IMPROVED RESISTIVE REACH WITH SEGMENTED DISTANCE PROTECTION ALGORITHM

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RESUMO

Traditional distance protection schemes applied till today have been based on assumption of protecting homogeneous power lines with limited power sources. However, with the fast pace of change of power systems, the protected networks grow in complexity. Installation of distributed generation in ever growing capacity leads to numerous power sources connected to all voltage levels from distribution to sub-transmission to transmission grids.

This new normal of power grids has led to increase of mixed networks with varying conductor types also to higher voltage levels in addition to distribution networks where mixed networks have been the reality for longer time. The addition of reactors into the system to mitigate the power quality effects, such as harmonics and excessive reactive power leads to further challenges when considering distance protection settings.

Amid the rapid change of the power systems, a concern on more frequent misbehavior of distance protection schemes has been raised. This paper discusses the impact of above mentioned changes of power grids in applying distance protection schemes in modern power grids. The benefits of segmented distance protection algorithm improving the resistive reach especially in mixed networks with multiple conductor and reactor types is discussed. The more accurate resistive reach leads to better protection sensitivity and dependability in distance protection schemes.

PALAVRAS-CHAVE

Distance protection, Impedance protection, distributed generation

1.0 - INTRODUÇÃO

The conventional distance protection scheme is based on multiple zones of operation set with adequate safety margins considering especially the instrument transformer inaccuracies. The most commonly utilized principle is based on instantaneous Zone 1 underreaching and covering 80% of the protected line. The time delayed Zone 2 should in all cases cover all the line and is typically set to 120 – 150 % of the protected line. The conventional distance scheme with three active zones is described in Figure 1.

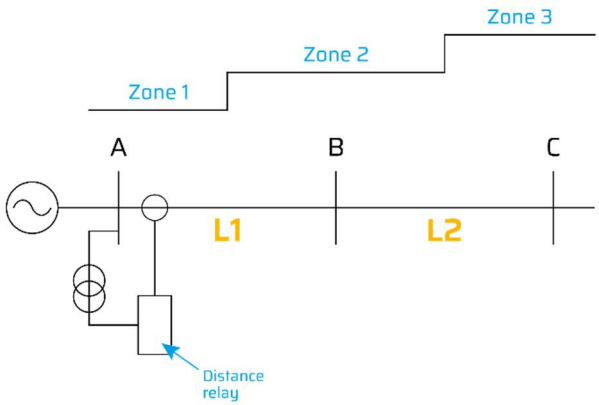


FIGURA 1 – The conventional distance protection scheme. The relay measures currents and voltages and calculates the impedance

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The modern distance protection relays contain multiple distance protection zones, often up to five or six independent zones that can be set to forward, reverse or non-directional. This allows for great flexibility in selecting the exact scheme to cover the protected lines. For traditional line protection applications it is common to use three zones for forward protection, one zone for reverse protection and one zone for undirectional protection. When distance protection is applied for ring networks the amount of reverse protection zones might need to be increased to three zones.

The most common protection relays also allow for using either MHO circular or Quadrilateral characteristics in setting the distance protection elements reach. These characteristics can typically be also mixed and matched for phase to phase or phase to earth faults. Decision on using either MHO or Quadrilateral characteristics is often based on previous experience and history of usage. In general, the quadrilateral characteristic has been gaining wider acceptance globally since its inception in microprocessor based relays. Selection of either MHO or Quadrilateral characteristics does impact on the resistive reach accuracy of the set zone in earth faults. For low impedance phase-to-phase faults operating characteristic does not have significant effect.

The distance protection is set against the protected line impedance. Therefore, inputting the right line impedance to the relay is of outmost importance for the accuracy of the protection. In the conventional distance protection algorithms, only a single line impedance setting is allowed. Single line parameter works perfectly well in homogenous protected lines. However, in case of non-homogenous lines this implies that an average setting should be selected. The conventional way of setting the distance protection involves typically also only a single earth fault compensation factor, assuming a constant homogeneous ground resistivity along the line. This seldom is the case in longer lines adding to the inaccuracy of the protection for earth faults. Figure 2 demonstrates a typical conventional quadrilateral characteristic used for protecting a line with single line impedance setting (Z, where Z= R + iX).

