Simulation of Faults in the Yeywa-Thaphaywa High Voltage Transmission Line using Fuzzy Logic

Zaw Htwe Oo
Ministry of Education
Naypyidaw, Myanmar

Abstract:- Faults in transmission networks frequently undermine the reliability and stability of electrical power supply, causing load shedding and posing risks to power system equipment. Effective fault classification is crucial to minimize power outages and ensure timely restoration. This study presents a fault classification method for transmission lines using fuzzy logic. The classification utilizes three-phase feeder currents, neutral current, and phase voltages as inputs to the Fuzzy Inference System (FIS). The proposed method accurately classifies the various types of faults in a high voltage transmission network, including line-to-ground fault, double line-to-ground fault, line-to-line fault, and three-phase faults. Numerous test cases demonstrate the technique's high accuracy. The simulations are carried out in MATLAB/SIMULINK using Sim Power Systems and the Fuzzy Logic Toolbox (MATLAB 2016a).

Keywords:- *Fault Classification (FC), Fuzzy Logic System (FLS), Power System Network, Transmission Line.*

I. INTRODUCTION

Modern power systems are intricate networks requiring fast, accurate, and dependable protection systems to ensure stability and reliability. Among the various components, protecting transmission lines is critical to safeguarding the overall power system. Protective systems play a crucial role in preventing the propagation of faults, which are inevitable in power systems, particularly in overhead transmission lines, where fault occurrences are more frequent compared to other components. Transmission line faults generate transients that can destabilize the system if not addressed promptly.

Advances in technology have led to the design and development of improved protective devices. However, using conventional techniques for fault types classification in double-circuit lines remains challenging because of the mutual coupling between the circuits [1]. This issue can be addressed by compensating for the zero-sequence current. Fault detection, classification, and isolation with minimal delay are the primary objectives of protective systems. To ensure system stability and service continuity, the faulty section must be isolated swiftly.

Various fault classification methods have been reported in the literature, with recent protection schemes utilizing artificial intelligence (AI) techniques. Most utilized AI techniques are artificial neural networks (ANN), neuro-fuzzy analysis, and some other fuzzy logic approaches. These methods enable fast, accurate, and reliable fault type classification, which is essential for fault distance protection schemes. The performance of fault location methods using fuzzy logic approaches, in particular, relies heavily on the accuracy of fault type classification. In this paper, a real-time fault type classification method using fuzzy logic approaches is proposed, capable of detecting and classifying faults within 100ms as a maximum delay or less than it, with high accuracy. The detection time can be further improved to enhance the speed of the protective system.

II. FAULTS IN TRANSMISSION LINES

The unsymmetrical faults are majority faults in power systems, and the line-to-ground faults are occurrence as the most common fault type. When such faults occur, they result in an unsymmetrical current, where the fault current in the affected phase increases significantly, leading to unequal phase displacement. In contrast, symmetrical faults, such as three-phase short circuits fault or three-phase short circuits fault with ground, produce symmetrical short circuit currents in all phases of the network. Such kinds of faults place heavy demands on circuit breakers due to the high fault currents.

During a fault, the current in the affected line increases significantly, surpassing the currents in the unaffected lines. In the event of a single line-to-ground fault, only one line shows a marked increase in current, whereas in double line-to-ground faults, the currents in two lines exceed that of the third line. Generally, fault conditions cause a rise in current magnitude and a drop-in voltage. The severity of these faults significantly influences the performance of the transmission line, which consequently affects power generation and consumers.

Moreover, when faults occur in any phase, the unaffected phases are often affected because the mutual coupling between these lines will affect to each other. This alters the waveforms in the unaffected lines, making it difficult to identify the fault type using conventional techniques. Table 1 provides an overview of different fault types and their severity [2].

ISSN No:-2456-2165 https://doi.org/10.38124/ijisrt/IJISRT24OCT1282

Table 1: Various Types of Fault and their Severity

Type of Fault	Severity	Occurrence
Three Phase (LLL)	Severe	5%
Double Line to Ground fault (LLG)	Severe	10%
Line to Line fault (LL)	Less Severe	15%
Single Line to ground fault (LG)	Very Less	70%

III. METHODOLOGY FOR FAULT CLASSIFICATION SCHEME

The method used in this study is implemented on the power system network model presented in Figure 1, where various fault types have been simulated through fuzzy membership functions and rules. Data is collected both before and after the fault, with the post-fault data from different fault types being utilized to assess the effectiveness of the proposed fault classification system using fuzzy logic approaches. The simulation model of the power system, created in MATLAB 2016, is based on the data obtained, as depicted in Figure 1.

Initially, the fault classification system using fuzzy logic approaches was tested in an online environment to find the optimal configuration. Once optimized, the system was applied to real-time fault detection. During the analysis, it was observed that the waveforms change significantly depending on the type of fault, whether it is a line to ground fault (LG), line to line fault (LL), double line to ground fault (LLG), or a three-phase fault (LLL). It is important to note that during faults, the voltage typically drops to zero while the current increases sharply.

The various fault types are defined by parameters δ_1, δ_2, δ_3, and δ_4, with the calculations for these parameters detailed below. The post-fault current samples are analyzed as described in the following sections.

$$\delta_1 = \frac{I_a - I_b}{\max(I_a, I_b)} \tag{1}$$

$$\delta_2 = \frac{I_b - I_c}{\max(I_b, I_c)} \tag{2}$$

$$\delta_3 = \frac{I_c - I_a}{\max(I_c, I_a)} \tag{3}$$

$$I_0 = \frac{1}{3}(I_a + I_b + I_c) \tag{4}$$

$$\delta_4 = I_0 \tag{5}$$

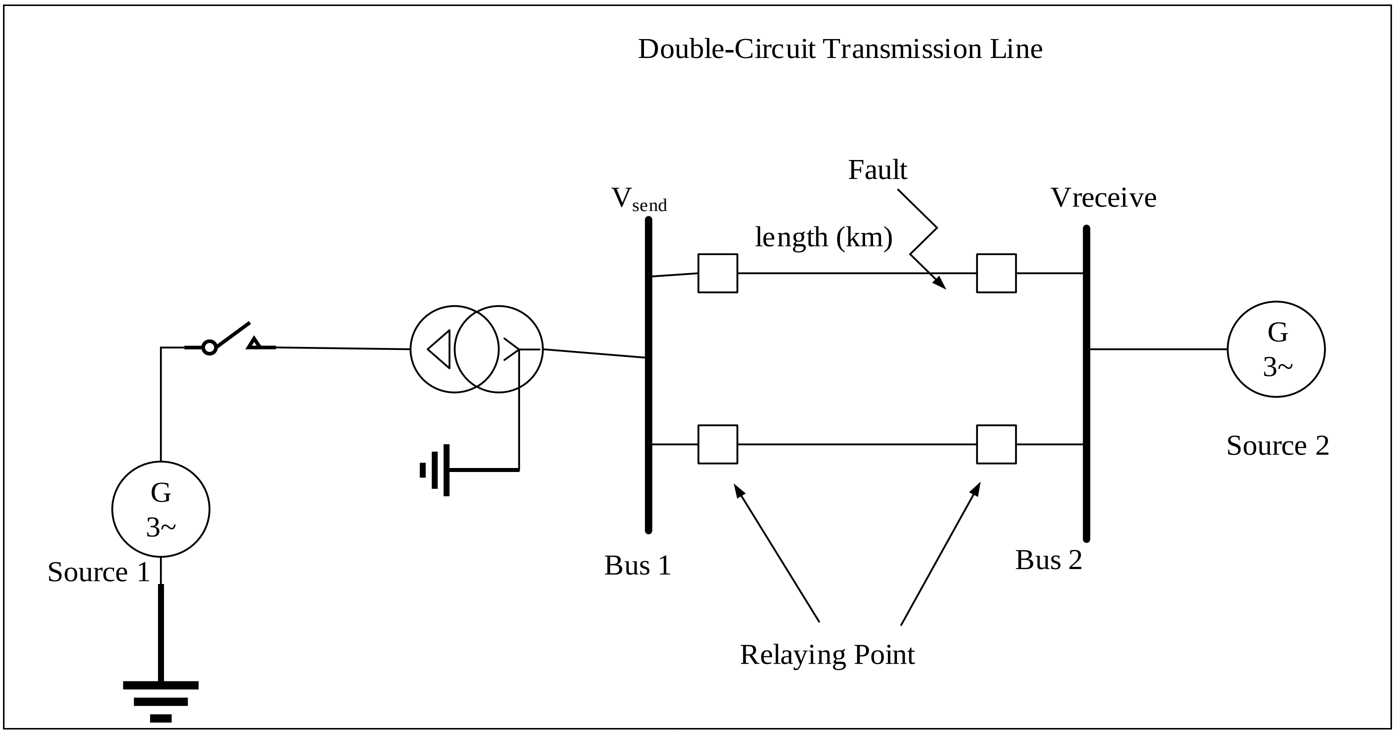

Fig 1: Single Line Diagram of a Two Bus Power System Model

In this approach, Ia, Ib, and Ic correspond to the samples of the phase current A, B and C, whereas I0 indicates the zero-sequence current of the network. The fault classification by fuzzy rule base method is established using the parameters δ1, δ2, and δ3. The zero-sequence current I0 is utilized to identify ground faults, with δ4 specifically representing the detection of ground faults.

