Fault Detection on Distribution Line Using Fuzzy Logic

Aadum Joseph Lekie, D. C. Idoniboyeobu, S. L. Braide

ABSTRACT: This research work express how fuzzy logic controller was developed to detect on a single line to ground fault , double line to ground fault, line to line fault and three phase fault are detected on Notore fertilizer plant 11KV distribution. Line and Substations in Onne, Rivers State, Nigeria was used as case study. The proposed fuzzy logic controller takes neutral, phase currents, current in the Red phase(IR), current in the Yellow phase (IY),current in Blue phase (IB) and current in the Neutral phase(IN) and phase voltages. Voltage in the Red phase (VR), voltage in the Yellow phase (VY) and voltage in the Blue phase (VB) as inputs. The inputs are assigned three linguistic variables (Low (L) Normal (N) and High (H)) with some degrees in triangular membership function. Also a single output (Fault) was assigned to the controller with ten linguistic variables [Red phase to ground fault (R-G), Yellow phase to ground fault (Y- G), Blue phase to ground fault (B-G), Red to Yellow phase fault (R -Y), Red to Blue phase fault (R - B), Yellow to Blue phase fault (Y-B), Red and Yellow phase to ground fault (RY- G), Red and Blue phase to ground fault (RB-G), Yellow and Blue phase to ground fault (YB-G), and Three phase fault (3-Ø) with varying degree of triangular membership function. Next, the Mamdani expert system were used for the implementation while the outputs of the ten rules were aggregated to form a defuzzified output with the help of Centre of gravity method. The results were displayed on a scope at every instant of fault occurrence on the network. The results obtained from defuzzified output of the controller on single line to ground fault, double line to ground fault, line to line fault and three phase fault are 0.0439, 0.616, 0.375 and 0.5 respectively. These results obtained falls within the range of zero to one (0 – 1) obeying the characteristics through which the controller were configured to operate. This shows that the result from the proposed fuzzy logic is optimal.

1. Background

Electrical Power System consists of various electrical components such as Generating units, transformers (Power and Distribution), transmission lines, isolators, circuit breakers, bus bars, cables, relays, instrument transformers, distribution feeders, and various types of loads [5].

It starts with energy Generation and the generated energy is transmitted from a control Centre after the voltage level has been step up to a higher level. This higher level of voltage is further step down to a level that is suitable for distribution. According to [30], distribution and utilization of electrical energy is the final stage in electricity delivery to end users. Electrical network in Nigeria has different levels of operating voltages. In distribution network, feeder voltage of 11KV is distributed from 33KV injection Substation and further step down by transformers to 0.145KV at the consumer's terminal. These lines which are mostly connected as overhead lines in Nigerian network are exposed to faults caused by lightning, short circuits, faulty equipment, wrong operations, human errors, overload, and aging etc. Electrical faults are destructive and evident in mechanical damages of equipment and loss of personnel. All of these challenges must be repaired for the line to return to service. The restoration can be faster if faults are identified and cleared by protective devices.

Faults are usually taken care of by interconnection of protection devices such as relays, Current transformers, Voltage Transformers, Circuit Breakers and fuses that detect fault and eventually isolate the affected sections from the entire power system. Faults can be of various types and their detection and clearing approach may differ.

2. Review of Related Research Works

Many research works on fault diagnosis incorporate artificial intelligent approaches which process the information from alarms and protection relays in power distribution and transmission systems [11];[42]; [14]; [4]. An expert system has been implemented in cooperation with SCADA to develop a more efficient and precise centralized fault diagnosis system in transmission networks [6]. The approach registers information such as fault location, causes of fault and identifies unwanted operation of protection devices.

