

L-PRO Line Protection Relay

Improving the Operation of Multi-Breaker Transmission Terminals



Introduction

The advent of multi-function numerical protection relays has done much to improve the protection of transmission terminals by increasing dependability and security of distance protection. In addition, multi-function relays improve operations by increasing the reliability of the control system by decreasing the number of discrete devices, and thereby decreasing the number of points of failure. While almost all numerical protection relays include auxiliary protection functions like automatic reclosing, synchronism check, and breaker failure functions, many are designed with only one set of current inputs, limiting the application of these auxiliary functions to single breaker transmission terminals. For the ring bus and breaker-and-a-half multi-breaker schemes that are commonly used in North America, separate discrete devices are still required for these specific auxiliary functions. Also, the large number of electro-mechanical transmission protection systems in service obviously require separate discrete devices for these specific auxiliary functions.

This application note describes how the L-PRO Line Protection Relay from ERLPhase, using multiple sets of current and voltage inputs, improves the operation of ring bus and breaker-and-a-half transmission terminals by using one device to provide the automatic reclosing, synchronism check and breaker failure protection functions for both circuit breakers. This application can reduce the number of wires required for a multi-breaker line terminal by 50% over traditional solutions. The approach greatly improves control system reliability by reducing engineering, wiring, and testing complexity, and by reducing the number of devices and connections to fail, with the added benefit of reduced capital costs for installation.

Current Practices

Networked transmission systems in North America typically use ring bus or breaker-and-a-half transmission terminals. This arrangement provides high reliability of the transmission system, the ability to maintain individual circuit breakers without line outages, and (in the case of breaker-and-a-half terminals) the ability to maintain buses without outages. This practice leads to complexity in the protection of transmission lines, particularly in terms of auxiliary protection functions, such as automatic reclosing, synchronism check, and breaker failure. Figure 1 is a simplified schematic of a breaker-and-a-half protection scheme.

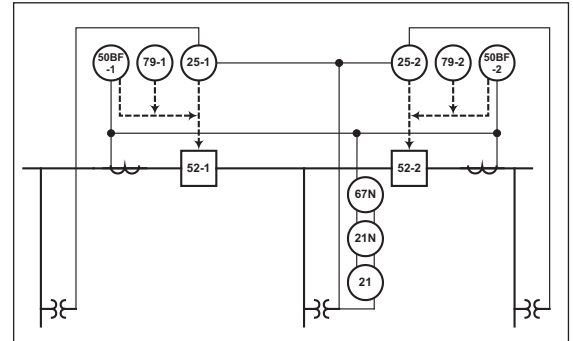


Figure 1: Simplified breaker-and-a-half protection scheme.

Primary Line Protection Practices

The common practice for primary line protection of an individual transmission line on ring bus or breaker-and-a-half transmission terminals is to electrically sum the currents from both circuit breakers, by physically connecting the CT leads. This method directly measures all current flowing into or out of the transmission line itself. Transmission line voltages are measured from voltage transformers directly connected to the transmission line.

Breaker Failure

The breaker failure function is performed by directly measuring the current flowing through an individual circuit breaker, after a trip command is issued to the circuit breaker. This requires the breaker failure relay to be able to identify the specific current flowing through each breaker of a ring bus or breaker-and-a-half scheme. Multi-breaker transmission line protection relays that electrically sum the currents from both breakers can therefore not be used, requiring a separate breaker failure relay for each breaker.

Automatic Reclosing

When automatic reclosing is used on a multi-breaker transmission terminal, both circuit breakers require a close signal after an operation. Some operating philosophies permit automatic reclosing of both circuit breakers. Other operating philosophies permit automatic reclosing of only one circuit breaker and require manual reclosing of the other breaker. In either case, one circuit breaker must be identified as the lead breaker to reclose (or the main circuit breaker for the line) and the other as the follower (or auxiliary) circuit breaker to reclose. The complexity comes from correctly identifying the lead and follower circuit breakers in all operating situations, including various system operating contingencies, and during breaker maintenance activities.

For electro-mechanical protection systems, it is customary to have separate reclosing relays for each circuit breaker. With multi-function numerical protection systems, as illustrated in Figure 2, the reclosing function from one relay is typically used for both circuit breakers.

