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Distance Protection Scheme for Transmission Lines

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Abstract - This paper presents a protection scheme for transmission lines using the principle of distance relay. Even though many schemes exist for the protection of transmission lines, distance protection scheme is optimal due to its appealing features like directionality, reliability, selectivity etc. This paper evaluates the performance of distance relay in a specific zone for different types of faults at different points along the line for various fault resistances. The relay is designed using MATLAB/SIMULINK and the performance of the distance protection scheme is verified using the simulation results.
Index Terms- Distance protection, transmission line, MATLAB.

I. INTRODUCTION

Most high-voltage transmission systems are interconnected in a network system of circuit elements, usually of more than one voltage sources. The interconnection of many lines presents a new set of conditions on the coordination of protective devices, since the fault currents may flow to the fault point from both ends of any meshed line element. It was indeed necessary to protect the transmission lines against faults. Initially, the overcurrent relays were used for the protection of transmission lines and then their advanced level i.e.directonal overcurrent relays were used. Due to the complexity and some inadequacies of those relays, distance relay [1] become common in exisistence in the protection of transmission lines, since it is immune to these problems. In Section I the fundamentals of distance protection scheme is discussed. Section II provides the analysis and evaluation of the simulation of distance relay. Section III provides the results of the simulation for different types of faults with various fault resistances. Section IV provides the conclusion for this paper.

A. Working Principle of Distance Relay

The working principle of distance relay or impedance relay is best suited for the protection of transmission lines. There is one voltage element from potential transformer and an current element fed from current transformer of the system. The deflecting torque is produced by secondary current of CT and restoring torque is produced by voltage of potential transformer. In normal operating condition, restoring torque is greater than deflecting torque. Hence the relay will not operate. But in faulty condition, the current becomes quite large whereas the voltage becomes less. Consequently, deflecting torque becomes greater than restoring torque and dynamic parts of the relay starts moving which ultimately close the No contact of relay. Hence clearly operation or working principle of distance relay, depends upon the ratio of system voltage and current. As the ratio of voltage to current is nothing but impedance a distance relay can be also called as impedance relay.

The operation of such relay depends upon the predetermined value of voltage to current ratio. This ratio is nothing but impedance. The relay will only operate when this voltage to current ratio becomes less than its predetermined value. Hence, it can be said that the relay will only operate when the impedance of the transmission line becomes less than predetermined impedance (voltage / current). As the impedance of a transmission line is directly proportional to its length, it can be concluded that the distance relay can only operate if fault is occurred within a predetermined distance or length of line.

The relay compare the secondary values of V and I, as to measure their ratio which is an impedance Z_m,

$$Z_m = Z_f * C.T.ratio \big/ V.T.ratio$$

Z_m is the measured impedance called secondary impedance.

B. Zones of Protection

The simulated distance relay can be evaluated by a number of performance characteristics incorporated by the zones polarised mho etc. In this paper the distance relay is evaluated using the mho characteristic with corresponding zones of protection [5] which is shown in the figure 1.

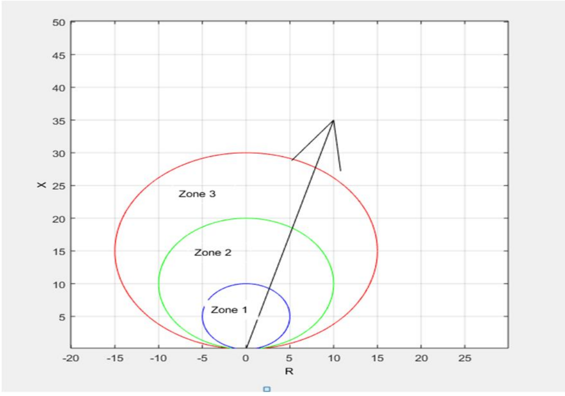

Fig. 1. Zones of protection

Numerical distance relays usually have a reach setting of up to 85% of the protected line impedance for instantaneous Zone 1 protection. The resulting 15% safety margin ensures that there is no risk of the Zone 1 protection over-reaching the protected line due to errors in the current and voltage transformers, inaccuracies in line impedance data provided for setting purposes and errors of relay setting and measurement of the distance protection must cover the remaining 15% of the line.

