SHORT FEEDER DISTANCE PROTECTION AND ITS APPLICATION LIMITS

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ABSTRACT

Growth and urbanisation in South Africa have over the years resulted in the demand for electricity rising to higher proportions. This results in load bases being centralised in certain geographical areas. Due to firm supply requirements of these loads, HV power lines are interconnected to form a ring network, resulting in short HV lines. HV lines are traditionally protected by distance schemes, due to their performance over the years. However, the distance schemes have underperformed in many instances where they have been used for short HV lines.
This paper explores these short comings of distance relays for existing lines here in South Africa. Comparison will also be drawn with current differential schemes.
This paper highlights the problems associated with distance relays using a case study as well.

1. INTRODUCTION

Literature indicates that lines with a length ≥ 15km should have distance protection as main protection. It also indicates that lines with a length ≤ 5km must use current differential relays as main protection. This leaves the power line length range of between 5km and 15km subject of debate as to which protection philosophy should be used between the two methods.
Although costs do have a major impact on the decision making process of selection of protection scheme in general, they will not be looked at in the context of this paper. The idea of this paper is to assist project engineers or protection applications engineers with the selection of the appropriate protection schemes for the short HV lines.
This paper looks at Eskom high voltage distribution levels which are 44kV and 132kV (with both voltage levels inclusive).

2. CURRENT DIFFERENTIAL RELAYS

Current differential protection relays operate based on Kirchoff's 1st law, which states that *"the sum of the currents entering a node must equal the sum of the currents exiting a node."* This operating principle is defined by the formula below:

$$|I_{diff}| = |I_1 + I_2| \qquad (1)$$

3. DISTANCE RELAYS

Distance protection relays operate based on Ohm's law, which states that *"electric current flowing in a circuit is proportional to the voltage and inversely proportional to the resistance."* This operating principle is defined by the formula below:

$$Z = \frac{V}{I} \qquad (2)$$

where:

$$Z = \sqrt{(X_L{}^2 + R^2)} \qquad (3)$$

Distance protection is used for transmission lines longer than 15 km. The use of communication link between impedance relays at the remote ends of the line results in unit protection. Distance protection is the determination of the fault position on the line by measuring the impedance of the faulted conductor between the relaying point and the point of short circuit [1].
The series impedance of the line is made up of resistance and inductive reactance. These R and X quantities depend on the length of the line, thus the line length can be given in terms of impedance. A distance relay situated at busbar A figure 1 measures the ratio of the line voltage from the VT to the line current from the CT. This rate (V/I) corresponds with the impedance 'seen' by the relay, which is proportional to the primary impedance of the system beyond the relaying point.

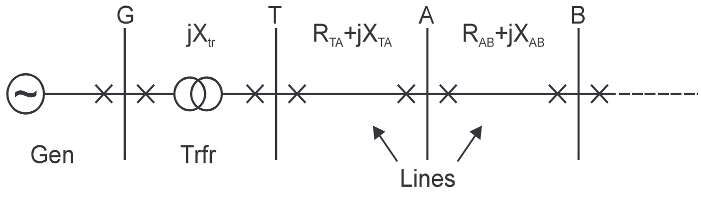


Figure 1. Network impedance representations

The main disadvantage of distance protection is that they require both voltage and current quantities to operate.
During load conditions locus of the impedance, which is predominantly resistive around the R axis in the shaded area, and seen by the relay, is situated as shown in the figure 2 below.

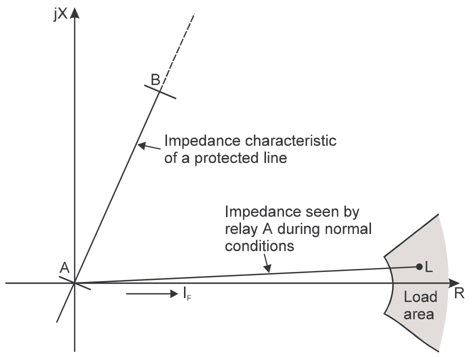


Figure 2. Impedance characteristics of a line

3.1 Tower Foot and Earth resistance

The behavior of the distance relays is similar for high tower foot, arc, fault and earth resistances as the relay see resistance or impedance changes. These resistances are seen by the relay during phase/s to ground faults. The higher the value of any of these resistances during a fault, the lower will be zero sequence fault currents, resulting in the impedance relays not picking up the faults or under-reaching.
The effects of these fault resistances could be quite high in short HV lines as they could be greater than the line impedance resulting in incorrect tripping.

3.2 Line Impedance

Again the current differential protection is not affected by the impedance of the line. The longer the line, the higher will be the line impedance. The current differential protection though becomes very expensive to setup due to the costs and limitations of telecoms channels like fibre optic, pilot cables.

3.3 Fault Levels of the network

It is very important that the fault levels of the network must be taken into account when selecting type of relay for protection of a line. High fault levels of the network imply that protection must be sensitive and fast enough to clear the faults without any damage, as damage to an electrical network is defined by the formula; $E = I^2 t$.

where;

E = energy responsible for the damage of equipment during a fault.
I = fault current flowing in that part of the network.
t = time taken by the fault current to flow in the faulty network.

