Parallel Line Mutual Coupling Compensation
in the L-PRO Transmission Line Protection Relay

Introduction

As power systems expand, extra transmission lines are needed. In many places, population density has put restrictions on the availability of transmission line right of ways, therefore multiple transmission lines are put on each transmission line tower. As a result, mutual coupling effects between circuits can influence impedance measurements performed by impedance-based distance relays that are often used to protect these lines during faults.

Bringing the zero sequence current from a parallel line into a distance relay used to protect a power line, can be used to correct the effect of mutual coupling from other parallel lines. This document describes how this correction can be done using the ERLPhase L-PRO relay.

Description

Parallel Line Application

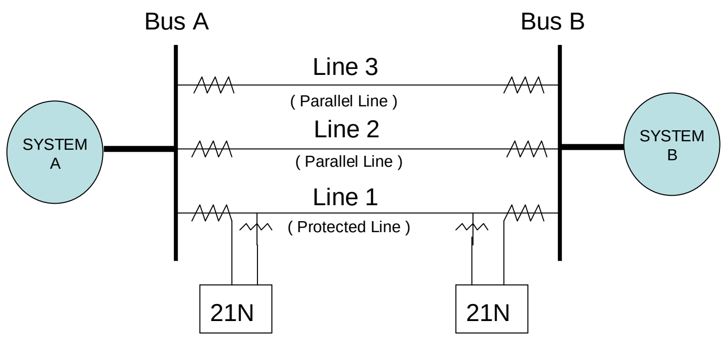

Figure 1

Figure 1: a line is shown using L-PRO distance line relays. Two parallel lines are also shown.

In this application an L-PRO relay is applied at each end of line 1, with lines 2 and 3 in parallel. The effect of the parallel lines is to produce a zero sequence mutual coupling effect between the three lines.

Discussion

The issue of mutual compensation relates to the setting reach that a ground distance relay encounters during ground faults when parallel lines are present. Distance relays used to measure phase–phase or three-phase impedances do not use zero sequence quantities, therefore are not bothered by zero sequence mutual compensation. Our discussion will start at this level. The reader can also find many references on this topic from past papers and presentations.

To understand why mutual coupling is important, let's look at the fundamental issues. To begin with, most ground distance relays use the line positive sequence impedance to determine their reach. This method is used for convenience so that the phase distance relays and the ground distance relays can be set to the same point on the protected line.

Ground Distance Relay Reach with No Parallel Lines

For a single line with no parallel lines present, the positive sequence reach for the ground distance relay is determined by:

$$Z \text{ positive sequence} = \frac{V_{ph\text{-}neutral}}{I_{phase} + 3k_o I_o}$$

$$\text{Where } k_o = \frac{Z_o - Z_1}{3Z_1}$$

The parameter k_o is called the self compensation factor and involves the difference and the ratios between the line positive and zero sequence impedances. The L-PRO offliner program calculates the k_o factor magnitude and phase angle automatically, based on the line Z_1 and Z_o.

Since $\mathbf{Z_1}$ and $\mathbf{Z_2}$ are vectors, $\mathbf{k_o}$ is also a vector with magnitude and angle.

The offliner setting software allows the user to override the default setting of $\mathbf{k_o}$. If the application requires a different value of k_o, the default value can be overridden.

A typical setting for a zone 1 distance relay is 80 to 85 % of the line positive sequence impedance for both phase and for ground faults. The zone 1 setting is made so that it will not overreach the end of the protected line since zone 1 is usually a direct tripping function. Some margin in the setting reach must be provided to allow for current, voltage transformer errors and line impedance variations.

