

Enabling Sensitive Directional Tripping for Non-Line Protection Applications With SEL-351 Series Relays

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INTRODUCTION

It is common to enable a sensitive, directionally supervised phase overcurrent element for non-line protection applications, such as on the low-voltage side of a dual-sourced transformer. The 67P relay shown in Figure 1 is an example of a non-line protection application at a utility-industrial interface.

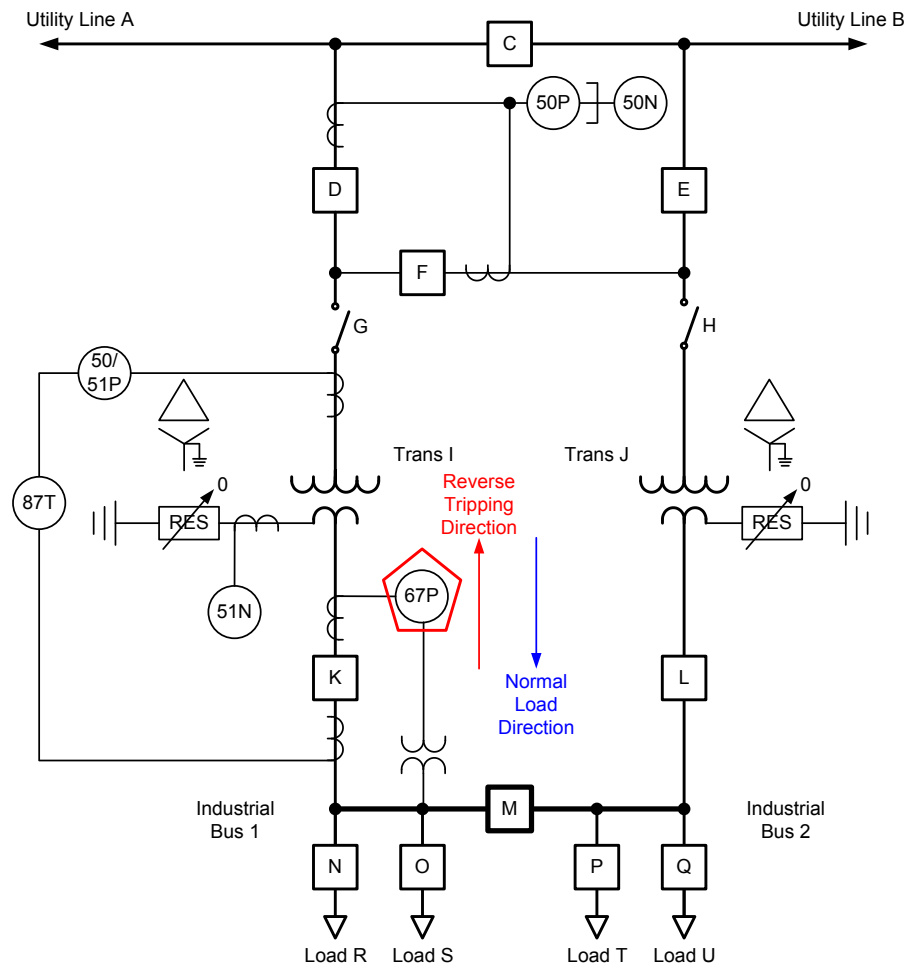


Figure 1 Simplified Protection One-Line Diagram

Reverse directional tripping is defined as tripping for faults or power flow from the low side toward the high side of the transformer. The relay voltage and current inputs must therefore be connected such that the “forward” tripping direction is in the same direction as the normal load flow, which in this case is from the high side toward the low side of the transformer. See the relay installation instructions in the SEL-351-5, -6, -7 Instruction Manual, available at www.selinc.com, for the proper potential transformer (PT) and current transformer (CT) connection polarities.

Directional phase overcurrent elements intended to provide sensitive overcurrent protection in the reverse direction are generally set to pick up for currents less than the maximum forward load current. This requires that the relay directional element be extremely secure to prevent undesired operation.

