

Loop Selective Direction Measurement for Distance Protection

Gustav Steynberg* and Gerhard Koch*

Abstract - Distance relays achieve selective tripping by measurement of all short circuit fault conditions inside set reaches. The direction of the fault, forward or reverse is commonly determined with a dedicated measurement to ensure selectivity under all conditions. For the direction decision (measurement) a number of alternatives are available. This paper describes a loop selective direction measurement and illustrates by means of a typical fault why this is superior to a non loop selective direction measurement such as that based on negative sequence quantities.

Keywords: Distance protection, Direction measurement, Polarization, Memory voltage, Faulted loop voltage, Negative sequence

1. Introduction

Distance relays must measure all short circuit fault conditions inside the set reaches. The set reach typically covers the protected plant (feeder, cable etc.) plus adjacent circuits in the forward direction as well as reverse reach covering the busbar and feeders and transformers in the reverse direction. Selective tripping depends on the individual zone settings and the correct direction decision.

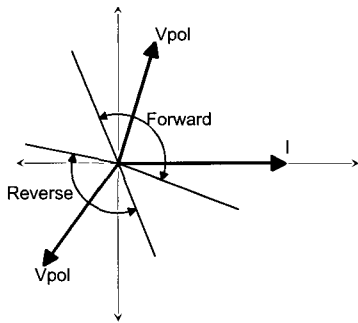


Fig. 1. Phasor diagram of current and voltage for direction measurement

For the direction decision (measurement) a number of alternatives are available, but the basic direction decision is obtained from the comparison of the angle between two phasors. In Fig. 1 this is represented by the current phasor I (fault loop current) and the polarizing voltage V_{pol} . The forward and reverse areas are defined by an angular range that the polarizing voltage may assume relative to the current. In Table 1 various polarizing signals are listed and compared with respect to their relative advantage and disadvantage.

Table 1 Alternatives for direction measurement

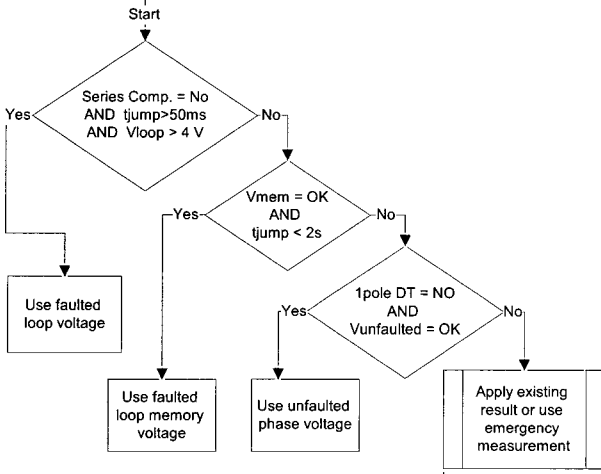
Direction measurement alternatives	Advantage	Disadvantage
Faulted loop current and faulted loop voltage	<ul style="list-style-type: none"> Always valid, even during power swing Valid for all loops Valid during single pole open condition 	<ul style="list-style-type: none"> Very small voltage (0 V) during close in faults returns invalid results Not valid close to series compensation Large transients in the first sampled voltages after fault inception may return invalid result
Faulted loop current and pre-fault memory voltage	<ul style="list-style-type: none"> Not affected by transient voltages during the fault Valid even if fault voltage = 0 V Valid also in series compensated system Valid during single pole open condition 	<ul style="list-style-type: none"> Only limited validity during power swings Memory voltage is only valid for a limited time due to frequency deviation during fault
Faulted loop current and un-faulted phase voltages	<ul style="list-style-type: none"> Valid even if fault voltage = 0 V Validity is not affected by frequency drift during fault 	<ul style="list-style-type: none"> Only valid for 1 ph and 2 ph faults Cannot be used during power swings Not valid during single pole open condition
Negative sequence current and voltage	<ul style="list-style-type: none"> Valid even if fault voltage = 0 V Validity is not affected by frequency drift during fault Always valid, even during power swing 	<ul style="list-style-type: none"> Not valid during single pole open condition Not valid for three phase faults Not valid for multiple faults (cross country fault) Not valid close to series compensation