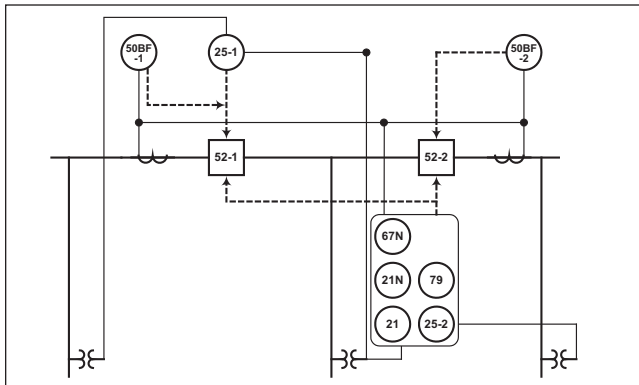


Figure 2: Multi-function numerical breaker-and-a-half protection scheme.

Synchronism Check

Closing a circuit breaker on a networked transmission system typically requires a synchronism check to ensure different sources are connected together only during synchronous conditions to prevent equipment damage. A synchronism check must be performed before closing either circuit breaker for the transmission line, as both circuit breakers may be connected to different sources. Electro-mechanical systems require a separate synchronism check relay for each circuit breaker, or a synchronism check relay designed for multiple sources. Multi-function numerical systems also typically require a separate synchronism check relay for each breaker, one typically included as a function in the line protection device, and one as an additional discrete device.

Traditional electro-mechanical protection systems for multi-breaker terminals (beyond the line protection itself) must provide 6 additional relays to provide reclosing, synchronism check, and breaker failure for both circuit breakers. These systems also introduce accompanying engineering design time, drafting time, extra wiring, and increasing points of failure. Multi-function numerical protection schemes (beyond the line protection itself) must provide at least 3 additional relays for reclosing, synchronism check, and breaker failure. The control logic to identify the main & auxiliary breaker, to change between the main and auxiliary breaker, and to account for one breaker being out of service, is typically a hard-wired control logic involving control switches and auxiliary relays. This logic is difficult to design, install, and test.

New Application

Employing multi-function numerical protection relays with multiple sets of CT and VT analog signal inputs improves the operations of multi-breaker transmission terminals by reducing the number of discrete devices required, reducing the amount of wiring required for correct operation, simplifying the operation of the line terminal, and providing flexibility in operations. The L-PRO Line Protection Relay is a distance relay designed for complete protection and operation of a multi-breaker line terminal. In addition to the traditional line protection functions, the L-PRO offers multiple sets of CT and VT inputs to provide the auxiliary protection functions of breaker failure, synchronism check, and automatic reclosing for both breakers. This basic application is shown in Figure 3.

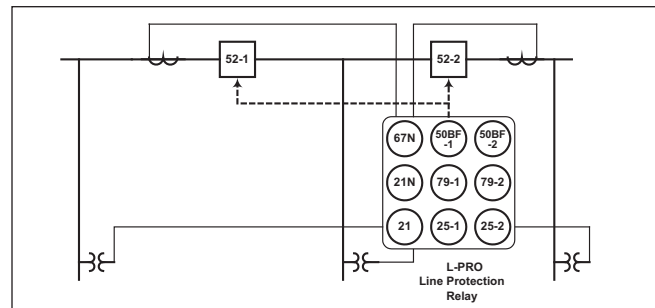


Figure 3: L-PRO multi-breaker application.

To apply the L-PRO in multi-breaker line terminal applications, there is an explicit setting called "Ring Bus". This setting enables reclosing and breaker failure for both circuit breakers. In ERLPhase relays, these breakers are identified as the "Main" and "Auxiliary" breakers.

Breaker Failure – There is a separate breaker failure element for both the Main and Auxiliary circuit breakers in the L-PRO relay. The breaker failure elements are traditional 2-stage breaker failure elements, initiated by an internal protection function trip or by an external signal. The breaker position is determined by flow of current through the breaker.