ISSN No:-2456-2165 https://doi.org/10.38124/ijisrt/IJISRT24OCT1282

➢ *Fuzzy Rule base for Fault Classification:*

- If δ_1 value is high, δ_2 value is medium, δ_3 value is low and δ_4 value is high, it is Line A to Ground (AG) fault;
- If δ_1 value is low, δ_2 value is high, δ_3 value is medium and δ_4 value is high it is Line B to Ground (BG) fault;
- If δ_1 value is medium, δ_2 value is low, δ_3 value is high and δ_4 value is high it is Line C to Ground (CG) fault;
- If δ_1 value is medium, δ_2 value is high, δ_3 value is low and δ_4 value is low it is Line A to Line B (AB) fault;
- If δ_1 value is high, δ_2 value is low, δ_3 value is medium and δ_4 value is low it is Line A to Line C (AC) fault;
- If δ_1 value is low, δ_2 value is medium, δ_3 value is high and δ_4 value is low it is Line B to Line C (BC) fault;
- If δ_1 value is medium, δ_2 value is high, δ_3 value is low and δ_4 value is high it is Line AB to Ground (ABG) fault;
- If δ_1 value is low, δ_2 value is medium, δ_3 value is high and δ_4 value is high it is Line AC to Ground (ACG) fault;
- If δ_1 value is high, δ_2 value is low, δ_3 value is medium and δ_4 value is high it is Line BC to Ground (BCG) fault;
- If δ_1 value is medium, δ_2 value is medium, δ_3 value is medium and δ_4 value is low it is three phase (ABC) fault;

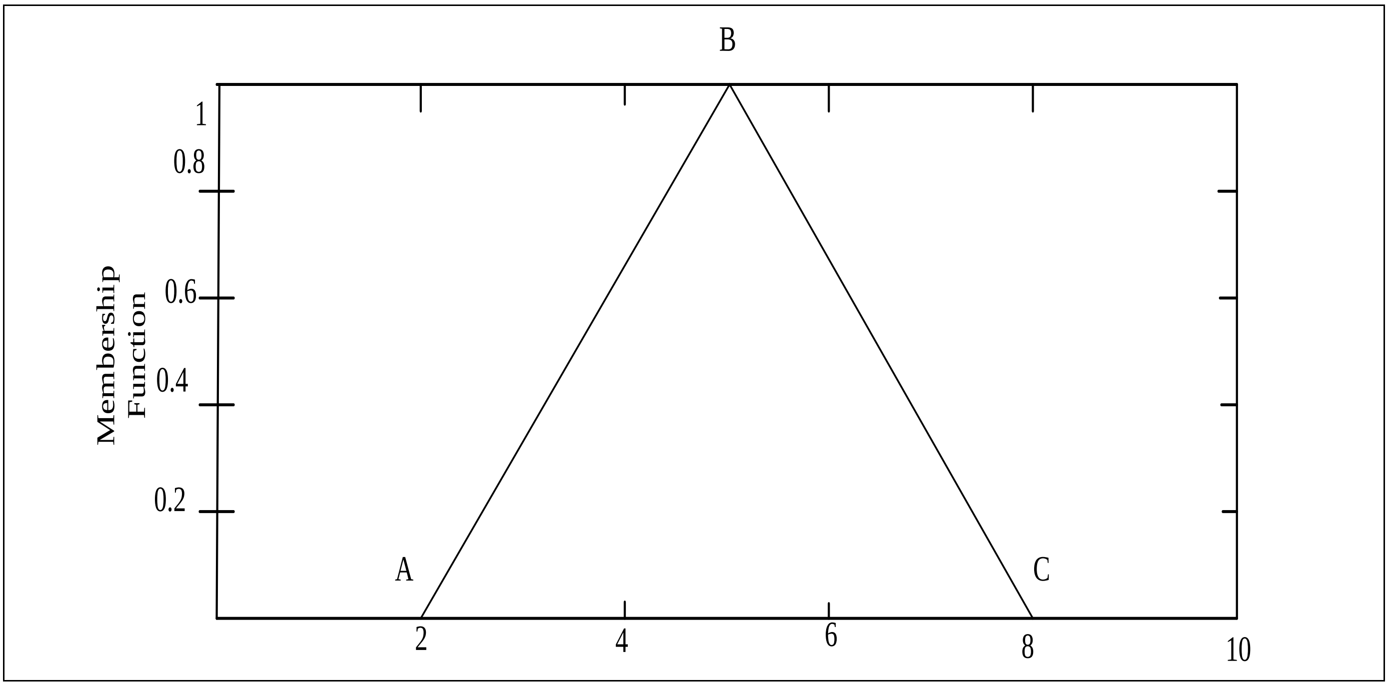

Fig 2: Triangular-Shaped Membership Functions

To represent various fuzzy variables in both the antecedent and consequent sections of the fuzzy rules, a triangular membership function is employed. This function is characterized by three points: A, B, and C, where a membership value of points A and C has 0.0, and a membership value of point B has 1.0. A comprehensive study was conducted to identify suitable triplet values for the triangular membership functions of δ_1, δ_2, δ_3, and δ_4. The chosen triplet values for the fuzzy variables are utilized the fuzzy rules in both the antecedent and consequent sections.

IV. MODELLING OF SELECTED TEANSMISSION LINE

The Yeywa Hydro Power Plant, located in the Mandalay Region, is connected to the national grid. It consists of four turbine generators, each rated at 230 MVA. Currently, one of the generators (230 MVA, unit 4G) is out of service, but the remaining three are fully operational, providing a total generation capacity of 790 MW, although only about 400 MW is consumed daily. The station is linked to the load center via five overhead feeder cables. Each feeder is connected to a 230-kV busbar through its respective switchgear and transformer. The power station's protection scheme incorporates various electrical apparatus, including current transformers, potential transformers, circuit breakers, relay isolators, and fuses.

