EE 590
The SEL-121F Distance Relay
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General Quality - 10
Writing - 9
Design - 9
Lab Potential - 10
Completeness - 10

48
INDEX

Introduction p.1
Relay Setup p.2-3
Lab Setup p.4-6
Prelab Solutions p.7-8
Lab p.9-10
Problems & Ideas for the Future p.11
Appendix A p.12
Appendix B p.13-14
Appendix C p.15
Introduction

The SEL-121F is a logic-based programmable distance relay. It is used for the zoned protection of power lines. It can be accessed locally through a terminal or remotely via modem.

- It can be coordinated with other relays in coordinated protection schemes.
- It has three zones of protection.
- It protects against all kinds of faults.
- Has the ability to control breaker reclosing.
- Gives the distance to and the fault specifications.
- Incorporates other relaying functions (50, 51, 67, etc..)

These are just a few of its capabilities.
How to Setup the SEL-121F for Operation

The Computer:

The computer must have a communications program to talk to the relay. The existing program being used is an old version of Procomm. A serial cable is attached to Port 2 on the relay, with the other end connected to COM 1 on the computer. The baud rate is selected to 2400 bps on Port 2. To change the baud rate the cover of the relay must be removed, then towards the front of the main board are jumpers which can be changed to select baud rates from 300 bps to 9600 bps. The serial data format is 8 data bits, 2 stop bits, and NO parity.

Relay Setup:

Once the communications program is set up, the relay can transmit. When first turned on, the relay will display the name of the existing data case and give a prompt.

To view any of the relay settings the user must be in access level 1. To enter level 1 type access, then enter the password OTTER (must be in capital letters). Now the user can view the current settings by typing showset (see Appendix A). The last 12 events (faults) can be viewed by typing history.

To change any of the settings the user must be in access level 2. To enter level 2 type 2access followed by the password TAIL (must be in capital letters). Now to make changes type the command set. The set command will step through each parameter prompting for the new value, if the existing value is correct just hit the carriage return key. If all corrections have been made, to exit type end and then a carriage return. The relay will then show the new settings and ask the user whether they are correct, if they are the relay will store the new settings.

Each Setting is described in detail in the Applications section of the manual.

Setting the relay logic is the next step. The relay has 10 logic masks which it uses to control output functions, such as tripping. The settings for the 10 masks can be viewed at the bottom of the screen when the showset command is given (see Appendix A). There are three rows of eight elements in each mask. A logic 1 activates a element under a particular mask, while a logic 0 deactivates an element. With the showset command the row of eight elements is transformed from two four bit binary words into two words in hexadecimal. For example, the row 11110100 would be displayed as F4.

The relay elements are briefly described in appendices B1 and B2.
The mask that is of most interest at this point is the MTU mask or Mask for Trip Unconditional. If any selected element under the MTU mask picks up, the relay will trip. To change or get a better look at the settings for this mask type logic mtu. The relay will display the first of the three rows, with the particular element above its setting (see bottom of Appendix A). For example, a logic 1 under the Z1P element will cause the relay to trip if it sees a phase disturbance in zone 1. At the prompt type in the new setting, logic 1 or 0, for each element in that row, with NO spaces in between, and hit the carriage return key. If no modification to that row is to be made just hit the carriage return. Repeat this process to the remaining two rows. After the three rows are completed the relay will prompt the user to confirm these changes, if Yes is selected the relay will save the changes.

THE OTHER NINE LOGIC MASKS ARE DESCRIBED ON PAGES 5-33 THROUGH 5-36 IN THE APPLICATIONS SECTION OF THE MANUAL. THEY ARE NOT DESCRIBED HERE BECAUSE THE EQUIPMENT NECESSARY FOR THEIR USE IS NOT AVAILABLE AT THIS TIME.

