



Valley Electric Association, Inc.

A Touchstone Energy® Cooperative 

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Company

System Wide Protection Criteria

Standard Protection Criteria



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Version 1.0

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1. INTRODUCTION

The purpose of this document is to provide a standard set of criteria for various protection applications in VEA’s electric system. This document provides guidance for relay selection and relay settings configuration. The goal is to provide consistency across VEA’s electric system and provide a starting point for the engineer designing and configuring the relays for a specific application. Though this document provides industry accepted guidelines for protection, good engineering judgment should always be used to determine the most appropriate settings for a specific application.

Note, throughout this Criteria, “VEA” will refer to both Valley Electric Transmission Association, Inc (VETA) and Gridliance West Transco LLC (GridLiance), as the owners of transmission facilities operated and maintained by Valley Electric Association, Inc. “Valley Electric” will mean only Valley Electric Association, Inc.

Acronyms and Abbreviations Used in the Settings Guidelines

| | | | |
|-------|---|------|--|
| 21P | Phase Distance | 87L | Line Differential |
| 21G | Ground Distance | 87T | Transformer Differential |
| 25 | Synchronism Check | BFI | Breaker Failure Initiate |
| 50G | Residual Ground Instantaneous Overcurrent | CCVT | Capacitively Coupled Voltage Transformer |
| 50GDT | Residual Ground Definite Time | CT | Current Transformer |
| 50P | Phase Instantaneous Overcurrent | DTT | Direct Transfer Trip |
| 50PDT | Phase Definite Time | LOP | Loss of Potential |
| 51G | Residual Ground Time Overcurrent | MTA | Maximum Torque Angle |
| 51P | Phase Time Overcurrent | PT | Potential Transformer |
| 79 | Automatic Reclosing | SIR | Source-to-Line Impedance Ratio |
| 87B | Bus Differential | SOTF | Switch-onto-Fault |

2. GENERAL PROTECTION PRINCIPLES AND GUIDELINES

2.1 Electrical Transmission Line Length Determination

The length of a transmission line in reference to protective relaying is defined in terms of its electrical length (impedance). A unit of measurement for determining the “length” of a line is to put it in terms of its electrical impedance compared to the source impedance. The source-to-line impedance ratio (SIR) gives a ratio of the source impedance behind a relay terminal to the line impedance in front of it. Typically, a short line is considered to have an $SIR > 4$, a medium line has $4 > SIR > 0.5$, and long line has $SIR < 0.5$ ¹. [1]

$$SIR = \frac{\text{Positive Sequence Source Impedance}}{\text{Positive Sequence Line Impedance}}$$

¹ Table 15-3 from IEEE 242-2001 [2]

2.2 Overcurrent Coordination Guidelines

Table 1 provides guidelines for the recommended minimum Coordination Time Interval (CTI) between two protective devices. Use these guidelines for all overcurrent protection coordination. The CTI between two devices should be evaluated at the maximum fault current seen by both devices.

Table 1: Minimum Coordination Time Interval (CTI)^{1,2}

| Downstream | Upstream | | | |
|-------------------------|-----------------|---------------------|-------------------------|--------------|
| | Fuse | Low-Voltage Breaker | Electromechanical Relay | Static Relay |
| Fuse | CS ² | CS ² | 13.2 cycles | 7.2 cycles |
| Low-Voltage Breaker | CS ² | CS ² | 13.2 cycles | 7.2 cycles |
| Electromechanical Relay | 12 cycles | 12 cycles | 18 cycles | 12 cycles |
| Static Relay | 12 cycles | 12 cycles | 18 cycles | 12 cycles |

3. TRANSMISSION LINE PROTECTION

The operating voltages of the VEA transmission system are 230kV and 138kV. The transmission system of the Fish Lake Valley area is operated at 55kV. The transmission system is a mix of two terminal and radial transmission lines. VEA’s operating practice is to maintain voltage within +/-5% of nominal system voltage for their transmission system. For emergency or contingency operation system voltage is maintained within +/-10%.

3.1 Application Overview

Table 2 provides guidelines for selection of primary and backup relays depending on the transmission line protection application. Additionally, the relay elements are listed for each protection application.

