Modelling of Distance Relays in EMTP

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Abstract - Distance relays are widely used for the protection of transmission lines. They respond to the impedance between the relay location and the fault location. As the impedance per kilometre of a transmission line is fairly constant, these relays respond to the distance to a fault on the transmission line. In a power system network, when a short circuit fault occurs on a transmission line, the distance relays protecting the line trip the circuit breakers at either end of the line and disconnect the line from the network. To study the behavior of a distance relay during a short circuit fault it is necessary to accurately model the dynamic behavior of the distance relay and then inject into the model, the voltage and the current signals seen by the relay during the fault.

The distance relays were modelled using MODELS language available in EMTP-ATP and also the voltage and the current signals can be obtained from power system transient simulator in this case also from EMTP-ATP. The algorithm used in the distance relays is based on the calculation of the voltage and the current phasors using the discrete Fourier transform (DFT). The model includes quadrilateral and polarized mho distance relays. The former is widely used in mainland Europe and the latter in the UK and the USA.

This paper describes how to model the dynamic behaviour of a quadrilateral or polarized mho distance relay using EMTP. To implement the swivelling behaviour of the dynamic expansion of the polarized mho, it is necessary to calculate the source impedance at each voltage and current sample is acquired and to change the operating characteristic in terms of the source/line impedance ratio.

This paper concludes with the example of how the distance relay performs when evaluating the voltage and current signals due to a fault located at various point on the network. The test network used in this paper is based on the IEEE-14bus system. This paper also describes the benefits achieved when using distance relays model within the EMTP-ATP power system transients simulator. The author believes that the computer simulation of relays will be increasingly used to evaluate relay performance and hopes that manufacturers will provide the parameters necessary to allow their relays to be accurately modelled.

Keywords: Modelling, EMTP, Transients, Transmission Line, Distance Relay, Protection

I. INTRODUCTION

Distance relays effectively measure the impedance between the relay location and the fault. If the impedance of the fault is low, the impedance is proportional to the distance from the relay to the fault. A distance relay is designed to only operate for faults occurring between the relay location and the selected reach point and remain stable for all faults outside this region or zone. In a time stepped distance scheme this ensures adequate discrimination for faults that may occur between different line sections. The basic principle used to measure the impedance involves the comparison of the local current with the local voltage. Where "local" refers to the signals measured at the relay location. For a fault at the remote end of the line, the voltage at the local relay equals the current multiplied by the impedance of the line, i.e. IZ. Therefore, the ratio of the voltage to the current measured at the relay equals the impedance of the line, Z. Since V/I is proportional to the line length between the relay and the fault, V/I is a measure of the impedance to the fault. However, the impedance of a feeder is related to its length so that if the impedance per unit length of a feeder is known the protection can in effect measure the distance to the fault.

The distance relay simulator described in this paper has been implemented using MODELS language in EMTP-ATP. The algorithm used in the distance relay is based on the calculation of the voltage and the current phasors using a full cycle Fourier algorithm, since it used in the majority of commercial digital distance relays. The model includes quadrilateral and polarized mho distance relays.

The IEEE-14 bus system test network was used in this paper and also the results of how the distance relay model performs when tested. The author believes that the computer simulation of relays will be increasingly used to evaluate relay performance and hopes that manufacturers will provide the parameters necessary to allow their relays to be accurately modelled.

II. CHARACTERISTICS

The majority of digital distance relays incorporate distance elements based on one or more of the following operating characteristics : (a) impedance relays (b) admittance or mho relays (c) reactance relays and (d) quadrilateral relays. These characteristics are recognised by protection engineers according to the shape of the operating zone. This paper will concentrate on simulating relays based on either mho or quadrilateral characteristics.

In the UK and the USA mho characteristic distance relays are widely used. The mho relay combines the main features of the impedance and directional relays. The mho characteristic is shown in Figure 1, The relay is inherently directional and will operate only for faults in the forward direction. The characteristic is adjusted by setting Z_R, the impedance reach along the diameter of the circle and θ the angle of displacement of the diameter from the R-axis, as shown in Figure 1. The angle θ is known as the relay characteristic angle. The mho distance relay operates for fault impedances Z_F that lie within this characteristic. A disadvantage of the mho (self-polarized) relay is that it has limited coverage of arc or fault resistance. The problem is aggravated in the case of short lines, since the required zone-one ohmic setting is low and the amount of the R axis covered by the mho circle is small relative to the expected values of arc resistance. This problem can usually be overcome by using quadrilateral or cross-polarized mho relays for the detection of earth faults.