ISSN No:-2456-2165 https://doi.org/10.38124/ijisrt/IJISRT24OCT1282

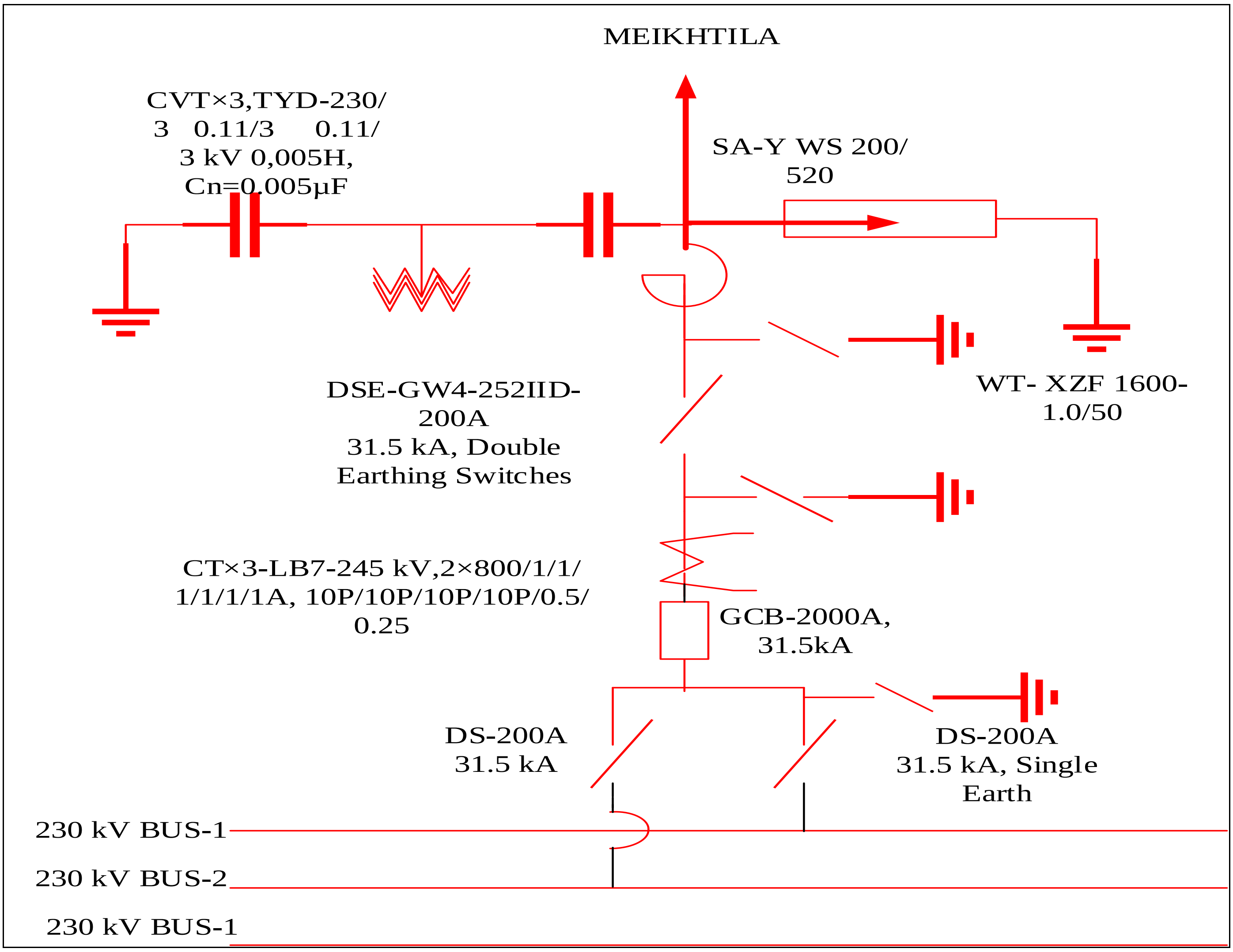

Fig 3: Single Line Diagram of 230 kV Yeywa-Thaphaywa (Meikhtila) Twin Bundle Double Circuit Transmission Line

A. Data Collection

The Yeywa Hydro Power Plant functions with a radial power network, generating 400 MW from a hydro turbine rated at 230 MVA. The 400 MW output is transmitted through indoor switchgear to out-station transformers that serve various sections of the plant and its facilities. The hydro turbine is installed in the powerhouse located on the Myitnge River, approximately 52 kilometers (32 miles) southeast of Mandalay. The plant has five transformers, which are distributed to feed various sections.

➢ *The Key Parameters for the Model are Derived from Line Characteristics and Conductor Specifications, as Follows:*

- Line length: 112.25 km
- Positive/Negative sequence impedance: 1.8167+j34.48 Ω
- Positive/Negative sequence admittance: 0.0007521872S
- Fault initiation time: 0.1 seconds
- Fault duration: 0.03 seconds
- Conductor type: Drake, 795 MCM

B. Voltage and Current Measurement for Preprocessing of Data

The waveforms of three phase voltage and current were generated and sampled at a frequency of 20 kHz. Enhancing the time performance of the fuzzy logic system can be accomplished by minimizing its overall size, which is achievable through optimizing the feature extraction process. This approach ensures that all significant and relevant information contained in the voltage and current waveforms is utilized effectively.

Figure 3 displays the current waveform for a phase A to ground (AG) fault, located 14.343 km from the terminal A on a length of 14.343 km transmission line. The current and voltage waveform represents samples taken at a frequency of 20 kHz. The voltages and currents ratios in each phase consists as the input of the fuzzy logic system during before and after conditions of the fault occurrence. The advantage of this scaling technique is that it helps reduce the training time for the fuzzy logic system.

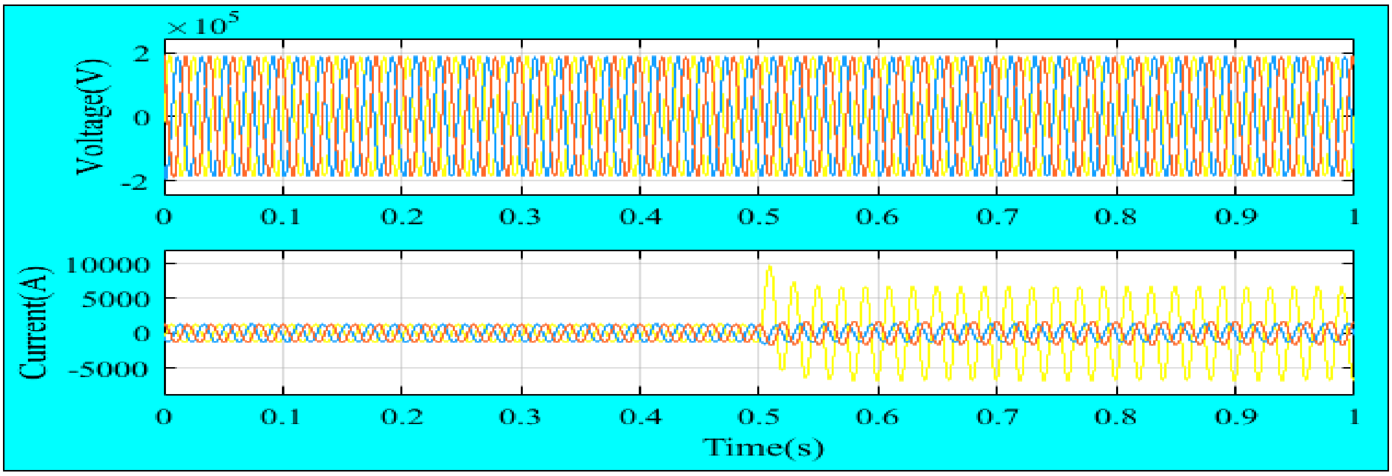

Fig 4: Data Preprocessing Illustration

The simulation duration is configured to 1 second, when the sampling time of the system is 100 µs, yielding a model sampling frequency of 20 kHz. In the model, voltage and current measurements are taken at the Yew bus (B1), and these values are used for fault classification. Ten types of faults are simulated, each with varying fault resistances and locations.

V. IMPLEMENTATION FOR FUZZY LOGIC SYSTEM

The fuzzy logic approach is simple and not a complex computational method. The concept of possibility of a fuzzy logic-based theory, is represented by a value between zero and one. Fuzzy logic offers a mathematical framework to address vagueness, which is often inherent in human decision-making processes. The membership function illustrates the extent to which an element belongs to a fuzzy set. Indeterminate terms like "high" and "low" can be modeled using fuzzy sets. By utilizing the RMS values of measured quantities, suitable fuzzy sets are created, such as Low, Normal, and High.

A. Algorithm of the Fuzzy Interference System

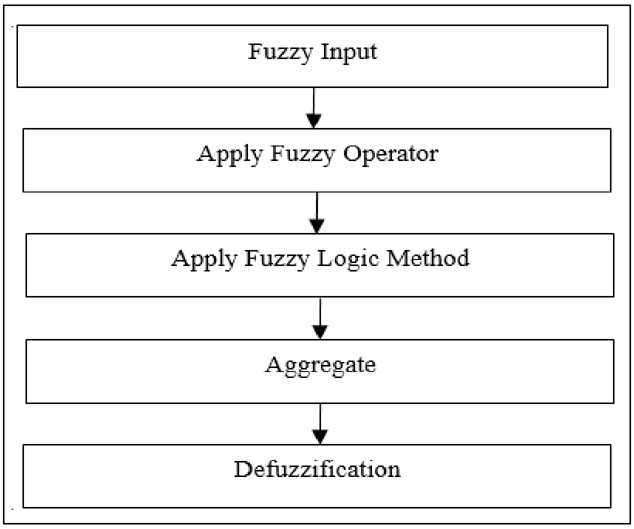

Fig 5: Fuzzy Logic Inference System.

B. Fuzzification

The Fuzzy Logic System (FLS) has four input variables: δ1, δ2, δ3, and δ4. The output variables represent ten different fault types, labeled Fault Type 1 through Fault Type 10. The three fuzzy subsets: 1) Low (L), 2) Normal (N) are, and 3) High (H) are comprised in the linguistic input variables. The linguistic variables of the output correspond to ten subsets of fuzzy method: 1) RG, 2) YG, 3) BG, 4) RY, 5) RB, 6) YB, 7) RYG, 8) RBG, 9) YBG, and 10) RYB. For both the input and output linguistic terms, the fuzzy ratings are presented in Tables 2, 3 and 4 respectively. Triangular-shaped membership functions are utilized for both the input and output variables, as illustrated in Figure 5. These membership functions were chosen through a trial-and-error method to enhance classification accuracy.