Table 2: Transmission Line Relay Applications and Elements

| Relay | Relay Type | Element | Element Name |
|---------------------------------|------------|---------|----------------------------|
| 230/138kV (Two Terminal) | | | |
| Primary/Backup Relay | SEL-311L | 87L | Line Current Differential |
| | | 21P1 | Zone 1 Mho Phase Distance |
| | | 21G1 | Zone 1 Mho Ground Distance |
| | | 21P2 | Zone 2 Mho Phase Distance |
| | | 21G2 | Zone 2 Mho Ground Distance |

² CS = Clear space between curves with upstream minimum-melting curve adjusted for pre-load.

| Relay | Relay Type | Element | Element Name |
|----------------------------|------------|---------|---|
| | | 21P3 | Zone 3 Mho Phase Distance (Application Specific) |
| | | 21G3 | Zone 3 Mho Ground Distance (Application Specific) |
| | | 51G | Directional Ground Time Overcurrent |
| | | SOTF | Switch-Onto-Fault |
| | | 79 | Automatic Reclosing (Only use this function if there is existing SEL-311L relaying at station using this function. Otherwise this function will be performed by a different relay.) |
| 138kV/55kV (Radial) | | | |
| Primary/Backup Relay | SEL-311C | 21P1 | Zone 1 Mho Phase Distance |
| | | 21G1 | Zone 1 Mho Ground Distance |
| | | 21P2 | Zone 2 Mho Phase Distance |
| | | 21G2 | Zone 2 Mho Ground Distance |
| | | 21P3 | Zone 3 Mho Phase Distance (Application Specific) |
| | | 21G3 | Zone 3 Mho Ground Distance (Application Specific) |
| | | 51P | Phase Time Overcurrent (LOP) |
| | | 51G | Directional Ground Time Overcurrent |
| | | SOTF | Switch-Onto-Fault |
| | | 79 | Automatic Reclosing (Only use this function if there is existing SEL-311L relaying at station using this function. Otherwise this function will be performed by a different relay.) |

3.2 Settings Guidelines

3.2.1 Line Current Differential Element (87L) [SEL-311L Only]

- Intended to provide fast-operating, primary protection for the entire line through fiber optic communication with no intentional time delay.
- Enable the phase, negative sequence, and ground elements.
- Alpha Plane Settings
 - Factory default settings can be used for transmission line applications where the following criteria is met [3]:
 - The total charging current is less than 3 A_{sec}.

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- The charging current unbalance is less than $0.5 A_{sec}$.
- The three-phase fault current for a bolted internal fault is greater than $6 A_{sec}$.
- The angle difference between local and remote currents during an internal fault is less than 82° .
- Set the angular extent of the restraint region (87LANG) considering maximum load angle, system non-homogeneity, asymmetrical channel delay, and CT saturation [6]. The factory default setting of 195 degrees is recommended unless the previously mentioned criteria are not satisfied.
- Set the outer radius setting (87LR) to detect internal three-phase faults with zero in-feed. The factory default setting of $6.0 A_{sec}$ is recommended unless the previously mentioned criterion is not satisfied. The default setting corresponds to 120% of a nominal 5 A secondary current.
- Current Differential Supervision Pickup
 - Set phase differential element (87LPP) supervision pickup to 120% of the emergency rating of the line to provide maximum sensitivity without picking up for normal operating conditions. Ensure that the setting is below the minimum remote end phase fault current.
 - Set the negative sequence (87L2P) and ground (87LGP) element supervision pickups to the typical value of $0.5 A_{sec}$ for maximum sensitivity.

3.2.2 Distance (21)

Zone 1 Phase and Ground (21P1 & 21G1)

- This element will be set as a forward underreaching element with a mho circle characteristic and no offset. This element provides high speed protection for a majority of the line.
- Zone 1 Reach Setting:
 - For two terminal lines, set to 80% of the positive-sequence line impedance.
 - For three terminal lines, set to 80% of the positive-sequence line impedance to the nearest terminal.
 - For lines with a tap, set to 80% of the shortest positive-sequence impedance to either the end of the tap or terminal.
 - If positive-sequence line impedance is less than one secondary ohm, use a reach of 60%. The reduction in reach is used to increase security for short lines, where faults will cause more extensive voltage drop at the relay PT location resulting in lower apparent impedance.
- Set Zone 1 Time Delay to 'OFF'. This element is intended to trip instantaneously.
- Always enable CCVT transient detection (ECCVT = Y). This logic will delay Zone 1 tripping for 1.5 cycles, only if the relay calculates SIR greater than or equal to 5, to allow CCVT transients created by faults to stabilize. [4]
- If available in the relay, set the phase fault detectors to $1.0 A_{sec}$ or the minimum in-section fault duty with strongest source removed, whichever is less.

Zone 2 Phase and Ground (21P2 & 21G2)

- This element will be set as a forward overreaching element with a mho circle characteristic and no offset. This element serves as the time-delayed backup for end of line faults and the remote end devices.