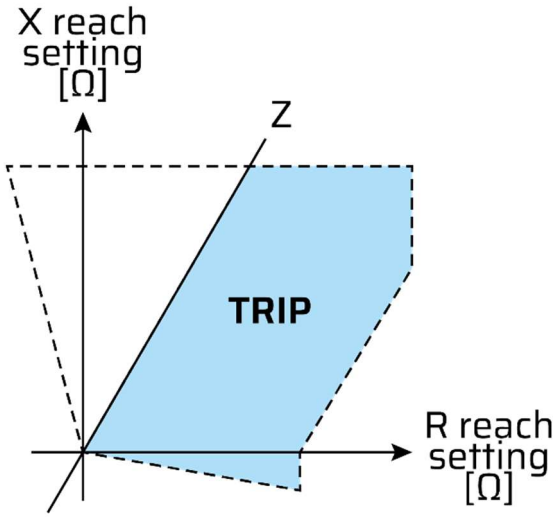


FIGURA 2 – Quadrilateral characteristics with single line impedance setting (Z). The R reach angle setting follows the line impedance setting.

2.0 - SETTING THE NEW SEGMENTED DISTANCE PROTECTION ALGORITHM

The conventional way of setting distance protection with single line impedance set point has shortcomings in adapting the protection on modern power grids that are prone to multiple conductor types and reactors within the protection zone. By introducing the new segmented distance protection algorithm, the protection schemes are well adaptable and can be set more accurately to correspond actual protected line. In the segmented distance protection algorithm, each line segment can be set to have its independent impedance value. Each segment can have its own earth fault compensation factor as well, resulting in a more accurate earth fault protection should the ground resistivity vary along the line.

2.1 Inputting line parameters in distribution protection example without reactor in the zone

If we consider a protected line consisting of three segments:

A = 30 km of underground cable (AHXAMK-W 3x120: R = 0,26 Ω/km X=0,13 Ω/km)
B = 60 km of overhead line (Raven 54/9: R = 0,54 Ω/km X=0,4 Ω/km)
C = 50 km of overheard line (Sparrow 34/6 0,85 Ω/km X=0,38 Ω/km)

Then we have

Impedance A-B:
R = 30km x 0,26 Ω + 60km x 0,54 Ω = 40.2 Ω
X = 30km x 0,13 Ω + 60km x 0,4 Ω = 27.9 Ω
Line length = 90km
Impedance B-C:
R = 50km x 0,85 Ω = 42.5 Ω
X = 50km x 0,38 Ω = 19 Ω
Line length = 50 km

Total protected line length 140 km

The positive sequence values of conventional distance relay are set as:

Line length: 90km
Line R:40.2 Ω
Line X:27.9 Ω

Or alternatively:

Line length: 140km
Line R:40.2 Ω
Line X:27.9 Ω

The Impedance of the line is calculated manually as an average value. The end point of the line length calculation needs to be decided as well.

The positive sequence values of protection relay with segmented distance protection are set as shown on the table 1.

TABELA 1 – Positive sequence values with segmented distance protection in the example

	Line length	Line R	Line X
Segment 1	30 km	0.26 Ω /km	0.13 Ω /km
Segment 2	60 km	0.54 Ω /km	0.40 Ω /km
Segment 3	50 km	0.85 Ω /km	0.38 Ω /km

The relay with segmented distance protection algorithm calculates the impedance based into the given line values. The zero sequence components are given in a similar way to the relay.

The resulting R/X characteristics of the example set points are shown in Figure 3. The blue “Average” line is the 140 km conventional setting, the blue Average2” represents the conventional 90 km setting, Seg A, Seg B and Seg C the actual line parameters as set by segmented distance protection algorithm. Similarly, the Figure 4 shows the comparison in terms of km / X characteristics.

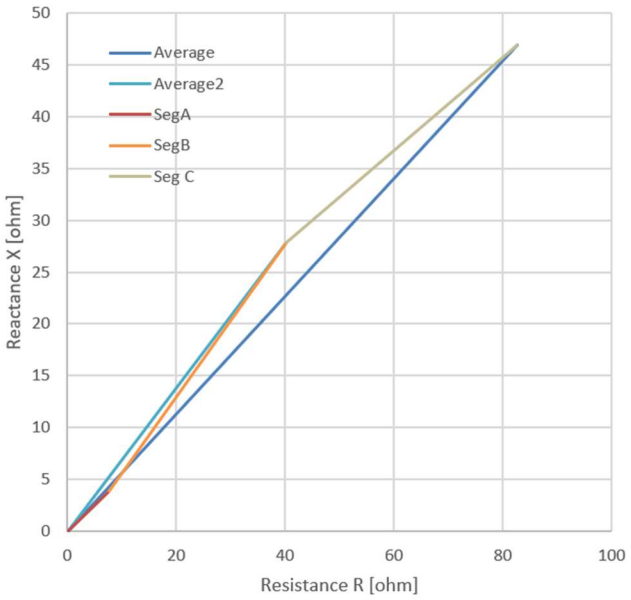


FIGURA 3 – R/X characteristic comparison of the segmented setting versus conventional setting of the line parameters in the example.

