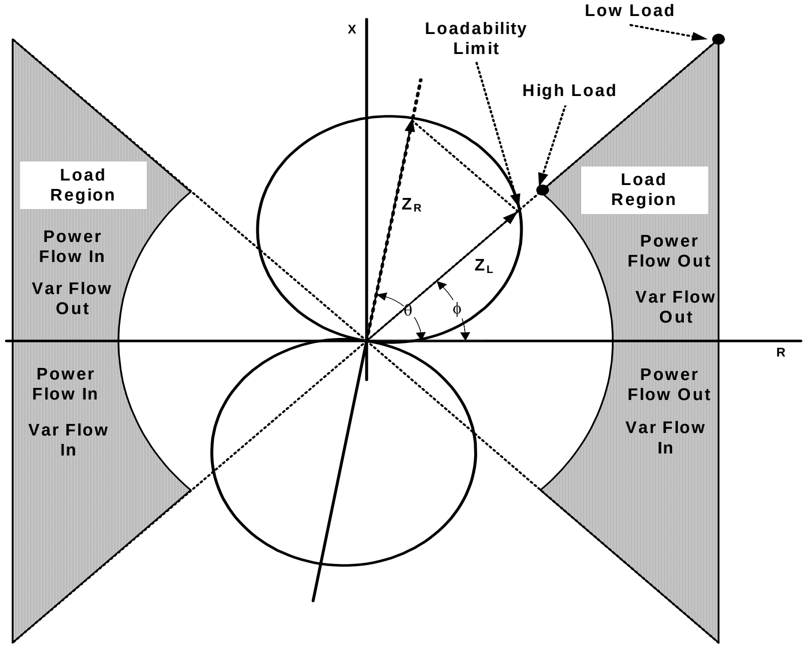
Performing Load Encroachment with an L-PRO

The loadability of an impedance relay is normally stated in MVA, at nominal operating voltage and a specific power factor. Load greater than this limit will cause the relay to operate.[1] This means load encroachment is defined as the measured impedance, due to load current and voltage, exceeding the impedance determined by the loadability limit of an impedance relay at a specific power factor. This condition is especially prevalent on long transmission lines, heavily loaded transmission lines, or where large impedance zones, such as 3rd zone, are set.

[1]See Ref [3], *Transmission Line Loadability*, pp. 2-3, for a more detailed description.

The load impedance, as measured by the relay, is a function of the direction of power flow, and the power factor of the load. As such, the load impedance magnitude and angle varies with changing system conditions.

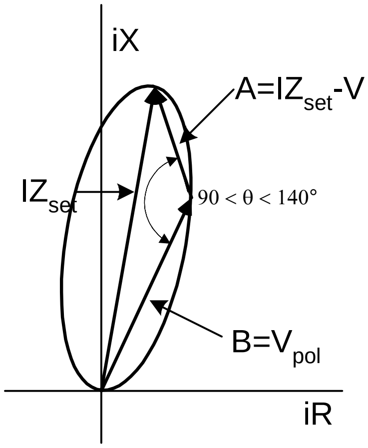


Ref [3], *Transmission Line Loadability*, p. 10. Redrawn.

Load encroachment occurs when the impedance crosses the loadability limit of the operating characteristic.

Typical Solutions to Load Encroachment

Obviously, load encroachment can cause an undesired operation of an impedance relay due to load conditions. The L-PRO provides two methods to prevent mis-operation due to load encroachment. The first method is to change the characteristic shape of the impedance tripping zone to a lens shape. This increases the load allowance of the zone, but may reduce coverage for certain types of resistive faults.



The second method is the ability to implement a “load blinder”. When the measured impedance is within the load blinder region, the over-reaching distance elements are blocked from tripping. There are several ways to implement load blinders. The implementation described in this document uses the 68 Out Of Step or Swing element of the L-PRO as a traditional “straight line” impedance blinder. This method requires the use of a ProLogic equation, and proper settings of the 68 Out Of Step element.