Table 2: Input Linguistic Variables δ_1, δ_2, δ_3 and Fuzzy Rating

Linguistic Variables	Fuzzy Rating
low	[-1.72 -1.08 -0.7 -0.2]
medium	[-0.4 0.1 0.35 0.56]
high	[0.35 0.43 1.08 1.72]

Table 3: Input Linguistic Variables δ_4 NS Fuzzy Rating

Linguistic Variables	Fuzzy Rating
low	[-2.88 -0.32 0.6 0.8]
high	[0.6 0.8 3.52 6.08]

Table 4: Output Linguistic Variables and Fuzzy Rating

Linguistic Variables	Fuzzy Rating
AG	[0 1 2]
BG	[1 2 3]
CG	[2 3 4]
AB	[3 4 5]
AC	[4 5 6]
BC	[4 5 6]
ABG	[6 7 8]
ACG	[7 8 9]
BCG	[8 9 10]
ABC	[9 10 11]

ISSN No:-2456-2165 https://doi.org/10.38124/ijisrt/IJISRT24OCT1282

C. Classification of Membership Functions and Fuzzy Inference System Rules

Under various fault conditions on the power system network, the fault voltages and currents are classified into the membership functions: Low, Normal, and High. Generally, when a fault occurs, the current magnitude increases while the voltage decreases. They are used to establish the fuzzy approach of fault classification system, allowing for accurate identification of fault conditions.