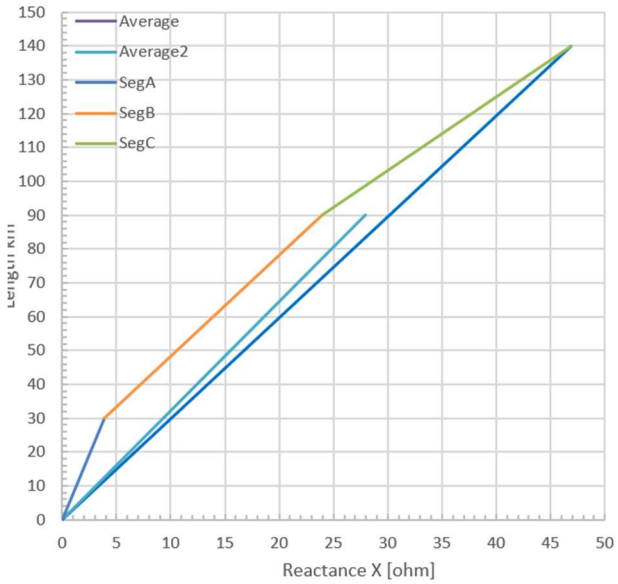


FIGURA 4 – km/R characteristic comparison of the segmented setting versus conventional setting of the line parameters in the example.

2.2 Inputting line parameters in distribution protection example with reactor in the zone

If we consider the same protected object as in the example A but with additional reactor in line A-B.

TAP out from the line to Reactor R = 0.5 Ω, X =15 Ω

As can be seen from the Figures 5 and 6 adding the reactor component in the middle of the line causes the conventional non segmented approach to be even more distorted from the actual values.

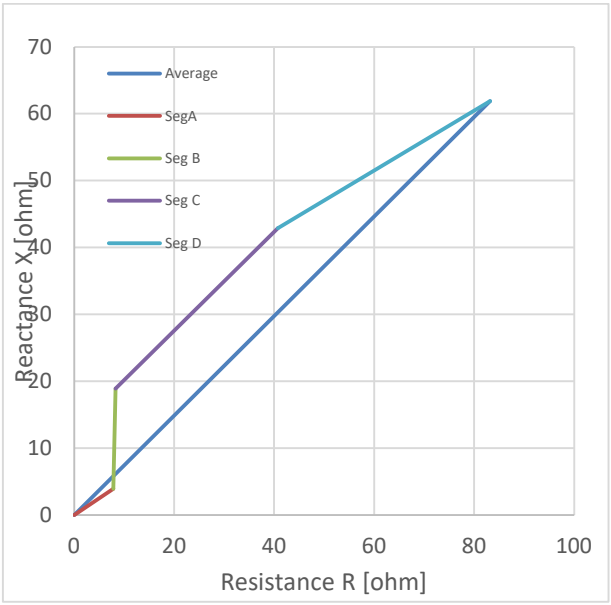


FIGURA 5 – R/X characteristic comparison of the segmented setting versus conventional setting of the line parameters with reactor in the line A-B.

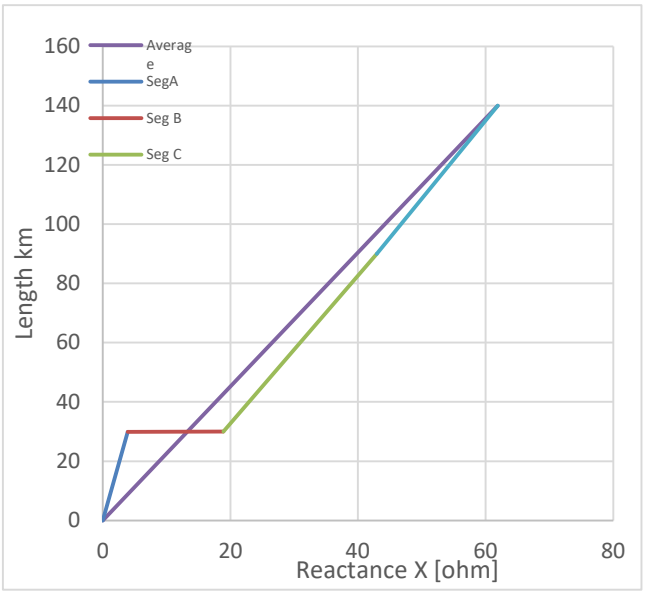


FIGURA 6 – km/R characteristic comparison of the segmented setting versus conventional setting of the line parameters with reactor in the line A-B.

