Enhancing Power System Reliability through Fault Analysis and Detection Techniques

[1]Mahendra Pratap Maurya [2]Prof. Sachindra Kumar Verma
[1]Department of Electrical Engineering, NRI Institute of Research & Technology, Bhopal India,
[2]Department of Electrical Engineering, NRI Institute of Research & Technology, Bhopal India,
Email [1]mahe648@cpri.in [2]Skvme19@gmail.com

* Corresponding Author: Mahendra Pratap Maurya

Abstract: *The power system, comprising generation, distribution, and transmission components, forms the backbone of modern society's energy infrastructure. This paper explores the intricate workings of power systems, delving into their various components, operational mechanisms, and the challenges posed by faults. Specifically, it investigates the classification of faults, their implications on system stability, and the crucial role of protective devices in mitigating potential damage. Furthermore, the research elucidates the complexities of symmetrical and unsymmetrical faults, offering insights into fault analysis methodologies. The study culminates in an exploration of advanced fault detection techniques, including the application of superconducting fault current limiters (SFCLs) in safeguarding power systems against catastrophic failures.*

Keywords: *Power system, Fault analysis, Symmetrical faults, Unsymmetrical faults, Protective devices, Fault detection, Superconducting fault current limiters (SFCLs).*

I. INTRODUCTION

The power system is a network which consists generation, distribution and transmission system. It uses the form of energy (like coal and diesel) and converts it into electrical energy. The power system includes the devices connected to the system like the synchronous generator, motor, transformer, circuit breaker, conductor, etc. The power plant, transformer, transmission line, substations, distribution line, and distribution transformer are the six main components of the power system. The power plant generates the power which is step-up or step-down through the transformer for transmission [1].

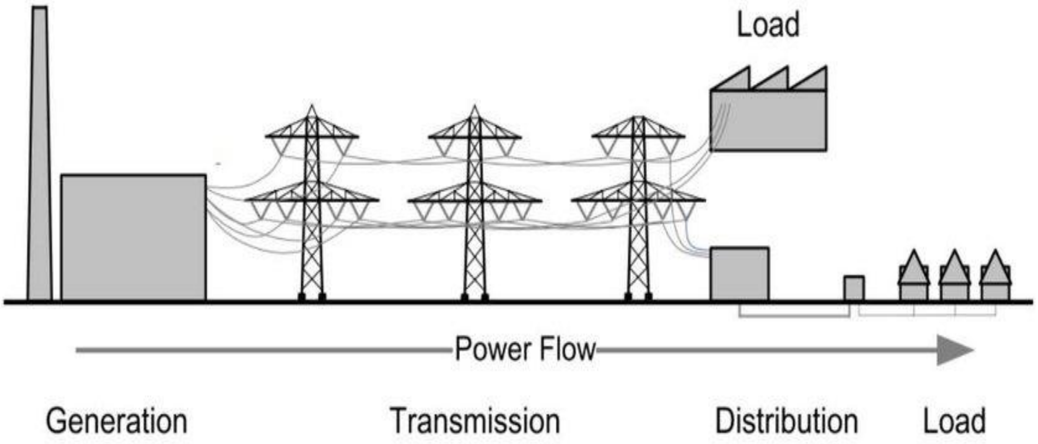

Figure 1 Conventional Structure of Power System

The transmission line transfers the power to the various substations. Through substation, the power is transferred to the distribution transformer which step-down the power to the appropriate value which is suitable for the consumers.

A. Working of Power Systems

An electric power system is a network of electrical components deployed to supply, transfer, and use electric power. An example of a power system is the electrical grid that provides power to homes and industries within an extended area. The electrical grid can be broadly divided into the generators that supply the power, the transmission system that carries the power from the generating centers to the load centers, and the distribution system that feeds the power to nearby homes and industries [2].

Smaller power systems are also found in industry, hospitals, commercial buildings, and homes. A single line diagram helps to represent this whole system. The majority of these systems rely upon three-phase AC power—the standard for large-scale power transmission and distribution across the modern world. Specialized power systems that do not always rely upon three-phase AC power are found in aircraft, electric rail systems, ocean liners, submarines, and automobiles [3].

B. Protective devices

The Power systems contain protective devices to prevent injury or damage during failures. The quintessential protective device is the fuse. When the current through a fuse exceeds a certain threshold, the fuse element melts, producing an arc across the resulting gap that is then extinguished, interrupting the circuit. Given that fuses can be built as the weak point of a system, fuses are ideal for protecting circuitry from damage. Fuses however have two problems: First, after they have functioned, fuses must be replaced as they cannot be reset. This can prove inconvenient if the fuse is at a remote site or a spare fuse is not on hand. And second, fuses are typically inadequate as the sole safety device in most power systems as they allow current flows well in excess of that that would prove lethal to a human or animal [4].

C. Fault in Power System

An overhead transmission line is one of the main components in every electric power system. The transmission line is exposed to the environment and the possibility of experiencing faults. Those are single line-ground, line-line, double line-ground and three phase faults.to detect those faults many authors developed different techniques. A fault in an electric power system can be defined as, any abnormal condition of the system that involves the electrical failure of the equipment, such as, transformers, generators, busbars, etc.

The fault inception also involves in insulation failures and conducting path failures which results short circuit and open circuit of conductors. Under normal or safe operating conditions, the electric equipments in a power system network operate at normal voltage and current ratings. Once the fault takes place in a circuit or device, voltage and current values deviates from their nominal ranges. The faults in power system causes over current, under voltage, unbalance of the phases, reversed power and high voltage surges. This results in the interruption of the normal operation of the network, failure of equipments, electrical fires, etc. Usually power system networks are protected with switchgear protection equipments such as circuit breakers and relays in order to limit the loss of service due to the electrical failures

D. Classification of faults

Electrical fault is the deviation of voltages and currents from nominal values or states. Under normal operating conditions, power system equipment or lines carry normal voltages and currents which results in a safer operation of the system. But when fault occurs, it causes excessively high currents to flow which causes the damage to equipments and devices. Fault detection and analysis is necessary to select or design suitable switchgear equipments electromechanical relays, circuit breakers and other protection devices. Electrical faults in three-phase power system mainly classified into two types, namely open and short circuit faults. Further, these faults can be symmetrical or unsymmetrical faults. [5]

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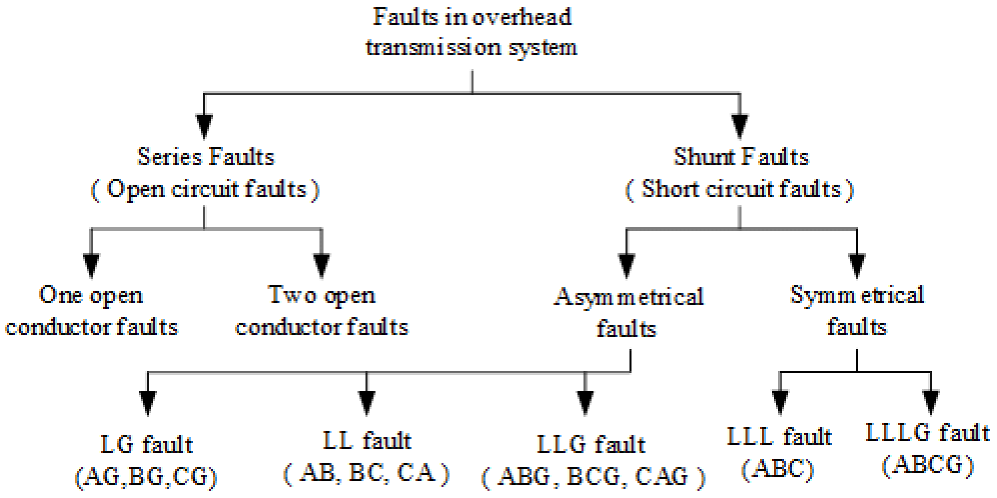

Figure 2 Classification of faults in Power Systems

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The normal operation of the power system at steady state is affected, sometimes dramatically, by the occurrence of such disturbances as overloads and short circuits. Of primary concern are short circuits, not only because they can cause large damage to the affected system component but also because they may lead to instability of the whole power system. Thus, there is a need to design protection schemes to minimize the risks involved with the occurrences of disturbances [6].

E. Fault Analysis

Fault analysis forms the basis for designing such protection systems. The proper coordination of the protective relays and the correct specification of circuit breaker ratings are based on the results of fault calculations [7]. The performance of the power system is simulated in what is called transient stability analysis under a variety of disturbances, such as short circuits, sudden large load changes, and switching operations. Power system protection is an important concern because short circuits present danger of damage to the equipment and loss of synchronism of the synchronous machines.[7]

II. LITERATURE REVIEW

Kunjin Chen et al 2016 [8] A comprehensive review on the methods used for fault detection, classification and location in transmission lines and distribution systems is presented in this study. Though the three topics are highly correlated, the authors try to discuss them separately, so that one may have a more logical and comprehensive understanding of the concepts without getting confused. Great significance is also attached to the feature extraction process, without which the majority of the methods may not be implemented properly. Fault detection techniques are discussed on the basis of feature extraction. After the overall concepts and general ideas are presented, representative works as well as new progress in the techniques are covered and discussed in detail. One may find the content of this study helpful as a detailed literature review or a practical technical guidance.

A.Triki-Lahiani et al 2017.[9] As any energy production system, photovoltaic (PV) installations have to be monitored to enhance system performances and to early detect failures for more reliability. There are several photovoltaic monitoring strategies based on the output of the plant and its nature. Monitoring can be performed locally on site or remotely. It measures production, focuses also on verification and follow-up of converter and communication devices' effective operation. Up to now, some faults diagnosis methods for PV components and systems have been developed. However, given the evolution of PV installations, more advanced monitoring techniques are continuously under investigation. In this paper, major photovoltaic system failures are addressed. Then techniques for photovoltaic monitoring proposed in recent literature are overviewed and analyzed to point out their differences, advantages and limits.

Rui Li et al [10] The change rate of the DC reactor voltage with predefined protection voltage thresholds is proposed to provide fast and accurate DC fault detection in a meshed multi-terminal HVDC system. This is equivalent to the measurement of the second derivative of the DC current but has better robustness in terms of EMI noise immunization. In addition to fast DC fault detection, the proposed scheme can also accurately discriminate the faulty branch from the healthy ones in a meshed DC network by considering the voltage polarities and amplitudes of the two DC reactors connected to the same converter DC terminal. Fast fault detection leads to lower fault current stresses on DC circuit breakers and converter equipment. The proposed method requires no telecommunication, is independent of power flow direction, and is robust to fault resistance variation. Simulation of a meshed three-terminal HVDC system demonstrates the effectiveness of the proposed DC fault detection scheme.

Adam Glowacz 2018 [12] The article describes acoustic based fault diagnosis techniques of a three-phase induction motor. Four real states of the three-phase induction motor were analysed: healthy three-phase induction motor, three-phase induction motor with broken rotor bar, three-phase induction motor with 2 broken rotor bars, three-phase induction motor with faulty ring of squirrel-cage. Two feature extraction methods of acoustic signals of the induction motor - SMOFS-32-MULTIEXPANDED-2-GROUPS (Shortened Method of Frequencies Selection Multiexpanded 2 Groups) and SMOFS-32-MULTIEXPANDED-1- GROUP were described. The Nearest Neighbour classifier, backpropagation neural network and modified classifier based on words coding were used for recognition of acoustic signals. Results of recognition were very good for the real data and developed fault diagnosis techniques based on acoustic signals. The described fault diagnosis approach can find applications in the industry.

X. Zhang et al 2015 [13] This paper presents a novel hybrid model for fault detection and classification of motor bearing. In the proposed model, permutation entropy (PE) of the vibration signal is calculated to detect the malfunctions of the bearing. If the bearing has faults, the vibration signal is decomposed into a set of intrinsic mode functions (IMFs) by ensemble empirical mode decomposition (EEMD). The PE values of the first several IMFs (IMF-PE) are calculate to reveal the multi-scale intrinsic characteristics of the vibration signal. Then, support vector machines (SVM) optimized by inter-cluster distance (ICD) in the feature space (ICDSVM) is used to classify the fault type as well as fault severity. Finally, the proposed model is fully evaluated by experiments and comparative studies. The results demonstrate its effectiveness and robustness for motor bearing fault detection and classification

OBJECTIVES

- Design and simulation of an optimized IEEE 13 bus model in MATLAB/Simulink
- Designing of fuzzy based system for identification fault symmetrical and unsymmetrical faults in the IEEE 13 bus system
- Evaluation of the system performance by analyzing the fault response time of the fuzzy rules at different fault conditions
- Removal of fault current by designing of an efficient Fault Current Limiter for the 13 bus system

III. METHODOLOGY

A fault in a power system is an abnormal condition that can cause a disruption in the normal flow of electricity. Faults can occur in different parts of the power system, such as transmission lines, transformers, switchgear, and distribution lines. Faults can be caused by a variety of factors, including equipment failure, environmental conditions, and human error. It's important to identify and address faults in a power system promptly to prevent equipment damage, power outages, and safety hazards. Fuzzy logic-based fault detection is a technique used in this study to detect faults in power systems. The IEEE 13 bus system is a standard test system that is used in this research work to evaluate the effectiveness of this technique.

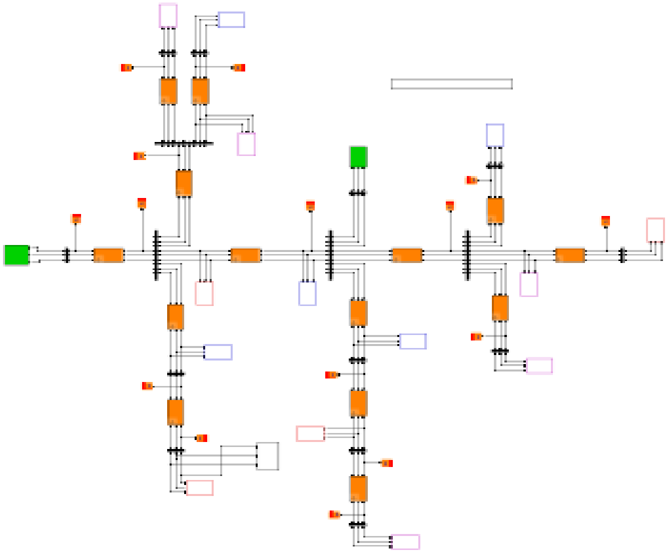

Figure 3. Modelled system for fault identification using fuzzy logic.

