Transmission Lines Protection from Open Circuit and Short Circuit Faults using Basic Logics

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Abstract: When demand grows and electricity transmission lines expand, distribution power systems' efficiency and dependability are becoming more and more important. Because electricity-related issues have a vital impact on the stability and dependability of the power system, they should be identified and fixed as soon as possible. Transmission lines, the main component of this network, provide electricity to the utility. These lines are regularly harmed by unexpected failures that arise from a variety of unanticipated factors. Researchers are attempting to quickly identify and diagnose these issues to prevent financial losses. Using logic gate setup approaches to detect SC and OC for short-distance protection (SDP), this research suggests a method to foresee power system problems. Early on in the system's life, this model anticipates both progressive and abrupt problems. To detect OC and SC in the models, three-phase measurements of voltages, currents, and active power are taken to the logic gate setup during faults and normal operating conditions. By simulating the fault with various settings and modeling it in MATLAB/Simulink, the long-term reliability of the technique is confirmed.

Keywords: *Transmission Lines Protection, Short Circuit and Open Circuit Fault, Detection of System Fault.*

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I. INTRODUCTION

For numerous reasons, fault identification of transmission lines that are comprehensive and responsive is important in today's power systems. First, because the power system's lines are always in use, there is constant wear and strain on them. Extended maintenance intervals resulting from them cause partial load shedding and have the potential to cause a blackout. Second, the consequences of a problem occurring in one region of the system do not stop there; other areas of the system are also impacted by this event. Consequently, the entire system could be in danger of failing owing to major issues affecting the network as a whole if a defect in the transmission system arises and is not found and fixed right away [1].

Any equipment could experience a short circuit fault, which is one of the dangerous occurrences that endangers the power system. The protective relays are in charge of fault detection and identification in the event of a short circuit fault in equipment. This stops the fault from spreading to other devices and prevents additional harm from occurring. The related relay detects the fault and sends a trip command to the faulty part's breakers, causing that portion to be cut off from the network. Expanding the defective zone might lead to system instability and blackout if the protection system is not functioning properly [2]. Following the removal and separation of the problematic component from the remainder of the system,

A major component of the power system is made up of the power transmission network. The short circuit fault rate in transmission lines is higher than in other power system components and equipment because they travel through diverse climatic conditions. Numerous elements are taken into account when examining the transmission system fault rates in [3]. The following is a list of some of the reasons for short circuit problems in transmission lines [4]: i) lightning strike; ii) snow and ice on the lines; iii) improper insulation; iv) trees falling on the lines; v) birds colliding with the lines; vi) strong winds (storm); vii) fog; viii) fall power towers, and ix) tearing of wires. The two primary categories of transmission line short circuit problems are transient and persistent. After the protective relays identify transient faults and momentarily open the breakers, their impact is mitigated. A transient fault might be created, for example, if a bird collides with transmission line phases. The breaker will be closed again after a little wait once the fault has been resolved in this

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instance since the recloser logic will take over. By reconnecting the line, the system will be immediately restored in this scenario [5].

Two of the ongoing flaws include tower breakage and shredding of transmission line wire. When a recloser operation fails, the fault for these types of faults will continue, and eventually, the breakers will be permanently opened. Subsequently, the repair team must precisely find and promptly rectify this defect. The right algorithms can, however, also be used to identify temporary defects to verify the line condition and address any unwanted issues.

Since the electric power transmission line moves electricity from the point of generation to the point of distribution, it is one of the most important components of the power system network. Continuous power delivery is largely dependent on these lines' operation. A fault on these lines, which is unavoidable and much beyond the control of manhood, is one of the most important factors preventing the uninterrupted provision of electric power [6]. A malfunction that goes unnoticed for an extended period could cause enormous damage or a blackout.

Therefore, to support fleet repair and the restoration of the power supply with the least amount of disturbance, it is important to possess a more advanced and well-coordinated transmission line relaying scheme that efficiently detects and characterizes any form of problem within the designated period [7], [8]. Impedance-based fault detection systems examine the impedance characteristics of the transmission line to find open circuit and short-circuit problems. Short circuit failures typically result in a large reduction of line impedance, but open circuit faults cause an infinite impedance. Impedance relays compare the measured impedance of the line with predetermined thresholds to find defects. For instance, if the impedance falls below a certain level, it signals a short circuit fault.

Because short circuit faults create an abrupt change in the impedance that the relay senses, long-distance relays are capable of detecting them. Current suddenly rises over predefined levels during a short circuit. Because of this, the damaged area is isolated and the circuit breaker is tripped by the overcurrent relay. Relays are devices that, since they include overcurrent protection, can help locate short circuits, but their capacity to locate open circuit faults might be limited. When open circuit failures generate a phase angle mismatch between the voltage and current at the fault location, phase comparison relays can identify it.

A. Need for Fault Detection in Power Transmission Lines

Faults can arise in power systems for several causes, including equipment failures, environmental conditions, and operational errors. Transmission lines, distribution lines, transformers, power plants, and other equipment are arranged in complex networks to build power systems.

The main components of overhead power transmission lines' regular operation are power, frequency, voltage and current. Along with power frequency components, there will also be voltage and current fault components when a line failure happens. The narrow pulse wave that travels down the line from the fault point to both sides of the fault point can be thought of as the fault component [9].

