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A Model of Distance Protection Relay

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Abstract—This paper presents a model of distance protection relay. It explains the principle of operation and discusses the two basic comparison techniques. A general expression consisting of the characteristics of mho, offset Mho and impedance types are derived. Tests and simulations performed on the model show satisfactory operation.

Keywords—Protection, operating signals, restraining signals, impedance, comparator.

I. INTRODUCTION

The distance protection relay is a protective relay which monitors the transmission line and operates to trip the circuit breaker when there is fault anywhere, no matter the distance, within (or sometimes beyond) the length of the line being protected.

The basic principle of the distance protection is based on the ohm's law: Z= V/I. Thus the line protection monitors the impedance of the line and becomes unstable when the line impedance is less than the pre-set value.

One form of the distance (line) protection can be seen to be analogous to a balanced beam relay shown in fig. 1

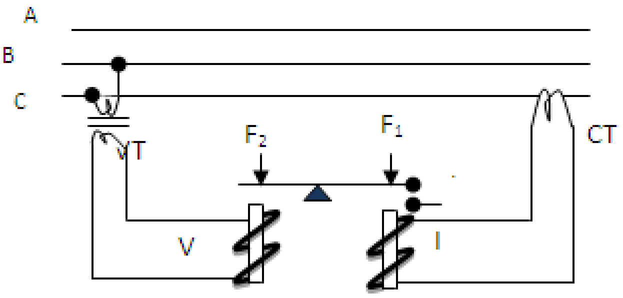


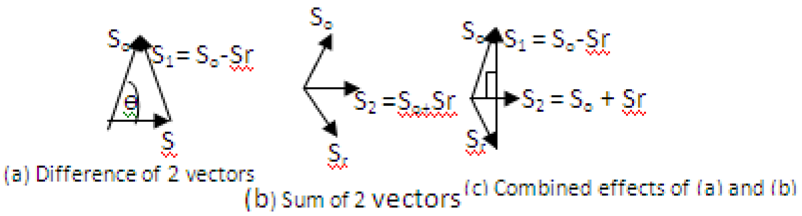
Fig 1: Balanced Beam Relay analogy of distance protection

In Fig1, C_1 is a current coil fed from a current transformer (CT). This coil produces the force F1 which tends to pull the end, A, of the beam down in other that the contact K, is closed. Coil C_2 when energized (from the VT) produces a counter force F_2 which tries to pull down the end, B, of the beam. Thus when both C_1 and C_2 are energized the beam remains stable and the contact, K remains open.

From these actions it can be seen that coil C_1 produces the operating signal, So, while coil C_2 produces the restraining signal, S_r. When there is short circuit, the current rises to increase the magnitude of F_1 and the voltage deepens to reduce the magnitude of $F_{2,}$ so that the balance is offset and the contact, K, closes to send a tripping signal to the circuit breaker.

1.1 Manipulation Of The Vectors S_o And S_r For Appropriate Action (Impedance Characristic)

The interaction between So and Sr can be analyzed using the vector diagrams of fig 2.



(a) Difference of 2 vectors
(b) Sum of 2 vectors
(c) Combined effects of (a) and (b)

Fig 2: (a), (b) and (c) Analysis of Vectors So and Sr

Fig 2(a) shows what can be regarded as the vectors of an amplitude comparator since the resultant, $S_{1,}$ is the difference of the amplitudes of the vectors So and Sr.

(b) Shows the vector sum of So and Sr while
(c) Shows the combined effects of (a) and (b). Fig2(c) can be regarded as the vectors of phase comparator at 90^0 criterion angle. When θ is $\pm 90^0$, the operation is marginal and at $\theta<90^0$, the restraint is removed and there is an output from the phase comparator. Thus the operation of an amplitude comparator can be equated to a $\pm 90^0$, criterion of a phase comparator as can be further seen in fig 3.
The inputs, S_1 and S_2, to the phase comparator are derived as follows:
$S_1=S_o-S_r$ (1)
$S_2=S_o+S_r$ (2)