Automatic Reclosing in the L-PRO – Automatic reclosing is applied by settings, individual to each of the L-PRO's 8 settings groups. Up to 4 reclosing shots are available, initiated by an internal protection function trip, or by an external signal. The L-PRO automatic reclosing function is specifically designed for application on multi-breaker line terminals, as shown by the reclosing element settings in Figure 7. The lead circuit breaker for reclosing is user-selectable (Main breaker then Auxiliary breaker, Main breaker only, Auxiliary breaker only, or Auxiliary breaker then Main breaker). Reclosing times are user-selectable for each lead breaker attempt. The follower breaker will reclose on each attempt after a follower timer expires, or will only reclose when the lead breaker reset timer expires (indicating a successful reclose).

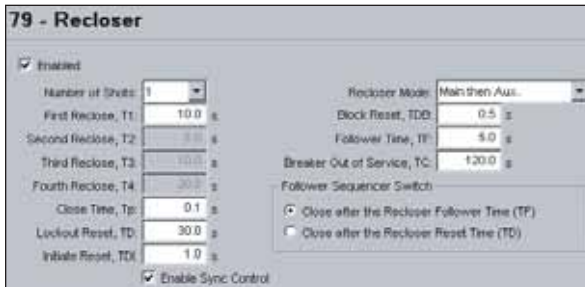


Figure 4: L-PRO Recloser settings.

To change the reclosing sequence, or to only reclose one circuit breaker when the other circuit breaker is out of service, requires only a settings group change.

Synchronism Check in the L-PRO – The L-PRO’s synchronism check function compares voltage between the line VTs and auxiliary bus VTs. The auxiliary bus VTs may be one single-phase VT or a three-phase set of VTs. The synchronism check function in the L-PRO can perform any combination of synchronism check, dead main-live auxiliary, live main-dead auxiliary, or dead main-dead auxiliary. Automatic reclosing only explicitly uses synchronism check on lead breaker reclosing attempts. To check synchronism when reclosing the follower breaker, use ProLogic equations to supervise the 79 Aux Reclose command, and a combination of ProLogic equations and output contact to swap between sets of the auxiliary bus VTs (as described in a separate Technical Note).

On the operations side, the **P-PRO** improves normal line terminal operations, reliability, maintenance activities, testing, and system upgrades. Specifically:

Fewer Devices and Wiring to Fail. By reducing the number of devices, reliability is increased (as there are fewer devices that can fail). While the failure of multi-function device will have a greater impact than the failure of a discrete device, the affected functions are auxiliary functions, where a failure doesn’t directly impact the primary protection of the line. Having fewer devices also reduces the wiring for a terminal. Every wiring termination is a potential point of failure, so reducing the amount of wiring increases reliability. Applying an L-PRO in this application can reduce the amount of wiring by 80% over electro-mechanical schemes, and by 50% over traditional numerical protection and control schemes.

Simpler Line Terminal Control Scheme. Implemented in IED Software. The traditional multi-breaker line terminal control scheme is implemented in the settings and logic of the L-PRO relay. This eliminates the need for complicated, hard-wired control designs, auxiliary relays, and timers.

Easier to Test. Control schemes, especially where automatic reclosing is involved, become easier to test. Since the logic is implemented in relay settings and software, the correct operation of the scheme can be tested in a laboratory environment, before actual field implementation.

Tested Schemes Can be Replicated at No Effort. The real benefit of performing control logic in software is replication. A tested, proven control scheme can be implemented at a different location simply by downloading the logic and settings into a new relay. This ensures reliability and consistency of design, simplifies testing commissioning, and training, and ensures correct operation.

Simpler Field Changes to Control Schemes. By implementing control logic in numerical relays, changes to the logic become simply a matter of re-programming the relays in the field. This eliminates the need for physical wiring changes, and the attendant engineering, drafting, and purchasing efforts.

Operations Improvement. The most complicated operational procedure for a multi-breaker line terminal where reclosing is applied, is to take one of the circuit breakers out of service for maintenance purposes. By using the L-PRO relay, the process of re-establishing which breaker is the main circuit breaker and blocking reclosing for the out-of-service breaker, becomes simply a matter of changing settings groups, either by SCADA command or local control.

