THE NEXT CHALLENGE: DISTANCE PROTECTION DESIGNED FOR EASE OF APPLICATION

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INTRODUCTION

Distance protection has been a well-respected technique for many decades. With each emergence of a new hardware platform, this has allowed an incremental improvement in performance, most notably in recent years with the ability to implement distance characteristics by means of numerical algorithms in a digital relay. Continual research and development still produces incremental performance enhancements, however with the techniques and algorithms becoming more mature, the real additional benefits to the user are not always so apparent.

This paper describes the design approach for a new integrated distance protection and control relay. At the specification stage, the decision was taken as to what would benefit the user most. Several questions were posed and debated from the viewpoint of a utility technician, engineer, or operator. (1) Am I generally happy with the performance of distance relays?.. (2) Do I want to see new algorithm principles?.. (3) How do I set and apply the relays to the power system?..

In summary the relay was born as a device that would use the most proven algorithms, with step enhancements only where it would bring an application benefit – using the benefit of hindsight since the last new product release. The main priority in the development was focused on making the product simpler to apply, make settings, and operate/interrogate.

The paper summarizes that it is possible to implement a fully-performing distance relay for universal application, without pushing the complexity and training requirements into the realms of rocket science.

BASIC REQUIREMENTS

Distance protection has two fundamental design requirements. (1) Firstly, the relay must trip quickly for any genuine in-zone fault, to ensure that the system stability is not compomised and damage is minimised. (2) Secondly, the relay must remain stable for all load and through-fed conditions. This latter point is particularly critical to avoid constraining the loadability of the line, and to avoid sympathetic unwanted trips from propagating through the power system under extreme conditions (such as power shortages, neighbouring circuit outages, power swings etc.). Good load avoidance is an essential defence mechanism in avoiding blackouts and unnecessary islanding.

A simplistic view of the trip and restrain (stable) requirements is shown in Figure 1.

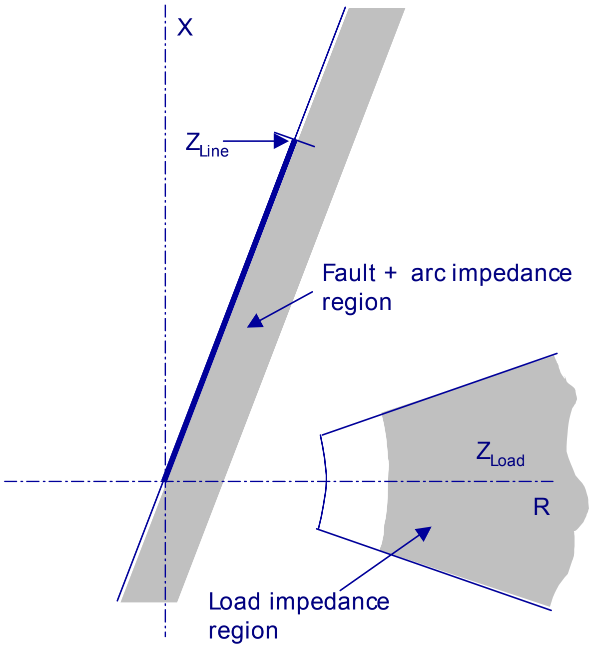

Fig. 1 Distance Relay Operating Requirements

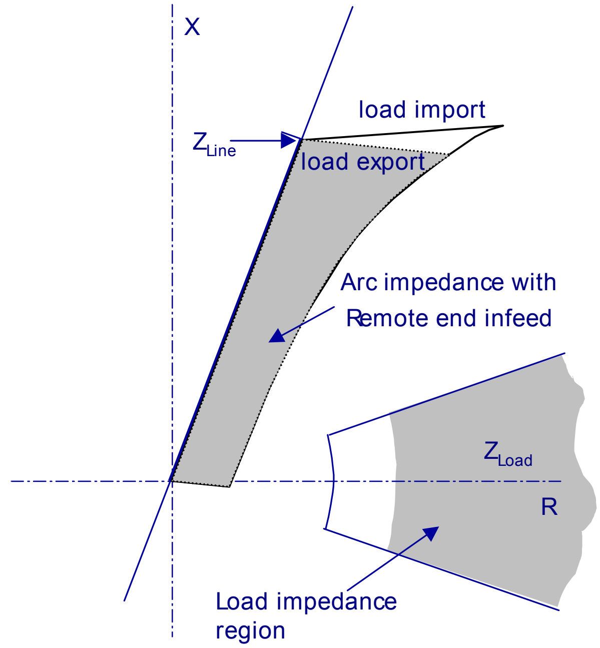

Fig. 2 Apparent Arc Resistance Increase

In the figure, the protected line impedance is shown, along with an extended area to the right where fault arcing resistance may appear. Typically, the amount of arcing resistance may be estimated from the van Warrington formula [1]. The effective fault impedance measured by a distance relay may thus lie within this shaded region. In order to ensure tripping for all genuine faults, the relay characteristic must include the shaded region, for all zones up to and including the longest reaching zone (typically Zone 3) reach point.

