IMPLEMENTATION OF FAULT LOCALIZATION ALGORITHM FOR LOW VOLTAGE DISTRIBUTION GRID USING LINE DISTANCE RELAY AND FAULT PASSAGE INDICATOR

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Abstract - *This paper presents a comprehensive overview of the real-time implementation of line distance algorithm relay that provides protection for distribution network. The algorithm is tailored to detect and localize faults efficiently, focusing on common fault types like single-phase to ground and three-phase faults. Faults were divided in three major categories: a)Faults in the beginning of the branch b)faults in the middle and c)Faults in end of the branch. The localization method was divided in three steps: a)Faulty branch identification b)Faulty section localization and c)Fault distance estimation. The methodology involves current measurements at the feeders start and voltage drop analysis across feeder branches. The study encompasses a wide range of fault resistance values from 0.1 ohm to 1000 ohm, addressing both single-phase to ground and three-phase faults. The results demonstrate the algorithm effectiveness in identifying faulty sections and precisely locating faults within the grid. Furthermore, SCADA integration enhances the real-time communication with maintenance team, facilitating swift responses to identifies faults and contributing to heightened grid reliability and operational efficiency. This paper gives an overview of the different advances of the technology and poses some of the challenges that this technology needs to solve.*

Key Words*: *Fault location, Fault detection, Fault passage indicator, Low voltage distribution grid, Line distance relay, SCADA.

1.INTRODUCTION

The protective system is very much essential for an Electrical Power System, which is used to isolate the faulty equipment from the system and protect the other equipment from the as quickly as possible. In case of short circuits or faults, the need for a protective system is felt, if not isolated it would totally damage the power system. Each part of the power system is protected. The protective systems include circuit breakers and protective relays to isolate the faulty section of the power system from the healthy ones. The function of a protective relay is to sense the abnormal conditions in the power system and gives an alarm or isolates that part from the healthy system. It minimizes the damage to the equipment and interruptions to the service when electrical fault occurs. Faults in typical distribution grid are responsible for 80% of customer interruptions[1]. Unlike transmission networks, distribution networks have a minimal protection scheme[2]. The detection of high impedance faults on electrical distribution systems has been one of the most persistent and difficult problems facing the electric utility industry. Depending on some factors including the feeders topology, the number of estimates may be on the order of tens, each one corresponding to a different feeder lateral. Some attempts have been made to mitigate this problem using expert systems or integrating information provided by measurement at the substation and the feeders protection scheme. However, such information is usually insufficient, inaccurate or unavailable. Thus the identification of exact fault location on multi-branched distribution feeders is a problem that has not been yet solved[3]. Impedance based fault location technique can be extensively used because of their low implementation cost. The traditional techniques are reactive in nature, meaning that they are used after a fault has already occurred. These include impedance-based, travelling-wave based and knowledge experience based techniques. Impedance based method use voltage and current measurements to determine the type of fault, which is then estimated on the fault location based on the apparent impedance. Although the impedance-based method is one of the oldest technique, it is still used because of its simplicity. Based on the signal used fault location techniques are classified into three different categories [4].

i)Techniques based on fundamental frequency of voltage and current.

ii)Techniques based on high frequency travelling waves generated by faults.

iii)Artificial intelligence approach.

Fault location techniques using fundamental frequency components, also known as impedance based fault location method, extract the fundamental frequency components of the voltage and current signals to calculate the impedance of the faulted line. Two approaches for fault detection in low impedance fault was examined, one based on current measurement at the feeders beginning and the other on highest voltage drop across feeder branches. Research has focus on fault diagnosis in low voltage smart distribution grids using gradient boosting tree models to detect, identify, and localize single-phase-to-ground and three-phase faults. Additionally a novel fault detection and localization methods for low voltage distribution grid, showcasing approaches to enhance grid reliability and efficiency.

II.SYSTEM DESCRIPTION

A.POWER SYSTEM FAULT ANALYSIS

The fault analysis of a power system is required in order to provide information for the selection of switchgear, setting of relay and stability of the system operation. A power system is not static but changes during operation (switching on or off generators) and during planning (addition of generators and transmission lines). Thus fault studies need to be routinely performed by utility engineers. Faults usually occur in power system due to either insulation failure, flashover, physical damage or human error. In the power system, there are primarily two types of faults.

i)Asymmetrical fault

ii)Symmetrical fault

ASYMMETRICAL FAULT: When the network is unsymmetrically faulted or loaded, neither the phase currents nor the phase voltage will possess three phase symmetry. Most of the system faults are unsymmetrical faults. It consists of unsymmetrical short circuit fault or unsymmetrical faults through impedance, or open conductor faults. If the insulation the system fails at any point or if a conducting object comes in contact with a bare conductor an unsymmetrical short circuit fault is said to occur. If unsymmetrical fault occur the unbalanced current will flow in the system. We are using symmetrical components to analyze unsymmetrical faults. To determine positive, negative and zero sequence impedance, we can use Thevenin's theorem or bus impedance matrix.