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2. Best Choice For Direction Measurement

To achieve the best results under all system conditions more than one of the alternatives in Table 1 must be used. The negative sequence direction measurement is however not one of the first choices of a modern numerical distance protection because it is not suitable for a full scheme distance relay that requires a separate direction decision for each of the six measured loops. For the other alternatives in Table 1 the current used for the direction measurement is always the measured fault loop current. The choice of the voltage depends on the prevailing condition as shown in Fig. 2 below:



t_{jump} = instant of fault inception

V_{loop} = faulted loop voltage (actual)

V_{mem} = memory voltage of the faulted loop

$V_{\text{unfaulted}}$ = un-faulted loop voltage corresponding to the faulted loop

Fig. 2. Direction measurement voltage selection flowchart

The best signals for direction measurement depend on the prevailing conditions (see Table 1). In the modern distance relay the best signal is selected automatically (see Fig. 2). The first choice is the faulted loop voltage, and it is used unless the relay is applied close to a series compensation, the transients in the measured voltage are too large ($t_{\text{jump}} < 50\text{ms}$) or the measured voltage is too small ($V_{\text{loop}} < 4\text{ V}$). Alternative to this the memory voltage is used as the next choice. It is always applied during the first 50 ms after jump detection and as first choice with series compensation. If both these alternatives are not successful (e.g. because of series compensation and a fault duration of longer than 2 seconds), the un-faulted loop voltage is next in line. It is applied if the fault is a single phase or phase to phase fault and if a single pole open condition is not present. Ultimately, if none of the previous selections can be applied the available direction decisions that were previously obtained are maintained (frozen). If no previous

direction decision is available at this point, an emergency measurement with $V_{\text{loop}} < 4\text{ V}$ but $> 1\text{ V}$ is attempted if series compensation is not present. Ultimately if all other selections fail the forward direction is selected by default.

With the measurement using the faulted loop current and a polarizing voltage having an angle equivalent to the faulted loop voltage, the forward fault is defined the faulted loop equation:

$$\underline{U}_{\text{loop}} = \underline{I}_{\text{loop}} \cdot \underline{Z}_{\text{loop}} \quad (1)$$

During the forward fault, the voltage $\underline{U}_{\text{loop}}$ will therefore lead the current $\underline{I}_{\text{loop}}$ by the angle of the loop impedance $\underline{Z}_{\text{loop}}$.

3. Negative Sequence Direction Measurement

With negative sequence direction measurement the angle between the negative sequence current and voltage are used to determine the fault direction. During unbalanced forward faults (single phase to ground, phase to phase and phase to phase to ground faults), the following relationship exists:

$$\underline{U}_2 = -\underline{I}_2 \cdot \underline{Z}_2 \quad (2)$$

Here \underline{Z}_2 is the negative sequence source impedance at the relay location and \underline{I}_2 and \underline{U}_2 are the respective negative sequence current and voltage measured at the relay location during the forward fault. Therefore \underline{U}_2 leads $-\underline{I}_2$ by the angle of the negative sequence source impedance \underline{Z}_2 . This can also be expressed as \underline{U}_2 lags \underline{I}_2 by the 180° minus the angle of the negative sequence source impedance \underline{Z}_2 .

4. Importance Of Loop Selective Direction Measurement

The example below will be used to show the importance of loop selective direction measurement, as described above and used in Siemens distance relays 7SA522 and 7SA6. For comparison the same fault will also be applied to a relay using negative sequence based direction measurement, which is the only further alternative according to Table 1. When loop selection is done with negative sequence current and voltage, only one direction decision is available for all six measured loops in the relay.

