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Minimization of Power System Outage Using Fuzzy Logic Control Mechanism

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Abstract: **- Power outage is one thing that is not needed in the power system network both by the power supply company and the consumer. Efforts have been made by researchers to reduce occurrence of outage in any given power system to the barest minimum. This report presents another sincere contribution made in the form of minimization of power system outage using the fuzzy logic controller. The different kinds of faults which take place in the research area (Afikpo distribution network) were determined, the nature of outages in the research area was also determined. The research area was modeled using the "simpowersystem" of the Matlab/Simulink software. Then an effective monitoring system was modeled using fuzzy logic controller designed in Simulink. The effect of the fault monitoring was demonstrated using same software and results compared. Simulation results show that the fuzzy inference system effectively captured the fault condition and went into the appropriate output logic state within the normal simulated time for alarm.**

Keywords: **Fuzzy logic controller; Minimization; Power outage; Matlab; Simulink.**

I. INTRODUCTION

1.1 Background of the Study

The purpose of an electrical power system is to generate and supply electrical energy to consumers. To ensure this, the system should be designed and managed to deliver this energy to the point of utilization with both reliability and economy.

According to [1], it is not possible however, to attain perfect level of continuity of service in power supply due to faults and abnormal conditions associated with the power system network. When any engineering system does not perform as required, we say that the system has failed. Thus reliability depends on how well a system does not fail.

Faults that occur in the power system are mainly human and/or natural. Wrong operation due to human error, accidents resulting from vehicles hitting electric poles or contacting live equipment, digging into underground cables etc are all human causes that can lead to system faults. However, natural events like lightning, wind, fire, physical contact by animals and contamination as well as equipment failure, corrosion wear and tear all result from natural faults.

Faults are defects in electrical circuits. Faults can be caused due to imbalances in the three phases supplied which can result to excessive supply and can damage installation through which the fault current is fed.

Since fault currents are sometimes greater than the normal currents, the faulty and associated part get damaged thereby defeating the aim of the power network. The extent of damage is minimized by rapid fault clearing.

Abnormal operating conditions of which also include :Overloads, Loss of synchronism, Under voltage, Over voltage, Under frequency, Reversal of direction of power flow, Poor power factor, Voltage swings, current swings, Temperature rise, Lightning , Switching surges of transient duration etc.

During abnormal operating conditions such as above, electrical equipment and plant are overstressed and are likely to fail. Hence each equipment and plant is provided with protective systems.

The greatest threat to the security of a supply system is the short circuit, which imposes a sudden and sometimes violent change on system operation. The large current which always follows, accompanied by the localized release of a considerable quantity of energy, can cause fire at the fault location and mechanical damage throughout the system particularly to machines and transformer windings. Rapid isolation of the fault by the nearest switchgear will minimize the damage and disruption caused to the system.

The electric power system is a very large capital investment. To maximize the return on this outlay, the system must be loaded as much as possible and kept in full operation continuously so that it may give the best service to the consumer and earn more revenue for the supply authority.

Since we cannot guarantee absolute freedom from failure of plant and system network, the risk of a fault occurring however slight for each item is multiplied by the number of such items which are closely associated in an extensive system as any fault produces repercussion throughout the network. When the system is large, the chance of a fault occurring and disturbance that a fault will bring are both so great that without equipment to remove faults the system will become bad.

Short circuit or shunt fault according to [2] occurs due to breakdown in insulation between phases or in the insulation of current carrying phase conductors relative to earth. Short circuit faults in 3 phase alternating current power circuits occur as follows:

(i) Single phase to ground
(ii) Two phases to ground
(iii) Phase to phase and third phase to ground
(iv) All the three phases to ground
(v) All the three phases short-circuited.

The installation of switchgears alone is not sufficient but discriminative protective gears designed according to the characteristics and requirements of the power system must be provided to control the switchgear [3]. This is so because a system is not properly designed and managed if it is not adequately protected. The conventional protective devices-fuses, circuit breakers, instrument transformers, relays etc are normally deployed in the entire power system network to detect and clear faults in a highly organized protective scheme[4]. They are usually located well enough to supervise fault regions for rapid fault detection and removal. This research work seeks to design a fuzzy logic control medium that will assist in the isolation of faulty region and hence minimize load failure in the power system network.

Afikpo is a town made up of seventeen communities in the southern region of Ebonyi state of Nigeria. It is the area of our research study.

The problem which this research seeks to address is this; whenever there is fault in any area within Afikpo, total power outage occurs in the entire Afikpo town (instead of the particular community where the fault occurs). This condition remains until the fault is localized and removed.

This problem stated above exist because the power system operators in Afikpo (EEDC) have not been maintaining the existing protection equipment (J & P fuse, HBC fuse etc) very well.

1.2 Research Objectives

The objectives of this research work was geared towards minimizing power system outages using fuzzy logic control, they are as follows;

(i) To determine the different kinds of faults that can occur in the power system with Afikpo distribution network as a case study.
(ii) To determine the nature of power outage in the Afikpo distribution network.
(iii) To model the Afikpo distribution network using the SimPowerSystems of the MATLAB/SIMULINK software for carrying out different fault analysis.
(iv) To model an effective fault monitoring system using the fuzzy logic controller designed in SIMULINK and gotten from the Fuzzy Logic toolbox.
(v) To demonstrate the effect of the said system on fault monitoring using the same software.
(vi) To compare results.

II. METHODOLOGY

Fuzzy logic allows a convenient way to incorporate the knowledge of human experts into the expert systems using qualitative and natural language-like expressions. Recent advances in the field of fuzzy systems and a number of successful real-world applications in power systems show that logic can be efficiently applied to deal with imprecision, ambiguity and probabilistic information in input data. Fuzzy logic based systems with their capability to deal with incomplete information, imprecision, and incorporation of qualitative knowledge have shown great potential for application in electric system fault detection.

The nature of the system of case study was well understood and here presented, and the procedure for fuzzy logic control design, as carried out in this project, shown. The test model was simulated and simulation results were shown.

The work flow algorithm of this project is shown in Figure 2 and Figure 3 below. The three phase currents and voltages were collected by connecting the lines as fuzzy reference signals to the fuzzy machine. Data collected is adequate as it is available for analysis.