- Zone 2 Reach Setting:
 - For two terminal lines, set to 120% of the positive-sequence line impedance. Ensure the element does not overreach any remote Zone 1 element with the strongest remote source out-of-service.
 - For three terminal lines, still set to 120% of the positive-sequence line impedance if possible. To avoid overreaching remote Zone 1 elements, ensure element is set less than 100% of the apparent positive-sequence line impedance, plus 50% of the shortest second line positive-sequence impedance. Determine apparent impedance under intact system conditions (maximum in-feed). Test overreach under contingency conditions.
- Set Zone 2 Time Delay to 20 cycles (0.33 seconds). Ensure this allows enough time for the remote relay's Zone 1 distance element to trip and the breaker to open or a breaker failure trip to occur.

Zone 3 Phase and Ground (21P3 & 21G3)

- This element will be set as a forward overreaching element with a mho circle characteristic and no offset. This element serves as a time-delayed backup for remote line faults with remote relay failure.
- Only enable this element for two terminal applications where remote terminal doesn't have breaker failure transfer trip capabilities or for radial line applications where the remote terminal doesn't have primary and backup relays.
- Zone 3 Reach Setting
 - Two terminal
 - Set the Zone 3 element reach to 120 % of the longest apparent positive sequence line impedance of remote terminal lines.
 - Radial
 - Set the Zone 3 element reach to 300 % of the positive sequence line impedance.
 - Ensure these elements do not reach through any transformers.
- Set Zone 3 Time Delay to 60 cycles (1 second) or more to allow for proper coordination.

3.2.3 Directional Settings

Use the following criteria for determining the directional polarization method:

- Use SEL default setting:
 - “E32 = AUTO”, “ORDER = QV”
- Where there is not sufficient negative-sequence fault current for a ground polarizing source, and the zero-sequence current polarization source is not available use the settings:
 - “E32 = Y”, “ORDER = QV”, “Z0F = -0.1”, and “Z0R = 0.1”

3.2.4 Overcurrent (50/51/67)

Phase Time Overcurrent (51P)

- This element serves as backup protection for LOP conditions.
- Set 51P1TC torque control setting to ‘LOP’ so that element is only enabled when an LOP condition occurs.
- Set pickup to 150% of the emergency line rating. Ensure element is set below 1/3 of the fault current for a remote bus line-to-line fault under contingency conditions.

- Use a very inverse (U3) curve type and set the time dial to trip in ~30 cycles (0.5 seconds) for a remote terminal fault with system normal.

Directional Residual Inverse Time Overcurrent (51G)

- This element provides backup protection to other relay ground elements.
- Set pickup to the lesser of, but not greater than 1 A sec:
 - 15 % of maximum expected load current.
 - Below 1/3 of the minimum remote end ground fault current with strongest source removed, when possible.
- Set directionally forward.
- Use a very inverse (U3) curve type.
- Set the time dial to trip element in Zone 2-time delay plus 5 cycles for a remote bus single line-to-ground fault under normal system operating conditions and to coordinate with area 51G elements.

3.2.5 Switch-Onto-Fault (SOTF)

- This element serves as sensitive phase protection against persistent faults during automatic reclosing.
- Include the following in the SOTF trip equation (SOTFT):
 - Zone 2 Phase Pickup (M2P).
 - Zone 2 Ground Pickup (Z2G).
 - Phase Instantaneous Pickup (50P2).
- Set phase instantaneous pickup to 50% of the remote bus 3-phase fault under contingency conditions.
- Set phase instantaneous torque control setting to be voltage supervised by voltage less than 85% of nominal.
 - Due to limited voltage elements in 311C/L relays, 3P27 (bus voltage less than 30%) can be used.
 - LOP should not be used due to not be asserted when breaker(s) open for a fault and line side potential devices are used.
- Set Close Enable (CLOEND) and 52A Enable (52AEND) time delays to 10 cycles (0.16 seconds).
- Set SOTF delay (SOTFD) to 15 cycles (0.25 seconds). Ensure timer expires and SOTF is disabled before reclosing of remote terminal.

3.2.6 Automatic Reclosing (79)

Pahrump substation is the central substation for VEA's system. Historically, the practice has been to automatically reclose a transmission line from the end further from Pahrump substation and then reclose the end closer to Pahrump substation (or in the case of lines connected to Pahrump substation, close the remote breaker first, then close the Pahrump line breaker). This practice is intended to minimize the impact on VEA's system if a fault is still present. For transmission lines connected to neighboring utilities, the neighboring utilities terminal of the line should be reclosed first, then VEA's terminal of the line. For radial transmission lines, the line will always be reclosed from the source end first.