Great care must be taken when setting SEL-351 series relays in these non-line protection applications in order to maintain security and still provide the intended sensitive operation. This application guide discusses the settings required to establish the desired security and sensitivity.

For more detailed information on this topic, please refer to the SEL-351A; SEL-351-5, -6, -7; or SEL-351S Instruction Manuals and the SEL technical paper “Use of Directional Elements at the Utility-Industrial Interface” [1].

INTENDED APPLICATION

The typical purpose of the traditional 67P element in non-line protection applications is to detect high-side transformer or lead faults when Disconnect Switch G is open or when Breakers D and F are simultaneously open, as shown in Figure 1. Traditional textbooks indicate that since normal power flow is toward the low side, the 67P element may be set fast and sensitive.

However, SEL-351 series relays supervise the 67P element with a positive-sequence or negative-sequence directional element. Further, the negative-sequence directional element has priority for better sensitivity. During times of normal power flow into the industrial bus with a simultaneous utility system ground fault, it is possible to exceed the 67P pickup (due to forward load) and satisfy the reverse directional element (due to negative-sequence sensitivity). For this reason, we recommend segregating fault-clearing responsibilities. The 67P element should be supervised through SELOGIC[®] control equations to only detect reverse three-phase faults. A negative-sequence overcurrent element, 67Q, should be enabled to detect reverse unbalanced faults.

In many applications, this same traditional 67P element is intended to trip for reverse power flow conditions (e.g., power flow toward the utility). If Breakers C and F were to open, power can flow from Source B to Source A by way of the transformers and distribution bus. In addition, if the low-side bus includes a generator, the industrial plant can be a source of power and fault current for the utility system. These conditions are generally neither desired nor permitted by contract.

In traditional textbooks, the 67P element is proposed to sense both reverse faults and power flow. With the exception of the SEL-351A-1, SEL-351 series relays have specialized elements for sensing faults, and the SEL-351-7 and SEL-351S-7 have separate elements better suited for sensing power flow. The proposed settings separate these two intended applications using multiple functions with the relay. Power elements should be used to detect balanced power flow, and directional overcurrent elements should be used to detect faults.

Additionally, SEL-351 series relays have line impedance settings for the user to enter. In non-line applications, such as in this example, there is no protected line, per se. A user might be tempted to leave default values for the line impedance enabled in the relay and allow the relay to automatically calculate directional element thresholds (E32 = AUTO). However, when E32 = AUTO, the relay develops directional thresholds from the line impedance settings. If the

line impedance settings are left at default values, and E32 = AUTO, the relay application may not be secure. Therefore, this application guide suggests manually entering directional element thresholds when there is no protected line or when line impedance values are not readily known.

SUGGESTED SETTINGS

The settings that we suggest enable the following functions:

- A directional power element, 3PWR1, to detect three-phase reverse power flow, if desired (requires an SEL-351-7 or SEL-351S-7).
- A positive-sequence, voltage-polarized phase overcurrent element, 67P1T (with load-encroachment supervision), to detect high-side, three-phase faults.
- A negative-sequence, voltage-polarized negative-sequence overcurrent element, 67Q1T, to detect high-side, unbalanced faults.

Additionally, these settings accomplish the following goals:

- Achieve the same or better sensitivity (pickup) and speed (time delay) as the traditional 67P element.
- Require no complex calculations or fault study for the settings.
- Improve security.

Default settings are shown as plain text in the screen capture below. The highlighted text represents changes the user needs to make in order to implement the directional tripping functions. Notes are shown in parentheses.

