Performance Analysis Of Overcurrent Protection Schemes In Power Systems

Conference Paper · October 2024

DOI: 10.1109/ASET60340.2024.10708727

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2024 Advances in Science and Engineering Technology International Conferences (ASET) | 979-8-3503-4413-4/24/$31.00 ©2024 IEEE | DOI: 10.1109/ASET60340.2024.10708727

***Abstract*— Overcurrent in electrical systems, characterized by the excessive flow of current, poses significant risks to electrical equipment and personnel safety. Overcurrent protection schemes play a pivotal role in protecting electrical circuits from the detrimental effects of excessive current flow. A robust protection mechanism safeguards electrical systems from potential damage, reduces risks, ensures uninterrupted electrical power supply, and enhances system reliability. This research paper aims to investigate the various overcurrent protection schemes employed in electrical circuits and power systems. By comprehensively examining these protection mechanisms, this study aims to provide insights into their role in mitigating the adverse effects of overcurrent events and enhancing the resilience of electrical power systems. The overcurrent protection schemes are simulated and modelled using MATLAB SIMULINK, with a subsequent comparison of their characteristics.**

Keywords*— *Faults, Overcurrent protection, Power systems

I. INTRODUCTION

A power system's protection scheme is made to constantly check the system to ensure maximum electrical supply continuity with the least amount of harm to people, property, and equipment. The fault damaged the equipment that carried the fault. The main issue with overcurrent faults is overheating, which may lead to a fire. Protection methods reduce the time required to find the fault because of the power system in a complex system. The purpose of protective relays is to lessen the impact of faults. However, each extra protective relay raises the risk of disruption due to the potential of the relay malfunctioning itself. The security provided by the protective scheme and the threat must be balanced by the protection engineer. It is impossible to build a power system that never fails. So, the engineers must learn to live with that failure. These failures are referred to as faults by the engineers. The aim of the project is to investigate the impact of overcurrent faults on the reliability and stability of power systems. There are three main objectives of the project; to analyze the performance metrics, identify the strengths, weaknesses, and limitations of each protection scheme, and evaluate the effectiveness of the protection schemes in mitigating overvoltage events under different fault scenarios and operating conditions.

II. LITERATURE

The most common protection method used is overcurrent protection. Overcurrent protection exists in many situations [1]. This report will investigate the performance of the various types of overcurrent protection employed in electrical systems for safeguarding the systems from overcurrent. In this study, the performance of overcurrent relays such as AC time relay, distance relay, differential relay, inverse definite minimum time (IDMT) relay, and directional relay will be investigated.

A. AC Time Relay

AC time relays provide essential timing functions to achieve time-delayed control functions. The key elements are relay coils, contacts, and timing mechanisms, which interact to initiate and terminate timing sequences based on predefined settings. These relays enhance system flexibility, efficiency, and safety, thereby mitigating the risk of equipment damage, process disruptions, and operational inefficiencies. Recent advancements in AC time relay technology include developments in solid-state relays, microprocessor-based control algorithms, and integration with digital systems, enabling enhanced performance, flexibility, and functionality.

B. Differential Relay

Directional relays play a crucial role in safeguarding both transmission and distribution networks. While directional relays have demonstrated effectiveness over the years, emerging applications and novel power system disturbances pose new challenges [1]. The differential relay is less sensitive to faults that occur outside the protected zone, but it's very sensitive to faults inside the safe zone. The operation of differential relays depends on the difference between two or more comparable electrical variables. Directional relaying is one of the most important protective relays used in situations where the fault current direction is not fixed, such as transmission lines, smart grids, and meshed distribution networks. Traditional directional relaying approaches have some limitations and may not suffice in all practical scenarios. Voltage often serves as a reference for fault direction detection in transmission lines, which is impractical in distribution networks due to the absence of potential transformers. Recent research leverages postfault current to detect the fault direction [2].