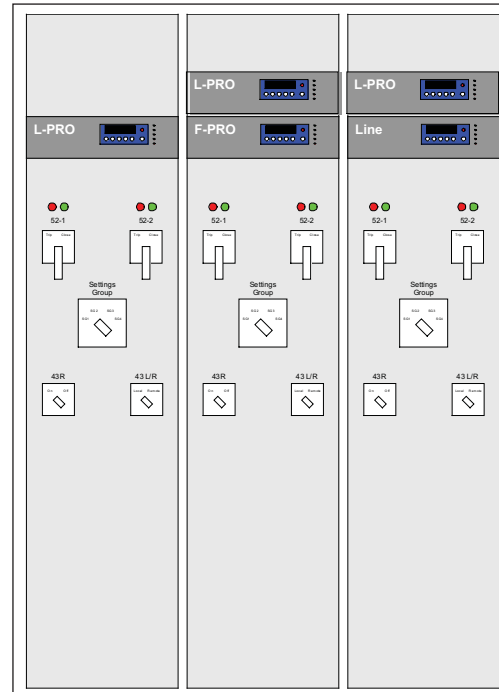


Figure 5: L-PRO typical panel layout.

The use of one device to perform all protection functions, or auxiliary protection functions, doesn’t impact clear and understandable operations practices for substation personnel. For example, a typical panel layout for this scheme will be similar to Figure 9, and includes separate breaker control switches and breaker status lights for each breaker.

Application Example

Figure 5 shows the basic functionality of a typical application of the L-PRO for primary line protection and line terminal auxiliary protection functions. This application includes phase distance protection, ground distance protection, and directional ground overcurrent protection for the transmission line. The L-PRO provides breaker failure protection for both the 52-1 and 52-2 breakers, and provides automatic reclosing and synchronism check for both breakers.

This application is described more completely by the Figure 10 AC schematic and the Figure 12 DC schematic. The AC schematic shows complete analog wiring for this L-PRO application, with separate CT inputs from the 52-1 and 52-2 breakers, and dedicated inputs for the line VTs.

The L-PRO can perform synchronism check with a single-phase or three-phase auxiliary voltage. When using a single-phase auxiliary voltage, the L-PRO automatically determines which phase is connected to perform synchronism check. The other auxiliary voltage inputs must be grounded. For a single-phase application on multi-breaker line terminals, it is necessary to use output contacts and ProLogic equations to select the appropriate synchronism VT to connect to the auxiliary VT input on the L-PRO. This logic is

described in detail in a separate Technical Note, with a basic concept of keeping the lead breaker synchronism source connected, then changing to the follower breaker synchronism source after the lead breaker closes.

The DC schematic shows this application's basic control scheme. Manual breaker close commands are issued by the relay to ensure the proper synchronism source is used, to interface correctly with the local/remote control conditions, and to simplify wiring. The scheme uses a selector switch connected to 2 digital inputs to change the settings group for different operating conditions (based on the logic in Table 1). The 52-a contact from both circuit breakers determines breaker position for the automatic reclosing and synchronism check functions.

Table 1: Setting Group selector logic.

EI3	EI4	Setting Group	Operating Conditions
L	L	1	Normal Operations
H	L	2	Aux Breaker Out
L	H	3	Main Breaker Out
H	H	4	Change Lead and Follower

(Settings Groups 5-8 not used)

Normal Operations

Normal system operations is defined, in part, as both circuit breakers in service, with automatic reclosing and synchronism check for both breakers. For normal system operation, Settings Group 1 is active and contains the protection settings, and control logic, for the typical system conditions. Breaker 52-1 of Figure 5 is the Main breaker, and Breaker 52-2 is the Auxiliary breaker. Reclosing is set to "Main then Aux", to reclose first 52-1, then 52-2 after a time delay.

Auxiliary Breaker Out of Service

When Breaker 52-2 is taken out of service for maintenance, the L-PRO relay is switched to Settings Group 2 by use of the settings group selector switch, or by SCADA command, to adapt the relay protection and control scheme operate for this condition. Reclosing is set to "Main Only", with synchronism check only performed from the Bus A synchronism source. A note on protection settings: it may be necessary to adapt the distance protection settings if having one of the line breakers significantly changes system source conditions.

Main Breaker Out of Service

When Breaker 52-1 is taken out of service for maintenance, the L-PRO relay is switched to Settings Group 3 by use of the settings group selector switch, or by SCADA command. Just as when the 52-2 breaker is out of service, this settings group ensures the relay protection and control scheme operates correctly for when the 52-1 breaker is out of service. Reclosing is set to "Aux Only", with synchronism check only performed from the Bus B synchronism source. The same concern about distance protection settings applies as when the 52-2 breaker is out of service.