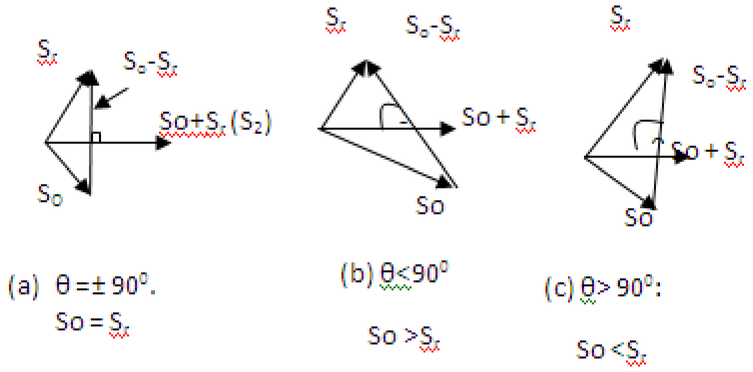


Fig 3: The three conditions: (a) So=Sr: Marginal operation
(b) $\theta<90^0$operation enabled
(c) $\theta > 90^0$ operation restrained

Referring to figs. 1 and 3 (a), since So= IZ (current converted to voltage) is fed from the CT and Sr=V (fed from the VT) are both the inputs of the amplitude Comparator. A t stable condition, $|IZ| = |V|$ (3)
(3) corresponds to the marginal operation of the amplitude comparator such that

$$\left.\begin{array}{l} S_1 = |IZ-V| \\ S_2 = |IZ+V| \end{array}\right\} \quad (4)$$

becomes the phase comparator input signals. Remembering that the criterion for operation is $\theta=\pm 90^0$ (Where θ is the angle between S_1 and S_2). See fig 2 (c)
Equation (3), for the amplitude comparator, can therefore be derived for the phase comparator as in eqn (4).

II. COMPARISON METHODS

2.1 Amplitude Comparison

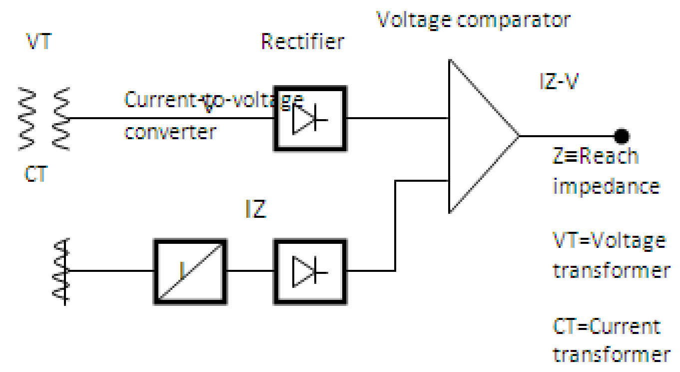


Fig 4: The Amplitude Comparator model

In Fig 4, the output of the comparator is IZ-V. Under stead state condition, $|IZ| = |V|$, eqn (3).
This assumes ideal condition. So eqn(3) can be modified to take care of conversion factors:

$$|A_1 IZ + C_1| = |A_2 V + C_2| \qquad (5)$$

where A_1,A_2,$C_1$and C_2 are factors.
Dividing eqn(5) by I

$$\left|A_1 Z + \frac{C_1}{I}\right| = \left|A_2 \frac{V}{1} + \frac{C_2}{I}\right| \qquad (6)$$

OR

$$= \left|K_2 Z + K_1 = K_4 Z' + K_3\right| \qquad (7)$$

Where: $A_1 = K_2$, $\frac{C_1}{I} = K_1$, $A_2 = K_4$, $\frac{V}{I} = Z'$ and $\frac{C_2}{I} = K_3$.

Now if $Z = Z'$
eqn(7) becomes

$$\left|K_1 + K_2 Z\right| = \left|K_3 + K_4 Z\right| \qquad (8)$$

Since $Z = R + jX$, eqn(8) becomes

$$\left|(K_1 + K_2(R + jX)\right| = \left|K_3 + K_4(R + jX)\right| \quad (9)$$

Then $\left|(K_1 + K_2R)^2 + (jK_2X)^2\right| = \left|(K_3 + K_4R)^2 + (jk_4X)^2\right|$

