FAULT (PU OF LINE)? 0.8
```

Figure 7.7: Example ONEBUS Input Data for Three-Phase Faults

The following output should result:

```
   VA       VB       VC       IA       IB       IC
 67.00    67.00    67.00    11.14     0.00     0.00       A-G
  0.0   -120.0    120.0    -48.5      0.0      0.0

   VA       VB       VC       IA       IB       IC
 67.00    67.00    67.00     0.00     9.64     9.64       B-C
  0.0   -120.0    120.0      0.0   -138.5     41.5

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

Figure 7.8: Example ONEBUS Result Screen for Three-Phase Faults

Use the calculated single-phase fault (AG) values to simulate a three-phase fault. Voltages are applied as indicated in the program. The calculated A-phase current magnitude is applied to all three relay current inputs. Each current is applied lagging the corresponding voltage phase angle by the transmission line angle. These values are shown in Table 7.3.

Table 7.3: Three-Phase Fault Voltages and Currents at MTA

VA	VB	VC	IA	IB	IC	
67.00	67.00	67.00	11.14	11.14	11.14	Volts/Amps
0.00	-120.00	120.00	-48.5	-168.5	71.5	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

   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 as per Figure 7.9a or Figure 7.9b. Figure 7.9a uses three current sources; Figure 7.9b uses only two.

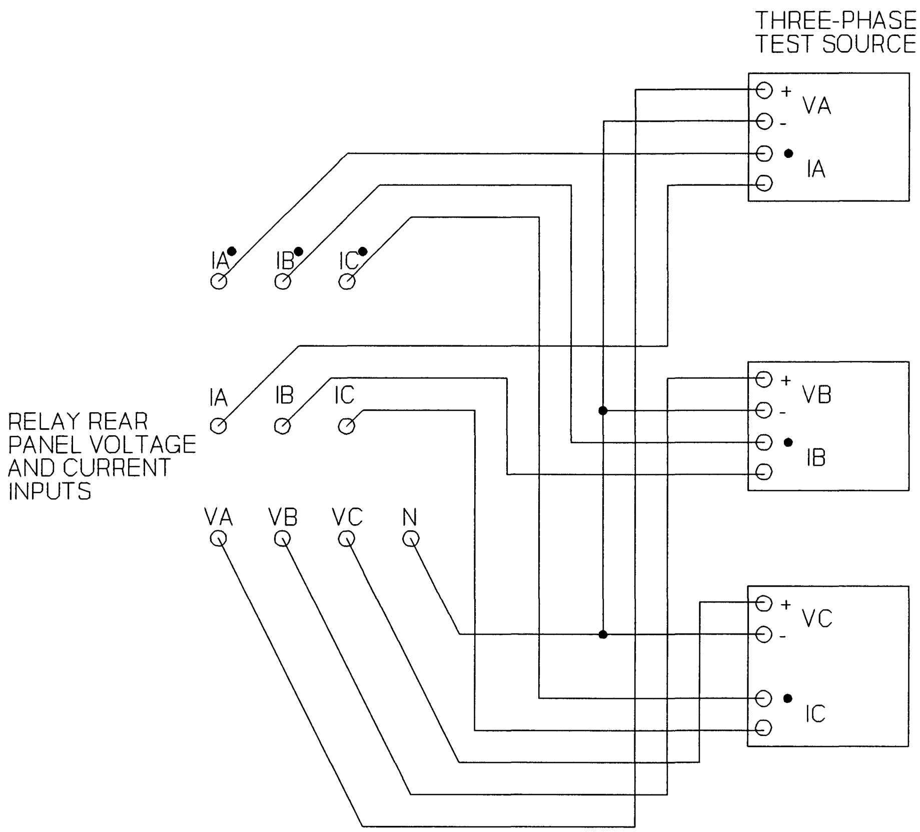


Figure 7.9a: Three-Phase Voltage and Current Source Test Connections for Three-Phase Mho Test

The two current source method yields the same results as does the three current source method but requires one less current source. For balanced three-phase faults, the residual or 3I0 is zero. From this you can see why two current sources are adequate for three-phase element testing:

$$3I0 = IA + IB + IC = 0$$

Therefore,

$$-IC = (IA + IB)$$

This has the same effect as performing the following steps:

a. Connect the dotted output of A and B current sources to the dotted IA and IB inputs of the relay.

b. Jumper together the undotted IA and IB current inputs of the relay. This forms the (IA + IB) quantity.

c. Connect a jumper between the undotted IA and IB current inputs to the undotted IC current input of the relay.

d. Connect the dotted IC current input of the relay to the common current source return of current Source A and B.

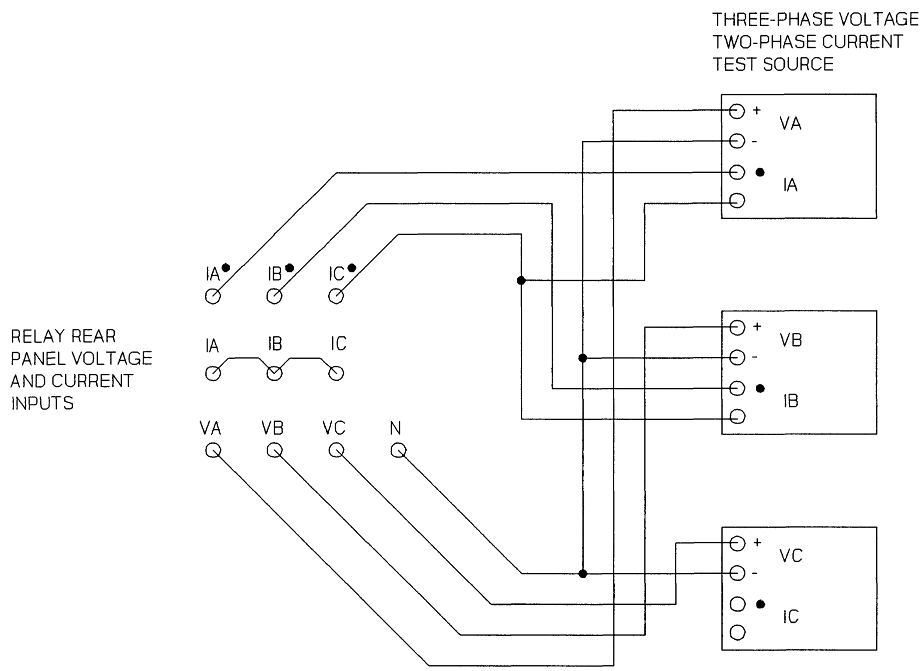


Figure 7.9b: Three-Phase Voltage and Two-Phase Current Source Test Connections for Three-Phase Mho Test

3. Determine the voltages and currents required to simulate a fault at the boundary of the desired relay reach (using ONEBUS or similar method). Table 7.4 shows currents and voltages required to test the example Zone 1 reach at MTA. These quantities were calculated using ONEBUS.

