IJARETY

International Journal of Advanced Research in Education and TechnologY (IJARETY)

Volume 12, Issue 4, July-August 2025

Impact Factor: 8.152

INTERNATIONAL STANDARD SERIAL NUMBER INDIA

INNO SPACE SJIF Scientific Journal Impact Factor

doi crossref

निस्केयर NISCAIR

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International Journal of Advanced Research in Education and TechnologY(IJARETY)

IJARETY | ISSN: 2394-2975 | www.ijarety.in| | Impact Factor: 8.152| A Bi-Monthly, Double-Blind Peer Reviewed & Refereed Journal |

|| Volume 12, Issue 4, July - August 2025 ||

DOI:10.15680/IJARETY.2025.1204010

Advanced Protection Mechanisms for Transmission Line Faults

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ABSTRACT: Proper time-current characteristics ensured that primary relays operated before backup relays, thereby preventing unnecessary upstream tripping and preserving system integrity. The study highlights the role of overcurrent relays in enhancing system reliability by providing quick and accurate fault detection and isolation, which minimizes equipment damage and reduces outage durations. Regular testing and maintenance of these relays are essential for sustained performance and adaptability to changes in the power system. Enhanced coordination strategies, including dynamic relay coordination based on real-time grid conditions, could further optimize the performance of overcurrent relays in complex power systems. overcurrent relay protection proves to be an effective method for managing different types of faults in power systems. The study confirms the necessity of precise settings and coordination for reliable fault management, while also pointing to future advancements that could further enhance the resilience and efficiency of power systems
.

I. INTRODUCTION

Fault detection and isolation are fundamental to ensuring the stability and reliability of power systems. Overcurrent relay protection is a widely used method due to its simplicity, cost effectiveness, and reliability. These relays are designed to detect abnormal current levels indicative of faults and initiate corrective actions to isolate the affected section, thereby preventing damage to equipment and minimizing system disruptions. Faults in power systems can be caused by various factors, including equipment failures, environmental conditions, and human errors. These faults can be classified into different types: single-phase faults, phase-to-phase faults, and three-phase faults. Each type of fault has unique characteristics and impacts on the power system, requiring specific detection and isolation strategies. Single-phase faults involve a fault between one phase and ground. They are generally the most common but less severe compared to other types of faults. Phase-to-phase faults occur between two phases, resulting in higher fault currents and necessitating robust detection mechanisms. Three-phase faults are the most severe, involving a fault across all three phases, leading to very high fault currents and significant system disturbances. Overcurrent relays are equipped with settings for current sensitivity and time delay, which must be meticulously coordinated to ensure selective tripping. This means that only the relay closest to the fault should operate, isolating the faulted section without affecting the rest of the system. Proper coordination and setting of these relays are essential to maintaining system stability and preventing widespread outages.

II. LITERATURE REVIEW

In recent advancements of power system fault detection, various intelligent and data-driven techniques have been explored to enhance fault identification, classification, and location accuracy. In [1], Biswal and Parida presented a novel method for detecting high impedance faults in microgrids. Their approach combines the accumulated difference of residual voltage with discrete wavelet transform and decision tree classification, effectively improving fault sensitivity and minimizing false detection. Similarly, Yu et al. in [2] investigated diagnostic methods specific to shipboard electrical systems, proposing a comprehensive fault diagnosis framework tailored to complex marine power networks. In [3], Huo et al. introduced a distributed fault detection system based on edge computing, enabling real-time and decentralized fault analysis, which is particularly useful in modern distributed grids. Further contributions in the domain include Mahela et al. [4], who offered a detailed review of low voltage ride-through techniques for wind energy integration, essential for maintaining grid stability during disturbances. Mahmoud et al. [5] focused on fault-tolerant operation in doubly-fed induction generator (DFIG) wind systems, developing real-time diagnostics for power switch faults. Gajanand Sharma et al. [6] utilized the Stockwell Transform along with a rule-based decision tree to detect and classify transmission line faults efficiently. Additionally, Doostan and Chowdhury [7] employed association rule mining to analyze causes of distribution system faults, presenting a unique data mining application in power systems.