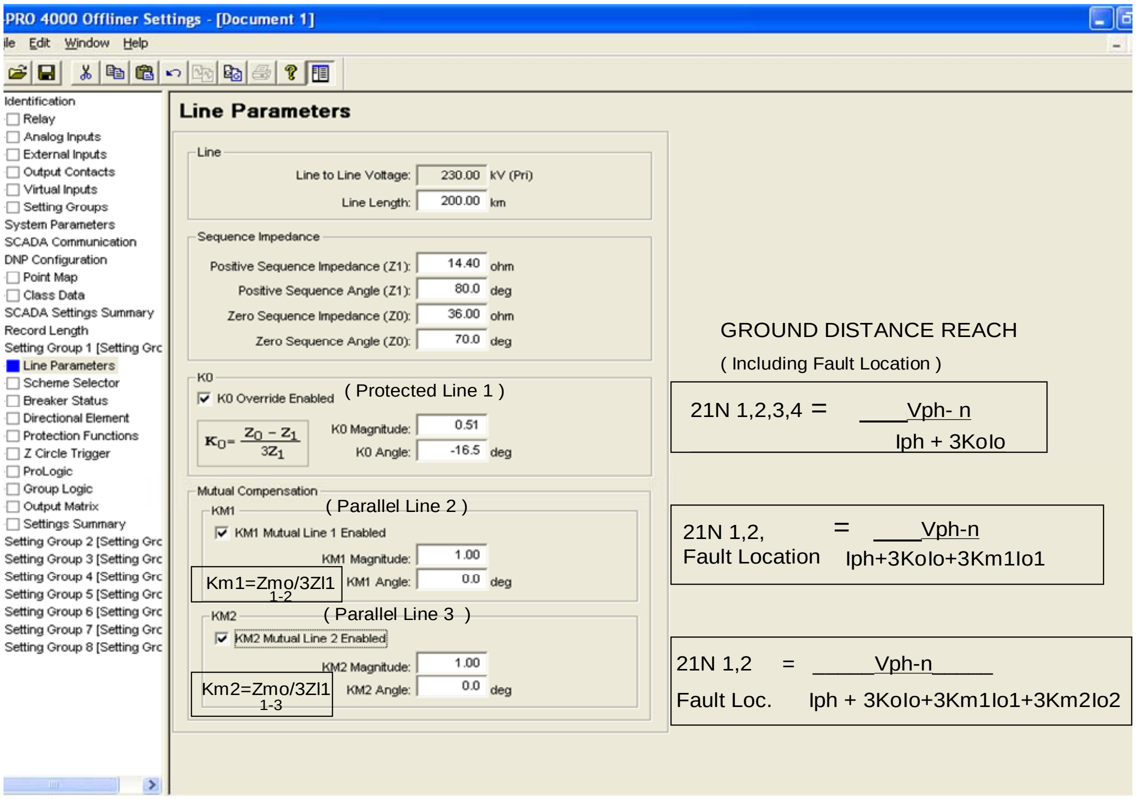

Figure 2: Offliner setting of mutual coupling.

Ground Distance Relay Reach with One or Two Parallel Lines

In Figure 2, it can be seen that L-PRO is equipped with the ability to bring in AC currents from up to two parallel lines into Inputs I_3 and I_4.

When parallel line(s) are present, the ground distance reach equation becomes:

$$Z_{\text{positive sequence}} = \frac{V_{ph\text{-}neutral}}{I_{phase} + 3k_o I_o + 3k_{m1} I_o + 3k_{m2} I_o}$$

For the case with one parallel line, only the 3km1Io is added to the single line equation, and 3km2Io is added if two parallel lines are encountered. In this equation, Km1 = Zmo(1-2)/ 3Z11, which means the mutual factor Km1 is the zero sequence mutual impedance between the protected line and the first parallel line (Zmo (1-2)) divided by 3 times the positive sequence impedance of the protected line 1. The second term in the denominator of the equation would be applied if a 3rd parallel line is encountered.

An interesting observation can be made in that if sources at each end of the lines are equal, a ground fault in the middle of the protected line will result in zero sequence currents in the parallel lines of zero, effectively reducing the equation to one where no compensation is applied.

The L-PRO relay has AC current inputs of I3 and I4 that can take in 3 sets of currents each (IA3, IB3 & IC3 and IA4,IB4 &IC4). If all three currents are connected to the relay, the 3Io current will be calculated by the relay and all the phase currents will be included in the fault recordings. On the other hand, if only 3Io (ground current) from a parallel line is brought into the L-PRO, this current will be used. With the single 3Io current from a parallel line, this current can be connected to any phase of the I3 input for Line 2 and any phase of the I4 input for Line 3.

When mutual compensation is elected in the settings, the 21N-1, 21N-2 and the phase to ground fault location is affected by the mutual compensation factor(s).