C. IDMT Relay

Ensuring the protection of electricity distribution networks presents a growing challenge amidst ongoing pressure to enhance performance. The standard tripping characteristic of an overcurrent relay typically involves a predefined relationship between the magnitude of the fault current and the time it takes for the relay to operate and trip the circuit breaker. For higher fault currents, the relay will trip faster to isolate the fault and protect the system from damage. This standard characteristic ensures coordination with other protective devices and prevents unnecessary tripping during transient faults or normal operating conditions [3]. IDMT relays continuously monitor the current flowing through the protected circuit using current transformers (CTs) installed in the circuit. The time taken for the IDMT relay to trip decreases as the magnitude of the fault current increases. Hence, the relay operates faster for higher fault currents to quickly isolate the fault and minimize damage to the system. The advent of microgrids with distributed energy resources serves as a solution to the ever-increasing power demand. But simultaneously, it imposes several challenges on the protection system in place. Bidirectional power flow, with substantial changes in magnitude and direction of fault current, may lead to the failure of the protection system. A genetic algorithm-based relay coordination scheme for microgrid protection is proposed in [4].

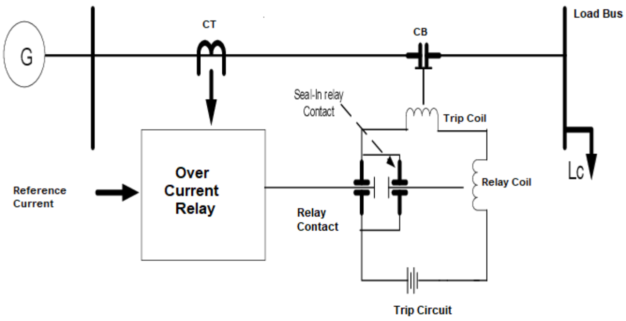

Fig. 1 IDMT relay

D. Distance Relay

A distance relay is a protective relay primarily utilized for safeguarding transmission lines. Fault Detection accuracy is the accuracy with which the relay can detect the location and type of fault within the protected zone. The distance from the relay location to the protected zone is known as the reach of the distance relay and the time taken by the relay to initiate tripping upon detecting a fault. The ability of the relay to coordinate with neighbouring relays and selectively trip the nearest circuit breaker to isolate the fault is called the Zone Selectivity. To find the impedance down the line to the fault, the detection scheme compares the voltage at the relay site with the fault current as detected by the relay. Fig.2 illustrates the configuration of the distance relay within a power system. Distance Relay operates by computing the fault impedance from measured voltage and current of the line within a short circuit loop. Mathematically, the impedance is determined using Ohm's law, expressed as

$$Z = V/I \tag{1}$$

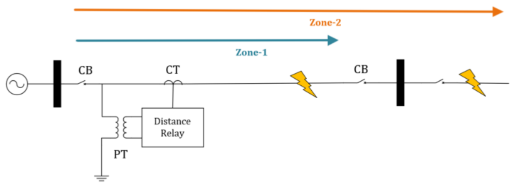

Fig. 3 Distance relay

E. Directional Relay

The working principles of a directional relay involve detecting the direction of fault currents within an electrical power system and initiating mitigating actions accordingly. Directional relays typically incorporate current transformers (CTs) installed at strategic locations within the power system, which can sense the direction and magnitude of currents flowing through the circuit. By comparing the phase angles of the current signals received, we can determine the direction of fault currents. Directional relays utilize a polarizing signal to establish a reference direction for fault detection with the relay's directional settings. When the relay detects the fault, it initiates protective actions, such as tripping circuit breakers to isolate the faulty section of the power system. Directional relays are characterized by being highly sensitive to fault currents while being immune to currents from other directions, thereby helping to maintain system stability and reliability. Fig. 3 illustrates the configuration of the directional relay within a power system and Fig. 4 shows the MATLAB model for the AC time relay.