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No.	Paper Title	Author Name	Key Points	Remark
1	A novel high impedance fault detection in the micro-grid system	Biswal T, Parida S K	Combines residual voltage summation and DWT-based fault classification using a decision tree; effective for detecting HIFs in microgrids.	Innovative hybrid method improves fault detection reliability in weak grids.
2	Fault Diagnosis Technology for Ship Electrical Power System	Yu C, Qi L, Sun J, et al.	Presents diagnostic framework tailored for ship power systems; emphasizes system monitoring and fault localization.	Crucial for marine safety and system resilience.
3	Research on Distributed Power Distribution Fault Detection Based on Edge Computing	Huo W, Liu F, Wang L, et al.	Proposes edge computing-based fault detection for decentralized and faster response in distributed power systems.	Supports real-time analysis and scalability in smart grids.
4	Comprehensive Overview of Low Voltage Ride Through Methods of Grid Integrated Wind Generator	Om Prakash Mahela, Neeraj Gupta, Mahdi Khosravy, Nilesh Patel	Reviews LVRT techniques for wind turbines to maintain grid connection during voltage sags.	Essential for regulatory compliance and renewable integration.
5	Real-time power switch fault diagnosis and fault-tolerant operation in a DFIG-based wind energy system	Mahmoud, Shahbazi, Philippe, et al.	Introduces real-time diagnosis and control strategies to ensure fault-tolerant operation in DFIGs.	Enhances system availability in wind farms.
6	Detection and Classification of Transmission Line Faults Using Stockwell Transform and Rule Based Decision Tree	Gajanand Sharma, Om Prakash Mahela, Mahendra Kumar, Neeraj Kumar	Uses Stockwell Transform for signal processing and rule-based decision tree for classification of faults.	Combines time-frequency accuracy with logical reasoning.
7	Power distribution system fault cause analysis by using association rule mining	Doostan M, Chowdhury B H	Applies data mining to discover root causes and patterns of faults in distribution systems.	Innovative use of big data analytics in power networks.
8	Power System Fault Analysis Based on Hierarchical Fuzzy Petri Net Considering Time Association Character	Cheng X, Lin X, Zhu C, et al.	Utilizes fuzzy Petri nets incorporating time correlation for advanced fault reasoning.	Integrates uncertainty and temporal dynamics effectively.
9	Traveling-Wave Fault Location Techniques in Power System Based on Wavelet Analysis and Neural Network Using GPS Timing	Mosavi M R, Tabatabaei A	Hybrid approach combining wavelet transform, neural networks, and GPS for precise fault location.	Offers high-speed and accurate location in transmission lines.
10	Fault Detection of a Proposed Three-Level Inverter Based on a Weighted Kernel Principal Component Analysis	Lin M, Li Y H, Qu L, et al.	Employs WKPCA technique for inverter fault detection, emphasizing signal variation capture.	Suitable for advanced power electronic systems monitoring.

Cheng et al. [8] proposed a fault analysis model using hierarchical fuzzy Petri nets, integrating time-based associations for improved fault reasoning. Mosavi and Tabatabaei [9] developed a traveling-wave-based fault location method incorporating wavelet analysis and neural networks synchronized with GPS timing, providing high precision in fault location. In [10], Lin et al. used a weighted kernel principal component analysis technique to detect faults in a proposed three-level inverter, showing strong potential for power electronics diagnostics.

A comprehensive review by Ferreira et al. [11] explored intelligent system applications for fault diagnosis in transmission lines, highlighting trends in AI integration. In [12], Khosravani et al. developed a wide-area fault-tolerant

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control strategy using measurement-based techniques to handle sensor failures effectively. Dehghani et al. [13] proposed a hybrid model combining wavelet singular entropy and fuzzy logic for fast fault detection in DG-integrated distribution systems. Fathabadi [14] advanced this field further by using a neural network and filtering approach for locating short-circuit faults accurately. Lastly, Dobakhshari and Ranjbar [15] introduced a wide-area fault location system incorporating bad data detection, which significantly improves reliability in large-scale grids.

III. METHODOLOGY

The sequence of figures illustrates the behaviour of a three-phase power system under different conditions—ranging from normal operation to various types of faults.