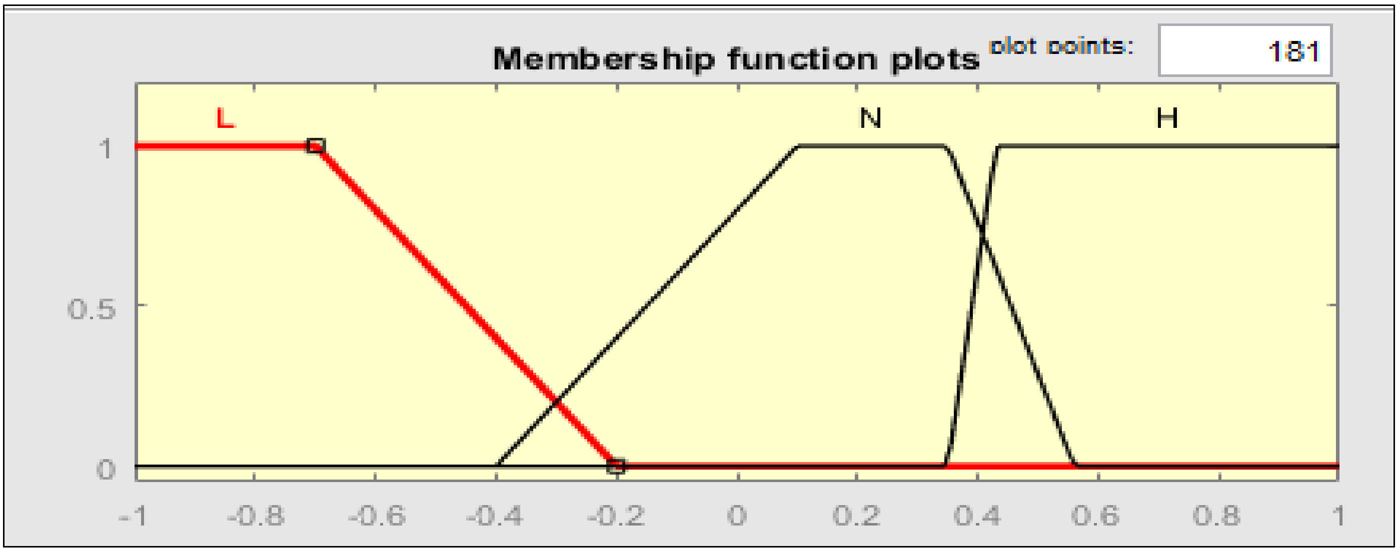

Fig 6: Fuzzy Membership Function for δ_1, δ_2, δ_3

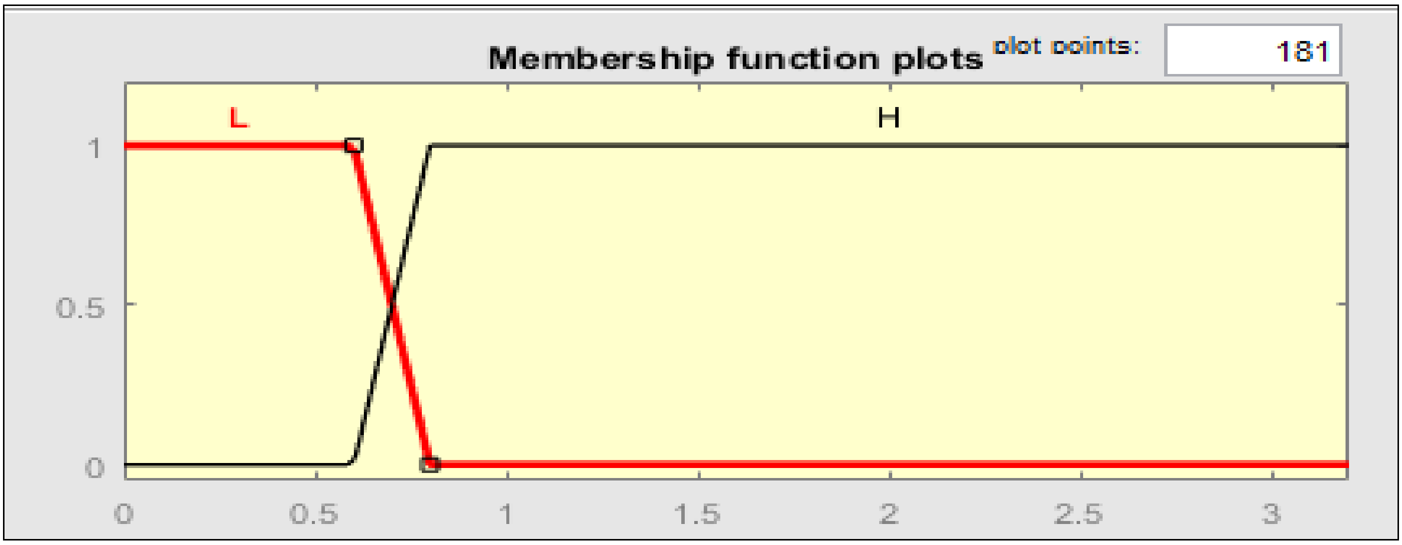

Fig 7: Fuzzy Membership Function for δ_4

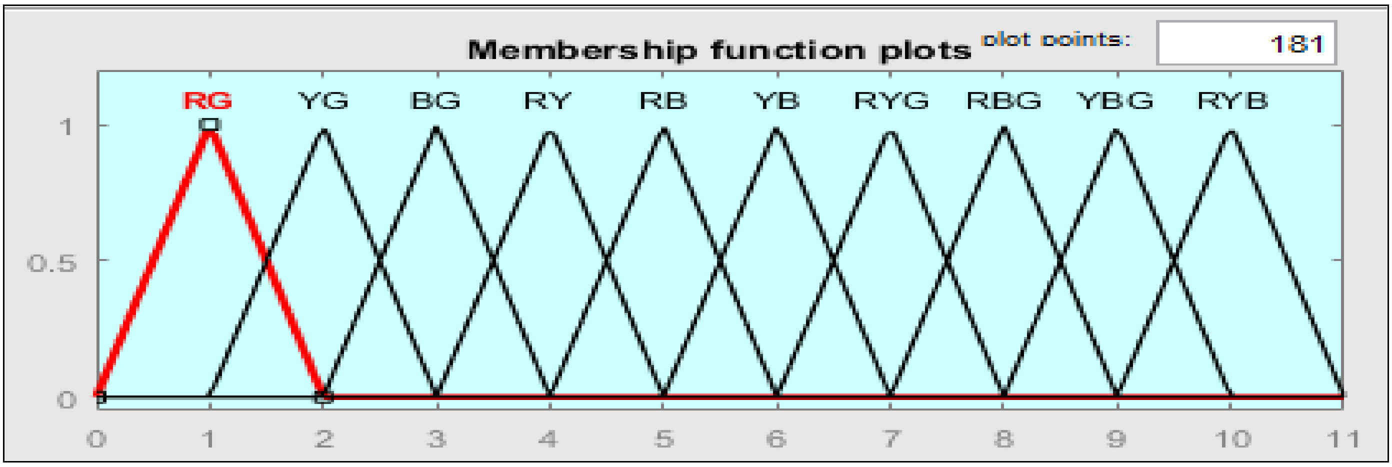

Fig 8: Functions for Different Types of Faults

ISSN No:-2456-2165 https://doi.org/10.38124/ijisrt/IJISRT24OCT1282

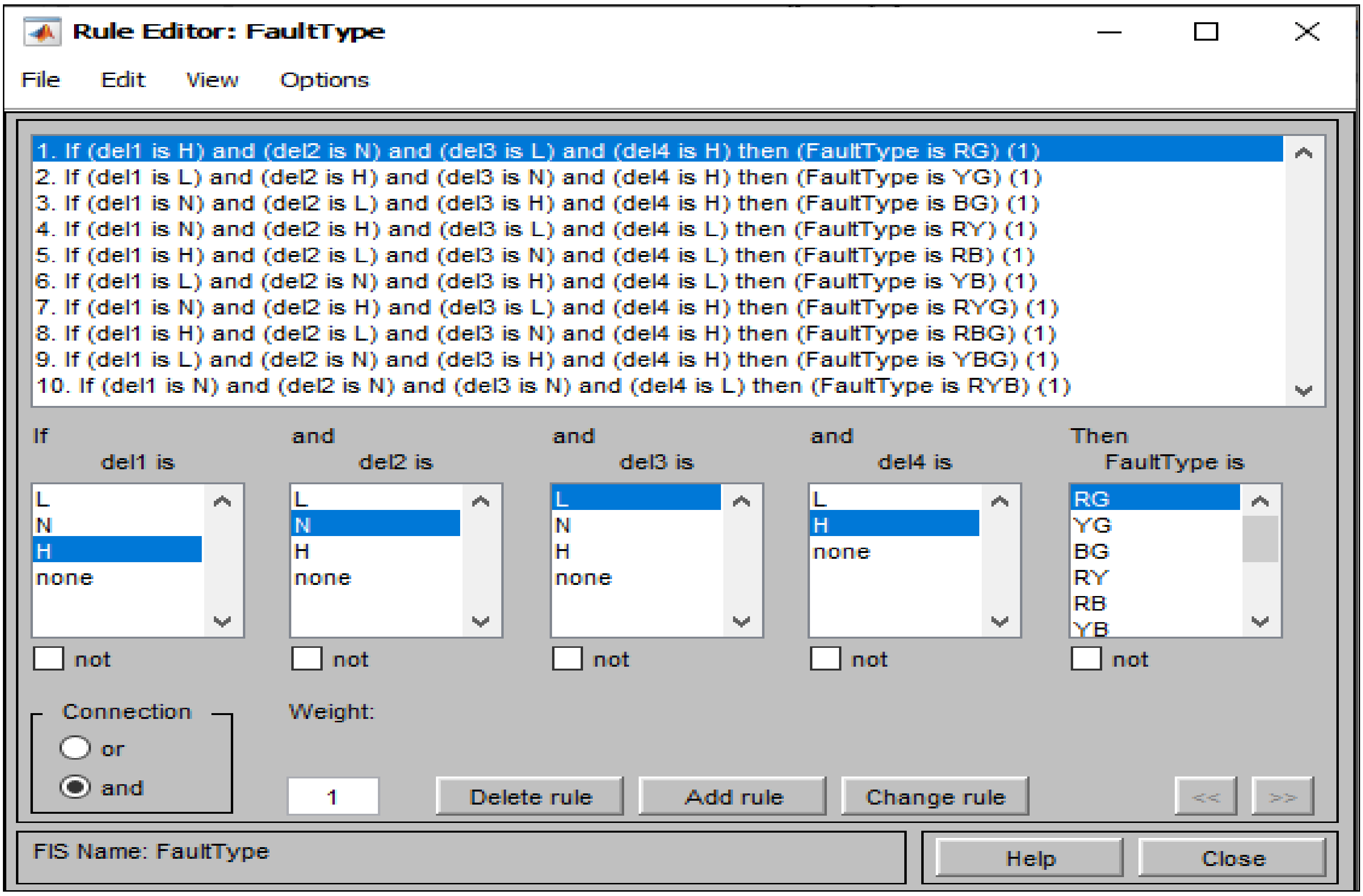

Fig 9: Fuzzy Inference System Rules

➢ *The Ten Types of Shunt Faults are Derived from the Fuzzy Rules. The Rules Structures are Constructed as Follows:*

- If δ1 value is High, δ2 value is Normal, δ3 value is Low and δ4 value is High, the fault type is single line to ground fault occurring in phase A (AG).
- If δ1 value is Normal, δ2 value is Low, δ3 value is Normal and δ4 value is High, the fault type is double line fault in phase AB(AB).
- If δ1 value is Normal, δ2 value is Low, δ3 value is High and δ4 value is High, the fault type is double line-to-ground fault in phase AB (ABG).
- If δ1 value is Normal, δ2 value is High, δ3 value is Low and δ4 value is Low, the fault type is three-phase symmetrical fault.
- If δ1 value is High, δ2 value is Low, δ3 value is Normal and δ4 value is Low, the fault type is single line to ground fault in phase A (AG).
- If δ1 value is Low, δ2 value is Normal, δ3 value is High and δ4 value is Low, the fault type is double line fault in phase AB (AB).
- If δ1 value is Normal, δ2 value is High, δ3 value is Low and δ4 value is High, the fault type is double line-to-ground fault in phase AB (ABG).
- If δ1 value is High, δ2 value is Low, δ3 value is Normal and δ4 value is High, the fault type is three-phase symmetrical fault
- If δ1 value is Low, δ2 value is Normal, δ3 value is High and δ4 value is High, the fault type is double line-to-ground fault in phase AB (ABG).
- If δ1 value is Normal, δ2 value is Normal, δ3 value is Low and δ4 value is Normal, the fault type is three-phase symmetrical fault.

VI. SIMULATION OF FAULT TYPE CLASSIFICATION

The transmission line model with a fuzzy logic controller (FLC) for fault classification, as shown in Figure 9, is used as the system model and analyzed using MATLAB/SIMULINK 2016a. Simulations were performed for various faulted and non-faulted conditions. The controller for fuzzy logic system, positioned within the block of fault classification, takes current and voltage inputs. The output comprises crisp values, with the neutral current acting as an input for the subsystem for additional analysis.