2.3 Setting reactive and resistive reach in distribution protection example with reactor in the zone

We can now consider the previous example line with reactor in the zone and set the first zone to underreach 80% of the line reactive length. Figure 7 compares the reach settings between the conventional method and the segmented method. Reactive reach does not differ between conventional and segmented methods. In resistive reach setting a significant difference can be noted. In segmented method the R reach follows exactly the protected object, whereas in conventional approach the R reach (blue line) does not follow the line correctly. The gap of resistive reach setting between methods is seen in pink colour.

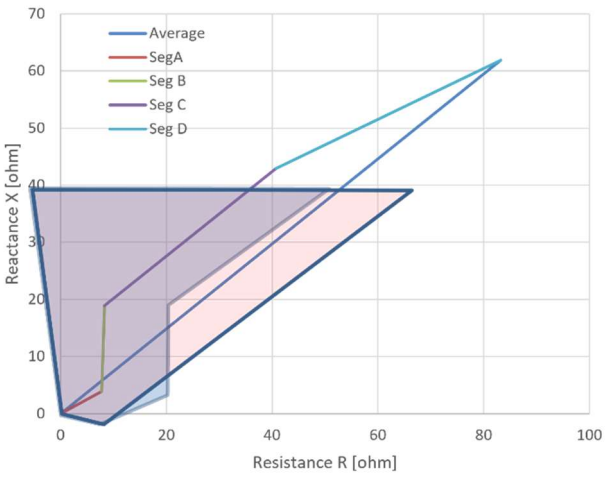


FIGURA 7 – Reach setting comparison of the segmented versus conventional setting methods with the example line parameters with reactor in the zone.

3.0 - BENEFITS OF THE NEW SEGMENTED DISTANCE PROTECTION ALGORITHM

3.1 Improved resistive reach accuracy

As seen in the example of the previous chapter, using the segmented method for setting the protected line and respective reach settings results in accurate modeling of the protected object and consequently exact fit of resistive reach to the protected line. The result is a very accurate resistive reach setting.
The new segmented method eliminates the need of using average values that result in average protection accuracy. With improved resistive reach setting the overall distance protection dependability is improved. The scale of improvement depends on the protected line. The more varying impedances and heterogenous ground resistivity conditions results in greater protection accuracy improvement. In homogenous and consistent grounding conditions the accuracy of conventional method without applying segmentation results in satisfying performance.

3.2 Improved earth fault protection accuracy

Ground heterogenous resistivity can be compensated correctly when line type changes for example from ground dug cables to overhead line or when the ground type changes significantly in the length of or parts of the protected line.

3.3 Improve distance to fault location calculation

Distance to fault calculation remains consistent throughout the protected line thus improving the distance to fault accuracy.

3.4 More effective auto-reclosing

The segmented distance protection allows for distinguishing if the fault is in the underground cable or overhead segment of the line. The self-healing faults can be eliminated by activating the auto-reclose sequence in overhead lines while inhibiting reclosing when the fault happens in underground cable segment.

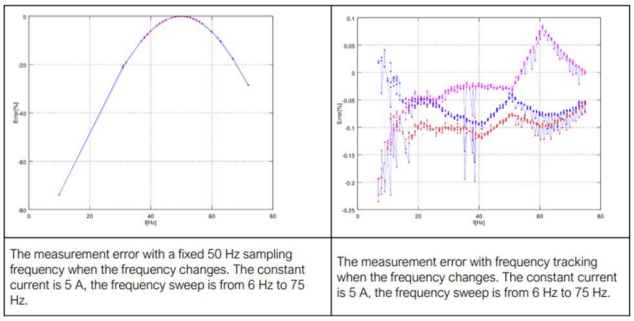
3.5 Easier setting

Traditionally the distance settings have been defined using a plain impedance plane. In new segmented method the actual distance zone and reactive reach can be thought in kilometers (or in any length measuring unit) from the relaying point. Setting can be inputted also directly as percentage of the protected line independent of how many segments are included.

4.0 - DISTRIBUTED GENERATION IMPACT ON PROTECTION

As we are witnessing larger penetration of distributed generation sources in the power grid, new scale of power quality concerns arises as well. Installation of large capacity power electronics causes higher than usual harmonics levels that may impact on protection accuracy. It will be essential to analyze more in details different relay manufacturer's harmonic filtering capabilities and possibly adapt the protection settings based on higher harmonic content.