***** NOTE: This description is meant as a quick reference, not a substitute for what is covered in the manual. Also, other commands of interest are also explained in the Communications section of the manual.
Setup for the SEL-121F Lab
&
Things to Know

Hooking up the relay to the simulator:

1. The line or source CTs may be used.

   If line CTs are used:
   
   - Use the 5 AMP connections
   - Make sure the source CTs are shorted out
   - Set the line CT setting to 60 using the two knobs, this setting with the 5 AMP connections gives a CT ratio of 60:60 or 1:1

   If source CTs are used:
   
   - Use the 5 AMP connections
   - Make sure the line CTs are shorted out
   - Set the source CT setting to 60 using the two knobs, this setting with the 5 AMP connections gives a CT ratio of 60:60 or 1:1

2. The positive terminals of the selected CT is connected to terminals 1, 2, and 3, on the back of the relay for the top, middle, and bottom phases respectively. The negative CT terminals are connected to terminals 7, 8, and 9, on the back of the relay for the top, middle, and bottom phases respectively.

3. The VT outputs are connected to terminals 29, 30, 31, and 32 on the back of the relay, representing the top, middle, bottom, and neutral voltages respectively.

Lab Setup: The simulator

1. Make sure the source impedance is set to 15 + j53.8.

2. Select the VT selector switch to VT4

3. UNDER NO CIRCUMSTANCES SHORT A VT

4. 100% line impedance is 75.7 degrees and a reactance of 4.2

5. For phase faults, 3-phase and phase to phase, a different mho curve is used. With this curve a polarizing voltage is required. This is why the button is pressed and then the other two phases are faulted for the 3-phase fault.
The Program:

The program is run by typing procomm and it is located in the prcm subdirectory on the C drive of the computer. Once in the program the relay can be turned on.

Lab Setup: The relay

1. Use the Set command in access level 2

   • R1 = 1.071, X1 = 4.2
   • R0 = 1.53, X0 = 6.0

   **** Note the Residual Current Compensation Factor (K) will not let the zero sequence impedance be equal to the positive sequence impedance. K = (Z0 - Z1)/3Z1, and the magnitude of K must be greater than .0833. Even though the simulators positive and zero sequence are equal, this has very little effect on the results.

   • LL = 50 (miles)
   • CTR = 1.0
   • PTR = 4.01
   • SPTR = 4.01
   • MTA = 75.7
   • 7901 = 40.00
   • 79RS = 240.00
   • PSVC = N
   • 27VLO = 0
   • 59VHI = 0
   • 25DV = 0
   • SYNCP = A
   • 25T = 300.0
   • VCT = 30.0
   • A1TP = 0
   • A1TD = 0
   • Z1% = 90.0
   • Z2% = 120.0
   • Z3% = 150.0
   • Z2DP = 30.0
   • Z2DG = 30.0
   • Z3D = 40.0
   • TDUR = 9.0
   • 50NG = 4.0
   • 50P = 4.0
   • 50H = 8.0
   • 51NP = 5.0
   • 51NTD = 3.0
   • 51NC = 2
   • 51NTC = Y
   • 67NP = 5.0
   • 67NTC = Y

2. Setting the logic: use the logic mtu command in access level 2. See bottom of Appendix A.

   • Set the first row to 11110111
   • Set the next two rows to 00000000

3. Make sure all other masks are set to 00 in Hex, this can be seen with the showset command.

Things to Know:

1. The distance relay logic is presented in Appendix C. Note that not only the distance elements must pickup, but also the 50P and 50N instantaneous over-current elements for phase and ground faults respectively.
2. Any element can be monitored directly by using the target command. This command changes what the LEDs on the front of the relay represent. See page 3-14 in the communications section of the manual for the designated targets. This can be very useful for troubleshooting problems.

3. With the printer hooked up to the computer, the user can print out a complete list of the events.
1) 3-Φ FAULT (100% Zline = 1.071 + j4.2)

\[ I_a = I_b = I_c = I_1 \]

\[ I_1 = \frac{277}{\sqrt{5 + j53.8} + (1.071 + j4.2)} = 4.60 \text{ AMPS} \]

With Zline = 1.6118 + j2.4

\[ \frac{Zline}{Z_{line, 100\%}} = \frac{2.48 \angle 75.7}{4.33 \angle 75.7} = 0.571 \text{ or } 57.1\% \text{ OF THE LINE} \]

\[ |I_{1, 57.1\%}| = \frac{277}{\sqrt{5 + j53.8} + (1.6118 + j2.4)} = 4.75 \text{ AMPS} \]

2) 0-Φ FAULT (RED PHASE)