It is also evident that the relay must avoid the load area. The shaded load region shows the load impedance that may be presented to the relay under normal system operation, for example with the neighbouring circuit in a double circuit line being in-service. However, in many cases a lower minimum load impedance needs to be avoided, as shown by the unshaded extension of the load cone. This may consider circuit overloading, which could be +20% or more of full load current, and also the doubling effect where an adjacent circuit trips/opens. Overall, it is common to ensure stability for 2.5 to four times full load current flowing.

Figure 2 shows how the previous analysis is a little simplistic, in a real power system. As each protected line has at least one remote end terminal, there is likely to be an additional current infeed to any in-zone fault. This remote infeed serves to magnify the apparent fault arc impedance as measured from one line end, with the effect becoming more pronounced as the fault position assumed moves towards the remote line end. Reference [2] details remote infeed effects.

Typically, this means that towards the remote end of the line, the relay trip characteristic must cover at least four times the van Warrington calculated resistance.

The relay requirement, however, remains unchanged – (1) Trip for faults, with or without arc resistance included, (2) Remain stable for load and overloading.

RELAY SETTINGS

From the previous section it is straightforward to deduce that distance relay settings fall into two categories. Category (1) is to ensure tripping for all faults within the reach of the distance zones. Thus all settings here are related to the impedance of the protected line, and follow-on adjacent lines.

Category (2) is to ensure load avoidance, commonly called “load blinding”. All such settings are related to the load flow, ensuring that line loadability is not constrained.

The relay featured in this paper has been designed such that the user merely inputs the protected line data, and the load data, and the relay will then selfset accordingly. With approximately 50% of all investigated "maloperations" found to be the result of poor settings, then a product which has been designed with such simplicity should reduce the risk of typical errors occurring.

The relay uses an intelligent overview of the protected line to implement a "Simple"-set option, and in doing so the user has only a few key parameters to set, rather than the proliferation of settings that can frequently accompany a multifunction relay. The ease of setting also translates to simpler commissioning and grading/selectivity.

SIMPLE AND ADVANCED SETTING MODES

In the majority of cases, "Simple" setting is recommended, and allows the user merely to enter the line parameters such as length, impedances and residual compensation. Then, instead of entering distance zone impedance reaches in ohms, zone settings are entered in terms of percentage of the protected line (example, Zone 1 = 80%), as shown in Figure 3.

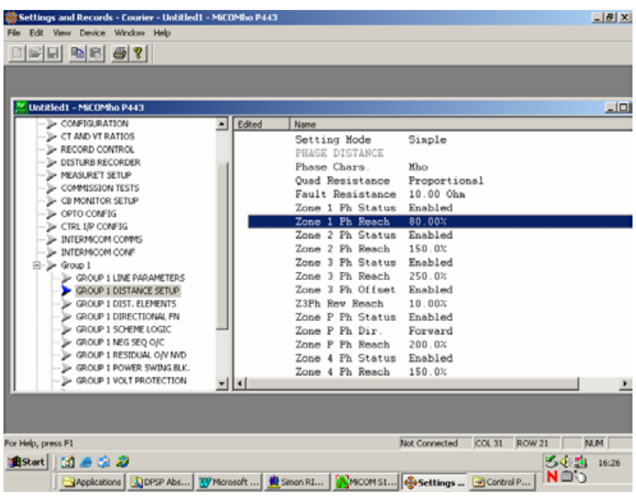

Fig. 3 Simple Setting of Zone Reaches

Each Zone can be set with a reach relative to the protected line, or if fine-tuning is required, an "advanced" setting option can be switched-in later.

The "Advanced" setting mode allows the user full access to all individual distance ohmic reach, filter and residual compensation settings per zone. This makes the relay adaptable to networks where the protected and adjacent lines are of dissimilar construction, requiring independent zone characteristic angles and residual compensation.

