L-PRO Distance Protection Relay for Ring Bus and Breaker-and-a-Half Bus Arrangements

Introduction

The L-PRO Distance Protection Relay can be used to protect multi-breaker transmission lines associated to substation bus arrangements like Ring Bus or Breaker-and-a-Half schemes, with breaker failure, and individual breaker monitoring.

The L-PRO relay has a dedicated auto reclosure logic function. Its recloser supports up to four reclosing shots with complete ring bus circuit breaker control, with or without synchronism check supervision or dead bus/dead line. Lead and follow breaker settings, combined with out-of-service timers for each breaker, are used to create flexible configuration options. The recloser mode setting is related to the Ring Bus Configuration (auxiliary CT line input) and must match the breaker configuration in the system parameters screen.

When two sets of CTs (main and auxiliary) are used as line current input (e.g. in ring bus or breaker-and-a-half application), the user must enable ring bus configuration to configure the relay. If enabled, the currents from the CTs are combined within the relay to obtain the line current (Kirchhoff's current law), as shown in Figure 1. Typically, the L-PRO uses the main VT inputs for the distance protection calculation, while the auxiliary VT inputs can be used for synchronism check.

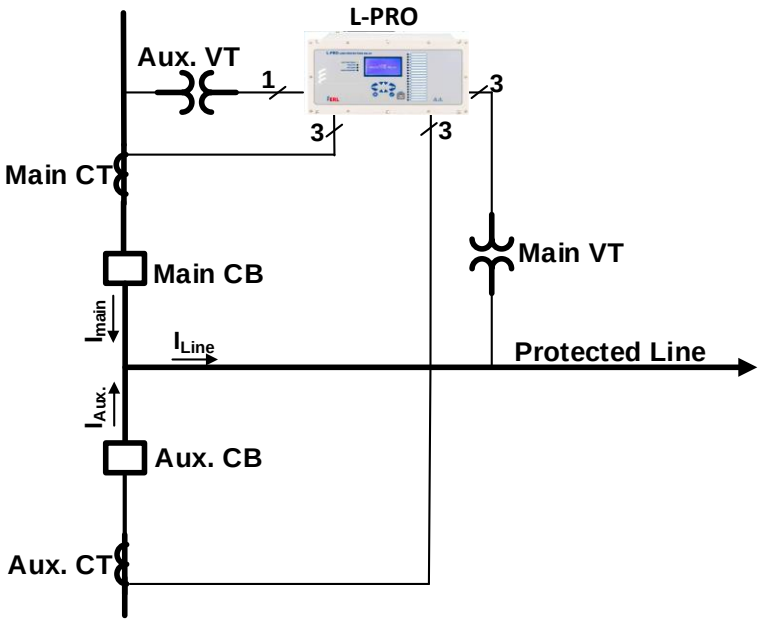


Figure 1 – Applying the L-PRO in Breaker-and-a-Half bus arrangement

Product Connections

The L-PRO relay AC wiring diagram can be found in the L-PRO Instruction Manual in Appendix I [1], and is shown in Figure 2. Note that the relay provides four independent current inputs named Main AC, Aux AC, CT Input #3 and CT Input #4. For ring bus or breaker-and-a-half application, the user must use Main AC and Aux AC CT inputs. Note that the CT ratio for both CTs must be the same.