SYMMETRICAL FAULT: When the network is symmetrically faulted, the phase currents and phase voltage possess three phase symmetry.[i.e. equal magnitude and equal phase shift(120^0)]. Symmetrical fault is the most severe fault and most amenable to calculate. The current flowing immediately after the fault consists of an AC component which eventually reaches steady state and a fast decaying DC component which decays to zero. For analysis, only the AC component is considered.

Fault current $|I_f|=E_{th}/(Z_{th}+Z_f)$

B.FAULT LOCATION METHODS

Two of the most common methods used for fault location are the impedance-based method and traveling wave method[5]. The impedance-based method uses phasor voltages and currents captured by fault recorders and known system parameters of the line to calculate the fault location. One of the methods introduces the digital fault locator, which measures the ratio of reactance of a line from the point of the fault to the device. The line impedance per unit length can then be used to calculate the distance to the fault. Fault resistance though can impact the accuracy of this method because higher resistance affects precision[6] and the other method builds by measuring the reactance at one end of the line and calculating phase shift between total current flowing from one end of the line and current through fault resistor[7]. Some of the research on the impedance based method utilizes both voltage and current measurements for fault location on distribution network[8-9].

C.LINE DISTANCE RELAY

A line distance relay (LDR) in a low tension distribution grid can be used to identify faults based on the impedance method. This method involves measuring the impedance between the relay and the fault location, which can help in determining the distance to the fault and the location of the fault on the grid. The LDR operates by comparing the current flowing through the protected line with the current flowing through the faulty line. When the fault occurs, the current through the faulty line increases, causing the relay to trip. The LDR can be set to rip when the current ratio exceeds a certain value, indicating a fault on the grid. By measuring the impedance between the relay and the fault location, the LDR can determine the distance to the fault and help in locating the fault on the grid. This information can be used to isolate the faulty section of the grid and restore power to the affected area. Distance relays are placed in the particular zone and usually communicate with the main system and other relays using the pilot relaying scheme. As the impedance of the distribution relay is directly proportional to its length, it can be concluded that a distance relay can only operate if fault has occurred within a pre-determined distance. Distance relays are most useful for reasonable line lengths(upto 20Kms or so) because their operating characteristics are based on the line parameters.

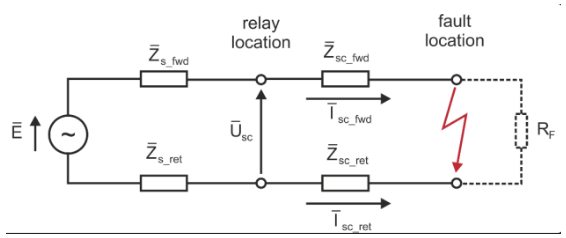


Fig 1-Fault location

TYPES OF IMPEDANCE RELAY

A distance or impedance relay is essentially an ohmmeter and operates whenever the impedance of the protected zone falls below the pre-determined value. There are two types of distance relays i)Definite-distance type impedance relay

ii)Time-distance impedance relay

Definite-distance type impedance relay

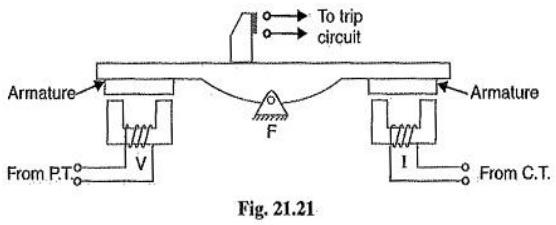


Fig 2-Definite-distance type impedance relay

Under normal conditions: The pull due to the voltage element is greater than that of the current element. So, the relay contacts remain open. When fault occurs: Then applied voltage to the relay decreases and the current increases. The ratio of voltage and current i.e., impedance falls below the pre-determined value. S0, the pull of the current element will exceed that due to the voltage element and this causes the beam to tilt in a direction to close the trip contacts.