With: \( I_1 = I_0 = I_0 \)

100% of line

\[ I_1 = \frac{277}{3 \left[ (15 + j53.8) + (1.071 + j4.2) \right]} = 1.53 \]

\[ I_0 = I_1 \]

\[ I_0 + I_1 + I_2 = 3I_1 = 4.60 \text{ AMPS} \]

57.1% of line

\[ |I_{1, 57.1\%}| = \frac{277}{3 \left[ (15 + j53.8) + (1.6118 + j2.4) \right]} = 1.583 \text{ AMPS} \]

\[ I_0 + I_1 + I_2 = 3I_1 = 4.75 \text{ AMPS} \]
The 3-φ fault current is the same as the φ-g fault current because the positive, negative, and zero sequence impedances are the same. Usually the zero sequence is much greater than the positive and negative, giving a much smaller fault current for the φ-g
PROTECTIVE RELAYING USING THE SEL 121F

Objective:

The objective of this experiment is to become familiar with the SEL-121F logic-based distance relay used for zoned line protection. This will be accomplished by running various faults with the power system simulator, and then retrieving data from the relay.

Prelab:

For the system below calculate the fault current for:

1. A three-phase fault with Z-line = 1.071 + j4.2
2. A three-phase fault with Z-line = .6118 + j2.4
3. A single-phase to ground fault with Z-line = 1.071 + j4.2
4. A single-phase to ground fault with Z-line = .6118 + j2.4

\[ Z_{source} = 15 + j53.8 \]
\[ Z_{line} = 15 + j53.8 \]
\[ Z_1 = Z_2 = Z_0 \]

Are the answers for parts 1 and 3 the same? What about parts 2 and 4? Explain why or why not.

Also, if the line length is 50 miles and the line impedance is 1.071 + j4.2, how many miles is a fault with an impedance of .6118 + j2.4?

Procedure:

The relay is setup with 100% of the line having an impedance of 1.071 + j4.2, which is the maximum setting for the power system simulator line impedance. Note that the line impedance is given in terms of the angle (75.7 degrees for this case) and the reactance (4.2 for the maximum). Faults are simulated using the four knobs directly under the word FAULT. Turning a fault knob to 1 simulates the fault. To initiate the fault press the black button on the right side of the simulator under sequence start, make sure the simulator is in ready.

The computer will display the type of fault, distance, and the fault current.
The history command may also be used to view the last 12 events.

1. Simulate a 3-phase fault at 100% of line length. To simulate the fault turn the top phase fault knob to 1 and the other three to 0. Then press and hold the sequence start button, and while holding the button, switch the other two phase fault buttons to 1 simultaneously. Does the relay show the correct distance? How does the fault current compare to that calculated in the prelab?

2. Repeat part 1 for the distance represented by $Z\text{-line} = .6118 + j2.4$.

3. Simulate a line to ground fault at 100% of line length. To simulate a L-G fault turn any one phase fault knob to 1 and the ground fault knob to 1. Make sure the fault impedance is set to zero. Then push the sequence start button. Does the relay show the correct distance? How does this fault current compare to that calculated in the prelab?

4. Repeat part 3 for the distance represented by $Z\text{-line} = .6118 + j2.4$. 
Present Problems with the Lab:

1. When running faults on the simulator, the currents are not within an acceptable error of what they should be. This causes problems with getting the relay to trip under conditions which should cause a trip. To get the relay to function properly under these circumstances, the positive and zero sequence impedances had to be increased to increase the zone of protection.

2. The relay itself introduces a small error when working with the simulator. This occurs because the Residual Current Correction Factor (K) will not allow the zero sequence impedance to be the same as the positive sequence impedance, as is the case with the simulator.

Ideas for the Future:

There are extensive applications that can be explored with this relay.