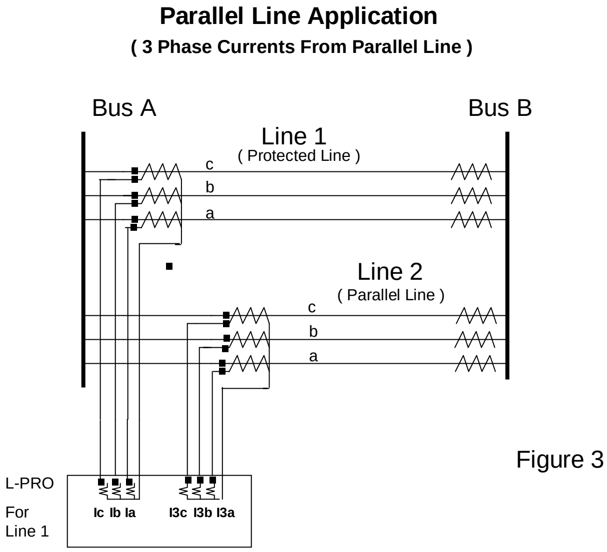

Figure 3: Parallel line application.

Example of how 3 phase connection of currents can be connected to L-PRO. In Figure 3, an L-PRO is shown protecting Line 1 at Bus A, and current from parallel line 2 is brought into the L-PRO input currents **I 3**. The currents from line 2 will be made available for recording and the summation of these currents will be used for the mutual compensation. The advantage of this connection is that other devices can be put into the current circuit from the parallel line.

As an alternative, it is possible to connect only the neutral current form the parallel line to the line protection to provide the mutual compensation.

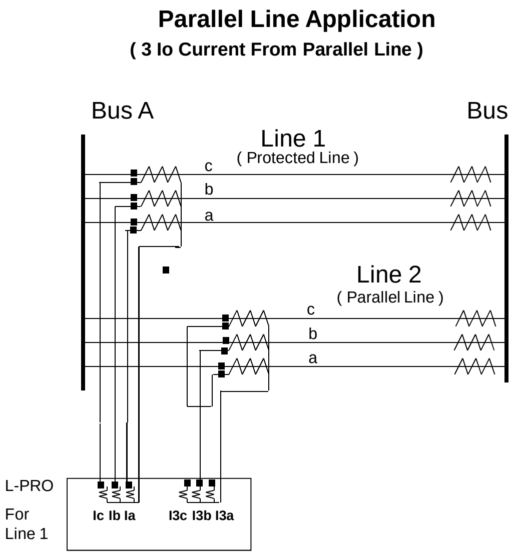

Figure 4

Figure 4: 3Io current from the parallel line is brought into the L-PRO input current 3 or 4 for mutual compensation. Because only one current is brought in, this input will automatically become a 3Io quantity independently to which phase it is connected. This type of connection has the advantage that only one current is required but has the disadvantage that it needs to be connected to the CT only after the neutral is formed.

L-PRO supports the use of mutual compensation for three lines. In this case, current inputs I 3 and I 4 can be used for mutual compensation.

Challenges Associated With Mutual Current Compensation

Application of mutual current compensation has several challenges that need to be considered.

These challenges include:

1. Wiring errors can be a real problem. If connections are not made properly, distance protection can be adversely affected. Strategies to test the validity of current connections during commissioning should be developed. Placing faults on systems is an ideal way to verify protection operations but this method has lost popularity over the last years because of the need to keep systems in service for reliability.
2. The condition of the parallel line needs to be identified for correct compensation to occur. From time to time the parallel line may be opened at one end, both ends, left ungrounded when open or grounded at both ends. Each of these conditions will result in different mutual coupling factors. This might be dealt with by using different setting groups within the relay to cater to different operating conditions. The setting groups could be automatically changed when parallel lines are opened, or ground switches are closed by using the setting group change logic capabilities within L-PRO.
3. Validation of mutual line compensation data should be performed. This can be done by using system models and simulated faults to drive test sets that can inject quantities into the L-PRO relays. Some data suggests that calculated mutual coupling data has errors of up to 50% in their values. This makes a case to possibly perform field tests to verify mutual coupling line data. In any case, conditions with various parallel line configurations should be validated to ensure in service protection quality.

Application Example

In order to evaluate the performance of L-PRO in parallel line protection, the faulty waveforms obtained using an EMT program were used. Figure 5 shows a test transmission system simulated in the EMT program.

In this application example, the current input I3 was used to input the three-phase mutual currents from Line 2.