Example 1: Fault on the tower of a double circuit line that results in L2-E in Circuit 2. This is a reverse fault

for the relay in Circuit 1. The arc of this fault is then blown into the adjacent circuit where it causes a further fault L1-E in Circuit 1. This evolved fault is now a forward fault for the relay under investigation on circuit 1:

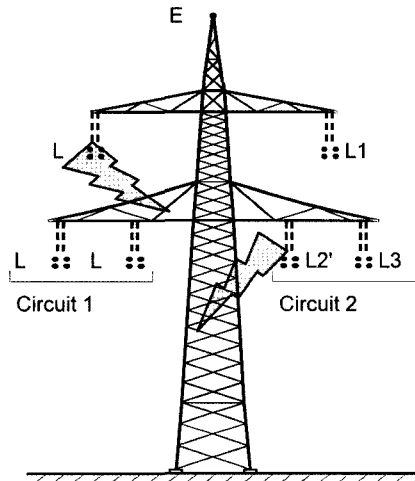


Fig. 3. Schematic diagram of faulted tower

The difficulty presented to the distance protection by this fault becomes apparent when the fault pattern is shown in the single line diagram below.

The relay is presented with the difficulty of detecting the L1-E fault in the forward direction and the L2-E fault in the reverse direction – **at the same time**. With negative sequence direction measurement this is not possible as only one decision for all 6 loops is made!

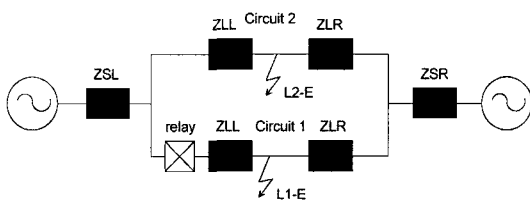


Fig. 4. Single line diagram of example fault distribution

5. Simulation Of Example 1

The fault pattern of Example 1 was simulated with a computer tool (Netomac) and injected into a relay with negative sequence direction measurement and then for comparison into the 7SA522 which uses the dedicated direction measurement per loop as shown above in Fig. 2.

As seen in Fig. 5, the initial reverse fault in phase L2 is followed 30 ms later by the evolved fault that includes the simultaneous forward fault in L1. The relay with negative sequence direction measurement detects the reverse fault condition correctly, but is not able to reach a direction

decision after the fault evolves to include the forward fault. In the phasor diagram (Fig. 6) this is apparent. The initial fault, in the left diagram, is clearly in the reverse direction as the negative sequence current lags the voltage by approximately 90° . After the fault evolves to include the forward fault on circuit 1, the negative sequence current and voltage are almost in phase as shown on the right in Fig. 6. With these signals, the negative sequence cannot provide a conclusive direction result. As a result no trip is issued as shown in Fig. 5.

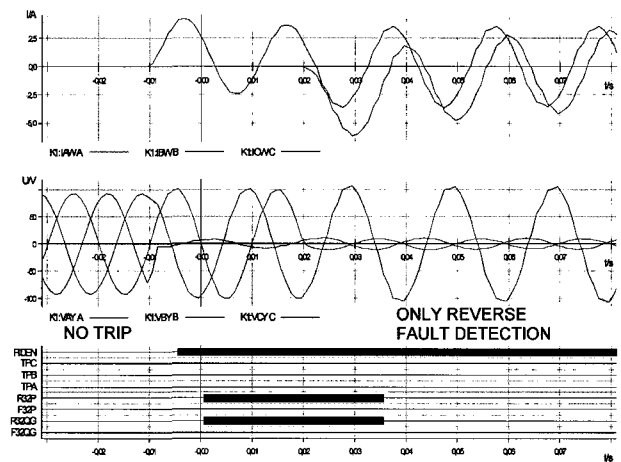


Fig. 5. Distance relay with negative seq. direction measurement

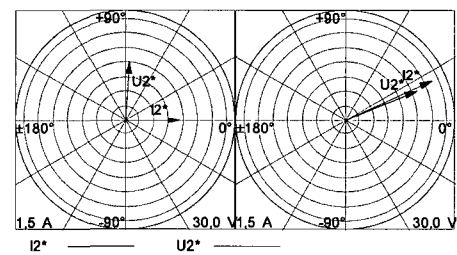


Fig. 6. Phasor diagram of negative sequence signals; left diagram of initial fault, and right hand diagram of evolved fault