Time-distance impedance relay

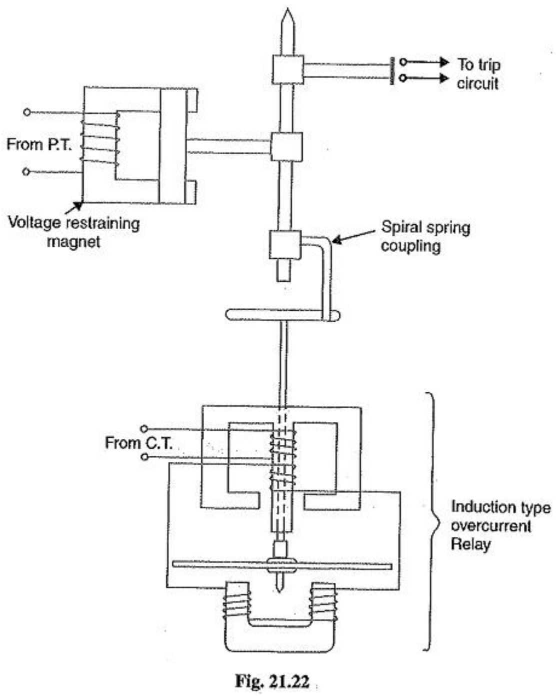


Fig 3-Time-distance impedance relay

A time-distance relay has its vital feature that it automatically adjusts its operating time according to the distance of the relay from the fault point.

i) Operating Time is directly proportional to voltage and inversely proportional to current.

ii) Operating Time is directly proportional to impedance.

iii) Operating Time is directly proportional to Distance.

Under normal conditions: The pull of the armature is more than that of induction element and hence the trip circuit contacts remain open.

Under fault occurs: The disc of the induction current element starts to rotate at a speed depending upon the operating current. As the rotation of the disc proceeds, the spiral spring coupling is wound up till the tension of the spring is sufficient to pull the armature away from the voltage excited element. The spindle carrying the armature and bridging piece moves rapidly in response to the tension of the spring and trip contacts are closed. This opens the circuit breaker to isolate the faulty portion.

High impedance fault detection relay

Specifically designed for detecting high impedance faults in low voltage networks, these relays play a crucial role in identifying and localizing faults that may not be easily detected by traditional protection methods.

Automated Fault Location Scheme

This scheme integrates smart distribution network to automate the fault location process in low voltage grids, reducing reliance on manual reporting and enhancing the efficiency of fault detection and localization.

D.DISTANCE PROTECTION

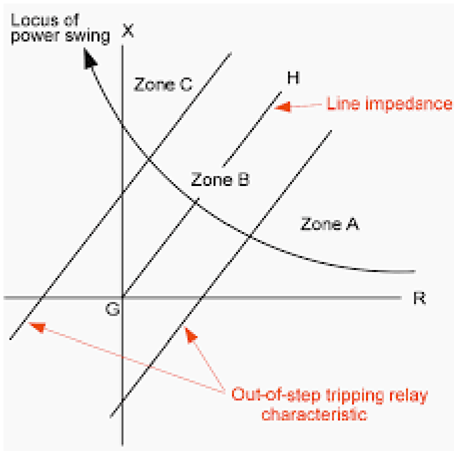


Fig 4-Distance relay operating curve

Distance relays are double actuating quantity relays with one coil energized by voltage and the other coil energized by current. The operating torque produced is such that when V/I reduces below a specified value, the relay operates. During a fault on distribution line, the fault current increases and the voltage at fault point reduces. The ratio V/I is measured t location of CTs and PTs. The voltage at PT location depends on the distance between the PT and the fault. If fault is nearer, measured voltage is lesser. If fault is further, measured voltage is more. Hence assuming constant fault resistance each value of V/I measured from relay location corresponds to distance between the relaying point and the fault. Hence such protection is called Impedance protection or Distance protection. The relay operates when the ratio V/I i.e., impedance is less than a predetermined value. As the ratio V/I affects the performance of these relays are also called ratio relays. Dependent on the ratio of V and I, there are five types of distance relay. They are Impedance relay, Reactance relay, Admittance relay (mho relay), Ohm relay and Offset mho relay.

E.IMPEDANCE BASED METHOD

Impedance based fault location algorithm calculate fault distance using the per unit length impedance of the line, voltage and current data, and circuit analysis techniques, such as Kirchhoff's voltage and current laws. Single-terminal and two-terminal algorithms are the two main groups of impedance based FLA.

