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Original Article

Analysis of Distance Protection Scheme for Detecting HIF and Various Faults in Power System

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Abstract - *This paper explains the operation of distance relays. The primary protection used in transmission lines is the distance protection scheme. Whenever a symmetrical or unsymmetrical fault occurs in the transmission line, the distance relay operates if the fault occurs within the designed range of the relay. The range of distance relay varies according to the type of fault that occurred in the line. The model has been made using MATLAB/Simulink. In this article we are using FFT analysis to increase the operating speed of the distance relay in MATLAB. The use of the Butterworth filter increases the response of distance relays by ten times. By using the Butterworth filter, the fundamental components of the signals are extracted. Additionally, a precise method for High Impedance Fault (HIF) detection in a power distribution network is suggested in this research. HIF is a major problem in power systems because of their low fault currents and intermittent nature. Traditional protection schemes often struggle to detect these faults accurately, leading to potential safety hazards and power system instability. This paper presents the methodology, experimental setup, and results of our investigation into the application of HIF faults and other faults in a system along with distance relays.*

Keywords - *Butterworth filter, Distance relay, FFT, HIF, MATLAB.*

1. Introduction

A distance relay is a double-actuating quantity relay in which current and voltage are used to activate separate coils. Relays function when the impedance they detect is lower than a certain value. When a transmission line malfunctions, the voltage at the fault decreases to zero and the fault current increases. The observed value increases with increasing fault distance and decreases with increasing fault proximity. The distance between the relaying point and the fault location is, therefore, equal to the value of V/I measured from the relay point.

Therefore, this type of defense is known as distance relay. The reach of the relay depends upon source impedance Z_S and source voltage E_f. So Overcurrent relay is not suitable for transmission line protection as the reach of the relay is not fixed; it changes as per the parameter. The current depends upon the type of fault and length of the line that is protected. So, it is not fixed; therefore reach of the relay is different for different faults.

Various types of faults occur in transmission lines, i.e. symmetrical, unsymmetrical faults and high impedance faults, as shown in Figure 1. In this paper behavior of distance protection schemes for different faults is analyzed.

1.1. Faults in Transmission Line

1.1.1. Series (Open Conductor Fault)

- One Open conductor
- Two Open conductor

1.1.2. Shunt (Short Circuit Fault)

Asymmetrical fault

1. LG Fault
2. LL Fault
3. LL-G Fault

Symmetrical Fault

1. LLL Fault
2. LLLG Fault.

When an overhead power line undergoes physical rupture and descends to the ground or establishes a connection with the ground via any intermediary object, it triggers a well-established phenomenon termed High Impedance Faults (HIFs). These events often coincide with the occurrence of an electric arc, posing potential fire hazards, inflicting damage to electrical infrastructure, and jeopardizing human safety. High Impedance Faults (HIFs) are commonly encountered faults in power distribution systems characterized by their low fault currents and intermittent nature. These faults often go undetected or misclassified by traditional protection schemes, posing serious safety risks and reliability issues. As mentioned by IEEE PSRC, a HIF arises when an energized conductor inadvertently connects with a non-conductive surface (such as soil, vegetation, tree branches, asphalt, or concrete), resulting in a restriction of fault current to a lower magnitude. Consequently, these faults elude detection by conventional over current protection mechanisms [11]. Therefore, the detection and pinpointing of HIFs remain pressing challenges for protection engineering, constituting an ongoing, unresolved issue.

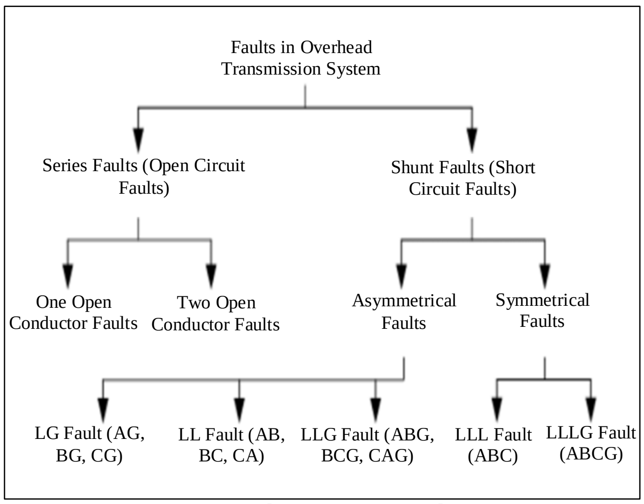

Fig. 1 Faults in transmission line

2. Literature Survey

In [1] fuzzy logic techniques are suggested for enhancing the relay's performance. Fuzzy logic allows for the integration of expert insights and linguistic variables to refine decision-making in intricate and uncertain scenarios. By leveraging fuzzy logic, the relay can adjust its operational characteristics based on factors such as line load, fault impedance, and system status. The incorporation of fuzzy logic into mho distance relays offers the potential to address under and over-reach problems more effectively, ensuring more adaptive and reliable protection for transmission lines and increasing the overall stability and dependability of the power grid.