EMT simulation model of
the 500kV, 300km, parallel transmission line

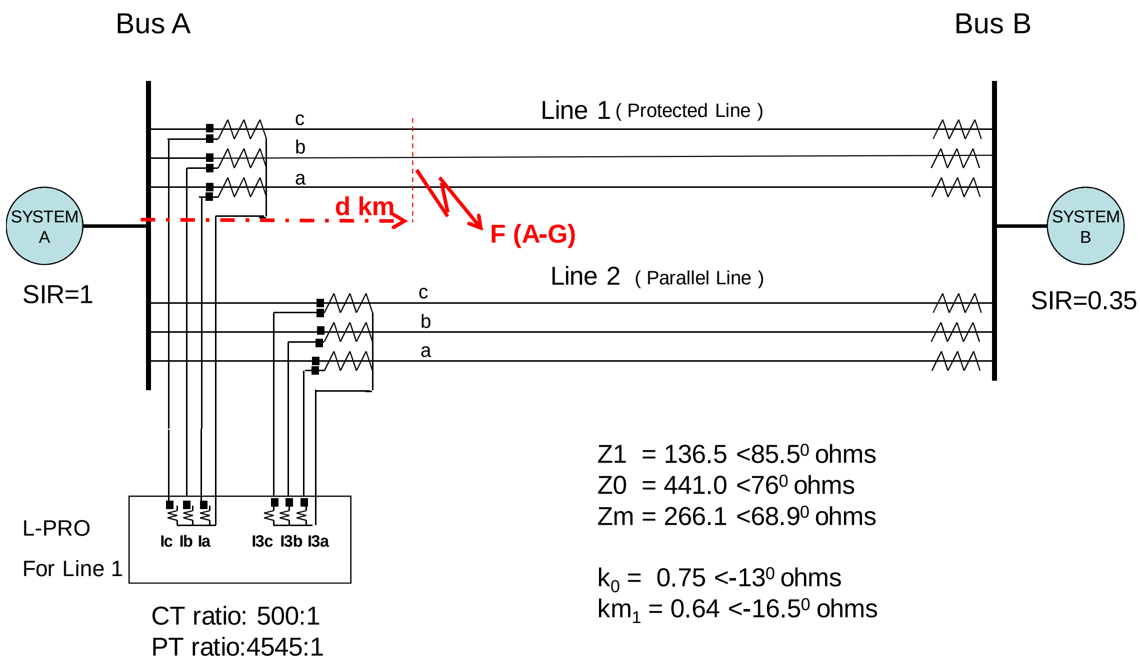

Figure 5

Figure 5: EMT simulation model of 500kV, 300km parallel transmission line.

Figure 6, below, shows the operation of the relay during a phase A-G fault created on line-1 at 2 km from the bus-1. As shown in the waveforms, we can observe a change in zero sequence currents on both lines. For this fault, 21N element of the relay operated correctly. The fault information extracted from the relay is given below:

"01:2012-04-25_10:33:09.014--21N3 AG 2.2km:Alarm
02:2012-04-25_10:33:09.018--21N1 AG 2.0km:Trip
03:2012-04-25_10:33:09.018--21N2 AG 2.2km:Alarm"

During this event, the fault distance calculated by the relay was 2 km.