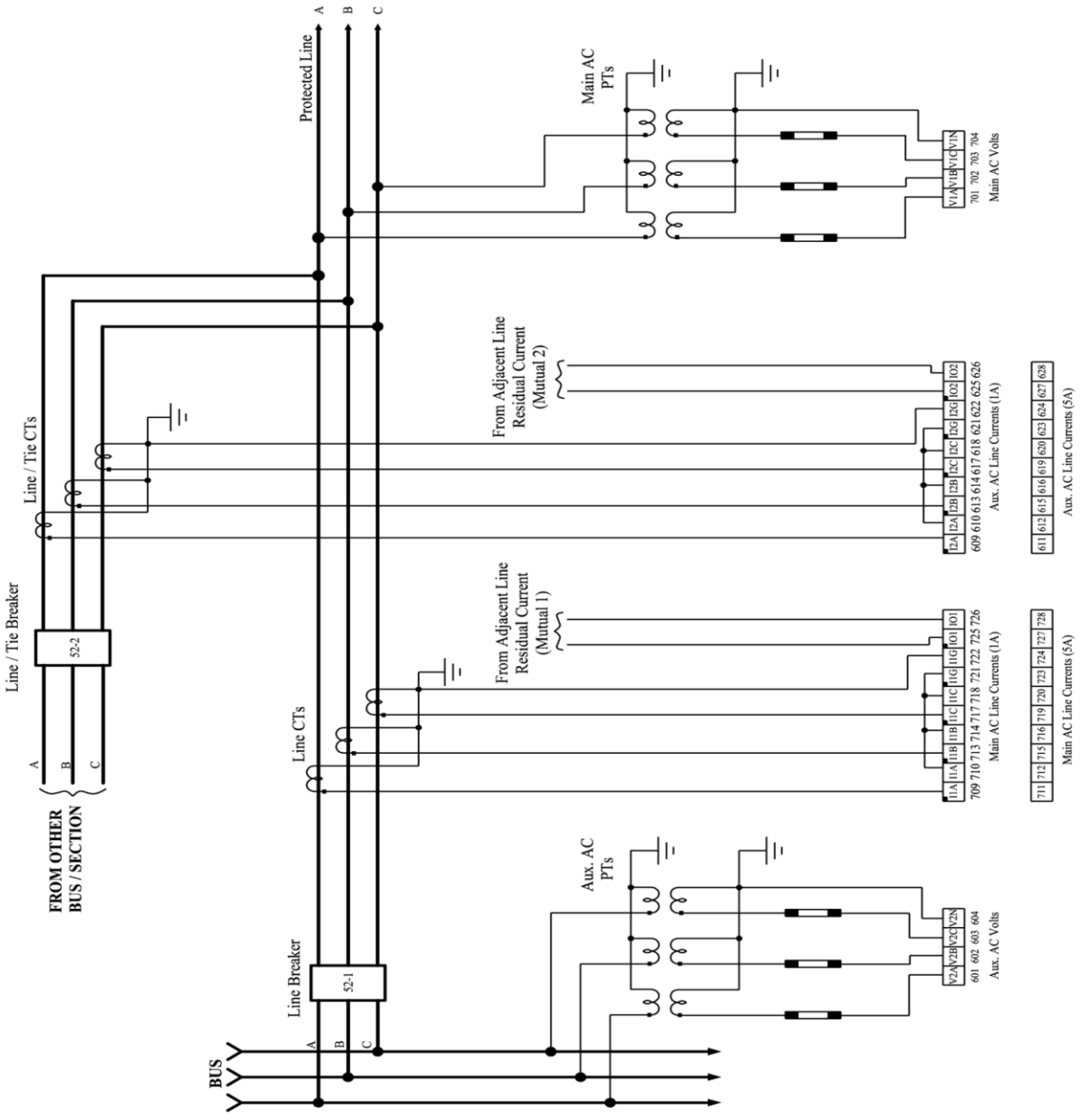


Figure 2 – L-PRO AC wiring diagram

Configuration Details for Current Inputs

To configure the L-PRO for ring bus or breaker-and-a-half bus arrangements, the relay needs to be configured to recognize that there will be two current inputs from two separate CTs with the same CT ratio. The two current quantities will be summed to perform the required calculations and to apply appropriate protective relaying algorithms.

The CT and PT ratios are specified for the corresponding analog inputs. All CT and PT ratios are specified with a ratio relative to one. The line protection uses the main current and the main voltage to operate. When two sets of CTs (main and auxiliary) are used as line current input (e.g. ring bus and breaker-and-a-half applications), the user must enable ring bus configuration to configure the relay. If enabled, the currents from the two sets of CTs are added to the relay to form the line current. For cases where voltage for line protection is obtained from bus PTs, the bus PTs are connected to the main voltage inputs.

To configure the current inputs, using the L-PRO Offliner Software (under System Parameters as shown in Figure 3) check the Ring Bus Configuration box and enter the corresponding CT ratios. The L-PRO Offliner software does not offer a specific setting for breaker-and-a-half bus configurations. However, since in this case the protected line is associated to two breakers, configuring the L-PRO relay as shown in Figure 3 will suffice for both ring bus and breaker-and-a-half applications. Once the configuration points discussed in this application note have been configured, the protection elements will use the summated currents for the purpose of protection.

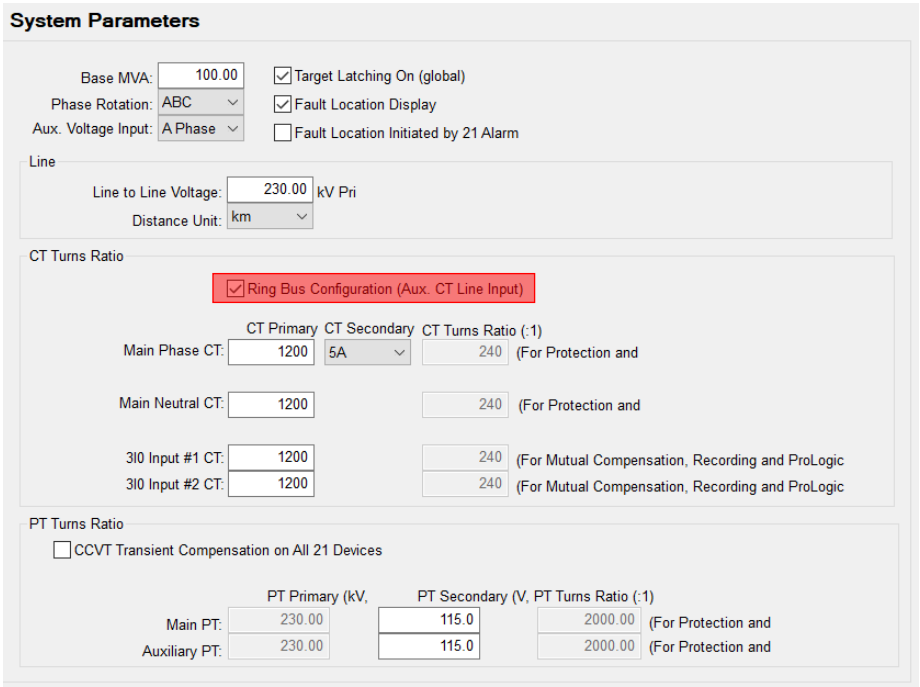


Figure 3 - Systems Parameters showing Ring Bus configuration for the L-PRO 4500

Recloser Operation

The L-PRO relay provides single-pole tripping and reclosing, as well as three-pole tripping and reclosing. The schemes available are user-programmable and consist of the following options:

- 3-Phase Trip and Reclose Scheme
- 1-Phase Trip and Reclose Scheme
- 1-Phase/3-Phase Trip and Reclose Scheme

Although, only one protection scheme can be selected at any given time (as shown in Figure 4), multiple protection schemes can be implemented on the L-PRO relay by using multiple settings groups to switch between protection schemes.

