SEL-49

LINE THERMAL RELAY
WITH DISTANCE RELAY
AND FAULT LOCATOR

DATA SHEET

- Estimates conductor temperature from current and ambient temperature
- Fault locator includes zero-sequence mutual coupling compensation
- Provides separate outputs for tripping and alarming
- Internal clock may be synchronized to time code input
- Automatically issues time-to-trip messages during overloads
- One-zone distance relay provides protection for all faults
- Targets indicate thermal and distance relay operations
- Includes event recording, automatic self testing, and other advanced features
GENERAL DESCRIPTION

The SEL-49 relay is a digital protective relay which provides transmission line protection from overloads and short circuits.

Overload protection is provided with the help of a thermal model which estimates the conductor temperature from measurements of the ambient temperature and conductor currents. The estimated conductor temperature is compared against low and high thresholds to signal alarm or tripping via separate output contacts.

A thermal predictor determines if the conductor will reach a critical temperature and provides the time remaining until that temperature will be reached should the overload continue. The SEL-49 relay automatically issues reports including time-to-trip, measured ambient temperature, estimated conductor temperature, and a heating and cooling budget. As the temperature nears the trip setpoint, the SEL-49 relay generates the reports more frequently. A report is also issued when conditions return to normal.

Figure 1 shows an electrical equivalent of the thermal model used by the SEL-49 relay. The heat power input P is determined from the electrical losses, plus the solar heating (solar heating is estimated from the time of day and relay location, and assumes a clear sky). Computation of the resistive heating component includes the effect of the resistance temperature coefficient. The ambient temperature (TA) may be entered as a constant or taken from a temperature transducer.

Thus, the heat input drives the thermal model, and the variable TC is the conductor temperature estimated by the model. The relay estimates the conductor temperature from the model differential equations which are solved recursively as time progresses.

The temperature predictor estimates the expected steady-state temperature, assuming the present rate of heating continues. If the predicted temperature exceeds the relay setting, the time remaining to reach the trip temperature is computed and reported.

Short-circuit protection is provided by single-zone mho relays for all fault types. The SEL-49 relay includes logic and timing features so that the mho relays can be used for backup protection or indirect, underreaching, and overreaching transfer-trip schemes.

The SEL-49 relay locates transmission line faults from its voltage and current measurements using the field-proven techniques of the SEL-21 relay. An enhancement is an input for the residual current from parallel circuits, allowing compensation for zero-sequence mutual coupling from parallel lines.

The SEL-49 relay also provides event reporting, control, remote setting, and metering capabilities.
Figure 1: Thermal Model

Thermal Variables

P - Heat power input
THC - Thermal heat capacity
TRA - Thermal resistance to ambient
TC - Estimated conductor temperature
TA - Ambient temperature
TI - Initial conductor temperature
TTH - High temperature threshold
TTL - Low temperature threshold
I - Conductor current
rac - ac resistance
rdelt - Temperature coefficient of ac resistance

(watts/Kft) (J/°C Kft) (watts/°C Kft) (°C) (°C) (°C) (°C) (Ampere) (ohms/Kft) (ohms/°C Kft)

Thermal Model Equation

\[
\frac{dTC}{dt} \ast THC = P - \frac{(TC - TA)}{TRA}
\]

Heating Equation

\[P = I^2 \ast (rac + (TC - 25) \ast rdelt) + Q_{sun} + Q_{sky}\]

Cooling Equation

\[\frac{(TC - TA)}{TRA} = Q_{radiated} + Q_{convected}\]
Thermal Equation Solved for TC

$$TC = \int_0^t (P/THC - (TC - TA)/(TRA * THC))dt + TI$$

THERMAL MESSAGE EXAMPLES

Short Report Under "Normal" Line Conditions

```plaintext
>>> TEMP

Example 230 kV Line, Drake Conductor  Date: 6/29/90  Time: 12:45:36
Line cond. : Normal
Load : 372.11 MVA
Limit : 424.83 MVA
Margin : 51.63 MVA
```

Long Report Under "Normal" Line Conditions

```plaintext
>>> TEMP L

Example 230 kV Line, Drake Conductor  Date: 6/29/90  Time: 12:45:29
Line Cond. : Normal  IsqfdR heating : 21.5 W/ft
Time to trip : 76.5 min  Solar heating : 8.5 W/ft
Line Temp. : 20.0°C  Atms. cooling : 30.3 W/ft
Amb. Temp. : 20.0°C  Net heating : -0.2 W/ft
Load : 372.61 MVA  902.9 amps
Limit : 424.90 MVA  1027.0 amps
Margin : 51.34 MVA  124.1 amps
```