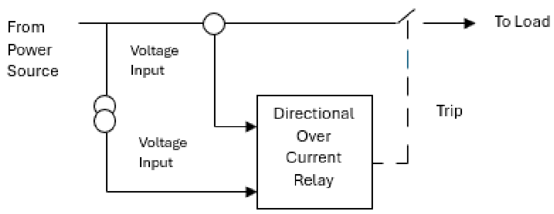

Fig. 4 Directional relay

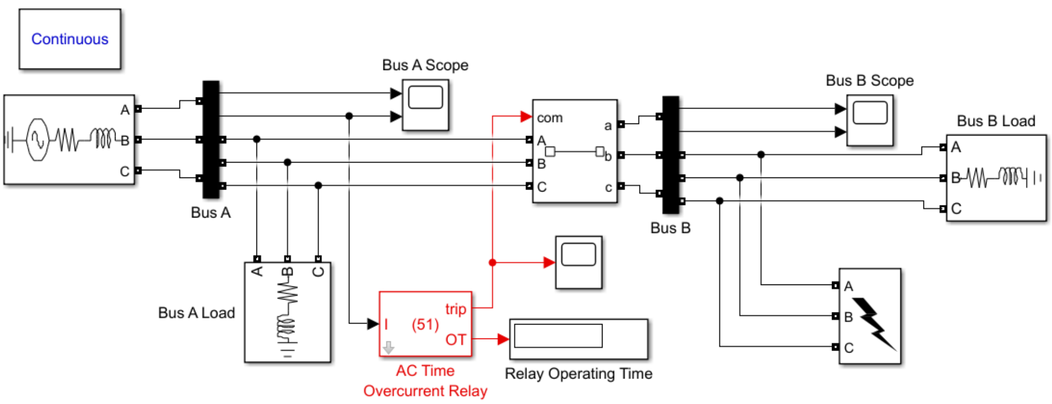

Fig. 2 AC time relay Model

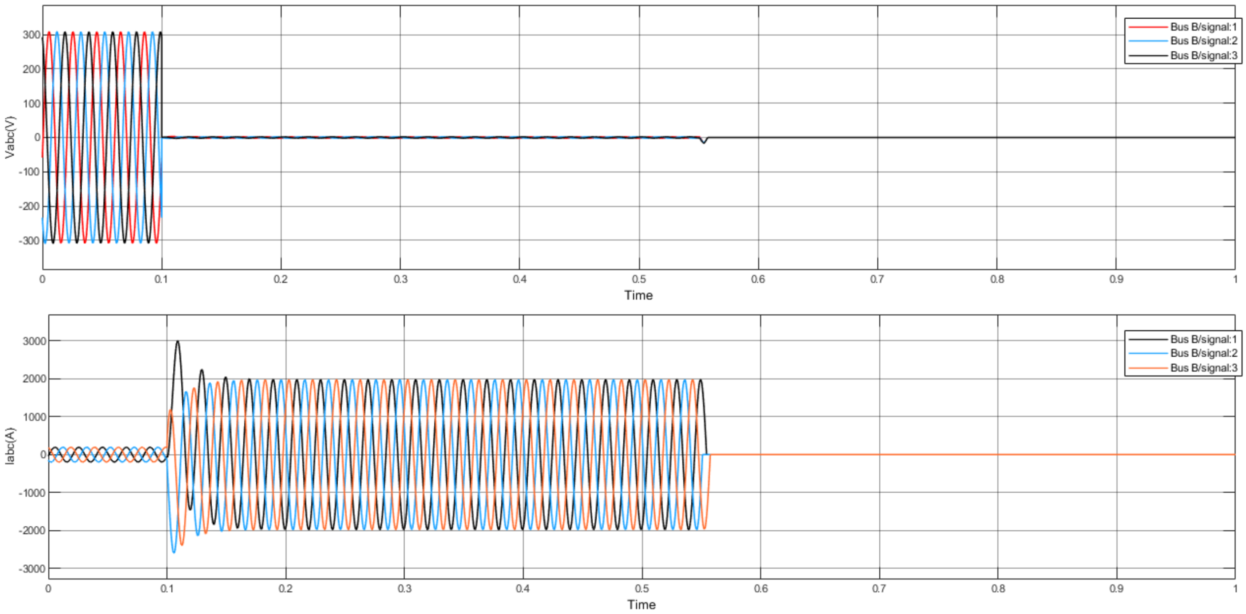

Fig. 5 AC time relay output

III. METHODS

In this research, the various overcurrent protection schemes in power systems are analyzed and their performances are compared. MATLAB SIMULINK and Sim power Systems Toolbox are used for modelling. The power system models were constructed with detailed specifications, including buses, generators, loads, and interconnections. Overcurrent protection schemes, such as AC Time Relay, Distance Relay, Differential Relay, IDMT Relay, MATLAB's Simulink, Sim power Systems Toolbox, and scripts, were used for modelling and simulation results.