And $\left|(K_1 + K_2R)^2 + (jK_2X)^2\right| - \left|(K_3 + K_4R)^2 - (jk_4X)^2\right| = 0$. Implying that;

$$R^2 - X^2 + 2R\frac{(K_1K_2 - K_3K_4}{K_2^2 - K_4^2} + \frac{K_1^2 - K_3^2}{K_2^2 - K_4^2} = 0 \qquad (10)$$

Comparing (10) with the equation of a circle,

$$R^2 + X^2 + 2gR + 2hX + C = 0$$

Where;

$$g = \frac{K_1K_2 - K_3K_4}{K_2^2 - K_4^2},$$

$h = 0$ and $C = \frac{K_1^2 - K_3^2}{K_2^2 - K_4^2}$,

the characteristic is a circle on the R-X diagram

With center

$$\left(-\frac{g}{2} - \frac{h}{2}\right).$$

When $K_1 = K_3$, the radius = $\left(-\frac{g}{2}\right)$ and the circle passes through the origin.

When $K_1 \neq K_3$, the circle becomes an offset envelop.

$K_{1'} > K_3$, produces a positive offset while $K_1 < K_3$, produces negative offset as shown in figs 8(c) and (d) respectively.

2.2 Mho Phase Comparison

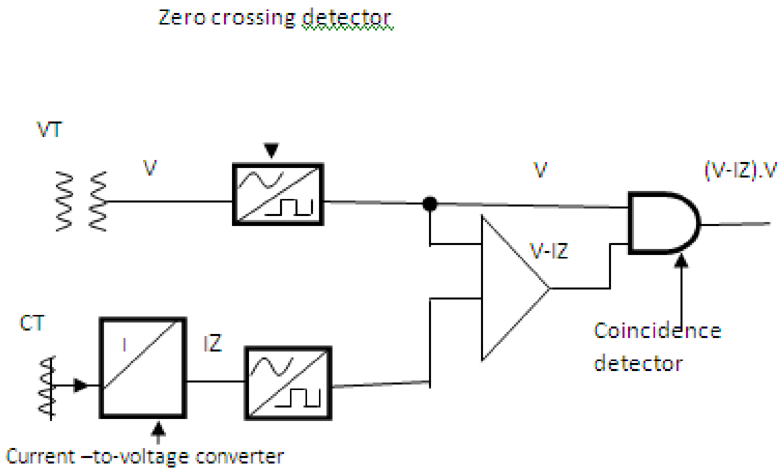
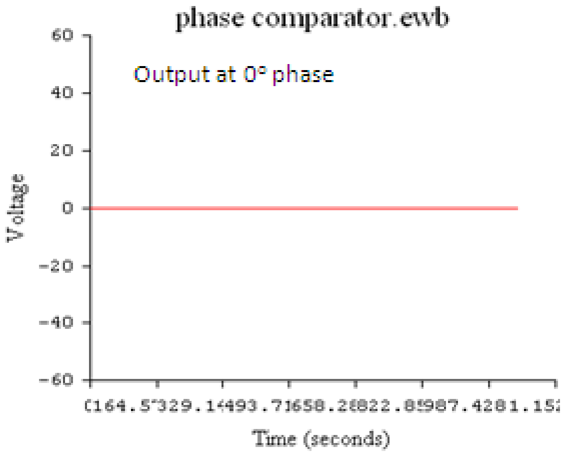
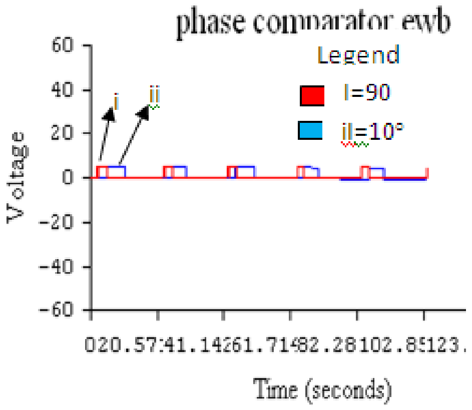


Fig 5: The basic Phase Comparator

One way of implementing phase comparator for MHO characteristic, is shown in fig.5. In this technique, the operating signal, So and the restraining signal, Sr, are fed into an AND gate used for coincidence detection. The width of the output signal from the coincidence detector is proportional to the phase difference of the input signals, So and Sr.