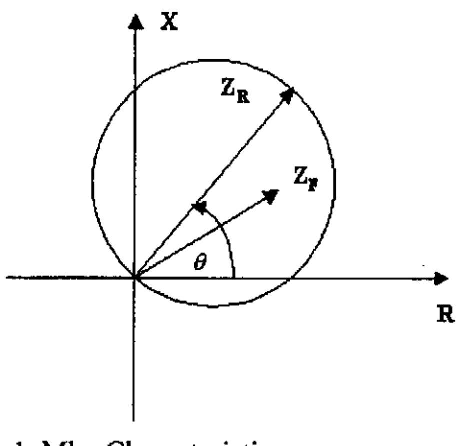


Fig. 1. Mho Characteristic

III. CROSS-POLARIZED MHO

As described earlier, a disadvantage of the self-polarized mho characteristic when applied to short overhead circuits is that it has limited coverage of arc or fault resistance. The optimum performance is

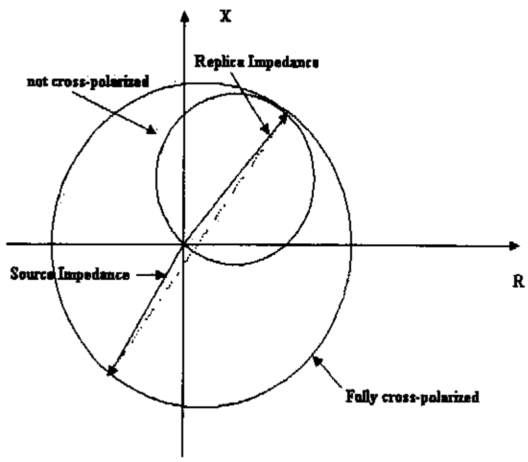


Fig. 2. Cross-Polarized Mho

obtained if a relay could adjust its characteristic to suit the length of the line i.e. if it could open out its circular characteristic along the R axis when applied to a short lines. In practise this can be achieved by changing the characteristic in accordance with the source/line impedance ratio (Z_S/Z_L) as shown in Figure 2. If the line is short and the source impedance is high, i.e. a weak source, the fault resistance coverage is high. However, if the source impedance is low, i.e. a strong source, the fault resistance coverage is low.

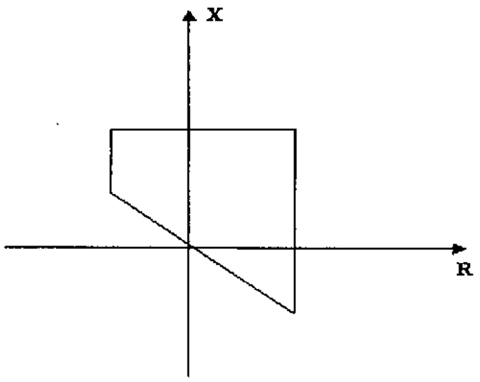
The fully cross-polarized mho characteristic can be obtained by calculating the equivalent impedance behind the relay location, i.e. the source impedance Z_S :-

$$Z_S = \frac{Vprefault - Vpostfault}{Iprefault - Ipostfault}$$

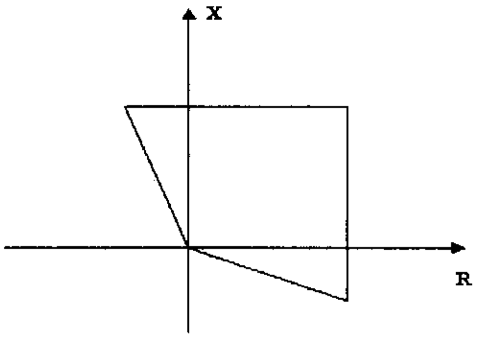
After the calculation of the source impedance the fully cross-polarized mho can be formed by adding the vector of the source impedance to the vector replica line impedance. The resulting vector and the associated fully cross-polarized circle are shown in Figure 2. In some situations the fully cross-polarized characteristic provides too much resistance coverage which results in maloperation of the elements protecting the healthy phase. One way to overcome this, is to use a partially cross-polarized characteristic. The partially cross-polarized mho characteristic is frequently used as a compromise between the excellent phase selection of the self-polarized mho and the superior arc resistance coverage and directional response of the fully cross-polarized mho [1]. For example the GEC Alsthom 'Micromho' and 'Quadramho' distance relays both use a partially cross-polarized mho shield-shaped characteristic with 16 percent square-wave polarization [1]. In this paper the distance relay uses a 50 percent partially cross-polarized mho characteristic. The 50 percent partially cross-polarized mho is obtained by multiplying the magnitude of the vector of source impedance with a factor p/(1+p) where p is equal to 50 percent in this case. The resulting vector is used to form a partially cross-polarized mho circle.