A. AC Time Relay

The relay is set to parameters such as pickup current level and time delay settings for delay. The model includes a mechanism to simulate a three phase fault, enabling the testing of the relay's response to severe fault conditions. By introducing faults at different locations and with varying characteristics, one can study the relay's operation time and overall performance. Simulations are run under various operating and fault conditions to observe the relay's accuracy and timing, ensuring its reliability and effectiveness in protecting the power system. The graphs in Fig.5. represent the voltage and current before and after the operation of an AC time relay during a fault condition in a simulated power system. The Vabc graph represents phase to ground voltages (Vab, Vbc, Vca) of a three phase power system. Initially, the waveforms exhibit a consistent sinusoidal pattern characteristic of a stable electrical grid. At approximately 0.2 seconds, all three voltage waveforms abruptly drop to zero, which suggests that a fault condition was introduced, resulting in the complete loss of voltage. This action is indicative of a circuit breaker operation which isolates the faulted segment due to the activation of the AC time relay, hence the flat line that follows, showing the system voltage post fault and relay operation.

B. Differential Relay

Fig. 6 depict the MATLAB model for a differential relay in a power system. The differential relay is typically used for the protection of equipment like transformers, generators, and motors. In a differential relay scheme, the current entering and leaving of the protected zone or equipment will be compared. If the difference between these two currents (the differential current) exceeds a preset threshold, it indicates a fault within the protected zone, and the relay will operate to isolate the affected section. In real power systems CTs are placed both ends of the protected equipment, to measure the incoming and outgoing currents. In the model, these would be simulated by current measurement blocks. Differential Relay Block is the core of the model, where the difference between the two currents is calculated. If the differential current is above the set threshold, which could be defined using a Simulink function block or a customized subsystem, the relay block would generate an output signal that represents the relay operation (a trip signal). Upon operation, the differential relay would send a trip signal to the circuit breaker, modeled in Simulink as a switch block. When the trip signal is received, the switch opens and isolates the protected equipment from the rest of the power system, thereby preventing further damage. To avoid false tripping due to transient conditions, such as inrush currents, differential relays often include a restraining mechanism. This is modeled using a logic block that compares the differential current against a restraint current, which is usually a function of the load current. The protected zone is represented by the section between the two sets of CTs. Any fault simulations within this zone would result in an imbalance between the incoming and outgoing current, triggering the relay.

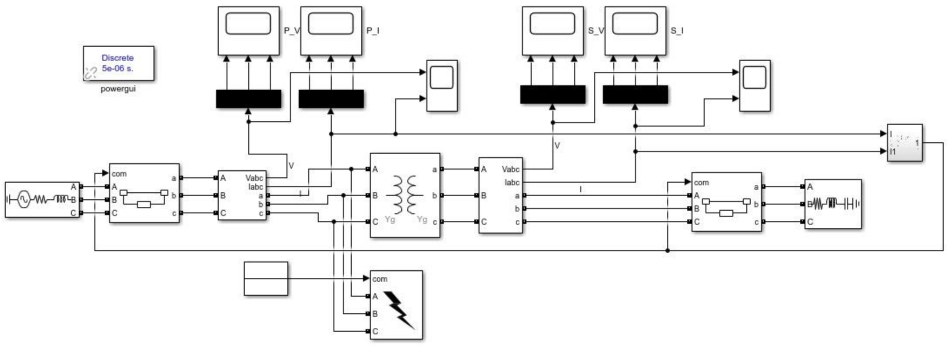

Fig. 6 Differential Relay

Fig 7 presents the three phase voltage (Vabc) and current (Iabc) plots, from a MATLAB Simulink modelling and simulation. The waveforms are in phase with each other and have the same amplitude and frequency, as in a balanced three-phase power system. There are no apparent disturbances or irregularities in the voltage signals throughout the observed timeframe, which suggests that there are no faults within the system or the faults are being perfectly balanced. The waveforms show balanced and consistent patterns, with all three phases mirroring each other in terms of amplitude and phase angle. The absence of any spikes or abnormal peaks indicates that there is no significant fault current flowing through the system, or the system is operating under post fault stabilized conditions. The current waveforms are also undistorted and stable throughout the simulation, indicating that the relay has successfully stabilized the post fault conditions to resume normal operation.