Transmission lines are used to transport massive amounts of electricity across vast distances, frequently through inhospitable or remote locations. Any issue with these lines has the potential to cause massive power outages that impact a large number of customers. To reduce the length and extent of outages, fault detection systems assist in promptly discovering defects, enabling operators to isolate the problematic region and restore power to unaffected areas [10].

Transmission lines, Transformers, circuit breakers, and switches are examples of expensive equipment that can sustain major damage from transmission line failures, including short circuits and line-to-ground disturbances. To stop additional equipment damage and lower maintenance and replacement costs, operators can quickly identify faults and trip safety devices to isolate the problematic area [11].

Short-distance Protection using logic gates to detect open circuits and short circuits in power transmission lines refers to a method or system designed to safeguard power transmission lines from faults such as open circuits and short circuits, particularly in sections of the lines that are relatively close to the monitoring or control points. In this context, logic gates are employed to analyze voltage or current signals from the power transmission lines and make decisions based on predefined logic conditions.

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B. Basic Fault Detection and Control System

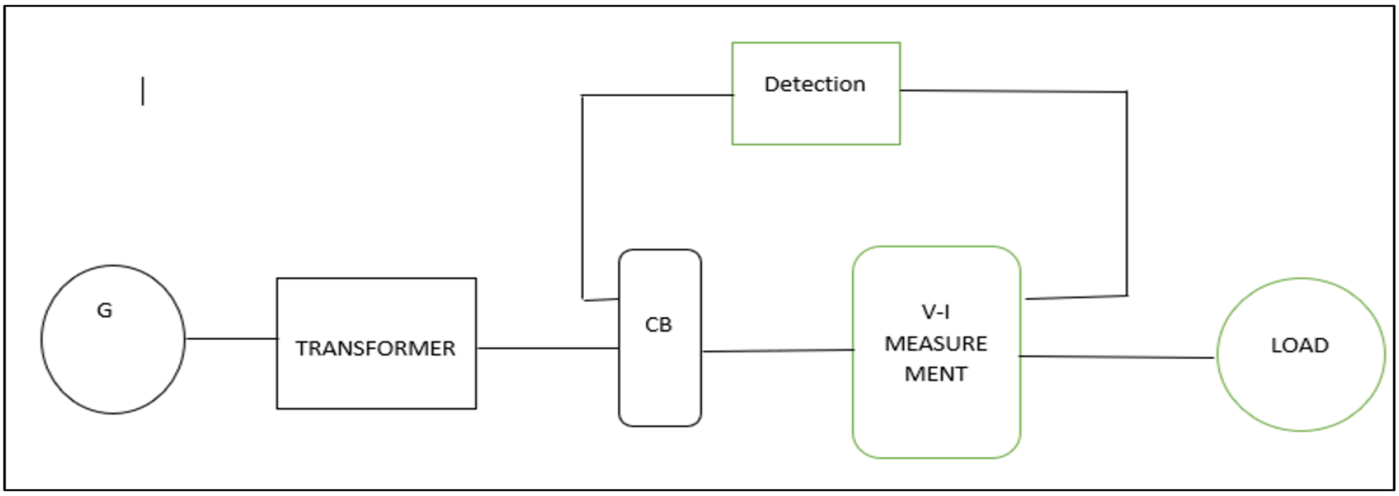

Fig 1 Block diagram BFDCS

It is normal practice in control of a power transmission system to represent a control system using a block diagram of Basic Fault Detection and Control System (BFDCS) for transmission lines. This connection of BFDCS is shown fig. 1.

Power source generates electricity from centralized power plants and transmitted to consumers via a network of interconnected transmission lines, substations, and distribution networks (12). The power source it offers allows for the creation of several types of energy, including mechanical and electrical. The power source for a power transmission line is typically the revolving electrical generator of a power plant.

The transformer is composed of two set of three phase wire coils that are coiled around a core. These coils are the primary and secondary windings. The primary winding is connected to the electrical power source/supply, while the secondary winding is connected to a load side.

For example, if the secondary winding has half of as many turns as the primary winding, the voltage at the secondary will be half that of the primary winding (13). Power transformers are crucial for safely and effectively transmitting electricity across long distances. The following are the key characteristics of power transformers in transmission lines: a) Electrical systems use power transformers to modify voltage levels b) the primary purpose of transmission lines is to increase voltage for efficient long-distance power transmission and then decrease it for end-user distribution.

Additionally, circuit breakers offer defense against short circuits, which happen when low-impedance wires are inadvertently connected. Extremely high currents from short circuits can endanger public safety and seriously harm equipment. Circuit breakers identify short circuits and trip the faulty portion of the circuit when they sense it (14). A manual approach of energizing and de-energizing a circuit is provided via circuit breakers. A circuit breaker can be reset once the overcurrent problem has been resolved, unlike fuses, which need to be changed when they open. The circuit can be restored by pushing the handle to the "OFF" position and back to the "ON" position. A licensed electrician should inspect a circuit if it reopens after being reset to the "ON" position.

V-I measurements are used to track the voltage and current at many locations in the power system, such as distribution networks, substations, transmission lines, and individual loads (15). Operators can evaluate the health of the electrical network, spot departures from standard operating procedures, and implement remedial measures to preserve system stability and dependability by using real-time V-I parameter monitoring (16).

The fault detection system described primarily utilizes various components for protection and to detect faults in electrical lines. The system can be either analog or digital. The analog type is still popular due to its greater reliability; however, it typically requires more physical space.