Use the following criteria for configuring the reclosing settings:

- For the lead breaker, reclosing will be supervised by a live bus – dead line condition.

- For the lagging breaker, reclosing will be supervised by a Synchronism Check (25). See breaker criteria for details on configuring synchronism check.
- Set the number of recloses to one (1).
- Set Three-Pole Open Interval Time to 60 cycles (1 second).
- Disable reclosing when:
 - Reclosing manual control switch is turned off or reclosing is disabled from SCADA.
 - Zone 1 3-phase fault has occurred (indicates major problem and is unlikely to clear). Use SEL relay word bit ‘FTABC’ which indicates a 3-phase fault.
 - LOP condition exists (not applicable when line-side PTs are used or if lead breaker in reclosing scheme).
 - Trip occurred within 3600 cycles (60 seconds) of reclosing.
 - SOTF trip has occurred.
- Reclose initiate when the primary or secondary relay has tripped.
- Reclose Supervision:
 - For lead breaker: Live bus/dead line is present (Confirms remote end CB is open and fault is cleared). Use a dead line threshold of 30 % of nominal voltage.
 - For lag breaker: Live line/live bus and synchronism is met. Use a live line threshold of 80 % of nominal voltage.
- Drive reclosing to lockout when:
 - CB fails to close within 60 cycles (1 second) of a close command.
 - CB reclose supervision conditions fail to occur within 300 cycles (5 seconds).
 - CB trips after reclose and before 3-pole reclaim timer times out.
 - CB reclosing is disabled by a hard wired control switch, relay front panel pushbuttons, or by SCADA.
 - Reclose initiate does not occur within trip.
 - Breaker failure direct transfer trip received from remote terminal.
 - Note that local breaker failure block close conditions are handled via hardwired lockout relay contacts in the close circuit.
- Relay will return to ready or reset state:
 - 900 cycles (15 seconds) after manual close following a recloser lockout.
 - 3600 cycles (60 seconds) after an automatic reclose.
- These settings must be set long enough to avoid reclosing for a slow clearing fault.

3.2.7 Trip Duration

- Set the trip duration to 9 cycles (0.15 seconds).

3.2.8 Sequence of Event Reporting (SER)

Include the following in the SER:

- All trips (in firmware).
- All inputs and outputs.

- All logic word bits used.
- All communication word bits.
- Avoid including any word bits that are expected to change state often. Including these runs the risk of filling up the memory buffer.

4. BREAKER PROTECTION

4.1 Application Overview

Table 3 provides guidelines on breaker failure and breaker control applications for VEA’s system and the selection of primary and backup relays. Additionally, the relay elements are listed for each protection application.

Table 3: Breaker Relay Applications and Elements

| Relay | Relay Type | Element | Element Name |
|---|------------|---------|--|
| 230kV/138kV/55kV | | | |
| Primary Relay SEL-351S | | 25 | Synchronism Check |
| | | 50BF | Breaker Failure |
| | | 52CS | Front Panel Breaker Control |
| | | 79 | Automatic Reclosing (Only use this function if there is NOT existing line relaying at station using this function. Otherwise this function will be performed by this relay.) |
| 138kV & 55kV (Transformer Breaker) | | | |
| Primary Relay | SEL-351S | 50BF | Breaker Failure |
| | | 52CS | Front Panel Breaker Control |
| 24.9kV | | | |
| Primary Relay | SEL-351S | | Refer to the <i>Distribution Feeder Protection</i> section of this document. |

4.2 Settings Guidelines

4.2.1 Breaker Failure (50BF)

VEA uses a current-based breaker failure protection philosophy. Use the following criteria for configuring the breaker failure settings:

- Use built-in relay breaker failure logic.
- Set the Phase Current Detector (50PP) to 0.5 A sec.
- Set the Ground Current Detector (50NP) to 0.5 A sec.
- Enable breaker position based failure logic.
- Set BFI timer to VEA standard of 10 cycles (0.16 seconds) for a 3-cycle breaker. This accounts for the following timing:
 - ½-cycle relay trip contact closure.

- ½-cycle breaker trip coil energization.
- 3-cycle breaker opening time.
- 6-cycle safety margin.
- Enable breaker re-trip (ERTR=Y) and set re-trip time delay (62RT) to 5 cycles.
- Do not latch breaker failure initiate (EBFIL=N).