Voltage and current sensors are installed on transmission lines for real time implementation and this involves a high cost. Artificial neural network (ANN) based program written in matlab 7.5 environment for the detection and analysis of fault in power distribution network has been developed to locate fault [30]. A fault location and fault state of lines and bus sections has been obtained using the information from alarm relays [14]. This technique provides effective information to the operator for decision making but most distribution systems are not completely equipped with alarm relays. A combination of ANN and fuzzy logic has been used to process the information from alarms and protection relays [42] for the purpose of identifying the faulty components and line sections. A wavelet based ANN approach is developed for fault detection and classification [41].

The approach uses oscillography data from fault recorders and therefore requires communication networks between remote power system and digital fault recorders. A substation fault diagnosis system has been developed using the Petri net theory [39]. In this method, the information from circuit breakers and faulty protection devices are configured based on mathematical formulations to calculate the precise fault section. Two Petri net concepts, namely, neural Petri net and fuzzy neural Petri net are used for locating faults at the lines or sections [4]. However, these methods are not suitable for fault diagnosis in distribution systems due to lack of information of alarm and protective relays. A new and accurate fault location algorithm using adaptive neuro-fuzzy inference system (ANFIS) has been developed for a network with both transmission lines and under-ground www.intechopen.com cables [27].

It uses fundamental frequency of three-phase current and neutral current as inputs while fault location is calculated in terms of distance in kilometer. Although it gives a good performance, there are some imperfections in the fault location due to the wide range in distance. An ANN based fault diagnosis method has been implemented in an unbalanced underground distribution system [29]. The method uses fundamental voltage and current phasors as inputs to the ANN for locating faults in the line sections. Another ANN based approach which combines the ant colony optimization algorithm has been developed for fault section diagnosis in the distribution systems [40]. The method locates faults in terms of the line sections but the exact fault points are still not known. Many researchers have made a research in fault detection in power system. Salim et al. (2009) proposed an Extended Fault-Location Formulation for Power Distribution Systems. The proposed method uses the voltages and currents as input data to detect the fault. [33] formulated an electrical protective relaying framework to detect and classify any fault type in an electrical power system is presented. This work use readings of the phase current only during the first (1/4)th of a cycle in an integrated method that combines symmetrical components technique with the principal component analysis (PCA) to declare, identify, and classify a fault. Fault Analysis of Multiphase Distribution Systems Using Symmetrical Components was proposed by [1].

[34] He investigated how the model-based fault detection and location approach of structural analysis can be adapted to meet the needs of power systems, where challenges associated with increased system complexity make conventional protection schemes impractical. [36] formulated On-Line Monitoring and analysis of Faults in Transmission and Distribution Lines using GSM technique. [35] presented a decentralized multi agent system (MAS) which works in real time with a power distribution system for fault detection applications. The agents use local voltage and current RMS values to locate a fault. [38] proposed location of single-phase faults in power distribution systems with distributed generation by means of impedance-based methods.

Recently, several methods have been developed for automated fault location in distribution system. Thus the fault detection and location on high voltage Distribution lines can be classified into the following three categories; Impedance method Travelling theory based method and Intelligent systems. [17] presented a general approach to locate any type of fault on either a single-circuit or a double-circuit transmission line when only current magnitude measurements are available. [15] evaluated the Fault Location based on Voltage Sags Profiles. The test results presents the strength and limitation of the method when applied for different fault resistances, loading variation and load models. [13] proposed travelling Waves for finding the fault Location in Transmission Lines. This wavelets can provide multiple resolutions in both time and frequency domains. This method identifies the fault using the return time of the pulse wave. [8] presented a novel approach in distribution protection technique of fault line selection based on analysis of generated transient and the potential of using discrete wavelet transform in protective relay was examined. [24] presented a wavelet based technique for detection and classification of abnormal conditions that occur on power distribution lines.