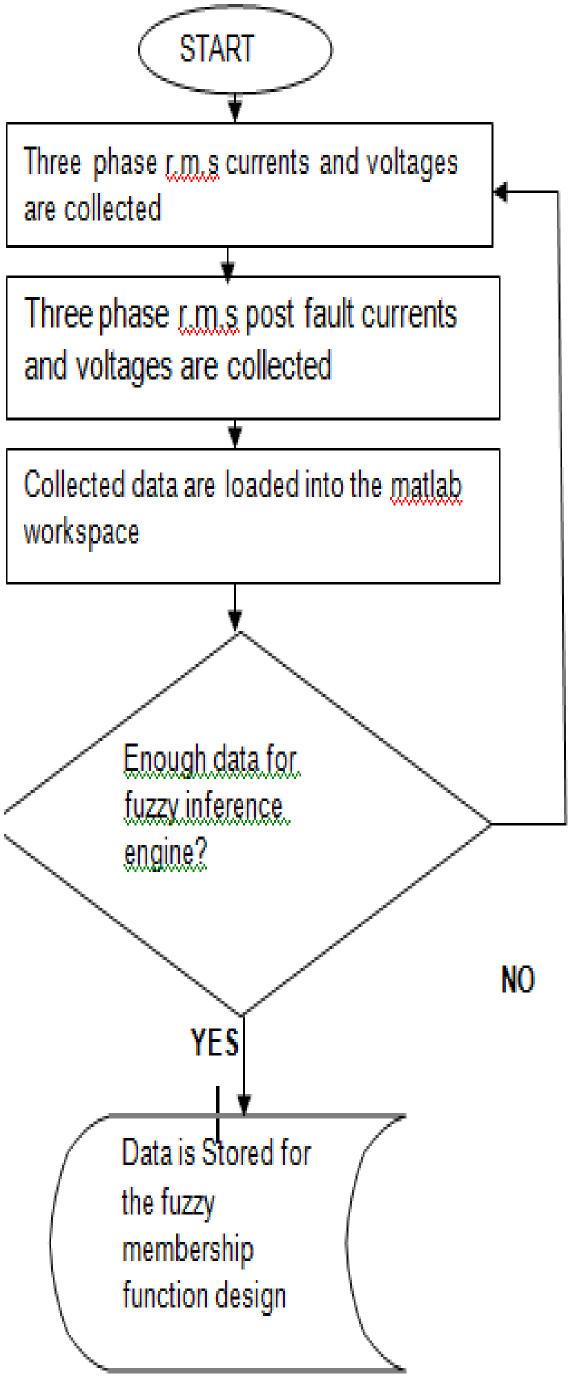


Fig. 2: Data collection flow control for the fuzzy system

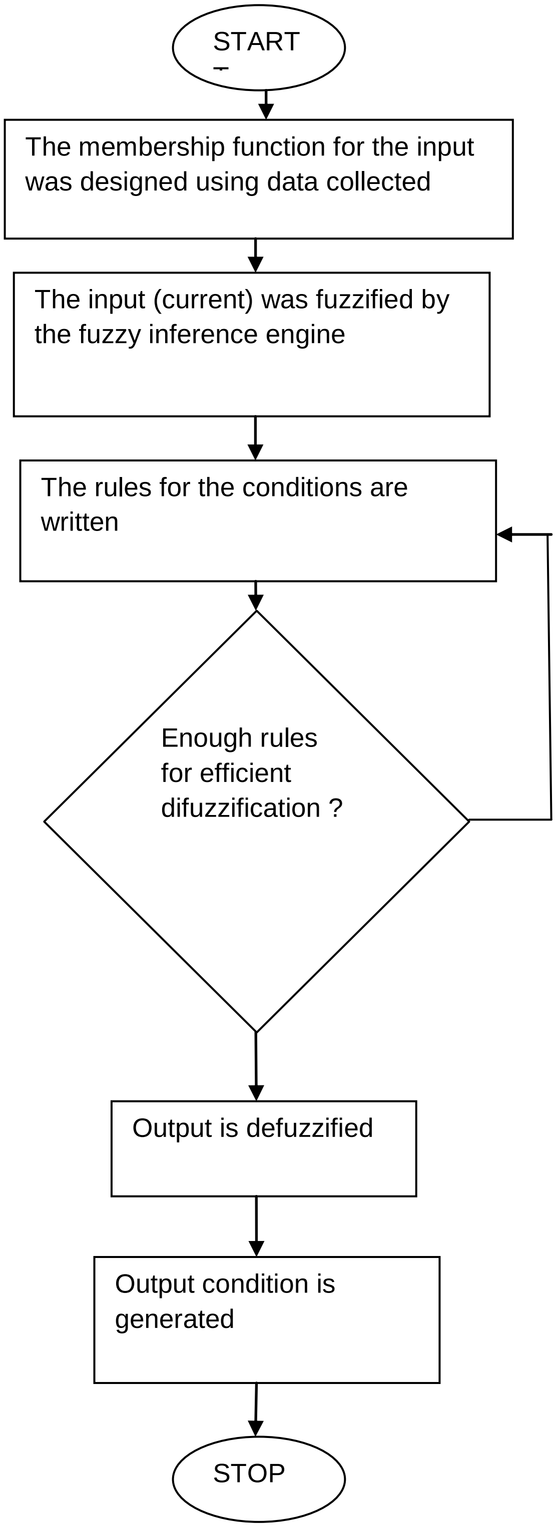


Fig. 3: Flowchart for fuzzy controller design

III. DESIGN AND IMPLEMENTATION

The Fuzzy Logic Controller

The ideas behind fuzzy logic have been around since 1965 when they were introduced by Lofti A. Zadeh. Fuzzy logic, however, has not been widely used since 1965; it has only gained popularity in the last 20 years, meaning that there are many new applications of fuzzy logic [5].

In a traditional bivalent logic system an object is either or not a member to the set of variables. In the fuzzy sets, the function that determines this degree of membership is called the fuzzy membership function (See figure 4)

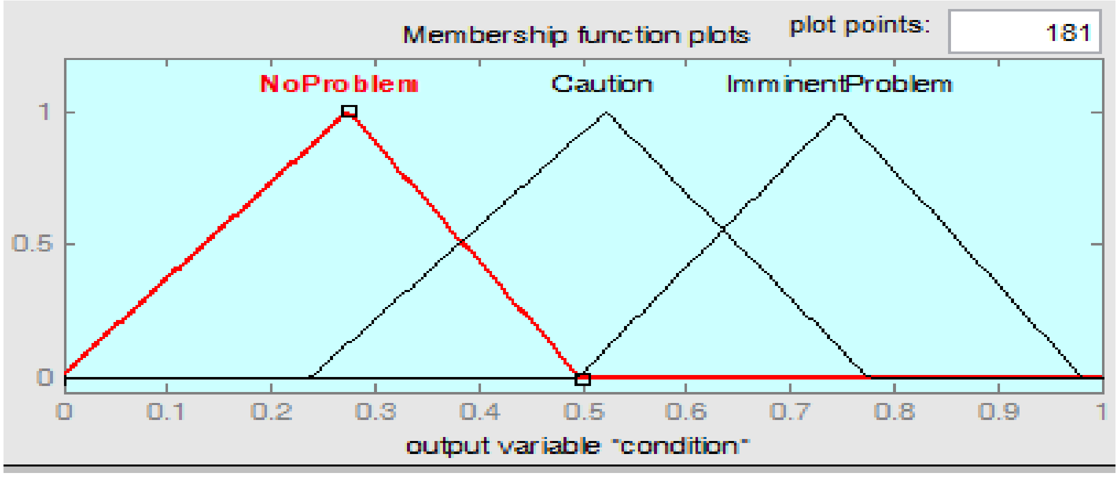


Fig. 4: Output membership function utilized in this thesis for fault conditions

The idea of fuzzy sets is that the members are not restricted to true or false definitions. A member in a fuzzy set has a degree of membership to the set.

For example, the set of fault condition values can be classified using a bivalent set as either No Problem (No trip) or Imminent Problem (Trip). This would require some cut-off value where the threshold of the fault current setting determines whether the system trips or not. If the cut-off point is set at 200Amps for instance, then this set does not differentiate between a no-fault current of 80Amps and a fault current of 190Amps. They are both not faulting currents. If a fuzzy set were to be used in this situation each member of the set, or each current value, would have a degree of membership to the set of fault condition. The function that determines this degree of membership is called the fuzzy membership function (See figure 4 above). There are countless different membership function topologies that can be used; the most common are triangular, Gaussian and sigmoidal. This function is a sigmoidal function. The attributes of the membership function can be modified based on the desired input [6].

Fuzzy Inference Process in This Research

Fuzzy inference is the process of formulating the mapping from a given input to an output using fuzzy logic. The mapping then provides a basis from which decisions can be made, or patterns discerned. Information flows from left to right, from two or more inputs to a single output (See figure 5).