Fuzzy logic is a type of mathematical logic that allows for approximate reasoning and decision-making in situations where there is uncertainty or ambiguity. Unlike traditional Boolean logic, which uses binary values (true or false), fuzzy logic allows for values that range from completely true to completely false, depending on the degree of membership in a fuzzy set. uzzy logic can be used to model complex systems or processes that are difficult to describe using traditional logic. For example, fuzzy logic can be used in control systems to handle imprecise input data or to control systems that have nonlinear dynamics. It can also be used in decision-making processes to evaluate the degree of satisfaction of different criteria. Fuzzy logic has been applied in a wide range of fields, including engineering, economics, finance, medicine, and artificial intelligence. Its applications include control systems, pattern recognition, forecasting, and optimization. Overall, fuzzy logic provides a powerful and flexible tool for dealing with uncertainty and ambiguity in complex systems. Fuzzy Logic in Identification of the Fault in the Power System

Fuzzy logic can be used to identify faults in a power system by creating a set of rules that describe the relationship between input variables, such as voltage, current, and frequency, and the presence of a fault.

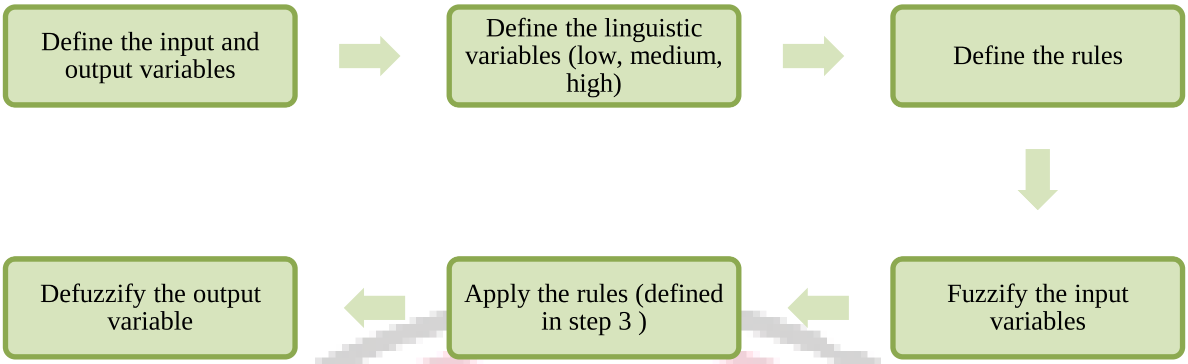

Figure 4. Flow chart of applying fuzzy logic for identification of fault

The input variables may include measurements of voltage, current, frequency, and other parameters, while the output variable is a measure of the presence or absence of a fault. For each input and output variable, a set of linguistic variables can be defined that represent different levels of the variable. For example, the linguistic variable for voltage could include "low," "medium," and "high." A set of rules can be defined that describe the relationship between the input variables and the output variable. For example, a rule might state that if the voltage is low and the current is high, then a fault is present. Fuzzy logic requires input variables to be represented as fuzzy sets, which assigns a degree of membership to each linguistic variable. This is done by mapping the measured values of the input variables onto the corresponding linguistic variables. The rules defined in step 3 are applied to the fuzzy input variables to determine the degree of membership of the output variable. The fuzzy output variable is transformed into a crisp value that represents the presence or absence of a fault.

A. SFCL for Fault Removal

A Superconducting Fault Current Limiter (SFCL) is an electrical device that limits the magnitude of a fault current in a power system by using the property of superconductivity. The SFCL works by utilizing the phenomenon of the Meissner effect, which occurs when a material is cooled below a certain critical temperature (known as the critical temperature or Tc), at which it becomes a superconductor and loses all electrical resistance. In an SFCL, a superconducting element is connected in parallel with a section of the power system, such as a transformer or a transmission line. During normal operation, the superconducting element has zero resistance and does not affect the flow of current in the system. However, in the event of a fault, the fault current increases and the superconducting element begins to resist the flow of current, effectively limiting its magnitude.

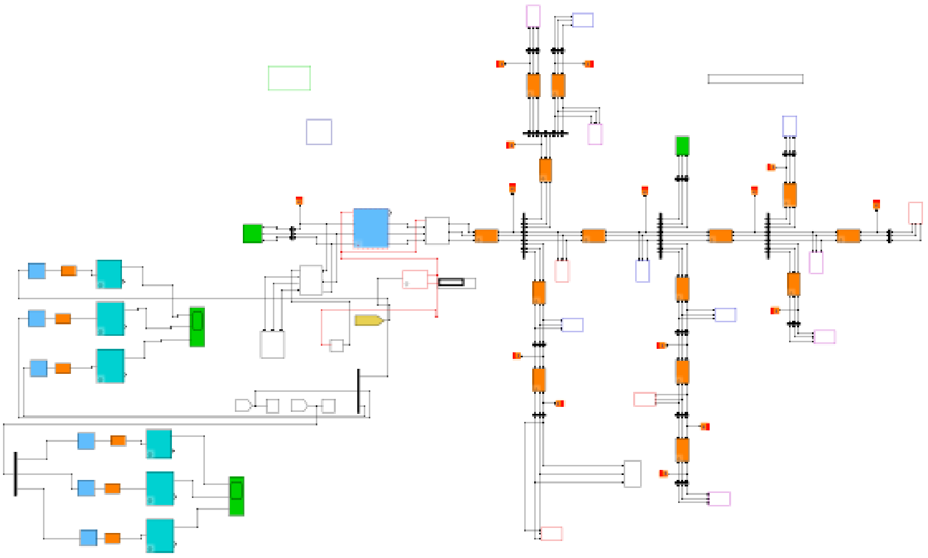

Figure 5 Modelled system for fault removal using SFCL

There are two main types of SFCLs: resistive SFCLs and inductive SFCLs. Resistive SFCLs use a superconducting element that has a resistance that increases rapidly with the magnitude of the current, while inductive SFCLs use a superconducting element that has an inductance that increases rapidly with the magnitude of the current.

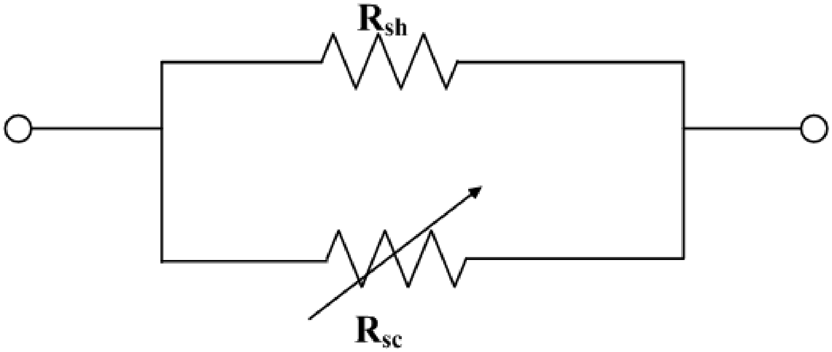

Figure 6. Resistive type SFCL

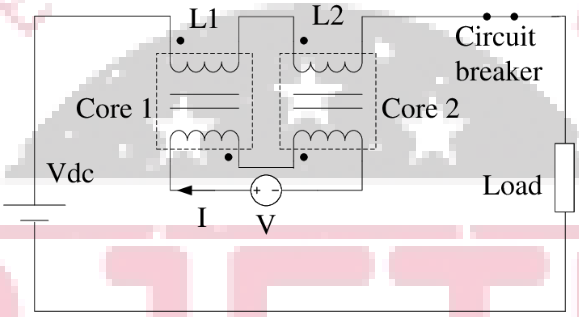

Figure 7. Inductive Type SFCL

When a fault occurs, the SFCL rapidly switches from the superconducting state to the resistive or inductive state, thereby limiting the fault current. After the fault has been cleared, the SFCL returns to its superconducting state and the power system resumes normal operation.

SFCLs have several advantages over traditional fault current limiters, such as their fast response time, their ability to limit both AC and DC fault currents, and their ability to operate over a wide range of fault current magnitudes. They can also be used in conjunction with other protective devices, such as circuit breakers and relays, to provide a comprehensive protection scheme for power systems.

However, SFCLs also have some disadvantages, such as their high cost and their need for cryogenic cooling to maintain superconductivity. SFCLs are used to limit the fault current during a fault. The resistance of the SFCL material can be modelled mathematically to predict its behavior during a fault.

IV. RESULTS AND DISCUSSIONS

The IEEE 13 bus system is a well-known benchmark system in power systems analysis. Fault detection and classification (FDC) is an essential task in power systems to ensure the safety, reliability, and continuity of electrical power supply. Fuzzy logic-based FDC is one of the popular approaches due to its ability to handle uncertainty and imprecision in power system data. Fuzzy logic-based fault detection and removal is a technique used in this study to detect and remove faults in power systems. The IEEE 13 bus system is a standard test system that is used in this research work to evaluate the effectiveness of this technique. The proposed logic detects the faults at maximum delay of 200 ms or less with higher accuracy.

A. Low Impedance Faults Analysis in the IEEE 13 Bus System

A low impedance fault is a type of fault that occurs in electrical power systems when the fault resistance is low or negligible. In such cases, the fault current can be very high, resulting in a significant amount of energy being dissipated in the faulted circuit. These faults can occur due to various reasons, such as short circuits, ground faults, insulation failure, or equipment malfunction. These faults can cause damage to the electrical equipment and lead to power outages and even fire hazards. Detecting low impedance faults is challenging, as the magnitude of the fault current is usually high and can be mistaken for normal operating current. One approach to detecting low impedance faults is to use protective relays, which are designed to sense the change in current or voltage levels and trigger a protective action, such as circuit breaker tripping or isolation of the faulted section of the power system. Another approach to detecting low impedance faults is to use advanced fault detection and classification techniques, such as fuzzy logic-based fault detection and classification or artificial intelligence-based approaches. These techniques can help improve the accuracy and speed of fault detection and reduce the risk of misoperation.

The presence of a fault in a three-phase power system can cause significant damage to electrical equipment and lead to power outages. When a fault occurs in a three-phase power system, it can result in unbalanced currents and voltages. The unbalanced currents can cause excessive heating and damage to electrical equipment, while the unbalanced voltages can cause incorrect operation of protective relays.

Fault Analysis in Three-phase Power System

Symmetrical and unsymmetrical faults are two types of faults that can occur in a three-phase power system. A symmetrical fault is a fault that occurs in a balanced three-phase system, where all three phases experience the same fault simultaneously. Symmetrical faults can be caused by equipment failure, lightning strikes, or short circuits. The fault current is balanced in all three phases, and the fault impedance is the same in all three phases. Symmetrical faults can cause high fault currents, voltage drops, and mechanical stresses on the equipment.

RESULTS OF SYMMETRICAL FAULT IDENTIFICATION

LLL/LLLG fault is a type of symmetrical fault that can occur in a three-phase power system. LLL fault stands for "Line-to-Line-to-Line" fault, while LLLG fault stands for "Line-to-Line-to-Line-to-Ground" fault.

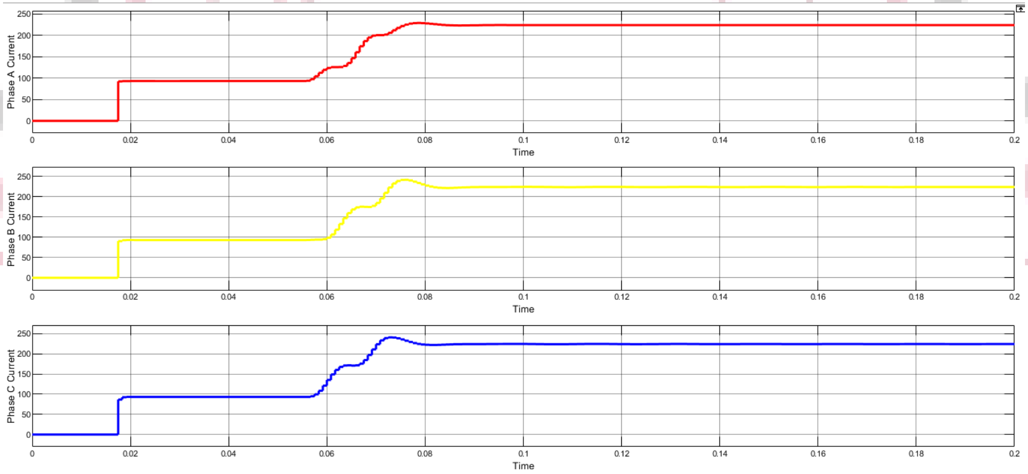

Figure 8. Variation in RMS current value at the time of fault identification in the LLL/LLLG fault

In the case of LLL/LLLG symmetrical faults, the presence of faults causes an elevated level of current at all three phases in IEEE 13. In this scenario, the windows indicate the rapid elevation in fault current as well as its RMS values over Phase A, Phase B and Phase C as shown in fig. 8

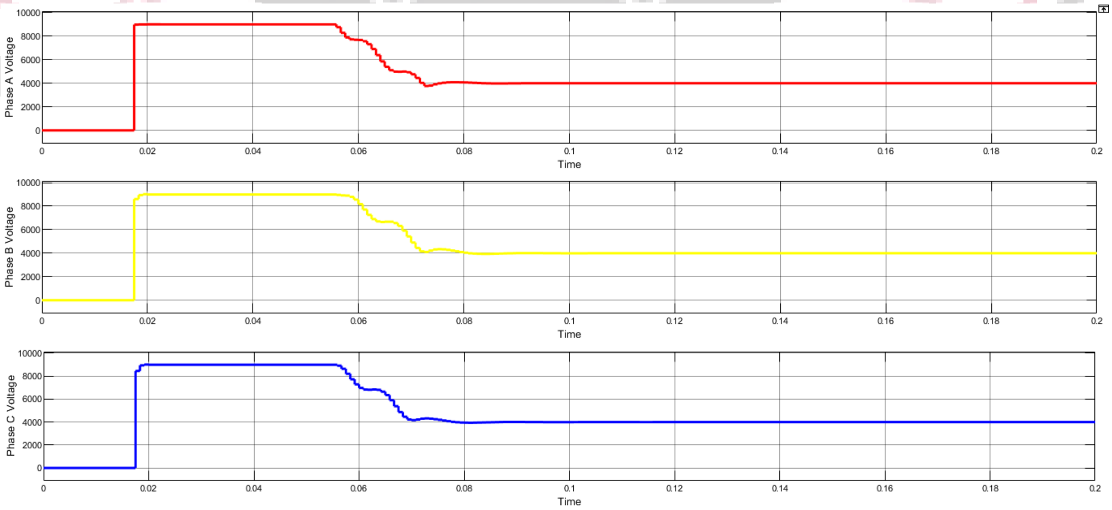

Figure 9. Variation in RMS Voltage value at the time of fault identification in the LLL/LLLG fault

The associated voltage output for IEEE 13 bus is displayed in fig 9, showing the voltage fall caused on by the failure. The increase in fault current, which lowers the voltage difference at the originating point, is to blame for this. The LLL/LLLG fault causes a fall in Phase A, Phase B and Phase C.