The proposed technique depends on a sensitive fault detection parameter (denoted SFD) calculated from wavelet multi-resolution decomposition of the three phase currents. [3] proposed Combination of discrete wavelet transform and probabilistic neural network algorithm for detecting fault location on transmission system. [37] formulated Wavelet Entropy and Neural Network for detecting fault in Non Radial Power System Network. [22] proposed a intelligent

ISSN 2229-5518

approach for high impedance fault (HIF) detection in power distribution feeders using combined Adaptive Extended Kalman Filter (AEKF) and probabilistic neural network (PNN). The AEKF is used to estimate the different harmonic components in HIF and NF (no-fault) current signals accurately under nonlinear loading condition. Thus these traditional approaches to fault problems have usually involved human experts. This may leads to error in fault detection. In this environment, artificial-intelligence-based techniques such as neural networks, fuzzy logic [18] and genetic algorithms can enhance a system's performance for accurate fault detection. AI based techniques model the adaptive and highly complex processes to formulate solutions to such open-ended problems, where traditional approaches cannot be applied. Among the AI based techniques, Artificial Neural Networks [23] (ANNs) based methods are widely used. However, the tools proposed so far exhibit limitations regarding the magnitude of the training set and the poor resolution. In order to overcome the shortcomings of the existing procedures, this work proposes a fuzzy logic based method for determination of fault detection along with fault location in a radial distribution system. It employs voltage and current signals obtained at the distribution substation as input variables to detect and locate the fault.

Several research work done on line protection employs rigorous mathematical methods that were not intelligent enough but in recent years intelligent based methods are being used in fault detection among which is fuzzy logic based system.

3. MATERIALS

Description of Power Station Used As a Case Study

The Power Station is independent of the national grid and it is sited at Notore fertilizer plant environs in Onne, Rivers State, Nigeria. It has two gas turbines power plants that are designated as 2006J and 2006JA that take care of generation. However, 2006JA is out of service but 2006J is fully in service with generation capacity of 25MW even though only about 10MW is consumed daily. The station has a total number of seventeen distribution transformers that are fed through overhead cables from a load Centre. All the feeder cables are connect 11KV busbar through their respective switchgears to the transformers. The Protection scheme includes the following Electrical devices: Current Transformers, Potential Transformers, Circuit Breakers, Relays, Isolators and fuses.

Single Line Drawing of the Feeder Network of Notore Fertilizer Plant shown in Fig.1

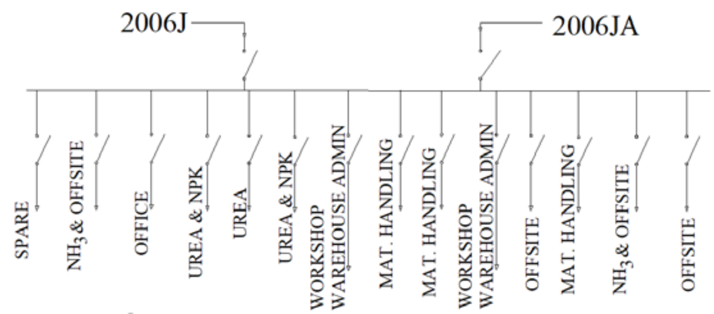


Figure 1: Single Line Drawing of the Feeder Network of Notore Fertilizer Plant

Data Collection

The radial power network is adopted in Notore fertilizer plant. This starts with a generation of 25MW from a gas turbine designated as 2006J out of which 10MW capacity is fed through indoor switchgears to out-station transformers installed to feed different sections of the plant and complex. The Gas turbine is located on 32^{0}N with coordinate (291903, 522963). The transformers are seventeen (17) in number and are shared to feed different sections of the plant. These transformers are described in table 1.