IV. QUADRILATERAL

The reactance relay has been generally superceded by relays with quadrilateral characteristic which combine the advantages of the reactance relay with directional and resistive reach control characteristics. This permits higher values of fault resistance to be covered. Quadrilateral characteristics are ideal for earth fault protection on lines of short to medium length where a high degree of tolerance to fault resistance is required. The shape of the quadrilateral distance characteristic included within this paper is based on either the operating characteristics of the SIEMENS 7SA502 or the 7SA513 digital line protection relays, these are shown in Figure 3.



(a) 7SA502



(b) 7SA513

Fig. 3. Quadrilateral

V. MODELLING OF DISTANCE RELAYS

The distance relay simulator described in this paper has been implemented using EMTP-ATP. The algorithm used in the simulated distance relay is based on the calculation of the voltage and the current phasors using the full-cycle Fourier algorithm [2]. Algorithms used to model the distance relay are usually based on either the full-cycle Fourier algorithm, a Fourier algorithm with a shortened window, a differential-equation algorithm, or a least-squares fitting algorithm. The Fourier algorithm was selected since it used in many commercial digital distance relays. The details of a Fourier algorithm can be accessed from many books and papers such as [3,4], therefore it will not included in this paper.

VI. MODELS LANGUAGE IN EMTP-ATP

Models is a general purpose description language supported by a set of simulation tools for the representation and study of time variant systems. The MODELS language Provides a format which focuses on the description of the structure of a model and on the function of its elements. A system can be described in MODELS as an agreement of inter-related submodels, independent from one another in their internal description and in the simulation [5]. A model written in the MODELS language includes declarations, simulation directives and operation procedure. Over the course of a simulation, the state of a model is updated at successive instants of time every time the model is called for execution by the environment in which it is used. The size of the time interval between two successive instants of execution of a model is referred to as the simulation time step of the model.

VII. TESTING NETWORK

The testing network is shown in Figure 4. This network is based on the IEEE-14 bus system[6].

However, some of the parameters have been modified to suit this study. For example, a parallel line replaces the single line between busbar-A and busbar-B and there is no transformer in the system since this study concentrates on the transmission line protection.

Although many types and location of faults have been simulated on the first network. This paper only considers the six locations shown in Figure 4. Attach location, three types of fault, single-phase to earth, phase-phase, three-phase fault, have been simulated. For each type of fault the voltage and current data samples are extracted and feeding to the distance relay model within EMTP-ATP. The distance relays at each location will analyse the fault according to their settings. The distance relays which closes to the fault then active in either zone one or two then send the signal to the switch to open the circuit.

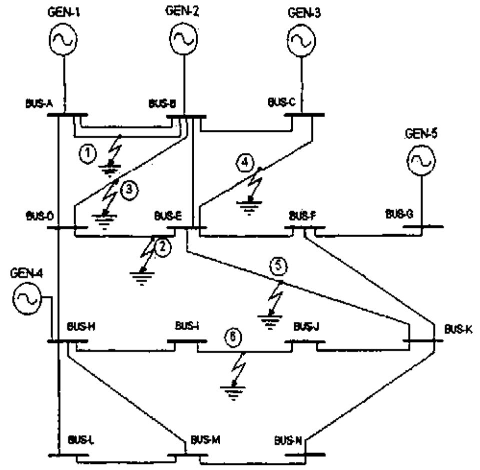


Fig. 4. Testing Network

VIII. TRANSMISSION LINE MODELS

In EMTP-ATP, users can define uncoupled lumped, mutually-coupled lumped and distributed parameter transmission line models. The model used in this study is the transposed line distributed parameter Clarke model. The Clarke model can be further subdivided into distortionless models, lumped resistance models and exact PI models. The lumped resistance models has been used in this paper. This model is one of the most common representation used by Bonneville Power Administration (BPA) [7]. A lossy line with series resistance R'and negligible shunt conductance G' is modelled as two equal length lossless lines section with lumped resistances of R'/4 at both ends and R'/2 in the middle see Figure 5.