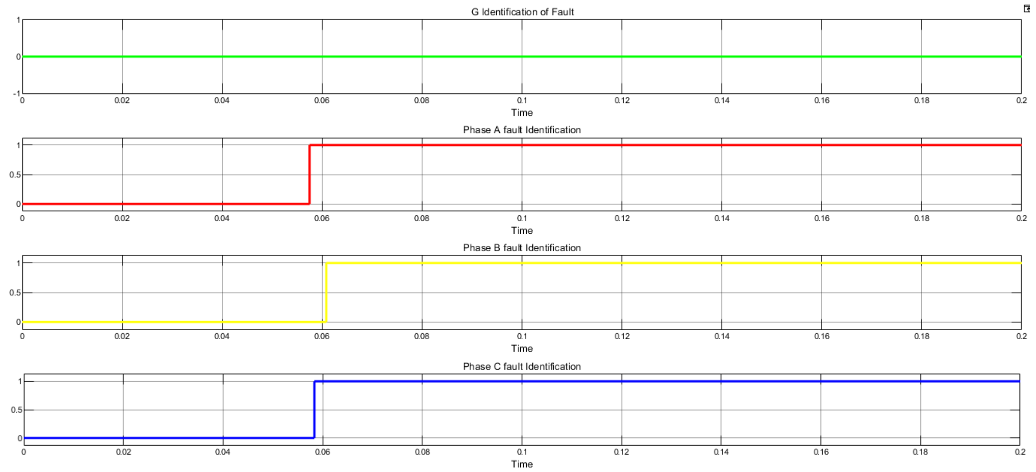

Figure 10. Fuzzy Fault identification window at bus 1 with LLLG (ABCG) fault

The fuzzy system's output for low impedance fault identification is displayed in fig. 10 a specially built window. The three phases with output 1 in the instance of the LLL/LLLG fault exhibit similar characteristics and demonstrate that the fault has affected all of the phases (Phase A, Phase B and Phase C).

B. RESULTS OF UNSYMMETRICAL FAULT IDENTIFICATION

An unsymmetrical fault is a fault that occurs in an unbalanced three-phase system, where one or two phases experience a fault while the other phases remain unaffected. Unsymmetrical faults can be caused by phase-to-phase (LL) or phase-to-ground faults (LG). The fault current is unbalanced in the affected phases, and the fault impedance is different in each phase. Unsymmetrical faults can cause unbalanced voltages, currents, and power flows, which can lead to equipment damage and power system instability

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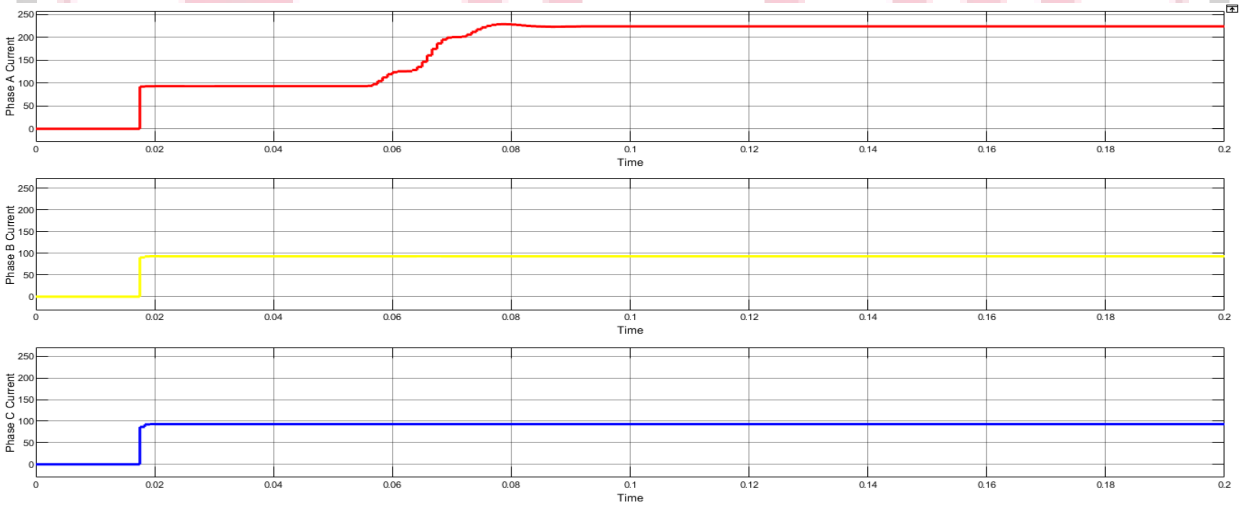

Figure 11. Variation in RMS current value at the time of fault identification in the LG (Phase A and Ground) fault

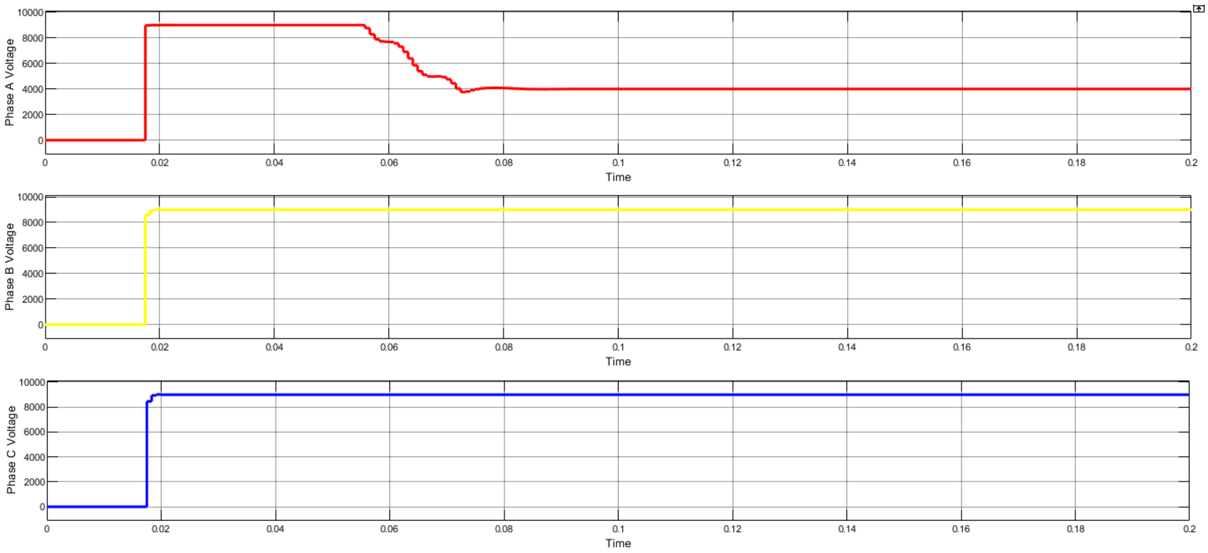

Figure 12. Variation in RMS Voltage value at the time of fault identification in the LG (Phase A and Ground) fault.

In the case of LG(AG) unsymmetrical faults, the presence of faults causes an elevated level of current at Phase A in IEEE 13. In this scenario, the windows indicate the rapid elevation in fault current as well as its RMS values over Phase A.

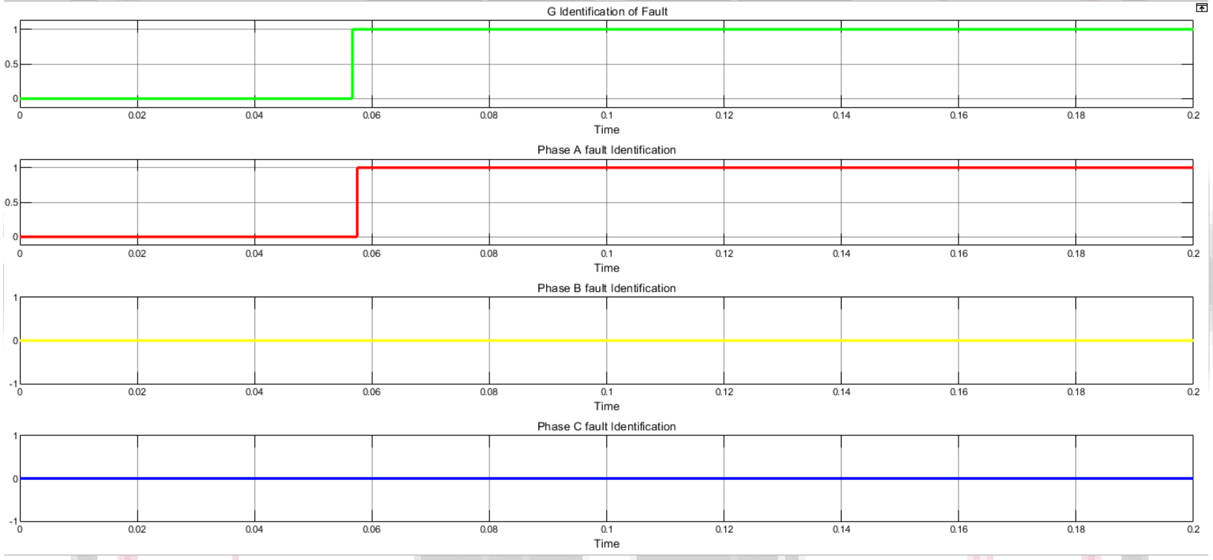

Figure 13. Fuzzy Fault identification window at bus 1 with LG (AG) fault.

The associated voltage output for IEEE 13 bus is displayed in fig. 13. showing the voltage fall caused in Phase A by the failure. The increase in fault current, which lowers the voltage difference at the originating point, is to blame for this. LG (AG) fault causes a fall in Phase A.

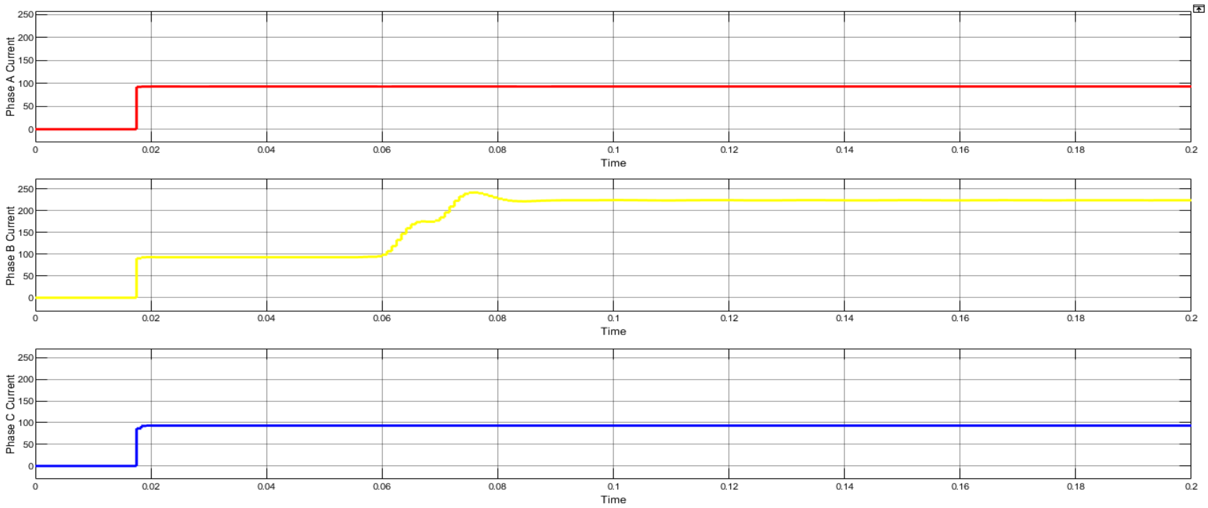

Figure 14. Variation in RMS current value at the time of fault identification in the LG (Phase B and Ground) fault.

In the case fig. 14. LG (BG) unsymmetrical faults, the presence of faults causes an elevated level of current at Phase B in IEEE 13. In this scenario, the windows indicate the rapid elevation in fault current as well as its RMS values over Phase B.