4.2.2 Synchronism Check (25)

- Use the following criteria for configuring the synchronism check settings:
 - Set Voltage Window Low (25VLO) and High (25VHI) thresholds to 90% and 110% of nominal.
 - Set Maximum Slip Frequency (25SF) to 0.500 Hz.
 - Set Maximum Angle Difference 1 (25ANG1) to 15 degrees.

4.2.3 Manual Closing

- Manual close and SCADA close will be allowed for the following conditions:
 - Synchronism (25).
 - Live Line Dead Bus (LLDB).
 - Dead Line Live Bus (DLLB).
- Dead Line Dead Bus (DLDB).

4.2.4 Trip Duration

- Set the trip duration to 9 cycles (0.15 seconds).

4.2.5 Sequence of Event Reporting (SER)

Include the following in the SER:

- All trips (in firmware).
- All inputs and outputs.
- All logic word bits used.
- All communication word bits.
- Avoid including any word bits that are expected to change state often. Including these runs the risk of filling up the memory buffer.

5. BUS PROTECTION

5.1 Application Overview

Ring-bus is the primary configuration used in VEA’s system for 230kV and 138kV bus work. Under this configuration, protection of the bus is provided by transmission line and transformer relays. For other bus configurations (such as a straight bus), Table 4 provides guidelines on the selection of primary and backup relays. Additionally, the relay elements are listed for each protection application.

Table 4: Bus Relay Applications and Elements

| Relay | Relay Type | Element | Element Name |
|--|------------|---------|--------------|
| 230kV or 138kV Transmission Bus | | | |

| Relay | Relay Type | Element | Element Name |
|--------------------------------|-------------------------|---------|---------------------------------|
| Primary Relay | SEL-587Z | 87B | High Impedance Bus Differential |
| 24.9kV Distribution Bus | | | |
| Primary Relay | SEL-351 | 50P1 | Fast Bus Overcurrent |
| | | 50G1 | |
| | | 50P2 | Feeder Relay Failure Backup |
| | | 50G2 | |
| | | 51P | Phase Time Overcurrent |
| 51G | Ground Time Overcurrent | | |

5.2 Settings Guidelines

5.2.1 High Impedance Bus Differential (87B)

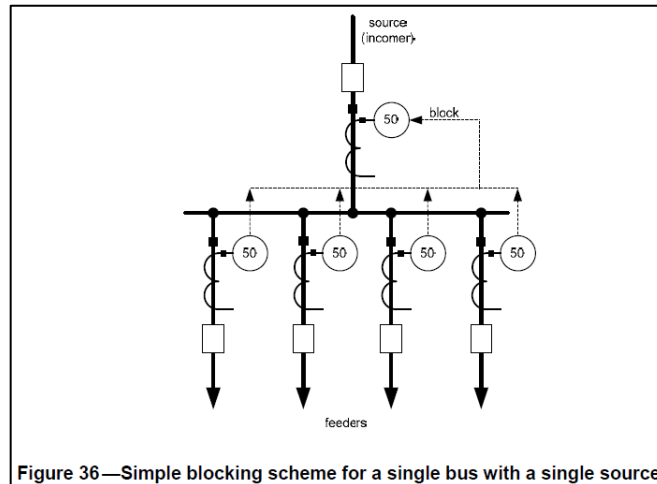
- Level 1
 - Set pickup according to equations in manual.
 - Minimum setting is 200V.
 - Set element to trip instantaneously.
 - Verify that the pickup setting is secure for through-faults on any auxiliary transformers in the differential zone.
- Level 2
 - Set pickup according to equations in manual.
 - Minimum setting is 20V.
 - Do not include level 2 element pickup in relay trip equation.
 - Element is used as an alarm for commissioning to ensure proper CT wiring to the relay.

5.2.2 Overcurrent (50/51/67)

Zone-Interlocked Overcurrent (50P1/50G1)

The zone-interlocked protection scheme provides faster bus protection compared to an overcurrent element. Figure 1 illustrates the setup for the scheme.

Figure 1: Zone-Interlock Scheme



Source: IEEE Std. C37.234-2009 [5]

For this scheme to function, the main breaker relay needs to receive a ‘Block Fast Bus Scheme’ signal. Refer to IEEE Guide C37.234 for more information on the design and configuration of Zone-Interlocked Protection Schemes. [5] Refer to the Beatty and Charleston Park Substation Issued for Record relaying schematics and as-left relay settings for detailed reference on how this scheme is implemented in VEA’s system.

