



DISTANCE RELAY CHARACTERISTICS SUITABLE FOR DYNAMIC LOADING

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KEYWORDS

Distance relay;
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Abstract: Modern distance relays are designed with different characteristics in order to demonstrate that they can provide better protection and at the same time results in significant improvement of the performance of distance relays during wide area disturbances by preventing the operation of distance relays under dynamic load conditions. However, blocking the operation of the distance elements if a fault occurs at this time may result in a further degradation of the system conditions. The paper discusses in detail the effect of dynamic loading on different types of distance relays characteristics and the relay loadability limits at a different power factor angle are calculated. The simulation result shows the impact of different MTA on a relay loadability limit. The comparison of MHO characteristics and lens characteristics are carried out in PSCAD/EMTDC software. The test network used in this paper is 230 kV, 300 km radial Transmission line systems.

1. INTRODUCTION

Distance Relay has widely used a protective relay in a long transmission line nowadays. The Distance Relay achieves selectivity on the basis of impedance. As the impedance is proportional to the distance between the fault point and relay so the relay is directly indicated a distance of fault location. Distance relay is always set for instantaneous operation in the first zone, delayed operation in the second zone and provide back protection in the third zone [1].

The most common use relay characteristics are MHO type. The MHO characteristic is a circular characteristic passing through R-X origin. It has an inbuilt directional feature. In MHO characteristic of distance relay maximum torque angle is generally set as line angle. The

quadrilateral characteristic is most preferred when protecting short transmission lines as this provides substantial resistive coverage and arc compensation than the traditional circular characteristics [7].

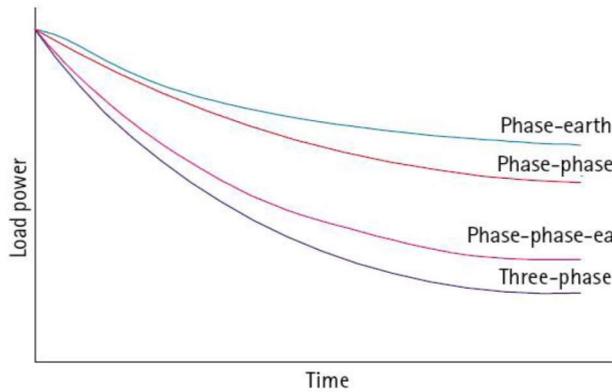
Recently lenticular or lens characteristics are used for heavily loaded long transmission lines. It has more immunity to load encroachment but less coverage of fault resistance. The lens characteristics generated by merging the common area between two MHO elements [8].

2. DISTANCE PROTECTION REQUIREMENTS FOR DYANAMIC

The day to day increase of the loading of transmission lines as the power industry is

undergoing fundamental changes or deregulated markets, economic and environmental requirements have to be considered when analysing the performance of distance relays, selecting protection devices with distance functions and calculating their settings [2].

FIGURE 1: Typical power/time relationship for various fault types



Since the dynamic stability is a function of the loading of the line and the duration of the fault, the operating time of the distance relay will affect the level of loading of the protected line. Shorter fault clearing times allow increased power transfer (fig.1) [4].

The detection of a fault and a decision to trip is made by modern distance relays in less than one cycle. However, the operating time of the relay and its give the distance of fault location are not the only factor to be considered while selecting a distance protection for a transmission line that requires dynamic loading but also the loading of transmission lines is typically limited by their rating. The thermal rating is usually based on a conservative assumption of weather conditions. Since weather conditions are continuously changing, most of the time the actual rating of the line can be significantly increased, especially if specialized monitoring equipment is being used [3]. For short transmission line load ability is decided by its thermal rating, while for medium transmission line its decided by voltage regulation and for

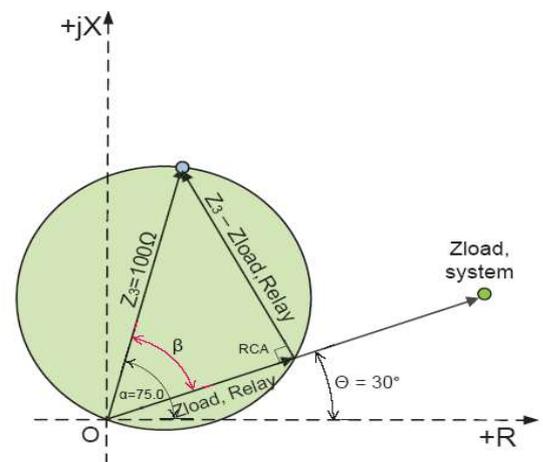
long transmission line load ability limit decided by steady state limit.