C. Inverse Definite Minimum Time (IDMT) overcurrent relay.

Fig. 8. shows the MATLAB Simulink schematic for modeling an Inverse Definite Minimum Time (IDMT) overcurrent relay. IDMT relays are employed as a protective relay in power system networks to detect and isolate overcurrent conditions which is caused by short circuits or equipment overloads. The key components of the IDMT Relay model is a three phase AC Source: which represents the power source for the system, providing the necessary three phase voltage to the power network[7]. The transmission line carries power from the source to the rest of the system. IDMT relay block performs the functionality of IDMT relays which has time-current characteristics such that the time taken for the relay to trip decreases as the magnitude of the current increases. The settings on the relay block (0.629 for Pickup, 50Hz for the nominal frequency, 25.1 for the Time Multiplier Setting, and 5 for the Current Setting) will dictate how the relay responds to overcurrent situations. AC Circuit Breaker block represents the circuit breaker, which opens to isolate the fault when triggered by the relay. The breaker's operation can be seen and monitored through the relay status indicator, which likely shows whether the breaker is open or closed. Fig 9 represents the three phase voltage and current waveforms from a MATLAB Simulink simulation of an IDMT relay in a power system. These phase voltage waveforms (V1, V2, V3), exhibit a stable sinusoidal pattern, which indicates that the three-phase voltages are balanced, and the power system is in a normal operating state and no fault conditions have been detected. The current waveforms (I1, I2, I3) also show a sinusoidal pattern with consistent amplitude across all three