68 Out Of Step Functions

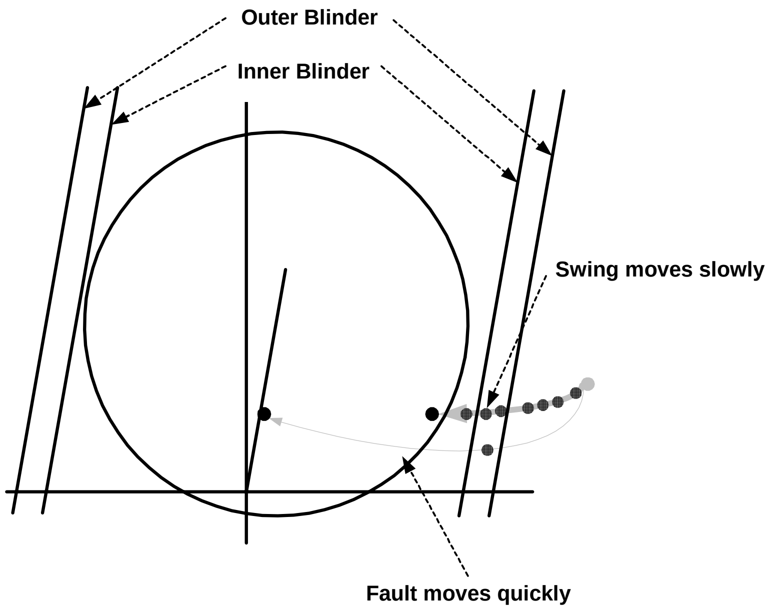
To understand this proposed application, it is necessary to understand out of step functions in general, and the 68 Out Of Step element in the L-PRO specifically. Out of step functions determine when a dynamic swing of the power system is taking place that may require some action, either tripping, or blocking tripping, for the protected line. Power swings on the system are caused by changes in generator output attempting to match significant changes in power system demand and supply; in behavior, these events are similar to load swings.

Most of these functions work by measuring the time it takes for measured impedance to move between two impedance zones. A fault moves instantaneously through these impedance zones to a point on the transmission line. A power swing event moves slowly enough through these zones to be compared against a timer. The timer starts when the measured impedance moves into the larger impedance zone. If the timer expires before the measured impedance moves either into the smaller impedance zone, or outside the initial zone, an out of step condition is declared.[2]

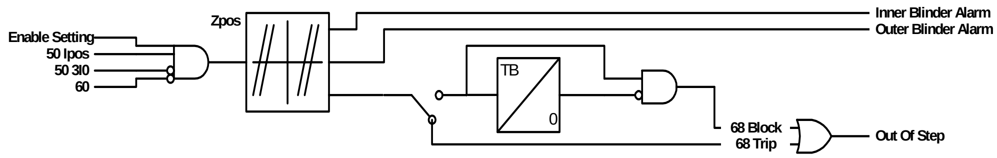
[2]Ref [4], *The Art & Science*, pp. 312-315, contains a more complete discussion.

There are two common implementations of Out of Step functions. One is to use concentric mho (or quadrilateral) characteristics, or a larger characteristic that envelopes the largest tripping zone. The L-PRO uses the second method, which is straight line impedance blinders, parallel to the line impedance angle. There is a set of outer and inner blinders for both load flow in and load flow out of the line terminal. The out of step element is armed when measured impedance moves inside[3] the outer blinder, also issuing the 68 OuterBlinder Alarm. An out of step condition is declared if the 68 OuterBlinder Alarm stays asserted for the length of the OOS Swing Timer, of between 0.0 to 1.0 seconds, and the measured impedance doesn’t move within the Inner Blinder.

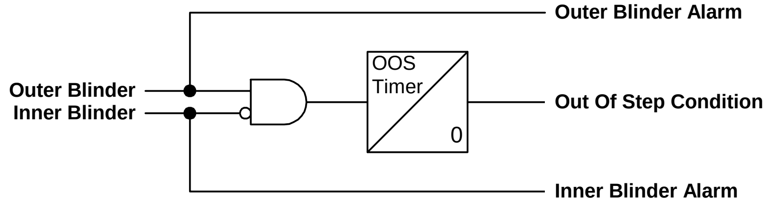
[3]”Inside” is defined as the side of the blinder towards the line impedance.