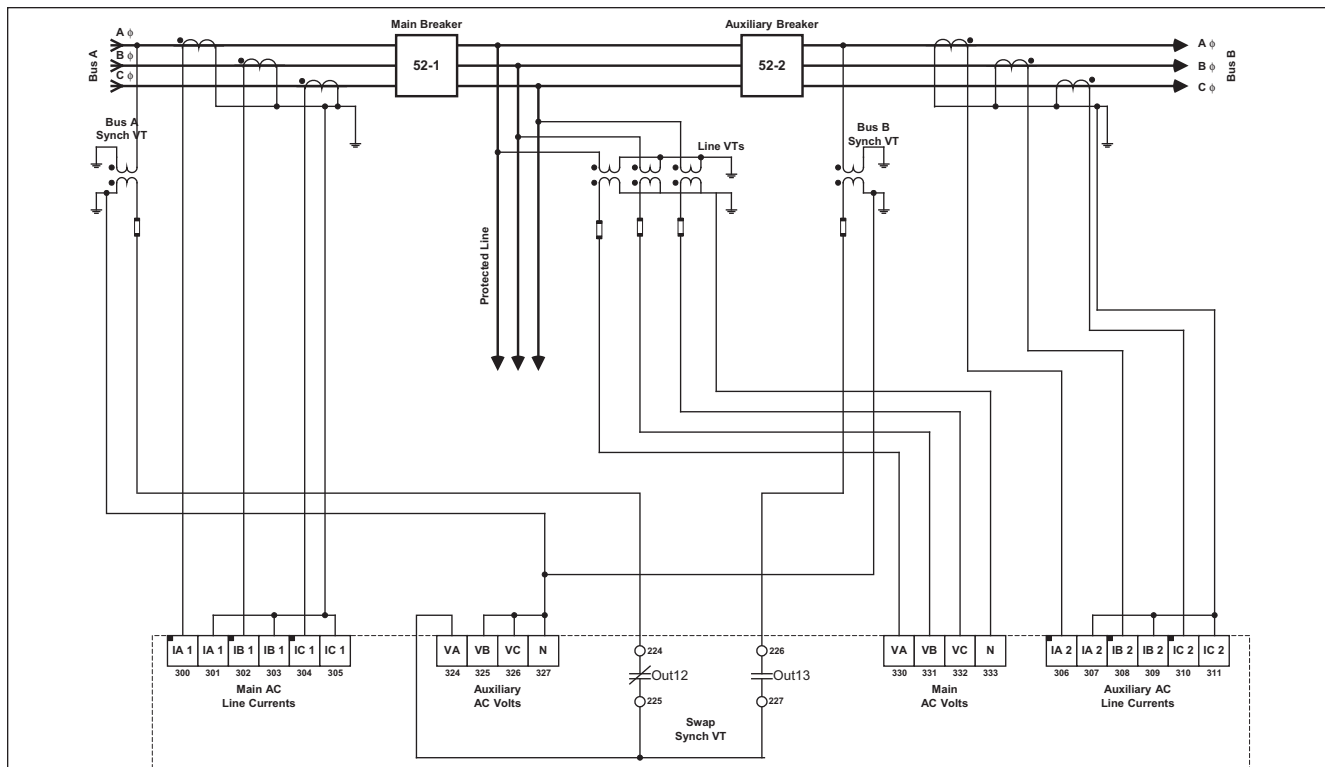


Figure 6: L-PRO Line Protection Relay: typical AC schematic.

Change Lead and Follower Breaker

There may be operating conditions where it is desirable to change which breaker is the lead breaker and which breaker is the follower breaker (for automatic reclosing). In this L-PRO application, this is simply a matter of changing the relay to Settings Group 4 using the settings group selector switch. The reclosing is set to "Aux Then Main".