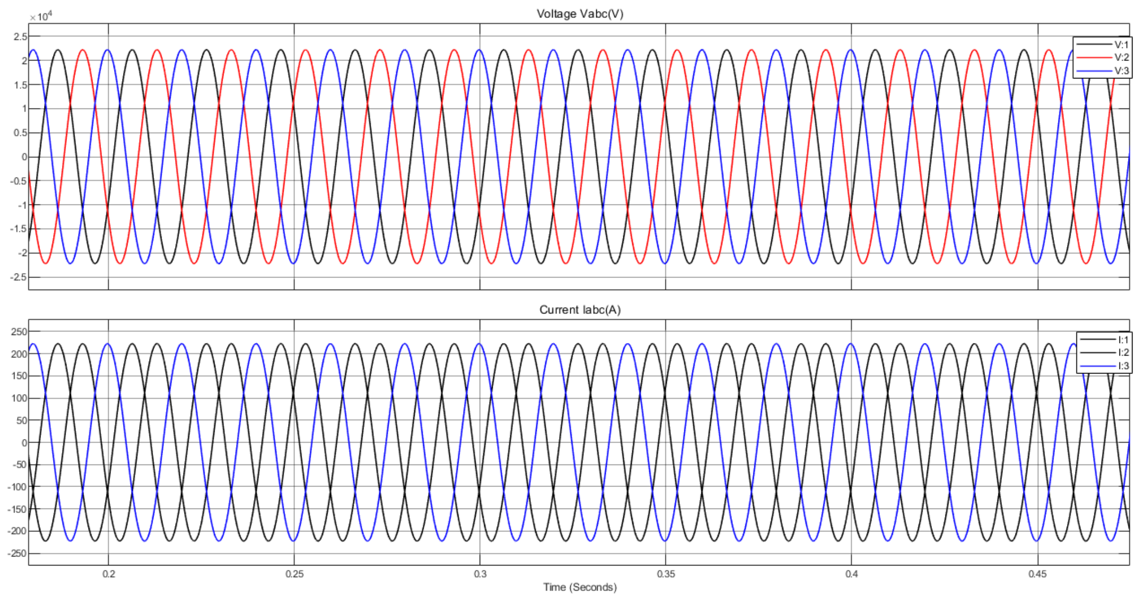

Fig.7 Differential relay output

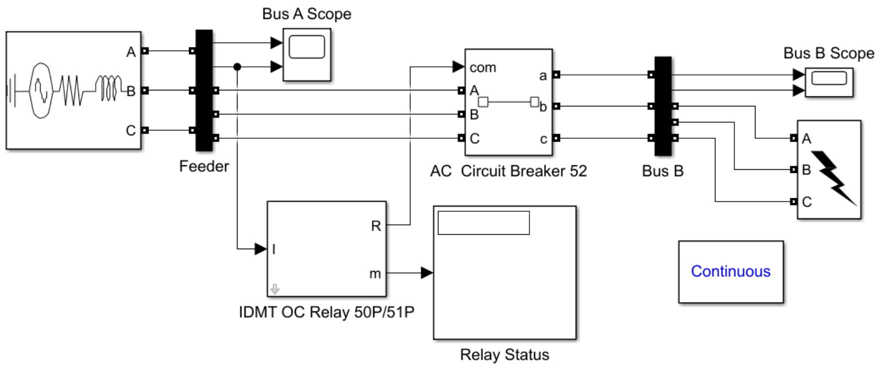

Fig. 8 IDMT relay Model

phases, indicative of a balanced load without any overcurrent events. To analyze the relay's performance, faults is introduced to the system to observe the relay's tripping characteristics and time delays. The IDMT OC relay model in MATLAB Simulink is set up to emulate the behavior of a physical IDMT relay. When an overcurrent situation arises, the relay block receives a signal proportional to the current from the feeder. Using the predefined settings, the relay determines whether the current is high enough and has persisted long enough to warrant a trip. If the current exceeds the pickup threshold and the time delay has elapsed (according to the IDMT characteristic), the relay sends a trip signal to the circuit breaker (S2). The circuit breaker then opens to disconnect the faulted section of the system, preventing damage to equipment and ensuring safety.

D. Distance Relay

Fig 10 depict a MATLAB Simulink model of a distance relay, which is used for line protection in power systems. The model simulates the normal operation of the power system with the distance relays monitoring the line impedance continuously. This type of relay operates by measuring the impedance of a line and comparing it to a predetermined threshold. When a fault occurs, the impedance typically drops, and if it falls below the set threshold, the relay will trip to isolate the faulted section of the line [10].The key components in the Distance Relay Simulink Model includes two AC sources which represent power generation units, with their power ratings and voltages specified. There are two transmission lines, Line1 and Line2, each with a specified length in kilometers. A three phase fault is used to introduce fault is introduced via the fault programming blocks along the transmission line to test the relay's response. Circuit Breakers (Brk1 and Brk2) are used to isolate a section of the power system when a fault is detected. They are controlled by the output trip signals from the distance relays. Distance Relay Blocks (MIHO Relay_B1 and MIHO Relay_B2) are modeled using the Mho characteristics, which are commonly used for distance protection. They measure the impedance seen at each end of the line and provide a trip signal if a fault is detected within the protected zone. RPT and SPT Blocks represent the reach point and starting point settings for the relay, which determine the sensitivity and operating range of the distance relay. If the impedance falls within the relay's operating zone, a trip signal is generated, instructing the associated circuit breaker to open, isolating the faulted section. The operation of the distance relay can be analyzed based on the type of fault, its location, and how the relay's trip time corresponds with the change in impedance. Figure.11. presents a series of waveforms represent the voltages and