1. Programmable output contacts and masks MA1-MA4 can be used to give external outputs for any relay element.

2. The relay contains functions involving breaker reclosing, which could be simulated with another generic relay.

3. The relay has the ability to use differential schemes.

4. There is also the possibility of using the transfer trip function with communications and the SEL-151 as a coordinated scheme.
SHOWSET <ENTER>

Settings for: Example 230 kV Line

R1 = 13.90 X1 = 79.96 R0 = 41.50 X0 = 248.57 LL = 100.00
CTR = 200.00 PTR = 2000.00 SPTR = 2000.00 MTA = 80.10
7901 = 40.00 79RS = 240.00
PSVC = S 27VLO = 26.60 59VHI = 106.20 25DV = 53.12 SYNCP = A
25T = 300.00 VCT = 30.00
A1TP = 0.00 A1TD = 0.00
Z1% = 80.00 Z2% = 120.00 Z3% = 150.00
Z2DP = 30.00 Z2DG = 30.00 Z3D = 40.00 TDUR = 9.00
50NG = 250.00 50P = 370.00 50H = 1500.00
51NP = 270.00 51NTD = 3.00 51NC = 2 51NTC = Y
67NP = 650.00 67NTC = Y 52BT = 30.00 REJOE = N LOPE = Y
TIME1 = 5 TIME2 = 0 AUTO = 2 RINGS = 7

Logic settings:

<table>
<thead>
<tr>
<th>MTU</th>
<th>MPT</th>
<th>MTB</th>
<th>MTO</th>
<th>MA1</th>
<th>MA2</th>
<th>MA3</th>
<th>MA4</th>
<th>MRI</th>
<th>MRC</th>
</tr>
</thead>
<tbody>
<tr>
<td>F4</td>
<td>08</td>
<td>00</td>
<td>FC</td>
<td>00</td>
<td>00</td>
<td>F0</td>
<td>04</td>
<td>F0</td>
<td>04</td>
</tr>
<tr>
<td>A2</td>
<td>00</td>
<td>00</td>
<td>A4</td>
<td>00</td>
<td>00</td>
<td>80</td>
<td>20</td>
<td>80</td>
<td>20</td>
</tr>
<tr>
<td>00</td>
<td>00</td>
<td>00</td>
<td>02</td>
<td>01</td>
<td>00</td>
<td>00</td>
<td>00</td>
<td>00</td>
<td>00</td>
</tr>
</tbody>
</table>

A detailed explanation of the relay and logic settings is given in the description of the SET and LOGIC commands. Each column in the logic settings display shows the masks for the Relay Word as follows:

Row 1, of any column: Z1P Z1G Z2PT Z2GT Z3 Z3T 3P21 32Q
Row 2, of any column: 67N 51NP 51NT 50NG 50P 50H IN1 REJO
Row 3, of any column: LOP 52BT 27S 27P 59S 59P SSC VSC

The logic settings are shown in hexadecimal format. Table 3.2 shows the equivalencies between hexadecimal (hex) and binary numbers to assist you in examining the logic settings display in event reports and the SHOWSET display.

Mask for Trip Unconditional (MTU)  

<table>
<thead>
<tr>
<th>Z1P</th>
<th>Z1G</th>
<th>Z2PT</th>
<th>Z2GT</th>
<th>Z3</th>
<th>Z3T</th>
<th>3P21</th>
<th>32Q</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>67N</td>
<td>51NP</td>
<td>51NT</td>
<td>50NG</td>
<td>50P</td>
<td>50H</td>
<td>IN1</td>
<td>REJO</td>
</tr>
<tr>
<td>1</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>LOP</td>
<td>52BT</td>
<td>27S</td>
<td>27P</td>
<td>59S</td>
<td>59P</td>
<td>SSC</td>
<td>VSC</td>
</tr>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

Event Report

Hexadecimal Code

| F4 |
| A2 |
| 00 |
- The ALARM output closes while the relay detects a loss-of-potential condition if you select LOPE = 2, 3, or 4.