(a) 0^o Phase angle



(b) 10^o and 90^o Phase angles

Fig 6: Output of the coincident detector at different phase angles: (a) 0^o, 10^o and $90^{o.}$

This output signal |V|.|IZ-V| , can be fed into a shift register or an integrator. If a shift register is used, the output of the register can be used to trip a circuit breaker through a summing amplifier and a level detector. If an integrator is used, the output of the integrator can be fed straight to a level detector. The level detector can be set to correspond to any desired phase angle trip level. Figs 7a-d display the outputs of the phase comparator when the phase angle between So and Sr are 0,30, 45, 60,150, 210, 90and 120 degrees, respectively.

In fig 5, the inputs to the coincidence detector are K_1V_1-K_2IZ and K_3V

Where K_1, K_2 and K_3 are factors.

For stability;

$$|K_1V_1 - K_2IZ| = |K_3V| \qquad (11a)$$

Dividing (11a) by I

$$\left|\frac{K_1V - K_2Z}{I}\right| = \left|K_3\frac{V}{I}\right| \qquad (11b)$$

If $\frac{V}{I} = Z_K$,eqn (11b) becomes

$$|K_1Z_K - K_2Z| = |K_3Z_K| \qquad (11c)$$

Now if $K_1Z_k = Z$

$K_2Z= (Zr+Zo)/2$ and

$K_3Z_k= (Zr-Zo)/2$ then

eqn(11c) becomes

$$\left|Z - \frac{Zr+Zo}{2}\right| = \left|\frac{Zr-Zo}{2}\right| \qquad (12)$$

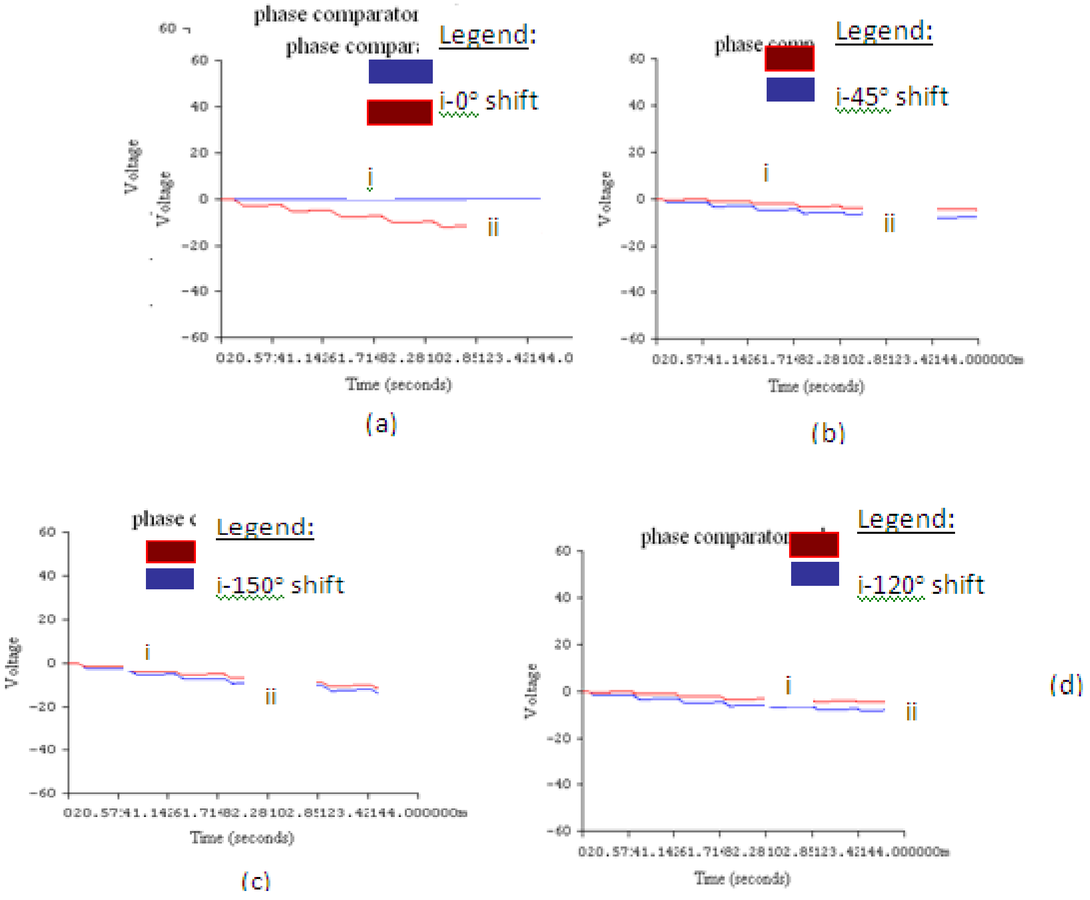


Fig 7. Outputs at various phase angles (a) 0^{o}& 30^{o} (b) 45^{o} &60^{o} (c) 150^{o}&210^{o} and (d) 120^{o}& 90^{o}

Now take Z= R±JX so that eqn(12) becomes