[Partial List of Settings Shown]

=>>SH0

Group 1
Group Settings:

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Z1MAG = 1.00 Z1ANG = 45.00 Z0MAG = 1.00 Z0ANG = 45.00 (Line Parameters)

LL = 1.00

E50P = 1 E50N = 1 E50G = 1 E50Q = 1 (Enable Negative-Sequence O/C)

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E32 = Y ELOAD = Y (Enable Directional and Load-Encroachment Supervision)

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ELOP = Y1 (Enable Loss of Potential)

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EPWR = 3P1 (Enable Three-Phase Directional Power Element)

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50P1P = pp.pp (Phase O/C Pickup)

67P1D = dd.dd (Phase O/C Delay)

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50N1P = nn.nn          (Measured Neutral O/C Pickup)
67N1D = dd.dd          (Measured Neutral O/C Delay)
50G1P = gg.gg          (Calculated Ground O/C Pickup)
67G1D = dd.dd          (Calculated Ground O/C Delay)
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50Q1P = (pp.pp) x 1.73  (Negative-Sequence O/C Pickup, Set to Phase O/C Pickup Time 1.73)
67Q1D = dd.dd          (Negative-Sequence O/C Delay)
.
.
.

ZLF   = 13.00   ZLR   = 128.00   PLAF   = 30.00   NLAF   = -30.00 (Load-Encroachment Settings)
PLAR  = 180.00   NLAR  = -180.00
DIR1  = R              (Directional O/C Elements Set to Trip for Reverse Direction Faults)
.
.
.

ORDER = Q   Z2F   = -0.3   Z2R   = +0.3   50QFP = 0.50
(Negative-Sequence Directional Elements)
50QRP = 0.25   a2   = 0.10   k2   = 0.20
.
.
.

3PWR1P = 10.00   PWR1T = -WATTS   PWR1D = dd.dd          (Three-Phase Directional Power Element)
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==>SHO L

SELogic group 1

SELogic Control Equations:
TR      = 67P1T + 67N1T + 67G1T + 67Q1T + 3PRW1 . . . (Trip Logic)
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67P1TC = R32P      (67P1T Element Torque-Controlled to Assert Only for Reverse Three-Phase Faults)
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67N1TC = 1          (67N1T Element Torque Control Always Asserted)
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67G1TC = 1          (67G1T Element Torque Control Always Asserted)
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67Q1TC = 1          (67Q1T Element Torque Control Always Asserted)
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OUT101 = TRIP      (Output Contact Programmed to Trip)
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ER      = /67P1 + /67N1 + /67G1 + /67Q1 + /3PWR1 . . . (Event Report Trigger Conditions)
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Line impedance values are changed from their factory default values, and the maximum torque angle or positive-sequence line impedance angle is set to 45 degrees to match the maximum torque angle of traditional electromechanical relays. The line impedance magnitudes are not used by the directional elements when $E32 = Y$. The positive-sequence line impedance angle is used by the positive- and negative-sequence directional elements when $E32 = Y$. In addition to matching traditional relay maximum torque angles, the 45-degree setting helps ensure that the reverse phase directional element will not pick up even for a severely leading power factor (forward real power flow with significant reverse VAR flow). Load-encroachment logic provides additional security in this regard.

Setting $ELOP = Y1$ disables all directional overcurrent elements during a loss-of-potential condition. If other forward directional overcurrent elements are used in the application, setting $ELOP = Y$ will allow these to operate as nondirectional overcurrent elements during a loss-of-potential condition. Either Y or Y1 settings will prevent the sensitive reverse directional elements from operating during a loss-of-potential condition.

Letters are shown for overcurrent pickup values that determine the sensitivity of the directional overcurrent relay elements. Substitute phase (50P1P), neutral (50N1P), and ground (50G1P) overcurrent pickup values based on normal fault and coordination studies. These 50x1P element pickup settings determine the sensitivity of the corresponding 67x1 directional overcurrent elements. Note that the 50P1P pickup setting only needs to be sensitive to three-phase faults because other elements will see unbalanced faults. For the negative-sequence element (50Q1P) that operates on three times the negative-sequence current, enter a pickup value that is 1.73 times larger than the calculated phase value (50P1P) to provide sensitivity to unbalanced faults equivalent to the sensitivity of 50P. Time delays are shown as “dd.dd;” substitute normal time delays based on fault and coordination studies. These time delays determine the operating time of the respective time-delayed output elements (67x1T, for example).