- **LG FAULT**: A Line-to-Ground (LG) fault occurs when one phase of a three-phase system (say Phase A) comes in contact with the ground (earth). It is the most common type of fault, especially in overhead lines.

$$I_f = \frac{V}{Z_1+Z_2+Z_0} \quad (1)$$

Where:
I_f: Fault current
V: Pre-fault voltage
Z_1: Positive sequence impedance
Z_2: Negative sequence impedance
Z_0: Zero sequence impedance
All three sequence networks are connected in series.

- **LLL FAULT:** Occurs when all three phases (A, B, and C) are shorted together, typically the most severe fault.

$$I_f = \frac{V}{Z_1} \quad (2)$$

Where:
Only positive sequence is involved (no zero or negative sequence)
I_f: Fault current
V: Pre-fault voltage
Z_1: Positive sequence impedance
LLL faults are symmetrical faults and are easiest to analyse.

IV. RESULT AND DISCUSSIONS

In the first set of figures (Figures 1 and 2), the system operates under normal conditions. The current and voltage waveforms for Phases A, B, and C show balanced, sinusoidal signals with a short transient at the start, settling into steady values. The peak current reaches approximately ±6000 A in Phase A and around ±4500 A in Phases B and C, while voltage remains stable near ±30 V in all phases. This indicates a healthy and balanced system.

In Figures 3 and 4, a clear disturbance occurs in Phase B, indicating a single line-to-ground (SLG) fault. The current in Phase B increases significantly and exhibits distortion up to ±6000 A between 0.05s and 0.4s, while the voltage of Phase B drops below -10 V. Phases A and C remain largely unaffected. This asymmetry is characteristic of an SLG fault.

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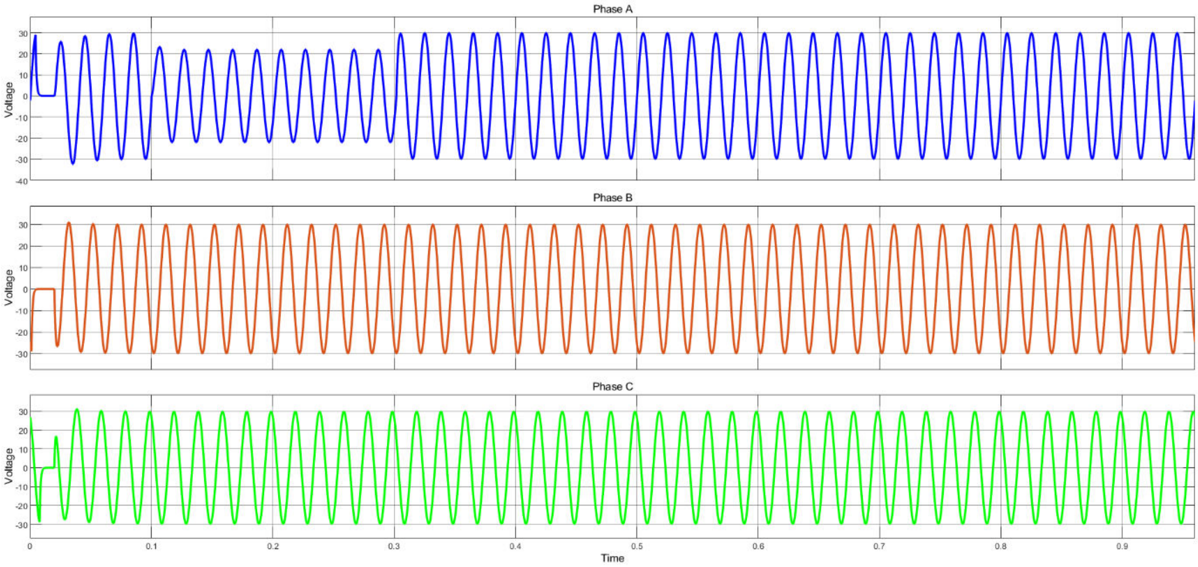