3. LOADABILITY LIMITATIONS

In some situations, however, the power load of the line is sufficiently large that it reduces the load impedance to a point which encroaches on the relay's characteristic shape. As a result, the distance relay identifies the encroachment as a fault and consequently trips the line out of service. This is a highly undesirable operation because a heavily loaded line has been taken out of service when no real fault exists.

It is important to note that there is a difference between lines loading and relay loadability. Permissible line loading is governed by thermal ratings of the conductor and terminal equipment, as well as voltage drop and stability criteria [4].

FIGURE 2: Calculating MVA pickup of rho element



For Calculating the distance relay maximum loadability limit following steps to be considered [6].

Draw the zone 3 impedance vector in the R-X diagram.

Draw the load impedance vector at a specified power factor, 30o shown in fig.2

Draw a right triangle forming the 90 ° relay characteristic between the load impedance

vector and the difference vector that is made up of Z3 – Zload. This is shown in fig.2

Calculate the interior angle β that is made between the load and line impedance vectors. This is done by subtracting the line impedance angle minus the power factor angle.

$$\angle\beta = \angle\alpha - \angle\theta \tag{1}$$

Calculate the load impedance that the relay will experience at the specified power factor using right triangle properties.

$$\cos\beta = \frac{Z_{load}}{Z_3} \tag{2}$$

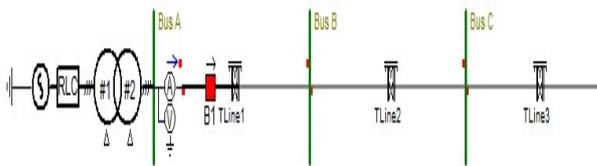
Calculate the maximum loadability of the relay in MVA

$$S_{relay} = \frac{kV_{LL}^2}{Z_{load}} \tag{3}$$

4. SIMULATED SYSTEM

In this paper three phase 230kV, 300 km, a single circuit transmission line is considered. Zone 1 cover 80km, zone 2 cover150 km, and zone 3 cover 220km of transmission line length. The various faults occur in 0.20 sec. The distance relay operates in zone 2 in 20 cycle delays and operates in zone 3 in 60 cycle delays. The system details are given in the Appendix.

FIGURE 3: Stimulated Systems

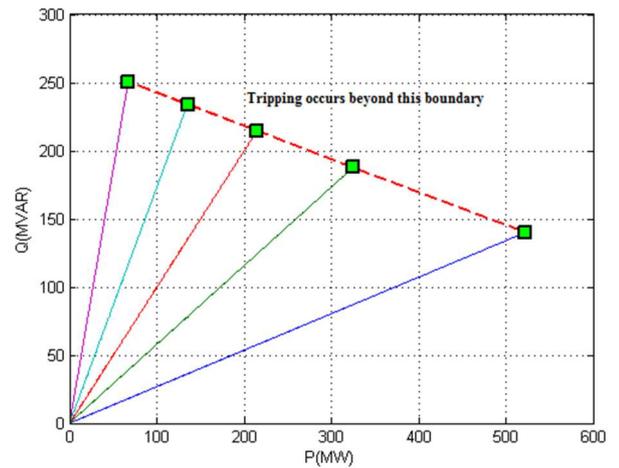


The three phase load connected at bus B and its value increased gradually to find relay maximum loadability limit for different power factor angle of load as shown below Table 1.

TABLE 1 Relay loadability for different power factor angle for Mho

Power Factor Angle	S(MVA/phase)	P(MW/phase)	Q(MVAR/phase)
0	630.46	630.46	0
15	541.04	522.60	140.03
30	375.80	325.45	187.89
45	303.77	214.79	214.79
60	270.37	135.18	234.14
75	259.53	67.16	250.68

FIGURE 4: P-Q diagram and loadability limit



The shown fig.4, which emphasizes the amount of real and reactive power needed to trip a line based on zone 3 settings at different power factor. It can be observed from Table 1 that for line, operating at unity power factor 630.46 MW/phase required.

