Definite time over-current protection on transmission line using MATLAB/Simulink

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ABSTRACT

This paper has investigated the application of the definite time over-current (DTOC) which reacts to protect the breaker from damage during the occurrence of over-current in the transmission lines. After a distance relay, this kind of over-current relay is utilized as backup protection. The over-current relay will provide a signal after a predetermined amount of time delay, and the breaker will trip if the distance relay does not detect a line failure. As a result, this over-current relay functions with a time delay that is just slightly longer than the combined working times of the distance relay and the breaker. This DTOC is tested for various types of faults which are 3-phase fault occurring at load 1, 3-phase fault occurring at load 2, a 3-phase fault occurring before primary protection, and the behaviour of voltage and current with a failed primary protection. All the results will be obtained using the MATLAB/Simulink software package.

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1. INTRODUCTION

Electricity generation [1], [2], transmission [3], [4], and distribution [5], [6] to users are the responsibility of utility companies a major aspect of this responsibility is the provision of a safe yet dependable power supply to the users [7]. Utility companies all over the world have complex protective devices installed on their power system equipment for the safety and protection of the transmission and distribution networks from problems. Time delay over current relays is used to protect many radial systems. The breaker closest to the fault point can be chosen with an adjustable time delay, while other upstream breakers with longer time delays stay closed [8]. In other words, the relays can be programmed to run sequentially to interrupt the least amount of load during a fault. When fault currents are significantly greater than normal currents, relay coordination is considered successful [9]. Additionally, the coordination of overcurrent relays often restricts the number of breakers in a radial system to five or fewer, as any more breakers could result in an excessively long delay for the relay that is nearest to the source [8].

The time gap between the primary and remote backup protection devices is known as the coordination time interval. It is the interval between the operating times of the backup relaying and the interval between the clearing of the fault by circuit breakers during the primary relaying [10]. A number of variables, such as current transformer (CT) error, the direct current (DC) offset component of the fault current, and relay over travel, make it difficult to determine the exact relay operating timings. To consider these aspects in the majority of real applications, typical coordination time coordination intervals between 0.2 and 0.5 s are chosen. Inappropriate over-current [11] relay parameter adjustments could result in catastrophe. It is crucial to verify the settings of power protection equipment and to ensure its operation under various fault scenarios to prevent negative things from happening. In this small work, MATLAB/Simulink is used to model the overcurrent relay [8], [10]. The main purpose of this work is to analyze the applications of the definite time over-current (DTOC) on various types of faults by using the MATLAB/Simulink. The other objectives of this work are: i) to observe the characteristics of the DTOC and ii) to develop the DTOC relaying modeling in normal and with faults coordination in MATLAB/Simulink.

2. LITERATURE REVIEW

2.1. Over-current relays

An overcurrent relay protects against over-currents as its name implies [12]–[15]. This relay compares the measured values to predetermined values using current inputs from a CT. The logical representation of an overcurrent relay is shown in Figure 1.

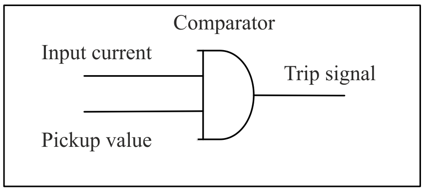


Figure 1. Logical representation of over-current relay [12]

The breaker will disconnect automatically to protect equipment from damage when it receives a signal trip. This will happen when the input current value is higher than the preset value. Fault pickup is the term used to describe the situation when a relay senses a fault. In the case of instantaneous overcurrent relays, the relay can send a trip signal right away after detecting the fault, or, in the case of time overcurrent relays, it can wait a certain amount of time before sending a trip signal. The relay computes this time delay, also known as the operation time of the relay, based on the protection algorithm built into the microprocessor [12].

2.2. Definite time over-current relay

The structure of a definite time overcurrent relay is provided in Figure 2. In this type, two conditions must be met for operation (tripping): the current must exceed the set value, and the fault must persist for a duration equal to the relay's time setting. When a distance relay is used as the primary protection for a transmission line, this over-current relay serves as backup protection. After a predetermined amount of time has passed, the overcurrent relay will instruct the breaker to trip if the distance relay did not identify a line fault. In this instance, the overcurrent relay operates with a time delay that is just slightly longer than the combined period that the distance relay operates normally, and the breaker operates [16], [17].