The reach setting of the Zone 2 protection should be at least 120% of the protected line impedance. In many applications it is common practice to set the Zone 2 reach to be equal to the protected line section +50% of the shortest adjacent line. Zone 3 reach should be set to at least 1.2 times the impedance presented to the relay for a fault at the remote end of the second line section. In this paper the relay performance is evaluated in zone 1 for different faults.

C. Fault Calculation Algorithms

The fault calculation algorithm used depends on the type of the fault that occurs. The line to line (LL) fault, double line to ground (DLG) fault and single line to ground (SLG) fault are classified as unsymmetrical faults. Three phase fault is the only symmetrical fault where all phases are in contact with each other. The distance Relay will first determine the type of fault with the help of a fault current magnitude detection algorithm. After that, the corresponding formula is used for fault impedance calculation.

Table I Fault impedance calculation formulae for different faults

Fault Type	ALGORITHM
AG	$\frac{V_A}{(I_A + 3K_0 I_0)}$
BG	$\frac{V_B}{(I_B + 3K_0 I_0)}$
CG	$\frac{V_C}{(I_C + 3K_0 I_0)}$
AB or ABG	$\frac{(V_A - V_B)}{(I_A - I_B)}$
BC or BCG	$\frac{(V_B - V_C)}{(I_B - I_C)}$
CA or CAG	$\frac{(V_C - V_A)}{(I_C - I_A)}$

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Where,
A, B and C indicates faulty phases
G indicates ground fault
$V_{A,}V_{B}$ and V_{C} indicates voltage phasors
$I_{A,}I_{B}$ and I_{C} indicate current phasors
Z_{0} =Line Zero-Sequence impedance
Z_{1} = Line positive-Sequence impedance
K_{0} =residual compensation factor where

$$K_{0} = \frac{(Z_{0} - Z_{1})}{KZ_{1}}$$

K can be 1 or 3 depend on the relay design

II. SIMULATION

A. Test System

The test system is designed using MATLAB/SIMULINK. The test system is formed by the components from SimPowerSystems toolbox [3]. The test system is fed with voltages and currents from both ends of the transmission line. Each phase is provided with a separate measurement and filtering block for current and voltage. The filtering is done by the components in the subsystem of the distance relay. The system parameters are as shown in the table II. The transmission line is chosen as three phase pi section model. The fault is created in the transmission line. And the distance relay is tested for different conditions. The relay setting is computed in the embedded MATLAB function for each phase separately .The single line diagram for the test system is shown in the figure 2.

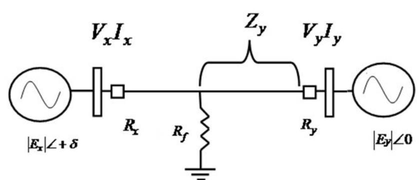

Fig. 2. Single line diagram of the test system

The simulation model for the test system is shown in the figure 3.

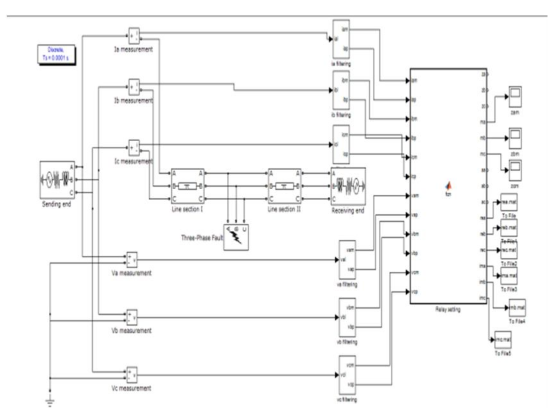

Fig .3. Simulation model of the test system

B. Development Of The Distance Relay

The numerical distance relay can process only the digital data. Hence it is necessary for an analog to digital conversion. And also it is necessary to filter the harmonic components to allow only the fundamental components. This is carried out by the filtering block

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in each phase separately for current and voltage [2].The filtering components are analog filter which is set with four times the fundamental frequency. The sample and hold circuit and quantizer is used to obtain the digital output. After which the digital filter and discrete Fourier transform is used to filter out the decaying offset DC components. Then the magnitude and phase is plotted for each phase. And ratio of voltage to current i.e. impedance is calculated in the embedded MATLAB function based on this magnitude and phase of current and voltage of each phase. The developed distance relay is shown in the figure 4.