The digital system is developed using digital processors such as microprocessors or microcontrollers. Alongside these processors, electrical and electronic circuits function as the input and output interfaces. These interfacing circuits typically operate at medium-level voltages, while the digital processors themselves operate at low-level voltages, typically less than 5V.

In this research paper, digital logic concepts have been used to detect faults in a simulated environment. The fault detection has been implemented in MATLAB using digital logic gates. The implementation details are discussed in the following sections.

To implement fault detection using logic gates specifically, an electrical engineer can design a system that monitors the status of transmission lines and triggers an alarm or isolation mechanism when a fault is detected. For instance, an AND gate can be used to check specific combinations of signals that indicate different types of faults.

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In real-time power system planning and operation, transmission lines are significantly influenced by system load, which can affect decisions related to grid modernization projects, increasing generation capacity, and upgrading transmission infrastructure(17).

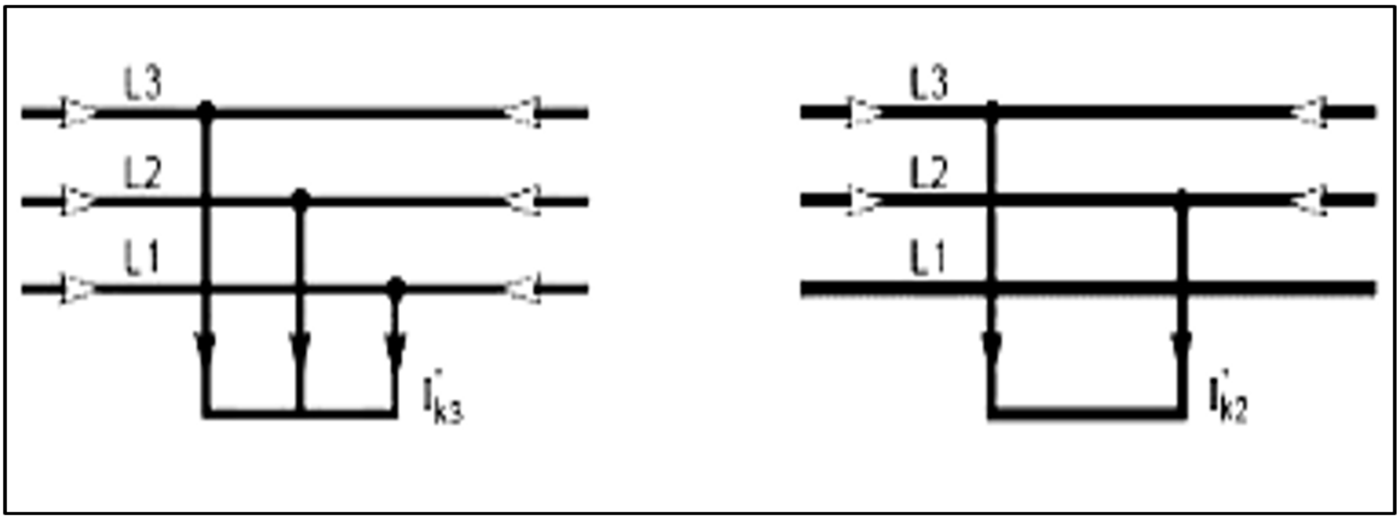
II. TYPES OF FAULTS IN POWER LINES

Symmetric Faults: A defect in a three-phase system is termed symmetric or balanced when it uniformly impacts each of the three phases. Typically, only 5% of all faults exhibit symmetric characteristics (18).

Asymmetrical Faults: The effects of an asymmetric or imbalanced fault vary between the three phases. All the lines are subcategories of asymmetric faults. Physical line contact, like a damaged insulator, or air ionization are common cause of the undesired signal between two lines and fault line to Ground.

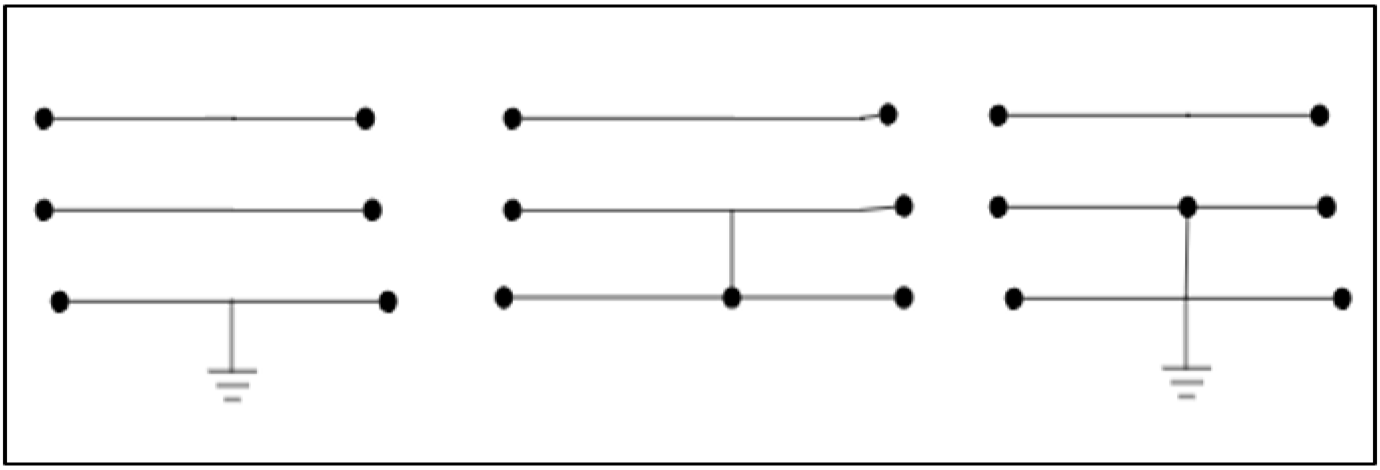
The physical unwanted signal from lightning or a storm physically touching one line and the ground. Line to Line to Ground Fault happens when two lines make touch with both the ground and each other, commonly caused by huge damage. (19). Typically, power network equipment ensures safe system operation with specified voltages and currents. when the unwanted signal occurs, they generate abnormal current flow patterns that could damage nearby equipment. (20). As seen in Figs. 2(a) and 2(b), examples include line-to-line-to-ground or line-to-line-to-line. Symmetrical faults are thought to occur at a frequency of between 3 and 6%. They leave the system in a balanced state and seriously harm power equipment.