Table 1: Description of Transformers on The Network

S/N	TRANSFORMERS	DESCRIPTION	VOLTAGE RATIO	RATING (MVA)	DISTANCE FROM LOAD CENTER	LOAD
1.	Utilities Transformers	a. TR2021	11/3.3	5MVA	595m	3.40MW
		b. TR2022	11/3.3	5MVA	595m	1.27MW

		c. TR2031	11/0.4 40	1.5MVA	595m	0.30MW

Rule No	I_R	I_Y	I_B	I_N	V_R	V_Y	V_B	FAULT TYPE
1.	H	N	N	H	L	N	N	SLG – (R to G)
2.	N	H	N	H	N	L	N	SLG - (Y to G)
3.	N	N	H	H	N	N	L	SLG - (B to G)
4.	H	H	N	N	L	L	N	DL – (R to Y)
5.	H	N	H	N	L	N	L	DL – (R to B)
6.	N	H	H	N	N	L	L	DL – (Y to B)
7.	H	H	N	H	L	L	N	DLG – (RY to G)
8.	H	N	H	H	L	N	L	DLG – (RB to G)
9.	N	H	H	H	N	L	L	DLG – (YB to G)
10.	H	H	H	N	L	L	L	3-Ø FAULT
11.	N	N	N	N	N	N	N	NO-FAULT

Note: High – (H), Low - (L), Normal – (N) are taken as fuzzy membership functions.

		d. TR2032	11/0.4 40	1.5MVA	595m	0.15MW
	Demin Transformers	a. TR2231	11/0.4 40	1.5MVA	1305m	0.57MW
		b. TR2232	11/0.4 40	1.5MVA	1305m	0.68MW
3.	Utilities Offsite Transformers a. Bulk Store	a. TR2833 b. TR2834	11/0.4 40	1.5MVA	6127m	-
4	b. Old Bagging	c. TR2831 TR2832	11/0.4 40	1.5MVA	3867m	-
	c. General workshop and Admin	d. TR2631	11/0.4 40	1.5MVA	3944m	0.02MW
5.	Ammonia (NH_3) Plant Transformers	a. TR0131	11/0.4 40	1.5MVA	1693m	0.53MW
		b. TR0132	11/0.4 40	1.5MVA	1693m	0.11MW
6	Urea Plant Transformers	TR 1321	11/3.3	5MVA	1360m	0.79MW
		TR 1322	11/0.4 40	1.5MVA	1360m	0.41MW
		TR 1331	11/0.4 40	1.5MVA	1360m	0.49MW
		TR 1332	11/3.3	5MVA	1360m	0.57MW

PROPOSED METHOD

This method of fault detection applies the three phase Red. Yellow and Blue) and the neutral phase IN feeder currents and phase voltages as the inputs to the fuzzy inference system (FIS).

Membership Functions

Different levels of the fault currents and voltages for different fault conditions on the distribution lines are classified into various degrees of membership functions- Low, Normal and High. These membership functions are used in forming the rule base for the fuzzy logic fault detection system. Table 3.2 shows the rule base formulation for the fuzzy based fault detection system.

Table 2 Fuzzy Rule Base Formulation

Where:

I(R): Current in Red Phase V(R) : Voltage in Red Phase

I(Y) : Current in Yellow Phase V(Y) : Voltage in Yellow Phase

I(B) : Current in Blue Phase V(B) : Voltage in Red Phase

I(N) : Current in Neutral

Therefore, rule 1 reading is taken as:

IF Red Phase Current = High, Yellow Phase Current = Normal,

Blue Phase Current = Normal, Neutral Current = High

THEN, Fault type is Red Phase to Ground (SLG).

3.4 Simulation of Fuzzy Logic Designer for Fault Detection

Simulation for this study starts by opening fuzzy logic designer, the Mamdani is chosen. Next is to feed seven input variables namely; I(R), I(Y), I(B), I(N), V(R), V(Y), V(B) as in Table 3.2 into the fault classifier controller. After that, three (3) membership of function of triangular type is chosen, namely; Low, Normal and High. The param for the membership functions are:

a) Low – [-0.5, 0, 0.5]

b) Normal - [0, 0.5, 1]

c) High – [0.5 1 1.5]

The membership function plots are 181.