The transmission line configuration is shown in Figure 6. This corresponds to a 400 KV three-phase, single circuit with two conductor/phase-bundle for each phase [8]. Each phase conductor is tubular with T/D = 0.231, DC resistance = 0.0522 ohms/km and outside diameter D = 3.18 cm. The ground wire are solid with T/D = 0.5, DC resistance = 0.36 ohms/km and outside diameter D = 1.46 cm, where T = thickness of tubular conductor and D = outside diameter of tubular conductor. The earth resistivity equals 100 ohm-meter and all line data is specified at 50 Hz, fundamental frequency. All of this data is required by the Clarke model to calculate the parameter of the transmission line.

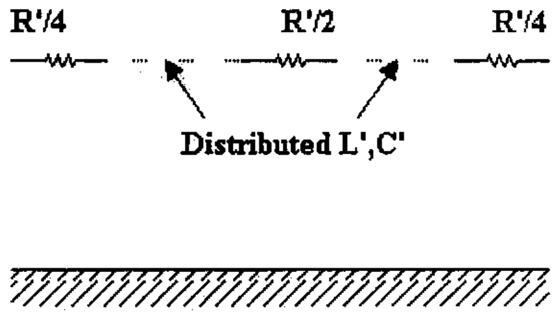


Fig. 5. Lumped Resistance Line Modelling

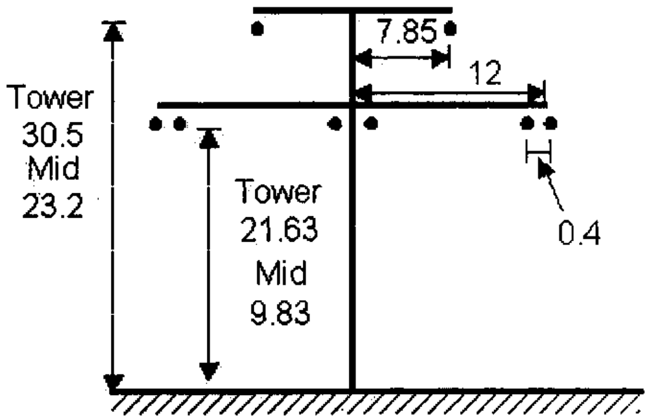


Fig. 6. Transmission Line Configuration

IX. RESULTS

The test network shown in Figure 4, contains 42 relays. All the voltages and currents at each location are extracted and feeding into the distance relay model. In this test all distance relays operate in the conventional three-zone time stepped settings. At location 1, a single-phase to earth fault occurred 10 percent from busbar-A on the line between busbar-A and busbar-B on circuit 2. Relay-3 operated in zone-one, relay-4 in zone-two, relay-2 in zone-two and relay-6,8,10,12 in zone-three. In this case, relay-3 able to send the trip signal to the circuit breaker within one-and-a-half cycle and relay-4 a little later as shown in Figure 4. More results are shown in Table 1.

X. CONCLUSIONS

The distance relay model using MODELS in EMTP-ATP can be used as a training tool to help users understand how the relay works. The distance relay model offers an inexpensive alternative to evaluating a relay on a test set and generally will involve significantly less time and effort. A major benefit to an electrical utility is that when a protection scheme on the network maloperates or behaves in a manner that is difficult to understand, a model of the protection can be tested in the laboratory using data recorded on site during the incident or using data generated by a power system simulator. In addition when new system configurations are proposed, the impact of these changes on the protection can be analyzed. This model also improve the simple mho distance relay model by introduce the cross-polarized mho model. This dynamic expansion of the cross-polarized mho achieved by calculating the source impedance as mentioned in the paper and it shows to be better than simple mho in the case of short distance transmission line.

The author believes that computer simulation of relays is increasingly used to evaluate relay performance and hope that manufacturers will provide the parameter necessary to allow their relays to be accurately modelled. When relay models are available to the users, the number of application and performance related questions that need to be answered by manufacturers will be reduced.

XI. ACKNOWLEDGEMENTS

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Table 1

Location	Type of Fault	Relay Response
2, 10%from E	Phase-earth	Ed-z1, De, Be, Ce, Fe-z2 and some in z3
3, 10%from D	Phase-earth	Db-z1, Bd,Ed,Hd,Ad-z2 and some in z3
4, 10%from E	Phase-earth	Ec-z1, Ce, Be,De,Fe, Ke-z2 and some in z3
5, 10%from K	3-phase	Ke-z1, Ek,Jk,Nk,Fk-z2 and some in z3
6, 10%from I	3-phase	Ij-z1, Ji,Hi-z2 and some in z3