The internal relay logic contains a few more elements to supervise the out of step blinders, to ensure the measured impedance is due to a legitimate swing event.



Internal relay element logic



Simplified logic for determining out of step condition

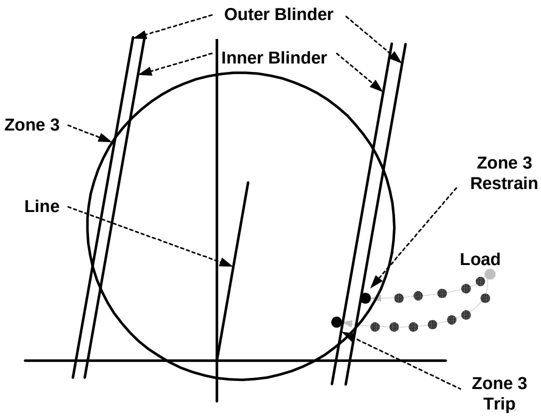
Using the 68 Out Of Step Element as a Load Blinder

The 68 Out Of Step element in the L-PRO can be applied as a load blinder, assuming that the element is not going to be used for out of step blocking or tripping functions.[4] The basic logic for this application is the same as any other load blinder. Tripping of an over-reaching zone is only permitted when the measured impedance is not in the load blinder region. For this application, the load blinder region is the region outside the Outer Blinder of the 68 Out Of Step element, so a Zone 3 trip is only permitted when the measured impedance is inside the Outer Blinder.

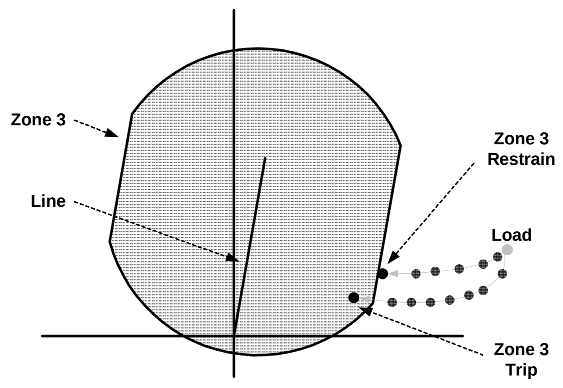
[4]You can use the functions for both a load blinder and out of step protection, in theory. In practice, the settings for the two applications use radically different criteria.

The resulting characteristic, as shown, is a very traditional operating characteristic for load allowance for distance relays, and is well known in the industry.[5]

[5]See Ref [3], *Transmission Line Loadability*, pp. 18-19, and Ref [5], *Numerical Distance Protection*, p. 22.



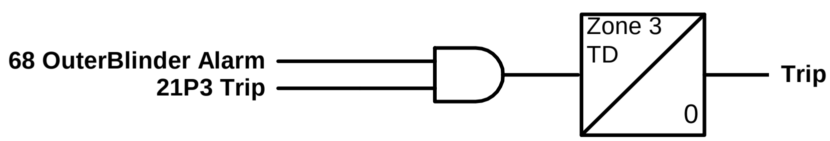
68 Out of Step as Load Blinder



Effective Zone 3 Characteristic - Steady State

Setting the Load Blinder Function

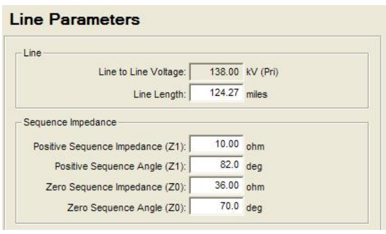
The resulting load blinder function will be a Zone 3 tripping function, with appropriate Zone 3 time delays, controlling a trip output contact, with a logic as shown.



There are three general steps to create the load blinder function in the L-PRO. The first step is to determine the maximum line loading conditions. The second step is to set the 68 Out Of Step element as the load blinder. The third step is to create a ProLogic equation for the “re-shaped” Zone 3 element.

Maximum Line Loading Conditions

The first step is to determine the load impedance, both magnitude and angle, for the maximum loading of the line. Be sure to consider conditions for load flow both in to and out of the line terminal. Remember, the blinders are set as impedance parallel to the line angle, so it’s important to consider the maximum line loading at various power factor conditions. In addition, determine the positive sequence current magnitude for this worst-case load condition.