F.FAULT PASSAGE INDICATOR

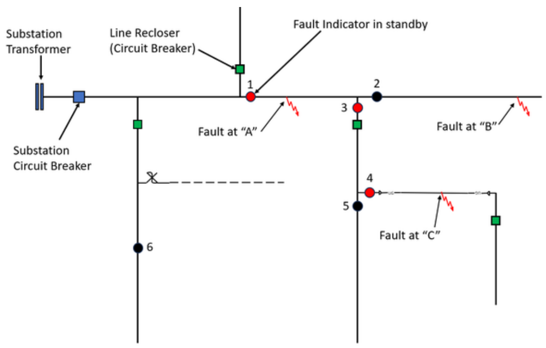


Fig 5-fault passage indicator in distribution line

A Fault Passage Indicator (FPI) is a device used in electric power distribution system. It operates by monitoring the electromagnetic field around the conductor caused by high current flows, which are associated with faults. When the fault occurs, the FPI detects the change in the magnetic field and provides an alarm by communicating through a remote terminal unit (RTU) to the distribution system. A Fault Passage Indicator in a low voltage distribution grid is a device used to detect and indicate faults that occur in the electrical distribution network. It works by monitoring the system 24/7 for fault occurrences and quickly identifying the fault location to reduce downtime.

G.CURRENT TRANSFORMER

In a low voltage distribution grid, a current transformer (CT) can be used in conjunction with a fault passage indicator (FPI) and a line distance relay to localize faults. The CT converts high current levels in the distribution network to a lower, state level that can be measured and monitored. The FPI uses these current and voltage measurements to detect and indicate faults, while the line distance relay uses the positive-sequence impedance between the relay and fault location to accurately pinpoint the fault location within the distribution grid. The CT plays a crucial role in this process by providing the necessary current measurements for the FPI and line distance relay to operate efficiently.

H.POTENTIAL TRANSFORMER

In a distribution line, Potential transformers are typically installed at substations to provide accurate voltage measurements for monitoring and control of the system. The operation of a potential transformer in a distribution line involves the voltage is induced in the primary winding of the potential transformer due to the voltage across the distribution line. The primary winding is connected in parallel to the distribution line, and the secondary winding is connected to the measuring and protection devices. When abnormal condition is detected in the distribution line, the potential transformer provides accurate voltage signal to the protective relays, which act to isolate the fault and prevent damage to the system. The PT behaves as an ordinary two-winding transformer operating on no load, and the VA ratings of PTs are low, ranging from 50 to 200VA.

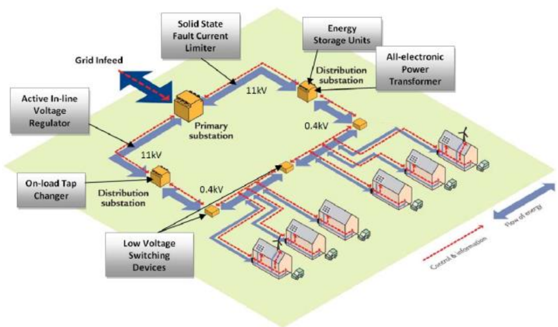


Fig 6-Distribution system

III.OPERATION

A.IMPEDANCE RELAY

Impedance relay consists of two elements, the voltage element of the relay is excited through a potential transformer from the line to be protected. The current element of the relay is excited from the current transformer in series with the distribution system. The torque produced by the current element is balanced against torque produced by the voltage element. Thus the current elements produces operating torque, pick torque which can be said to be positive torque. The voltage element produces remaining torque, reset torque which can be said to be negative torque. So this relay is voltage restrained over current relays.

B.FAULT PASSAGE INDICATOR

Setting up the FPI: Before starting the implementation, the FPI requires some settings for fault detection which is over-current threshold and time of detection.

FPI indication: The FPI normally includes the visual indication of the fault i.e., a LED, flash etc. A particular indication system is a glass filled with liquid and a red pigment[10]. When the fault is detected, a metal ball in the bulb moves due to the strong magnetic field associated with the large current, shaking the pigment and coloring the liquid. In urban, highly populated areas it can be difficult to access the substations, or the substation is located in private property. For this reason, alternative system is to obtain the FPI indication. The FPIs incorporated the ability of communicating through radio frequency with the SCADA system. However, SCADA systems have not been widely used in distribution level. Later, other communication such as Power Line Communication (PLC) in combination with Remote Terminal Unit (RTU).

Resetting the FPI: Once the FPI has tripped, the indication must remain on till the locating crew clear the fault. When the fault is cleared and the service is restored, the FPI has to return back to its original state, so that the device has to return back to normal state.