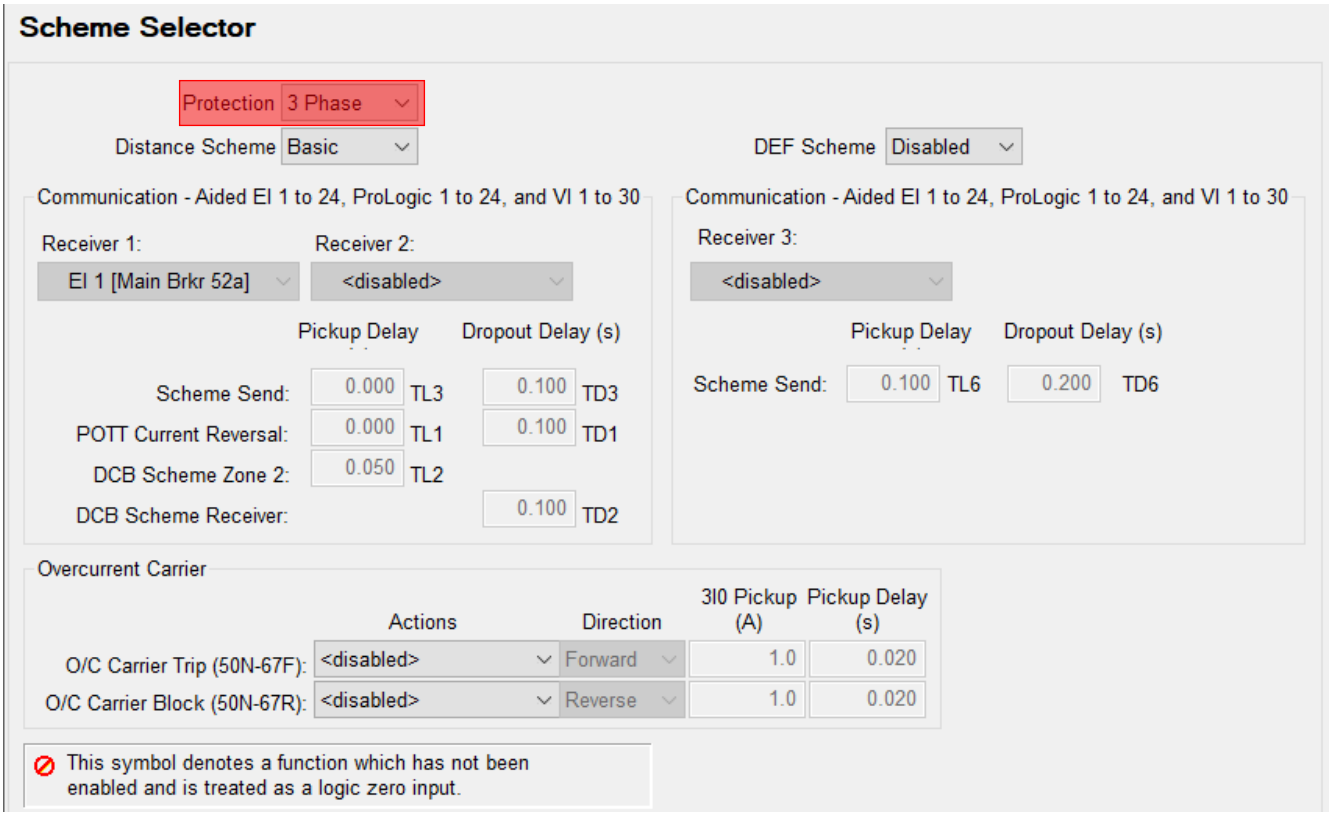


Figure 4 – Scheme Selector settings for the L-PRO 4500

The External Input Names shown in Figure 5(a) are assigned in the L-PRO Offliner software under Identification > External Inputs. From Setting Group > Breaker Status, External Input 1 was assigned to identify the status of the Main Breaker, and External Input 2 for the Aux. breaker status, as shown in Figure 5(b).