$$\left| R + jX - \frac{\left[(R_r + jX_r) + (R_o + jX_o) \right]}{2} \right| = \left| \frac{(R_r + jX_r) - (R_o + jX_o)}{2} \right| \equiv \left[R - \left(\frac{Rr + Ro}{2} \right) \right]^2 + \left[X - \left(\frac{Xr + Xo}{2} \right) \right]^2 = \left(\frac{Rr - Ro}{2} \right)^2 + \left(\frac{Xr - Xo}{2} \right)^2 \quad (13)$$

Rr, Ro, Xr and Xo are values for particular characteristics, hence eqn(13) can be written in a more generalized form as

$$(R - A)^2 + (X - B)^2 = C \quad (14)$$

Where A, B and C are given as follows:

$$\left. \begin{aligned} A &= \frac{Rr - Ro}{2} \\ B &= \frac{Xr + Xo}{2} \quad \text{and} \\ C &= \left(\frac{Rr - Ro}{2} \right)^2 + \left(\frac{Xr - Xo}{2} \right)^2 \end{aligned} \right\} \quad (15)$$

(13) is a general equation consisting of Mho, offset Mho, and impedance relay characteristics. Substituting the proper values of A, B and C, the appropriate characteristics can be derived.

When Ro=Xo= 0, the Mho characteristics is derived and shown in fig. 8a. Consequently, eqn(15) becomes;

$$\left. \begin{aligned} A &= \frac{Rr}{2} \\ B &= \frac{Xr}{2} \quad \text{and} \\ C &= \left(\frac{Rr}{2} \right)^2 + \left(\frac{Xr}{2} \right)^2 \end{aligned} \right\} \quad (16)$$

For a positive offset Mho characteristics, Ro=-Ro and Xo= -Xo. So that eqn(15) becomes

$$\left. \begin{aligned} A &= \frac{Rr + Ro}{2} \\ B &= \frac{Xr - Xo}{2} \\ C &= \left(\frac{Rr + Ro}{2} \right)^2 + \left(\frac{Xr + Xo}{2} \right)^2 \end{aligned} \right\} \quad (17)$$

For impedance characteristic, there is no displacement at the center of origin;