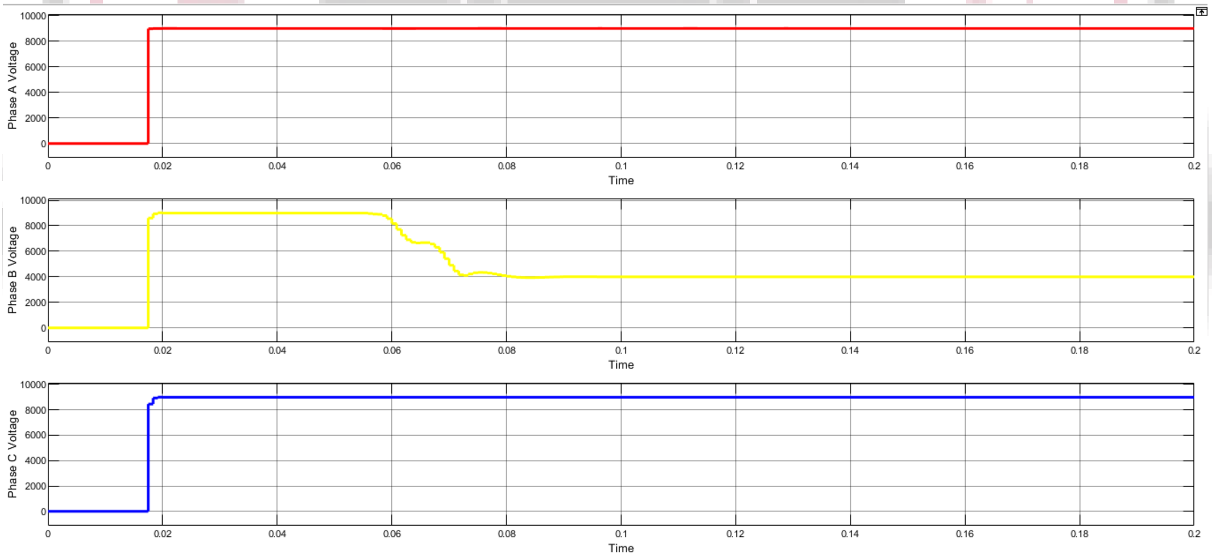

Figure 15. Variation in RMS Voltage value at the time of fault identification in the LG (Phase B and Ground) fault.

The associated voltage output for IEEE 13 bus is displayed, showing the voltage fall caused in Phase B by the failure. The increase in fault current, which lowers the voltage difference at the originating point, is to blame for this. LG (BG) fault causes a fall in Phase B.

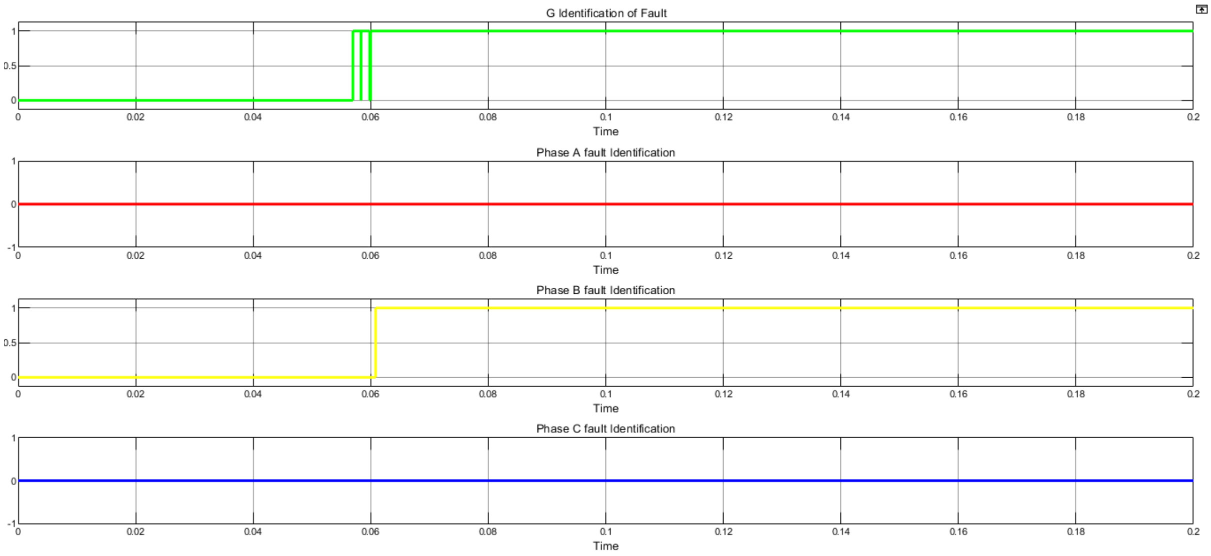

Figure 16. Fuzzy Fault identification window at bus 1 with LG (BG) fault.

The fuzzy system's output for low impedance fault identification is displayed in fig.16. in a specially built window. The three phases with output 1 in the instance of the LG (BG) fault exhibit similar characteristics and demonstrate that the fault has affected only Phase B.

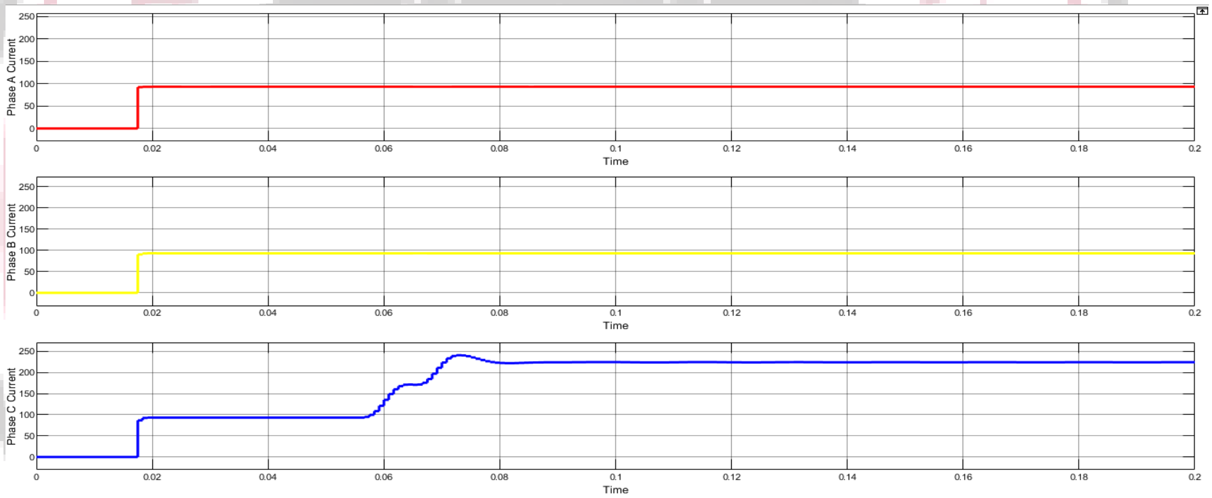

Figure 17. Variation in RMS current value at the time of fault identification in the LG (Phase C and Ground) fault.

In the case of fig. 17. LG (CG) unsymmetrical faults, the presence of faults causes an elevated level of current at Phase C in IEEE 13. In this scenario, the windows indicate the rapid elevation in fault current as well as its RMS values over Phase C.

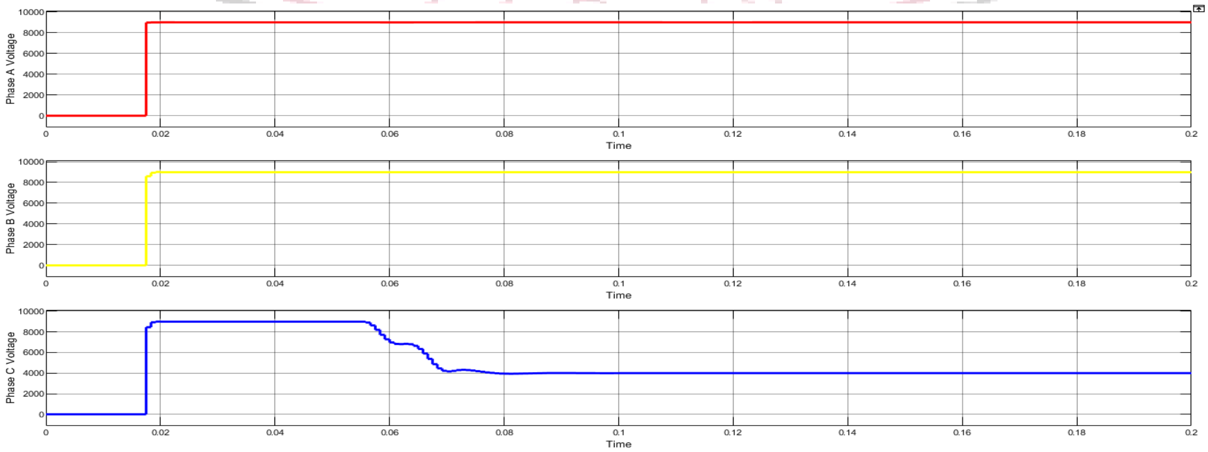

Figure 18. Variation in RMS Voltage value at the time of fault identification in the LG (Phase C and Ground) fault.

The associated voltage output for IEEE 13 bus is displayed in fig. 18.showing the voltage fall caused in Phase C by the failure. The increase in fault current, which lowers the voltage difference at the originating point, is to blame for this. LG (CG) fault causes a fall in Phase C.

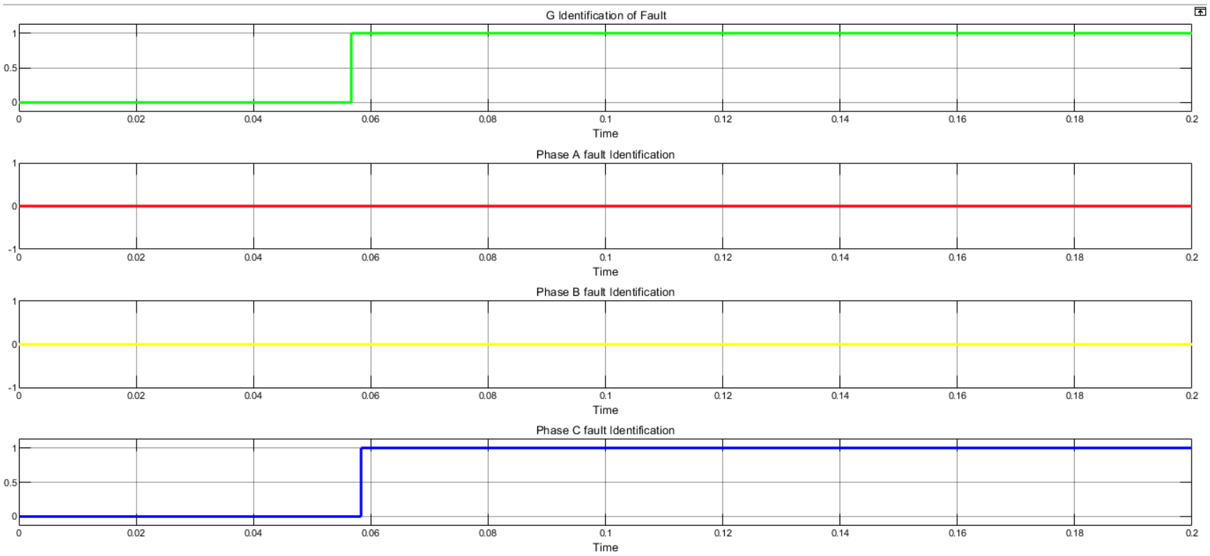

Figure 19. Fuzzy Fault identification window at bus 1 with LG (CG) fault.

The fuzzy system's output for low impedance fault identification is displayed in fig .19. a specially built window. The three phases with output 1 in the instance of the LG (CG) fault exhibit similar characteristics and demonstrate that the fault has affected only Phase C.

LL Fault

LL fault is a type of fault that can occur in a three-phase power system. LL fault stands for "Line-to-Line" fault, where two of the three phases of the power system are short-circuited together.

L Fault (AB Fault)

Here in this section, Phase A, and G (ground) is considered for identification of fault.

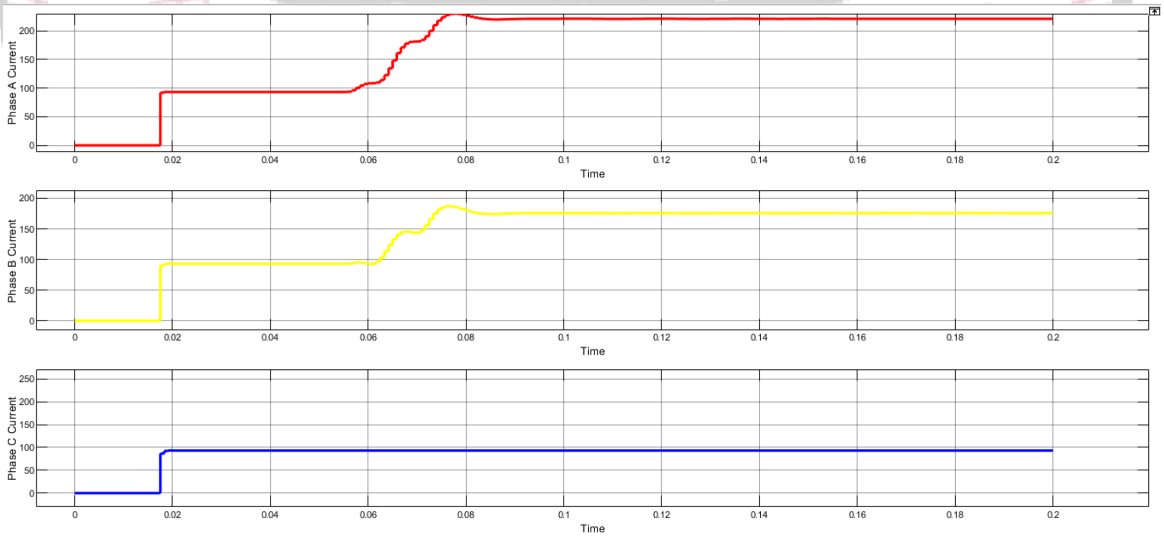

Figure 20. Variation in RMS current value at the time of fault identification in the LL (Phase A and Phase B) fault.