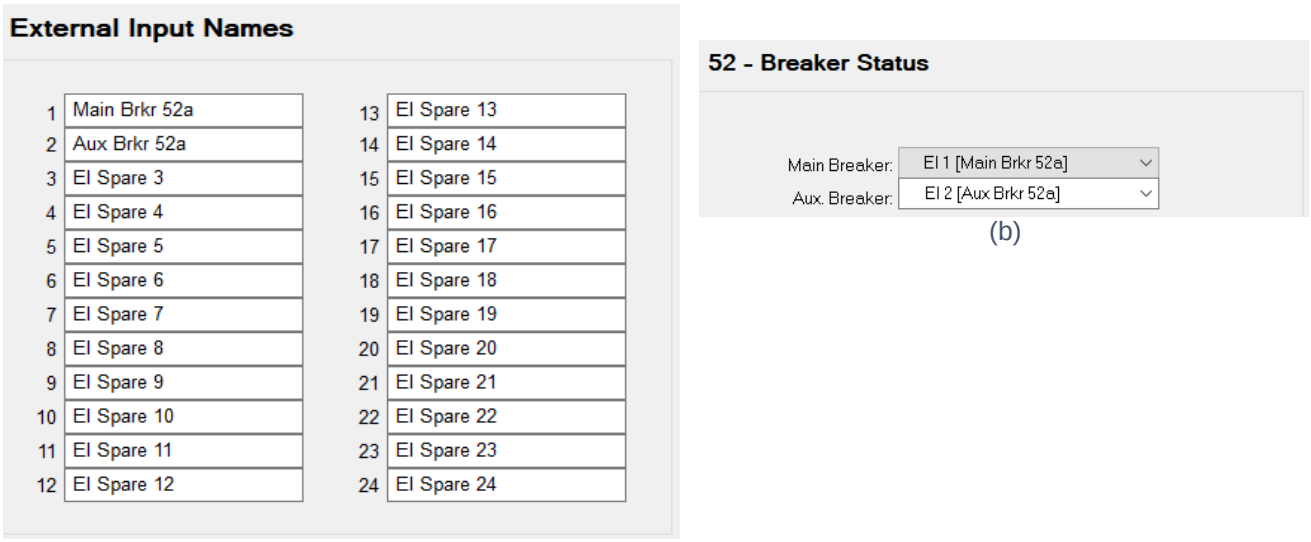


Figure 5 – Configuration screens for (a) external Input configuration, and (b) breaker Status configuration

The L-PRO offers external inputs that are used to monitor the status of both Main and Aux Breakers. This setting is enabled using the L-PRO Offliner Software under Breaker Status, when the Breaker signal setting is selected as Status Monitoring for both breakers, as shown in Figure 5(b).

Recloser for Two Breakers

Reclosing in multi-breaker arrangements such as ring bus and breaker-and-a-half applications requires special attention. Since two breakers (Main and Auxiliary) are available, it is necessary to select the appropriate 'Recloser Mode'. Four reclosing modes are possible, as shown in Figure 6. A Lead/Follower logic is often used in multi-breaker arrangements. Either of the Main or Auxiliary breakers can be assigned as the Lead breaker. For example, if the recloser mode is set to 'Main then Aux.', the Lead (Main breaker) will be the first to reclose after the recloser dead time, with the Follower (Auxiliary breaker) reclosing after the Recloser Follower Time (TF) or Recloser Reset Time (TD). Sufficient time (TF or TD) must be allowed to enable the Lead breaker to reclose successfully before the Follower breaker recloses.

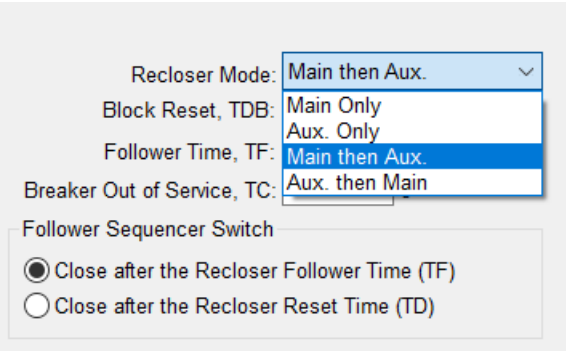


Figure 6 – Recloser Mode selection

The recloser logic can operate in three-phase mode, single-phase mode, and single- and three-phase mode. Table 1 gives a description of the time delays that are required for these recloser modes.

Table 1 – Protection Scheme Timers

Timer	Description	Reclosing scheme
T1-T4	Lead breaker open interval times for each reclosing shot	3-Phase Trip and Reclose
T1	Lead breaker open interval time	1-Phase Trip and Reclose
TM	Pickup delay within which the relay reclosing action must be attempted for single phase faults, after which the relay trips all three poles and lockout.	1-Phase Trip and Reclose
TL5	Single-phase pickup delay	1-Phase/3-Phase Trip and Reclose
TD4	Drop out time delay between 2 consecutive three-phase faults. If another three-phase fault occurs before timer TD4 drops out, the relay will trip all three-phases and lockout.	1-Phase/3-Phase Trip and Reclose
TD5	Drop out time delay between 2 consecutive single-phase faults. If another single-phase fault occurs before timer TD5 drops out, the relay will trip all three-phases and lockout.	1-Phase Trip and Reclose or 1-Phase/3-Phase Trip and Reclose
TF	Follower breaker time delay	1-Phase-, 1-Phase/3-Phase-, 3-Phase-Trip and Reclose
TD	Recloser reset timer after single phase lockout	1-Phase Trip and Reclose

The following sub-sections discuss the various recloser schemes supported by the L-PRO relay.

Three-Phase Trip and Reclose Scheme

This scheme allows the L-PRO relay to issue three-pole trip always (even if the fault is single-phase in nature) and reclosing is done for the three poles after a period of time. The recloser logic control is capable of reclosing a single line breaker or two breakers when the line is associated to a ring bus or breaker-and-a-half bus arrangement, in a variety of sequences. The breaker reclosing sequence refers to the breakers as lead and follower breakers, as mentioned earlier. The first breaker selected to reclose is called the lead breaker and the second breaker that is reclosed is called the follower.