In a previous study [2], the mho distance relay was developed with precision. However, altering its operational zone required adjustments to the relay constant. Numerical relays offer the advantage of interfacing with peripheral devices, which enhance the overall cost-effectiveness of system protection equipment. The relay data was analyzed and visualized on an (R-X) plot. This approach proved advantageous for extended transmission lines due to their resilience against power surges.

In a subsequent study [3], the author employed a fuzzy logic controller to enhance the performance of the distance relay. This methodology has demonstrated significant enhancements in various systems aimed at safeguarding transmission lines. Past studies related to HIF detection have delved into a range of methodologies, encompassing impedance-based techniques, wavelet transforms, and Artificial Intelligence (AI) algorithms.

Although impedance-based methods have demonstrated potential, they frequently exhibit sensitivity to system parameters and possess constrained fault detection capabilities. Conversely, wavelet transform-centric approaches boast enhanced fault detection efficacy but necessitate substantial signal processing and feature extraction efforts. Notably, in recent times, AI methodologies, with a particular focus on neural networks, have garnered attention owing to their adeptness in assimilating intricate patterns and proficiently categorizing data. For example, the initial model proposed utilized measurements focusing on a low-frequency spectrum [11].

Subsequent research efforts have aimed to refine this model by incorporating additional elements such as linear resistances and inductances [12]. However, more sophisticated models have sought to provide a more comprehensive understanding of the physical conditions during HIF occurrences by including non-linear resistances within the diode-based framework [13]. Additionally, models grounded in thermal equations of the arc, supported by the Mayr and Cassie equations; determine arc model parameters and high resistance values through experimental measurements [17].

Moreover, researchers have explored various techniques for HIF detection, including a Kalman filter-based approach to identify variations in the fundamental frequency of the fault current and its harmonics [9]. Another study introduced an algorithm based on evidential reasoning to differentiate and classify switching events from HIFs.

In order to identify high-impedance faults in distribution networks, this research proposes a transient-based approach. It does not require data synchronization or knowledge of feeder or load parameters. Rather, it monitors high- and low-frequency voltage components at several points in the power system using the discrete wavelet transform, determining the most likely location where the disturbance has occurred [16].

3. Power System Modeling

In this model, a fixed value of K_1, K_2, and K_3 is kept, i.e. to 8, 10, and 12, respectively, to achieve the zone protection. 60% in zone 1, 80% in zone 2 and 100% in zone 3, i.e. 120 km in zone 1, 160 km in zone 2 and 200 km in zone 3, respectively. Different faults are created in the model at different locations, and the Simulink model is further analysed.

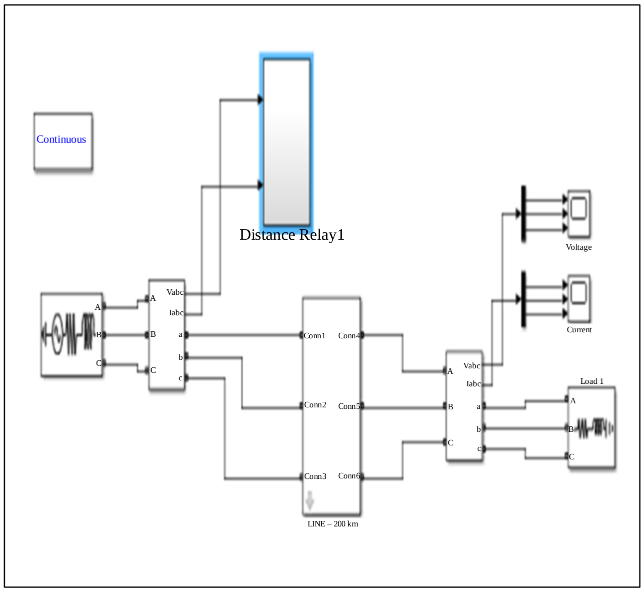

Fig. 2 Simulink model

Table 1. Fault impedance calculation for different types of faults

Fault Type	Formula
AB	$(V_A-V_B)/(I_A-I_B)$
BC	$(V_B-V_C)/(I_B-I_C)$
AC	$(V_A-V_C)/(I_A-I_C)$
AG	$V_A/(I_A+(3*K_0*I_0))$
BG	$V_B/(I_B+(3*K_0*I_0))$
CG	$V_C/(I_C+(3*K_0*I_0))$
ABC	V_A/I_A