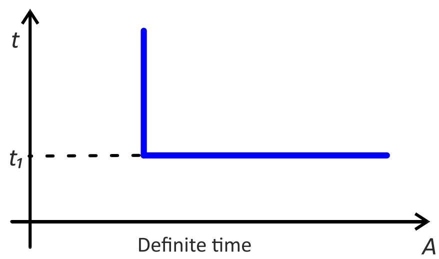


Figure 2. Definite time of overcurrent relay [12]

Two requirements must be met for this sort of overcurrent relay to operate or trip. First, the current must be greater than the setting value and second, the fault must persist for at least as long as the relay's setting time [18]. Regarding its use, the definite time overcurrent relay can function in different conditions in electrical systems. It can serve as a backup protection system for transmission lines with time delays that have distance relays. Additionally, it can serve as a backup protection system for a power transformer's differential relay with a time delay. The primary defense, in addition to serving as a backup, is provided by incoming feeders and bus couplers with customizable time delay settings [19], [20].

3. METHOD

3.1. Method of coordination of DTOC relay simulation

Relay coordination plays a critical role in maintaining the integrity and stability of power systems. It ensures that faults are accurately detected and isolated while minimizing disruption to the overall system operation. Through careful design, analysis, and simulation, engineers can achieve effective coordination of protective relays, allowing for a safe and efficient operation of the power system. Figure 3 depicts the application of DTOC [21] relaying without fault coordination modeling, which has been implemented using MATLAB/Simulink. The purpose of this modeling is to analyze the behavior and performance of the relay system under different fault scenarios. By studying the relay operation and coordination in a simulated environment, engineers can optimize and fine-tune the relay settings to achieve the desired level of reliability and selectivity.

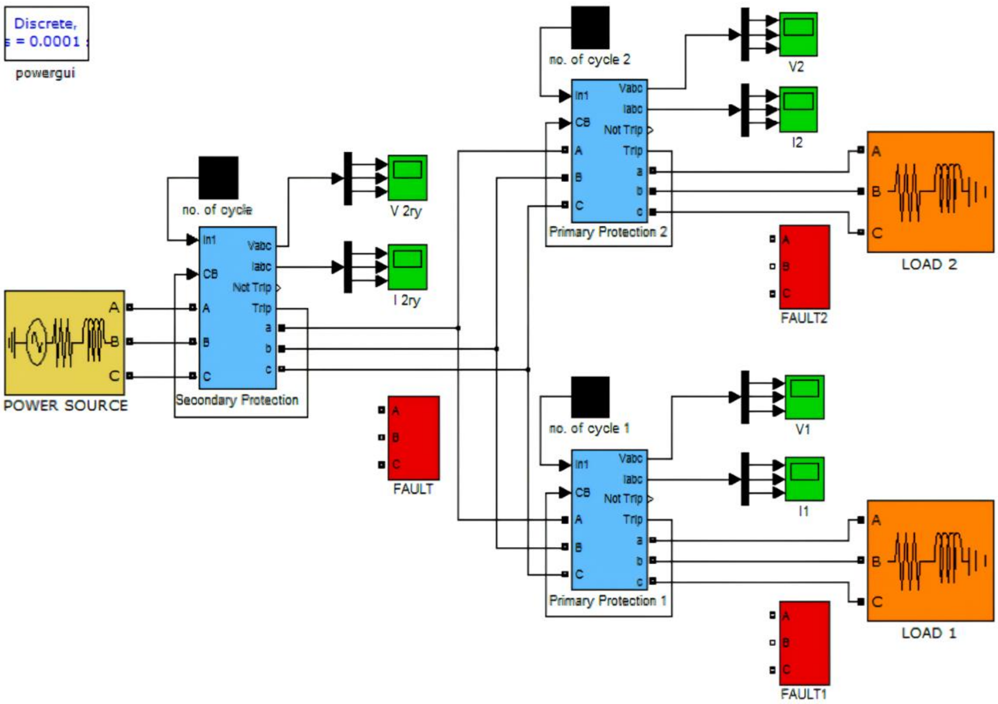


Figure 3. DTOC relaying without faults coordination modelling in MATLAB

3.2. DTOC relaying setting

In power systems, the DTOC relay is the main defense mechanism for power systems. The relay begins to operate for DTOC characteristics after an intended time delay (operation time). Current must be greater than the setting value for the relay to operate (trip) [22], and the fault must be ongoing for at least the relay's setting in time. Modern relays may have multiple protection stages, each of which has its current and timing settings. The operating time is constant for operation of DTOC relay. The amount of current above the pick-up value has no bearing on how well it operates. It contains pick-up and time dial settings, an intended time delay system that lets you choose the required time delay, and it's simple to coordinate. It offers constant travel time irrespective of fault location and in-feed variation [23], [24].