In general, non-symmetrical defects are less severe but more common; they are also known as imbalanced faults. In these instances, the current flows in the phases differ due to varying impedance values in each phase, creating a systemic imbalance. Non-symmetrical faults typically manifest in three primary forms of lines (22). Among these fault types, Line-to-ground faults are the most prevalent, constituting 65 to 70% of all fault occurrences (23) The following diagram of unequal mistakes is depicted in Fig. 3.



(a) (b)

Fig 2 Symmetric faults (a) Line to Line to Line to Ground (b) Line to Line to Line (21)



(a) (b) (c)

Fig 3 Nonsymmetric faults (a) Line to Ground (b) Line to Line (c) Line to Line to Ground

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III. DEVELOPMENT OF FAULT DETECTION AND CONTROL SYSTEM FOR OC AND SC USING MATLAB

Using MATLAB, fault analysis of a 3-phase transmission line can be performed by simulating different fault scenarios. The analysis includes studying fault currents, voltages, and their effects on protection devices.

A. Model 1

A model has been developed using MATLAB for open-circuit (OC) fault detection and control, as shown in Fig. 4. The major components of the model include a three-phase load, measurement blocks to monitor the RMS values of current, and scopes to observe and analyze the graphs of line currents and voltages. The core of the system consists of comparison blocks and logical signal generators. An AND gate is used at the final decision-making stage.

There are two types of AND gates used in the model: a two-input AND gate along with logical output comparators at input stage and a three-input AND gate at the final decision level. The control signal for the circuit breaker is generated from the output of the three-input AND gate.

The current in each line is compared with preset threshold values. For normal operation, the input voltage source level is adjusted to ensure that the current flow in the system remains within acceptable limits while monitoring the status of the circuit breaker. Fig. 4 displays the OC fault test status.

In the first stage of comparison, both lower and upper current limits are set as preset values. During fault analysis, when one of the lines becomes an open circuit, the model disconnects the source using the circuit breaker. However, when one or more phases experience open-circuit faults, system balance is disrupted. This leads to uneven current distribution, potential overloading of the remaining operational lines, and the absence of current flow in the affected lines. Such imbalances can result in either overcurrent or zero-current conditions in other lines connected to the system. Automatically, this above situation trigger the circuit breaker and isolate the transmission lines from load.