Where A, B and C are the three phases of the system

3.1. R-X Characteristics of Distance Relay

Distance relay is used for transmission line protection. Different types of faults like L-G, L-L, L-L-G, L-L-L and L-L-L-G faults can be analysed using distance relays. This research has taken a 200 km line in which different faults have to be created and fault calculations have been done. In this project FFT analysis has been utilised to make distance relay work fast. FFT has been applied in it, due to which distance relay has started working fast. The values of K_1, K_2, and K_3 can be taken as per the zone requirements. RX diagram is being formed as per the zone: the first zone is 60%, the second zone is 80%, and the third zone is 100%.

3.2. Fast Fourier Transform (FFT)

The Discrete Fourier Transform (DFT) or inverse of a sequence can be computed using a technique called the Fast Fourier Transform (FFT). A signal's original domain, usually time or space, can be converted into a representation in the frequency domain and vice versa using Fourier analysis. FFT is the basis for frequency domain analysis, also referred to as spectral analysis, which is used in signal processing for signal filtering, spectrum estimation, data compression, and other applications. With FFT modifications such as the short-time Fourier transform, analysis can be done concurrently in the frequency and time domain.

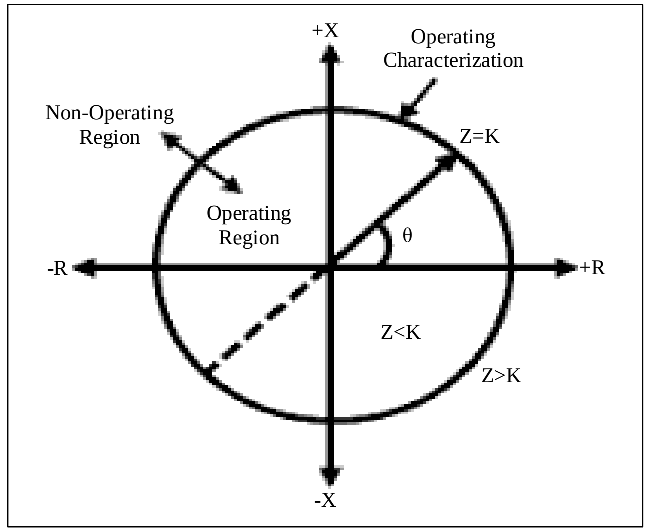

Fig. 3 R-X Characteristics of distance relay

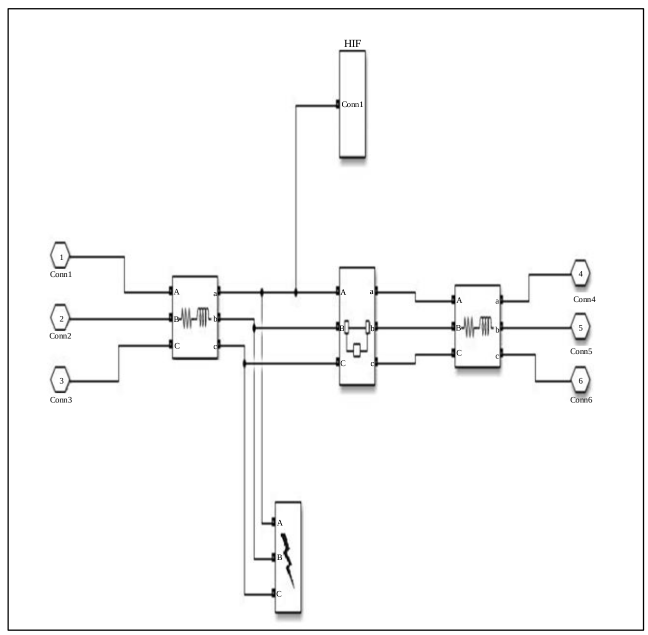

Fig. 4 200 km transmission line

3.3. Butterworth Low Pass Filter

An analog filter design known as the Butterworth filter produces a maximally flat filter response with no ripple in the pass or stop bands but at the expense of a rather broad transition band. The frequency response of the Butterworth Filter approximation function's passband is also commonly referred to as a "maximally flat" (no ripples) response since it is meant to be as flat as mathematically possible from 0Hz (DC) until the cut-off frequency at -3dB with no ripples.