The response if the same fault is applied to a 7SA522 relay is shown in Fig. 7 below. The relay response dynamically follows the evolving fault:

The reverse fault in ph L2 is detected correctly. As shown in Fig. 8 below, the current in phase L2 clearly leads the voltage (faulted loop voltage u_{L2} in the right hand diagram and memory voltage recorded prior to the fault on the left) by approximately 90° which clearly indicates a reverse fault.

When the fault evolves to include ph L1 in the forward direction the 7SA522 detects this and issues a correct single pole trip.

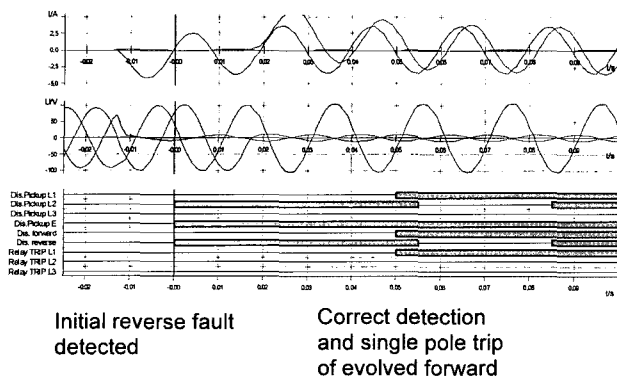


Fig. 7 Response of 7SA522

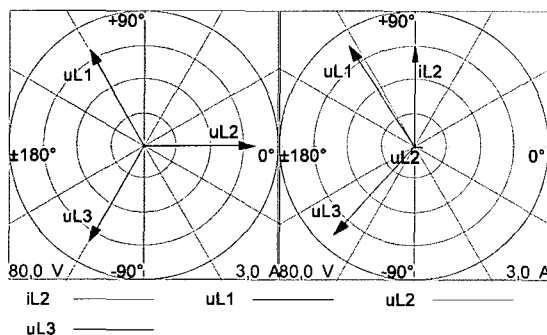


Fig. 8. Phasor diagram of initial reverse fault; on the left the prefault voltage that is used for memory voltage polarizing

After the fault evolves, the reverse fault is still present and still detected in reverse as $iL2$ still leads $uL2$. The forward fault detection is however obtained at the same time for phase L1 as the current $iL1$ clearly lags $uL1$ (memory and faulted). Thereby correct phase selective tripping is achieved as shown in Fig. 7 above.

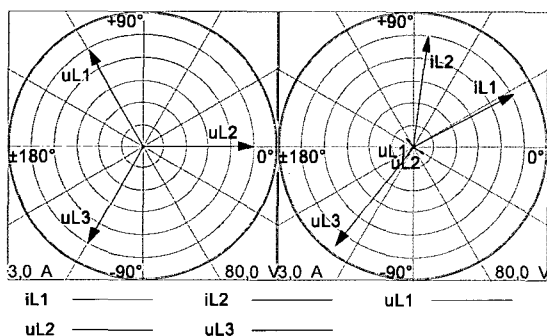


Fig. 9. Phasor diagram of the evolved fault

6. Conclusion

Particularly in meshed systems with double circuit overhead lines, distance protection with loop selective direction measurement is essential to ensure correct selective tripping. Other methods such as negative sequence direction measurement are shown to be insufficient.

References

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- [2] Siemens, SIPROTEC 7SA522 V4.3 Manual.



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He was born in Cape Town in South Africa, on December 18, 1959. He graduated from the University of Cape Town with a BSc in Electrical Engineering. His employment experience includes the South African National Utility, Eskom, and after immigrating to Germany in 1993, Siemens AG PTD PA. His special fields of interest are power system protection, and in particular distance protection.



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