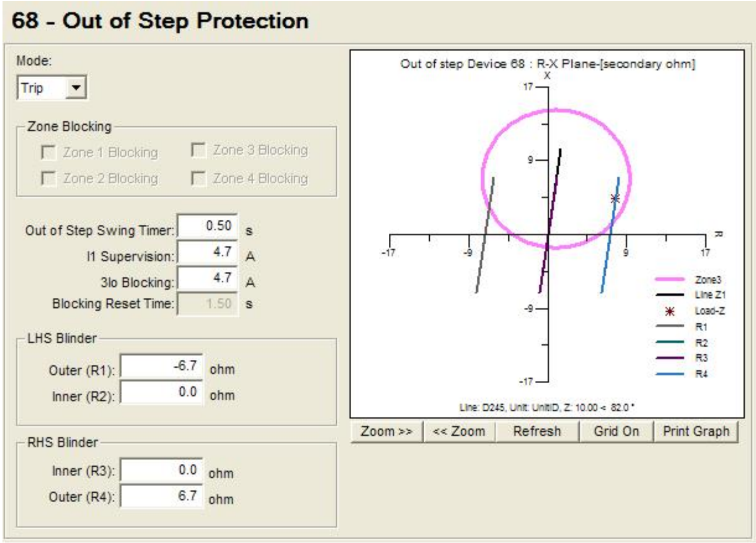


Setting the 68 Out Of Step Element

To set the 68 Out Of Step function, first enable the function, and set the Mode to “Trip”. Set the Outer Blinders for a safety margin inside of the maximum load flow conditions into and out of the line terminal. The left Outer Blinder and the right

Reference the setting example at the end of document.

Outer Blinder are set separately from each other. The settings for the inner blinders are unimportant, as they aren't used in this application.

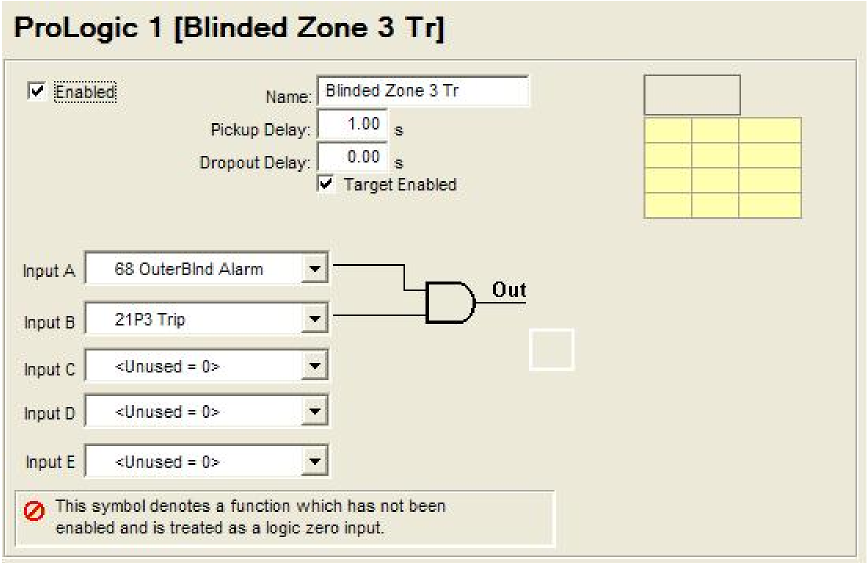


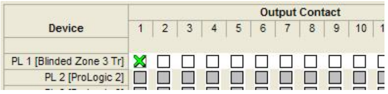
The I1 Supervision setting is the minimum positive sequence current required for the 68 Out Of Step element to operate. Make this value equal to the positive sequence load current that represents the impedance of the smaller Outer Blinder setting. The 3I0 Blocking setting prevents the 68 element from operating, to ensure the element only operates for relatively balanced conditions. A setting equivalent to the I1 Supervision setting should be high enough to ensure correct operation of the 68 Out Of Step element.