By general rule, current differential protection is the protection better protection for clearing faults speedily and being quite sensitive. This is due to the measurement techniques of current differential protection schemes, that current entering a line must be equal to current leaving that line.

3.4 Fault / Arc Resistance

Fault / Arc resistance does affect the performance of the impedance relays. This phenomenon is also briefly discussed to highlight some of the problems associated with it. This also brings to the fore that again impedance relays are having quite a limitation and can trip for a fault in zone 1 with zone 2/3 times due to the high resistant characteristics on most fault arcs involving earth.

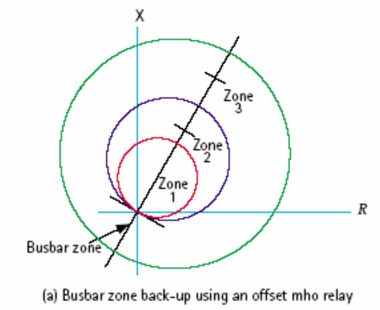
Veld fires cause quite a number of line faults in Eskom network. When the air is polluted by smoke, the insulation strength is degraded. This can results in flashovers between the conductors and ground. This flashover distance can be very large.
Arcs are generally resistive and large arc resistances can even be greater than the conductor impedance to the fault, resulting once again in incorrect tripping of the distance scheme. It is important to note that an arc is mainly resistive and as the voltage and current are in phase. At the point of entering the ground, additional resistance is introduced.

This resistance can be large depending on the ground moisture content and the availability of rocky surfaces.
The following impedance formula reflects the change of measured impedance seen by the relay and ground resistance.

$$I_F = \frac{V_A}{Z_F + R_{arc} + R_{ground}} \tag{4}$$

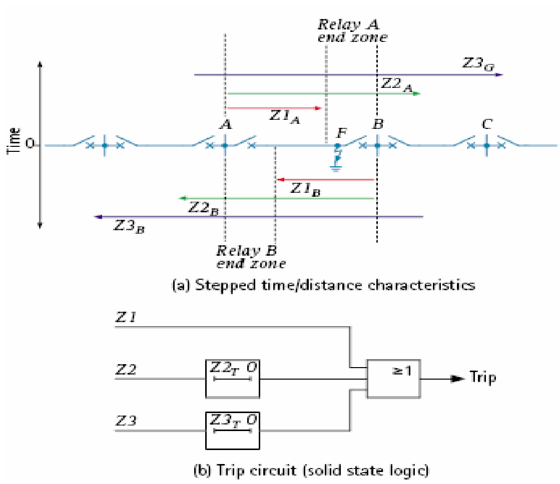
3.5 Zones of Protection

Distance schemes are configured to ensure that they clear close up faults instantaneously. The same cannot be said for fault on adjacent feeders. This is because faults on adjacent lines should be tripped by the protection schemes of those lines to ensure that only the faulted part/s of the network are isolated, due to quality of supply imperatives.
Zones of protection are therefore brought in to ensure that the protection selectivity is achieved [2].
There are three popular zones of protection in distance schemes. They are configured in their respective zone elements. The zone elements are set to see fault in a limited impedance range. This enables discrimination between the zones, which enables the protection schemes to differentiate tripping times for each eventuality. These zones of protection are highlighted in figures 3 & 4 below.



(a) Busbar zone back-up using an offset mho relay

Figure 3. Mho relay 3 zones



(a) Stepped time/distance characteristics

(b) Trip circuit (solid state logic)

Figure 4. Stepped distance characteristics & tripping logic

3.6 Source to Line Impedance Ratio

Source to line impedance ratio affects mainly the impedance relays. Therefore the analysis below will mainly look at the impedance relays and try to show how this phenomenon affects the performance of these relays.
Current differential relays wouldn't be affected by this phenomenon as they operate due to the difference of currents seen by these relays being above a certain setting.

When the ratio of the source impedance to the setting of the impedance relay is very high, the impedance relay could be slow [3]. In high source impedance and a short line, there is hardly any difference in fault voltage measured by the impedance relay at the end of the zone or out of the zone.
Looking at figure 6, when a three phase fault occurs at F the voltage at the fault point becomes zero and the voltage drop along the faulted line is IF (R + jX) d, with the R and X measured in ohms / km and the distance in km.

$$\left(\frac{V_A}{I_F}\right) = (R + jX)d \tag{5}$$

This is proportional to the impedance "seen" by the relay. If d = 75% of AB then AF = 75% of AB.
From busbar B, where the impedance locus was before the fault, it suddenly changed to AF just after the fault.