- Route the ‘Block Fast Bus Scheme’ relay input (typically IN106) through a SELogic variable timer with a dropout time of 3600 cycles (60 seconds) and supervise overcurrent element in trip equation with SELogic variable word bit (i.e. 67P1T*!SV1T). This will ensure that fast bus protection is disabled through the duration of a feeder fault event with reclosing attempts.
- Set phase pickup (50P1) to 130% of the transformer maximum rating.
- Set ground pickup (50G1) to 50% of the transformer maximum rating.
- Set element delay (67P1D/67G1D) to 30 cycles (0.5 seconds).
 - Ensure 15-20 cycles (0.25-0.33 seconds) of coordination with upstream\downstream devices.

Feeder Relay Failure Backup (50P2/50G2)

These protection elements are used to trip a feeder breaker in the event that a feeder relay has failed. Auxiliary relays are wired into the feeder breaker DC control circuits to enable breaker tripping from the main relay in the event the feeder relay has failed. Refer to the Beatty and Charleston Park Substation Issued for Record relaying schematics and as-left relay settings for detailed reference on how this scheme is implemented in VEA’s system.

- Set phase pickup (50P2) to 100% of the transformer maximum rating.
- Set ground pickup (50G2) to 50% of the transformer maximum rating.
- Set element delay (67P1D/67G1D) to 15 cycles (0.25 seconds).
 - Ensure 15-20 cycles of coordination with upstream\downstream devices.

Phase Time Overcurrent (51P)

- Set pickup to 150% of transformer maximum rating.
- Verify pickup is less than the low side bus fault.
- Use a very inverse curve (SEL-U3) when possible.

- Set the electromechanical reset option to YES when substation feeders use electromechanical relays. Set the option to NO when feeders use digital relays.
- Choose a time dial that coordinates with the slowest feeder phase overcurrent element.

Ground Time Overcurrent (51G)

- Set element pickup to 30% of the transformer base rating.
- Set element curve type and time dial to provide coordination with feeder/line ground overcurrent elements.

5.2.3 Trip Duration

- Set the trip duration to 9 cycles (0.15 seconds).

5.2.4 Sequence of Event Reporting (SER)

Include the following in the SER:

- All trips (in firmware).
- All inputs and outputs.
- All logic word bits used.
- All communication word bits.
- Avoid including any word bits that are expected to change state often. Including these runs the risk of filling up the memory buffer.

6. TRANSFORMER PROTECTION

6.1 Application Overview

Table 5 provides guidelines on transformer applications for VEA’s system and the selection of primary and backup relays. Additionally, the relay elements are listed for each protection application. Generally, “Winding 1” elements refer to protective elements applied to the high-voltage winding of the transformer. “Winding 2” elements refer to the protective elements applied to the low-voltage winding of the transformer.

Table 5: Transformer Relay Applications and Element

| Relay | Relay Type | Element | Element Name |
|--|------------|---------|-----------------------------------|
| 230/138kV Autotransformer Transformer with Delta Tertiary | | | |
| Primary Relay | SEL-387 | 87T | Transformer Current Differential |
| | | REF | Restricted Earth Fault |
| | | 51P1 | Winding 1 Phase Time Overcurrent |
| | | 51G1 | Winding 1 Ground Time Overcurrent |
| | | 51P2 | Winding 2 Phase Time Overcurrent |
| | | 51G2 | Winding 2 Ground Time Overcurrent |
| Backup Relay | SEL-587 | 87T | Transformer Current Differential |
| | | 51P1 | Winding 1 Phase Time Overcurrent |
| | | 51G1 | Winding 1 Ground Time Overcurrent |
| | | 51P2 | Winding 2 Phase Time Overcurrent |

| Relay | Relay Type | Element | Element Name |
|---|-------------|---------|---|
| | | 51G2 | Winding 2 Ground Time Overcurrent |
| 138/24.9kV or 55/24.9kV Distribution Delta-Wye Transformer | | | |
| Primary Relay | SEL-587 | 87T | Transformer Current Differential |
| | | 50P1 | Winding 1 Phase Instantaneous Overcurrent |
| | | 51P1 | Winding 1 Phase Time Overcurrent |
| | | 50G1DT | Winding 1 Residual Ground Definite Time Overcurrent |
| | | 51P2 | Winding 2 Phase Time Overcurrent |
| | | 51G2 | Winding 2 Ground Time Overcurrent |
| Backup Relay | SEL-501 (X) | 50P1 | Winding 1 Phase Instantaneous Overcurrent |
| | | 51P1 | Winding 1 Phase Time Overcurrent |
| | | 50G1DT | Winding 1 Residual Ground Definite Time Overcurrent |
| | SEL-501 (Y) | 51P2 | Winding 2 Phase Time Overcurrent |
| | | 51G2 | Winding 2 Ground Time Overcurrent |

6.2 Settings Guidelines

6.2.1 Differential Elements (87R, 87U)

Calculate TAP settings using the maximum rating of the transformer.