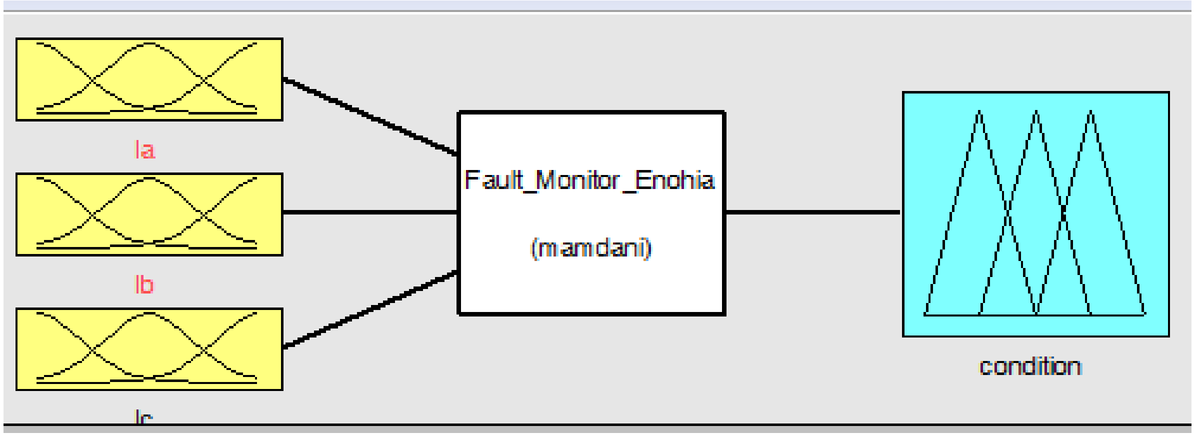
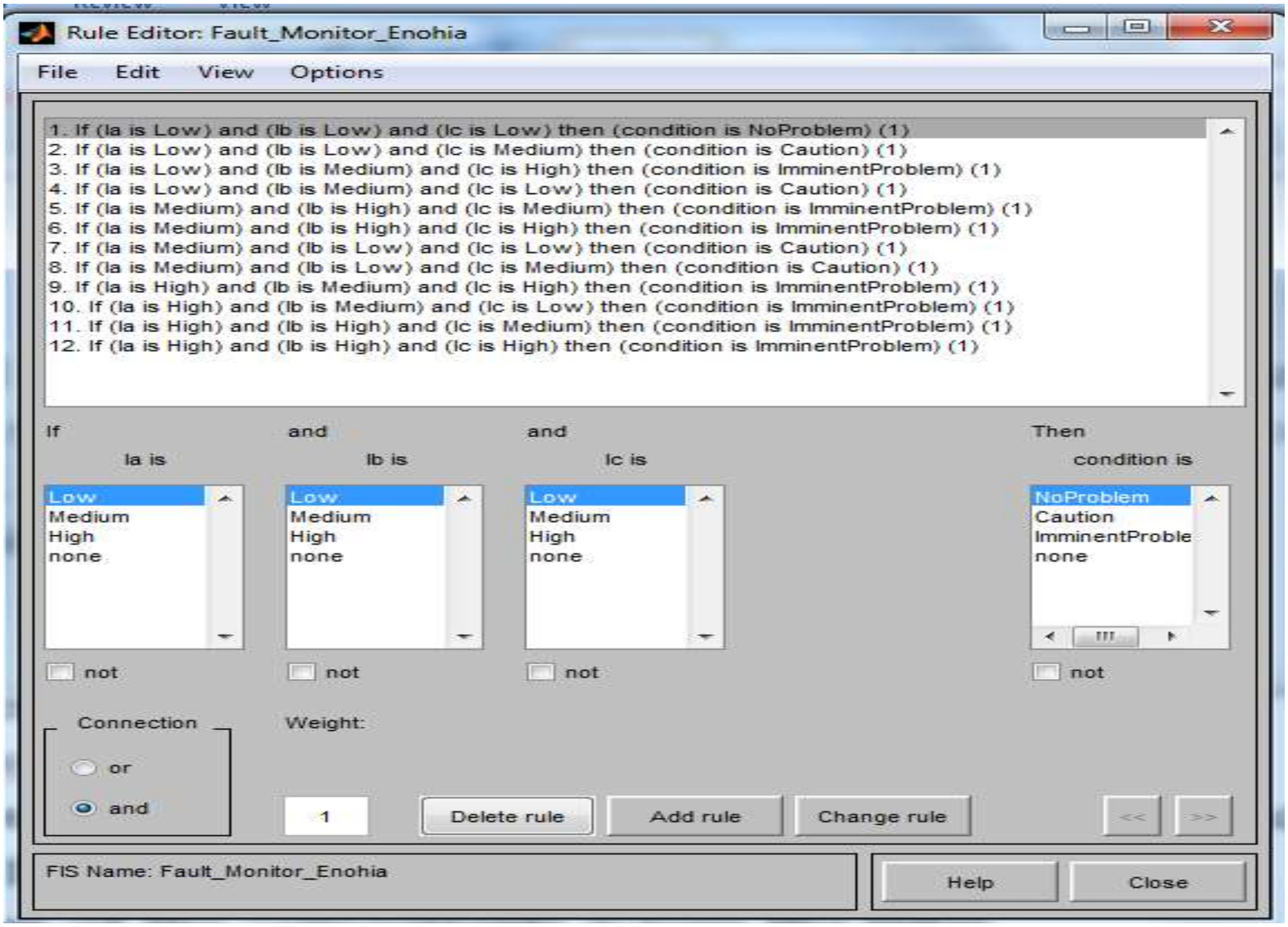


Fig. 5: Fuzzy Inference Process

The parallel nature of the rules is one of the more important aspects of fuzzy logic systems. Instead of sharp switching between modes based on breakpoints, logic flows smoothly from regions where the system's behavior is dominated by either one rule or another [7].



1. If (Ia is Low) and (Ib is Low) and (Ic is Low) then (condition is NoProblem) (1)
2. If (Ia is Low) and (Ib is Low) and (Ic is Medium) then (condition is Caution) (1)
3. If (Ia is Low) and (Ib is Medium) and (Ic is High) then (condition is ImminentProblem) (1)
4. If (Ia is Low) and (Ib is Medium) and (Ic is Low) then (condition is Caution) (1)
5. If (Ia is Medium) and (Ib is High) and (Ic is Medium) then (condition is ImminentProblem) (1)
6. If (Ia is Medium) and (Ib is High) and (Ic is High) then (condition is ImminentProblem) (1)
7. If (Ia is Medium) and (Ib is Low) and (Ic is Low) then (condition is Caution) (1)
8. If (Ia is Medium) and (Ib is Low) and (Ic is Medium) then (condition is Caution) (1)
9. If (Ia is High) and (Ib is Medium) and (Ic is High) then (condition is ImminentProblem) (1)
10. If (Ia is High) and (Ib is Medium) and (Ic is Low) then (condition is ImminentProblem) (1)
11. If (Ia is High) and (Ib is High) and (Ic is Medium) then (condition is ImminentProblem) (1)
12. If (Ia is High) and (Ib is High) and (Ic is High) then (condition is ImminentProblem) (1)

Connection: ● and

Weight: 1

FIS Name: Fault_Monitor_Enohia

Fig. 6: Rules set for Enohia Fault Monitoring

Fuzzy inference process comprises five parts:

1. Fuzzification of the input variables
2. Application of the fuzzy operator (AND or OR) in the antecedent
3. Implication from the antecedent to the consequent
4. Aggregation of the consequents across the rules
5. Defuzzification

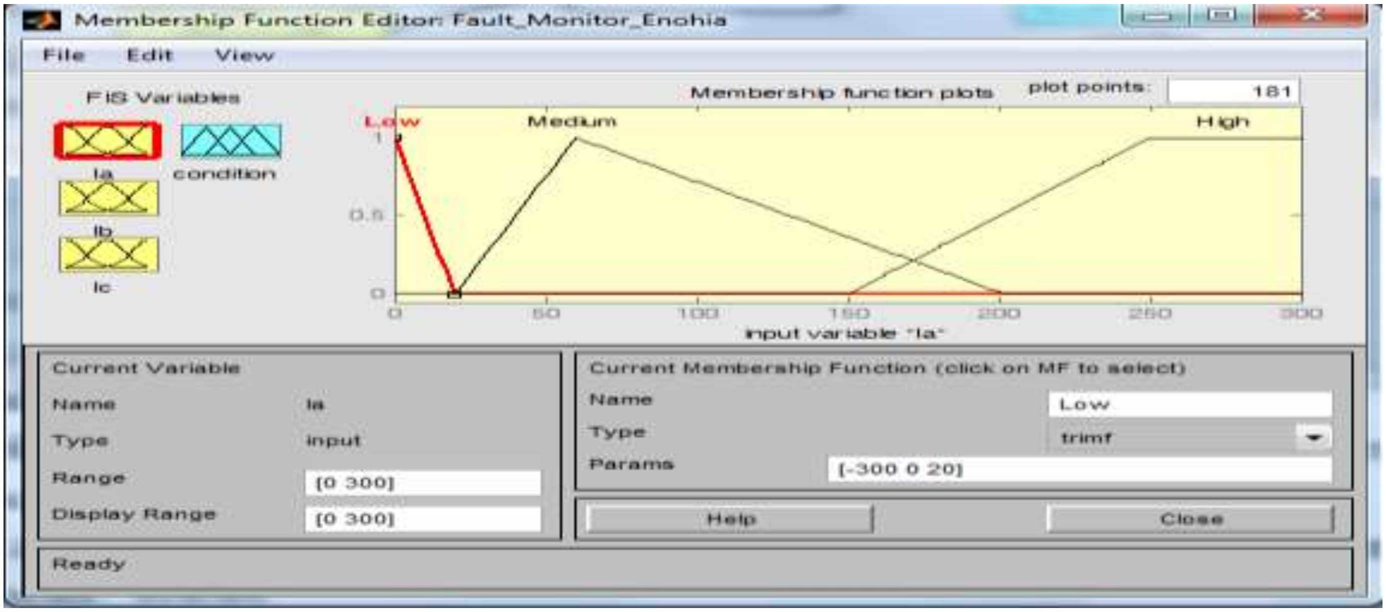
A fuzzy inference diagram displays all parts of the fuzzy inference process from fuzzification through defuzzification.