In Figure 3 it is noted that the relay in question can be applied with mho, or quadrilateral characteristics – to suit the utility's preference. When a quadrilateral characteristic is applied, this requires zone resistive reaches to be set – the right and left-hand lines. Again, simple-setting is applicable, whereby the user sets a base arc resistance as a reference, and can choose whether to fix the same resistive reach coverage for all zones, or whether to set Proportional characteristics. In the latter case, the relay fixes a reference fault at 100% of the protected line reach, and uses that to scale the resistive reach for the zone according to the same percentage as the reactance reach. Thus, all zones would share a common X/R (or Z/R) aspect ratio.

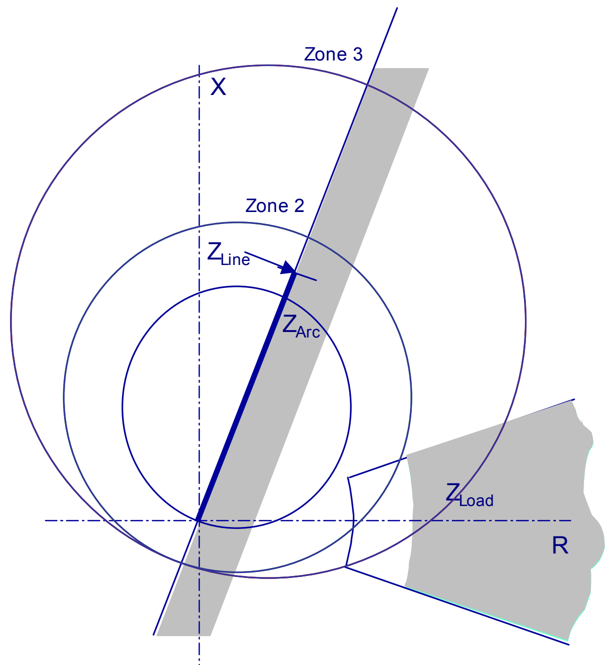

Fig 4. Mho Relay set for Line Protection

Taking the mho characteristic as a reference case, Figure 4 illustrates the relay trip characteristics, were the relay applied solely according to line protection constraints (ie. ignoring loadability). It is evident that due to the length of the protected lines, zones 2 and 3 stray into the expected load area. This is unacceptable, as spurious trips would result.

This is an example of where we must consider category (2) from previous discussions, and ensure load-blinding based on the expected load flows.

LOAD BLINDING

The relay in question uses an advanced load blinder which is designed to allow better resistive reach coverage. The blinder is basically formed from an underimpedance circle, with radius set by the user and two blinder lines crossing through the origin of the impedance plane. It cuts the area of the impedance characteristic that may result in an operation under maximum dynamic load conditions (Figure 5).

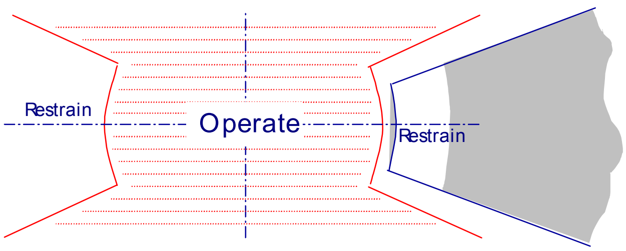

Fig. 5 Load Blinder "Cone"

The radius of the circle should be less than the minimum dynamic load impedance. The blinder angle should be set half way between the worst case power factor angle, and the line impedance angle.
In the case of a fault on the line it is no longer necessary to avoid load. So, for that phase, the blinder can be bypassed, allowing the full mho characteristic to measure. Phase undervoltage detectors are the chosen elements to govern switching of the blinders. Under such circumstances, the low voltage could not be explained by normal voltage excursion tolerances on-load. A fault is definitely present on the phase in question, and it is acceptable to override the blinder action and allow the distance zones to trip according to the entire zone shape. The benefit is that the resistive coverage for faults near to the relay location can be higher.
The undervoltage setting must be lower than the lowest phase-neutral voltage under heavy load flow and depressed system voltage conditions. The typical maximum V< setting is 70% Vph-neutral.