C.METHODS

Several methods have been proposed for fault location but are not readily applicable to distribution systems. This is due to heterogeneous lines, lateral branches, and load taps in distribution system. The primary methods used to locate the location of faults in distribution networks are impedance, traveling wave and post diagnostic method[11]. In addition to all the methods, the Fault Indication is the most practical and affordable way for distribution systems, thus providing the best probable fault location.

IV.IMPLEMENTATION

In low tension distribution network, the fault detection and localization process using line distance relay involves the measurement of current and voltage to accurately identify and locate faults. Gong & Guzman proposed a fault location technique that utilizes current and voltage measurements obtained from digital relays. These measurements are crucial for impedance-based fault location methods in distribution networks, allowing for precise fault localization. Additionally, the use of Fault Passage Indicators (FPIs) enhances fault detection by detecting the passage of fault current through the lateral coming from the bus on which they are installed. FPIs play a vital role in determining the location of faults by analyzing current signals from current transformers and voltage signals from voltage transformers at the relay. By combining these measurements and techniques, the fault detection and localization system in low voltage distribution network can swiftly identify faults and accurately pinpoint their locations for efficient maintenance and restoration actions. Distance protection, specifically using distance relays, is a crucial method for safeguarding transmission and distribution networks. These relays are designed to trip circuit breakers when a fault occurs within a specified "reach" distance, providing more sophisticated fault detection than simple overcurrent relays. The development of distance relays has significantly improved the protection of overhead lines and improved the protection of overhead lines and underground cables at various system voltages, making them economically viable for most systems. Distance relaying is essential power lines by estimating the physical distance between the relay's sensing transformer and the fault location. It offers more reliable zone protection by calculating the impedance of the protected zone and tripping breakers if a fault is detected within that zone. The use of distance relays has evolved to provide primary and remote back-up functions in a single operating arrangement, offering quick service for short circuits along protected elements and enabling high-speed auto-reclosing for major transmission circuits.

A.DATA ACQUISITION

Line distance relays and fault passage indicator are strategically placed throughout the grid. These devices collect data on fault inception, fault type (ex., phase-to-ground, phase-to-phase), and for line distance relays, the apparent impedance to the fault location. This data is transmitted via the Supervisory Control and Data Acquisition (SCADA) system to central server.

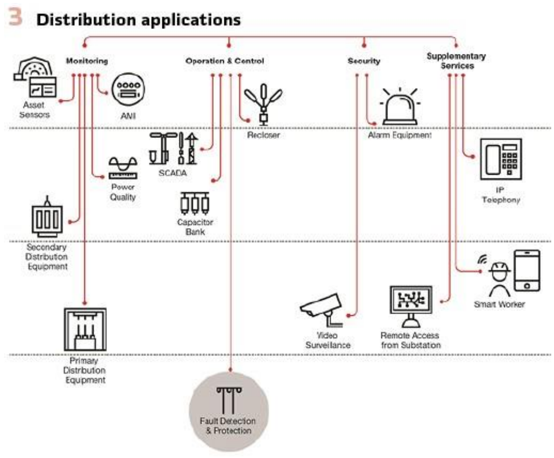


Fig 7-Distribution applications

B.ALGORITHM DESIGN

A fault localization algorithm is developed and implemented on central server. This algorithm utilizes the received data from the relay and FPIs to estimate the fault location. Common approaches include impedance-based methods using line distance relay data, travel time-based methods using FPI data, or a combination of both for enhanced accuracy.

C.COMMUNICATION PROTOCOL INTEGRATION

The SCADA system and the fault localization algorithm need to be configured to seamlessly exchange data. This involves establishing a communication protocol the defines the message format, data structure, and transmission methods for fault data between the relays /FPI_s and the central server.

D.SYSTEM TESTING AND VALIDATION

Once the algorithm and communication protocols are established, comprehensive testing and validation are crucial. Simulated fault scenarios are injected into the grid, and the algorithm's response is compared against actual fault locations identified through manual field inspection. This process helps in refining the algorithm and ensuring its accuracy and reliability.