Table 7.4: Zone 1 Three-Phase Element Test Quantities at MTA

VA	VB	VC	IA	IB	IC	
67.00	67.00	67.00	11.14	11.14	11.14	Volts/Amps
0.00	-120.00	120.00	-48.5	-168.5	71.5	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 it 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 11.14 A, calculate the three-phase distance element reach as follows:

   Zone 1 reach secondary,

   $$Z1_{sec} = \frac{67V\ \angle 0°}{11.14A\ \angle{-48.5°}} = 6.01\Omega\ \angle 48.5°\ \text{secondary along the MTA}$$

   In primary ohms,

   Zone 1 reach primary along the MTA,

   $$Z1_{pri} = (6.01\Omega\ \angle 48.5°)\left(\frac{PTR}{CTR}\right) = 60.1\Omega\ \angle 48.5°\text{primary}$$

   Where PTR = 600 and CTR = 60.

7. Obtain two other convenient test points. Consider a square inscribed in a mho circle with one diagonal being the diameter along the MTA. To test the mho element at these points on the circle, rotate the current phase angle by plus or minus 45° and multiply phase current magnitude by 1.414.

   For the three-phase example, the required voltages remain unchanged. The current magnitudes are 11.14 A (1.414) = 15.75 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°	-3.5°	-123.5°	116.5
MTA -45°	-93.5°	146.5°	26.5

8. Test the relay at the two additional current phase angle settings (MTA +45° and MTA -45°). Record the results.

E. Phase-Phase Mho Element Tests

Purpose: Determine the pickup of the phase-phase distance element at three points on the mho characteristic: MTA, MTA +45° and MTA -45°.

Method:

1. Use the LOGIC command to program a single output relay (A1 - A4) to follow the appropriate instantaneous phase-phase distance element. Select a phase-phase element from the Relay Word as indicated below:

   Z1P = Zone 1 Instantaneous Phase-Phase Element
   Z2P = Zone 2 Instantaneous Phase-Phase Element
   Z3P = Zone 3 Instantaneous Phase-Phase Element

   Please note the Z1P element includes any delay set by the Z1DP timer.

   The following example outlines the test procedure for the Zone 1 phase-phase distance element.

2. Connect the sources of voltage and current to the relay rear panel terminals (see Figure 7.10a or Figure 7.10b). Note that Figure 7.10a shows two current sources; Figure 7.10b shows only one current source.

   The single current source method yields the same results as two sources and assures that the phase angle between the two involved currents is always 180°.

   These steps connect a single current source to the relay for a BC phase-phase fault test.

   a. Connect B current source dotted output to dotted relay IB input.

   b. Jumper undotted relay IB and IC current inputs together.

   c. Connect dotted relay IC current input to common current source return of current Source B.

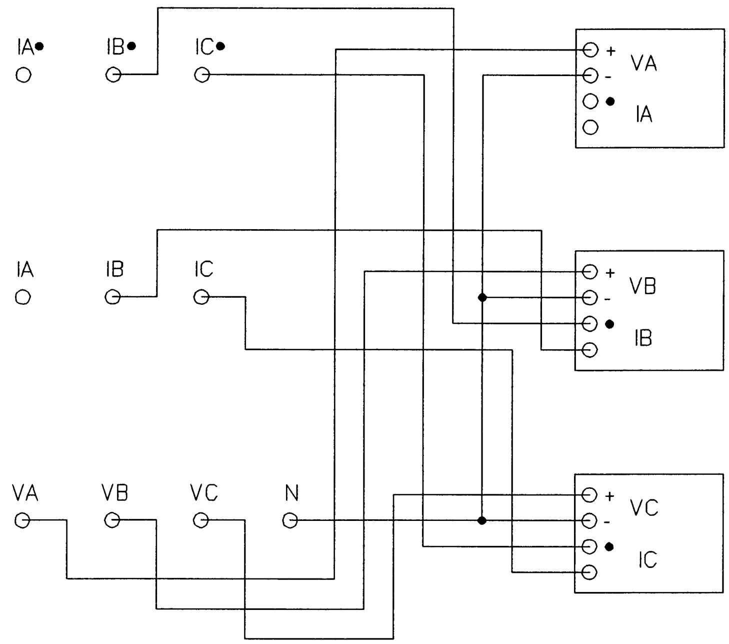


Figure 7.10a: Three-Phase Voltage and Two-Phase Current Source Test Connections for Phase-Phase Mho Test

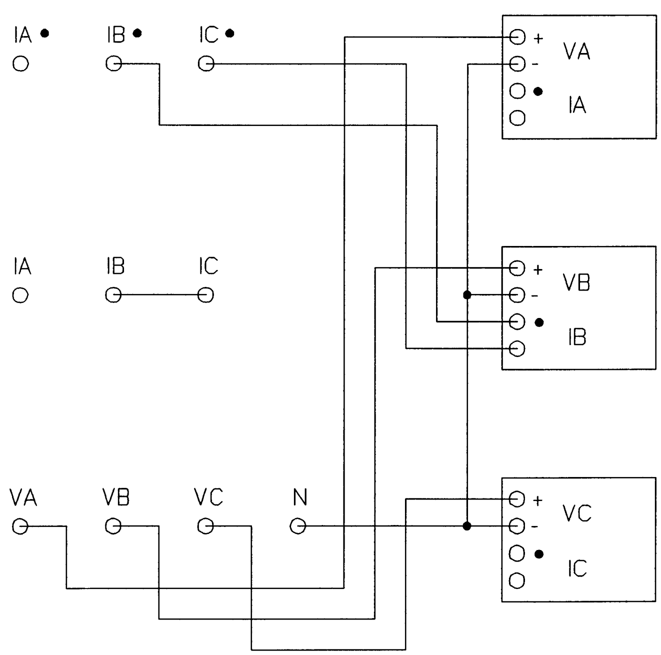


Figure 7.10b: Three-Phase Voltage and One-Phase Current Source Test Connections for Phase-Phase Mho Test

3. Determine the voltages and currents required to simulate a phase-phase fault at the boundary of the desired relay reach (using ONEBUS or similar method). Currents and voltages required to test the Zone 1 phase-phase element reach of the example settings appear in Table 7.6.

Table 7.6: Zone 1 Phase-Phase Test Voltages and Currents, BC Fault

VA	VB	VC	IA	IB	IC	
67.00	57.24	57.24	0.00	7.72	7.72	Volts/Amps
0.0	-125.8	125.8	0.0	-138.5	41.5	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).

   BC Fault

   $VB = 57.24\ V\ \angle -125.8°$
   $VC = 57.24\ V\ \angle 125.8°$
   $VBC = VB - VC = 92.85\ V\ \angle -90°$

   $IB = 7.72\ A\ \angle -138.5°$
   $IC = 7.72\ A\ \angle 41.5$
   $IBC = IB - IC = 15.44\ A\ \angle -138.5°$

   Zone 1 reach secondary along the MTA,

   $$Z1_{sec} = \frac{VBC}{IBC} = \frac{92.85\ V\ \angle -90°}{15.44A\ \angle -138.5°} = 6.01\Omega\ \angle 48.5°\ \text{secondary}$$

   In primary ohms,

   Zone 1 reach primary along the MTA,

   $$Z1_{pri} = (6.01\Omega\ \angle 48.5°)\left(\frac{PTR}{CTR}\right) = 60.1\Omega\ \angle 48.5°\ \text{primary}$$

   Where PTR = 600 and CTR = 60.