DELTA CURRENT DETECTION

Many of the application difficulties for distance protection have historically been related to correct faulted phase selection. For example, in the case of a close-up reverse earth fault, a large amount of neutral current will be measured by the relay. This neutral current is also included in the earth loop impedance measurement for the unfaulted phases (by means of residual compensation), and the 120o displacement between phase voltages may allow the fault to appear in a forward trip characteristic.
Similarly, it can be difficult to ensure that the correct phase-phase element will be allowed to measure in the case of a double phase to earth fault, whilst restraining the involved earth pair zones. The latter is necessary to avoid overreach – particularly where quadrilateral characteristics are employed.
In this respect, the author's company decided to use a proven and successful technique, used in the previous two generations of their transmission line protection – delta current phase selection [3]. Figure 6 overleaf shows the principle.

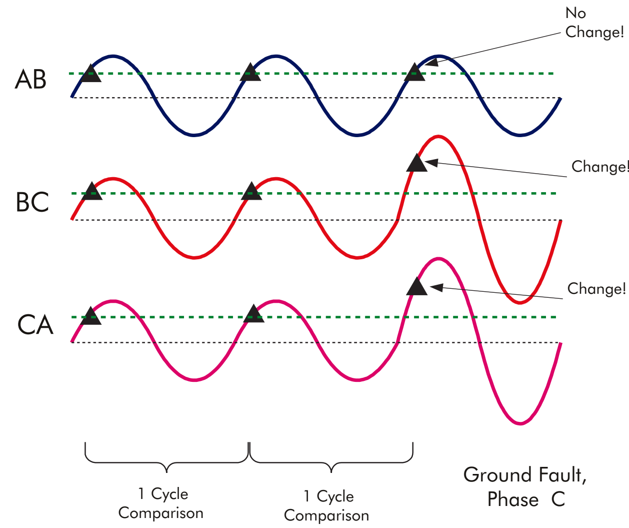

Fig 6. Delta Current Phase Selection

Selection of the faulted phase(s) is performed by comparing the magnitudes of the three phase-to-phase superimposed currents. A single phase fault produces the same superimposed current on two of these signals and zero on the third. A phase-to-phase or double phase-to-earth fault produces one signal which is larger than the other two. A three phase fault produces three superimposed currents which are the same size. Figure 6 shows how the change in current can be used to select the faulted phase for a CN fault.
A superimposed current is deemed to be large enough to be included in the selection if it is greater than 80% of the largest superimposed current.
The large advantage of using delta – which is effectively the magnitude of a step change – is that it is naturally biased towards detecting a fault. Faults produce a definite step change, whereas power swings and other unfaulted phase effects yield a lesser delta. Delta phase selection is used to control the distance elements, and has the advantage that it has no associated settings – the sensitivity is internally biased, and equally applicable for strong, and weak infeeds. The relay is thus easier to apply than designs which use underimpedance, overcurrent, or other starters to detect a fault.

POWER SWING BLOCKING

Superimposed current is also used as the criterion to detect power swings. Power swings generate a continually changing current, and hence prolonged pickup of delta detectors. Pickup for longer than 50ms is used to initiate power swing blocking, and keep relay stability. An advantage again is that no threshold settings or impedance starters are required – the technique works by its nature in all applications.

The relay tracks the profile of the delta current, and if at any point there is an unexpected step change in the prevailing delta, blocking must cease as a fault is now present. Thus, the trip time and zone selectivity for any fault inception during a power swing is as fast and reliable as had no swing been present.

CONCLUSION

This paper demonstrates how a distance relay designed for ease of application has fewer settings, and has a lower scope for accidental setting errors. A straightforward “Simple-set” mode can allow zone reaches to be applied as percentages of the protected line. The Simple-set mode does not artificially place performance constraints on the application, and the use of proven techniques such as delta phase selection and power swing blocking allow universal deployment (for strong and weak infeeds, interconnected, and weakly-interconnected systems that may be prone to power swings). Relay settings can be split into two categories: (1) those related to line protection/fault detection, and (2) those to ensure load avoidance. Recent experience from blackouts in several countries shows that the dynamic changes of load may result in undesired operation of distance elements due to the load impedance entering the distance characteristic. A simple and effective load blinding technique as decribed in this paper forms an effective defence against such unwanted tripping. The authors note that distance relays should not constrain the loadability of transmission lines. The distance relay is designed according to the power system needs – not vice versa.

REFERENCES

[1] Network Protection and Automation Guide, ISBN-2-9518589-0-6, ALSTOM (AREVA), 2002.

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[3] Keeling D., Pickering S., High Speed Numerical Techniques for Transmission Line Protection, IEE 6th International Conference, Nottingham, UK.