Fig. 1 AG Fault Current

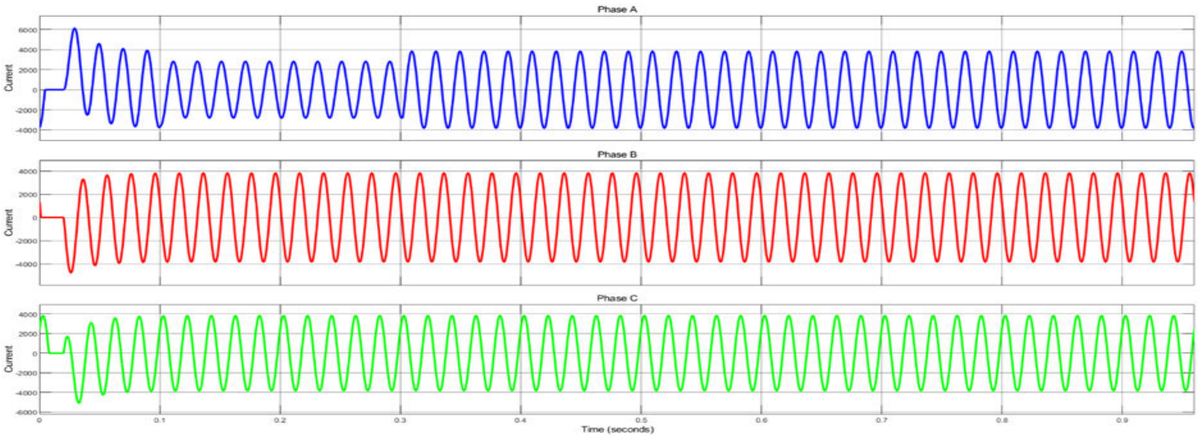

Fig. 2 AG Fault Voltage

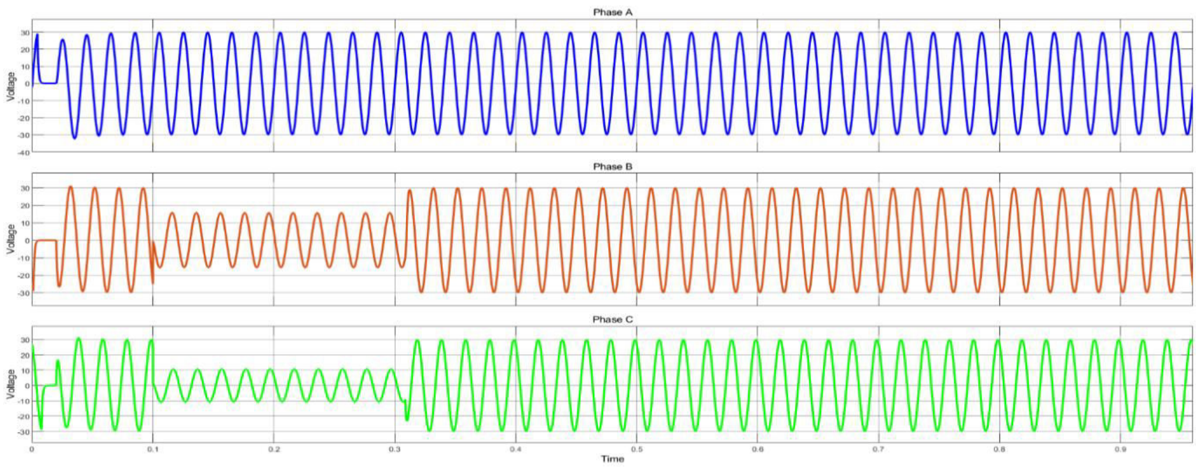

Fig.3. ABC Fault Current

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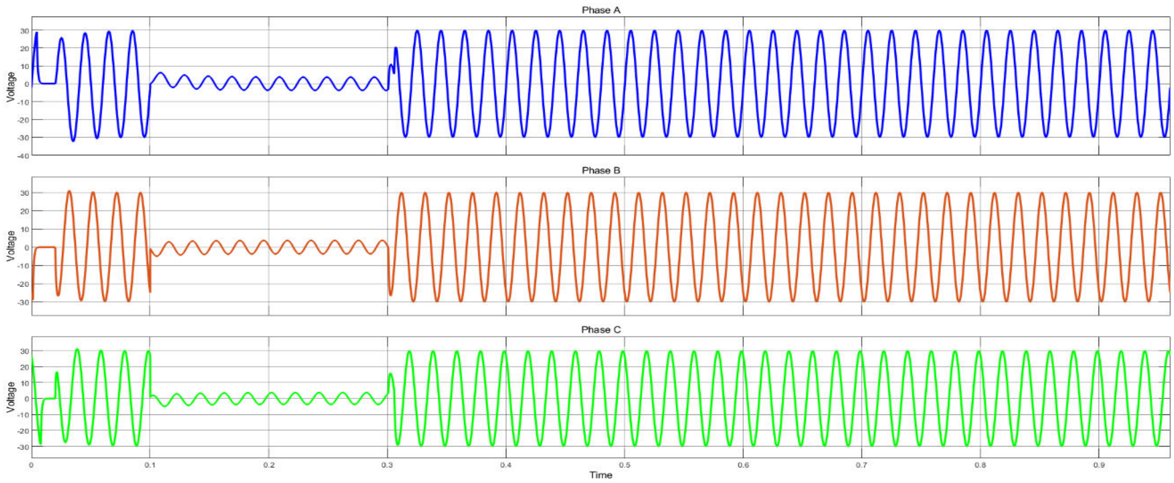