7. Find two other convenient test points. Consider a square inscribed in a mho circle with one diagonal being the diameter along the MTA. To test the mho element at these points on the circle, rotate the current phase angle by plus or minimum 45° and multiply phase current magnitude by 1.414.

   For our Zone 1 BC phase-phase example, the required voltages remain unchanged. The current magnitudes are (7.72)(1.414) = 10.92 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°	-93.5 °	86.5°
MTA -45°	176.5°	-3.5°

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).

<u>32Q and 32V Tests</u>

1. You can check the negative-sequence element and voltage polarized part of the zero-sequence element with the same method. 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 7.11 illustrates the difference between using a single voltage and current and using three voltages and a single current. For the sake of simplicity, this test uses the single voltage and current method. The relay declares ground faults in the forward direction when I2 (I0) leads ±90° from the MTA.

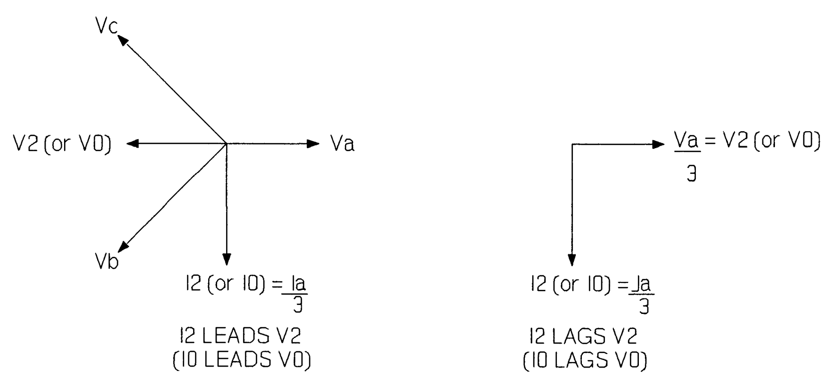


Figure 7.11: Three Voltage vs. One Voltage for Directional Tests

2. Apply IA greater than 50N2P setting. 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 directional element in the relay setting procedure. Apply the currents shown in Table 7.9 to the IA and IP current inputs with the test connection in Figure 7.12.

Table 7.9: 32I Test Currents

IA	Ipol	
> 50N2P setting	3.00	Amperes
0.0	0.0	Degrees

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

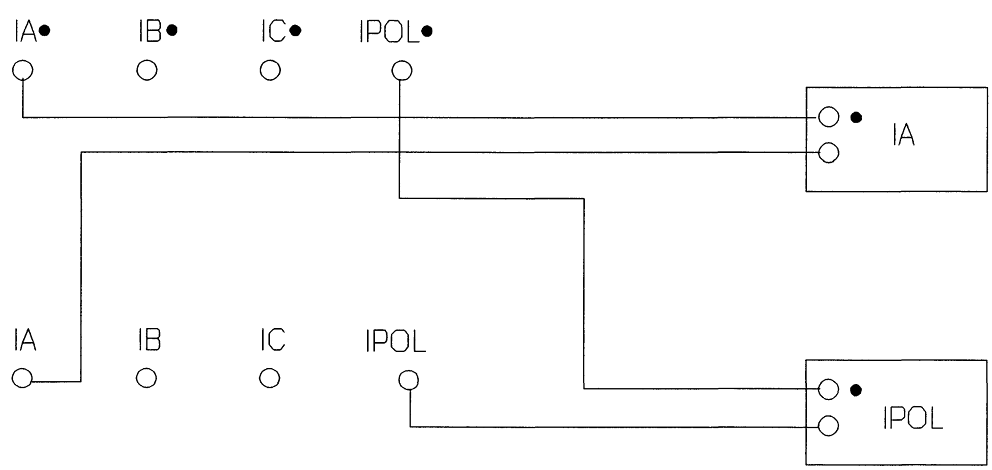


Figure 7.12: Current Polarized Directional Element Test Connection

6. Move the phase angle of IA with respect to the angle of IP to determine the zero torque axis. The maximum torque angle of the current polarized directional element is 0° (e.g.,

the A-phase current angle in phase with the IPOL current). The boundary of the characteristic should be at ±90°.

RESIDUAL OVERCURRENT ELEMENT TESTS

Purpose: Verify the pickup thresholds of the 67N1, 67N2, 67N3, and 51NP residual overcurrent elements.

Method:

1. Using the LOGIC command, set the desired programmable output (A1 - A4) to follow the appropriate overcurrent element. Select one of the overcurrent elements from the Relay Word as indicated below:

   67N1 = Zone 1 Instantaneous Residual Element (pickup set by 50N1P setting)
   67N2 = Zone 2 Instantaneous Residual Element (pickup set by 50N2P setting)
   67N3 = Zone 3 Instantaneous Residual Element (pickup set by 50N3P setting)
   51NP = Residual Time-Overcurrent Pickup Element

2. Disable all directional and LOP functions for this test. Set 51NTC, 32QE, 32VE, 32IE, ZONE3=F, and LOPE = 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 closed) to start an external timer.

3. Set another programmable output to follow 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 =2

$$t_M = 1.16 \text{ seconds}$$

For example, if the 51NP pickup setting is 1.67 amps secondary and the relay measures 5.0 amperes of residual current, the 51NT bit in the Relay Word asserts 1.16 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	
5.00	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. (Optional) 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 nondirectional 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. Pickup of the 50H element generates an event report.

PHASE TIME-OVERCURRENT ELEMENT TEST

Purpose: Verify the 51PT residual time-overcurrent element pickup and operating time.

Method:

1. Set a programmable output (A1 - A4) to follow the 51PP time-overcurrent pickup element. Use the assertion of this output (open to close) to start an external timer.

2. Set another programmable output to follow the time-overcurrent element timeout via the 51PT bit in the Relay Word. Use the assertion of this output to stop the external timer.

3. Calculate the expected operating time of the 51PT element using the appropriate equation for the curve number. This is selected by the relay 51PC setting. TD is the relay 51PD 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 inverse curve (2) is:

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

   Where M = Multiples of Pickup = 3
   TD = Time Dial =3

   t_M = 2.77 seconds

   For example, if the 51PP pickup setting is 2.0 amps secondary and the relay measures 6.0 amperes of phase current, the 51PT bit in the Relay Word asserts 2.77 seconds after the 51PP bit in the Relay Word asserts if the Zone 2 phase distance element is picked up.

4. To assure that the Zone 2 element is asserted when phase current reaches the 2.0 amp pickup level, apply the voltages shown in the table below.