**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 | 50AG 50BG 50CG  (50NG setting)  |
| High-set single-phase OC relays | 50AP 50BP 50CP  (50P setting)  |
| Zone 3 ground mho distance | 50AH 50BH 50CH  (50H setting)  |
| Zone 3 phase mho distance | 21AG3, 21BG3, 21CG3  (Z3 % setting)  |
| Zone 2 ground mho distance | 21AB3, 21BC3, 21CA3  |
| Zone 2 phase mho distance | 21AG2, 21BG2, 21CG2  (Z2 % setting)  |
| Zone 1 ground mho distance | 21AB2, 21BC2, 21CA2  |
| Zone 1 phase mho distance | 21AG1, 21BG1, 21CG1  (Z1 % setting)  |
| Residual time-overcurrent pickup | 21AB1, 21BC1, 21CA1  |
| Residual time-overcurrent trip | 51NP  (51NP, 51NTC settings)  |
| Residual inst overcurrent | 51NT  (51NP, 51NTD, 51NC, 51NTC settings)  |
| Residual inst overcurrent | 67N  (67NP, 67NTC settings)  |
| Negative-sequence directional | 50N  (50NG setting)  |
| Negative-sequence overvoltage | 32Q  forward direction  |
| Negative-sequence overcurrent | 47QL  loss-of-potential logic  |
| Positive-sequence overvoltage | 46QL  loss-of-potential logic, trip unlatch logic  |
| Dead polarizing voltage check | 47P  loss-of-potential logic  |
| Dead synchronizing voltage check | V1 < 27VLO  |
| Live polarizing voltage check | VS < 27VLO  |
| Live synchronizing voltage check | V1 > 59VHI  |
| Live synchronizing voltage check | VS > 59VHI  |
| Synchronism check element | 25  VPOL - VS < 25DV  |
Optically Coupled Logic Inputs

Programmable Input IN1
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

Zone 2 delay for phase faults Z2DP
Zone 2 delay for ground faults Z2DG
Zone 3 delay Z3D

Time delayed inverse of 52A 52BT
Minimum Trip Duration TDUR

Enables from Setting Procedure

Select torque control for 51N 51NTC
Select torque control of 67N 67NTC
Remote-End-Open Perm. Trip Enable REJOE
Loss-of-potential enable LOPE

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."
Distance Relay Logic

\[ 3P21 = (21AB3*21BC3*21CA3) * 3P50 \]
three-phase fault condition

\[ FDS = 3P21 + 32Q \]
forward-direction supervision

\[ Z1P = (21AB1*50AP*50BP + 21BC1*50BP*50CP + 21CA1*50CP*50AP) * FDS \]
\[ NOT(LOP * LOPE=Y, 1, 2, OR 3) \]

\[ Z2P = (21AB2*50AP*50BP + 21BC2*50BP*50CP + 21CA2*50CP*50AP) * FDS \]
\[ NOT(LOP * LOPE=Y, 1, 2, OR 3) \]

\[ Z3P = (21AB3*50AP*50BP + 21BC3*50BP*50CP + 21CA3*50CP*50AP) * FDS \]
\[ NOT(LOP * LOPE=Y, 1, 2, OR 3) \]

\[ Z1G = (21AG1*50AG + 21BG1*50BG + 21CG1*50CG) * 50N * FDS \]
\[ NOT(LOP * LOPE=Y, 1, 2, OR 3) \]

\[ Z2G = (21AG2*50AG + 21BG2*50BG + 21CG2*50CG) * 50N * FDS \]
\[ NOT(LOP * LOPE=Y, 1, 2, OR 3) \]

\[ Z3G = (21AG3*50AG + 21BG3*50BG + 21CG3*50CG) * 50N * FDS \]
\[ NOT(LOP * LOPE=Y, 1, 2, OR 3) \]

\[ Z3 = Z3P + Z3G \]
Zone 3 phase or ground fault

\[ Z2PT = Z2P * Z2PD \]
Zone 2 phase timeout

\[ Z2GT = Z2G * Z2GD \]
Zone 2 ground timeout

\[ Z3T = Z3 * Z3D \]
Zone 3 timeout

Synchronism and Voltage Checking Logic

\[ SSCI = 59S * 59P * 25 * NOT(52A) * \]
\[ NOT(50NG) \]
synchronism check initiate

\[ SSC = SSCI for 25T; 0 dropout delay \]
sync check timer output

\[ LSDP = 59S * 27P * NOT(50NG) \]
live sync/dead polarizing

\[ LPDS = 59P * 27S * NOT(50NG) \]
live polarizing/dead sync

\[ VCTI = LSDP * (PSVC=S,E) + LPDS * \]
\[ (PSVC=P,E) \]
voltage condition timer initiate

\[ VSC = VCTI for VCT; 0 dropout delay \]
voltage condition timer output