ProLogic Equation for New Zone 3 Characteristic

To create the Zone 3 load blinder, combine the 68 OuterBlinder Alarm with the 21P3 Trip indication in a ProLogic equation. The reach of the 21P3 elements should be set as required for adequate protection, with the time delay set to 0.00 seconds. The tripping time delay for Zone 3 is set as the Pickup Delay in the ProLogic equation.[6] Assign this ProLogic equation to an output contact to trip the circuit breaker.

[6] Setting the 21P3 Pickup Delay Timer, with no time delay in the ProLogic equation, may result in instantaneous trips for some load conditions.





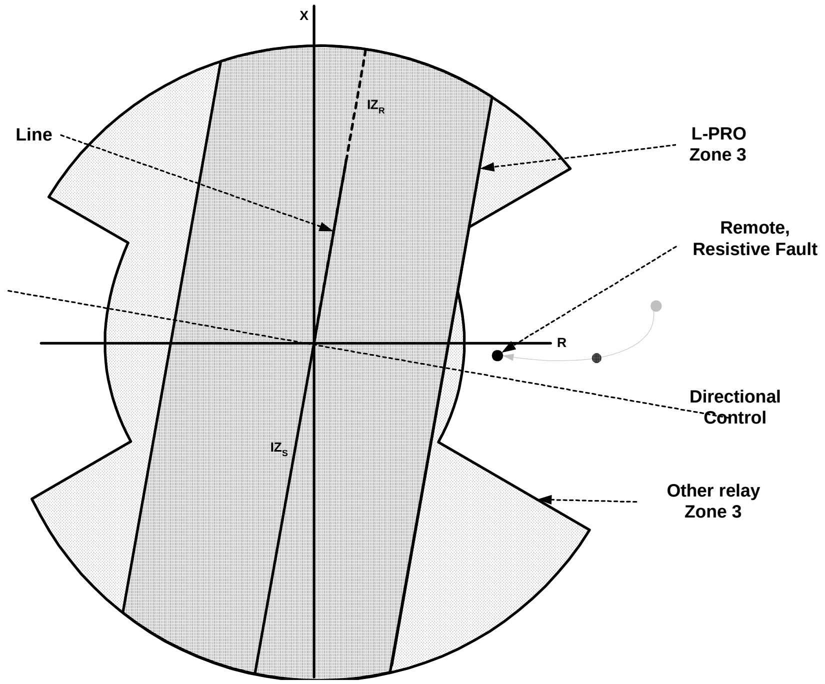
Operating Issues with Load Blinders

Load blinders adapt the operating characteristic of impedance zones, by restraining tripping for certain regions of impedance. Load blinders may therefore incorrectly restrain tripping for remote, purely resistive, faults. This is an acceptable tradeoff, as purely resistive faults are unlikely to occur.

A second issue with load blinders is the dynamic characteristic of most impedance relays. The majority of impedance relays use memorized voltage quantities to determine the characteristic, so the characteristic changes over time as the memorized voltage decays during fault events. However, load blinder characteristics are steady state, in that they operate at a consistent impedance based on directly measured current and voltage.

The L-PRO uses memorized positive sequence voltage as a polarizing quantity, so it has a dynamic characteristic. This document does not directly discuss dynamic operating characteristics, as this is a detailed topic in itself, and is not unique to the L-PRO.[7] The dynamic characteristic has some practical impact on performance, regardless of the relay used. The figure shows the dynamic impedance zone as impacted by the 68 Out Of Step blinder, and a more contemporary load blinder. Both methods have an impact on the operating characteristic. It's important to remember that for dynamic characteristic relays, the impedance tripping zone and the load blinder don't look at precisely the same quantities. For example, the L-PRO uses the memorized positive sequence voltage, in conjunction with the directly measured current and voltage, to determine whether an impedance is inside or outside of the zone. The 68 Out Of Step element, used as a load blinder, uses an impedance calculated from the directly measured voltage and current. So there are some fault events, as shown in the drawing, that all load blinders will incorrectly restrain tripping.

[7] See Ref [6], *Dynamic Characteristics of Mho Distance Relays* for a detailed discussion.