In the case of LL (AB) unsymmetrical faults, the presence of faults causes an elevated level of current at Phase A & C in IEEE 13. In this scenario, the windows indicate the rapid elevation in fault current as well as its RMS values over Phase A & B.

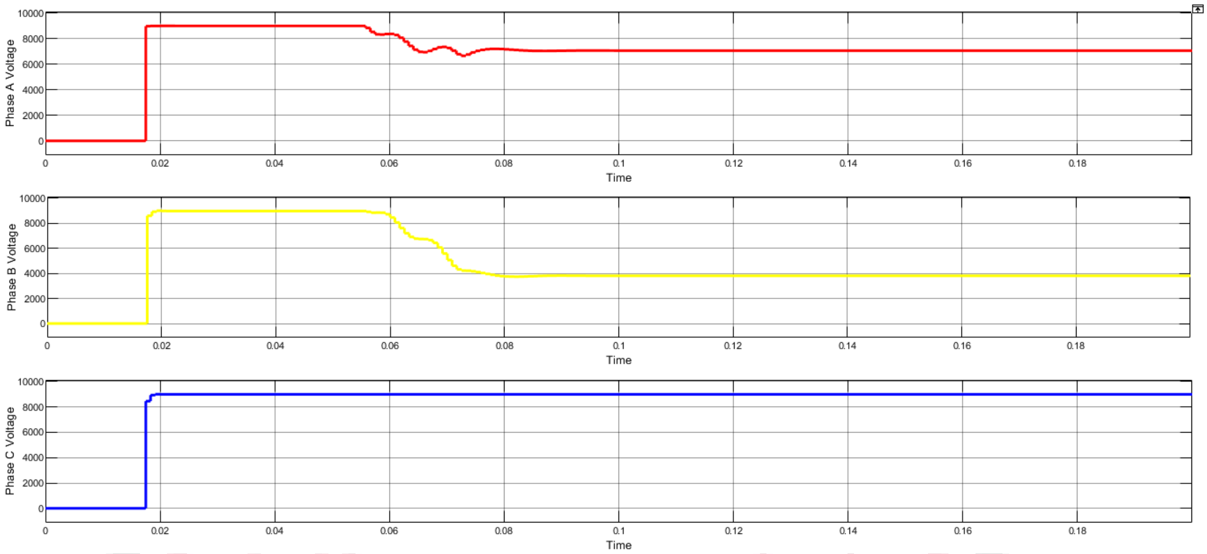

Figure 21. Variation in RMS Voltage value at the time of fault identification in the LL (Phase A and Phase B) fault.

The associated voltage output for IEEE 13 bus is displayed, showing the voltage fall caused in Phase A and B by the failure. The increase in fault current, which lowers the voltage difference at the originating point, is to blame for this. LL (AB) fault causes a fall in Phase A & B.

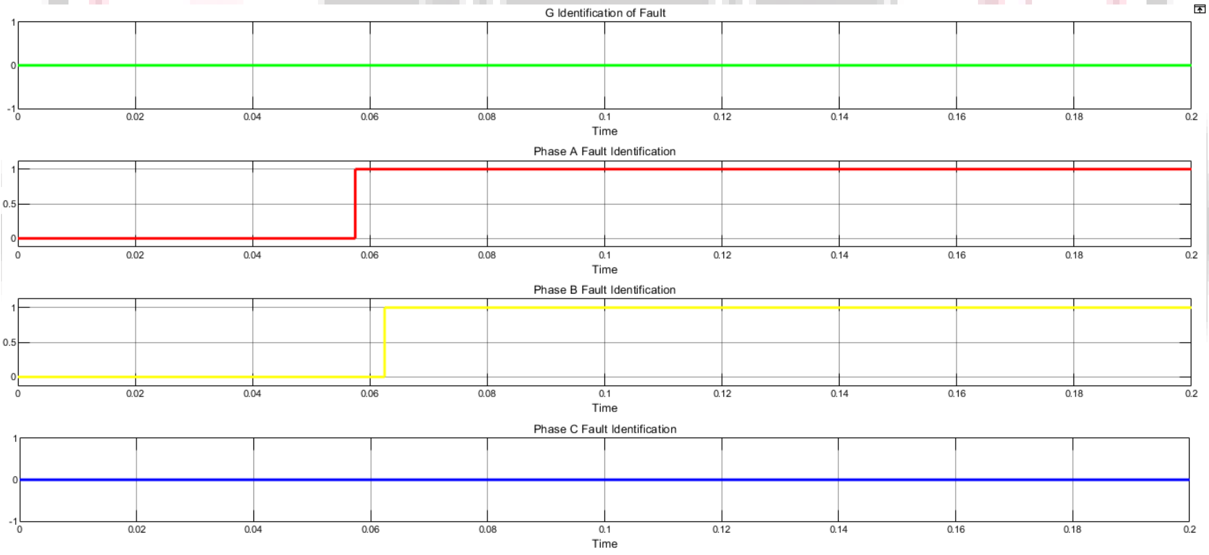

Figure 22. Fuzzy Fault identification window at bus 1 with LL (AB) fault.

The fuzzy system's output for low impedance fault identification is displayed in fig. 22. a specially built window. The three phases with output 1 in the instance of the LL (AB) fault exhibit similar characteristics and demonstrate that the fault has affected only Phase A & B.

LL Fault (AC Fault)

Here, in this section, Phase A, and Phase C is considered for identification of fault.

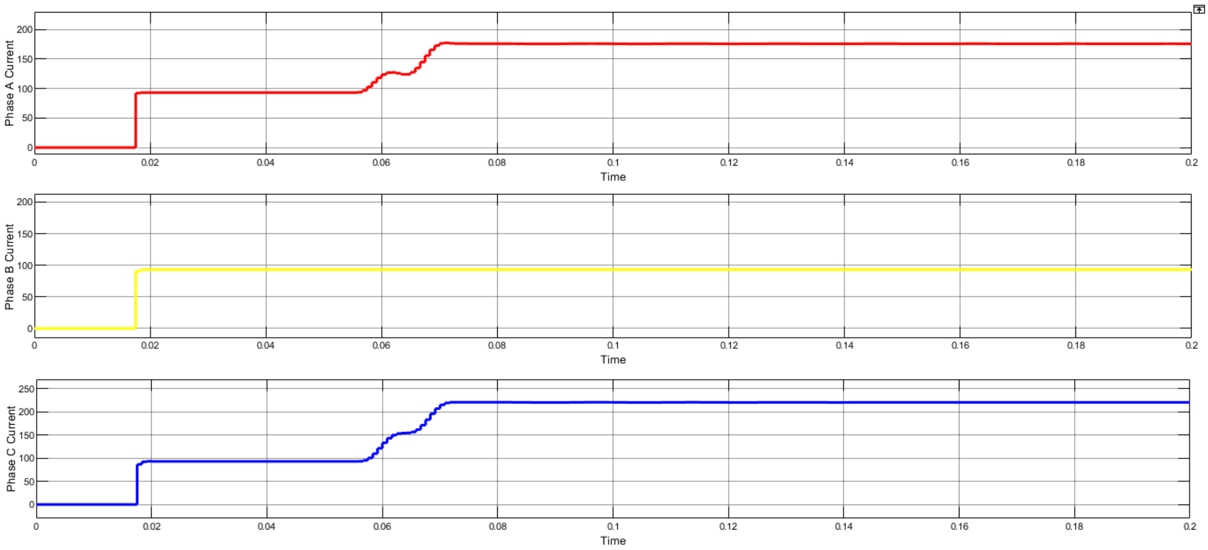

Figure 23. Variation in RMS current value at the time of fault identification in the LL (Phase A and Phase C) fault.

In the case fig. 23. LL (AC) unsymmetrical faults, the presence of faults causes an elevated level of current at Phase A & C in IEEE 13. In this scenario, the windows indicate the rapid elevation in fault current as well as its RMS values over Phase A & C.

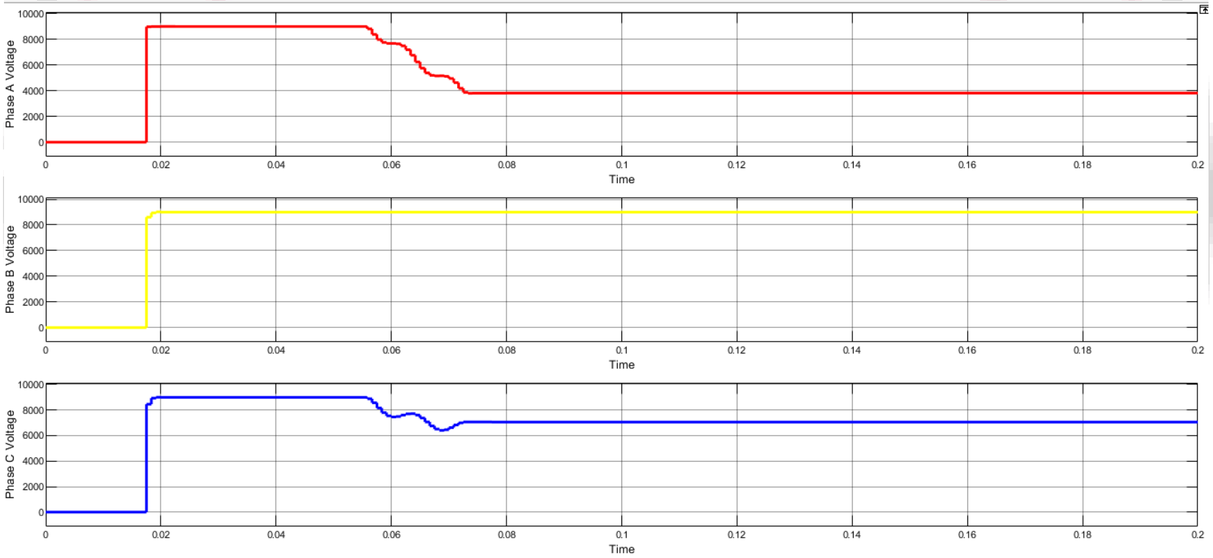

Figure 24. Variation in RMS Voltage value at the time of fault identification in the LL (Phase A and Phase C) fault.

The associated voltage output for IEEE 13 bus is displayed fig. 24. showing the voltage fall caused in Phase A and C by the failure. The increase in fault current, which lowers the voltage difference at the originating point, is to blame for this. LL (AC) fault causes a fall in Phase A & C.

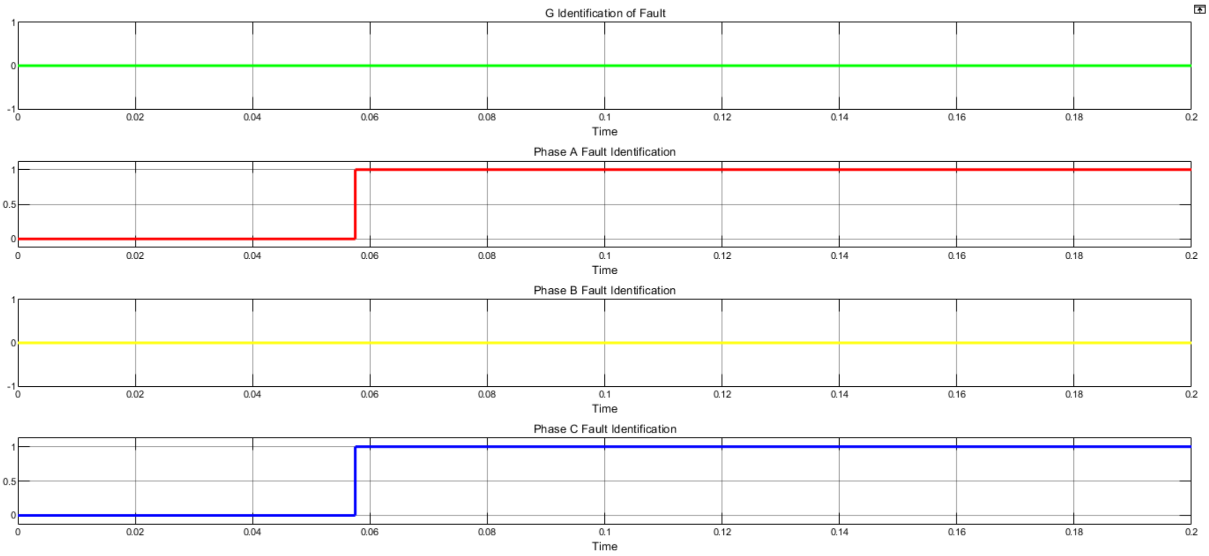

Figure 25. Fuzzy Fault identification window at bus 1 with LL (AC) fault.

The fuzzy system's output for low impedance fault identification is displayed in fig. 25. a specially built window. The three phases with output 1 in the instance of the LL (AC) fault exhibit similar characteristics and demonstrate that the fault has affected only Phase A & C.

LL Fault (BC Fault)

Here in this section, Phase A, and Phase C is considered for identification of fault.