4.1 Impact of MTA on relay loadability

The angle of maximum torque of distance relay using the mho characteristics is the angle at which it has the maximum reach. For microprocessor relays, the MTA is the same as the positive sequence line impedance angle. The

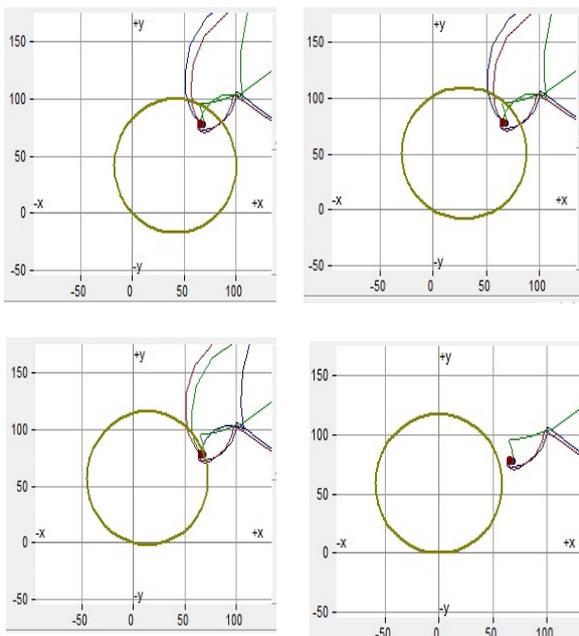
MTA or line impedance angle varies depending on the voltage level of the transmission line. For example, in the extra high voltage or EHV transmission lines, the angles are higher and for lower voltage transmission and sub-transmission systems, the angles tend to be lower because the ratio of reactance to resistance is usually lower [5].

Referencing the formula given in below [4], it can be shown that the percentage increase in MVA loading when going from a lower maximum torque angle to a higher torque angle is

$$\%increase = 100 * \left(\frac{\cos(MTA_{old} - loadangle)}{\cos(MTA_{new} - loadangle)} - 1 \right) \tag{4}$$

For seeing the impact of MTA on relay loadability if the load is increased above the 375.80 MVA/phase at power factor angle 30°, which is mention in Table 1 connected to the bus B, the distance relay will maloperate in zone 3. The results shown in below fig.5 relay loadability for different MTA. Results show that as the MTA of relay characteristics increase then relay loadability limit is increased.

FIGURE 5: Relay loadability (a) MTA 45° (b) MTA 60° (c) MTA 75° (d) MTA 90°



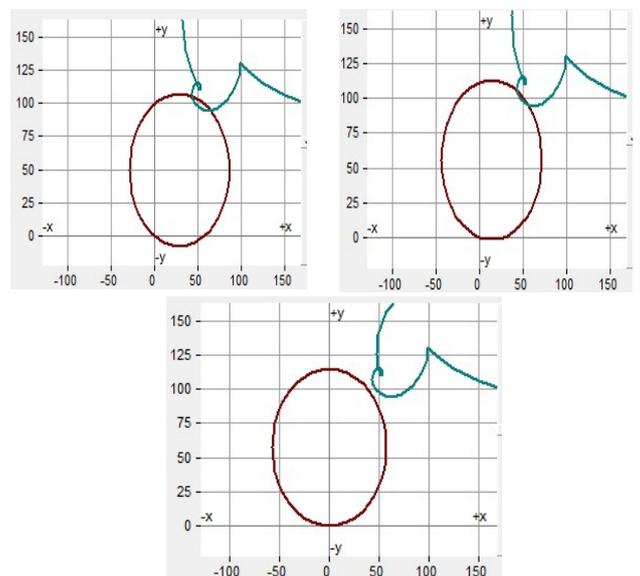
It can be shown in below Table 2. percentage MVA loading increase or decrease for different value of MTA. It can be found using the equation (4).