Next is the selection and configuration of the output variable. One output variable is chosen and designated as fault in this research work. The membership functions selected are ten in number and their values (params) are:

1. R-G: [-0.125 0 0.125]
2. Y-G:[0 0.125 0.25]
3. B-G:[0.125 0.25 0.375]
4. RY:[0.25 0.375 0.5]
5. YB:[0.375 0.5 0.625]
6. RB:[0.5 0.625 0.75]
7. RY-G:[0.625 0.75 0.875]
8. YB-G:[0.75 0.875 1]
9. RB-G:[0.875 1 1.125]
10. 3-PHASE:[1.125 1.25 1.375]

After that, the controller (fault classifier) is programmed to accept rules that are based on electrical fault principles. Rules for this research work are ten in number and they are:

1. If (I(R) is HIGH) and (I(Y) is NORMAL) and (I(B) is NORMAL) and (I(N) is HIGH) and (V(R) is LOW) and (V(Y) is NORMAL) and (V(B) is NORMAL) then (FAULT is R-G) (1)

2. If (I(R) is NORMAL) and (I(Y) is HIGH) and (I(B) is NORMAL) and (I(N) is HIGH) and (V(R) is NORMAL) and (V(Y) is LOW) and (V(B) is NORMAL) then (FAULT is Y-G) (1)

3. If (I(R) is NORMAL) and (I(Y) is NORMAL) and (I(B) is HIGH) and (I(N) is HIGH) and (V(R) is NORMAL) and (V(Y) is NORMAL) and (V(B) is HIGH) then (FAULT is B-G) (1)

4. If (I(R) is HIGH) and (I(Y) is HIGH) and (I(B) is NORMAL) and (I(N) is NORMAL) and (V(R) is LOW) and (V(Y) is LOW) and (V(B) is NORMAL) then (FAULT is RY) (1)

5. If (I(R) is NORMAL) and (I(Y) is HIGH) and (I(B) is HIGH) and (I(N) is NORMAL) and (V(R) is NORMAL) and (V(Y) is LOW) and (V(B) is LOW) then (FAULT is YB) (1)

6. If (I(R) is HIGH) and (I(Y) is NORMAL) and (I(B) is HIGH) and (I(N) is NORMAL) and (V(R) is LOW) and (V(Y) is NORMAL) and (V(B) is LOW) then (FAULT is RB) (1)

7. If (I(R) is HIGH) and (I(Y) is HIGH) and (I(B) is NORMAL) and (I(N) is HIGH) and (V(R) is LOW) and (V(Y) is LOW) and (V(B) is NORMAL) then (FAULT is RY-G) (1)

8. If (I(R) is NORMAL) and (I(Y) is HIGH) and (I(B) is HIGH) and (I(N) is HIGH) and (V(R) is NORMAL) and (V(Y) is LOW) and (V(B) is LOW) then (FAULT is YB-G) (1)

9. If (I(R) is HIGH) and (I(Y) is NORMAL) and (I(B) is HIGH) and (I(N) is HIGH) and (V(R) is LOW) and (V(Y) is NORMAL) and (V(B) is LOW) then (FAULT is RB-G) (1)

10. If (I(R) is HIGH) and (I(Y) is HIGH) and (I(B) is HIGH) and (I(N) is NORMAL) and (V(R) is LOW) and (V(Y) is LOW) and (V(B) is LOW) then (FAULT is 3-PHASE) (1)