Reclosing can be done with or without Sync Check supervision. The output matrix is used to determine the inputs and the outputs to the three-phase 79 recloser. The line breaker(s) is deemed to be open if the current through it is below 4% × I_n, where I_n is the nominal current rating. For a 5 A rated relay, this maximum current is 0.2 A_{RMS}.

The lead breaker's open interval times are settable for each reclosing shot (T1 to T4) for the three-phase recloser. The follower breaker's open time interval is common for each reclosure attempt. This follower breaker reclose time can be set to use the 79-follower timer (TF) or the 79-reset timer (TD). Please see the L-PRO Function Logic Diagram for details.

Lead or follower breaker logic is determined by the recloser's setting options. This allows the lead breaker to be either the main or auxiliary breaker. The recloser automatically selects the follower breaker into the lead position after the breaker out-of-service time delay (TC) is exceeded. If the follower breaker is removed from service, after time TC, there is no further follower breaker reclose attempts. The breaker status is reset when the breaker status changes to closed for at least 10 seconds, or if the relay power supply is toggled Off then On again. A

breaker is considered to be closed if the current measured through it is greater than 4% × I_n (0.2 A secondary for a 5 A relay).

Lockout indication is provided for both the lead and follower breaker. The lead and follower lockout indications are set for a fixed time delay pickup of the close signal time (TP) plus 1.0 second. When the recloser goes to the lead lockout condition, the breaker out-of-service timers are set to zero seconds and automatically pick up. If the recloser is in the lead lockout state, the logic remains in that state for setting (TD) seconds after the main or auxiliary breaker is manually closed. The follower lockout condition occurs when the follower breaker receives a close signal and the breaker remains open. If the recloser is in the follower lockout state, the logic remains in that state for setting (TD) seconds after the follower breaker is manually closed.

The recloser provides flexibility with lead and follower breaker options. The lead breaker is in the main or auxiliary position. This allows the user to control the lead circuit breaker with complete Dead Main Live Auxiliary, Live Main Dead Auxiliary, Dead Main Dead Auxiliary or Live Main Live Auxiliary supervision (angle limit and voltage limit). The user also has the ability to control the 79 recloser remotely or locally with external or virtual inputs. The 79 recloser monitors the breaker contact “52a” status, and automatically moves the follower breaker into the lead position when the lead breaker is removed from service after an out-of-service time delay setting. For details of auto-recloser examples, please see “L-PRO Setting Example” in Appendix L of the L-PRO Instruction Manual.

Sync control is provided on the lead breaker only, because the follower breaker always recloses after the lead breaker has successfully closed. The flexibility provided with the 79 recloser function allows the user to control one or two circuit breakers with complete Dead Main Live Auxiliary, Live Main Dead Auxiliary, Dead Main Dead Auxiliary or Live Main Live Auxiliary supervision (slip frequency), as shown in Figure 7. ProLogic can be used to supervise follower breaker closing attempts if an external input is used to signal that the follower breaker has a valid sync check signal from an external device (e.g. PLC).

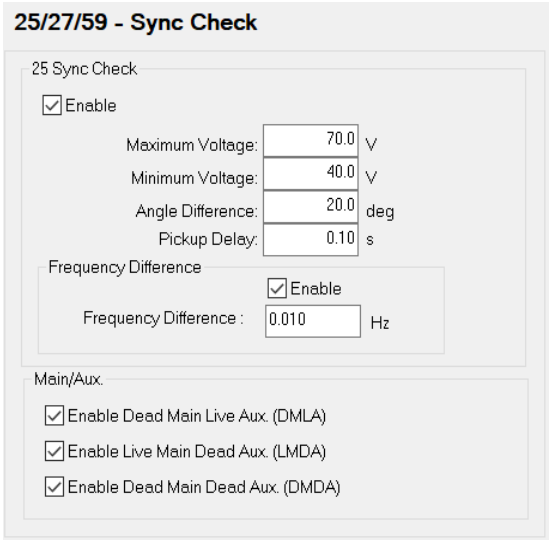


Figure 7 – Sync Check settings

Single-Phase Trip and Reclose Scheme

It should be noted that employing this scheme implies that the high voltage line breakers must be capable of opening and reclosing in a single-phase mode. A thorough systems study on the line and surrounding equipment must be performed in order that appropriate scheme settings be determined to obtain satisfactory performance of this scheme.

The Single-Phase Trip Setting blocks the three-phase (79-3) recloser function from any attempts to reclose on a three-phase basis. If a single-phase fault occurs on the line, the faulted phase is identified and only that phase is opened. After a period of time (as defined by the pickup time of timer T_1 in the single-phase recloser 79-1), the faulted phase will be reclosed. If the fault starts as a single-phase fault and then evolves into a multi-phase fault (or commutates to a different phase while the first phase is open), three-phase line tripping will occur and reclosing will be inhibited. If the first single-phase fault is detected, then reclosed upon, and if the fault persists, the L-PRO relay will issue a three-pole trip and lockout.

Timer TD5 dropout time determines how soon a subsequent single line-to-ground fault can occur after the first one, in order for the line to attempt another single-pole trip and reclosing. If a single-phase fault is detected and that phase opens but fails to reclose before timer TM times out, the L-PRO relay will issue a three-pole trip and lockout. It is important that timer TM be set longer in duration than the single-phase recloser time. Only one single phase reclose is attempted. If upon reclosure the fault persists, before timer TD5 has had a chance to dropout, a three-pole trip will be issued by the L-PRO relay, and will subsequently lock out. To get the line out of a lockout state, the line must be manually reclosed and stay in service for longer than the single-phase lockout timer TD reset time.