Time grading/discrimination of action must be properly coordinated with the operational DTOCs relays. The relay sub-system must function well first since it is certain that the other systems are in good condition. Symmetric ground faults occurred simultaneously throughout the power system, but temporal discrimination allowed the relay closest to the load side to function. To ensure that the right time lag is operational time, the time constant is altered. Since the subsystem has a shorter time lag value, it will trip out first [25].

3.3. Type of fault that will be tested

In Figure 4, the effectiveness of the protection modeling is demonstrated through the implementation of DTOC relaying with fault coordination modeling using MATLAB/Simulink. This modeling aims to assess the performance and reliability of the protective relays under different fault scenarios. The modeling includes testing four types of faults to evaluate the effectiveness of the protection system:

a. A three-phase fault occurring at load 1: this scenario simulates a fault event at a specific load in the power system. By analyzing the response of the DTOC relays in detecting and isolating this fault, engineers can assess the accuracy and speed of the protective relays in responding to faults at a specific location.
b. A three-phase fault occurring at load 2: this fault scenario introduces a fault event at a different load in the power system. The purpose is to evaluate the protective relays' coordination and selectivity in identifying and isolating the fault location while maintaining the continuity of power supply to other unaffected loads.
c. A three-phase fault occurring before primary protection: this fault scenario investigates the behavior of the protection system when a fault occurs before the primary protective relay. It evaluates the secondary relays' backup protection and their capacity to find faults and react to them without primary protection.
d. The voltage and current behavior with a failed primary protection: this scenario focuses on evaluating the system's response when the primary protective relay fails to operate. By monitoring the voltage and current signals, engineers can analyze the backup protection's effectiveness and the system's reliability in the absence of primary protection.

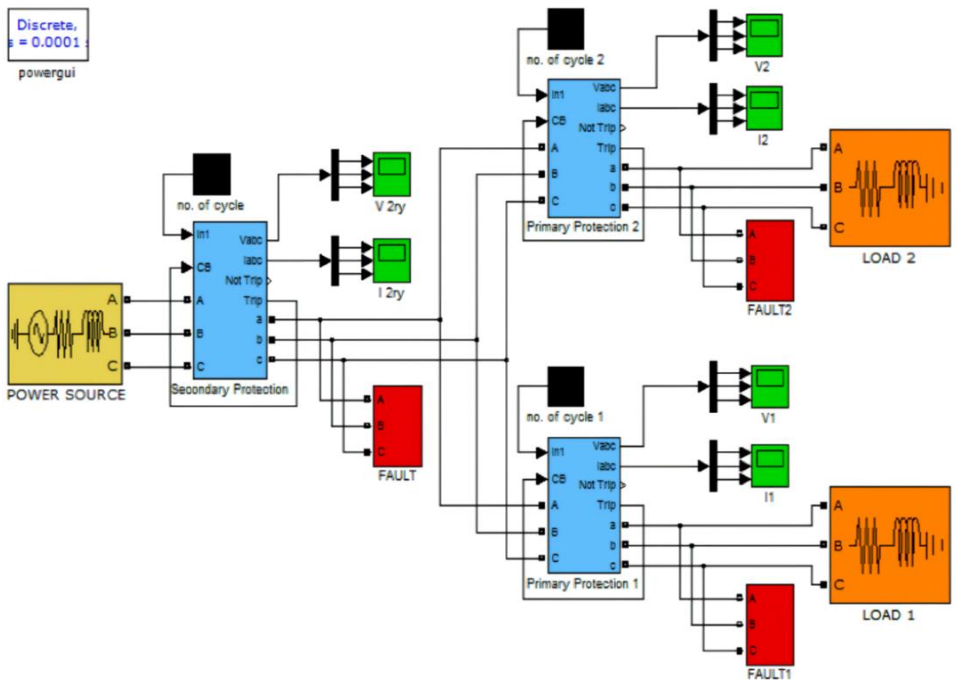


Figure 4. DTOC relaying faults coordination modelling in MATLAB

The circuit parameters used in the simulation are shown in Table 1. In the circuit, the breaker will trip according to the number of cycles that have been set. Period and frequency are mathematical reciprocals of one another. Frequency means oscillations (cycles) per second in hertz (Hz), expressed as, f=1 cycles/sec. Then, the operating time can be expressed as in (1):

$$T\ (sec) = \frac{n(no.of\ cycle)}{f(frequency)} \qquad (1)$$

Table 1. Parameter of the component in the circuit

Component	Parameter
Three-phase source	Voltage (V): 11 kV Internal connection: Y (grounded) Frequency (Hz): 50 Hz
Three-phase series RLC load (load 1/load 2)	Voltage (V): 11 kV Configuration: Y (grounded) Frequency: 50 Hz Power (W): 200 MW
Primary protection 1/2	No. of cycle to trip: 3 cycles
Secondary protection	No. of cycle to trip: 5 cycles