   Table 7.11: Zone 2 Phase-Phase Test Voltages and Currents, 51P Test

VA	VB	VC	IA	IB	IC	
67.00	35.21	35.21	0.00	2.00	2.00	Volts/Amps
0.0	-162.1	162.1	0.0	-138.5	41.5	Degrees

5. As phase current approaches 2.0 amps, the programmable output contact you set in Step 1 will close, indicating pickup of the 51P element. Turn off phase currents and reset the external timer.

6. Apply a multiple of pickup current to phases B and C with the voltages above. Record the operating time of the 51PT element and compare it to the calculated time.

Note: For high multiples of pickup current, the Zone 1 phase distance element may operate. To simplify this test, set the Z1P element to zero in the tripping programmable logic masks MTU, MTO, and MBT.

7. (Optional) 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.

MEMORY VOLTAGE POLARIZATION TEST

Purpose: Test the memory polarization duration for zero voltage close-in three-phase faults in front of the relay.

Method: 1. Using the factory relay settings, apply a zero voltage three-phase fault at the bus in front of the relay. Pre-fault and fault voltages and currents appear in Table 7.12. Pre-fault voltages are needed to charge the memory polarization filters.

Table 7.12: Three-Phase Close-In Fault

Pre-fault Quantities:						
VA	VB	VC	IA	IB	IC	
67.00	67.00	67.00	0.00	0.00	0.00	Volts/Amps
0.0	-120.0	120.0	0.0	0.0	0.0	Degrees
Fault Quantities:						
VA	VB	VC	IA	IB	IC	
0.00	0.00	0.00	11.00	11.00	11.00	Volts/Amps
0.0	0.0	0.0	-48.5	-168.5	71.5	Degrees

2. In the generated event report, count the number of quarter-cycles between the time voltages collapse to zero and when the Zone 1 three-phase mho element drops out. The Zone 1 three-phase element should be asserted for a minimum of 16 quarter-cycles.

LOSS-OF-POTENTIAL TEST

Purpose: Verify the SET LOP and CLEAR LOP conditions. The following equations show the SET 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) x (51NP/3.15) for 51NP ≥ 3.15 A
47P = 14 V of V1
50M = Current in any phase over the 50M setting

Method: Table 7.13 provides the voltage and current sets required to create SET and CLEAR LOP conditions.

Table 7.13: 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 the another programmable output to follow the 50M bit in the Relay Word.

3. Start a timer when the 50M programmable output asserts (open to close).

4. Stop the timer when the 50MF bit asserts the output relay (open to close) and verify the accuracy of the 50MFD timer.

Z2DG AND Z3DG TIMER TESTS

Purpose: Verify the Z2DG and Z3DG timer accuracy.

Method:

1. Program the 67N2 bit in the Relay Word into one of the available outputs (A1 - A4) to start an external timer.

2. Program the Z2GT bit into a different output to stop the timer.

3. Apply a Zone 2 AG fault as in Table 7.14 for a duration which exceeds the Z2DG setting.

Table 7.14: Standard Zone 2 AG Fault Using Factory Relay Settings

2AG Fault						
VA	VB	VC	IA	IB	IC	
57.07	69.44	67.20	4.97	0.00	0.00	Volts/Amps
0.0	-121.3	122.5	-58.7	0.0	0.0	Degrees

4. Repeat Steps 1 to 3, substituting 67N3 for 67N2 and Z3GT for Z2GT in the appropriate programmable output. Table 7.15 shows a standard Zone 3 AG fault. Apply this 3AG fault for a duration which exceeds the Z3DG setting.

Table 7.15: Standard Zone 3 AG Fault Using Factory Relay Settings

3AG Fault						
VA	VB	VC	IA	IB	IC	
58.63	69.06	67.16	4.20	0.00	0.00	Volts/Amps
0.0	-121.1	122.1	-58.7	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 7.14.

3. For Z2DG settings greater than approximately six cycles, the relay generates two event reports: one for the 67N2 element pickup, the other for TRIP output assertion (and the Z2GT bit of the Relay Word).

4. Calculate the Z2DG time delay using the difference between the 67N2 element pickup in the first event report and the TRIP (and Z2GT bit) assertion in the second event report.

5. The Z3DG timer can be tested with the same method using the Zone 3 AG fault in Table 7.15.

Z3DP TIMER TEST

Purpose: Verify Z3DP timer accuracy.

Method:

1. Program the Z3P bit in the Relay Word into one of the available outputs (A1 - A4) to start an external timer.

2. Program the Z23T bit into a different programmable output to stop the timer.

3. Apply the Zone 3 BC fault shown in Table 7.16 for a duration which exceeds the Z3PT setting.

Table 7.16: Standard Zone 3 BC Fault Using Factory Relay Settings

3BC Fault						
VA	VB	VC	IA	IB	IC	
67.00	60.83	60.83	0.00	4.82	4.82	Volts/Amps
0.0	-123.4	123.4	0.0	-138.5	41.5	Degrees

Note: If an external timer is not available, use event report time tags and the following steps to calculate Z3DP time delays.

1. Mask only the Z3PT 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 3 BC fault as given in Table 7.16.

3. For Z3DP settings exceeding approximately six cycles, the relay generates two event reports: one for the 21P3 element pickup, the other for TRIP output assertion (and the Z3PT bit of the Relay Word).

4. Calculate the Z3DP time delay using the difference from the 21P3 element pickup in the first event report to TRIP (and Z3PT bit) assertion in the second event report.

SWITCH-ONTO-FAULT TESTS

Purpose:

1. Verify 52BT timer accuracy and MTO (switch-onto-fault) Logic Mask.
2. Verify that elements enabled to trip via the MTO logic mask are only enabled when the breaker is open for a duration exceeding the 52BT setting (52BT bit is asserted in Relay Word).

Method:

1. Program one of the available output contacts (A1 - A4) to follow the 52BT bit in the Relay Word.
2. Use 52A contact input deassertion (control voltage on to off) to start an external timer.
3. Use 52BT programmed contact output assertion (open to close) to stop the timer.
4. Compare the timer value to the 52BT setting.
5. To make sure the elements in the MTO logic mask are only enabled when 52BT = 1, apply a fault to pick up an element masked into the MTO logic mask but not the MTU mask.
6. Table 7.17 contains pre-fault and fault voltage and current quantities for a Zone 2 AG fault.

Table 7.17: Zone 2 AG Fault Quantities

Pre-fault:

VA	VB	VC	IA	IB	IC	
67.00	67.00	67.00	0.00	0.00	0.00	Volts/Amps
0.0	-120.0	120.0	0.0	0.0	0.0	Degrees

2AG Fault:

VA	VB	VC	IA	IB	IC	
57.07	69.44	67.20	4.97	0.00	0.00	Volts/Amps
0.0	-121.3	122.5	-58.7	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.

RECLOSER TEST, LLC = N, DLC = N

Purpose: Verify that the reclosing relay functions properly when LLC = N, DLC = N.