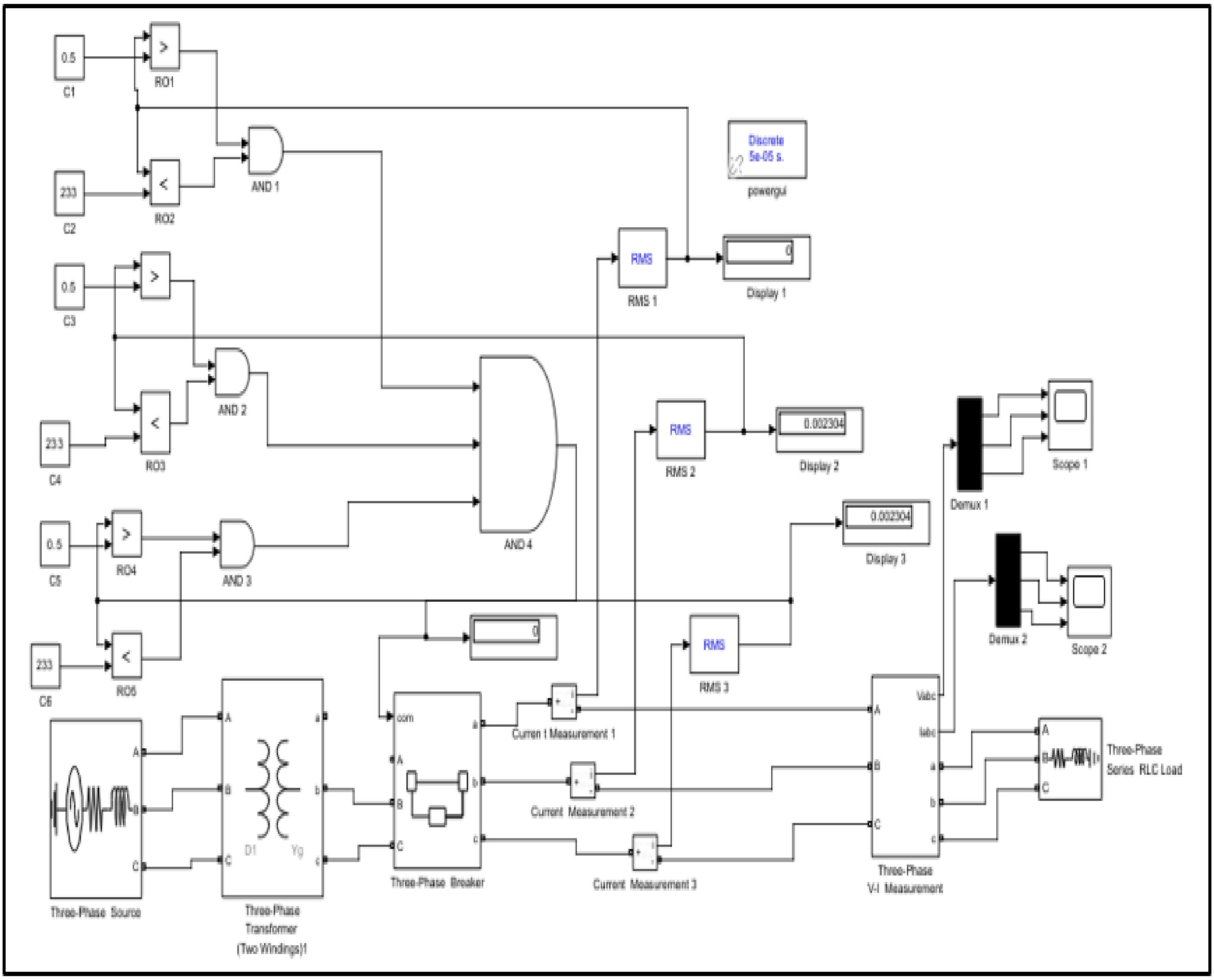

Fig. 4 Model Simulink of OC fault Circuit

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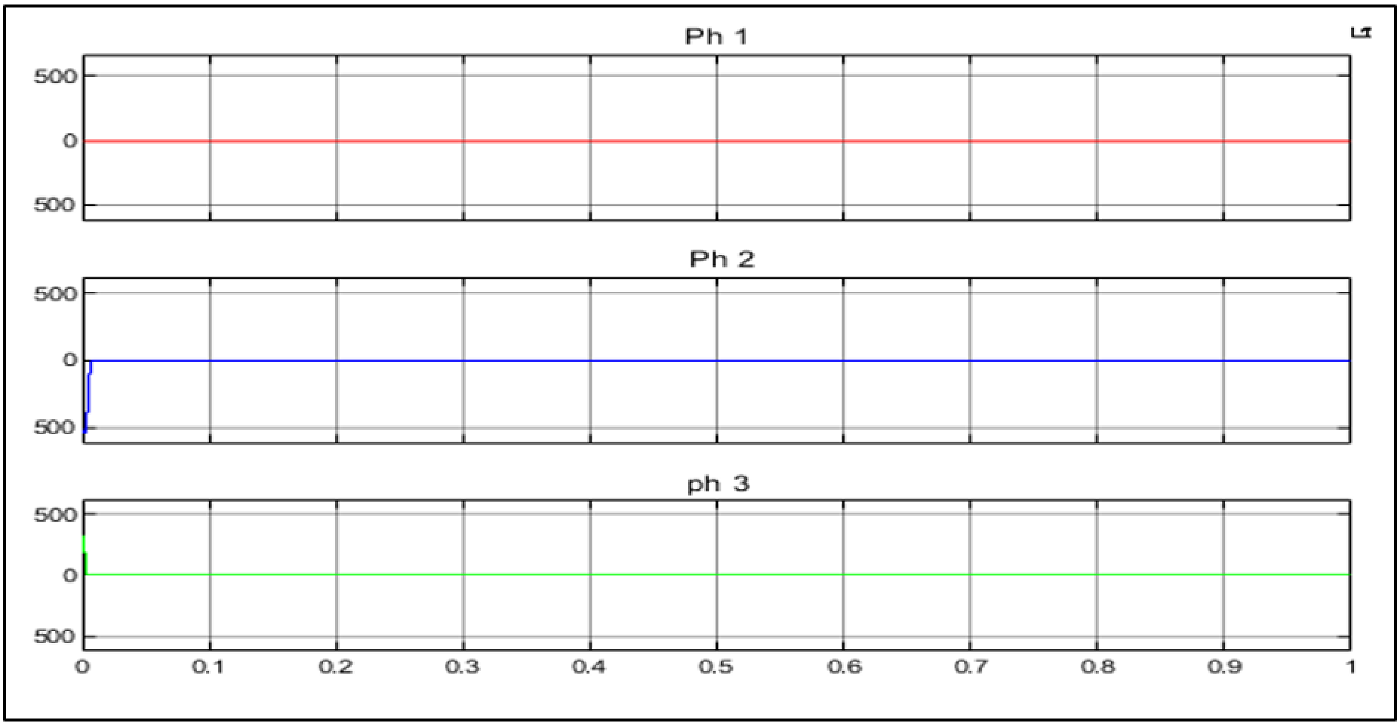

Fig 5 Current status after the OC fault detection

The current measurement of the open circuit fault circuit is shown in fig.5, above. The first phase line produces an open circuit, informing the consumer of an indication of an open fault in the system, while the remaining lines become zero.In fig.6, which shows the voltage measurement of the open circuit fault circuit, the first phase line indicates that there is an open fault in the system by becoming an open circuit, while the remaining lines become zero.