Protection functions that can initiate a “single-pole trip and reclose” are defined by the user in the output matrix setting screen. The user has full control to dictate which protection functions should initiate the recloser logic. Time delayed trips for instance may be considered backup functions where recloser initiation is undesired. In this case these types of operations can be set to block any attempted reclosures in any of the chosen reclosure schemes. These protection functions can also be set to initiate transient fault or dynamic swing recordings, as well as breaker failure initiations on the output matrix.

During the single-pole open condition while in the single-pole tripping mode, unbalanced line load current will create negative and zero sequence line quantities. In order to override these unbalances, provisions have been made in the relay logic to allow the user to apply modified line protection relay settings that will be automatically applied while the line is in a “phase open” condition. These settings can be determined through load flow and fault study cases for the protected line. Once the phase recloses, the protective settings that have been modified will return to their original settings. This way, protection security can be maintained while the line goes through a single-pole trip and reclose operation.

Single-Phase/Three-Phase Trip and Reclose Scheme

With this scheme setting, the relay will trip and reclose a single-phase for an initial single-phase fault and will trip and reclose all phases for a three-phase or multi-phase fault. If the fault is a permanent one, only one attempt to reclose will take place before lockout will occur. If sufficient time elapses between the first fault and subsequent new line faults (as determined by the TD4 and TD5 dropout times), the protection will try to keep the line in service by tripping and reclosing the line as required.

It should be noted that the relay has two types of reclosers, a single-phase type 79-1 and a three-phase type 79-3 recloser. The single-phase recloser has only one shot, determined by a timer T1. This time delay applies for both the Single-Phase Scheme and for the Single-Phase/Three-Phase Scheme settings. The three-phase recloser has a common setting for the first reclose of the Three-Phase or the Single-Phase/Three-Phase Trip and Reclose Schemes. Figure 8 shows the recloser setting screen with the Single-Phase/Three-Phase recloser option selected.

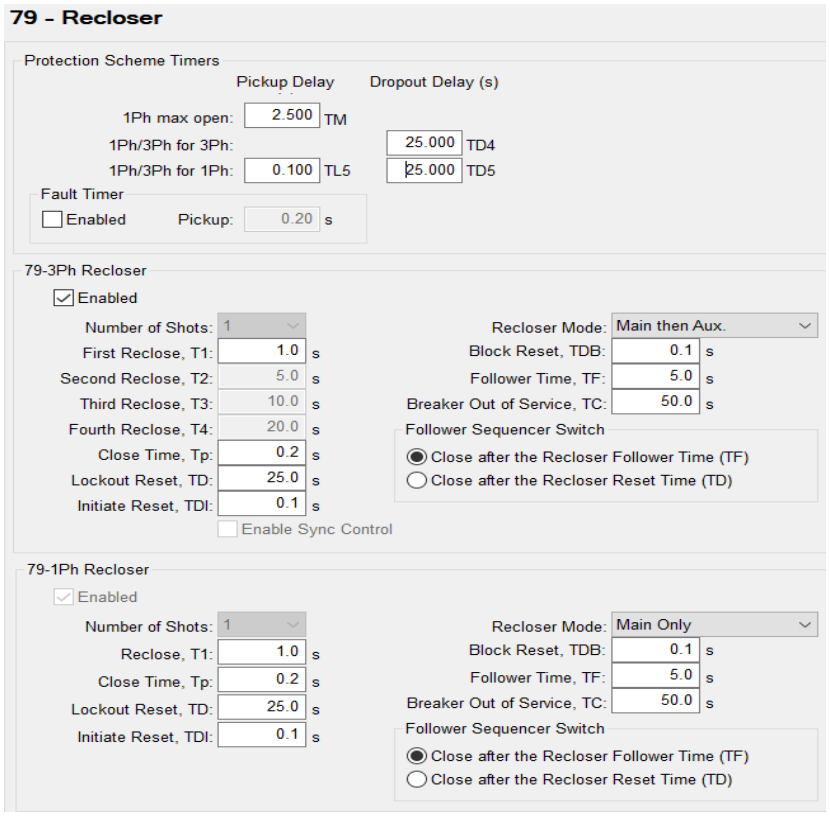


Figure 8 – Recloser Settings for 79-1Ph/79-3Ph Recloser option

Breaker Failure Protection

The L-PRO relay can be used to provide Breaker Failure (50BF) protection for both the main and auxiliary circuit breakers in ring bus and breaker-and-a-half schemes. These are referred to as the 50BF Main and 50BF Auxiliary protection functions. The 50BF Auxiliary function is only available for the 10CT, 6PT L-PRO relay model. Also, it is only available for ring bus and breaker-and-a-half bus configurations.

The 50BF function is shown in Figure 9. The L-PRO supports single-phase and three-phase modes of operation. In single-phase mode, the BF function monitors the trip and current signals on the faulted phase, and issues a single-pole trip. In three-phase mode, a three-phase BF initiation is used irrespective of the fault type (single-phase or multi-phase). The output of the BF function for this mode is a three-pole trip.

When breaker failure is detected by a trip or other internal logic configured using the BFI column of the output matrix and the breaker current still exists, two user-settable timers are started. If the pickup timers elapse and the current still exists (which indicates breaker failure), the output of this function is set high. The 50BF-1 output can be used to retrip the breaker with its second trip-coil. If this fails to clear the fault, the 50BF-2 can be used to trip adjacent breakers, such as bus breakers.