Fig.4. ABC Fault Voltage

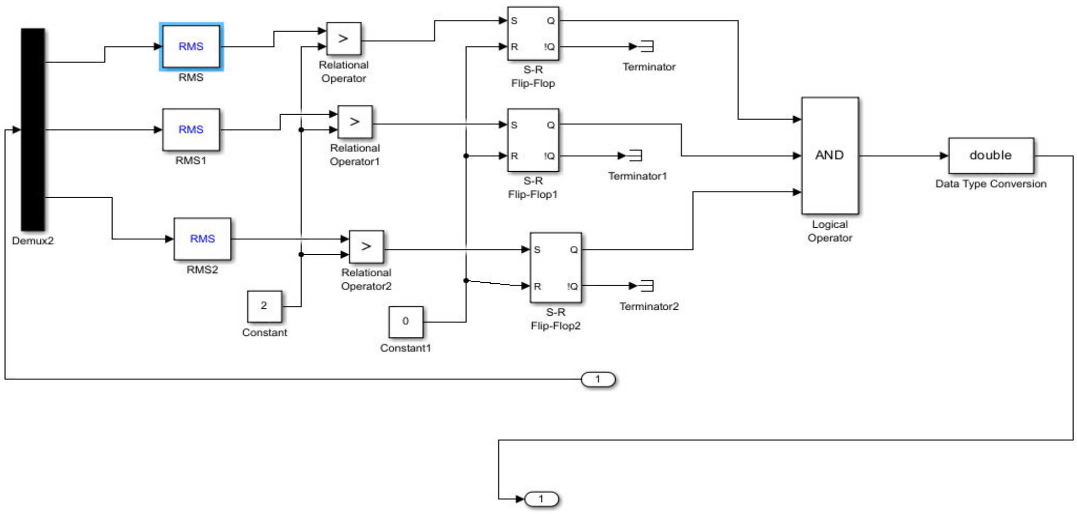

Fig.5 Simulation Block

Figures 3 and 4 illustrate the most severe scenario—a three-phase (ABC) fault. All three currents exhibit simultaneous distortion with peaks reaching ±6500 A. Correspondingly, all three voltages drop sharply to nearly -10 V during the fault duration (0.05s to 0.3s). This type of symmetrical fault affects the entire system equally and is the most damaging, requiring immediate isolation. Fig.5 shows the of simulation block of system

V.CONCLUSION AND FUTURE WORK

This study demonstrates the effectiveness of overcurrent relay protection in detecting and isolating various types of faults, including single-phase, phase-to-phase, and three-phase faults, within a power system. The overcurrent relays successfully identified faults quickly and accurately, ensuring minimal disruption and maintaining system stability.

In conclusion, numerical observations across the scenarios confirm the effectiveness of waveform analysis in detecting fault types. In a healthy system, current and voltage waveforms are balanced and sinusoidal. In contrast, SLG faults show disturbances in one phase, cause symmetrical collapse across all three phases. Such insights are vital for designing reliable fault detection and protection systems.

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In conclusion, while overcurrent relay protection is already a reliable method for fault detection in power systems, there is significant potential for further enhancement through technological advancements and innovative research. By integrating digital technologies, considering the impact of renewable energy, and exploring advanced detection and coordination techniques, the resilience and efficiency of power systems can be substantially improved.

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