Short Report During Abnormal Line Conditions

```plaintext
>>> TEMP

Example 230 kV Line, Drake Conductor  Date: 1/1/90  Time: 23:45:14
Line cond. : OVERLOAD
Time to trip : 16.9 min
Line Temp. : 25.8°C
Load : 565.26 MVA
Limit : 461.70 MVA
Margin : -95.56 MVA
```
Long Report During Abnormal Line Conditions

Example 230 kV Line, Drake Conductor  Date: 1/1/90  Time: 23:45:35
Line cond. : OVERLOAD  IsqdR heating : 44.2 W/ft
Time to trip : 16.4 min  Solar heating : 0.0 W/ft
Line Temp. : 27.9°C  Atms. cooling : 4.3 W/ft
Amb. Temp. : 20.0°C  Net heating : 39.9 W/ft
Load : 564.7 MVA  1405.1 amps
Limit : 469.51 MVA  1168.2 amps
Margin : -95.19 MVA  -236.8 amps

APPLICATIONS

Match the loading of transmission lines to the environmental conditions. The SEL-49 relay provides a TEMP (temperature) command which shows the heating budget for the modeled transmission line under its present operating conditions. One particularly important quantity shown is the maximum steady-state current which can be handled given the ambient temperature, the amount of solar heating calculated at that point in time, and the thermal model settings.

Protect against overloads that result in overtemperature conditions without tripping on temporary overloads that do not last long enough for the conductor temperature to exceed a specified value. During overloads, the SEL-49 relay automatically generates messages indicating the time remaining before the temperature setpoint is exceeded if the overload continues.

Apply the SEL-49 relay as a fault locator and compensate for residual current in parallel circuits.
SPECIFICATIONS

**Relay Functions**
- Thermal protection for overhead lines
- Estimation of time to overheat
- Automatic report generation
- Mho characteristics for all fault types
- Mho units are sound-phase polarized
- Negative-sequence directional supervision
- Separate timers for line and ground faults
- Instantaneous positive-sequence overcurrent unit
- Instantaneous positive-sequence overvoltage unit
- Instantaneous negative-sequence overcurrent unit
- Instantaneous negative-sequence overvoltage unit
- Ground switch detection
- Blown potential fuse detection
- Automatic phase-sequence checking of voltages and currents upon power-up
- Separate outputs for high and low set thermal relays

**Mho Unit**

**Operating Time**
10 - 32 ms; 20 ms typical, including output relay delay

**Steady-State Error (distance relays)**
Less than 3% of set reach

**Transient Overreach**
Less than 5% of set reach

**Thermal Status Reporting**
Report includes: estimated time to trip, line condition, summary of heating and cooling inputs, estimated line temperature, and ambient temperature.

**Fault Location**
Algorithm compensates for prefault load flow and fault resistance for improved accuracy over a wide range of system conditions. Demonstrated accuracy is about one percent of line length. Fault location is reported in miles or kilometers and secondary ohms. Residual current input provides compensation for zero-sequence mutual coupling.

**Fault Reporting**
A data record including fault date, time, type, location, duration, current, relay settings, and units which operated is generated after each fault. Phasor information on currents and voltages indicates prefault, fault, and postfault conditions. This report may also be generated upon command or triggered by a contact closure. The state of all contact inputs and outputs is also reported.

**Self Testing**
Analog ac channels checked for offset. Stall timer monitors processor and five-volt supply. Power supply voltage level checking. Settings, RAM, ROM and A/D converter checking. These self tests are designed to detect virtually any hardware or firmware failure. Failure of any test generates alarm message and closes ALARM contacts. Critical failures disable protection and control to prevent misoperation.
**Thermal Model**

- **Range**
  Models conductors with time constants from 5 to 40 minutes

- **Reach Setting**
  .5 to 32 ohms; other ranges available

**Signal Inputs**

- Three voltage channels (67 V L - N nominal)
- Four current channels (5 A nominal; 500 A for 1 second)
- One temperature input (0 - 5 V corresponds to -23.3 to 65.6°C)
- IRIG-B isolated input: 10 - 20 mA

**Setting Means**

- Digital, via serial communications ports. Parameters are entered in response to prompting messages. Parameters of line are entered in primary ohms. Line length and CT, PT ratios are entered, and displayed quantities are scaled into primary units (e.g. miles, kV, A). Nonvolatile memory retains settings in two identical arrays. Self tests compare these arrays. Should any difference ever be detected, an alarm is generated and relay and control functions are disabled to prevent misoperation.