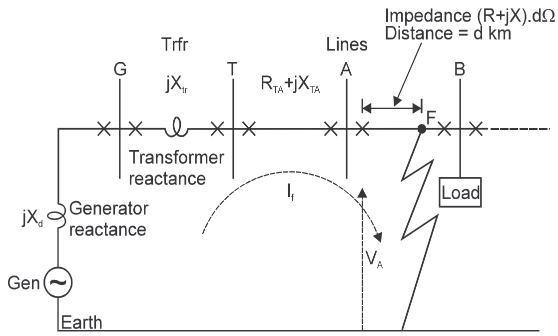


Figure 5. Impedance network during a fault

From equation 5:
R = line resistance in per km
X = line reactance in per km
d = geographical distance from the relaying point A.

4. CASE STUDY

Theory especially about distance protection philosophy is very interesting. Although it is very interesting it needs to be tested in a practical context, so as to ensure that the behavioral characteristics of these relays are similar as explained in theory.
The case study under question is for a 66kV line between Alpha and Beta Substations (names withheld) in the Western Cape Region. The parameters of this line are as follows:

Length	:	6.78km
Voltage	:	66kV
$Impedance_1$	:	(0.989+j1.503) Ω / km
$Impedance_0$	:	(1.533+j5.454) Ω / km
Technology	:	Overhead
Conductor	:	Bear
Protection	:	Distance (both sides)
Schemes	:	BBC LZ32
Telecoms	:	Medium not installed

The fault pattern for this power line is shown in Table 1:

Table 1. Fault operation on the Alpha_Beta line

DATE	*FAULT*	*PHASE*	*TYPE*	*ALPHA TRIP*	*BETA TRIP*
02 Feb 06	Ground	B	E/F	Z2	B/U E/F
11 Feb 06	Fire	R, W, B	O/C	Z2	Z1 Trip
06 Apr 06	Transient	B	E/F	Z2	Z1 Trip
25 Apr 06	Transient	W	E/F	Z2 & 3	B/U E/F
22 May 06	Ground	R, B	2P & E/F	Z3	Z2
08 Aug 06	Joint broke	R, W	2P & E/F	Z2 & 3	B/U E/F
02 Sep 06	Transient	W	E/F	Z2 & 3	B/U E/F
18 Sep 06	Transient	R	E/F	Z2	B/U E/F

Table 1 paints a good picture of the performance of the distance schemes in short HV lines. It should be noted that on the Alpha Substation side almost all faults were cleared by zone 2, which is highly unacceptable as some faults were few metres out of that substation.
This show quite clear that the use of distance schemes in short HV lines should be avoided.
As most of these faults were earth-faults, the distance schemes battle to clear the faults in Z1 time (instantaneously) which is a major requirement and expectation from distance relays, especially for voltages of 66kV and above.

Figure 6 below shows the voltage dip profile for the 66kV system at Beta substation on the 22 May 2006. The voltage dip of up to 50% for both the red and blue phase was experienced. The striking aspect about this voltage dip is that it lasted for about 320ms.

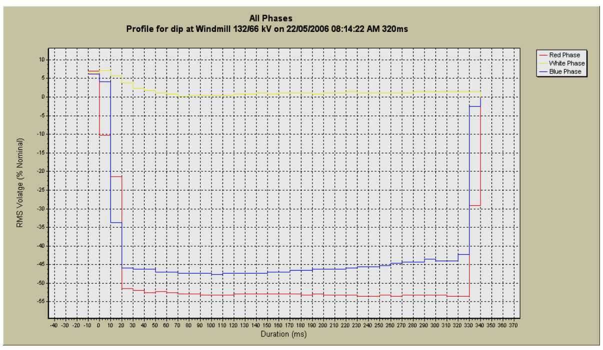


Figure 6. Voltage profile of line during a fault

This implies that the fault was sustained for this long time although it was on Z1 of the Beta substation and Z2 of the Alpha substations.
Both Alpha and Beta substation feeder protection relays operated incorrectly, as they operated in Z2 and Z3 times respectively. This is highly unwanted as these sustained faults degrade the network in the long run.

5. CONCLUSION

The use of distance protection for short HV lines is discouraged, unless permissive overreach function is possible with a communication link. Distance schemes should however be used in cases where one or more line/s are two substations forming a transmission / distribution interface. Failure of telecoms channels in these cases can cause current differential relay to operate as normal O/C & E/F, which could be quite detrimental.
The case study results indicates quite clear that a fault in that line for the 22 May 2006 incident was cleared by the relay's Z3 element from the Alpha substation side. This once again highlights the problems that are encountered by the application of distance scheme in short HV lines.

6. REFERENCES

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7. BIOGRAPHY

Sobhuza Tshobeni received the National Diploma Electrical Engineering from Eastern Cape Technikon, South Africa in 1999. He also received a Bachelor of Technology Degree Electrical Engineering at the Cape Peninsula University of Technology (CPUT), South Africa in 2006.
He joined Eskom Distribution Division in 1999 when he works as a Principal Technician responsible for protection applications of all substations in the Western Cape Region. He is registered as Pr Techni Eng with the Engineering Council of South Africa and is a Member of South African Institute of Electrical Engineers.