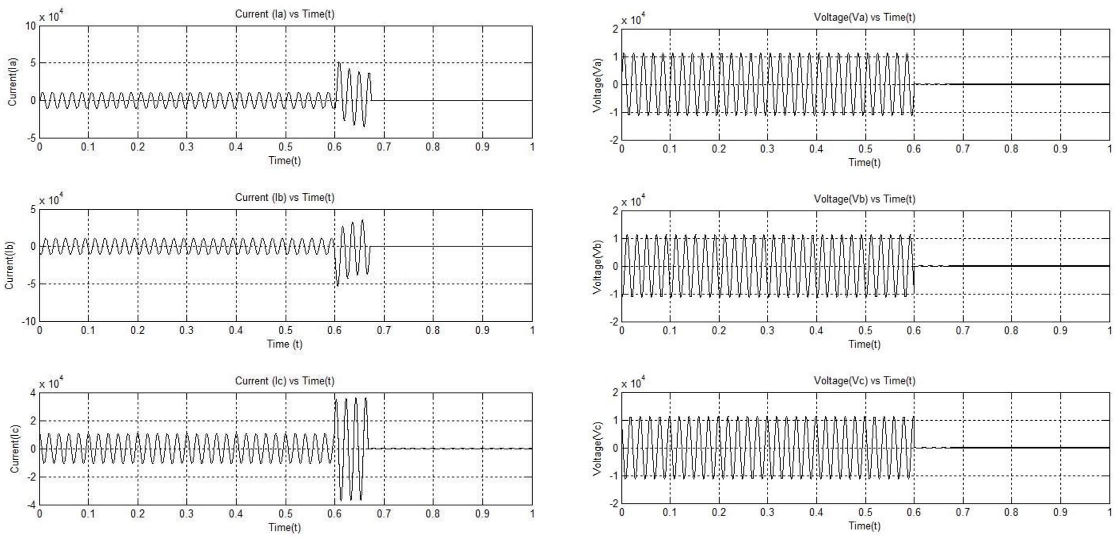
4. RESULTS AND ANALYSIS

The results obtained from the fault coordination modeling in MATLAB/Simulink indicate that the location of faults significantly impacts the behavior of current and voltage in the power system. Different fault scenarios were considered to assess the performance and effectiveness of the protective relays in the coordination and response to faults.

In the case of a three-phase fault occurring at load 1, the modeling analysis demonstrated how the protective relays detected and isolated the fault at the specific load. By analyzing the current and voltage responses, engineers were able to evaluate the accuracy and speed of the protective relays in identifying and mitigating the fault at the intended location. Similarly, in the scenario of a three-phase fault occurring at load 2, the fault coordination modeling allowed engineers to assess the coordination and selectivity of the protective relays. The focus was on identifying and isolating the fault location while ensuring an uninterrupted power supply to other unaffected loads.