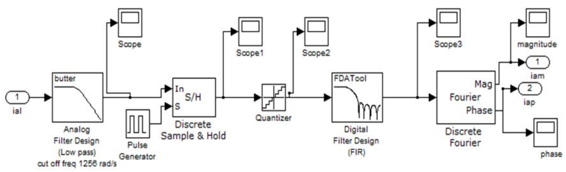

Fig .4. Developed distance relay model

Table II. Simulated system data

PARAMETERS	VALUE
System Voltage	500 kV
System frequency	50 Hz
Line length	100 km
Line positive sequence series impedance	0.0185+j0.3766 Ω/km
Line zero sequence series impedance	0.3618+j1.2277 Ω/km
Source positive sequence series impedance	1.43+j16.21 Ω
Source zero sequence series impedance	3.068+j28.746 Ω

III. RESULTS AND DISCUSSIONS

Thus the distance protection scheme for different types of fault at various fault points for different fault resistances is simulated and the results for the same are discussed below. Figure 5 and 6 shows the current waveform and voltage waveform of the test system for the faulted phase. As discussed in section I, figure 7 shows the R-X plot with single protection zone for different types of faults at various fault points.

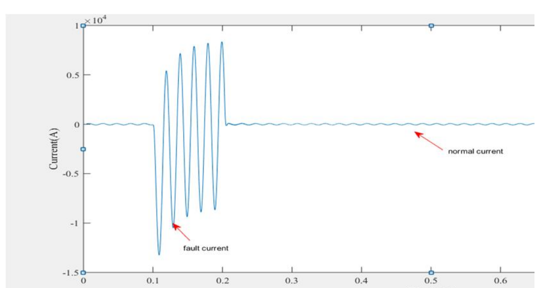

Fig. 5 Current waveform of the test system

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Figure 5 shows the current waveform which indicates, during the normal operating condition the system is stable. But when fault occurs there is a sudden rise in the line current.

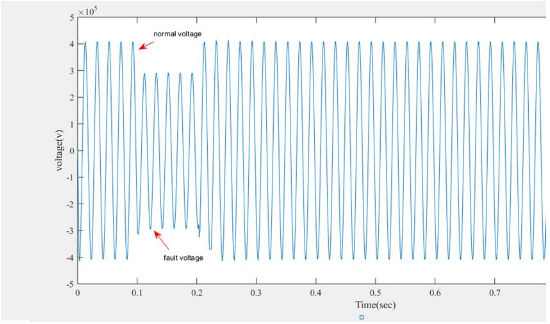

Fig .6. Voltage waveform of the test system

Figure 6 shows the voltage waveform which indicates, during the normal operating condition the system is stable. But when fault occurs there is a dip in the system voltage. So in order to protect the system during fault period distance protection scheme is used

A. R-X Plot For Single Line To Ground Fault

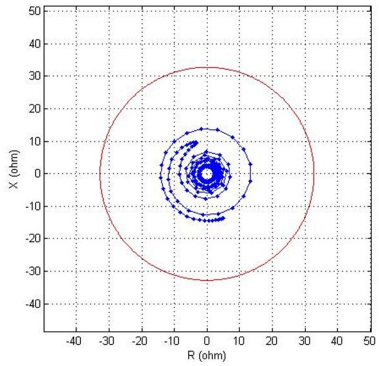

Fig.7.A.1 R_f = 5 ohm at 50 km

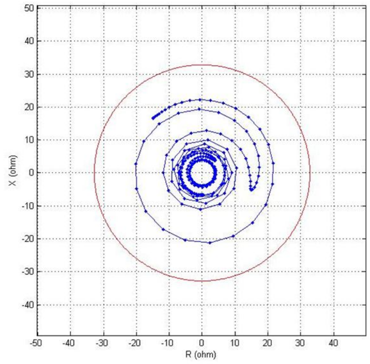

Fig.7.A.2 R_f = 10 ohm at 80 km

In the figure 7.A, the red zone from the above plot shows the zone of protection and the fault points are represented using blue lines. Since the fault points lies within the zone of protection, we could conclude that for single line to ground fault the proposed distance

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protection scheme serves its purpose.