Step 1: Fuzzify Inputs

The first step is to take the inputs and determine the degree to which they belong to each of the appropriate fuzzy sets via membership functions. In Fuzzy Logic Toolbox software, the input is always a crisp numerical value limited to the universe of discourse of the input variable (in this case the interval between 0 and 300) and the output is a fuzzy degree of membership in the qualifying linguistic set (always the interval between 0 and1) [8].

Fuzzification of the input amounts to either a table lookup or a function evaluation.

The inference system used for Enohia is built on three rules, and each of the rules depends on resolving the inputs into a number of different fuzzy linguistic sets: current is low, medium or high.



Current Variable
Name Ia
Type input
Range [0 300]
Display Range [0 300]

Current Membership Function (click on MF to select)
Name Low
Type trimf
Params [-300 0 20]

Ready

Fig. 7: Membership functions used for fuzzification of input

Before the rules can be evaluated, the inputs must be fuzzified according to each of these linguistic sets. For example, to what extent is the current really low?

Step 2: Apply Fuzzy Operator

After the inputs are fuzzified, we know the degree to which each part of the antecedent is satisfied for each rule. If the antecedent of a given rule has more than one part, the fuzzy operator is applied to obtain one number that represents the result of the antecedent for that rule. This number is then applied to the output function. The input to the fuzzy operator is two or more membership values from fuzzified input variables. The output is a single truth value. In the toolbox, two built-in AND methods are supported: min (minimum) and prod (product). Two built-in OR methods are also supported: max (maximum), and the probabilistic OR method prob OR. The probabilistic OR method (also known as the algebraic sum) is calculated according to the equation:

$$ProbOR\,(a,b) = a + b - ab \qquad - \qquad 3.1$$

Where a is the input variable a, and b is input variable b

Fuzzy Logic Control

The basic fuzzy logic control system is composed of a set of input membership functions, a rule-based controller, and a defuzzification process. The fuzzy logic input uses member functions to determine the fuzzy value of the input. There can be any number of inputs to a fuzzy system and each one of these inputs can have several membership functions.

The set of membership functions for each input can be manipulated to add weight to different inputs. The output also has a set of membership functions. These membership functions define the possible responses and outputs of the system [9]

The fuzzy inference engine is the heart of the controller in this thesis, and also the fuzzy logic control system. It is a rule based controller that uses If-Then statements to relate the input to the desired output. The fuzzy inputs are combined based on these rules and the degree of membership in each function set. The output membership functions are then manipulated based on the controller for each rule. Several different rules will usually be used since the inputs will usually be in more than one membership function.

All of the output member functions are then combined into one aggregate topology. The defuzzifaction process then chooses the desired finite output from this aggregate fuzzy set. There are several ways to do this such as weighted averages, centroids, or bisectors. This produces the desired result for the output.

The Test System and Fuzzy Model

The fuzzy model for the test system was implemented in MATLAB using the fuzzy logic toolbox. This toolbox allows for the creation of input membership functions, fuzzy control rules, and output membership functions [10].

To implement this system in Simulink, the system will need to have three different inputs: the fault currents of all three phases on each of the individual feeders considered in the Afikpo network.

These three inputs will then be processed by a fuzzy logic controller that will output a degree of condition (see figure 5). This degree of condition is then decoded into one of three possible outputs: No problem, Caution, and Imminent Problem.

These input function ranges of fault currents can now be used in determining the fuzzy membership sets. The fuzzy system will have these three inputs and one indicating output (see figure 5). The fuzzy system used is the mamdani system, and the centroid method for defuzzification. The input membership function for the fault current (See figure 6) will have three different membership functions: low, medium, and high. The range of this function is 0 to 320 Amps for the highest fault current; these are the possible input values.

The low and high membership functions continue on to infinity in either direction to include any current value out of range.

Once all of the input and output membership functions have been defined the heart of the control can now be defined; the rules. The fuzzy rules are in the form of IF-THEN statements. These statements look at both inputs and determine the desired output. In this system increasing voltage and increasing temperature will lead to an imminent problem. A low temperature with a relatively high voltage will not necessarily be an imminent problem though. The rules defined for this system are shown in figure 6.

These rules are the defining elements of this system. They determine the output based on the input. Now that the fuzzy control system has been entirely defined it is exported into the Simulink model.

The model includes some decoding logic that will output different discrete levels for each of the possible outputs. This could serve as digital input to some other system for control or protection.

Simulation

The inputs for this test system have been shown; they are fault current conditions for all different types of faults simulated from the test system using the model with data gotten from the Afikpo 33kV injection substation. The system can be simulated using this data. The output signals generated are shown below. These results could be then used to compute probability distribution functions and or send alarm notes to a central controller. Each outgoing feeder is built with a fuzzy logic controller that implements one of three control topologies.