4.1. 3-phase fault occurring at load 1

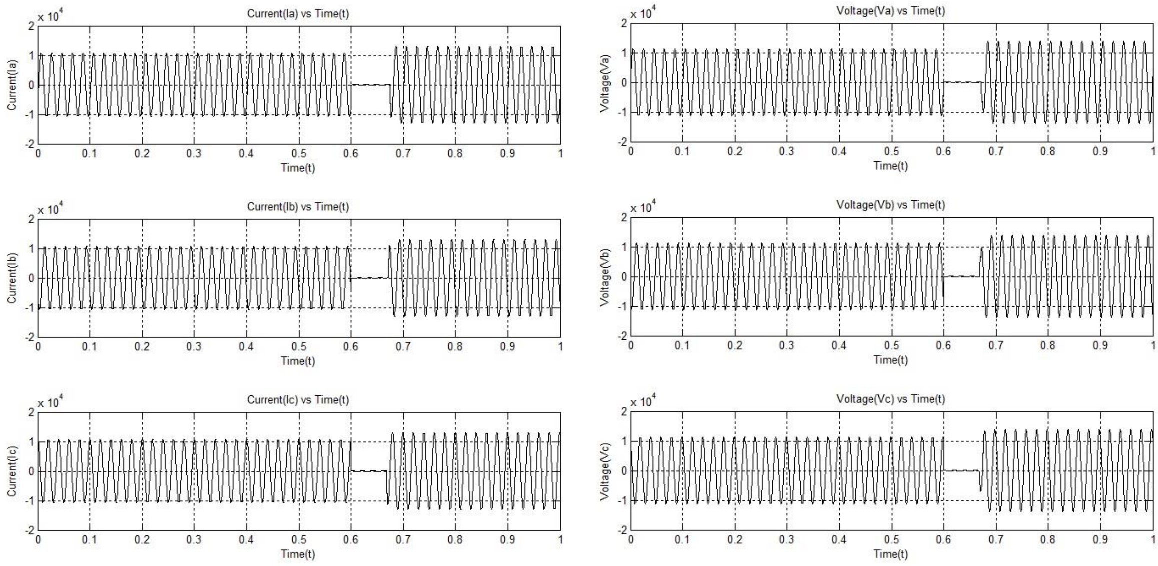
At normal condition, the current and voltage were steadily flowing to load 1 without any interruption. When the fault occurs at load 1, the fault is between the load and the primary protection 1. Figure 5(a) shows that when the fault occurs, the current magnitude in all the phases rose rapidly, starting at time 0.6 s until 0.675 s, and sends a signal to the primary protection 1 (relay and circuit breaker) to disconnect the circuit to protect load 1 from damage. Figure 5(b) shows the result for voltage at load 1 when the fault occurs at load 1. From the result, the voltage started to stabilize at time 0.6 s which means that when the relay and circuit breaker disconnect the circuit, there is no voltage supplying load 1.



(a) (b)

Figure 5. When a fault occurs at load 1; (a) current waveform of load 1 and (b) voltage waveform of load 1

Figure 6(a) shows that load 2 experienced some power supply losses at time 0.6 s until 0.675 s due to the fault that occurs at load 1. But in a short period, it received power supply when the primary protection 1 had disconnect the circuit for load 1 to ensure continuous power supply to load 2. Figure 6(b) shows load 2 having no voltage supply at time 0.6 s until 0.675 s due to the fault that occurs at load 1.



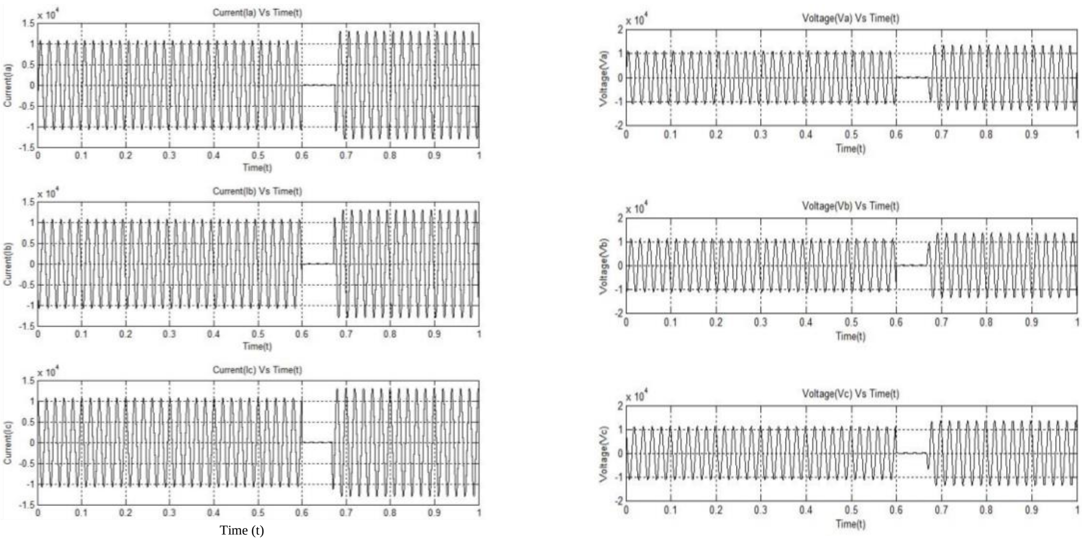
(a) (b)

Figure 6. When a fault occurs at load 1; (a) current waveform of load 2 and (b) voltage waveform of load 2