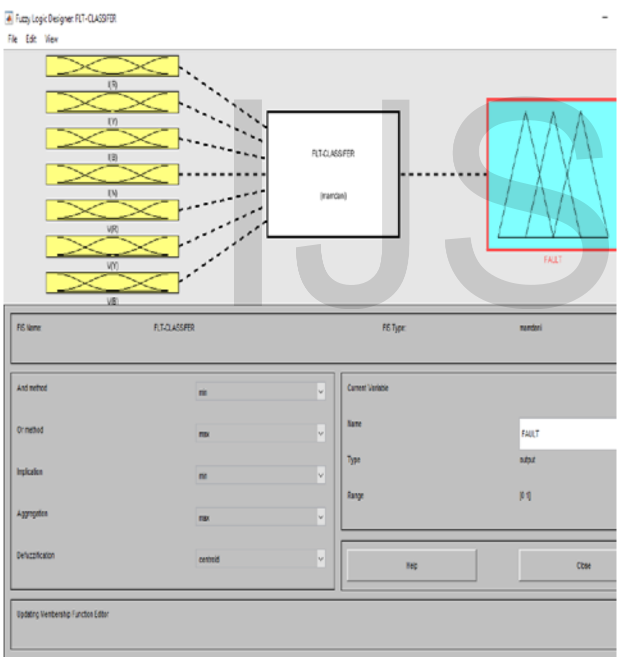


Fig 2. Fuzzy Logic Designer

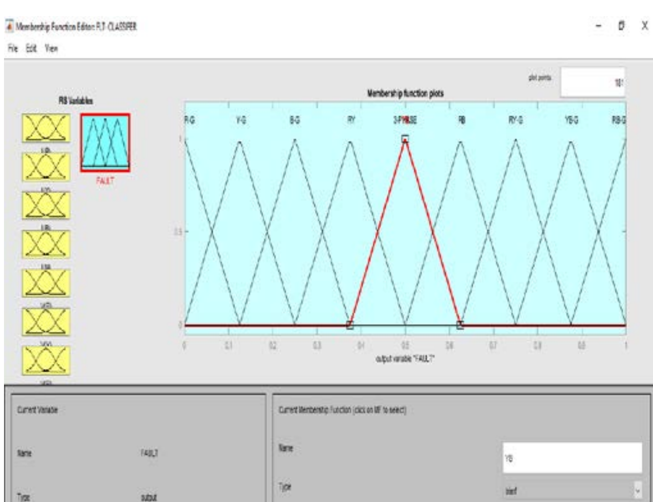


Fig. 3: Membership Function Editor

3.4 Proposed Fuzzy Algorithm

The proposed algorithm is as follows:

01 Start

02 Input Variables for input

03 Define input Membership Function

04 Set input range

05 Input variable for output

06 Define output Membership Function

07 Set input range

08 Define controller

09 Set rules for the controller

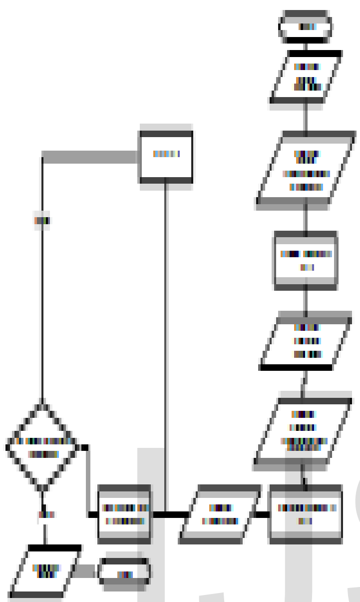
10 If rules are satisfied

Then go to step 11
Else go to step 09
11. Stop

Flow chart of the above Algorithm is in Figure 3.3 below.

Figure 5 Flow chart of Fuzzy Algorithm

ISSN 2229-5518



Fuzzy Logic Controller on the Distribution Network Used As Case Study

The Distribution Network used as Case Study is drawn in Simulink of Matlab, 2018 Version and the proposed fault detector is added to monitor fault. Four different fault situations are created from Simulink fault block and results are displayed on a scope. The blocks are in figure 4, 5, 6, 7. Figure 6 evaluates single line to ground fault, Figure 7 evaluates line to line fault, Figure 8 evaluates Double line to ground fault and Figure 9 evaluates three phase fault.