Fault Recording Traces

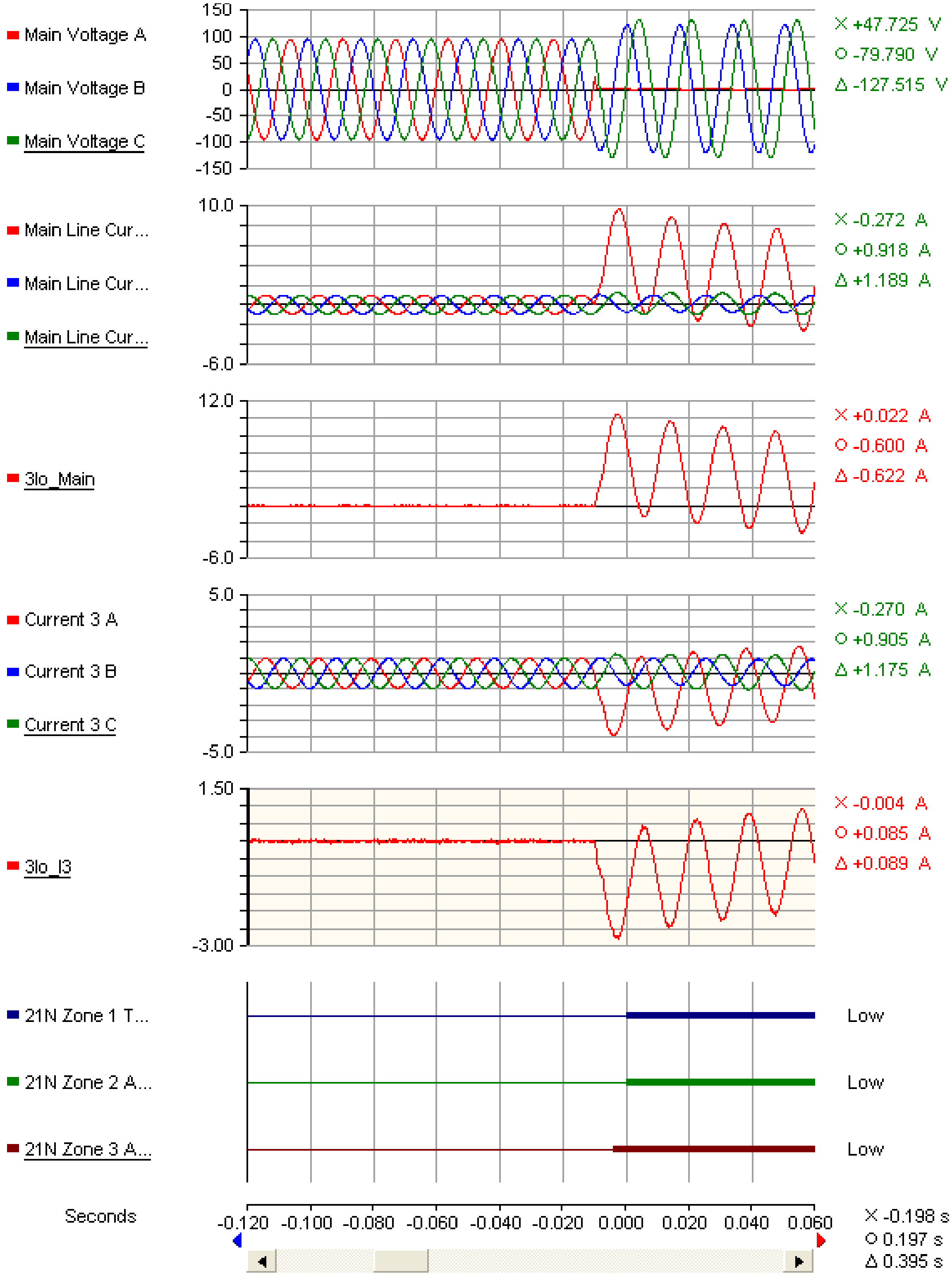

Figure 6: Operation of the relay during a phase A-G fault created on Line 1 at 2km from the bus-1.

In order to evaluate the 'effect of the zero-sequence current of the parallel line' on the performance of the relay (21N distance element and fault location), testing was repeated for faults simulated at different locations by enabling and disabling the mutual effect of the parallel line. Results obtained in this study are summarized below.

Actual fault distance	**Before enabling the mutual line effects**		**After enabling the mutual line effects**	
	Relay Operation	Calculated Distance	Relay Operation	Calculated distance
D2km	21N-Zone1 Trip 21N-Zone2 Alarm 21N-Zone3 Alarm	1.9km	21N-Zone1 Trip 21N-Zone2 Alarm 21N-Zone3 Alarm	2.0km
150km	21N-Zone1 Trip 21N-Zone2 Alarm 21N-Zone3 Alarm	142.5km	21N-Zone1 Trip 21N-Zone2 Alarm 21N-Zone3 Alarm	150.5km
210km	21N-Zone1 Trip 21N-Zone2 Alarm 21N-Zone3 Alarm	202.4km	21N-Zone1 Trip 21N-Zone2 Alarm 21N-Zone3 Alarm	206.4km
300km	21N-Zone3 Alarm	459 km	21N-Zone2 Alarm 21N-Zone3 Alarm	300.0km

Table 1: Effect of mutual compensation on 21N and fault location.

As it can be seen from the results, both 21N and fault location functions on L-PRO operated correctly after enabling the mutual compensation from the parallel line.

Conclusions

The use of mutual compensation for ground distance impedance measurements can be beneficial for ensuring correct distance reach and for improved fault location measurements. An example case was presented showing the effect of mutual compensation on the performance of 21N and fault location elements of the L-PRO distance relay.

It is important that the connections and setting parameters be correctly installed to achieve correct measurement. Strategies should also be adopted by the user to deal with mutual coupling different parallel line conditions such as line outages, one end open, grounding at both ends, etc. An ultimate decision to use or not to use mutual compensation should be carefully assessed by the user, weighing the pros and cons associated with each decision.