4.2. 3-Phase fault occurring at load 2

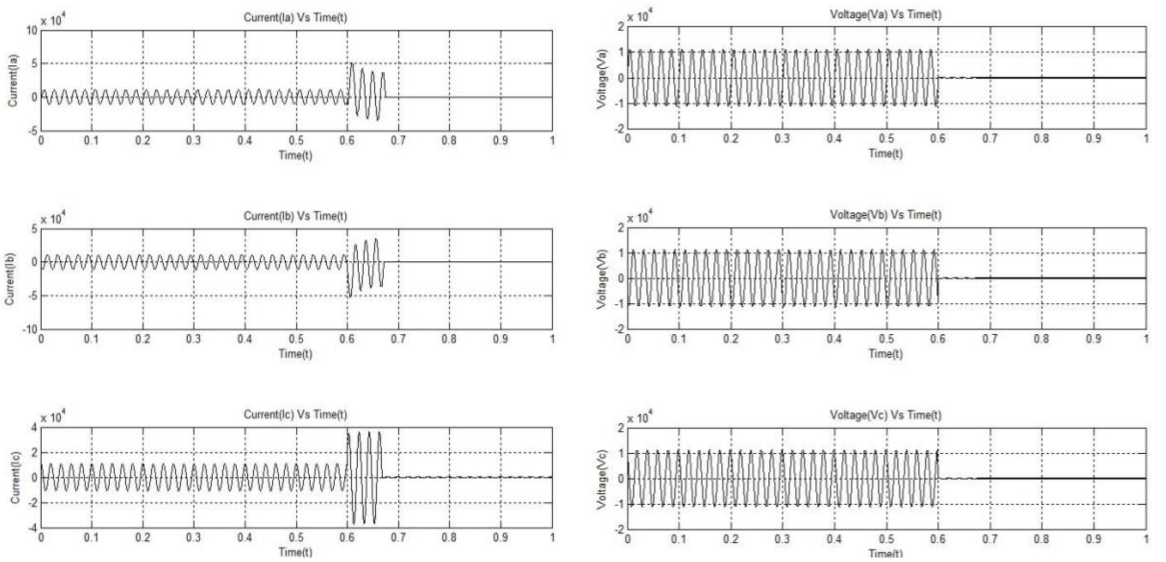
As for the three-phase fault occurring at load 2, the current and voltage were in normal state condition until the interruption had occurred at load 2 at time 0.6 s until 0.675 s where the 3-phase fault happens. It is similar to fault occurring at load 1 where the fault is between the primary protection 2 and load 2.

Figure 7(a) shows that there is a steady state condition at time 0.6 s until 0.675 s, which means that there is no current supplied to load 1 when the fault occur at load 2. As for the voltage in Figure 7(b), the results for the voltage at load 1 show the same as in Figure 7(a). From Figure 8(a), the current magnitudes were increased by about 4 V at a time 0.6 s due to the short circuit and it can damage the load. To prevent this, the primary protection 2 (relay and circuit breaker) will disconnect the circuit for load 2 when it receives the signal during the fault. The supply for load 1 will experience some voltage drop for a moment and the supply will be restored in a short period by referring to Figure 7(a). Figure 8(b) shows the voltage at load 2 when the fault occurs at load 2. The result shows that the steady state condition started from time 0.6 s which means there is no voltage supplied when the circuit is disconnected.



(a) (b)

Figure 7. When a fault occurs at load 2; (a) current waveform of load 1 and (b) voltage waveform of load 1