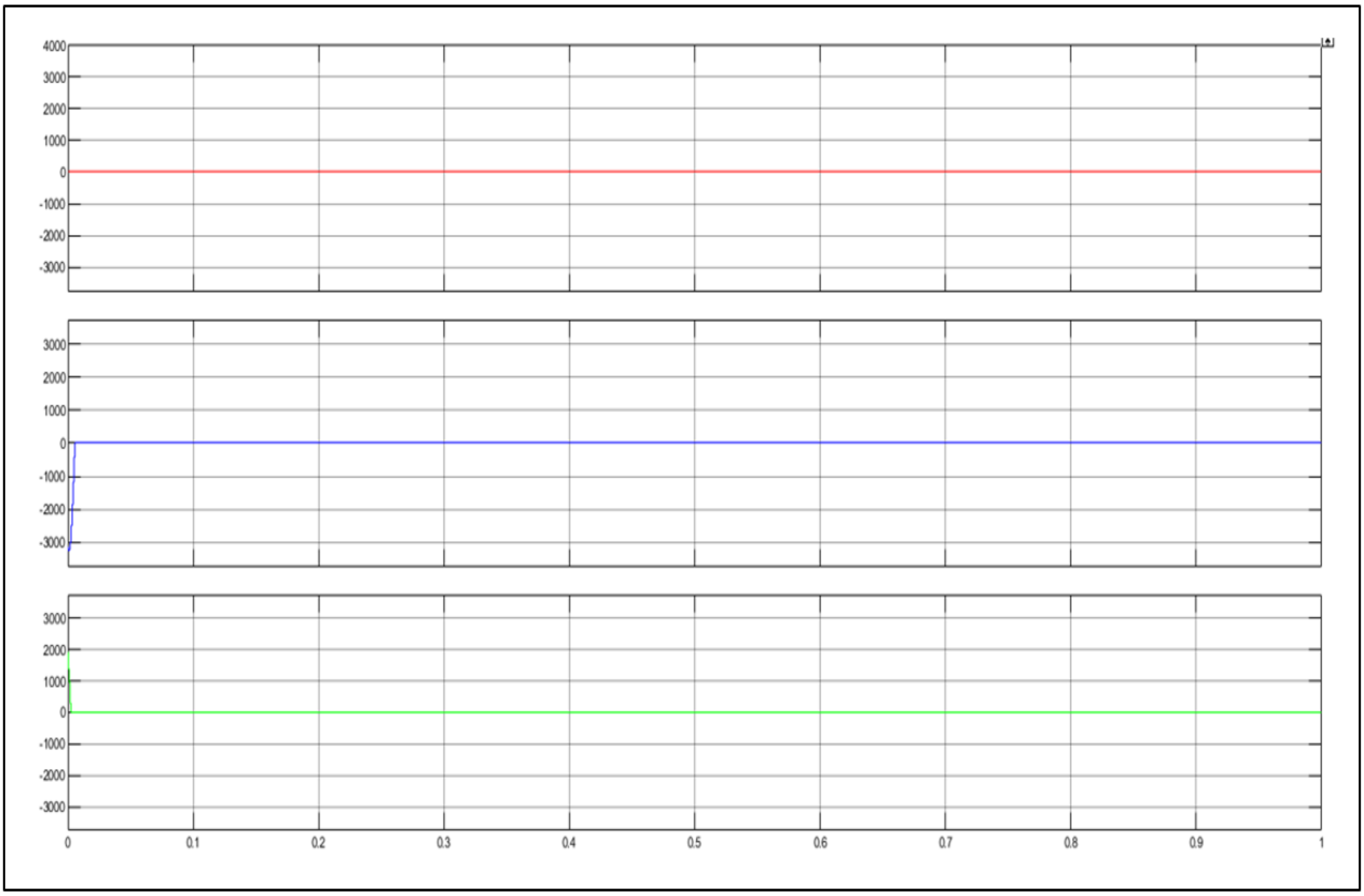

Fig. 6 Voltage status after the OC fault detection

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B. Model 2

The same concept used in the open-circuit (OC) fault detection model has also been applied to develop the short-circuit (SC) fault detection model. However, to simulate an SC fault condition, a Controlled Fault Block function has been integrated into the existing circuit. This addition enables the deliberate creation of a short-circuit fault scenario within the simulation environment. The complete short-circuit fault testing model is illustrated in Fig. 7 on the next page.

In digital logic gate configurations, a short-circuit fault can severely disrupt the normal operation of the circuit. Such a fault creates a low-resistance path that allows excessive current to bypass the intended circuit elements. This unintended path can lead to the propagation of incorrect logic levels across the system, resulting in faulty outputs. In extreme cases, it may also cause physical damage to the components due to overheating or overcurrent.

The current sensing circuitry plays a crucial role in monitoring the amount of current flowing through the transmission line. If the current rises above a predefined threshold, it may indicate the occurrence of a short-circuit fault. In this model, the system compares simulated line current values with set reference values. A short-circuit condition is identified either when the line current exceeds this threshold or when the numerical output values from the logic gate configuration are found to be lower than the actual current flowing through the line. In both cases, a fault signal is generated to trigger the circuit breaker, thereby isolating the faulted section and protecting the rest of the system.

The line Current Measurement of SC Fault seen in the aforementioned fig.8. suggests a short circuit that begins and ends after 0.2 seconds. After 0.2 seconds, the step function of the larger three-phase fault will occur, causing all of the lines to become zero. The model allows engineers to test how effectively the protection scheme responds to different fault scenarios, helping them optimize circuit breaker timing, threshold settings, and overall system protection.