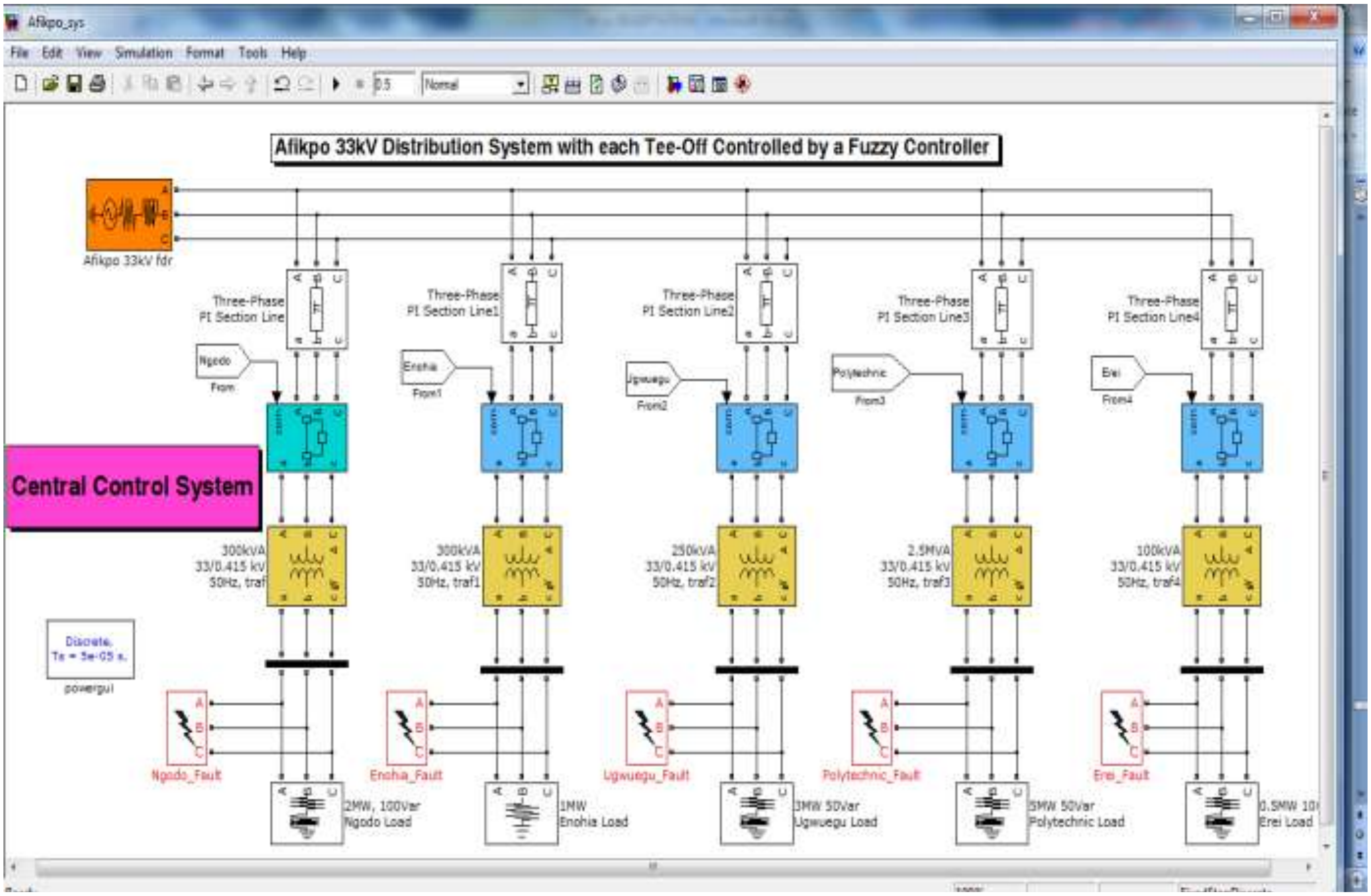


Fig. 8: The design model of the test system

From figure 8 above, it is noticed that each tee off to a community is controlled by a fuzzy controller, if a fault occurs in a given community (say Ngodo), the fuzzy controller monitoring the community will analyze the fault and send signal to operate a circuit breaker connected to it so that only the community will be isolated. Thus, the outage will be restricted to the community of fault occurrence.

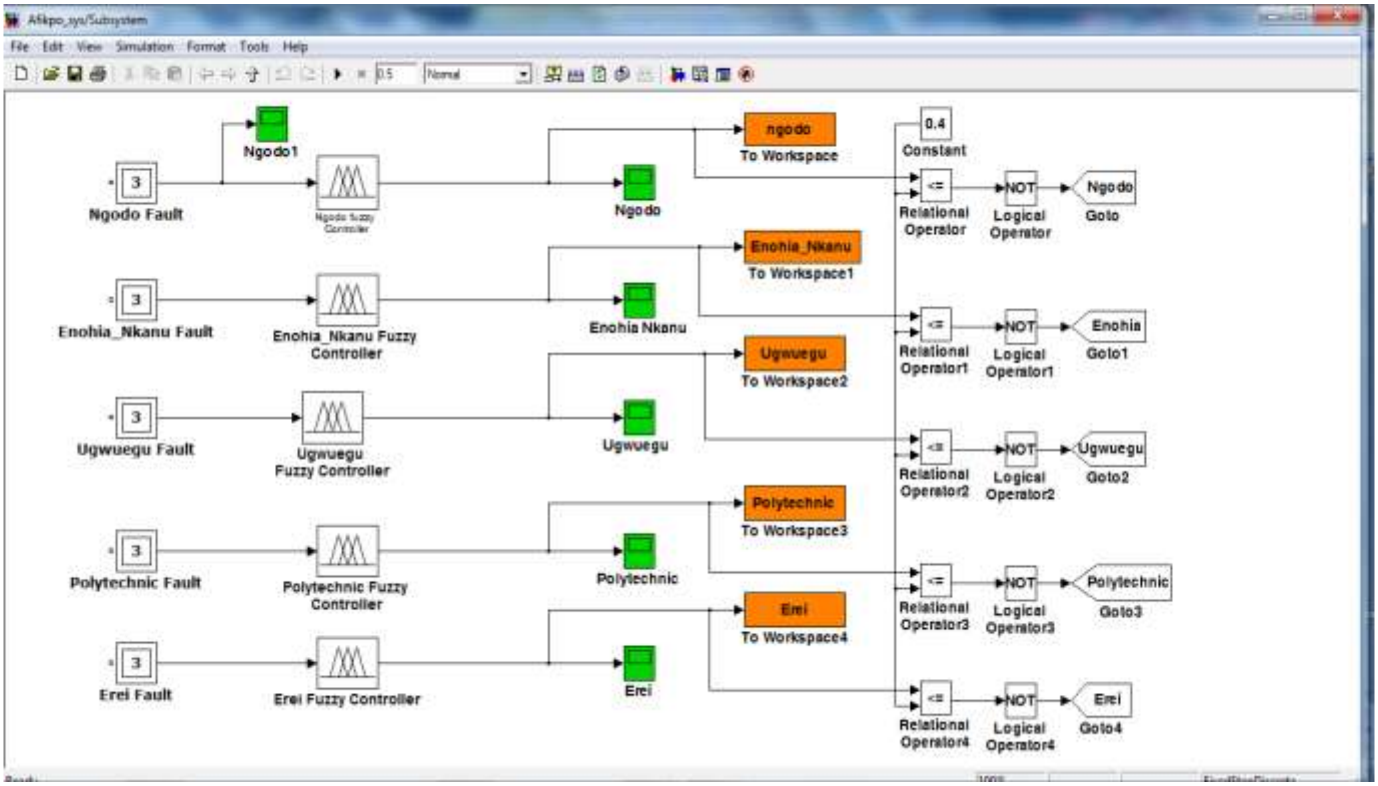
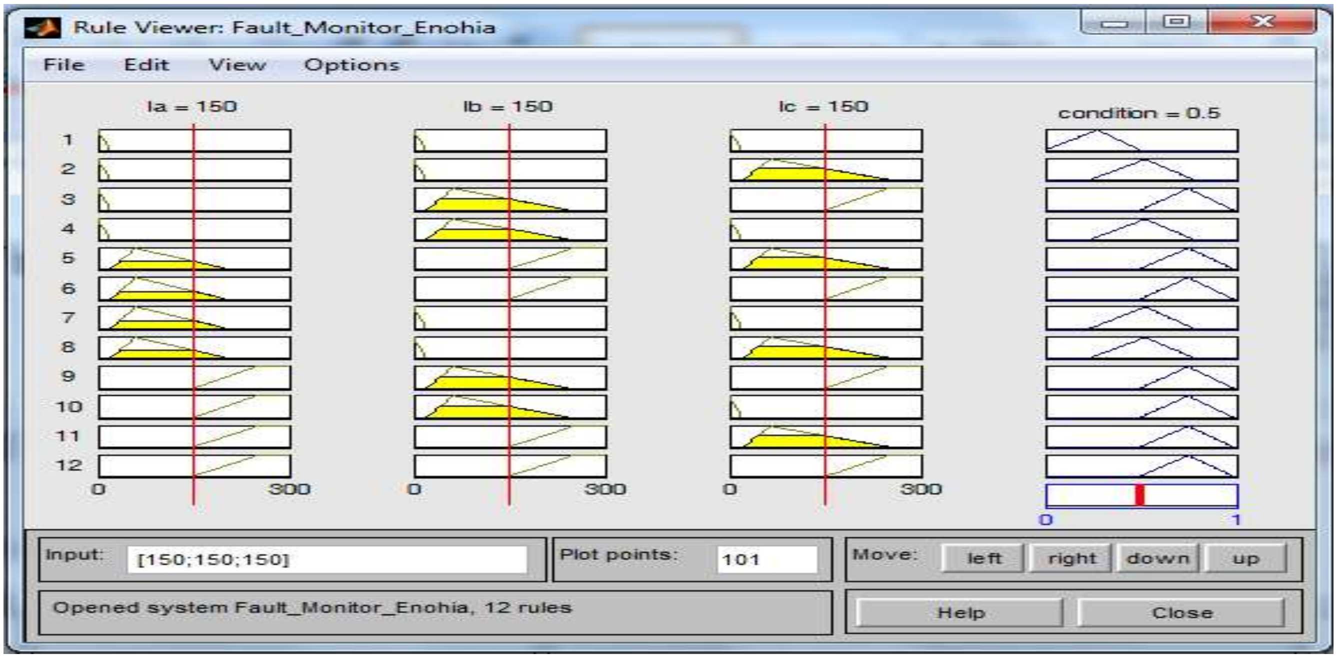


Fig. 9: The Central Control system designed in a subsystem



Input: [150;150;150]

Plot points: 101

Opened system Fault_Monitor_Enohia, 12 rules

Fig. 10: The Rule Viewer

IV. DATA PRESENTATION AND ANALYSIS

Table 1: Input Data for Simulation in Simulink

Test Feeder	**Ngodo**	**Enohia**	**Ugwuegu**	**Polytechnic**	**Erei**
Feeder length	5km	4km	8km	6km	6km
Transformer capacity	300kVA	300Kva	100kVA	2.5MVA	100kVA
Line parameters [positive sequence]	0.0002Ω O.637µH	0.00085Ω 1.85mH	0.00076Ω 2.98mH	0.00034Ω 2.43mH	0.00223Ω 3.34mH
Maximum loading (A)	417.37	417.37	139.1	3478.12	139.1
System Frequency	50Hz	50Hz	50Hz	50Hz	50Hz
Fuzzy Inference	**Mamdani**	**Mamdani**	**Mamdani**	**Mamdani**	**Mamdani**

The graphs below represent the result of the simulation of the system.