Restrained differential pickup (O87P):

- SEL recommends a typical value of 0.3 times TAP (current at transformer maximum rating).
- Ensure pickup exceeds maximum steady state CT error (typically 5%), plus transformer excitation current (typically 3%) [6].
- The pickup must meet the relay's minimum requirement:

$$O87P \geq 0.1 * \frac{I_N}{TAP_{Min}}$$

I_N is 5 (the secondary current rating of the CT)

TAP_{Min} is the minimum TAP value of winding 1 and winding 2

- Set slope 1 to 30%.
- The break between Slope 1 and Slope 2 must occur before any CT goes into saturation for a through fault.
 - 3.0 times TAP is a typical setting recommended by SEL.
- Set slope 2 to 50%.
- Set the unrestrained differential pickup (U87P) to be sensitive to transformer high side faults, but not to transformer inrush (typically 8-12 times base transformer rating).

- Enable harmonic restraint with the second (PCT2) and fourth (PCT4) harmonic elements set to 15%, and the fifth (PCT5) harmonic blocking element to ‘OFF’.
- Enable DC ratio blocking to provide security for transformer inrush cases with little harmonic content.
- Enable harmonic restraint to allow second and fourth harmonic components to be added for restraint.

6.2.2 Restricted Earth Fault (REF)

- A restricted earth fault element will be utilized where the appropriate CT wiring is inputted into the differential relay.
 - Compares the direction of neutral and winding residual current for more rapid and sensitive ground fault detection in grounded-wye windings.
- Used on both high- and low-side wye windings:
 - Set 50GP1 & 50GP2 to a value greater than 10% of full transformer rating.
 - Note that a01 & a02 must be less than I0(2)/I1(2).
 - Typically set for 0.1. Verify this value is secure for system unbalance.
- If available in the relay, disable REF element when CT saturation is detected by the relay.

6.2.3 Overcurrent Elements (50/51/67)

Winding 1 Phase Instantaneous Overcurrent (50P1)

- Set pickup to 125% of the maximum through fault current or transformer inrush current; whichever is greater.
- Ensure element picks up for winding 1 bushing faults only, otherwise disable element.

Winding 1 Phase Time Overcurrent (51P1)

- Set pickup to 150% of transformer maximum rating.
- Verify pickup is less than the low side bus fault.
- Use a very inverse curve (SEL-U3) when possible.
- Set the electromechanical reset option to YES when transformer low-side relays are electromechanical type. Set the option to NO when transformer low-side relays are digital type.
- Choose a time dial that fits underneath the transformer thermal and mechanical damage curve in the fault current region (approximately 3.5-time base current and above), and coordinates with the transformer low-side phase overcurrent element.
 - Note that the relay curve will not be below the damage curve in the overload region (approximately 3.5-time base rating and below).

Winding 1 Definite Time Residual Ground Overcurrent Element (50G1DT)

- Enable this element for two-winding transformers where the high-voltage winding is connected in a delta configuration.
- Set element pickup to 30% of the transformer base rating to provide protection for ground faults inside the transformer. This element does not need to be coordinated with low-side ground overcurrent elements because the delta winding will not pass zero-sequence current.
- Set element time delay to 6 cycles (0.1 seconds) to avoid mis-operation for transformer inrush currents.

Winding 1 Ground Time Overcurrent (51N1)

- Use a neutral time overcurrent element (51N) if relay is connected to a transformer neutral CT. Otherwise, use a residual ground time overcurrent element (51G).
- Set this element if winding 1 is connected in a wye configuration.

- Set element pickup to 30% of the transformer base rating.
- Set element curve type and time dial to provide coordination with transformer low-side ground overcurrent elements.

Winding 2 Phase Time Overcurrent (51P2)

- Set pickup to 150% of transformer maximum rating.
- Verify pickup is less than the low side bus fault.
- Use a very inverse curve (SEL-U3) when possible.
- Set the electromechanical reset option to YES when substation feeders use electromechanical relays. Set the option to NO when feeders use digital relays.
- Choose a time dial that coordinates with the slowest feeder phase overcurrent element.

Winding 2 Ground Time Overcurrent (51N2/51G2)

- Use a neutral time overcurrent element (51N) if relay is connected to a transformer neutral CT. Otherwise, use a residual ground time overcurrent element (51G).
- Set element pickup to 30% of the transformer base rating.
- Set element curve type and time dial to provide coordination with feeder/line ground overcurrent elements.