B. R-X Plot For Line To Line Fault

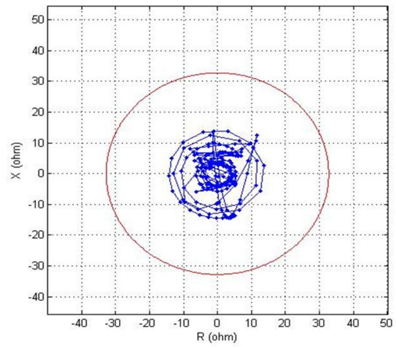

Fig.7.B.1 R_f = 5 ohm at 50 km

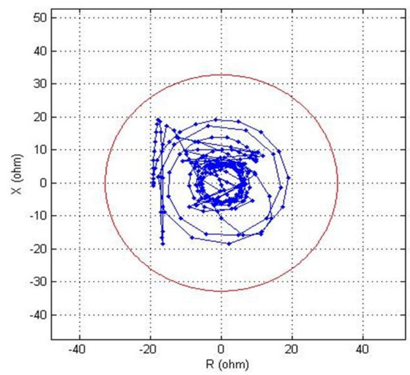

Fig 7.B.2 R_f = 10 ohm at 80 km

Figure 7.B shows the R-X diagram for line to line fault with fault resistance of 5 ohm and 10 ohm at 50 km and 80 km respectively. Since the fault points lies within the protection zone we can say that the suitable protection is provided by the relay.

In order to check the efficiency and reliability of the relay the fault point and fault resistance is varied and the performance of the relay is examined. After performing the simulations the results shows that even after varying the fault point and fault resistance the proposed scheme provides the necessary protection in zone 1.

C. R-X Plot For Double Line To Ground Fault

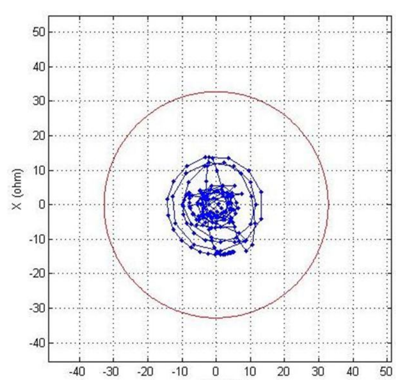

Fig 7.C.1 R_f = 5 ohm at 50 km

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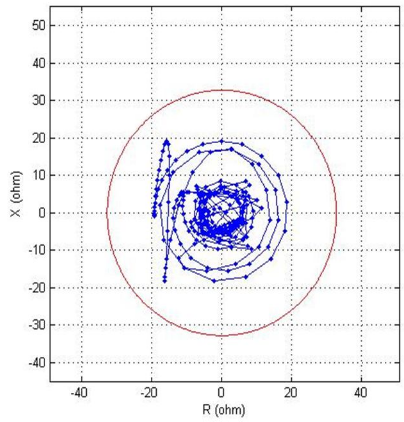

Fig.7.C.2 R_f = 10 ohm at 80 km

From figure 7.C we can observe that the distance protection scheme modeled provides protection for double line to ground fault also.

D. R-X Plot For Three Phase Fault

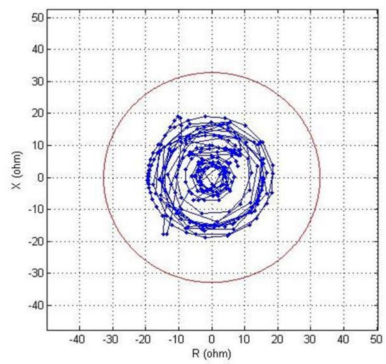

Fig 7.D.1 R_f = 5 ohm at 50 km

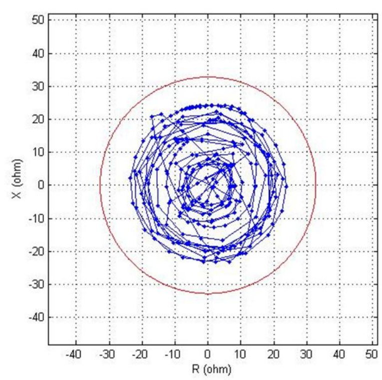

Fig 7.D.1 R_f = 10 ohm at 50 km

Thus performing similar analysis to three phase fault as we did for the previous faults, we obtain a result similar to the above faults. That is even after varying fault resistances at different fault points the relay provides the desirable protection without any

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discrepancies.

So we could conclude that the proposed distance protection scheme provides protection to all kinds of faults indicating the performance of the relay.

In this paper the simulation results are provided for zone 1 of protection alone, this protection is done instantaneously. For zone 2 and zone 3 the protection is done after a time delay. And also it can be justified that relay protection is comparably high for lesser fault resistance to higher fault resistance. And it is similar for fault points also the relay protection is comparably higher for shorter distances compared to higher distances.