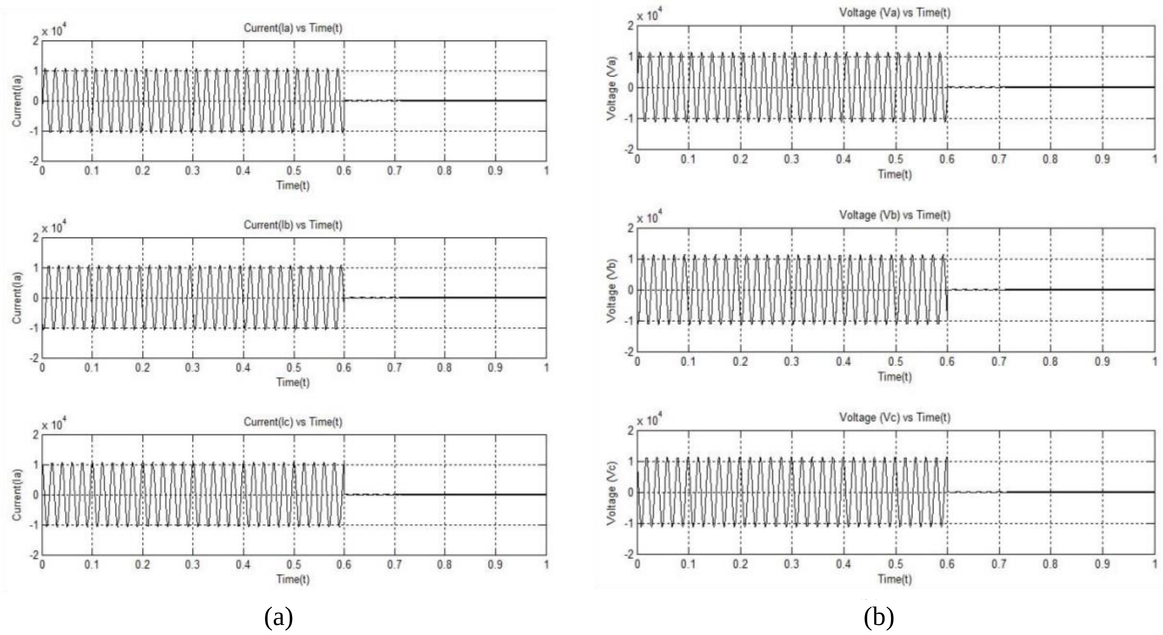


(a) (b)

Figure 8. When a fault occurs at load 2; (a) current waveform of load 2 and (b) voltage waveform of load 2

4.3. 3-Phase fault occur before primary protection

When the fault occurs before the primary protection, the secondary protection will operate, and it will disconnect the power source from continuing to deliver the current. Figures 9(a) and (b) show that sudden supply drop to zero for current and voltage at load 1 when the fault occurs at time 0.6 s. Figures 10(a) and (b) for current and voltage at load 2 during the fault occurs before primary protection shows similarity as Figures 9(a) and (b).



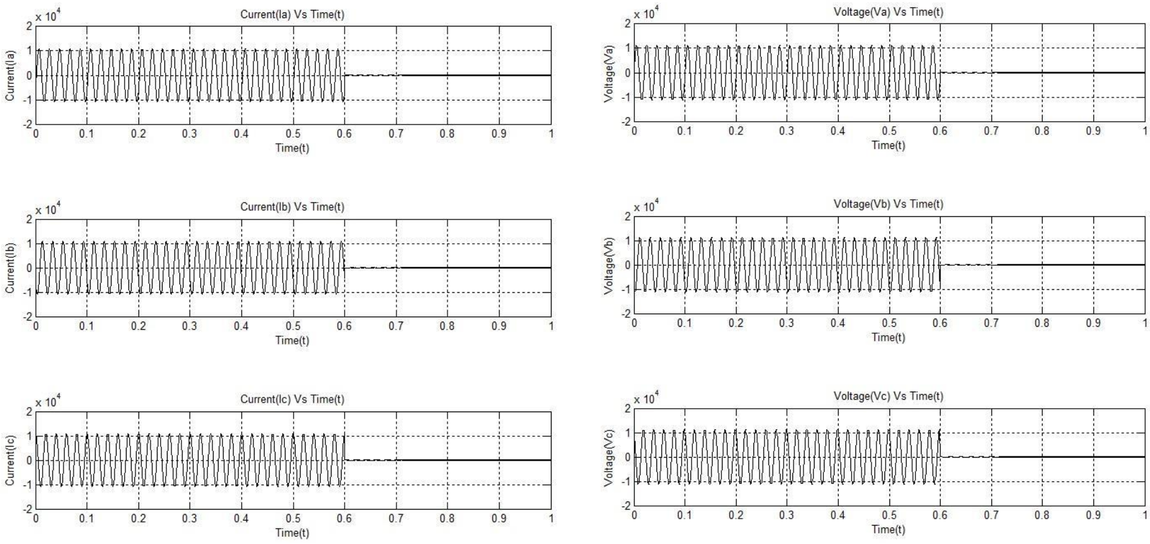
(a) (b)

Figure 9. When a fault occurs before primary protection (a) current waveform of load 1 and (b) voltage waveform of load 1

4.4. The behavior of voltage and current with a failed primary protection

In this case, the results in Figures 11 and 12 were produced when the fault occurred at load 1 and load 2 but the primary protection did not operate as predicted; this can cause damage to the connected load.

Backup protection will cover the missed operation of the primary protection. When this problem occurs, the situation will be the same as when the fault occurs before the primary protection, where both loads will be disconnected from the power source due to the operation of the secondary protection.