E.DEPLOYMENT AND MONITORING

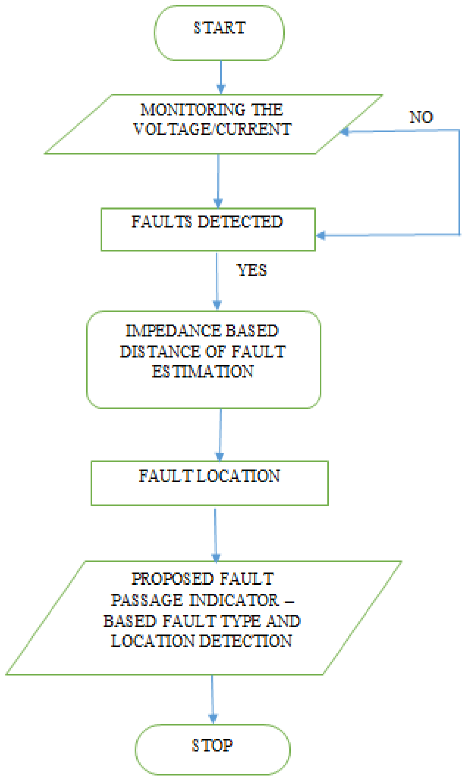
Upon successful testing and validation, the fault localization system is deployed on the actual distribution grid. The system continuously monitors the grid for faults, and when a fault occurs, the algorithm estimates and transmits the fault location to the system operators, enabling them to take swift corrective actions and minimize outage durations.

F.SCADA COMMUNICATION

The implementation of SCADA communication for fault localization in low tension distribution grids involves a systematic process to enhance fault detection and localization efficiency. Initially, the optimal placement of Fault Passage Indicator (FPIs) is determined through optimization tasks to ensure network reliability and cost-effectiveness. Substantially, a fault localization algorithm is developed, leveraging the equipment already installed, such as fault indicators, to achieve precise fault localization in terms of time frequency. This algorithm is integrated with the SCADA system to enable real-time data transmission and remote monitoring capabilities, facilitating fault detection and localization with minimal time delays. The SCADA communication system plays a pivotal role in enabling communication between system components like relays, FPIs and the SCADA system, ensuring efficient data transmission and enhancing fault detection and localization capabilities. This helps to protect the power system from damage to the equipments.

V.ALGORITHM OF RELAY

The algorithm for setting a line distance relay in low voltage distribution networks involves technical efficiency criteria and probability statistical methods. It focuses on studying and developing technical effects to enhance the efficiency of relay protection schemes. It recommends setting options for different stages of protection based on sensitivity and minimizing excessive actions, optimizing the first stage for high-speed operation, and ensuring technical efficiency for effective distance relay protection functioning. It aims to improve the reliability and performance of distance relay protection systems in low voltage distribution networks.



Step 1- Start

Step 2-Measure the electrical impedance of the network, which is the ratio of voltage to current at a specific point on line.

Step 3-Distance relays use voltage and current measurements to calculate the impedance to the point of fault.

Step 4-Distance relays calculate the ratio of voltage to current to apparent impedance, which is crucial for fault detection and localization.

Step 5-When the fault is detected, protective relays exits to protect the power system from faults and damage otherwise go to step 2.

Step 6-Stop.

VI.SOFTWARE SIMULATION

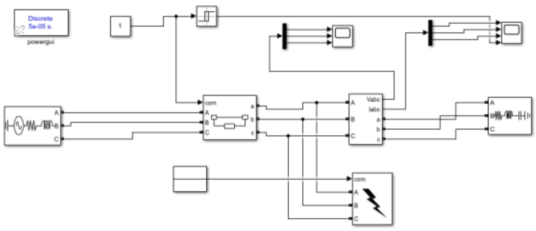


Fig 8-Transmission line protection

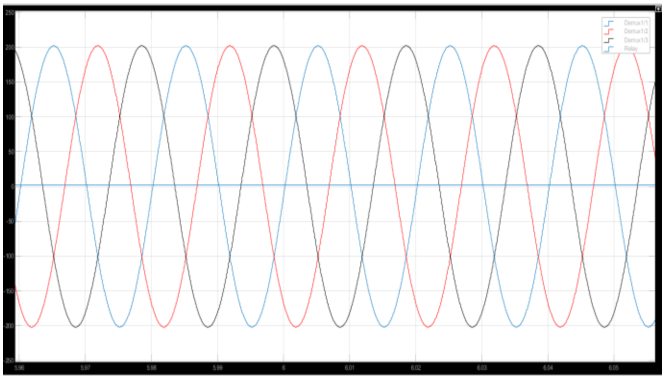


Fig 9-Simulink graph for Power system protection

Fig-8&9-Power system protection involves simulating and optimizing power system to ensure reliable and efficient operation. This process includes modeling power generation equipment, integrating power plant into the electric grid, and estimating generator control system parameter.