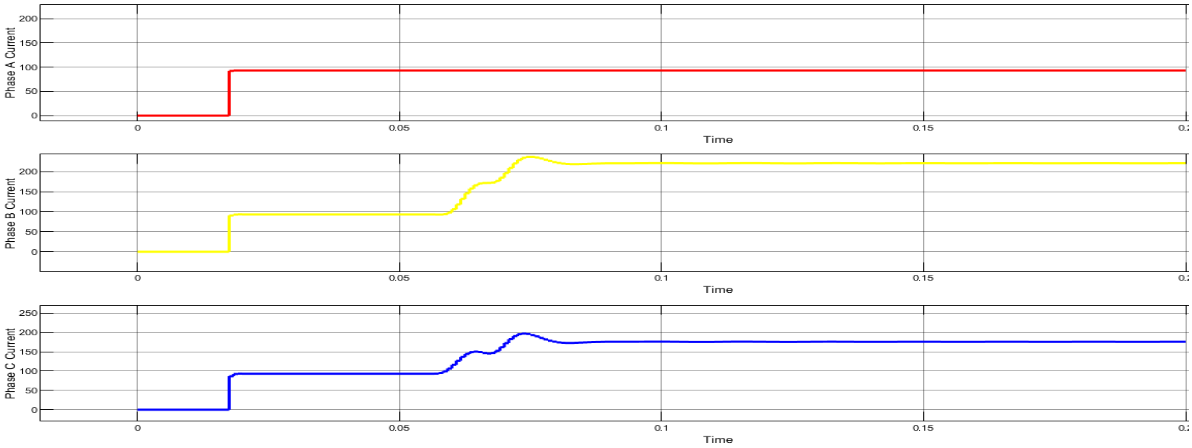

Figure 26. Variation in RMS current value at the time of fault identification in the LL (Phase B and Phase C) fault.

In the case of LL (BC) unsymmetrical faults, the presence of faults causes an elevated level of current at Phase B & C in IEEE 13. In this scenario, the windows indicate the rapid elevation in fault current as well as its RMS values over Phase B & C.

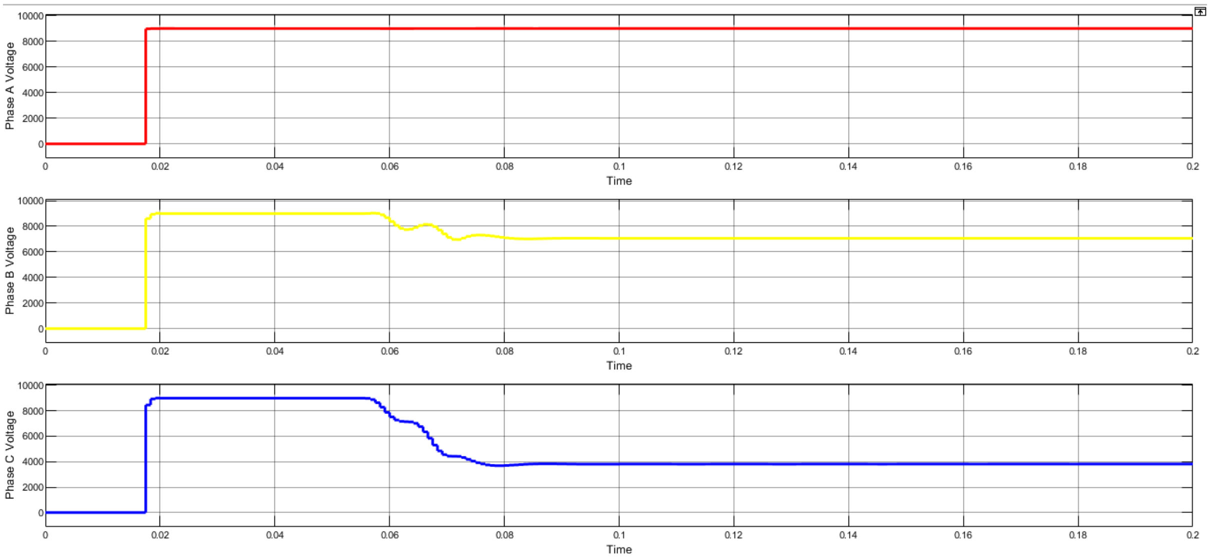

Figure 27. Variation in RMS Voltage value at the time of fault identification in the LL (Phase B and Phase C) fault.

The associated voltage output for IEEE 13 bus is displayed fig. 27. showing the voltage fall caused in Phase B and C by the failure. The increase in fault current, which lowers the voltage difference at the originating point, is to blame for this. LL (BC) fault causes a fall in Phase B & C.

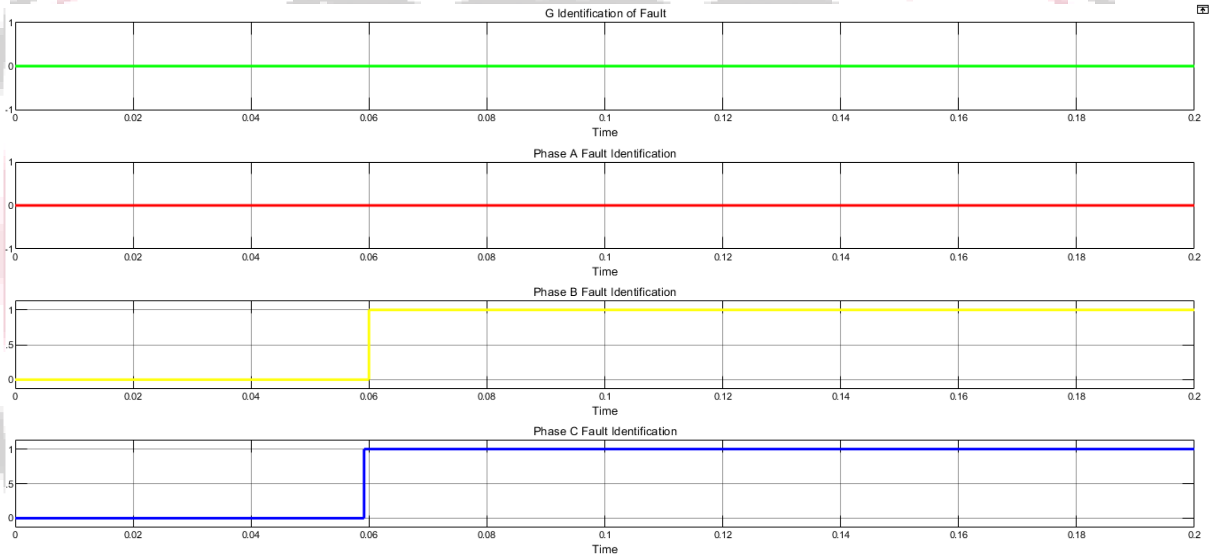

Figure 28. Fuzzy Fault identification window at bus 1 with LL (BC) fault.

The fuzzy system's output for low impedance fault identification is displayed in fig. 28. a specially built window. The three phases with output 1 in the instance of the LL (BC) fault exhibit similar characteristics and demonstrate that the fault has affected only Phase B & C.

LLG Faults

LLG fault is a type of fault that can occur in a three-phase power system. LLG fault stands for "Line-to-Line-to-Ground" fault, where one phase of the power system is short-circuited to ground and another phase is short-circuited to a different phase

LLG Fault (ABG Fault)

Here in this section, Phase A, Phase B and Ground is considered for identification of fault.

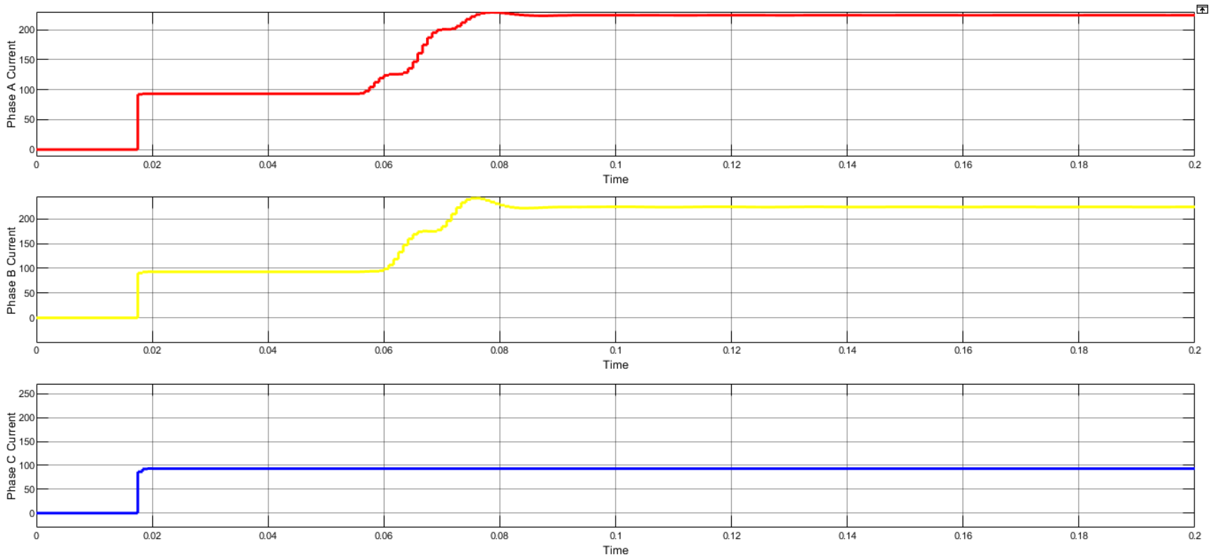

Figure 29. Variation in RMS current value at the time of fault identification in the LLG (Phase A, Phase B and Ground) fault.

In the case of LLG (ABG) unsymmetrical faults, the presence of faults causes an elevated level of current at Phase A & B in IEEE 13. In this scenario, the windows indicate the rapid elevation in fault current as well as its RMS values over Phase A & B.

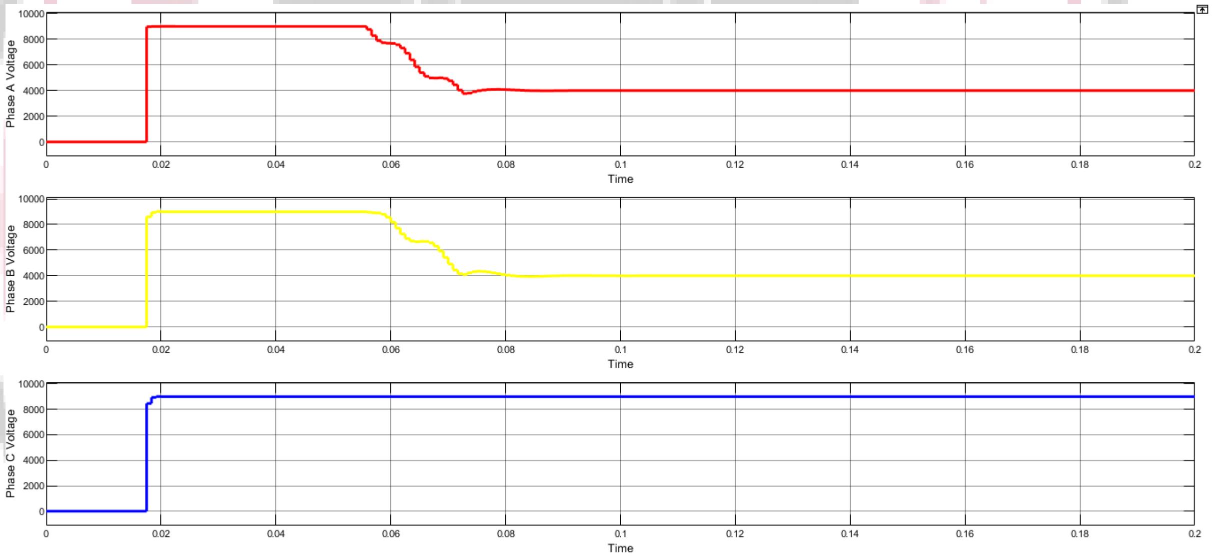

Figure 30. Variation in RMS Voltage value at the time of fault identification in the LLG (Phase A, Phase B and Ground) fault.

The associated voltage output for IEEE 13 bus is displayed fig. 30. showing the voltage fall caused in Phase A and B by the failure. The increase in fault current, which lowers the voltage difference at the originating point, is to blame for this. LLG(ABG) fault causes a fall in Phase A & B.

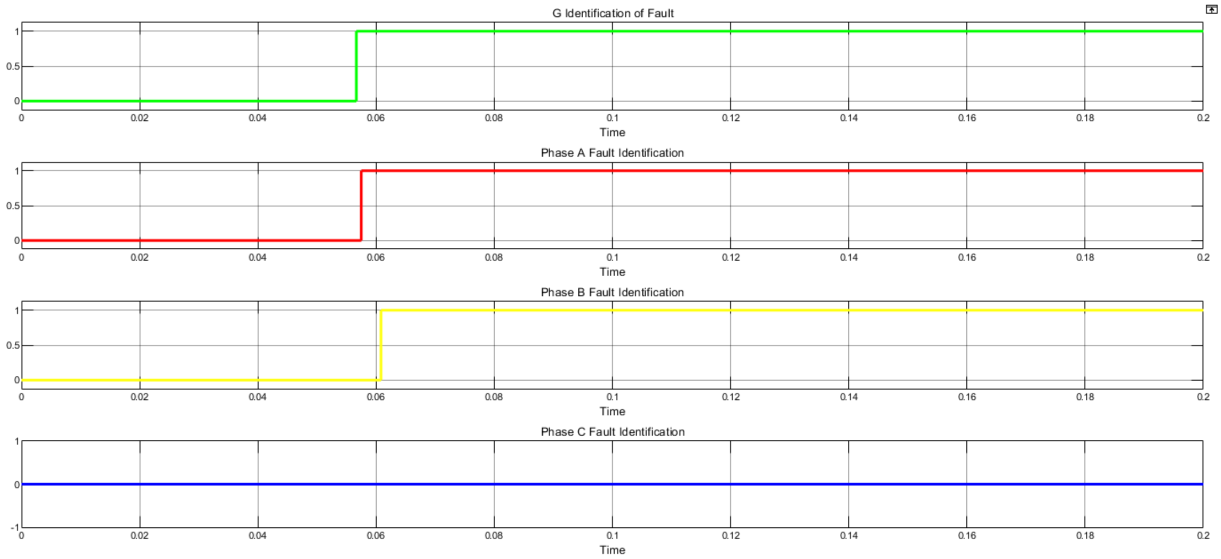

Figure31. Fuzzy Fault identification window at bus 1 with LLG (ABG) fault.