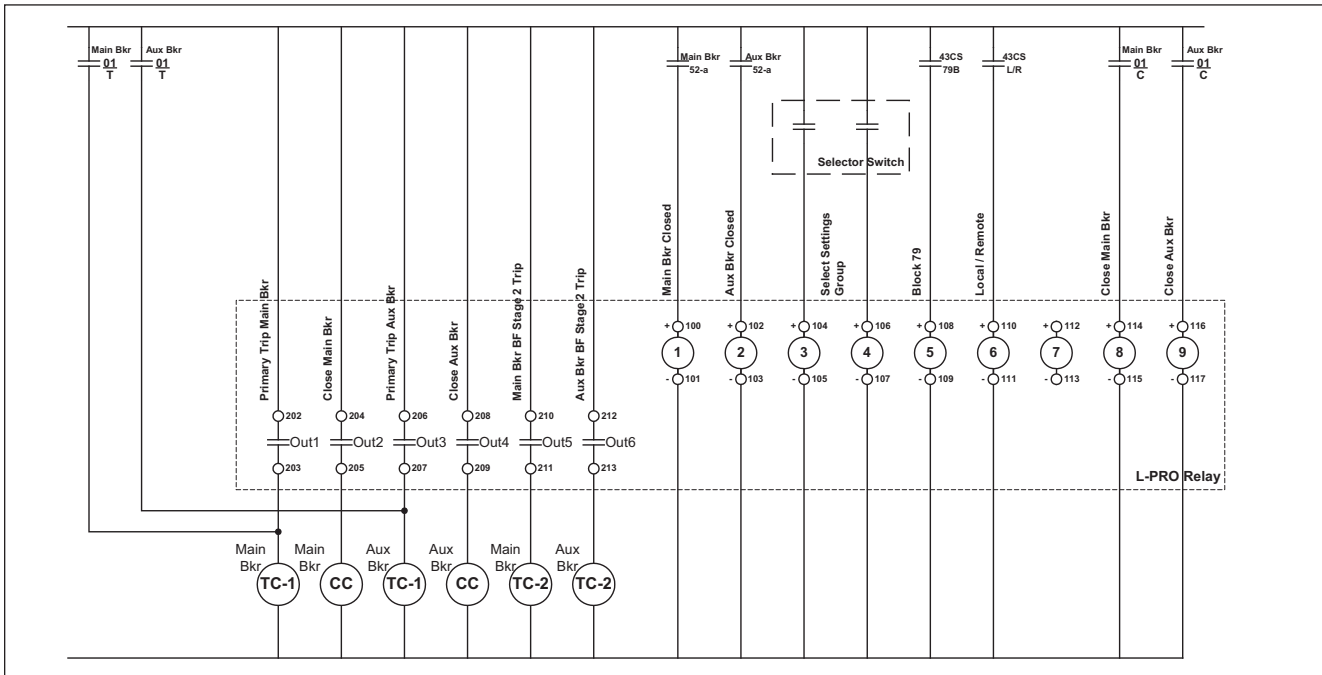


Figure 7: L-PRO Line Protection Relay: typical DC schematic.

Other Benefits

Beyond the improvement of reliability and simplification of the control schemes, there are additional benefits to using the L-PRO Line Protection Relay to perform the auxiliary protection functions for multi-breaker line terminals. The first of these is true Digital Fault Recorder (DFR) quality waveform recording, at 96 samples per cycle, to capture separate waveforms for both the main and auxiliary circuit breakers. This becomes a simple and low cost way to add true disturbance recording when upgrading line terminals. Recording at 96 samples per cycle allows the L-PRO to capture CT saturation, DC offset, and true peak fault currents (necessary information to provide analysis of unusual fault events). The L-PRO also has 2 additional sets of current inputs, used to trigger fault recording based on the operation of other lines or buses, and includes low-speed swing recording, sampling at 1 sample per cycle (to provide recording of power swings and similar system events).

This application note discusses the use of the L-PRO Line Protection Relay to perform both traditional line protection functions, as well as the auxiliary protection functions for the line terminal. However, typical protection practices for transmission lines use 2 sets of line protection to provide redundancy of protection. The L-PRO is designed to meet this practice. Considering numerical line protection exclusively, the L-PRO provides the primary or redundant line protection, as well as the auxiliary protection functions. As shown in Figure 14, this reduces the number of discrete relays for a line terminal to just 2 devices, and easily supports the use of primary and redundant relays that use different operating principles.