Ro=-Rr and Xo = -Xr in eqn(13), so that eqn(15) becomes

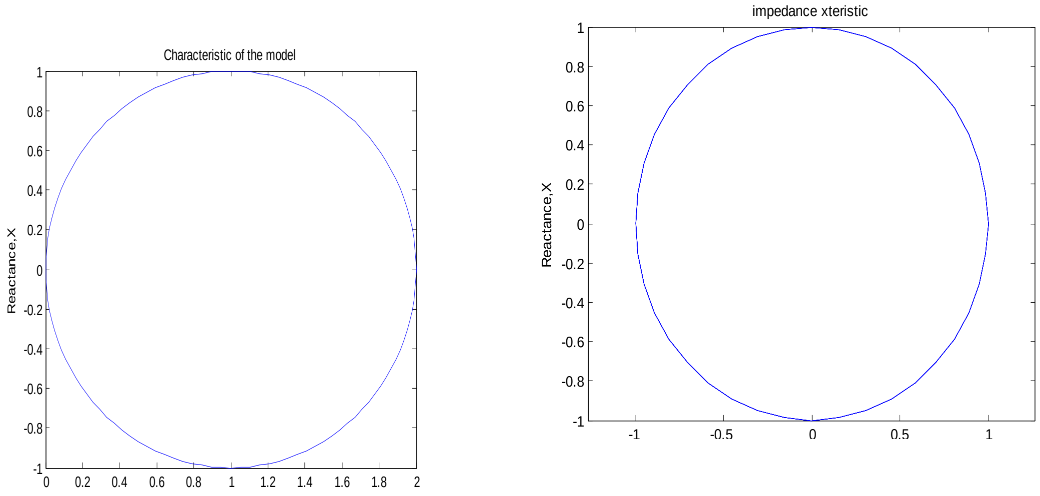
A=B=0 and

$$C = R_r^2 + X_r^2$$

Therefore, the criteria for operation of impedance relay becomes

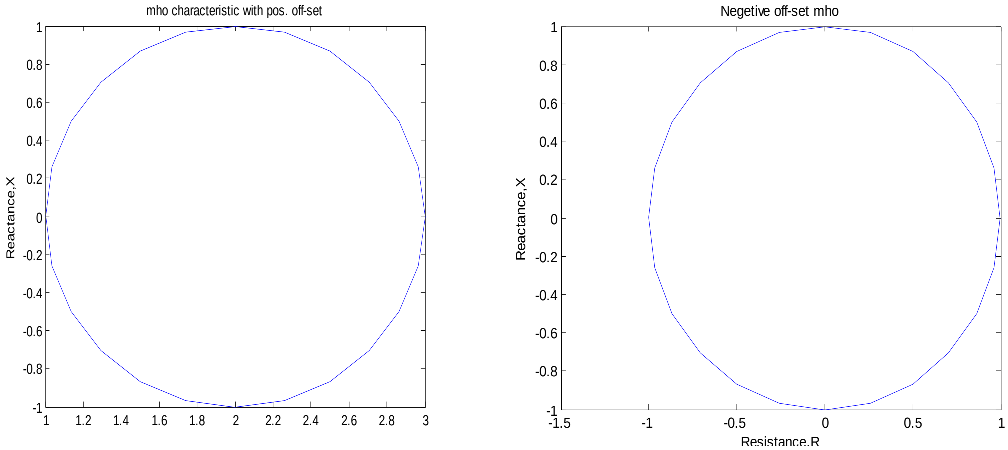
$$R^2 + X^2 \le R_r^2 + X_r^2 \quad (18)$$

Therefore a Mho, offset Mho and impedance characteristics can be realized with eqn (13) by substituting appropriate values of A,B, and C in eqn(15). See figs 8(a),(b),(c) and (d) for; mho relay, impedance relay, positive off-set mho and negative off-set mho relay characteristics, respectively.



(a)Mho characteristic

(b)Impedance characteristic



(C)Positive off-set mho

(d) Negative off-set mho

Fig8; Characteristics for (a) Mho relay (b) Impedance relay (c) and (d) +ve and –ve off-set mho respectively.

III. THE MHO REACH

The reach of a distance relay is the maximum length of the line it can protect effectively. The impedance of the line is usually quoted as

$Z = R + jX$ per Km

If Z^+ and Z^0 are the positive and zero sequence impedances, respectively, of the line per Km, then

$$Z = Z^+ + Z^0$$

So for a line of length, L Km, the primary impedance,

$$Z_p = ZL\Omega$$

The secondary impedance, Zs, of the line is

$$Zs_s = ZL\frac{CTR}{VTR}\Omega \qquad (19)$$

Where CTR = Current Transformer Ratio
VTR = Voltage Transformer Ratio
Zone I reach (80% of the line) setting = 0.8ZsΩ
Zone II reach (120%-125% of the line) setting = 1.25ZsΩ
Zone III reach (about 250% of the line) setting = 2.5ZsΩ and
Zone III negative offset (15%-20% of the line) setting ≈ 0.2ZsΩ (in the reverse direction).
These reach settings are at the discretion of the protection engineer.

IV. CONCLUSION

A model of the distance protection relay has been presented. There are two basic comparison techniques: Amplitude and phase techniques. In impedance measurement, the phase comparator can be equated to the amplitude comparator at $\underline{+}90^o$ phase difference between the input quantities. A general equation consisting of mho, impedance and offset mho characteristics were derived. Simulation results on the model indicate satisfactory operation.

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