TABLE 2 Impact of MTA on relay loadability

MTA _{old}	MTA _{new}	% MVA increase	% MVA decrease
60°	30°	-	13.50
	45°	-	10.34
	75°	22.5	-
	90°	73.20	-

The reach of mho relay is affected in spite of the presence of fault resistance. Due to the effect of fault resistance distance relay will measure more impedance rather than actual. Therefore mho relay under reaches because of the fault resistance. The impact of MTA of relay characteristics also affect the fault resistance withstand. To demonstrate above case the single line to ground fault is created at 215km from the relay in zone 3 with the R_f 25 Ω at a different MTA.

FIGURE 6 :SLG fault with R_f 25 Ω (a) MTA 60° (b) MTA 75° (c) MTA 90°



It is clearly evident that for MTA 45° and fault resistance 49 Ω if the single line to ground faults occurs in zone 3 the distance relay will under reach. The fault resistance withstands with relay characteristics increases if MTA decrease shown in below Table 3.

TABLE 3 Fault resistance capability for different MTA with respect to MTA 60°

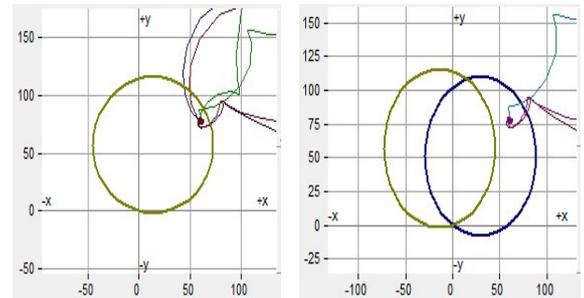
MTA old	MTA new	R _f (Ω)	% R _f increase	% R _f decrease
60°	45°	49	32	-
	75°	25	-	32.4
	90°	15	-	60

4.2 Lens Characteristics

The lens characteristic reduces the zone coverage and therefore increases the amount of permissible load. With a 'lens' characteristic, the aspect ratio of the lens (a/b) is adjustable, enabling it to be set to provide the maximum fault resistance coverage consistent with non-operation under maximum load transfer conditions. It is used for prevent the load encroachment condition which undesirable for distance relay. During the load encroachment condition distance relay will maloperate in zone 3. By using the lens characteristics the relay loadability limit increase and relay will not maloperate in zone 3. Lens characteristics are made by intersection of two mho circle.

In this paper to create the load encroachment condition for relay at substation A, the load at bus B is increased gradually. For 230 kV transmission line and for 30° power factor angle load if the load is increased 376 MVA/phase the distance relay will maloperate in zone 3 with mho characteristics but using lens characteristics relay will not maloperate because load impedance remain outside of intersection of two mho circle. Hence relay loadability limit increase as shown in below fig.7.

FIGURE 7: overloads condition (a) with mho (b) with lens



The relay loadability limit of different power factor angle of load using lens characteristics is given in below Table 4. It's show that relay loadability limit of lens characteristics is more than compare to mho characteristics.

TABLE 4 Relay loadability for dieerent power factor angle for lens

Power Factor Angle	S(MVA/phase)	P(MW/phase)	Q(MVAR/phase)
15	9634.6	9305	2493
30	951.45	823.97	475
45	518.88	366.91	366.91
60	325.46	162.73	281.85

5. CONCLUSION

The MHO and lens types of distance characteristics analyzed in the paper demonstrate that by properly selecting and setting the distance characteristics, the user can define an optimal protection element that will provide sufficient arc resistance coverage and at the same time eliminate the possibility for tripping under maximum dynamic load conditions. The simulation result show that lens characteristics are more useful for preventing

load encroachment phenomenon. This technical paper has presented the reader with valuable concepts on how to calculate the loadability limits of a distance relay. The impact of MTA on relay loadability is also described. With the increase in a MTA the relay loadability limit is increased but at the same time fault resistance coverage by the relay decrease.

APPENDIX

Parameter	Value	Unit
System Voltage	230	kV
Line Length (AB, BC, CD)	100	km
Line Positive Seq. Series Impedance	0.1236 + j0.5084	Ω/km
Line Zero Seq. Series Impedance	0.451 + j1.3277	Ω/km
Sources Positive Seq. Impedance	+ j18.28	Ω

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