Note: Perform this test using a breaker simulator to simulate the action of the breaker 52A auxiliary contacts. A simple latching relay works well as a breaker simulator.

Method:

1. Program the MRI (Mask for Reclose Initiate) with the 67N1 bit in the Relay Word. Make certain this same bit is not masked into the MRC (Mask for Reclose Cancel).

2. Program the MTU (Mask for Unconditional Trip) with the 67N1 bit also.

3. Set LLC = N, DLC = N, CVC = 0, and VSA = 0. Set 79RS = 900 cycles (15 seconds).

4. Apply a Zone 1 AG fault as shown in Table 7.18. Make certain the 52A input is energized for 79RS cycles prior to applying the fault. The TRIP output contact closure should result in the circuit breaker simulator de-energizing the 52A input and removal of current inputs to the relay.

Table 7.18: Zone 1 AG Fault Quantities

Pre-fault:						
VA	VB	VC	IA	IB	IC	
67.00	67.00	67.00	0.00	0.00	0.00	Volts/Amps
0.0	-120.0	120.0	0.0	0.0	0.0	Degrees
1AG Fault:						
VA	VB	VC	IA	IB	IC	
52.89	70.48	67.32	7.07	0.00	0.00	Volts/Amps
0.0	-121.8	123.5	-58.7	0.0	0.0	Degrees

5. Immediately following the closure of the TRIP outputs, remove the A-Phase fault current. This allows TRIP to deassert and the 79OI1 timer to run. Record the duration between opening of the TRIP output contacts or 52A input (whichever occurs later) and CLOSE output contact closure.

6. Following the first CLOSE output, reapply the fault before the 79RS timer expires.

7. Immediately following the second TRIP output closure, remove the A-Phase fault current. This allows the TRIP to deassert and second open interval time, 79OI2, to run. Record the duration between deassertion TRIP output contact or 52A input (whichever occurs later) and CLOSE output contact closure.

8. Repeat steps 6 and 7 to operate the third open interval timer, 79OI3.

9. The duration of the first open interval should approximately equal the 79OI1 setting. The duration of the second open interval should be approximately equal the 79OI2 setting. The duration of the third open interval should be approximately equal the 79OI3 setting.

RECLOSER TEST, LLC = N, DLC = Y

Purpose: Verify that the reclosing relay functions properly when LLC = N, DLC = Y.

Note: This test should be performed using a breaker simulator to simulate the action of the breaker 52A auxiliary contacts. A simple latching relay works well as a breaker simulator.

Method:

1. Program the MRI (Mask for Reclose Initiate) with the 67N1 bit in the Relay Word. Make certain this same bit is not masked into the MRC (Mask for Reclose Cancel).

2. Program the MTU (Mask for Unconditional Trip) with the 67N1 bit also.

3. Set LLC = N, DLC = Y, CVC = Y or N, and VSA = Y or N. Set 79RS = 900 cycles (15 seconds).

4. Apply a Zone 1 AG fault as shown in Table 7.18. Make certain the 52A input is energized for 79RS cycles prior to applying the fault. TRIP output contact closure should result in the circuit breaker simulator de-energizing the 52A input and removal of current inputs to the relay.

5. Immediately following TRIP output closure, remove the A-Phase fault current and voltages. This allows the 790I1 timer to run. Record the duration between opening of the TRIP output contacts or 52A input (whichever occurs later) and CLOSE output contact closure.

6. Following the first CLOSE output, reapply the fault before 79RS timer expiration.

7. Immediately after the second TRIP output closure, remove the A-Phase fault current and voltages. This allows the second open interval timer, 79OI2, to run. Record the duration between deassertion TRIP output contacts or 52A input (whichever occurs later) and CLOSE output contact closure.

8. Repeat Steps 6 and 7 to operate the third open interval timer.

9. The duration of the first open interval should approximately equal the 79OI1 setting. The duration of the second open interval should be approximately equal the 79OI2 setting. The duration of the third open interval should be approximately equal the 79OI3 setting.

10. (Optional) To verify that the first reclosing shot is cancelled when the dead-line voltage condition is not met, leave balanced voltages applied to the relay for VCT time after the first TRIP. Remove balanced voltages following VCT timer expiration.

RECLOSER TEST, LLC = Y, DLC = N

Purpose: Verify that the reclosing relay functions properly when LLC = Y, DLC = N.

Note: Perform this test using a breaker simulator to simulate the action of the breaker 52A auxiliary contacts. A simple latching relay works well as a breaker simulator.

Method:

1. Program the MRI (Mask for Reclose Initiate) with the 67N1 bit in the Relay Word. Make certain this same bit is not masked into the MRC (Mask for Reclose Cancel).

2. Program the MTU (Mask for Unconditional Trip) with the 67N1 bit also.

3. Set LLC = Y, DLC = N, CVC = Y or N, VSA = Y or N. Set 79RS = 900 cycles (15 seconds).

4. Apply a Zone 1 AG fault as shown in Table 7.18. Make certain the 52A input is energized for 79RS cycles before you applying the fault. TRIP output contact closure should result in the circuit breaker simulator de-energizing the 52A input and removal of current inputs to the relay.

5. Immediately following TRIP output closure, remove the A-Phase fault current and apply balanced voltages. This allows the TRIP to deassert and the 790I1 timer to run. Record the duration between deassertion TRIP output contacts or 52A input (whichever occurs later) and CLOSE output contact closure.

6. Following the first CLOSE output, reapply the fault before the 79RS timer expires.

7. Immediately after the second TRIP output closure, remove the A-Phase fault current. Apply balanced voltages if CVC = Y and VSA = Y. This allows the second open interval timer, 790I2, to run. Record the duration between deassertion of the TRIP output contacts or 52A input (whichever occurs later) and CLOSE output contact closure.

8. Repeat Steps 6 and 7 to operate the third open interval timer, 79OI3.

9. The duration of the first open interval should approximately equal the 79OI1 setting. The duration of the second open interval should be approximately equal the 79OI2 setting. The duration of the third open interval should be approximately equal the 79OI3 setting.

10. (Optional) To verify that the first reclosing shot is cancelled when the live-line condition is not met, remove balanced voltages from the relay for VCT time following the first TRIP.

INPUT CIRCUITS TEST

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

Method:

1. Set target LEDs to display the contact inputs by typing **TAR 5 <ENTER>**. The front panel LEDs should now follow the contact inputs.

2. Apply control voltage to each input and make sure the corresponding target LED turns on. Energizing the DT and ET inputs should trigger an event report. Table 7.19 lists the contact inputs.

Table 7.19: Contact Inputs

Direct Trip	(DT)
Permissive Trip	(PT)
Block Trip	(BT)
Direct Close	(DC)
52A	
External Trigger	(ET)

SERIAL PORTS TEST

Purpose: Verify operation of serial Port 1.