4. Result and Discussion

Various tests are performed, and the Simulink model is analysed for different faults in the power system, including HIF, i.e. high impedance fault, as shown in Table 3. R-X behavior of distance relay, when L-G fault occurs in the system is shown in the figures below.

Table 2. Zone-wise analysis of L-G fault at different fault locations

Fault Type	Fault Location 20% (40 km) - Zone	Fault Location 40% (80 km) - Zone	Fault Location 100% (200 km)- Zone
A-G	1	1	3
A-B	1	1	3
A-B-G	1	1	3
A-B-C	1	1	3

4.1. R-X Behavior of Distance Relay when L-G Fault Occurs

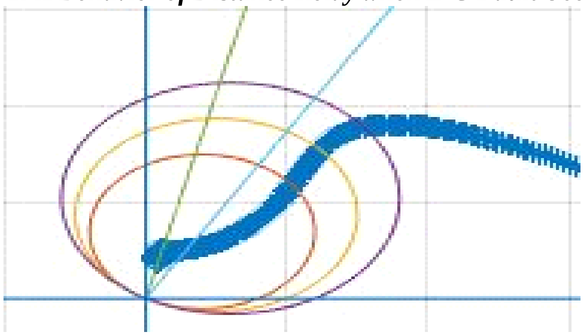

Fig. 5 20% of fault location

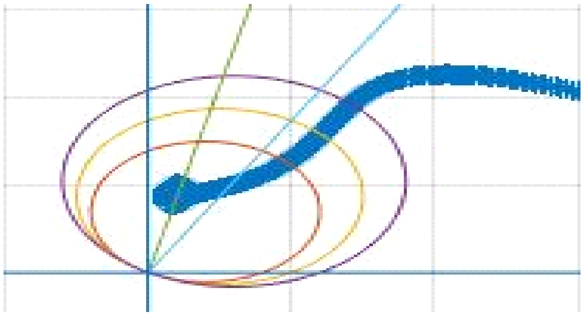

Fig. 6 40% of fault location

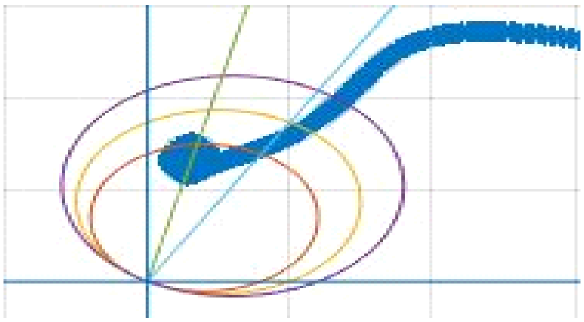

Fig. 7 60% of fault location

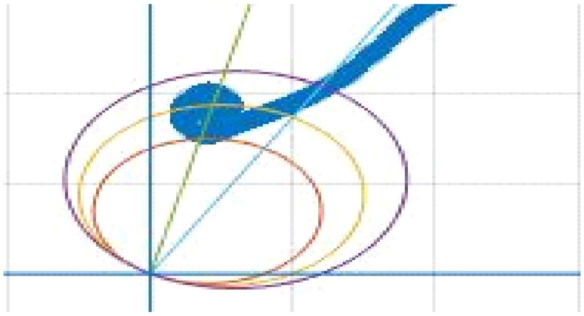

Fig. 8 80% of fault location

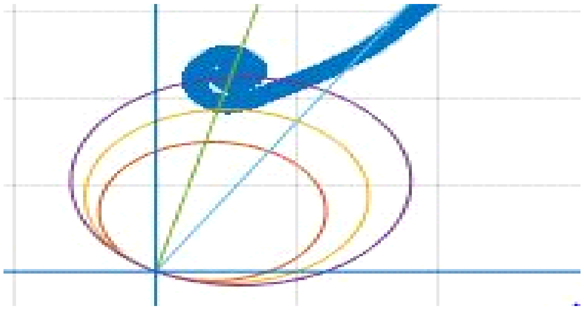

Fig. 9 100% of fault location

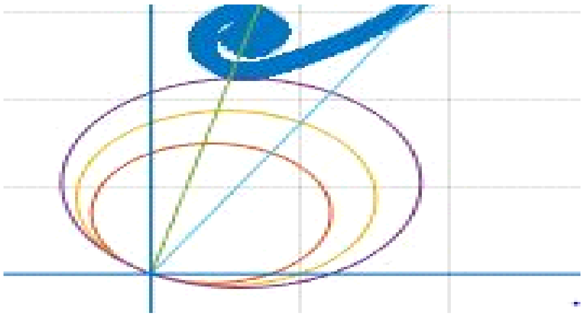

Fig. 10 120% of fault location

Similarly, we can analyze different types of faults, like L-L, L-L-G, L-L-L and L-L-L-G faults, at different fault locations. High impedance fault is also analyzed in the Simulink model, and its response is shown below in the table, and waveforms are shown.