Effective Zone 3 Characteristic - Dynamic

Conclusions

The L-PRO Line Protection Relay provides two methods for load allowance for over-reaching impedance zones: changing the shape of the operating characteristic to a lens shape, or using the 68 Out Of Step blinders to supervise the impedance zone. As discussed in this document, using the 68 Out Of Step element is easy to set and implement, and provides a bit more resistive fault coverage than the lens characteristic. The resulting operating characteristic is a well-known, and traditional, operating characteristic. The only practical tradeoff is the 68 Out Of Step element can't be used for out of step tripping and blocking functions at the same time.

Setting Example

Assume: 138 kV line
Maximum load of 346 MVA at 30° power factor angle

Set the load blinder for a 5% load margin

Line Impedance:	$10.0 \angle 82° \ \Omega_{secondary}$	
CT Ratio:	1600:5	(320:1)
VT Ratio:	138,000:69	(2000:1)

Zone 3 Setting: $14.4 \angle 82° \ \Omega_{secondary}$

Solution

Determine the impedance for the load plus the safety margin, at the specified power factor. Determine the outer blinder setting for this load point.

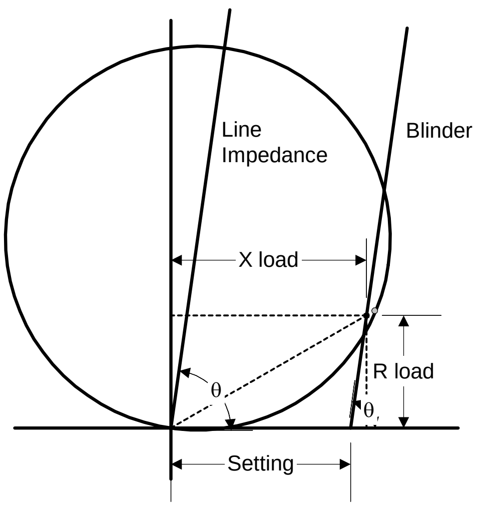
Load Margin = 346 MVA x 1.05
= 363 MVA
= 568 $VA_{secondary}$

Load Impedance = V^2 / S_{load} at the power factor angle
= $69^2 / 568$ @ 30°
= $8.38 \angle 30° \ \Omega_{secondary}$
= $7.26 + j4.19 \ \Omega_{secondary}$

$$\text{Setting} = R_{load} - \left\{ X_{load} \times \frac{\cos(Line\ Angle)}{\sin(Line\ Angle)} \right\}$$

$$= 7.26 - \left\{ 4.19 \times \frac{\cos(82^o)}{\sin(82^o)} \right\}$$

$$= 6.67 \ \Omega_{secondary}$$



Set at 6.7 $\Omega_{secondary}$

Determine the I1 Positive supervision setting for the maximum load safety margin.

For balanced conditions, such as a reasonably balanced load, the positive sequence current equals the measured current.

$$I1 = S / (\sqrt{3} \times V)$$
$$= 568 / (\sqrt{3} \times 69)$$
$$= 4.75\ A_{secondary}$$

Set at 4.7 $A_{secondary}$

If significant load unbalance is expected, this setting may need to be reduced to account for a possible reduction in the amount of positive sequence current.

References

[1] *L-PRO Line Protection Relay User Manual Version 3.3 Revision 2*, ERLPhase, Winnipeg, MB, Canada; 2003.

[2] *RecordBase View User Manual Version 1.5 Revision 2*, ERLPhase, Winnipeg, MB, Canada; 2003.

[3] T. Seegers, E. Krizauskas, et. al, *Transmission Line Protective Systems Loadability,* IEEE Power Engineering Society Power System Relay Committee Special Report, New York, NY; 2000.

[4] C. R. Mason, *The Art & Science of Protective Relaying*, Wiley, John & Sons, Inc., 1956.

[5] G. Ziegler, *Numerical Distance Protection*, Siemens, Erlangen, Germany; 1999.

[6] S. B. Wilkinson and C. A. Mathews, *Dynamic Characteristics of Mho Distance Relays*, GE Power Management, Markham, Ontario, Canada.