The fuzzy system's output for low impedance fault identification is displayed in a specially built window. The three phases with output 1 in the instance of the LLG (ABG) fault exhibit similar characteristics and demonstrate that the fault has affected only Phase A & B.

LLG Fault (BCG Fault)

Here in this section, Phase B, Phase C and Ground is considered for identification of fault.

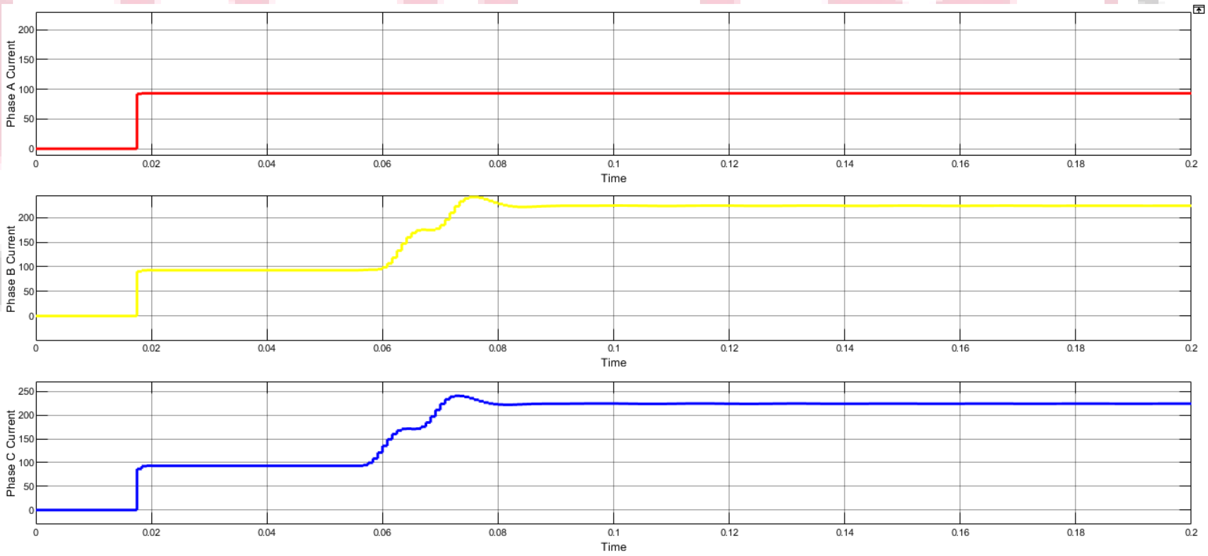

Figure 32. Variation in RMS current value at the time of fault identification in the LLG (Phase B, Phase C and Ground) fault.

In the case of LLG (BCG) unsymmetrical faults, the presence of faults causes an elevated level of current at Phase B & C in IEEE 13. In this scenario, the windows indicate the rapid elevation in fault current as well as its RMS values over Phase B & C.

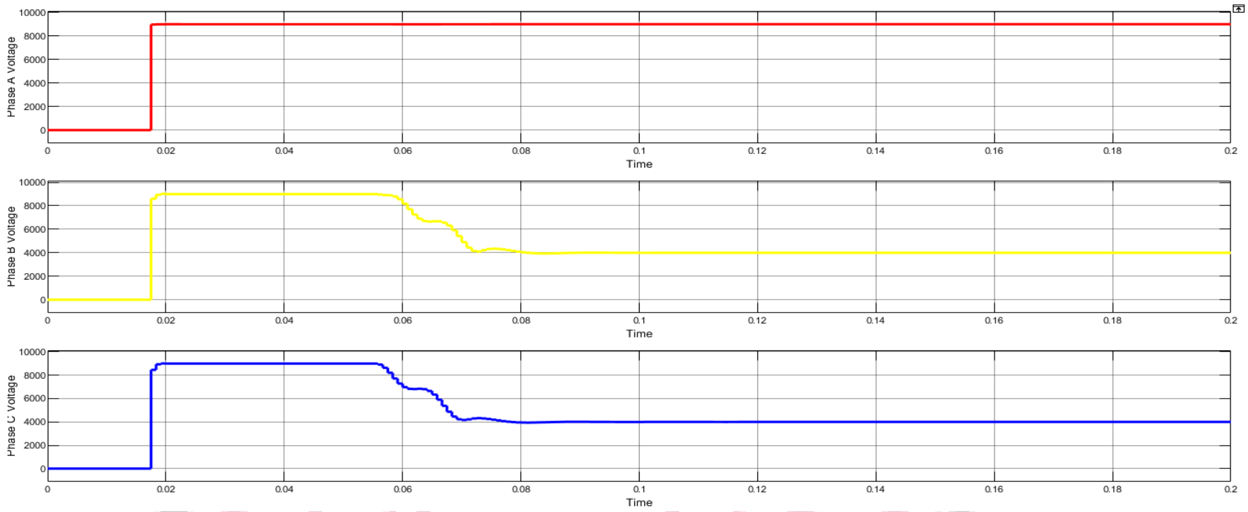

Figure 33. Variation in RMS Voltage value at the time of fault identification in the LLG (Phase B, Phase C and Ground) fault.

The associated voltage output for IEEE 13 bus is displayed, showing fig.33. the voltage fall caused in Phase B and C by the failure. The increase in fault current, which lowers the voltage difference at the originating point, is to blame for this. LLG(BCG) fault causes a fall in Phase B & C.

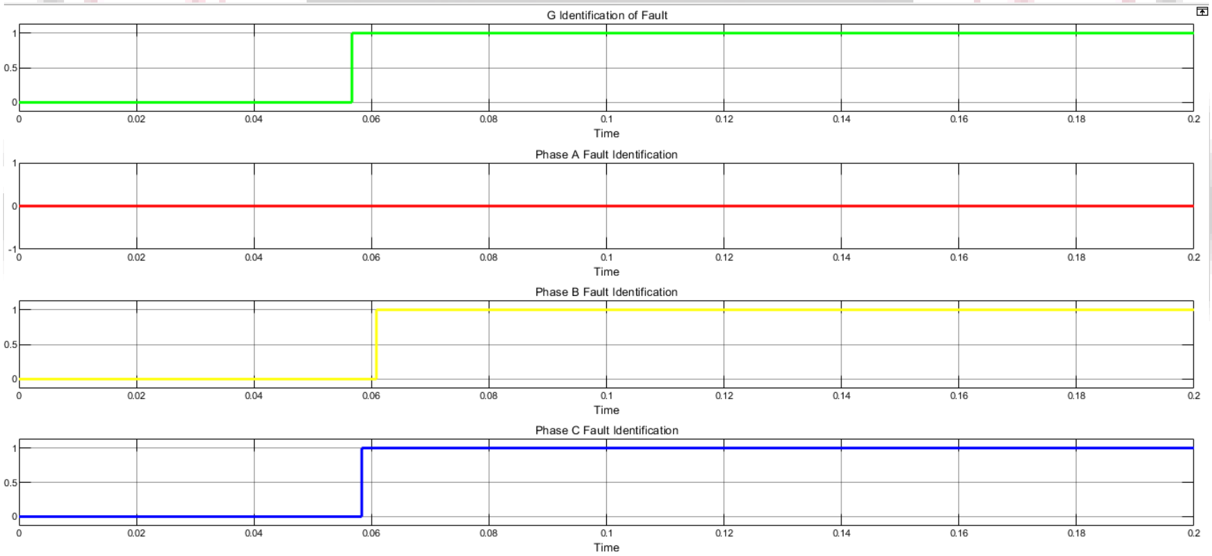

Figure 34. Fuzzy Fault identification window at bus 1 with LLG (BCG) fault.

The fuzzy system's output for low impedance fault identification is displayed in a specially built window. The three phases with output 1 in the instance of the LLG (BCG) fault exhibit similar characteristics and demonstrate that the fault has affected only Phase B & C.

LLG Fault (ACG Fault)

Here in this section, Phase A, Phase B and Ground is considered for identification of fault.

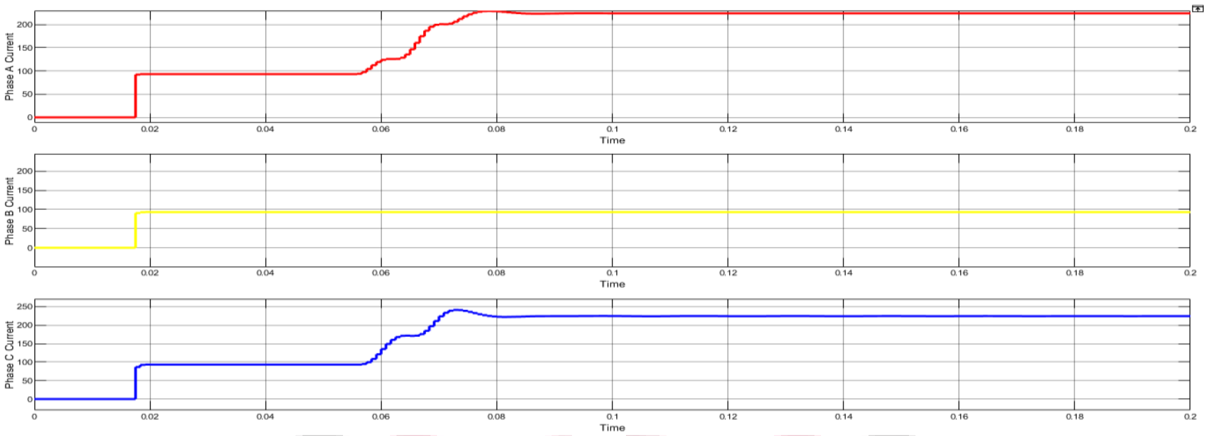

Figure 35. Variation in RMS current value at the time of fault identification in the LLG (Phase A, Phase C and Ground) fault.

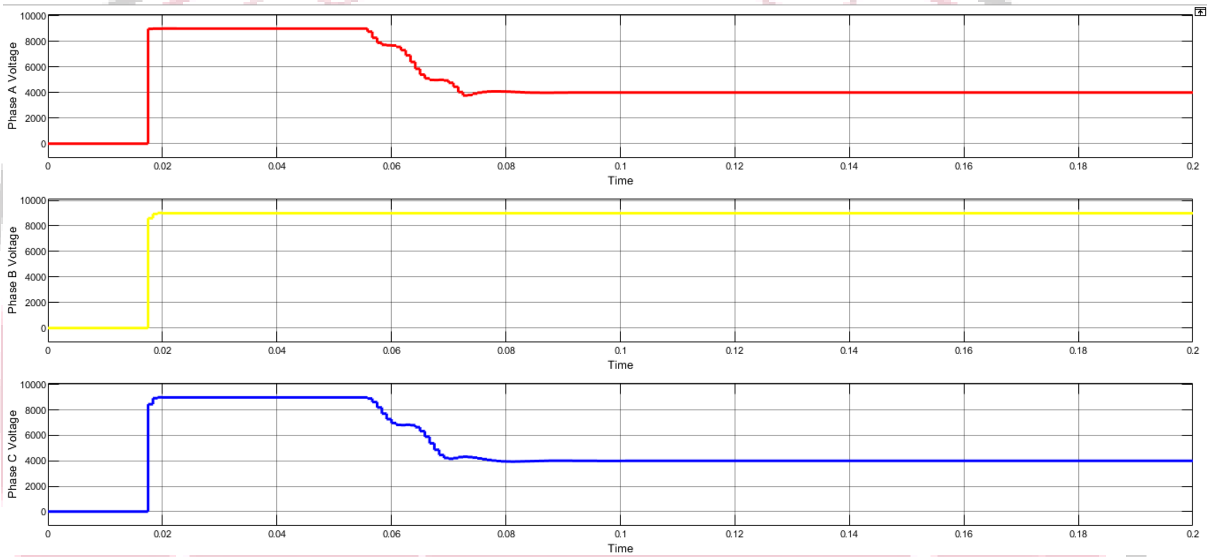

Figure 36. Variation in RMS Voltage value at the time of fault identification in the LLG (Phase A, Phase C and Ground) fault.

In case of LLG (ACG) unsymmetrical faults, the presence of faults causes an elevated level of current at Phase A & C in IEEE 13. In this scenario, the windows indicate the rapid elevation in fault current as well as its RMS values over Phase A & C.

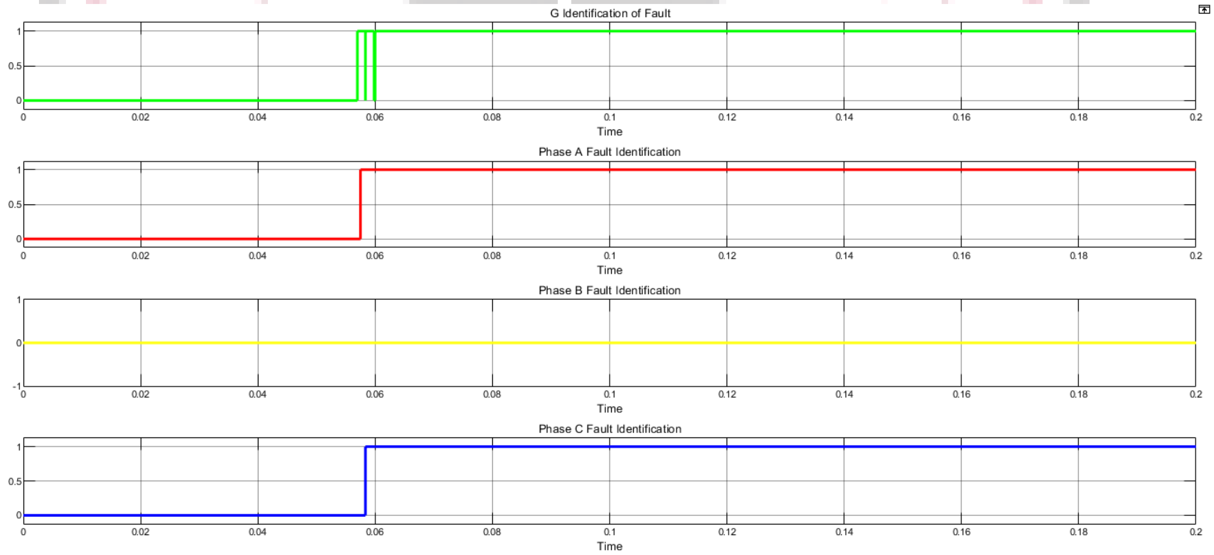

Figure 37. Fuzzy Fault identification window at bus 1 with LLG (ACG) fault.