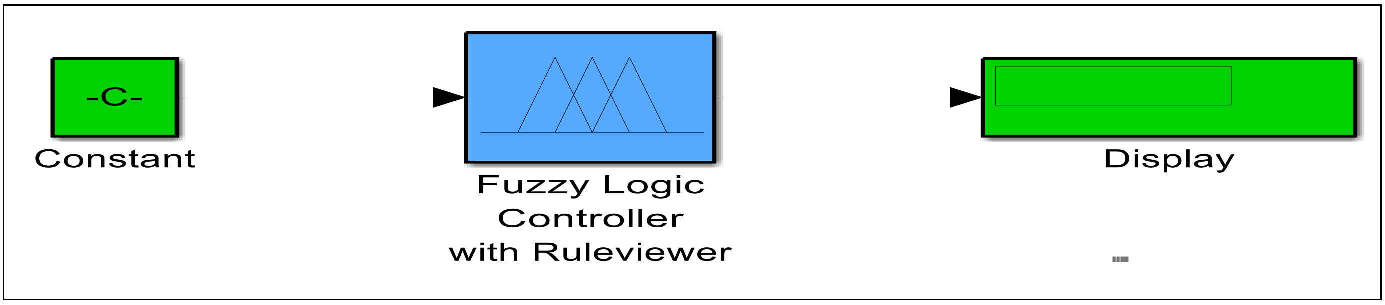

Fig 10: Simulink Block for Fault Type Classification Model

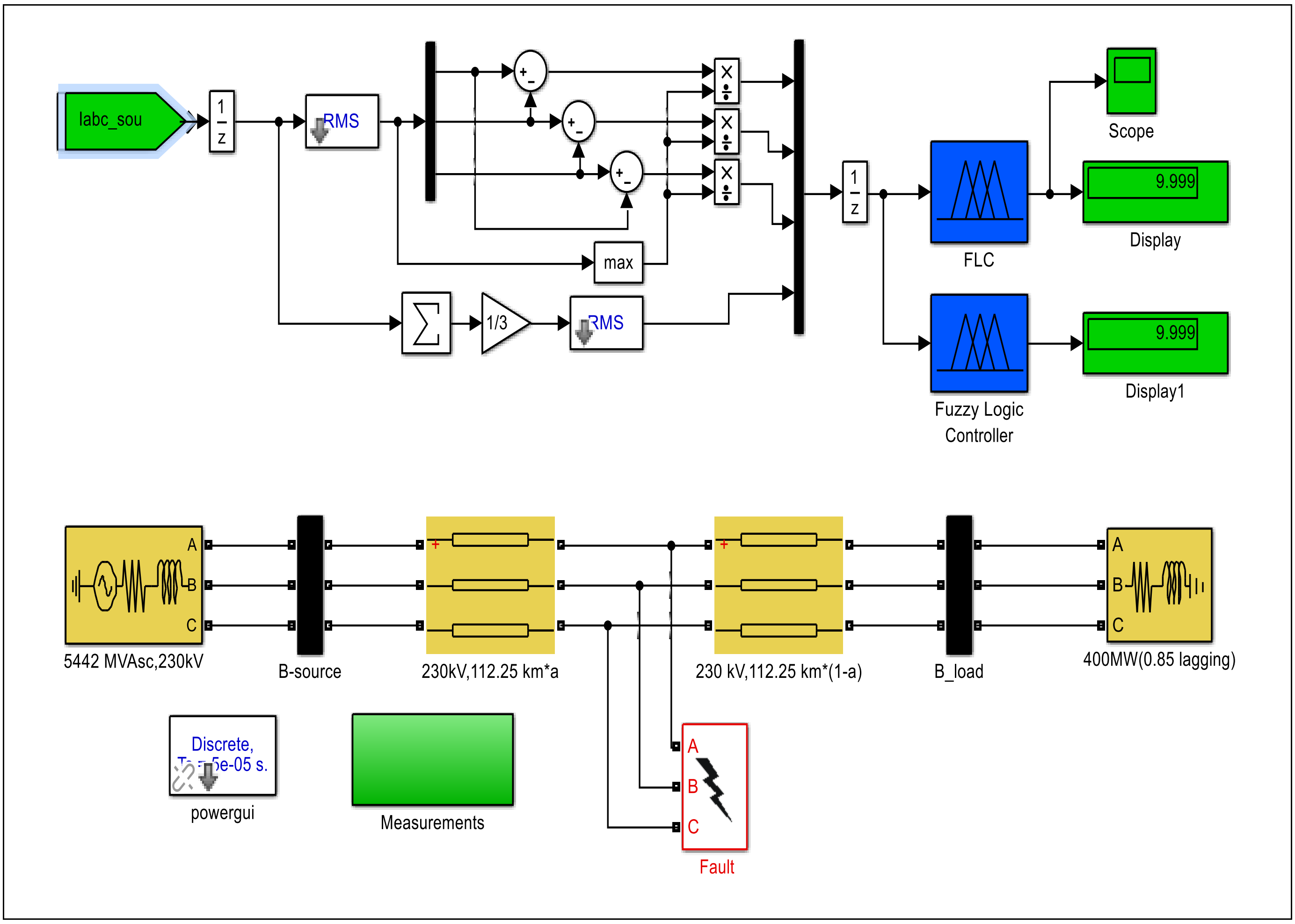

Fig 11: Transmission Line Model with FLC for Fault Classification

The output from the fuzzy controller which positioned in the subsystem, is directed to the interval test block. Fuzzy membership functions of various fault are created to address different fault types. Under normal conditions, these membership functions are defined within the range of -1, 0 and 1. When no fault is present, the fuzzy controller's output stays within this range, and this output is sent to the interval test block. The interval test block returns TRUE if the input lies between the specified lower and upper limits, meaning it falls within the -1 to 1 range, indicating no fault. If the input is outside this range, the block returns FALSE, signaling the presence of a fault.

This fuzzy-based fault identification system is capable of detecting all ten types of faults, which include single line to ground faults in phases A, B, and C, double line faults in phases AB, BC, and AC, double line to ground faults (ABG, BCG, ACG), and three-phase symmetrical faults. These faults are simulated in the logical model of the power system, and the results from the fault detection block are presented and summarized in Table 5.

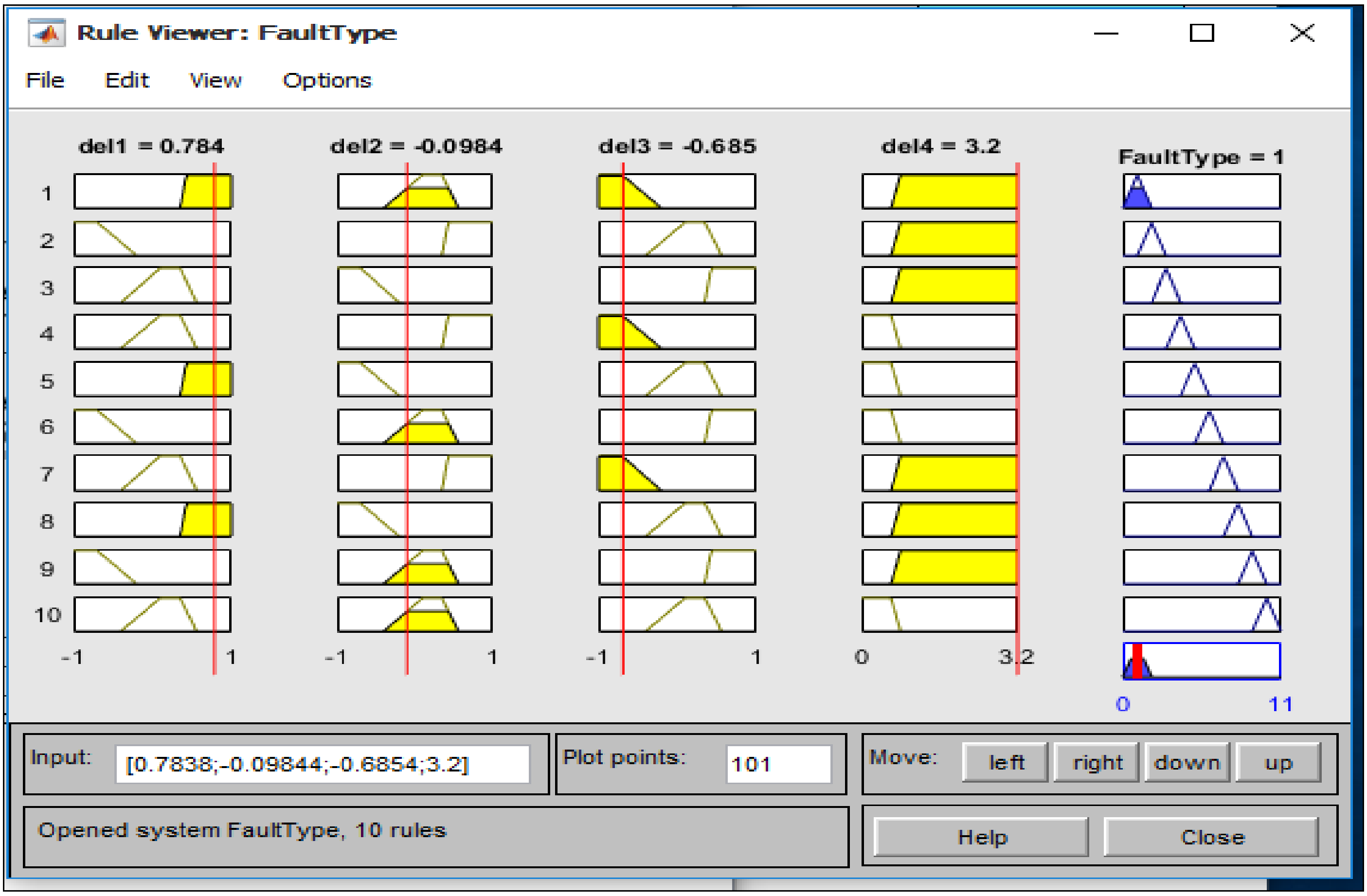

Fig 12: Rule Viewer for 10 Types of Fault

Figure 12 presents five plots in each column and ten plots in each row. The first four columns from the left illustrate the inputs to the fuzzy controller, while the fifth column shows the output. The figures at the top of each column depict the antecedents and consequents of the rules for line to ground faults as interpreted by the controller. The eleventh plot in the eighth column displays the aggregate weighted decision for the inference system, with the defuzzied output indicated by a bold vertical line on this plot.