A transient fault was initiated at 200msecs for a double phase to ground fault lasting for 100ms as shown in figure 11 below.

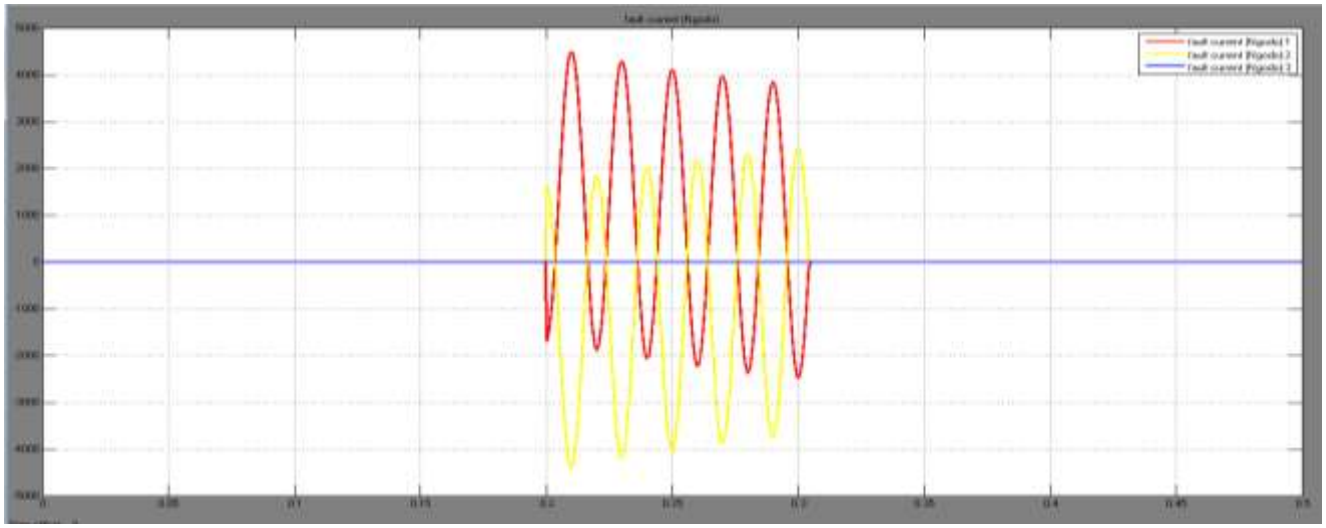


Fig. 11: Transient fault between the red and yellow phase-to-ground initiated on Ngodo feeder for 100ms

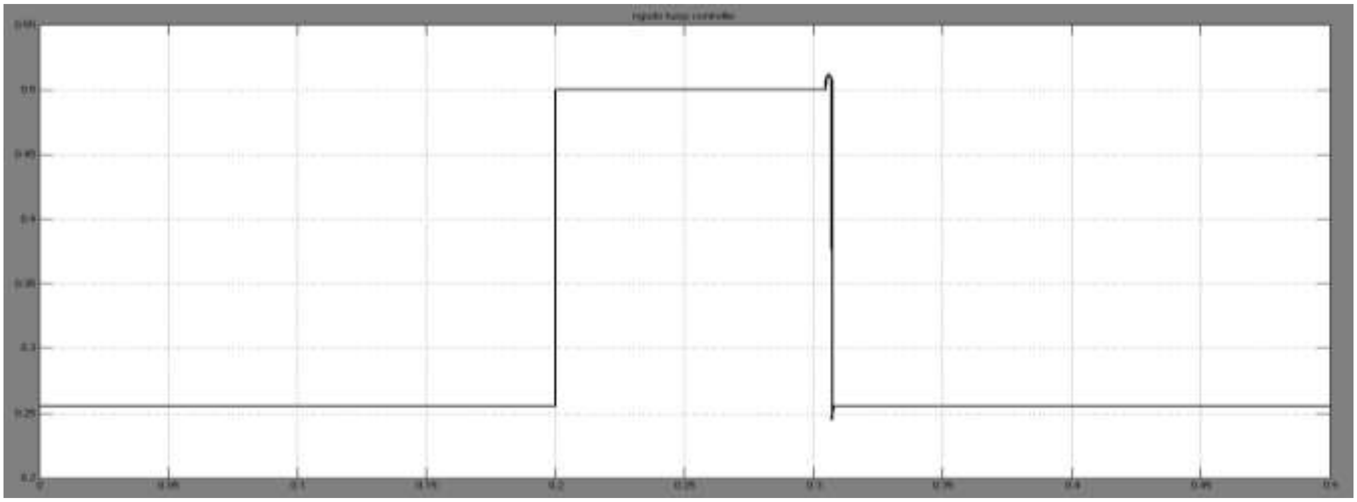


Fig. 12: Ngodo fuzzy inference system capturing the fault condition. [Fuzzy output versus Time (sec)]

The fuzzy logic controller engine shows a very efficient way of capturing the transient fault irrespective of the type of fault involved. At the low level state (less than 0.3); the output condition maps 'no problem' to its defuzzification crisp value. At the high level state (0.5 and above) means inception of fault; and the fuzzy engine sets the 'imminent problem' to its defuzzification crisp value. The output of this fuzzy controller can be interfaced with a circuit breaker capable of isolating the fault region as a modification of the current practice.

This system can also be interfaced with a protection scheme to sound an alarm and consequently trip that particular feeder which has been faulted. The inference engine follows through on fault till that particular fault is cleared. A closer look on figure 12 buttresses this point. The inference engine went into the 'no problem state' a few microseconds after 300msecs; the simulated time for fault clearance.

Figure 13 shows that the fault didn't clear at exactly 300millisecs but a few microseconds later; the inference engine captured that contingency perfectly.

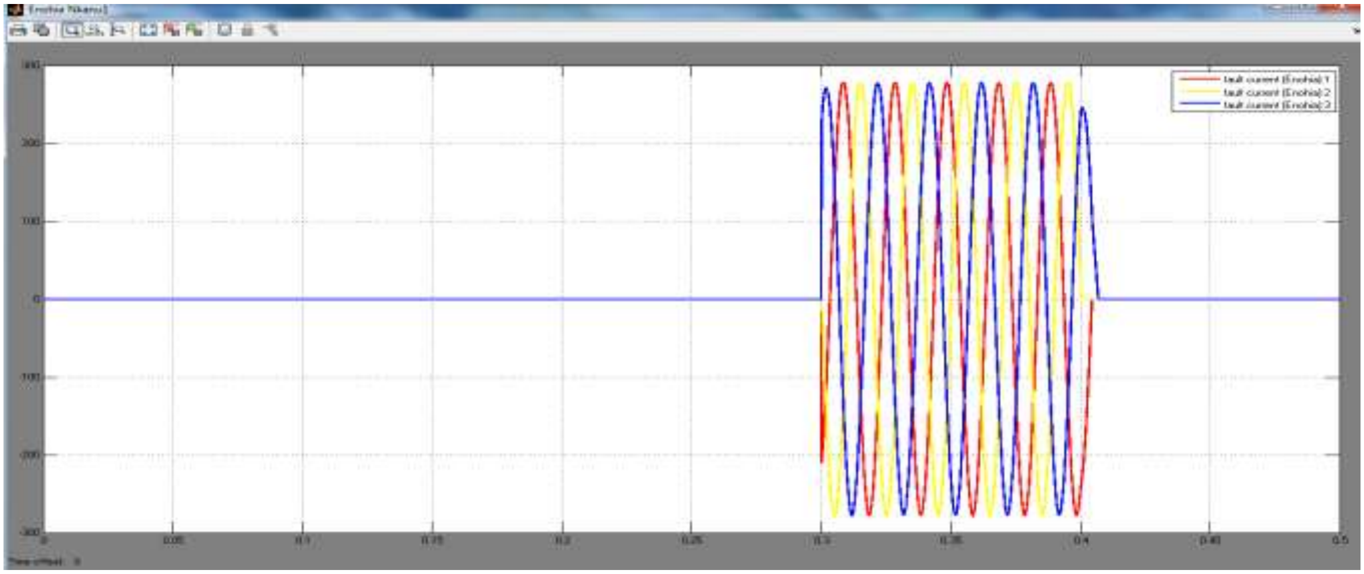


Fig. 13: A three phase ungrounded fault initiated for 100mS on Enohia feeder after Ngodo's feeder fault has been cleared.