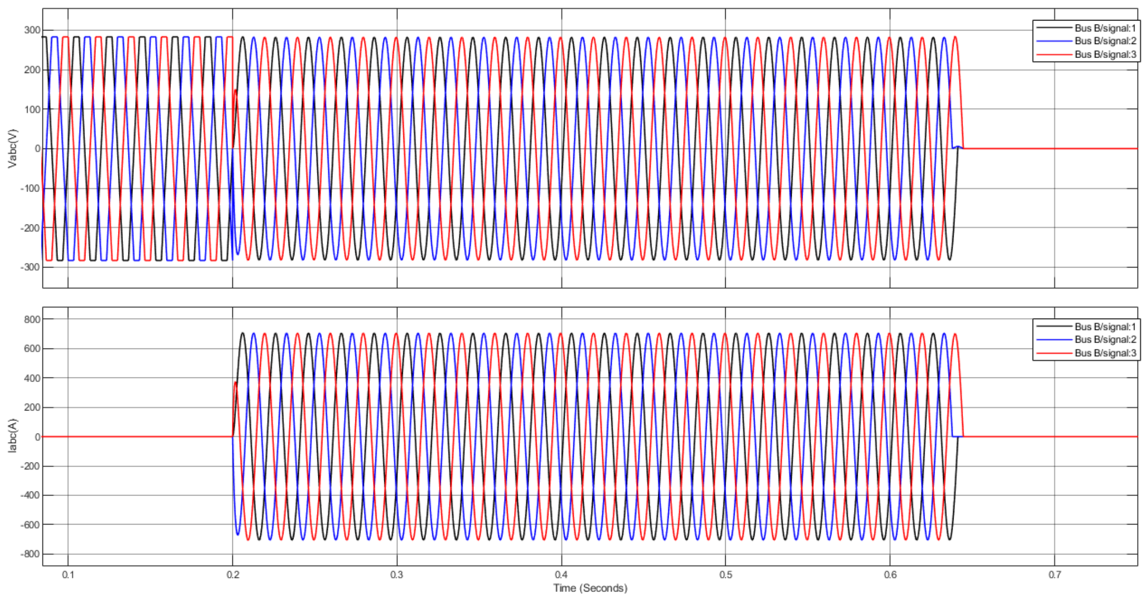

Fig 9 IDMT Relay

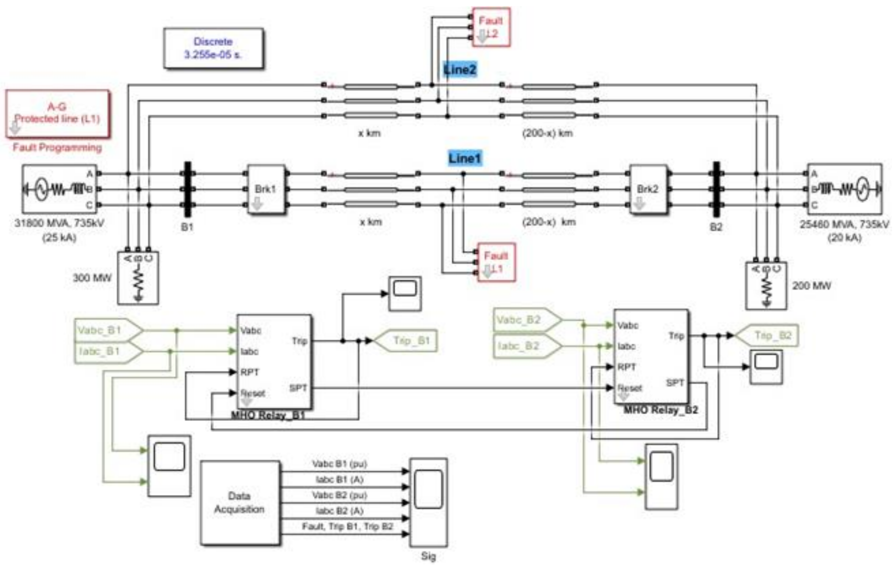

Fig. 10 Distance relay Model

currents at two buses (B1 and B2) in a power system, as well as the status of fault and trip signals for distance protection relays at these buses from a MATLAB Simulink simulation. The voltage waveforms for Bus B1 (Vabc B1) are shown in the first row. They display normal, balanced three-phase voltage conditions until around 0.15 seconds when a disturbance causes all three-phase voltages to drop, indicating a fault on the system. The corresponding current waveforms for Bus B1 (Iabc B1) initially show balanced three-phase currents, but at the same time as the voltage disturbance, there is a significant spike in current for phase 1, suggesting this phase is most affected by the fault.

IV. COMPARITIVE ANALYSIS

The results of the study offered an insight into the behaviors of various types over current relays. This relay type's performance is based on overcurrent magnitude and the time delay before tripping. IDMT Relay provides overcurrent protection with inverse definite minimum time characteristics, offering faster operation for larger currents and slower operation for currents closer to the threshold. Distance Relay employed for line protection, measures the impedance along a line and operates if the impedance falls below a certain setpoint, indicating a line faults.

The Simulation Observed that it effectively detected and isolated a fault condition, as evidenced by the changes in the voltage and current waveforms and the activation of trip signals. This relay's performance is sensitive to fault locations and impedance measurements. Distance Relay operates based on the measured impedance and is more focused on the location of the fault. the Distance Relay showed an actual trip response. However, the IDMT Relay would typically have a variable response time depending on the current's magnitude, while the AC Time Relay's response could be set to either a fixed or variable time based on its time-current characteristics. Table I provides a comparative analysis of over current relays. Table II. provides a comprehensive summary of the qualitative performances of