For this fault condition, the rule can be read as:

If (del1 is 0.784) and (del2 is -0.0984) and (del3 is -0.685) and (del4 is 3.2) then (Fault A-G is 1).

Table 5: Desired Output and Actual Output of FLC

SN	FAULT TYPE	Fault Distance	**Desired Output**				**FLC Output**			
			A	**B**	**C**	**G**	**A**	**B**	**C**	**G**
1	AG	10	1	0	0	1	1	0	0	1
2	BG	20	0	1	0	1	0	1	0	1
3	CG	30	0	0	1	1	0	0	1	1
4	AB	40	1	1	0	0	1	1	0	0
5	AC	50	1	0	1	0	1	0	1	0
6	BC	60	0	1	1	0	0	1	1	0
7	ABG	70	1	1	0	1	1	1	0	1
8	ACG	80	1	0	1	1	1	0	1	1
9	BCG	90	0	1	1	1	0	1	1	1
10	ABC	100	1	1	1	0	1	1	1	0

In the condition of both before and after the occurrence of faults, the voltages and currents of the system can be illustrated as follow:

ISSN No:-2456-2165 https://doi.org/10.38124/ijisrt/IJISRT24OCT1282

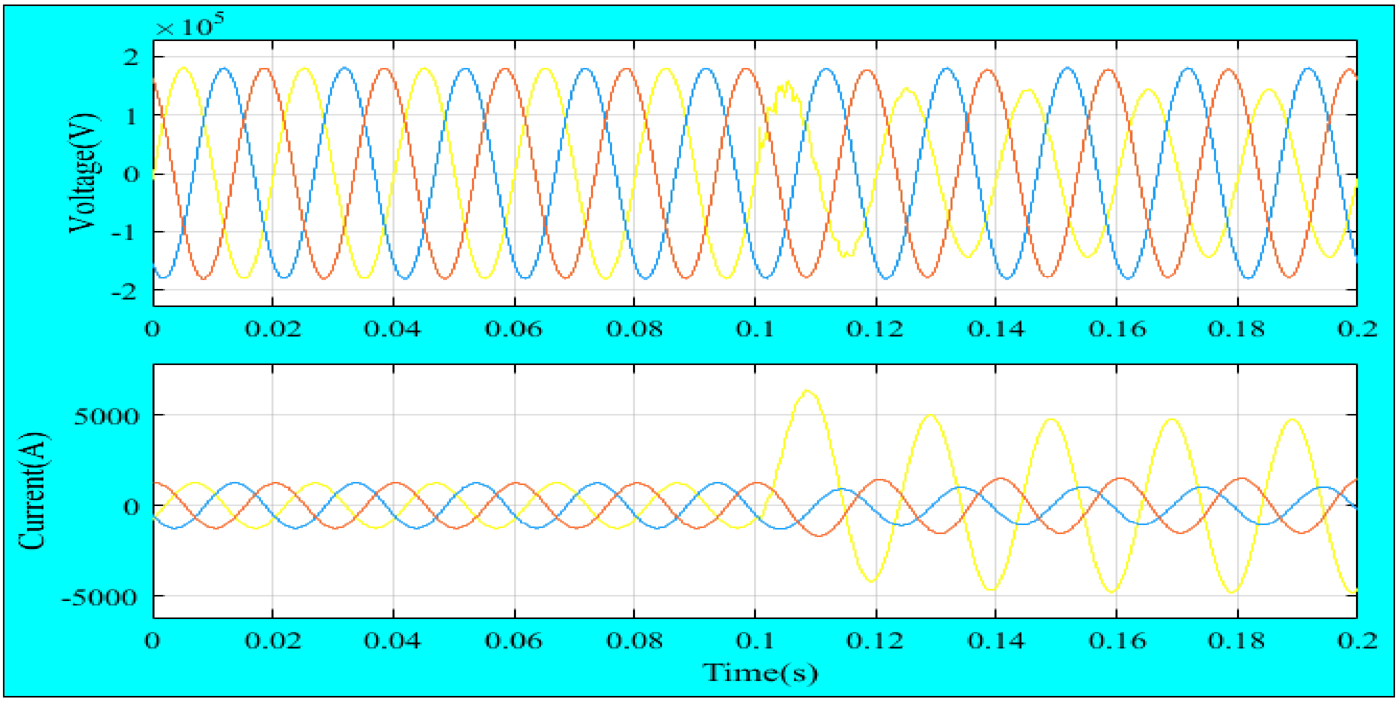

Fig 13: Voltage and Current Signals for Fault Case (AG)

Figure 13 presents the output results for a single line to ground fault, displaying the output waveform of voltage and current for phase A and the ground.

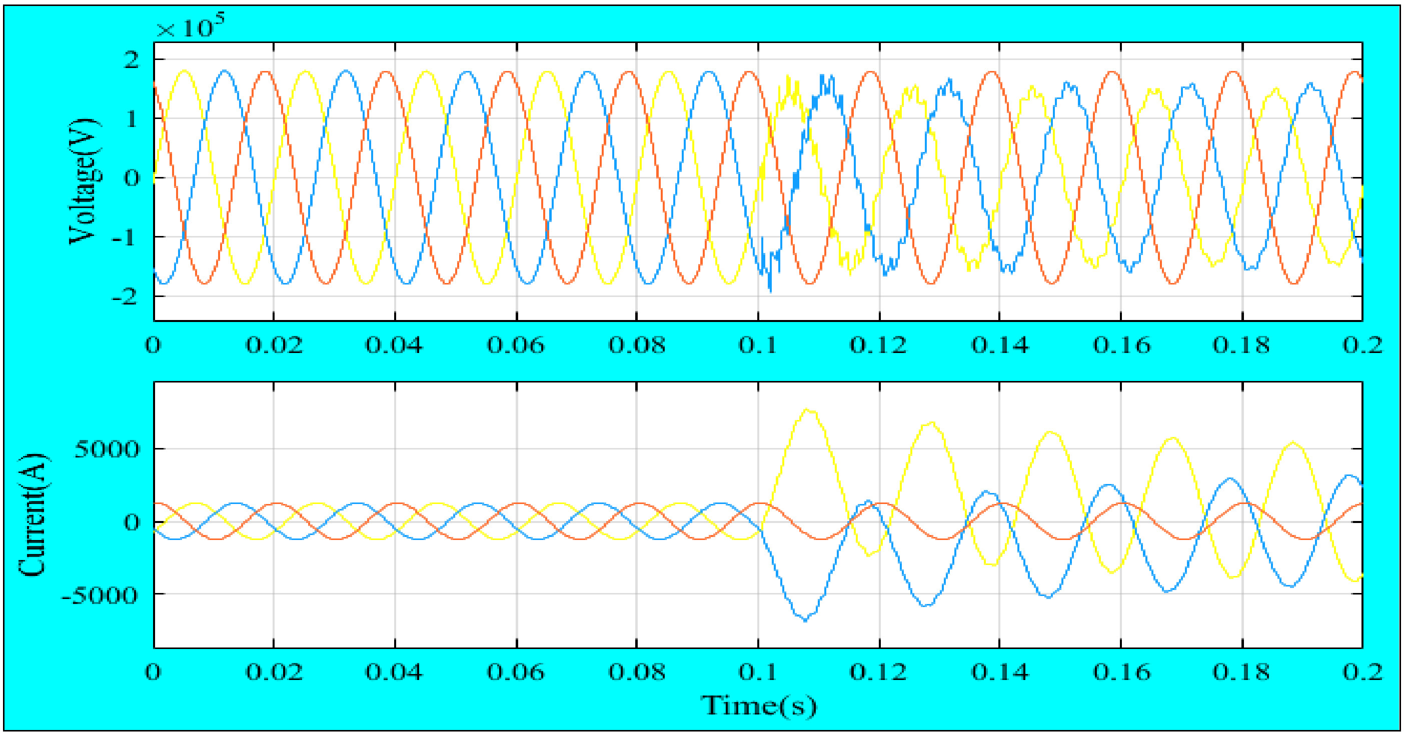

Fig 14: Voltage and Currents Signals for Fault Case (AB)

The double line fault model was simulated on the transmission line. The fuzzy logic controller processed the fault signal processed and displayed on the scope. Figure 14 illustrates the faulted signals for phase A and phase B, which are clear of ground faults.