Table 3. Zone wise analysis of HIF fault at different fault locations

Fault Location	Zone
20% at 40 km	Zone 1
30% at 60 km	Zone 1
40% at 80 km	Zone 1
50% at 100 km	Zone 1
60% at 120 km	Zone 1
70% at 140 km	Zone 2
80% at 160 km	Zone 2
90% at 180 km	Zone 3
100% at 200 km	Zone 3

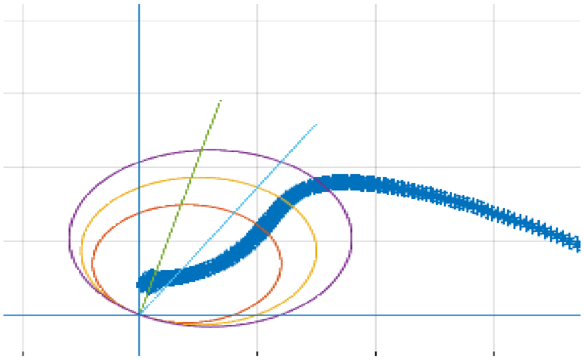

Fig. 11 20% fault location

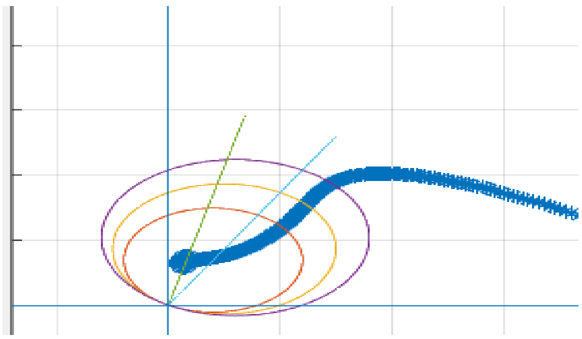

Fig. 12 30% fault location

It has been observed that high impedance fault behavior is different, and the response of distance relay is different. Due to impedance, the zone of protection changes for the same distance as for other different faults and their range Varies, and a certain delay is introduced in protection.

5. Conclusion and Future Scope

This research proposes a novel non-communication distance relaying technique for high-speed protection of the transmission line's whole length. The fault which occurs in transmission lines varies according to the different fault conditions. It is observed that fault occurring in 20%, 40%, 60%, 80%, and 100% of fault location of L-G is seen in different zones of the RX diagram. Similar results can be seen for the L-L, L-L-G, and L-L-L faults. This concludes that different fault which occurs in transmission lines have different fault conditions.

The fault location of each fault varies according to the properties of the fault which occurred. So, we need to make our distance relay work according to the different types of faults and different types of fault locations in the transmission line. The distance relay so designed has been given certain values of K_1, K_2, and K_3, which decides the zone for the RX diagram. If we change the values of K_1, K_2, and K_3, then zone settings can be changed. Here we are able to see that our distance relay is working instantly without any delay. Using the MATLAB/SIMULINK package, a Mho-type distance relay was successfully created; each component of the relay is used as a distinct function.

Every function has been developed with unique SIMULINK blocks. The proposed relay model was able to identify the correct fault type by evaluating its behaviour under various fault scenarios. Based on viewpoint impedance calculations, the relay model can always identify the appropriate zone of operation. As anticipated, the relay detects the fault locations; a change in the fault location results in a change in the measured impedance. The impedance route, which illustrates how the model behaves in various fault scenarios, was shown and examined.

In the future, new approaches, such as neural networks, can be implemented to detect faults at very high speeds and protect systems with random faults. This research presents a novel approach for analyzing the behavior of high impedance faults and their effect on distance relay protection schemes. In future, the detection of HIF can be done using machine learning so that detection, classification and location of different faults, including HIF, can be done at very high speed and with proper accuracy. Leveraging the capabilities of artificial neural intelligence, specifically neural networks, can improve fault detection performance compared to traditional methods.

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