The configuration of the current detectors (50BF Breaker Current Pickup), Pickup Delay 1 (T_1), and Pickup Delay (T_2) for the main and auxiliary breakers are shown in the 50BF configuration screen in Figure 10(a). The pickup current setting depends on the system strength and the bus arrangement. Generally, feeder fault detector pickup current must be set above the feeder maximum load current (and lower than the minimum fault current), in order to prevent the current detectors from picking up for non-fault conditions. However, in ring bus and breaker-and-a-half bus arrangement, it might be impossible to set the current detectors using the maximum load current or the minimum fault current, since the current through the main and auxiliary breakers might be

difficult to predict. A common practice in some utilities is to set the current detectors as sensitive as possible [2]. A pickup setting of 20% $\times I_n$ could be applied, where I_n is the nominal current.

Figure 10(b) shows the settings for the 50LS Main and 50LS Aux. Low Set Overcurrent function which served as the BF Initiation (BFI) logic in this example. The BFI input could in fact be the output from any of the protection functions in the L-PRO relay. Furthermore, a ProLogic output, external protective relay output, or virtual input may be used as the input to the BFI logic.

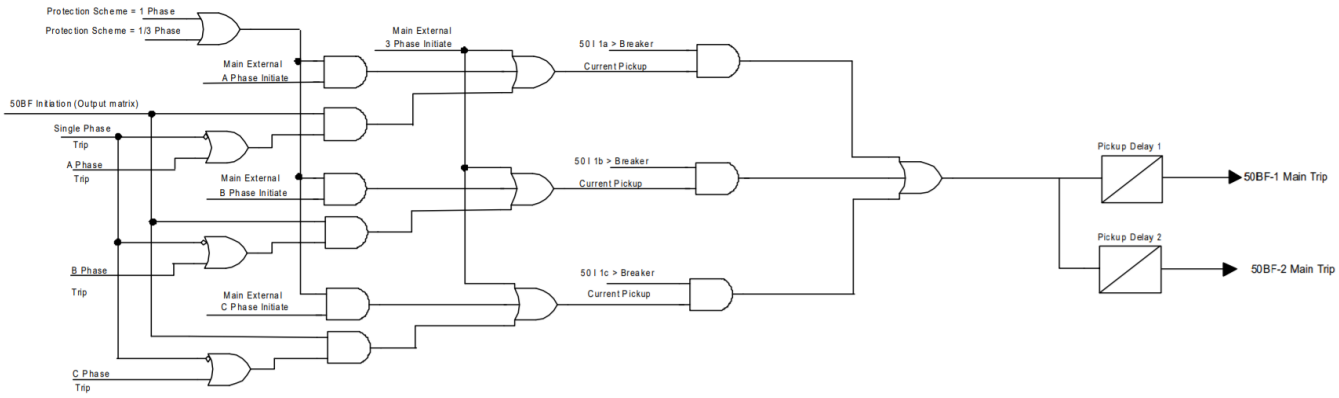
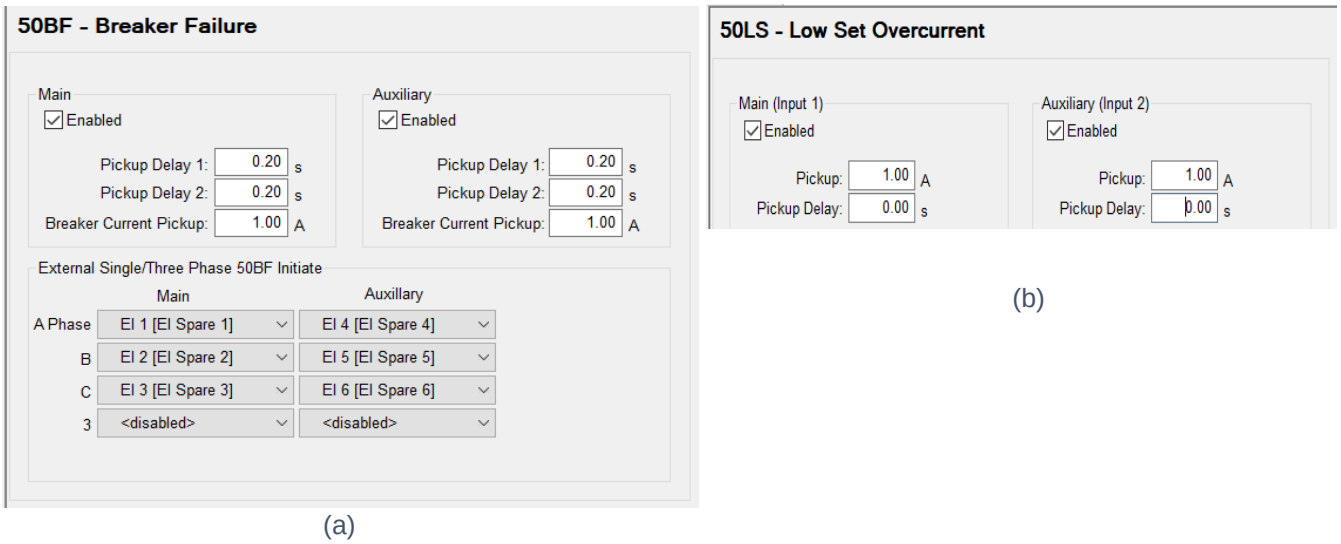


Figure 9 – L-PRO Breaker Failure Logic



(a) (b)

Figure 10 - Breaker Failure configuration (a) 50BF function settings, and (b) 50LS function settings

The 50BF scheme requires pickup time delays to coordinate the scheme with the feeder protection. Pickup Delay 1 (T_1) may be calculated using:

$$T_1 = T_{BK} + T_{PR} + T_{M1} \quad (1)$$

where T_{BK} is the breaker interrupting time, T_{PR} is the protection relay reset time, and T_M is the safety margin.