Directional control is enabled, but automatic settings are turned off ($E32 = Y$). The Level 1 directional setting, $DIR1 = R$, is used to provide reverse directional control for all Level 1 directional overcurrent element time-delayed outputs, 67P1T, 67Q1T, 67N1T, and 67G1T.

Load encroachment is enabled ($ELOAD=Y$), and maximum forward load is conservatively calculated using 5 amperes and 72 volts per phase, secondary, with an additional 10 percent margin to be even more conservative. This is appropriate for a system with nominal 5-ampere CTs and 67 line-neutral PTs. Other information, such as maximum expected transformer loading, can be substituted here. Load angles are based on ± 30 -degree power factor angles. The reverse load-encroachment area is effectively disabled by setting the impedance pickup at its maximum value (128 secondary ohms) and the reverse load angle settings the same (180 degrees). Load-encroachment supervision, once enabled, is automatically included in the positive-sequence directional supervision used for the 67P1T element.

For more details on calculating load-encroachment settings, see SEL Application Guide 93-10, “The SEL-321 Relay Load-Encroachment Function Setting Guidelines” [2].

The forward and reverse negative-sequence impedance directional thresholds ($Z2F$ and $Z2R$) are set to -0.30 and $+0.30$ ohms secondary, respectively. “Bracketing” zero with these settings helps to prevent the negative-sequence directional element from asserting under balanced voltage and unbalanced load current conditions. Negative-sequence voltage is zero under balanced voltage conditions; therefore, negative-sequence impedance as determined by $V2/I2$ is zero.

Negative-sequence directional control is automatically used by the relay to supervise the negative-sequence, 67Q_n, and phase overcurrent, 67P_n, relay elements. Further programmable logic, shown here in the torque-controlled equation $67P1TC = R32P$, is required to ensure that the sensitive directional phase overcurrent element, 67P1, ignores the negative-sequence directional element and is directionally controlled by only the reverse positive-sequence directional element, R32P. All other fault detectors are left at their sensitive factory default values. All directional elements have minimum current detectors to improve security. For example, 50P32P is used in the positive-sequence, voltage-polarized directional element, and 50QFP and 50QRP are used in the negative-sequence, voltage-polarized directional element. When applying directional control for very sensitive overcurrent settings, verify that these directional element current detectors are set lower than the overcurrent element settings.

As indicated earlier, the phase overcurrent element is torque-controlled by the reverse positive-sequence directional element, R32P. The positive-sequence directional element logic used in SEL-351 series relays ensures that this element only asserts for balanced current flow in the reverse direction and when the measured positive-sequence impedance does not lie in the forward load region. The time-delayed output of the negative-sequence overcurrent element, 67Q1T, is added to the other typical overcurrent protection functions in the programmable trip logic equation, TR. The 67Q1T element will respond to unbalanced faults.

If it is necessary to detect directional **power** conditions, we recommend using the elements included in the SEL-351-7 or SEL-351S-7 that are designed for that specific purpose. Because of the high sensitivity of the power elements and changing phase angles or frequency during a system disturbance, a minimum operate time of 5 cycles is generally recommended to avoid undesirable operation. Power elements may operate during faults as well, so programmable logic (not discussed here) may be used to disable the power element operation when a fault-detecting element is asserted, giving fault-detection priority to those elements designed and enabled for that function.

CONCLUSION

With the suggested settings in this application guide, SEL-351 series relays can provide sensitive yet secure directional overcurrent protection for a variety of non-line protection applications.

REFERENCES

- [1] D. Costello, M. Moon, and G. Bow, "Use of Directional Elements at the Utility-Industrial Interface," proceedings of the 5th Annual Power Systems Conference, Clemson, SC, March 2006. Available: <http://www.selinc.com>.
- [2] J. Kumm, "The SEL-321 Relay Load-Encroachment Function Setting Guidelines," SEL Application Guide (AG93-10), 2006. Available: <http://www.selinc.com>.

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