The complexity of the comparison logic suggests this may be implementing a differential protection scheme, where currents at different points in the system are compared to detect internal faults while ignoring external disturbances.

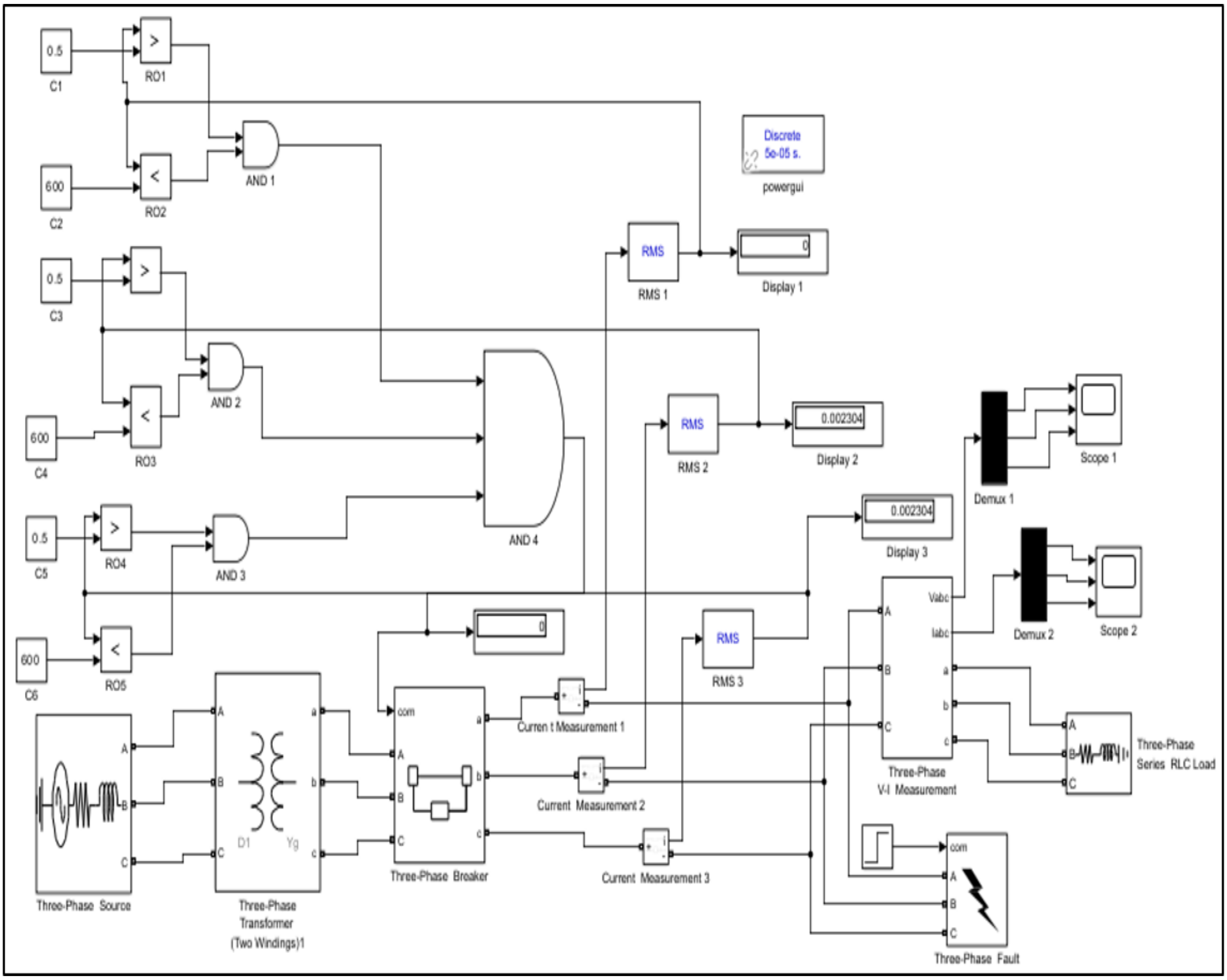

Fig 7 Model Simulink of SC fault Circuit

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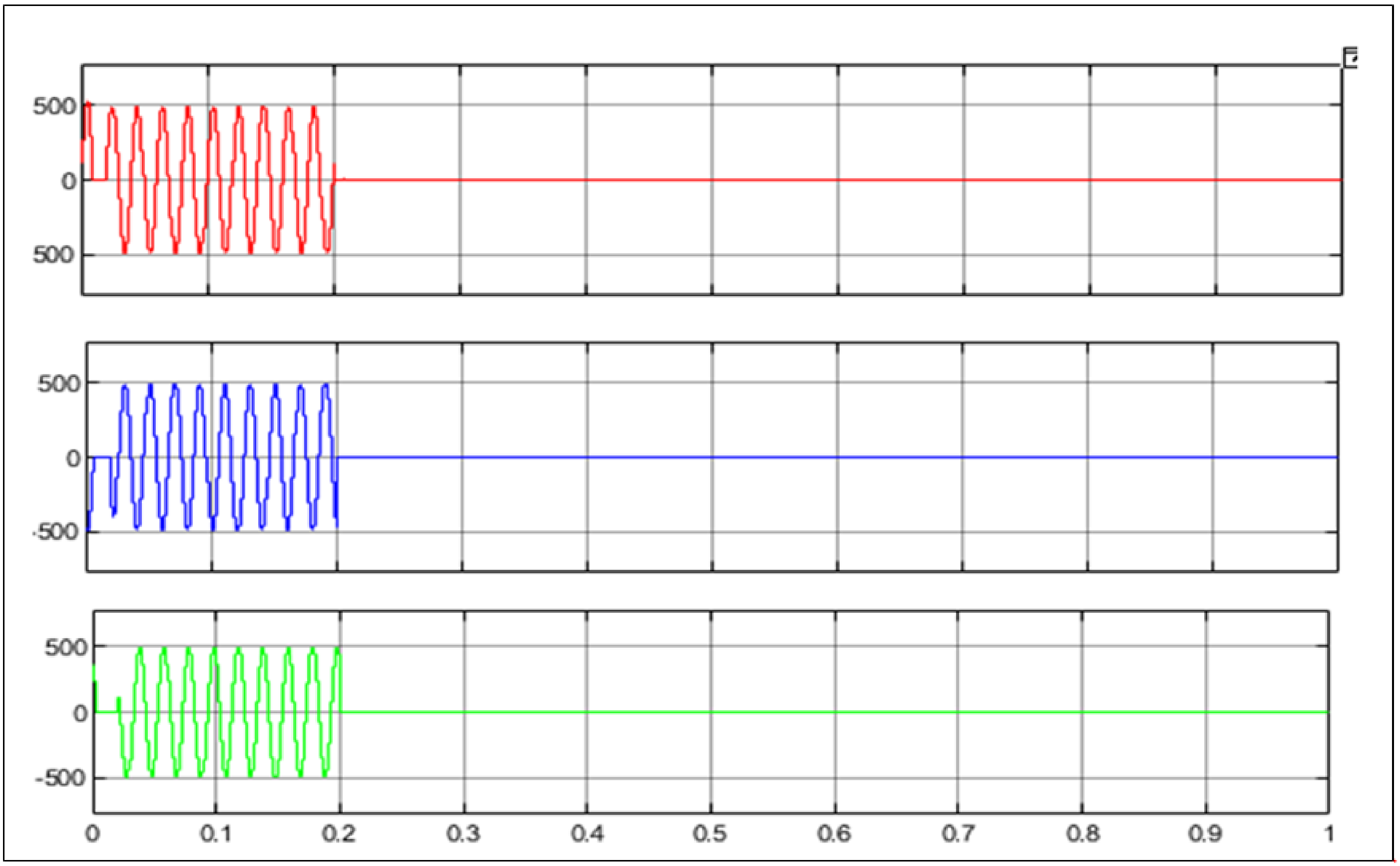

Fig 8 Current status after the SC fault detection

IV. CONCLUSION AND FUTURE SCOPE

One of the most prevalent and costly components in the transmission and distribution system is the power transformer. Regular monitoring of transformer health is not only cost-effective but also enhances overall reliability. Traditionally, transformer maintenance adhered to predetermined schedules. However, advancements in communication technology have allowed operators and authorities to remotely receive fault information from transformers through digital fault detection setup. This capability enables them to take proactive measures before a fault escalates to a critical level. These faults can arise from various issues, either transient or irreversible, posing a potential threat to the power system. Significant harm may occur, leading to power supply interruptions and affecting connected industries. Faults in the system are classified as Line to Ground, Line to Line, and Three lines in a three-phase electrical system. An automated system detects faults and disconnects the supply to address issues promptly, preventing extensive damage to the system's equipment. In the case of a permanent malfunction, as opposed to a transient disruption, the system automatically cuts off the supply for an appropriate duration, whether short or long.

In conclusion, logic gate-based digital fault detection provides a clear, practical foundation for understanding fault identification in power systems. It not only introduces learners to core digital concepts but also opens the path to advanced applications using AI/ML techniques in MATLAB, paving the way for the next generation of intelligent, efficient, and robust fault detection systems.