Lack of inertia caused by replacing traditional synchronous generators in the system by new renewable generation sources leads potentially to more severe voltage and frequency variations in future power grids. Therefore, it will be necessary to pay greater attention to the impact of frequency variation in protection accuracies. Figure 8 below compares test results of current measurement accuracy when using a fixed 50 Hz (or 60 Hz) sampling frequency to an adaptive frequency tracking sampling method. Fixed frequency method results in significant loss of measurement accuracy right above or below nominal frequency. The adaptive frequency tracking method provides practically no loss of accuracy throughout the tested frequency swipe of 6 to 75 Hz. [1]



The measurement error with a fixed 50 Hz sampling frequency when the frequency changes. The constant current is 5 A, the frequency sweep is from 6 Hz to 75 Hz.

The measurement error with frequency tracking when the frequency changes. The constant current is 5 A, the frequency sweep is from 6 Hz to 75 Hz.

FIGURA 8 – Comparison of test results of fixed sampling frequency method to adaptive frequency tracking method. [1]

Effect of the distributed generation can cause network frequency instability as mentioned before as well as lack of short circuit power since inverters cannot support short circuit current in similar way than rotating generators with inertia. This may become a problem for the non-directional instant short circuit protections as well as distance protection when the network generators are unable to support sufficient level of short circuit currents.

The presence of intermediate infeed complicates the coordination between primary and backup protection schemes. The direction and magnitude of fault currents can vary due to the presence of intermediate infeed, affecting the directional sensitivity of protection relays. Intermediate infeed sources, such as wind turbines or solar farms, contribute to the total fault current, and their variable output can change the fault current levels dynamically. This variability can alter the expected fault current levels, making it challenging for protection relays to accurately detect and locate faults. Ensuring that all protection devices operate correctly and in the right sequence becomes more complex. [2], [3]

The old protection design principles are based on the well-known characteristics of conventional generators. These principles do not consider the intermediate infeed and the power capabilities of distributed generation, which vastly differ from conventional generators.

Commonly, the protection settings have been set to known-to-be-good values or even the manufacturer-specified defaults, which can lead to overly broad tripping zones. Varying short circuit currents, along with the increasing level of transients, have led to maloperations of the protection systems. To avoid this, careful analysis and adaptation of protection settings are needed to ensure reliable operation.

The areas with high installed and planned capacity of distributed generation require new protection schemes for dependable and safe operation of the power grid. As solar and wind park capacities are at increase and microgrids are gaining popularity the conventional overcurrent-based protection schemes are challenged. Therefore, using distance protection function in the new schemes previously not applied to may create new opportunities on improving the power grid protection. [2], [4]

In complex networks, particularly those with infeed generation, fiber optic communication between different points of the protected network can be used to enhance the selectivity of the protection. This communication can be utilized to modify protection settings and interlocking schemes under various conditions with minimal time delay. For instance, information about the current power generation data from the infeed generation plant can be transmitted to the main substation to compensate for the plant's short-circuit current generation.

As fiber optic communication between substations become more common, it is possible to achieve even better selectivity and adaptation using multi-end communication schemes between several substations. The communication bus between substations also allows for the utilization of line differential protection as the primary protection method

Distance protection schemes can be adapted to account for the variability in generation from distributed generator sources. This adaptability ensures that protection settings remain effective under different operating conditions. By accurately determining the location of a fault, distance protection also ensures that only the affected section of the grid is isolated, minimizing the impact on the rest of the network.

Distance protection can quickly and accurately identify fault locations, reducing the time required to clear faults and thereby enhancing the overall reliability of the grid. With the ability to handle power flows in both directions, distance protection can effectively manage the complexities introduced by microgrids that can operate in both grid-connected and islanded modes.

5.0 - CONCLUSÃO

As power systems grow in complexity protection engineers are facing new type of challenges. Distributed generation impact on protection dependancy overall needs to be studied more carefully. The new segmented distance protection method improves resistive reach accuracy significantly compared to the tradtional distance protection algorithms. The segmented protection method is well applicable to any voltage level. Applying the segmented method helps in avoiding under – or overreaching of the distance function making the protection more dependable and allowing for applications beyond traditional use of distance relays. The benefits rendered by applying segmented approach are evident especially in mixed networks containg components with multiple reactances and segments with different ground resistances.

6.0 - REFERÊNCIAS BIBLIOGRÁFICAS

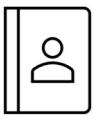
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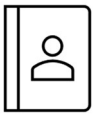
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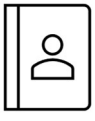
7.0 - DADOS BIOGRÁFICOS



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