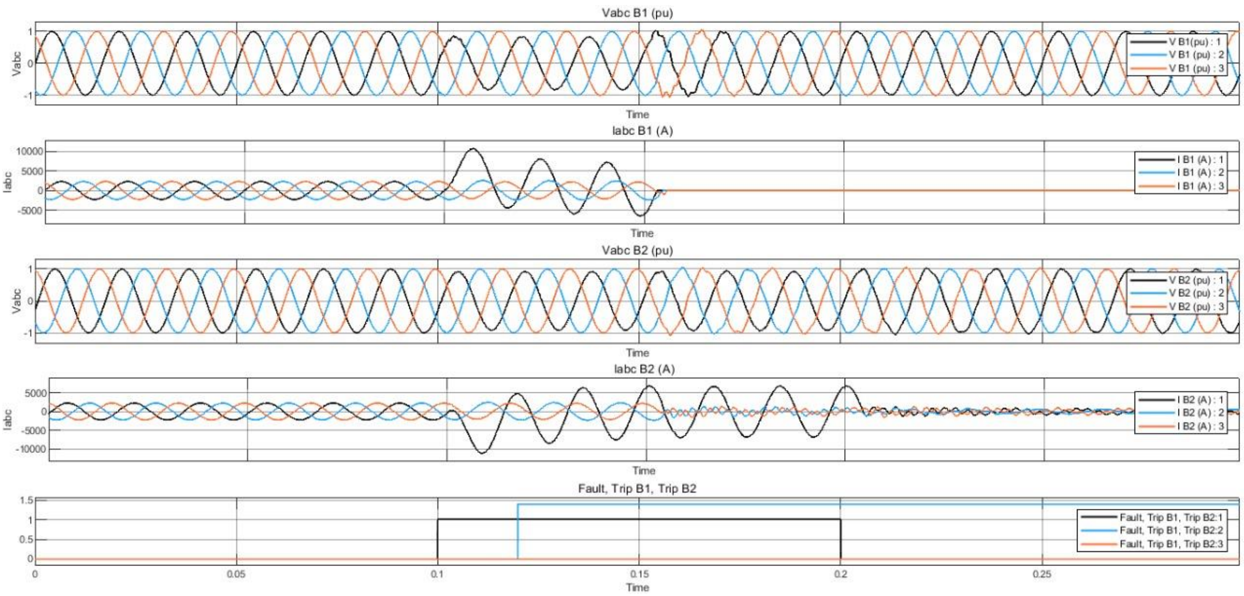

Fig.11 Distance relay output

the relays studied.

TABLE I RESPONSE TIME

Relay Type		Fault injection time (s)	Detection Time(s)	Response time (s)
AC time relay		0.100	0.558	0.458
Differential relay		0.500	0.502	0.002
IDMT relay		0.200	0.645	0.445
Distance relay		0.100	0.157	0.057
		0.190	0.204	0.085

V. CONCLUSION

The study investigated the critical role of overcurrent relays in safeguarding electrical systems against over current faults. The delay characteristics of various overcurrent relay has provided valuable insights into their operation and application in electrical protection systems. Differential relay has demonstrated faster response with fault detection within 0.502 seconds and response time of 0.002 seconds as response time. Through the exploration of standard time delay characteristics, inverse time delay characteristics, and other variations such as IDMT relays, a deeper understanding has been gained on of how these relays detect and respond to overcurrent conditions in electrical circuits.

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TABLE II. QUALITAVIVE ANALYSIS OF OVER CURRENT PROTECTION SCHEME

Protection Scheme	Description	Application	Reliability	Cost	Complexity	Speed of Operation	Maintenance	Sensitivity
AC Time Relay	Provides time-delayed operation based on alternating current (AC) signals.	Used for timing functions in applications where time-delayed operation is required.	Moderate	Low	Moderate	N/A	N/A	Low
Distance Relay	Operates based on the impedance measured at the relay location.	Used for protecting transmission lines by measuring impedance and initiating tripping actions.	High	Moderate	Moderate	N/A	Moderate	High
Differential Relay	Compares the currents entering and leaving a protected zone to detect internal faults.	Commonly used for protecting transformers, generators, motors, and busbars.	High	High	High	N/A	N/A	High
IDMT Relay	Operates with an inverse time-delay characteristic, tripping faster for higher fault currents.	Widely used for overcurrent protection in distribution networks and motor circuits.	Moderate	High	Moderate	N/A	N/A	Moderate