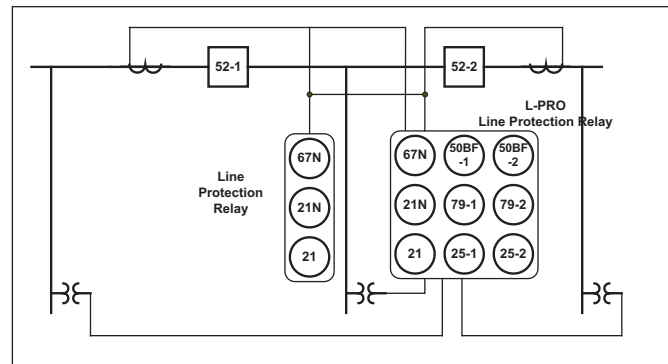


Figure 8: L-PRO Line Protection Relay: typical DC schematic.

IEDs with multiple sets of current and voltage inputs are ideally designed for future digital substation. The IEC 61850 and IEC 60044 digital communications standards for substations include provisions for communications between current and voltage transducers and IEDs (current and voltage values digitized at the source) and communicated to appropriate IEDs. Therefore, electrically summing the input currents for multi-breaker terminals is no longer possible. These currents must be mathematically summed in the IED algorithm. Relays with multiple current and voltage inputs, like the L-PRO, are already designed to meet this new requirement.

Conclusions

This application note has shown the L-PRO Line Protection Relay's ability to simply provide breaker failure, automatic reclosing, and synchronism check for both circuit breakers of multi-breaker line terminals. This application greatly improves the operations of these terminals through simpler control schemes, and improved reliability due to fewer devices and less wiring.

Operations and reliability improvements come from both hardware changes to the protection and controls scheme, and the resulting simplified control scheme logic. The most obvious of these changes is the reduction in the amount of wiring required (as great as a 50% reduction in wires over traditional control schemes). CT and VT leads, breaker status indications, and control outputs are only connected to a single device. Using fewer wires simplifies control circuit design (reducing the possibility for both design and installation mistakes). It also reduces the number of points of failure in the protection and control system. Reducing the number of devices also reduces the likelihood of a device failure.

There are also 2 significant cost savings to be gained by combining auxiliary relay function into one IED. The obvious one is a reduced capital cost, by eliminating discrete relays required for auxiliary protection functions. This is especially true when using the L-PRO, since reclosing, synchronism check and breaker failure protection for both circuit breakers are combined with line protection functions found in the relay.




















The other significant cost saving is due to reducing the amount of wiring involved. Consolidating several auxiliary devices into one IED means that CT leads, VT leads, and control inputs need only be run to one location. This reduces the number of wires, amount of wire, and time spent wiring and testing, as well as the amount of time spent designing and drafting the control scheme.

Selecting whether to apply the L-PRO to perform the auxiliary protection functions depends on the specific application, and operating philosophy, of the utility. A general recommendation for new line terminals, or for complete upgrade of existing line terminals, is to use the L-PRO to take advantage of the total protection offering. However, a utility may desire to keep auxiliary protection functions separate from primary line protection. For multi-breaker terminals, it still makes sense to use separate CT leads from each circuit breaker to the L-PRO, to provide waveform capture for both circuit breakers during fault events and dynamic swing events.

References

- [1] L. L. Grigsby, Editor, The Electric Power Engineering Handbook, CRC Press LLC, Boca Raton, FL; 2001.
- [2] IEEE PC37.104, Guide for Automatic Reclosing of Line Circuit Breakers for AC Transmission & Distribution Lines, Institute of Electrical and Electronics Engineers, Inc., New York, NY; 2003.
- [3] L-PRO Line Protection Relay User Manual Version 3.2 Revision 1, ERLPhase Corporation, Winnipeg, MB, Canada; 2002
- [4] IEEE Std. C37.113-1999 Guide for Protective Relay Applications to Transmission Lines, Institute of Electrical and Electronics Engineers, Inc., New York, NY; 2000.

List of Symbols

	Voltage Transformer		Inverter Logic Gate
	Current Transformer		AND Logic Gate
	Circuit Breaker		Timer Logic Element
	Control Logic		Circuit Breaker Trip Coil
	Phase Distance Protection		Circuit Breaker Close Coil
	Ground Distance Protection		Fuse
	Directional Ground Overcurrent Protection		Control Contact
	Synchronism Check		Relay Output Contact
	Automatic Reclosing		Relay Digital Input
	Breaker Failure Protection		