IV. CONCLUSION

This paper presents the distance protection scheme for transmission lines. The numerical distance relay was modeled in such a way that it operates only at the fundamental by incorporating the filtering components. The relay setting is programmed using MATLAB/SIMULINK. The robustness of the relay is tested for different types of faults with different fault resistance and distance of the fault occurrence and satisfactory results are obtained.

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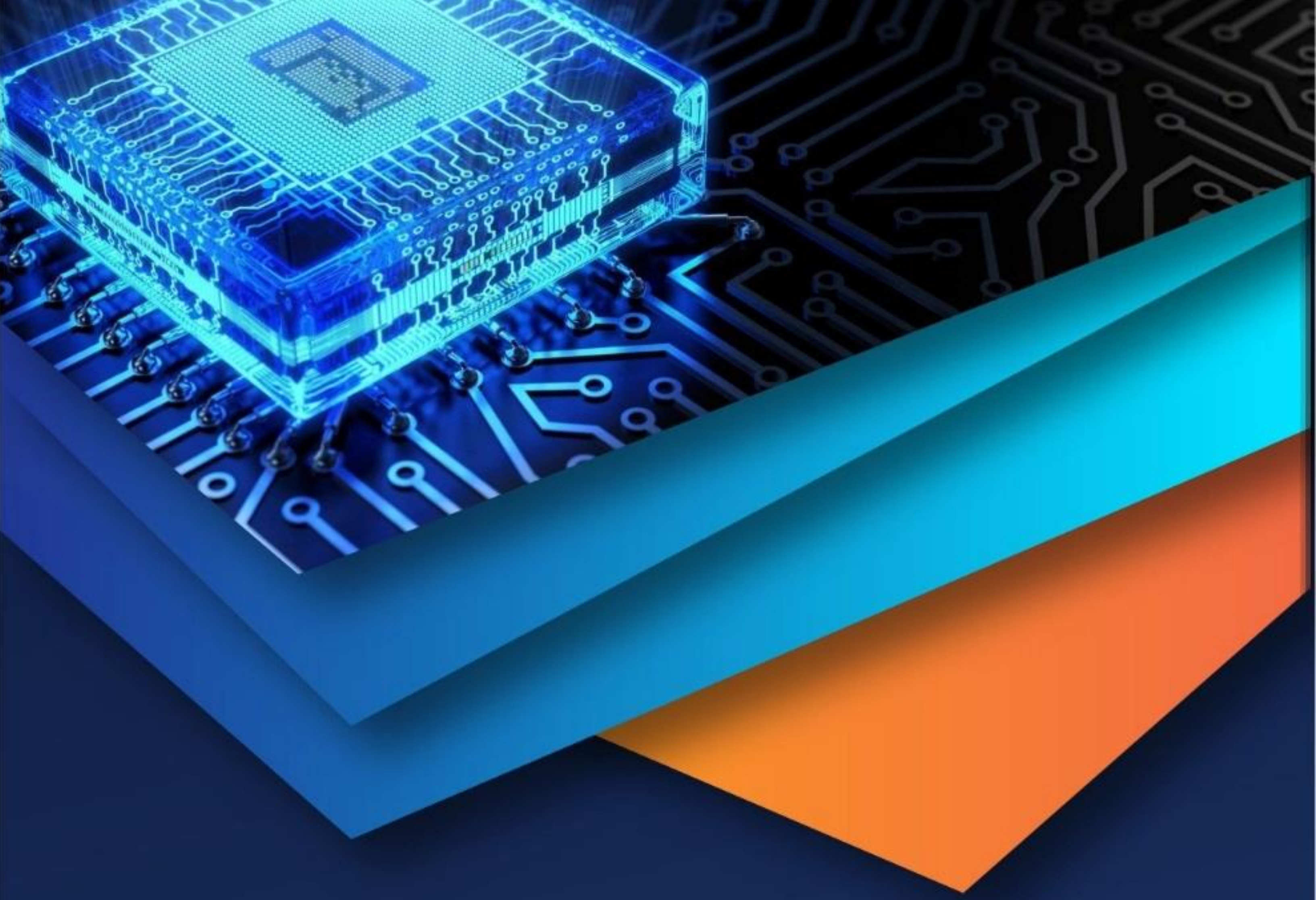

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