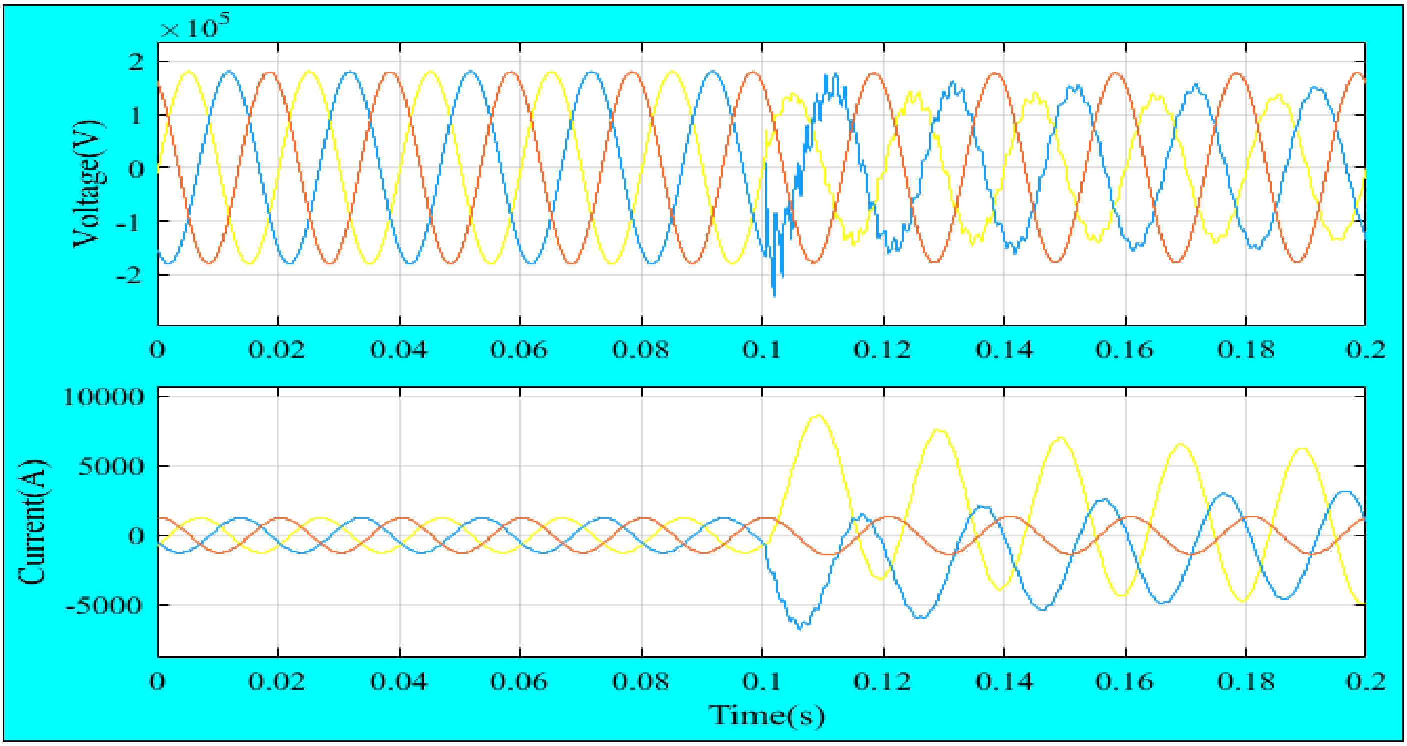

Fig 15: Voltage and Currents Signal for Fault Case (ABG)

The double line to ground fault model was simulated on the power system network using the MATLAB/SIMULINK fault block. The simulation processed the conditions for phases A and B are faulted to ground. Figure 15 displays the voltage and current signals for the double line to ground fault.

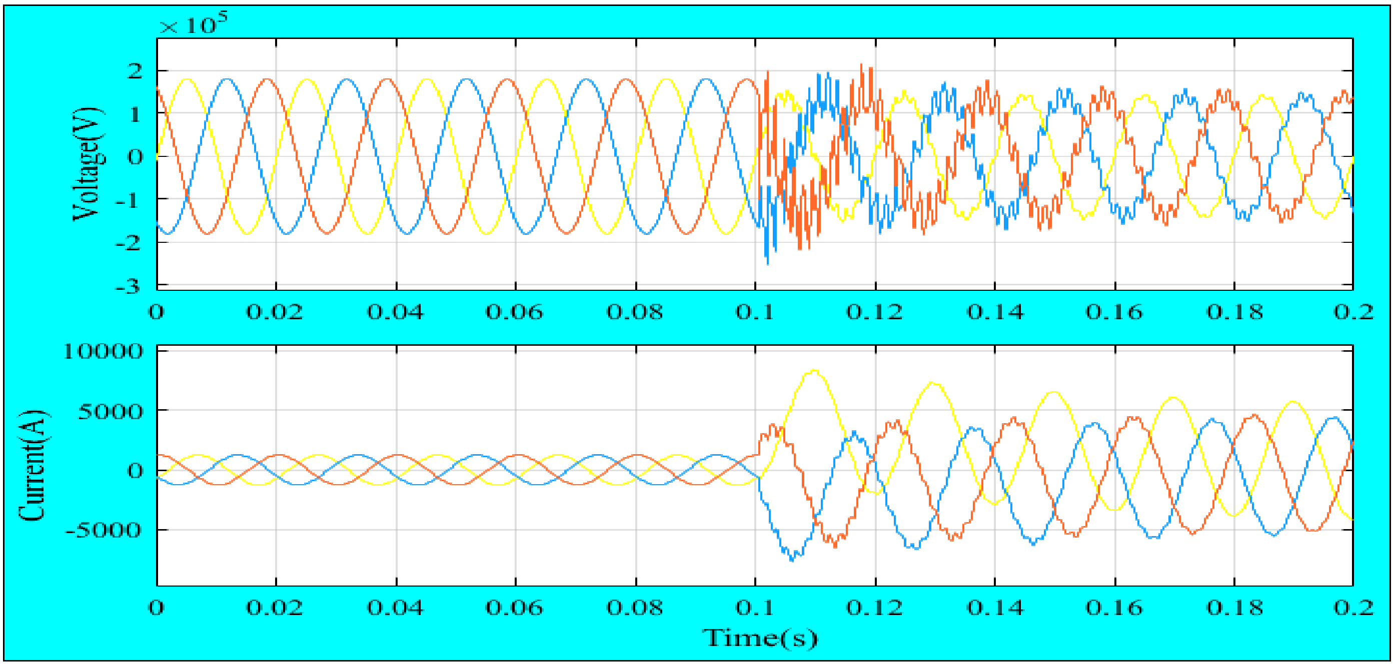

Fig 16: Voltage and Currents Signal for Fault Case (A-B-C)

Figure 16 presents the results of a simulation conducted on the transmission line, illustrating faulted conditions in phases A, B, and C, but clear of ground with all three phases.

VII. CONCLUSION

An effective fault classification technique utilizing a fuzzy logic system has been developed for the protection of power transmission lines by a digital way. This protection approach only requires the analysis of three phase post fault current and voltage samples from one end of the line. The suitable rule base of the fuzzy logic method for fault types classification is determined based on whether the fault involves the ground or not. From the simulation results, we can obtain with the proposed protection scheme to demonstrate its reliability and effectiveness under various fault conditions.

For successfully implementation, line currents, phase voltages, and neutral current of the system serve as inputs to the fuzzy logic method. It can be facilitating the automatic real time protection for the system by the good accuracy of the proposed method. The system operates swiftly, reliably, and securely. Furthermore, the proposed logic is uncomplicated, necessitating only a minimal number of linguistic rules. Overall, the results indicate that the proposed technique for the classification of fault types in power transmission line is fast, easy, reliable, and secure.

REFERENCES

[1]. Adhikari, S., Sinha, N., and Dorendrajit, T., "Fuzzy Logic Based On-Line Fault Detection and Classification in Transmission Line", Springer Plus, 5:1002, 2016

[2]. Sapkal, S.R. and Bhole, A.A., "Identification of Faults in Power System Using Fuzzy Logic Technique", International Journal of Engineering Research and Development, Volume 12, Issue 6, 2016

[3]. Aadum Joseph Lekie, D. C. Idoniboyeobu, S. L. Braide, "Fault Detection on Distribution Line Using Fuzzy Logic", International Journal of Scientific & Engineering Research Volume 9, Issue 12, December-2018

[4]. S. Khushboo, T. Supriya, "Fuzzy Logic Based Fault Classification Scheme for Digital Distance Protection", International Journal for Research in Applied Science & Engineering Technology (IJRASET), Volume 5 Issue X, October 2017.