**System Outputs and Inputs**

- Eight relay outputs rated for breaker tripping. Six optically-isolated contact inputs. Two serial communications ports (RS-232-C) for use with CRT, printing terminal, printer, modem, computer, etc. One clock port for demodulated IRIG-B clock signal. Ports are EMI protected.

**Power Supply**

- 48 Volt: \( V_{dc} \), 180 watts
- 125VAC or \( V_{ac} \), 200 watts

**Surge Filtering**

- Power supply line filter
- All control inputs and outputs bypassed to ground
- Contact inputs filtered by RC networks
- Relay outputs protected by MOVs
- SWC tested

**Dimensions**

- 5½" x 19" x 13."
- Mounts in standard 19" relay rack.

**Weight**

- 20 pounds
OUTPUT EQUATIONS

This section summarizes how the thermal unit, mho units, control inputs, and commands via communications link affect relay outputs.

The SEL-49 output relay states depend on the states of the following:

Relay elements
Control inputs
Setting parameters
Commands received over communications link
Self test status

Since so many binary variables are involved, we define functioning using Boolean logic equations. First, all the logic variables are defined as either primary logic variables, intermediate logic variables, or output logic variables. Next, the values of the intermediate logic variables are derived from the primary logic variables. Finally, output variables are defined using the primary and intermediate logic variables.

DEFINITION OF VARIABLES

Primary Logic Variables

Relay Elements

Thermal relay low set
Thermal relay high set
Single-phase overcurrent relays
Ground distance relays
Phase distance relays
Positive-sequence overcurrent relay
High-set pos-seq overcurrent relay
Positive-sequence overvoltage relay
Negative-sequence overcurrent relay
Negative-sequence overvoltage relay
High-set neg-seq overvoltage relay
Negative-sequence directional relay
* This logic variable is also asserted if a three-phase fault is indicated by operation of all ground mho units or all phase mho units.

** Depends on relay reach. For all reaches above two ohms secondary, the lower limit applies.

**Control Inputs**

- Direct trip: DT
- Transfer trip: TT
- Block trip: BT
- Direct close: DC
- Circuit breaker monitor: 52A
- External trigger: EXT

**Commands via Communication Channels**

- Close command received: CC
- Open command received: OC

**Mho Timers**

- Ground fault timer timeout: 21GT
- Line fault timer timeout: 21LT

**Relay Enables Logic Switches**

- Thermal trip enabled: THE
- Mho trip enabled: ZE
- Transfer trip output enabled: TTE
- Neg-seq directional supervision enabled: 32QE
- Blown potential fuse detect enabled: BPFE

**Intermediate Logic Variables**

- Composite distance relay: 21
- Composite distance relay timeout: 21D
- Forward direction fault: GD
- Blown potential fuse detected: BPF
- Ground switch detect: GS
Output Logic Variables

Circuit breaker trip
Circuit breaker close
Transfer trip initiate
Over high temp. threshold
Over low temp. threshold
System alarm

TRIP
CLOSE
TTI (A1 on rear panel)
TH (A2 on rear panel)
TL (A3 on rear panel)
ALARM

DEFINITION OF INTERMEDIATE VARIABLES

\[
21 = \left( \begin{array}{c}
21A*50A + 21B*50B + 21C*50C \\
+ 21AB*50A*50B + 21BC*50B*50C \\
+ 21CA*50C*50A phase fault
\end{array} \right)
\]

composite distance relay fault

ground fault

\[
21D = \left( \begin{array}{c}
(21A*50A + 21B*50B + 21C*50C)*21GT ground fault and timer \\
+ (21AB*50A*50B + 21BC*50B*50C) phase fault and timer \\
+ 21CA*50C*50A)*21LT
\end{array} \right)
\]

composite distance relay fault

forward direction fault

GD = \left( \begin{array}{c}
32Q \\
+ NOT(46Q*47Q) \\
+ NOT(32QE)
\end{array} \right)

neg-seq directional pickup

not enough neg-seq for 32Q

32 sup. not enabled
BPF = (  
  47QH*NOT(46Q)*BPF 
)

blown potential fuse detected
large neg-seq voltage
small neg-seq current
blown fuse detect enabled

GS = (  
  46PH * NOT (47P) 
)
ground switch detect
large pos-seq current
no pos-seq voltage