Advancements in fault detection techniques represent one of the key areas of future growth in digital fault detection systems. Engineers and researchers are continuously exploring innovative methods to enhance the precision, speed, and efficiency of these systems. Among these methods, logic gate-based fault detection offers a foundational approach that is particularly useful for learners and early-stage practitioners. It allows them to understand the critical importance of detecting faults in power transmission lines and offers insight into how a basic digital fault detection system can be implemented using digital processors such as microcontrollers or microprocessors.

In both open-circuit (OC) and short-circuit (SC) conditions, logic gate configurations, in combination with comparison blocks and current sensing circuits, enable accurate detection of fault events. For instance, in the OC model, current values are compared against preset thresholds, and logic gates determine whether the conditions indicate a fault. Similarly, in the SC model, a controlled fault block is used to simulate short-circuit conditions, with logic gates evaluating whether current flow exceeds the defined safety limits. These basic models serve as an ideal starting point for learners to understand the relationship between electrical parameters and logic-based control.

Once learners gain proficiency in implementing such basic fault detection models, they can advance their understanding by integrating Artificial Intelligence (AI) and Machine Learning (ML) algorithms to create intelligent fault detection systems. MATLAB, as a powerful tool for

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simulation and analysis, supports both traditional and AI-based modeling. With AI/ML integration, these systems can be designed to recognize complex fault patterns, predict potential failures, and adapt to real-time data, thereby offering greater reliability and responsiveness.

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