Transmission or distribution line simulation can be done using MATLAB/Simulink software.

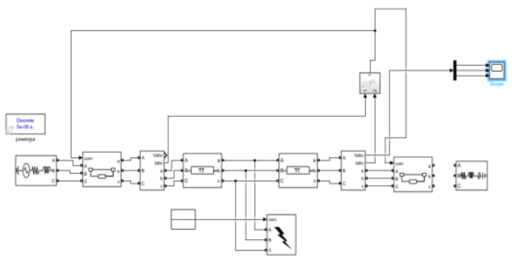


Fig 10-Transmission line protection Simulink block

Distribution systems deliver electricity from transmission lines to end-users at lower voltages within localized areas. While sharing similarities with transmission line simulators, distribution system models often focus on different aspects like load variations, voltage regulation, and network configuration for optimal performance. Protection schemes for distribution systems may differ from those used in transmission lines due to the varying fault characteristics and network configurations.

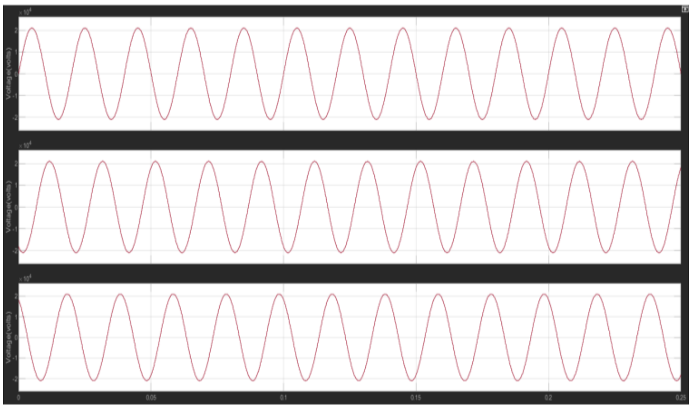


Fig 11-Under normal operating condition-Simulink graph

Fig-11 involves modeling the transmission line and simulating the impacts on the system. In the same way, low voltage distribution grid can also be protected.

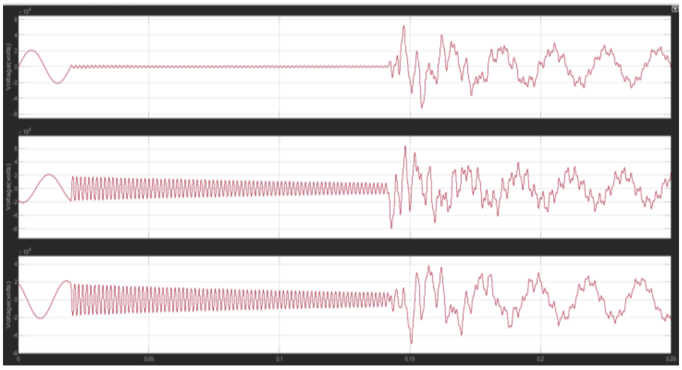


Fig 12-Fault at initial condition-Simulink graph

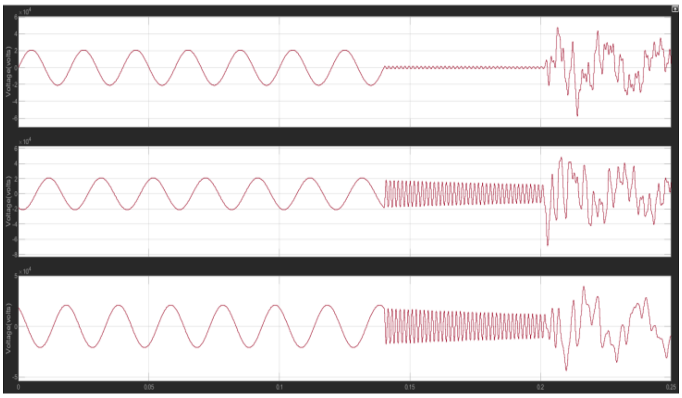


Fig 13-Fault at middle of the line-Simulink graph

Fig-12 and 13 allows for a detailed examination of fault scenarios in low voltage distribution networks, providing insights into fault detection and localization strategies for enhancing system reliability and performance. By simulating faults at different positions along the distribution lines, voltage and current waveforms are analyzed to determine the fault location accurately.

LINE DISTANCE RELAY

The MATLAB/Simulink block for simulating a line distance relay in distribution network involves modeling and testing a digital distance relay for line protection. This simulation includes the measurement of impedance changes between fault-free and faulted lines to detect fault accurately. The simulation utilizes MATLAB/Simulink's capabilities to model the relay's behaviour, test its performance, and ensure reliable protection of the power system.