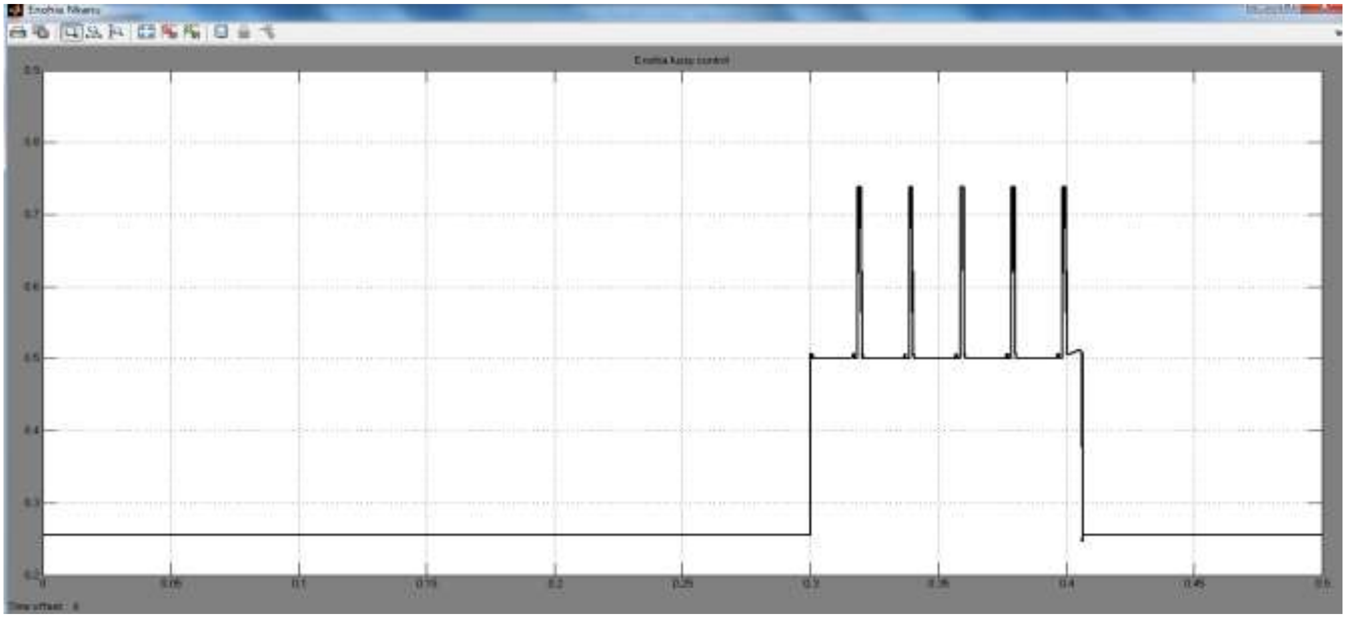


Fig. 14: The fuzzy engine responsible for the Enohia feeder monitoring.

Because the defuzzification process has the centroid as its aggregation method, the spikes on the three phase fault shows the magnitude of the three phases when they are above the zero crossing value. In 100millisecs, 5 cycles is experienced for a 50Hz frequency (See figure 15). The spiked signal (above 0.74) can be extracted by a computational scheme to tell the type of fault (in this case a three phase fault) for classification purposes. See figure 18 for the inference engine response on a three phase grounded fault

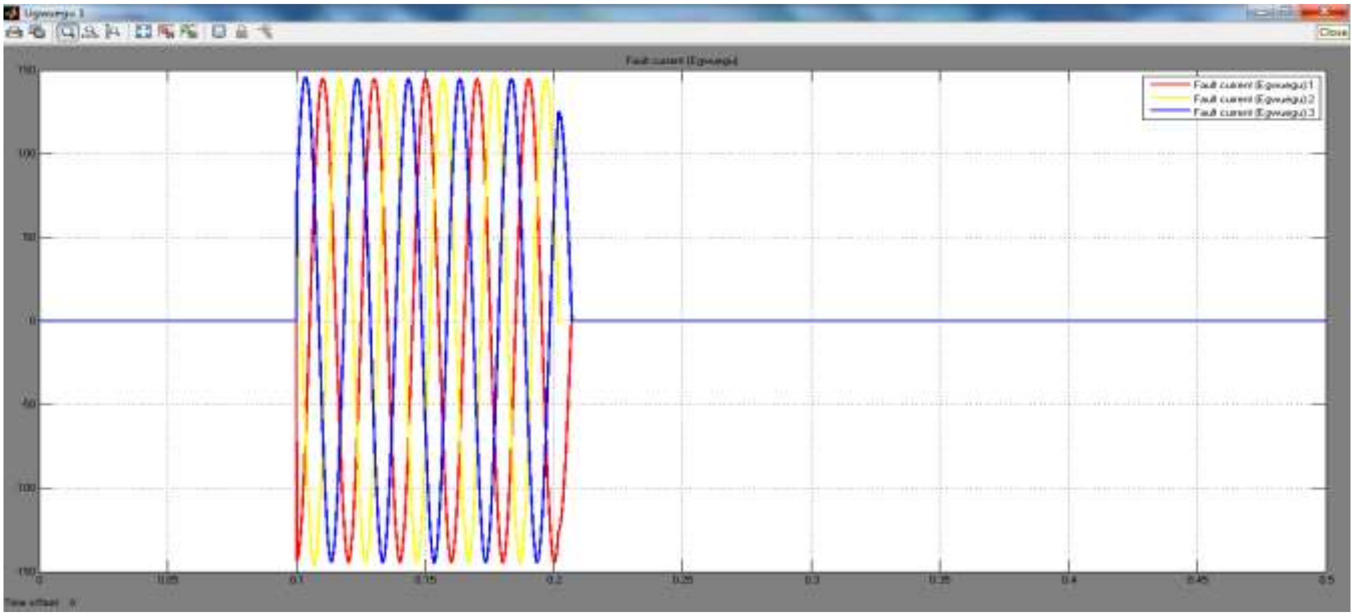


Fig. 15: Three phase fault on Ugwegwu feeder

The fault was simulated at 100millisecs lasting for another 100millisecs, before Ngodo fault initiation. It is important to note that, these initiated contingencies were done in one simulation at varying fault times on the individual feeders.