(a) (b)

Figure 10. When a fault occurs before primary protection; (a) current waveform of load 2 and (b) voltage waveform of load 2

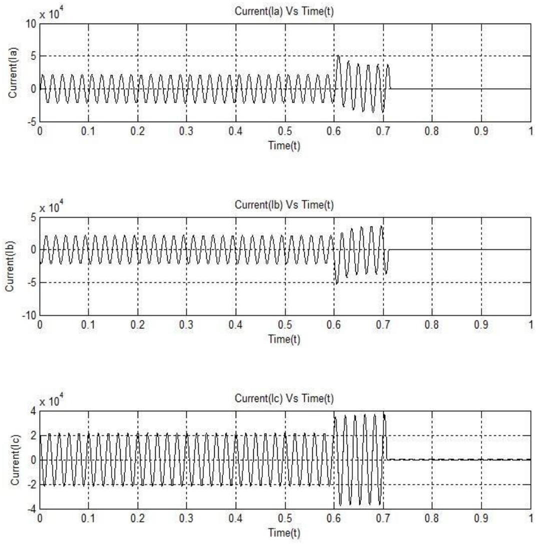


Figure 11. The current at the secondary protection when primary protection fails

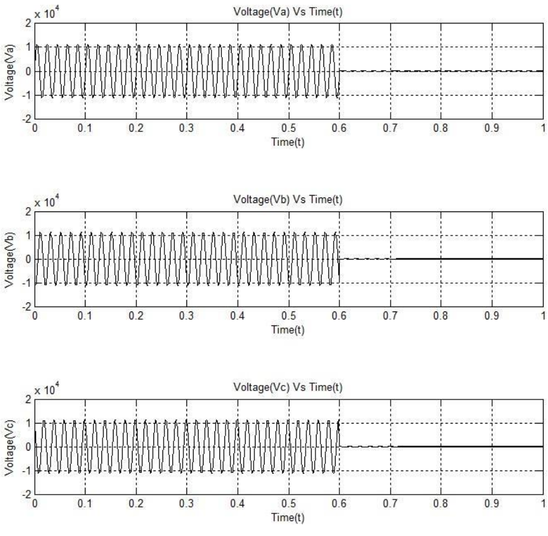


Figure 12. The voltage at the secondary protection when primary protection fails

5. DISCUSSION
5.1. System under protection

Table 2 shows the system consisting of four cases that vary in terms of operating protection, number of cycles, and operating time. The protection system will act according to the setting of the relay. It was coordinated in a manner that if some elements fail to operate for any reason, the backup (secondary) protective relay will operate in a directional way-out. The number of cycles was determined according to the priority of the protection. The relay at the load will be given the most priority, where it needs to be the first to operate and the secondary relay will be the backup protection if the main relay does not operate.

Table 2. Operating time taken for protection device

Cases	Operating protection	Number of cycles	Operating time (s)
3-phase fault occur at load 1	Primary protection 1	3	0.06
3-phase fault occur at load 2	Primary protection 2	3	0.06
3-phase fault occur before primary protection	Secondary protection	5	0.06
The behaviour of voltage and current with a failure primary protection	Secondary protection	5	0.1

So, the backup relay needs to be set for a longer time delay to give the priority relay to be operating first. As for the priority relay, it will be given a smaller number of cycles so that it will operate faster from the secondary to clear the fault. The secondary relay will be set for more numbers of cycles so that it will not operate sooner. The number of cycles cannot be too much because it will cause the relay to operate much slower and the over current could damage the sensitive appliance.

5.2. Discrete time over current

Changes in generation or the high-voltage transmission system have very little impact on the fault-current magnitude, which mostly depends on the fault site. Fast fault clearing reduces damage, increasing the likelihood that the reclosing will be successful. The primary current pickup should be as high as possible while remaining low enough for the relay to dependably function under the lowest possible fault-current scenario.

6. CONCLUSION

In real conditions, a few factors must be considered for setting the relay, such as time multiplier settings, pickup value, characteristic curves. to ensure the safety and fast operation of the over-current relay. If not, the relay cannot detect the faulty conditions and will not trip, thus, cannot send a false tripping command. By using MATLAB/Simulink software, it can simulate any position of fault occurrence without any obstacle and the result can be seen through the scope. From the output, we can design the suitable operation or protection than can be provided to a certain situation. From several types of overcurrent relay, definite time overcurrent relay usually acts as back up protection relay whenever the main protection fails to execute the fault completely. However, in a certain time, this definite time overcurrent relay act as the main protection to outgoing feeders and bus couplers with adjustable time delay setting. Therefore, it can be concluded that all the objectives of this mini work have been achieved. As a contribution, this DTOC relay is a reliable component that ensures the safety of equipment. This is because it can react or used as back-up protection if the distance relay (primary protection) cannot perform well as a protection tool.

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