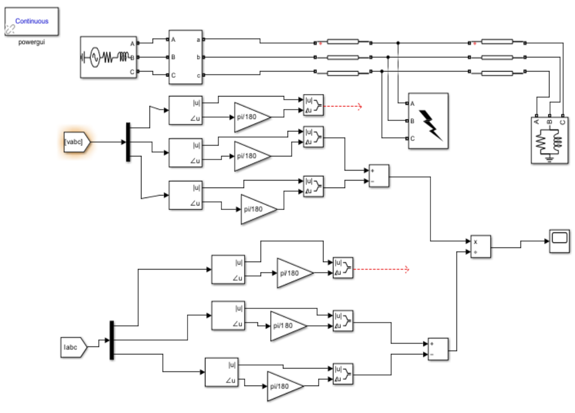


Fig 14-Line distance relay Simulink block

VII.RESULTS AND DISCUSSIONS

The proposed fault location method relies on the electric waveforms recorded at the secondary electrical substation by utilizing Line Distance Relay and Fault Passage Indicator with current transformer and voltage transformer.

VOLTAGE AND CURRENT WAVEFORM

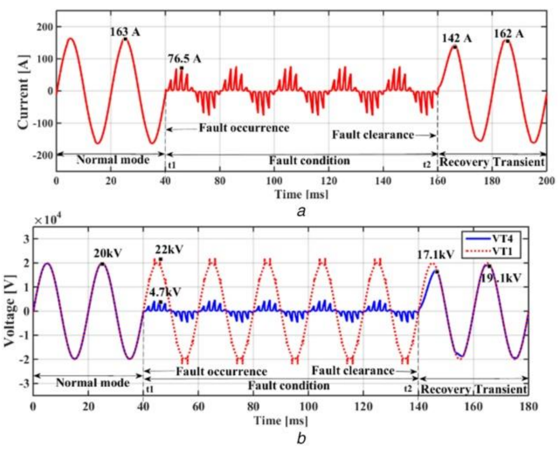


Fig 15-Fault location

During a fault in a low voltage distribution network, the voltage and current waveforms undergo specific changes that are crucial for fault detection and localization. When a fault occurs, the current waveform experiences a sudden increase due to the short circuit created by the fault. This increase in current is detected by protective relays, triggering them to isolate the faulty section from the rest of the network. The voltage waveform, on the other hand, may exhibit variations depending on the type and location of the fault. The analysis of voltage and current waveforms during a fault is essential for accurate fault detection and localization in low voltage distribution networks.

The area of fault clearance is of importance for the power distribution company since it is imperative to uphold the reliability of power delivery to reach a high level of satisfaction with the customers and reduce regulatory imposed negative incentives. The power restoration and fault location process is highly reliant on technicians. The process varies depending on in which level of the grid the fault occurs. This report primarily focused on the local grids in voltage levels. With the aim of identifying a single method applicable to all faults, in all grid structures, which reduces the infield work and the total outage time[12]. The different methods for fault location are Impedance based method, Traveling wave and Knowledge based methods. The Traveling wave and Knowledge based methods both displayed a high level of accuracy, but neither could be regarded as methods for full scale implementation. The high cost for implementation and the unavailability of commercially ready equipment where the main objective against the traveling wave method. The main benefits of impedance method was the low implementation cost and high accuracy.

VIII.CONCLUSION

The purpose of this paper is to identify fault location using impedance based method. In low voltage distribution networks, fault occurrence is a common challenges, with the majority of faults being temporary and self-clearing, ranging from 75%-90%. Those temporary faults typically last between 15 to 400 minutes per customer per year. With about 80% of all faults occurring at the distribution level, fault location in distribution networks has become a significant area of interest, previously more focused on transmission networks. SCADA systems in distribution systems highlights their significant role in enhancing performance, reliability, and durability. SCADA systems are crucial for power distribution, utilizing modem technologies to automate tasks and improve overall system efficiency. In summary, the paper recommends the following criteria for selecting the most suitable fault location algorithm i)Line distance relay data ii)Fault Passage Indicator. Faults caused by animal or tree contact with distribution network, or insulation failure in power system equipment have one single location. However, when lighting strikes an overhead line, the voltage across the insulator is so large that it causes a back flash-over and fault. In this case, impedance-based fault location algorithm is used to locate fault.

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