The fuzzy system's output for low impedance fault identification is displayed in a specially built window. The three phases with output 1 in the instance of the LLG (ACG) fault exhibit similar characteristics and demonstrate that the fault has affected only Phase A & C.

Designing of Fault Removal Circuit SFCL

SFCL stands for Superconducting Fault Current Limiter. It is a device that is used to limit the fault current that occurs during a power system fault. SFCLs are based on the principle of superconductivity, where materials exhibit zero electrical resistance when cooled below a certain temperature. During a fault in a power system, the current can increase to very high levels, which can cause damage to the equipment and also result in a blackout. SFCLs are used to limit this fault current by inserting a superconducting material in the path of the current. The superconducting material has zero resistance and can carry large amounts of current without any losses. SFCLs are used in various applications, including power transmission and distribution systems, renewable energy systems, and industrial power systems. They offer several advantages, such as increased system stability, reduced equipment damage, and improved reliability.

SFCL in Removing LLL FAULT (ABC)

As we have seen in previous sections that RMS values of voltage decreases and RMS value of current increases gradually whenever the fault takes place in any of the phase. In this section we have considered LLL (ABC) Fault.

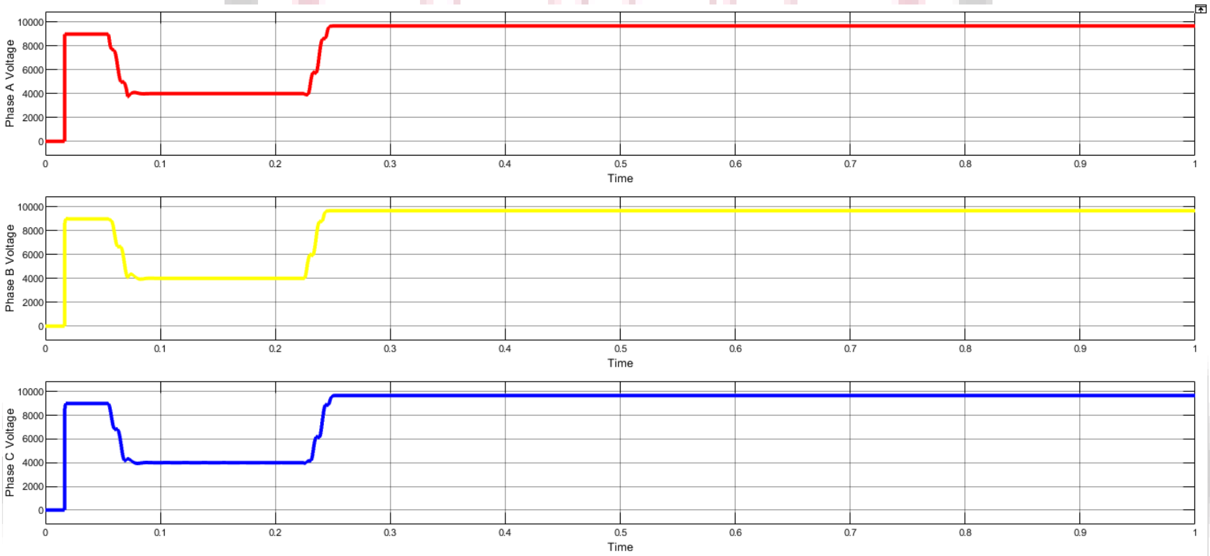

Figure 38. Variation in RMS voltage values in ABC fault after applying fault removal circuit.

Initially it was observed that as the fault takes place, value of voltage drops gradually but as the fault limiter devices was applied, after the duration of 0.162 seconds it starts gaining its actual value.

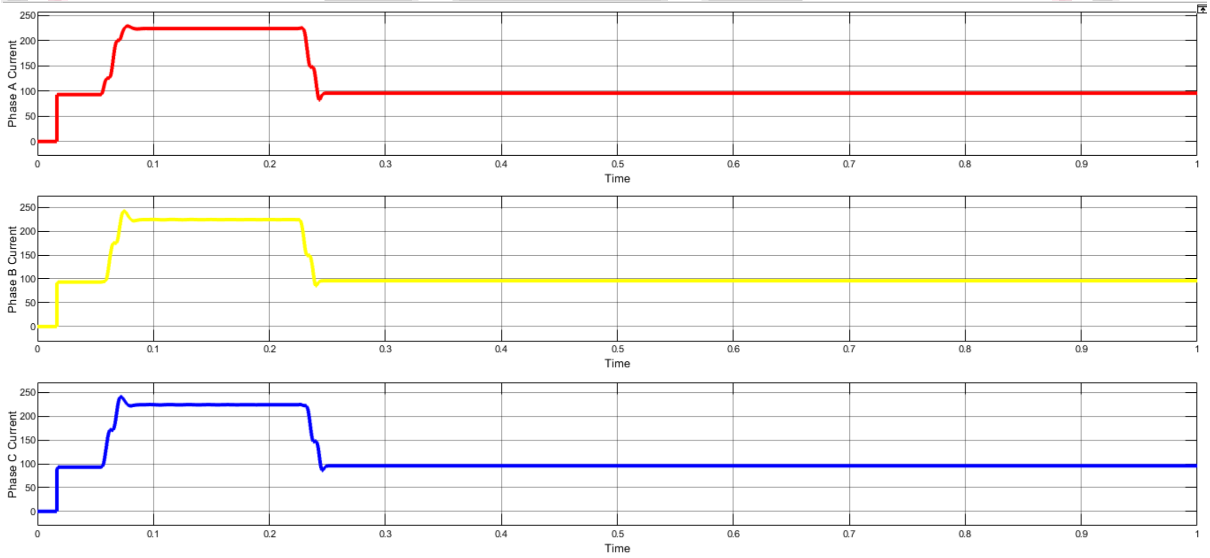

Figure 39. Variation in RMS current values in ABC fault after applying fault removal circuit.

Value of current rise gradually as the fault takes place which can cause the damage of equipment but as the fault limiter device was applied, after the duration of 0.162 seconds it starts retaining its actual value.

SFCL in Removing LG FAULT (AG)

Initially it was observed that as the fault takes place, value of voltage drops gradually but as the fault limiter device was applied, after the duration of 0.1839 seconds it starts gaining its actual value.

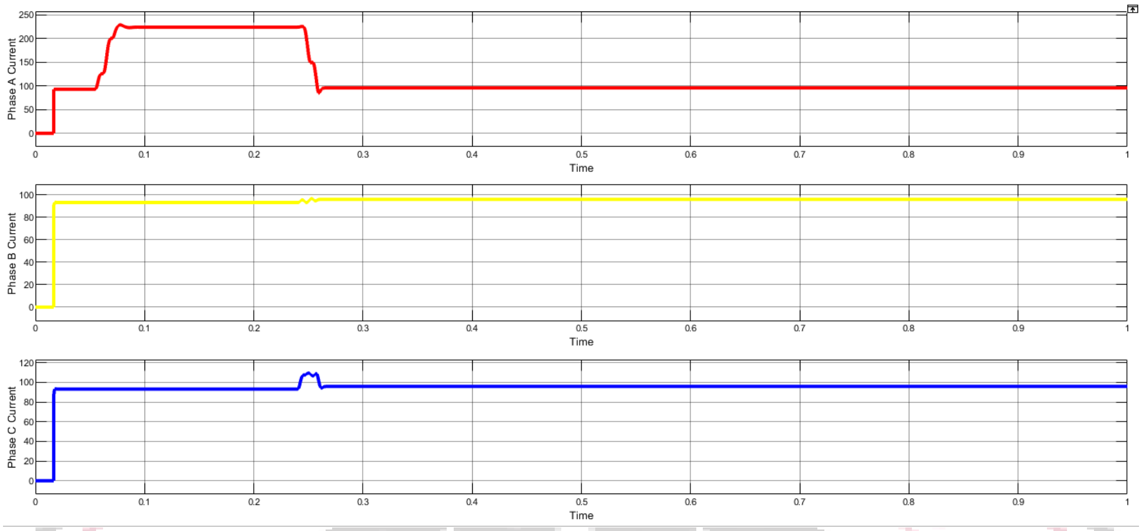

Figure 40. 32Variation in RMS current values in ABC fault after applying fault removal circuit.

Value of current rise gradually as the fault takes place which can cause the damage of equipment but as the fault limiter device was applied, after the duration of 0.1839 seconds it starts retaining its actual value.

SFCL in Removing LL FAULT (AB)

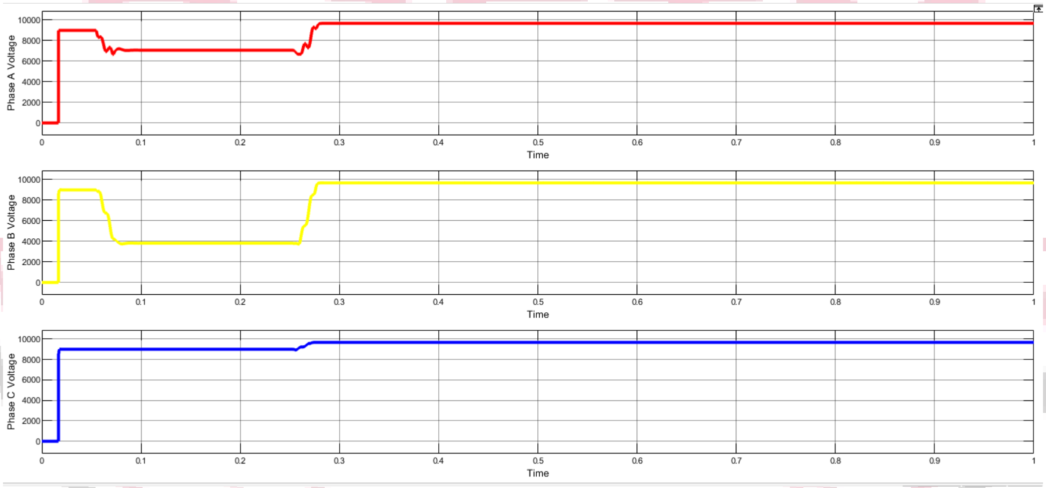

Figure 41. Variation in RMS voltage values in AG fault after applying fault removal circuit.

Initially it was observed that as the fault takes place, value of voltage drops gradually but as the fault limiter device was applied, after the duration of 0.1962 seconds it starts gaining its actual value.

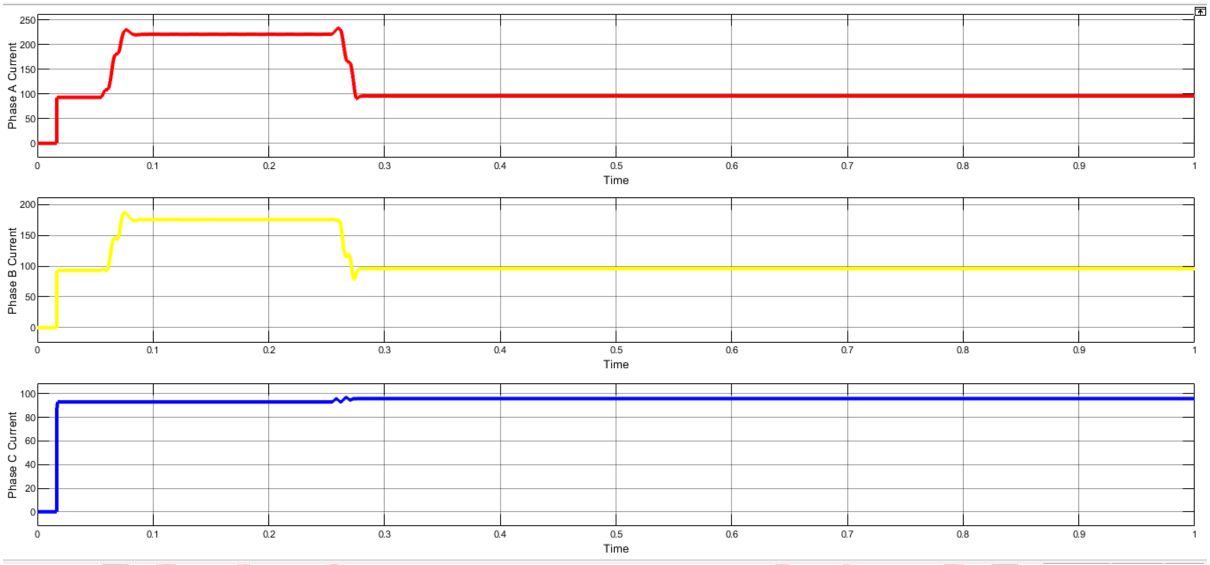

Figure 42. Variation in RMS current values in AB fault after applying fault removal circuit.

Value of current rise gradually as the fault takes place which can cause the damage of equipment but as the fault limiter device was applied, after the duration of 0.1962 seconds it starts retaining its actual value.

V. CONCLUSION

In conclusion, the reliability and resilience of power systems are paramount in ensuring uninterrupted energy supply to consumers. By comprehensively analyzing faults and deploying advanced fault detection techniques, such as SFCLs, power system operators can proactively safeguard against potential disruptions. Moreover, ongoing research and innovation in fault analysis methodologies promise to further enhance the robustness of power infrastructure, laying the foundation for a more sustainable and resilient energy future.

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