If 50BF-2 is used for tripping adjacent breakers (bus breakers), T_2 can be calculated as:

$$T_2 = T_1 + T_{M2} \quad (2)$$

where T_{M2} is a safety margin allowing 50BF-1 sufficient time to first operate. T_{M2} can be set to zero if no additional tripping is required.

The following are examples of BF timer settings for a 50BF scheme using typical three-cycle and five-cycle breakers:

- Three-Cycle Breaker: 62BF = $T_1 = T_{BK} + T_{PR} + T_{M1} = 3.0 + 1.55 + 5.0 = 9.55\ cycles\ or\ 159\ mS$
- Five-Cycle Breaker: 62BF = $T_1 = T_{BK} + T_{PR} + T_{M1} = 5.0 + 1.55 + 5.0 = 11.55\ cycles\ or\ 193\ mS$

Note that the calculations above are based on the fact that the main protection relay may have a reset time; in this example the reset time was assumed to be 1.55 cycles with a safety margin of 5 cycles. Total clearing time (which includes breaker failure time) of each breaker should coordinate with the critical clearing times needed for system stability. Additional information on the design of BF protection schemes and the calculation of BF protection pickup time delays can be found in [2, 3].

In order to perform its function, the output of the 50BF function must be set to close the L-PRO output contacts. This is done by mapping the 50BF output to any of the L-PRO output contacts, using the Output Matrix screen shown in Figure 11. This figure shows output contacts 22-25 and input signals (50LS Main and 50LS Aux.) to the BFI.

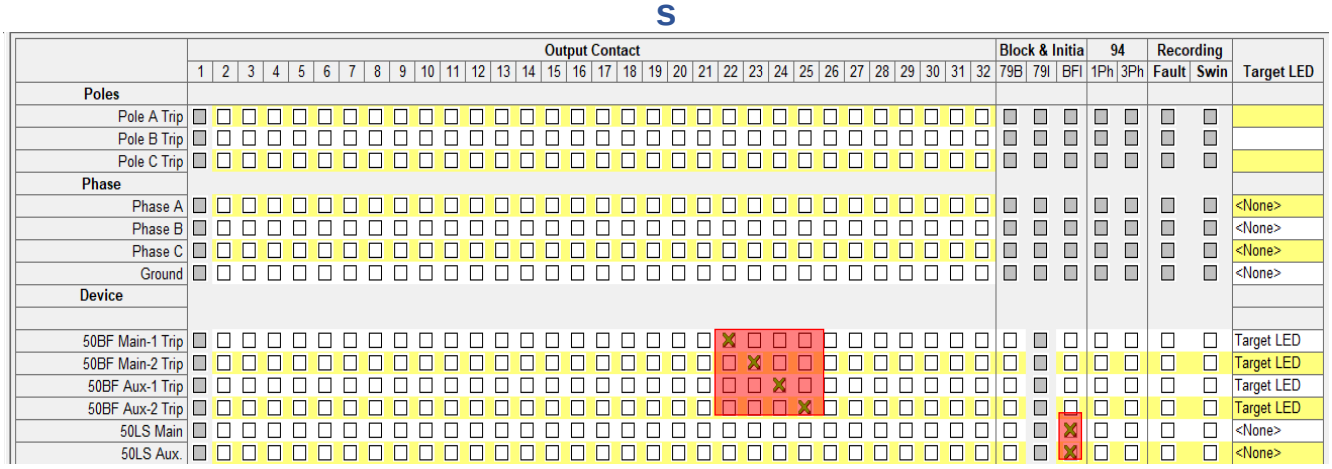


Figure 11 - Breaker Failure Output Matrix configuration settings

Conclusion

The L-PRO can be used in multi-breaker applications such as ring bus and breaker-and-a-half schemes. The currents from two sets of CTs (Main and Aux. CTs) are internally combined within the relay. This application note showed the L-PRO settings required in the implementation of such multi-breaker applications.

Some benefits of using the L-PRO relay in multi-breaker applications include:

- Improves breaker maintenance by reviewing breaker performance for every breaker operation
- Provides an auto-reclosure function for applications that use two circuit breakers
- Reduces cost for breaker failure implementation by providing a 50BF integrated protection function in the L-PRO relay
- Requires less wiring for current circuits and eliminates the need for auxiliary contact status points

References

1. L-PRO Instruction Manual Version 2.5 Rev 1
   ERLPhase TESLA 4000 user manual. [Available online at
   www.erlphase.com/downloads/manuals/TESLA_4000_manual.pdf]

2. IEEE C37.119, IEEE Guide for Breaker Failure Protection of Power Circuit Breakers.

3. IEEE Std C37.102-2006, IEEE Guide for AC Generator Protection.