Method: The initial checkout procedure assumes you connected a terminal to Port 2. Set the baud rate of Port 1 to match that of Port 2 and switch your terminal from Port 2 to Port 1. Be sure you can communicate through this port. If your relay is equipped with front and rear panel Port 2 connectors, ensure that both operate properly.

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.

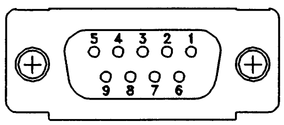
POWER SUPPLY VOLTAGES TEST

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.

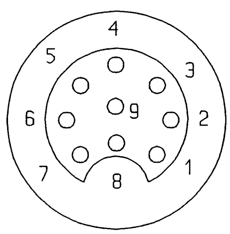
2. At the Auxiliary Port, use a voltmeter to read the +5 and ±12 volt outputs. The 12 volt outputs are derived from the 15 volt supplies using three-terminal regulators. The following pins are the read points:

SEL-221C	SEL-121C
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-221C Relay 9-Pin Connector Pin Number Convention



(female chassis connector, as viewed from outside panel)

Figure 7.14: SEL-121C Relay 9-Pin Connector Pin Number Convention

3. Compare the +5 volt readings from the status report and voltmeter. The voltage difference should be less than 50 mv, and both readings should be within 0.15 volts of 5 volts.

The 12 volt supplies should be within 0.5 volts of their nominal values.

RELAY CALIBRATION

The SEL-221C Relay is factory calibrated to a very high degree of accuracy. If you suspect that the relay is out of calibration, please contact the factory. We can provide instructions for returning the relay for factory recalibration.

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 V+ and V-.

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 commands.

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 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.

Firmware Upgrade Instructions, SEL-121C Relay

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-221C 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

APPENDICES
TABLE OF CONTENTS

Appendix A - Firmware Versions . . . . Appendix A-1

Appendix B - Internal Diagrams . . . . Appendix B-1

Appendix C - Onebus: Program to Compute Test Set
Settings for Testing Distance Relays . . . . Appendix C-1

APPENDIX A - FIRMWARE VERSIONS

This manual, dated March 10, 1995, covers SEL-221C and SEL-121C 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
Firmware Revision 1, 121C Main Board Configurations	
	- Added 50MF Setting
SEL-121C-R105	Base Product
SEL-121C-R302	ACB Rotation
Firmware Revision 4, 121C/221C Main Board Configurations	
	- Added 50MF Setting
SEL-121C-R403	Base Product
SEL-121C-R501	Kilometers Version Product

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-121C-R403**-V656mptrs2-D930707

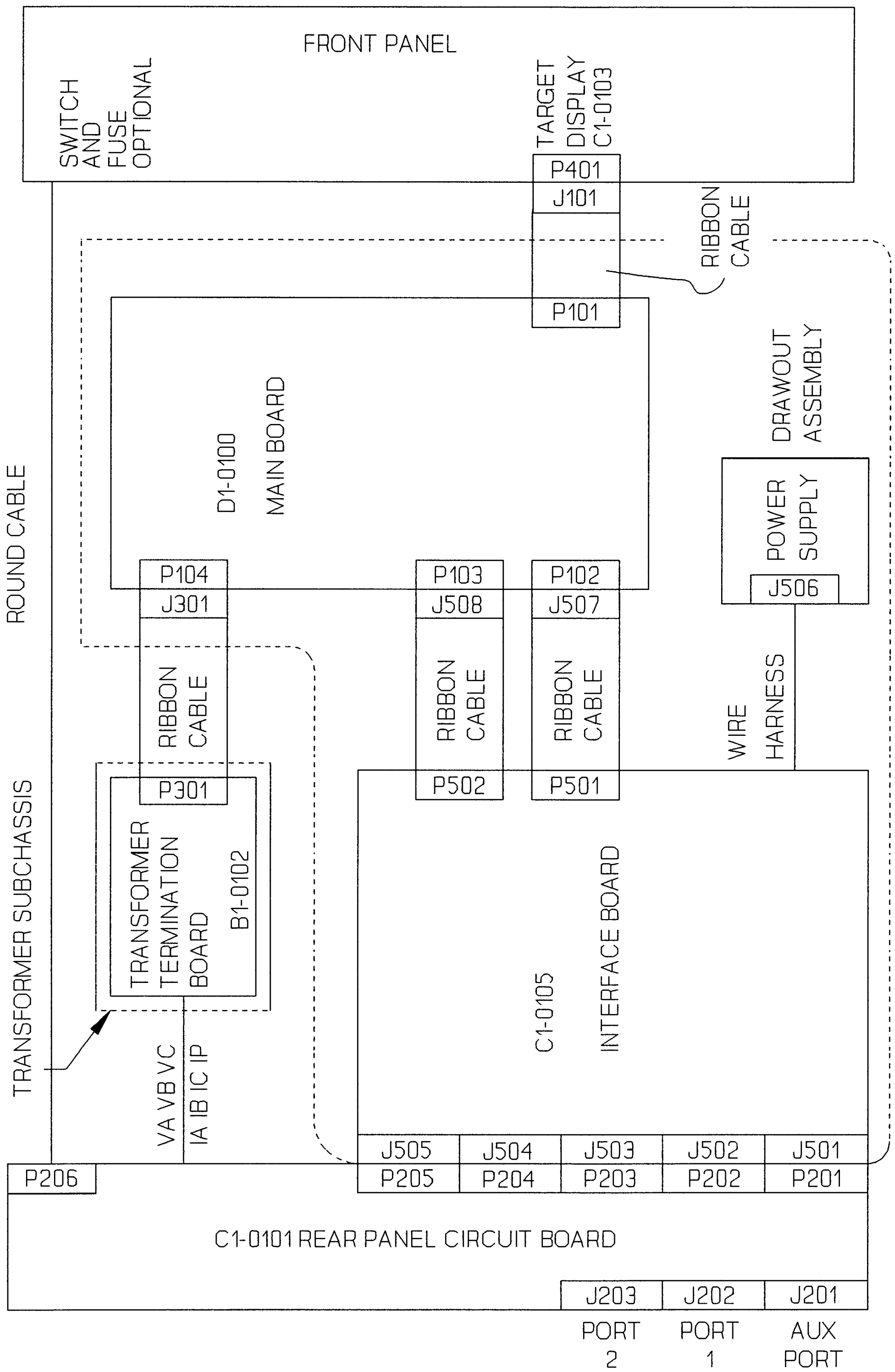
For a detailed explanation of the FID refer to Section 4: EVENT REPORTING.