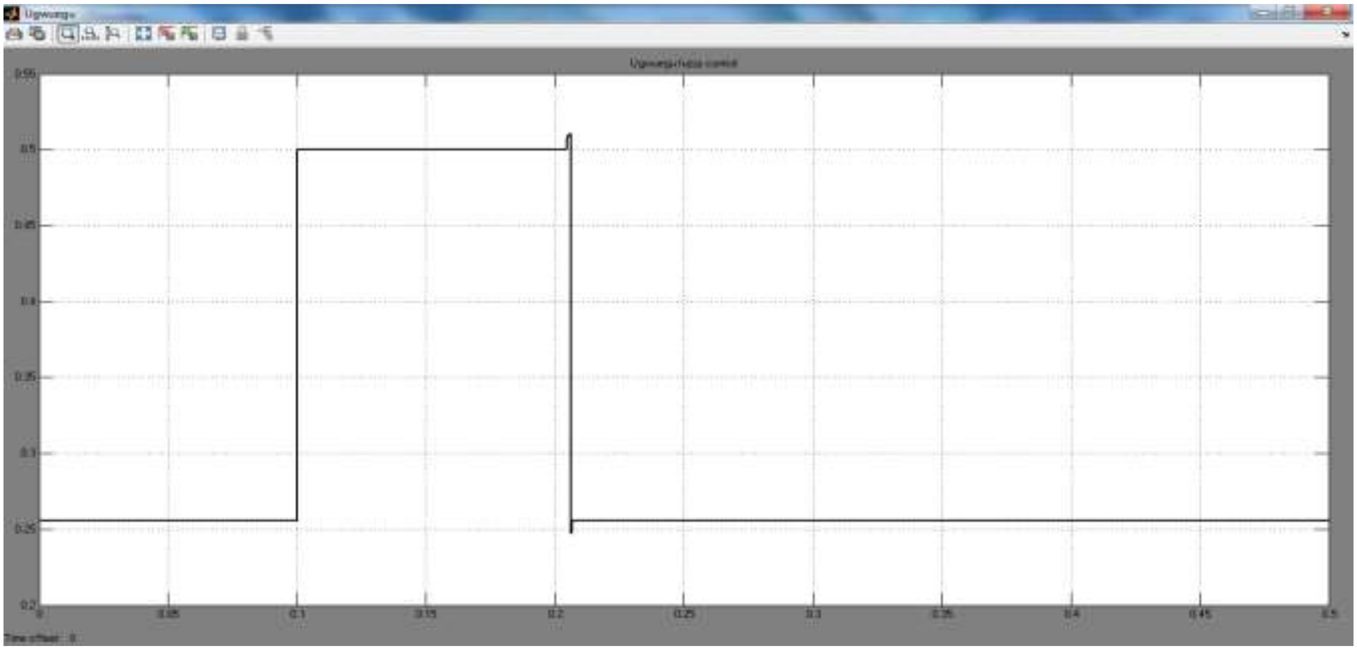


Fig. 16: The fuzzy inference engine response to the three phase fault.

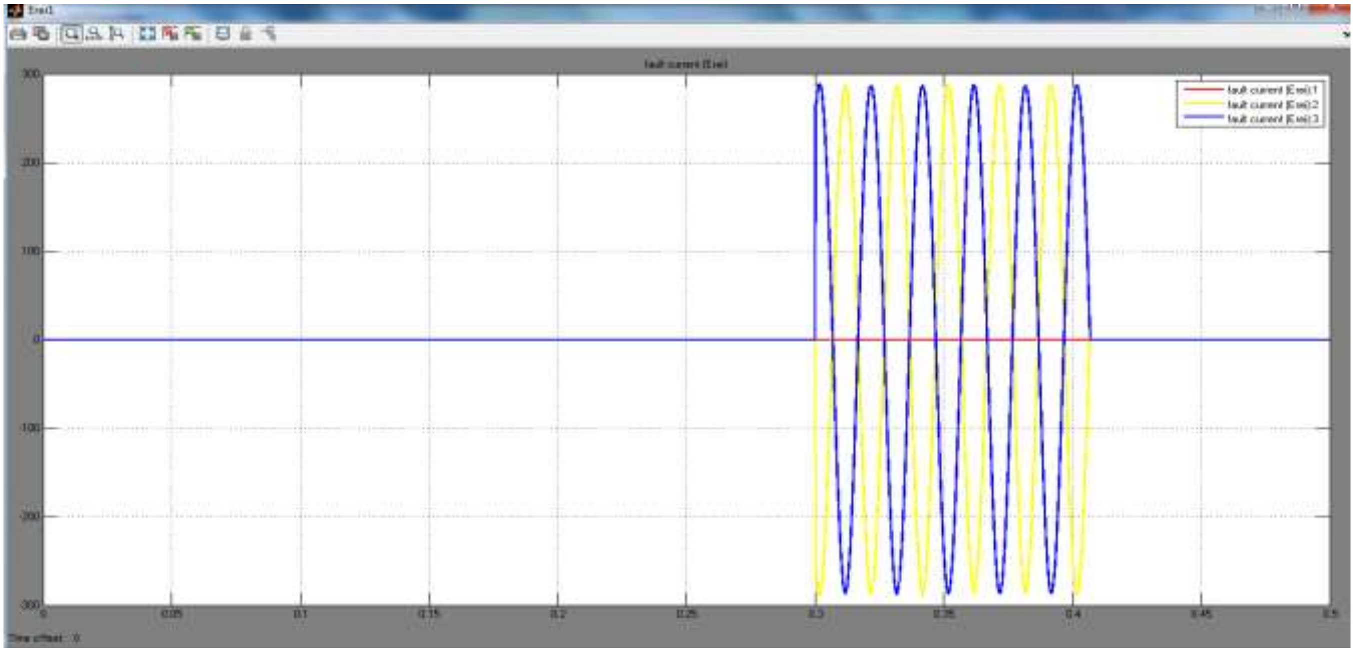


Fig. 17: Fault on the yellow and blue phase (double phase to ground) fault on Erei feeder occurring at 300millisecs

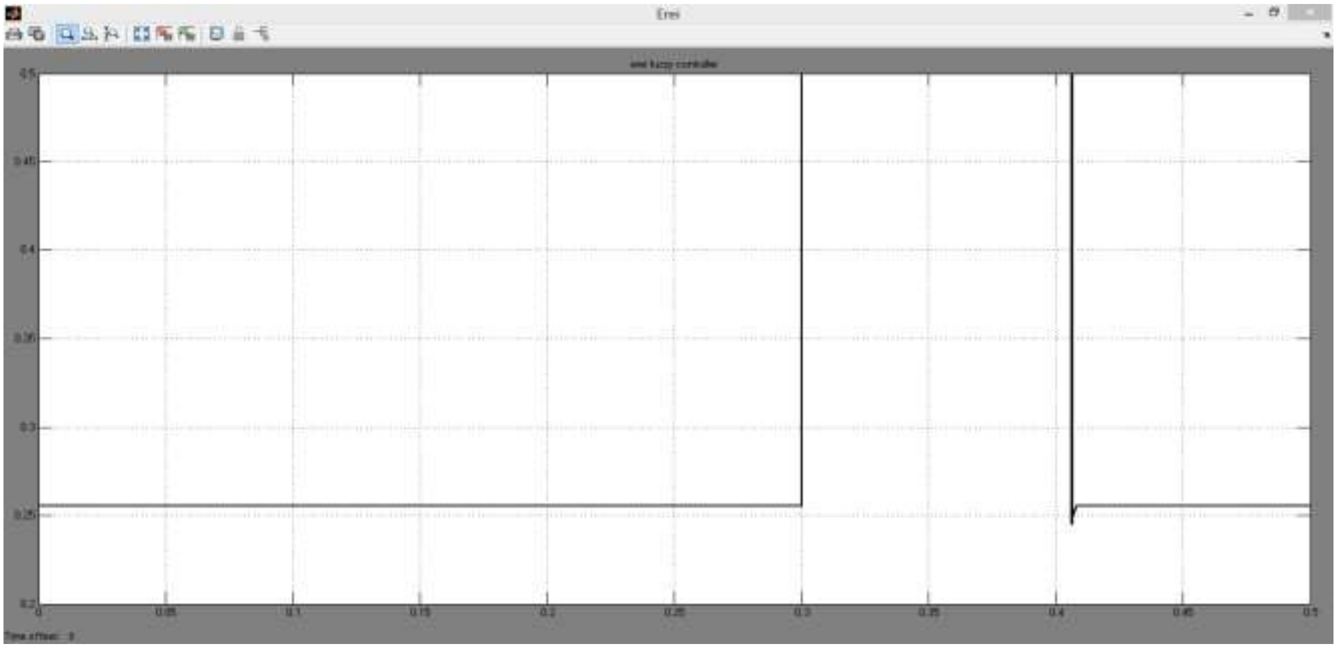


Fig. 18: The fuzzy inference system monitoring the Erei feeder**.**

V. CONCLUSION

The fault analysis simulated in this research indicate the potential of using such system as a procedure in studying complex systems and performing a meaningful evaluation and/or analysis on the impact of power system fault analysis and how fuzzy systems can be used to evaluate different types of faults. The simulation result is shown that the inputs for the simulation are all from fault currents modeled on each of the feeders in the test system. The outputs of the system will be one of three options, 0, 1, and 2 which represent the possible warning indicators of the condition of the individual feeders, that is, no problem, caution and imminent problem respectively. The objective of the study was achieved, since power outage that should have affected a larger region of the town is now restricted to the particular locality of its occurrence.

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