6.2.4 Trip Duration

- Set the trip duration to 9 cycles (0.15 seconds).

6.2.5 Sequence of Event Reporting (SER)

Include the following in the SER:

- All trips (in firmware).
- All inputs and outputs.
- All logic word bits used.
- All communication word bits.
- Avoid including any word bits that are expected to change state often. Including these runs the risk of filling up the memory buffer.

7. DISTRIBUTION FEEDER PROTECTION

7.1 Application Overview

Table 6 provides guidelines on the selection of relay and the relay elements for this protection application within the Distribution Substation.

Table 6: Distribution Feeder Relay Applications and Elements

| Relay | Relay Type | Element | Element Name |
|-----------------------------------|------------|---------|--|
| 24.9kV Distribution Feeder | | | |
| Primary Relay | SEL-351S | 51P1 | Phase Time Overcurrent |
| | | 51P2 | Phase Time Overcurrent (Hot Line Tag) |
| | | 51G1 | Ground Time Overcurrent |
| | | 51G2 | Ground Time Overcurrent (Hot Line Tag) |

7.2 Settings Guidelines

7.2.1 Overcurrent Elements (50/51/67)

Phase Time Overcurrent (51P1)

- Set pickup to the breaker continuous rating (typically 600 Amps-primary).
- Use an extremely inverse curve (SEL-U4).
- Select a time dial to provide coordination with downstream fuses and/or reclosers.
- Set the electromechanical reset option to ‘YES’ when nearest downstream protective device is an electromechanical relay. Otherwise, set the option to ‘NO’.
- Use the pickup relay word bit of this element (51P1) to provide a ‘Block Fast Bus Scheme’ signal to the 24.9kV bus main breaker relay. OUT103 is typically used for this signal.

Phase Time Overcurrent (51P2)

- This element provides faster protective for when Hot Line Tag is enabled.
- Set pickup to the breaker continuous rating (typically 600 Amps-primary).
- Use a short-time inverse curve (SEL-U5).
- Set the time dial to minimum to provide fast tripping.
- Set the electromechanical reset option to ‘YES’ when nearest downstream protective device is an electromechanical relay. Otherwise, set the option to ‘NO’.

Ground Time Overcurrent (51G1)

- Set pickup to 35% of breaker continuous rating (210 Amps-primary for 600 Amp rated breaker).
- Use a very inverse curve or extremely inverse curve (SEL-U3 or SEL-U4).
- Select time dial to provide coordination with downstream fuses and/or reclosers.
- Set the electromechanical reset option to ‘YES’ when nearest downstream protective device is an electromechanical relay. Otherwise, set the option to ‘NO’.
- Use the pickup relay word bit of this element (51G1) to provide a ‘Block Fast Bus Scheme’ signal to the 24.9kV bus main breaker relay. OUT103 is typically used for this signal.

Ground Time Overcurrent (51G2)

- This element provides faster protection for when Hot Line Tag is enabled.
- Set pickup to 35% of breaker continuous rating (210 Amps-primary for 600 Amp rated breaker).
- Use a short-time inverse curve (SEL-U5).
- Set the time dial to minimum to provide fast tripping.
- Set the electromechanical reset option to ‘YES’ when nearest downstream protective device is an electromechanical relay. Otherwise, set the option to ‘NO’.

7.2.2 Automatic Reclosing (79)

Use the following criteria for configuring the reclosing settings:

- Set the number of recloses to two (2).
- Set Three-Pole Open Interval Time to 30 cycles (0.5 seconds) for first shot and 120 cycles (2 seconds) for second shot.
- Disable reclosing when:
 - Reclosing manual control switch is turned off or reclosing is disabled from SCADA.

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- Stall open interval timing (79STL) and block reset timing (79BRS) until trip conditions have cleared.
- Drive reclosing to lockout when:
 - CB fails to close within one (1) second of a close command.
 - CB reclosing is disabled by a hard wired control switch, relay front panel pushbuttons, or by SCADA.
- Relay will return to ready or reset state:
 - 3600 cycles (60 seconds) after manual close following a recloser lockout.
 - 3600 cycles (60 seconds) after an automatic reclose.

7.2.3 Trip Duration

- Set the trip duration to 12 cycles (0.2 seconds).

7.2.4 Sequence of Event Reporting (SER)

- Include the following in the SER:
 - All trips (in firmware).
 - All inputs and outputs.
 - All logic word bits used.
 - All communication word bits.
- Avoid including any word bits that are expected to change state often. Including these runs the risk of filling up the memory buffer.

8. WORKS CITED

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