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

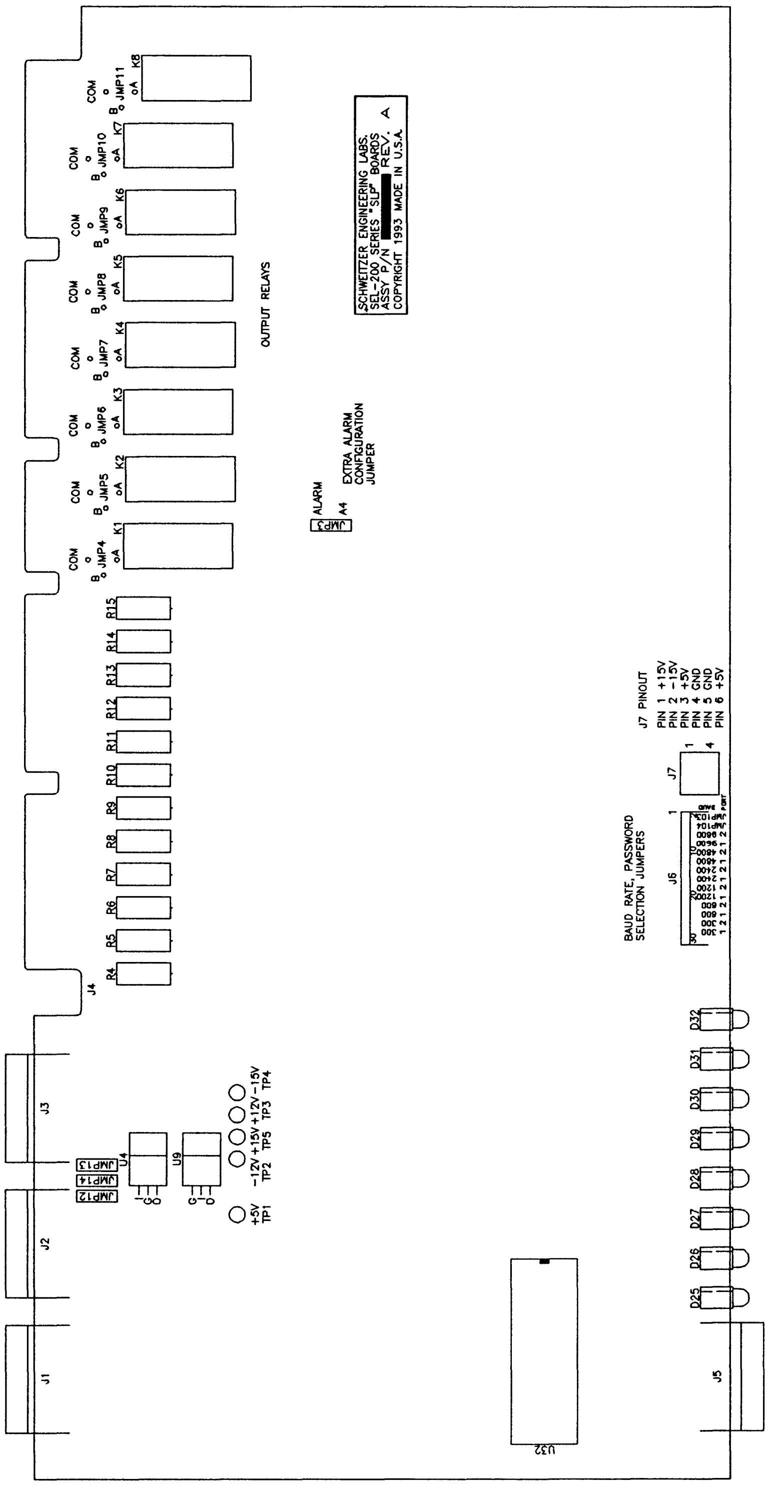
Firmware Part/Revision No.	Description of Firmware
Firmware Revision 1, 121C Main Board Configurations	
SEL-121C-R104	Base Product
SEL-121C-R301	ACB Rotation
SEL-121C-R102	Base Product
SEL-121C-R101	Base Product
SEL-121C-R100	Base Product

Firmware Part/Revision No.	Description of Firmware
Firmware Revision 4, 121C/221C Main Board Configurations	
SEL-121C-R602 SEL-121C-R402 SEL-121C-R601 SEL-121C-R400	ACB Rotation Base Product ACB Rotation Base Product

APPENDIX B - INTERNAL DIAGRAMS



SEL-121C Module Interconnections Diagram



DWG. 1099-I01

SEL-200 Series (Shallow) Main Board Troubleshooting Test Points and Jumper Locations

APPENDIX C - ONEBUS: PROGRAM TO COMPUTE TEST SET SETTINGS FOR TESTING DISTANCE RELAYS

The BASIC program in this note determines voltages and currents which would appear on distance relay terminals for ground and phase faults on a radial system with source impedance at the same angle as line impedance. It is useful in determining test voltage and current settings for SEL distance relays and fault locating equipment.

The program was initially designed to run on a TRS-80 Model 100 briefcase computer but may be installed on virtually any personal computer or laptop.

The program first prompts you for the positive- and zero-sequence impedances of the transmission line. Enter the data in secondary ohms for the entire length of the protected line.

Next, you may enter fault resistance, which is used in the ground-fault computations.

Enter source impedance as a per-unit value with a base of the previously-entered transmission line data. For example, if the radial system has a source impedance of about ten percent of the entered line impedance, enter 0.1 for the per-unit distance from the source to the bus.

Specify the distance from the bus to the fault as a fraction of the total line length. To obtain the voltages and currents for a fault one-half the way down the line from the bus, enter 0.5 for the distance from the bus to the fault.

After you enter this data, the program begins computations. The display then shows voltages and currents for both an AG and BC fault. These data can be entered into any active test source.