DEFINITION OF OUTPUT VARIABLES

Close TRIP contact =  
  (  
    NOT(BT)*  
    ( DT  
      + OC  
      + 49H*THE 
    )  
  )  

energize the trip coil circuit
no block trip input
direct trip input
open command received
high temp. and thermal trip
valid mho fault and enable
mho fault and trans. trip input
Open TRIP contact =

open the trip relay

( NOT(52A)*

 circuit breaker open

 NOT(49H*THE)

 no thermal trip condition

 + NOT(((21D*GD*46P*47P + GS)NOT(BPF))*ZE) no valid enabled mho fault

 + NOT(((21*GD*46P*47P + GS)NOT(BPF))*TT) no valid transfer trip

)

Assert CLOSE contact

close the breaker

( NOT(52A)*

 circuit breaker open

 DC direct close input asserted

 + CC close command issued

)

Assert TTI output

initiate transfer tripping

( 21*GD*46P*47P*NOT(BPF)*TTE

 valid mho fault and transfer trip enabled

)

Assert TH output

signal that over high temp. threshold

( 49H

 49 high set pickup

)

Assert TL output

signal that over low temp. threshold

( 49L

 49 low set pickup

)
Assert ALARM output

(  
  + BPF  
  + relay or control disabled disable during setting  
  + loss of power  
  + processor stall  
)

Pulse ALARM output

(  
  pulse alarm for one second  
  failed Level 1 access on third try  
  + attempt Level 2 access  
  + fail Level 2 access  
  + offset, master offset self test failure  
)

SETTING PROCEDURE

The setting procedure consists of answering prompting messages with new data or typing <ENTER> to indicate no change. Once all data are provided, the new settings are displayed and a prompt issued requesting approval to enable the relay with the new settings. Error messages are included to indicate when entered data result in out-of-range settings.
SET COMMAND EXAMPLE

>>>SET
Enter data or <ENTER> for no change

Example 230 kV Line, Brake Conductor

R1 (ohms pri) = 13.90
X1 (ohms pri) = 79.96
R0 (ohms pri) = 61.50
X0 (ohms pri) = 248.57
RMO (ohms pri) = 37.35
XMO (ohms pri) = 223.90
MCT Ratio = 200.00
CT Ratio = 200.00
PT Ratio = 2000.0

Line Length (miles) = 100.00
Max Torque Angle (deg) = 80.80
Z Reach (% line) = 120.00
Z Delay-Ground (cyc) = 0.00
Z Delay-Line (cyc) = 0.00
50VD Pickup (A pri) = 200.00
+Seq OTHres(A pri) = 6000.0

Default Sol. ht. (watts/Kft) = 4000.0
Solar abs. coeff. (no units) = 0.97
Conductor Diameter (inches) = 1.11
Long. of I. Std. (deg. w.t.) = 125.00
Long. of cond. (deg. w.t.) = 117.00
Lat. of cond. (deg. n. lat.) = 47.00
AC resistance (ohms/Kft) = 22.16
I.C. of res (ohms/°C Kft) = 83.33
Ther. heat cap (K/°C Kft) = 392.10
Ther. res to amb (°C Kft/Kw) = 1.86
Est. ambient temp. (°C) = 20.00
Est. offset temp. (°C) = 0.00
High temp. thresh. (°C) = 90.00
Low temp. thresh. (°C) = 80.00
PORT 1 timeout (minutes) = 5
PORT 2 timeout (minutes) = 0
Automatic port (1, 2, 3, 4) = 2
Modern answer rings = 3
Trans Trip Init (Y or N) = Y
Who Zone trip (Y or N) = Y
Neg-Seq Dir Sup (Y or N) = Y
Blown Pot Fuse (Y or N) = Y
Thermal trip en (Y or N) = Y
Temp. sensor (Y or N) = Y
Solar model en (Y or N) = Y

New settings for:
Example 230 kV Line, Brake Conductor

R1 = 13.90  X1 = 79.96  R0 = 61.50  X0 = 248.57  RMO = 37.35
XMO = 223.90  MCT = 200.00  CTR = 200.00  PTR = 2000.00  LL = 100.00
MTA = 80.80  ZK = 120.00  ZKG = 0.00  ZDL = 0.00  50PD = 200.00
DPS = 6000.00  DSH = 4000.00  SAC = 0.97  DIA = 1.11  LSTD = 125.00
LON = 117.00  LAT = 47.00  RAC = 22.16  RTC = 83.33  THC = 392.10
TRA = 1.86  EAT = 20.00  EOT = 0.00  TH = 90.00  TL = 80.00