The bottom line of the display offers you a choice of entering new impedance data (I), changing the distance from the source to the bus (B), specifying a new fault location (F), or quitting (Q).

```
1       REM SCHWEITZER ENGINEERING LABORATORIES, INC.
2       REM 2350 NE Hopkins Court
3       REM Pullman, WA  99163-5603
4       REM
10      REM COMPUTE DOBLE SETTINGS FOR A ONE-BUS SYSTEM
20      REM HOMOGENEOUS SYSTEM
30      REM SOURCE VOLTS= 67 L-N
40      REM
50      REM ENTER IMPEDANCES FOR 100% OF LINE
60      INPUT "ENTER Z1: R,X";R1,S1
70      INPUT "ENTER Z0: R,X";R0,S0
75      INPUT "ENTER RF FOR GND FLTS";RF
80      REM
90      REM ENTER BUS LOC. FROM SOURCE
100     INPUT "DIST SOURCE TO BUS (PU OF LINE)";S
120     INPUT "DIST BUS TO FAULT (PU OF LINE)";F
130     REM
140     REM  PHASE A TO GROUND
150     REM COMPUTE POS SEQ CURRENT
160     X = R0+2*R1: Y = S0+2*S1
170     R3 = R1-R0:   S3 = S1-S0
180     AR=1/(S+F):  AI=0
190     BR=X      :  BI=Y
195     BR=BR+3*RF/(S+F)
200     GOSUB 2000
210     I = RR    :   J = RI
220     IA = 3*67*I:  JA=3*67*J
225     IB=0:JB=0:IC=0:JC=0
230     AR=X:AI=Y:BR=I:BI=J
232     GOSUB 1000
234     UA=67*(1-S*RR):VA=67*(-S*RI)
240     AR=R3      :AI=S3
250     BR=I       :BI=J
260     GOSUB 1000
270     TR=S*RR    :TS=S*RI
280     UB=67*(-0.5+TR)
290     VB=67*(-SQR(3)/2+TS)
300     UC=67*(-0.5+TR)
310     VC=67*(SQR(3)/2+TS)
315     FF$="A-G"
320     GOSUB 4041
500     REM  B-C FAULT
510     AR=1: AI=0
520     BR=2*R1*(S+F):BI=2*S1*(S+F)
530     GOSUB 2000
540     I=RR:J=RI
550     IA=0:JA=0
560     AR=I:AI=J:BR=0:BI=-67*SQR(3)
570     GOSUB 1000
580     IB=RR:JB=RI:IC=-IB:JC=-JB
590     UA=67:VA=0
600     AR=I:AI=J:BR=S*R1:BI=S*S1
610     GOSUB 1000
620     AR=RR:AI=RI:BR=0:BI=SQR(3)
630     GOSUB 1000
635     TR=RR:TS=RI
640     UB=67*(-0.5+TR)
650     VB=67*(-SQR(3)/2+TS)
660     UC=67*(-0.5-TR)
670     VC=67*(0.5*SQR(3)-TS)
675     FF$="B-C"
680     GOSUB 4041
900     INPUT "IMP BUS FAULT OR QUIT (I,B,F,Q)";A$
910     IF A$ = "I" THEN GOTO 50
920     IF A$ = "B" THEN GOTO  75
930     IF A$ = "F" THEN GOTO 120 ELSE GOTO 999
999     END
1000    REM MULT SUBROUTINE
1010    REM AR,AI * BR,BI = RR,RI
1020    RR=AR*BR-AI*BI
1030    RI=AI*BR+AR*BI
1040    RETURN
2000    REM DIVISION SUBROUTINE
2010    REM AR,AI / BR,BI = RR,RI
2020    D = BR*BR + BI*BI
2030    RR = AR*BR + AI*BI
2040    RR = RR/D
2050    RI = BR*AI - AR*BI
2060    RI = RI/D
2070    RETURN
3000    REM RECT TO POLAR CONV
3010    REM AR,AI, TO RH, TH
3020    PI = 3.14159265358
3030    IF (AR=0 AND AI=0) THEN    RH=0: TH=0: RETURN
3040    IF (AR=0 AND AI>0) THEN    RH=AI: TH=90:RETURN
3050    IF (AR=0 AND AI<0) THEN RH=-AI: TH=-90: RETURN
3060    IF (AR>0) THEN TH=(180/PI)*ATN(AI/AR)
3070    IF (AR<0) THEN TH=(180/PI)*ATN(AI/AR)+180
3080    IF TH>180 THEN TH = TH-360
3090    RH=SQR(AR*AR+AI*AI)
3100    RETURN
4041    AR=UA:AI=VA:GOSUB 3000
4042    UA=RH:VA=TH
4043    AR=UB:AI=VB:GOSUB 3000
4044    UB=RH:VB=TH-VA
4045    AR=UC:AI=VC:GOSUB 3000
4046    UC=RH:VC=TH-VA
4047    AR=IA:AI=JA:GOSUB 3000
4048    IA=RH:JA=TH-VA
4049    AR=IB:AI=JB:GOSUB 3000
4050    IB=RH:JB=TH-VA
4055    AR=IC:AI=JC:GOSUB 3000
4060    IC=RH:JC=TH-VA
4061    VA=0
4100    PRINT " VA   VB   VC   IA   IB   IC"
4130    PRINT USING"##.# ";UA;UB;UC;IA;IB;IC,
4132    PRINT FF$
4140    PRINT USING"#### ";VA;VB;VC;JA;JB;JC
4150    RETURN
```

SEL-221C/121C RELAY COMMAND SUMMARY

Access Level 0

ACCESS Answers 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 Answers password prompt (if password protection is enabled) to enter Access Level 2. This command always pulses the ALARM contacts closed for one second.

DATE m/d/y Shows or sets date. DAT 2/3/91 sets date to Feb. 3, 1991. IRIG-B time code input overrides existing month and day settings. DATE pulses ALARM contacts when year entered differs from year stored.

EVENT Shows event record. EVE 1 shows newest event; EVE 12 shows oldest.

HISTORY Shows DATE, TIME, TYPE, DIST (distance), DUR (duration), CURR (maximum fault current) and SHOT for the last twelve events.

IRIG Forces immediate attempt to synchronize internal relay clock to time code input.

METER n Displays primary phase-to-neutral and phase-to-phase voltages and currents and real and reactive power. Option n displays meter data n times.

QUIT Returns control to Access Level 0; return target display to Relay Targets.

SHOWSET Displays settings without affecting them.

STATUS Shows self-test status.

TARGET n k Shows 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 Shows or sets time. TIM 13/32/00 sets clock to 1:32:00 PM. IRIG-B synchronization overrides this setting.

TRIGGER Triggers and saves an event record (event type is EXT).

Access Level 2

CLOSE Closes circuit breaker, if allowed by jumper setting.

LOGIC n Shows or sets logic masks MTU, MPT, MTB, MTO, MA1-MA4, MRI, and MRC. Command pulses ALARM contacts closed for one second and clears event buffers when new settings are stored.

OPEN Opens circuit breaker, if allowed by jumper setting. TDUR=0 also disables the OPEN command.

PASSWORD Shows or sets passwords. Command pulses ALARM contacts closed momentarily after password entry. PAS 1 OTTER sets Level 1 password to OTTER. PAS 2 TAIL sets Level 2 password to TAIL.

SET n Initiates set procedure. Optional n directs relay to begin setting procedure at that setting. SET TDUR initiates setting procedure at TDUR setting. SET initiates setting procedure at beginning. Command pulses ALARM contacts closed and clears event buffers when new settings are stored.

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EVENT	Shows event record. EVE 1 shows newest event; EVE 12 shows oldest.
HISTORY	Shows DATE, TIME, TYPE, DIST (distance), DUR (duration), CURR (maximum fault current) and SHOT for the last twelve events.
IRIG	Forces immediate attempt to synchronize internal relay clock to time code input.
METER n	Displays primary phase-to-neutral and phase-to-phase voltages and currents and real and reactive power. Option n displays meter data n times.
QUIT	Returns control to Access Level 0; return target display to Relay Targets.
SHOWSET	Displays settings without affecting them.
STATUS	Shows self-test status.
TARGET n k	Shows 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	Shows or sets time. TIM 13/32/00 sets clock to 1:32:00 PM. IRIG-B synchronization overrides this setting.
TRIGGER	Triggers and saves an event record (event type is EXT).

Access Level 2

CLOSE	Closes circuit breaker, if allowed by jumper setting.
LOGIC n	Shows or sets logic masks MTU, MPT, MTB, MTO, MA1-MA4, MRI, and MRC. Command pulses ALARM contacts closed for one second and clears event buffers when new settings are stored.
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