TMS = 5  TIMD = 0  AUTO = 2  RING = 3
TTI = Y  ZE = Y  32ME = Y  BPF = Y
TRE = Y  TSE = Y  SGE = Y

OK (Y/N) ? Y
Working...
ENABLED

>>>
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</table>

Event: AG Location: 50.28 mi 4.08 ohms sec
Duration: 5.00 sec Current: 1372
k = 13.90 X1 = 79.96 80 = 41.50 xo = 248.57 RM0 = 37.35
XMO = 223.90 MCTR=200.00 CTR = 200.00 PTR = 200.00 LL = 100.00
MAG = 80.8 2X = 120.00 ZAG = 0.00 ZOL = 0.00 50FID = 200.00
45Hs = 6000.0 DSH = 4000.0 SAC = 0.97 DIA = 1.11 LSTD = 125.00
LON = 117.00 LAT = 47.00 RAC = 22.16 RTC = 65.33 THC = 392.10
IKA = 1.86 tA = 20.00 tUI = 0.00 mH = 90.00 ml = 80.00
The settings shown at the bottom of the event report are briefly explained below.

Example 230 kV Line,
Drake Conductor

R1 = 13.90 Relay identification string.
X1 = 79.96 Positive-sequence resistance of 13.90 ohms primary.
RO = 41.50 Positive-sequence reactance of 79.96 ohms primary.
XO = 248.57 Zero-sequence resistance of 41.50 ohms primary.
RMO = 37.35 Zero-sequence reactance of 248.57 ohms primary.
XMO = 223.70 Zero-sequence mutual reactance of 37.35 ohms primary.

MCTR = 200 Current transformer ratio for mutual circuit of 200:1.
CTR = 300 Current transformer ratio for line of 300:1.

LL = 100.00 Line length of 100 miles or kilometers.
MTA = 80.8 Mho maximum torque angle of 80.8°.
Z % = 120.0 Mho reach of 120% of line.
Z DG = 0.0 Mho delay of 0 cycles for ground faults.
Z DL = 0.0 Mho delay of 0 cycles for line-to-line faults.
50FD = 200.00 Phase overcurrent fault locator setting 200 amps.
46PH = 6000 High-set positive-sequence overcurrent relay pickup of 6000 A.

DSH = 4000 Default solar heating rate of 4000 W/Kft.
SAC = 0.97 Solar absorption coefficient of 0.97.
DIA = 1.11 Conductor diameter of 1.11 inches.
LSTD = 125.00 Standard longitude of 125° west.
LON = 117.00 Longitude of relay location of 117° west.
LAT = 47.00 Latitude of relay location of 47° north.
RAC = 22.16 AC resistance of 25°C of 22.16 milliohm/Kft.
RTC = 83.33 Resistance tempco of 83.33 microohms/Kft.-°C.
THC = 392.10 Thermal capacity of conductor of 392.10 KJ/°C-Kft.
TRA = 1.86 Thermal resistance to ambient of 1.86°C/KW-Kft.
EAT = 20.00 Estimated ambient temperature of 20.00°C.
EOT = 0.00 Estimated offset temperature of 0.00°C.
TH = 90.00 High temperature threshold of 90.00°C.
TL = 80.00 Low temperature threshold of 80.00°C.

TIM1 = 5 Communications PORT 1 timeout (minutes).
TIM2 = 0 Communications PORT 2 timeout (minutes).
AUTO = 4 Automatic Fault Locator and Self Test reports to go to both ports.
RING = 3 Modem on PORT 1 to answer after three rings.

TTI = Y Transfer Trip Initiate relay is enabled.
ZE = Y Mho relay is enabled for direct tripping.
32QE = Y Negative-sequence directional supervision is enabled.
BPFE = Y Blown-potential fuse condition blocks tripping.
THE = Y Thermal tripping is enabled.
TSE = Y Ambient temperature sensor reading is used.
SGE = Y Solar heat generator is enabled.

11/85 Revised 10/88
SEL-49 Vertical Front and Rear Panel Drawing

SEL-49
LINE THERMAL RELAY
FAULT LOCATOR

4 SLOTS
1/4" DIA.,
X 3/8" LONG

DWG. NO. A7-0805A
SEL-49 External Current, Voltage, and Temperature Connections
SEL-49 External Connection Diagram