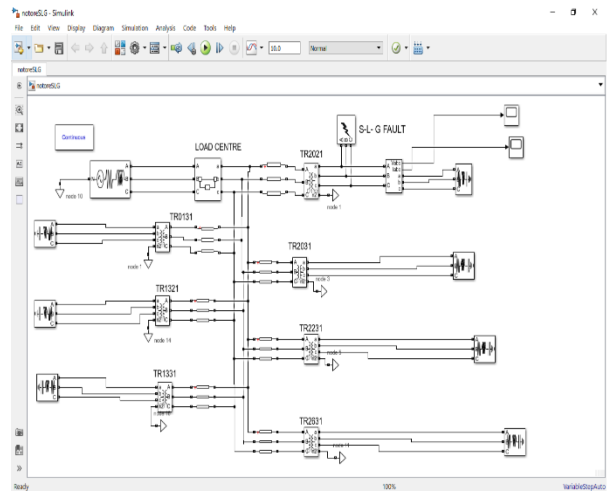


Figure 6 Simulink Block For Single Line To Ground Fault

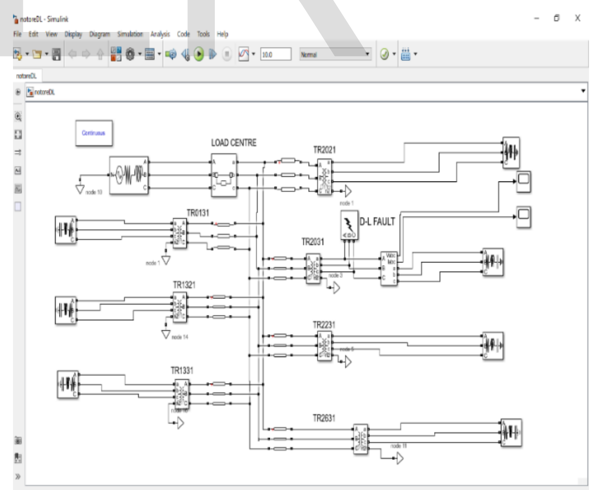


Figure 7 Simulink Block For Line To Line Fault

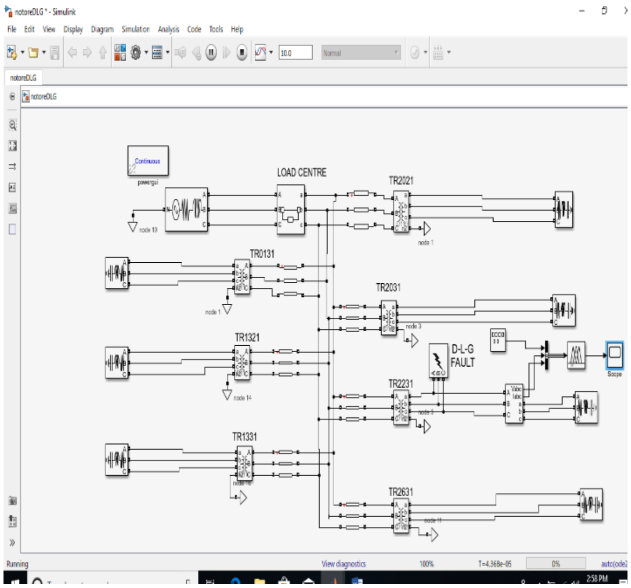


Figure 8 Simulink Block For Double Line To Ground Fault

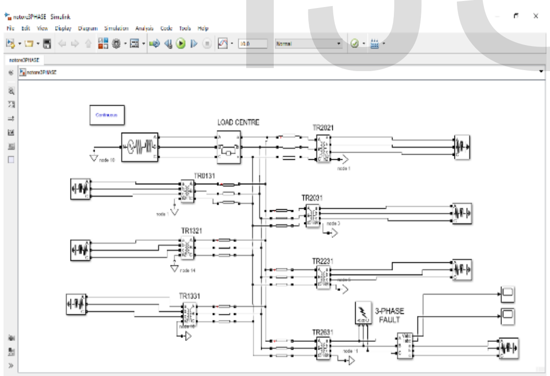


Figure 9 Simulink Block For Three Phase Fault

4. RESULTS

The fuzzy logic based fault diagnostic system as described in this work was tested on the radial distribution system used as case study. The test was done in Simulink/Matlab, 2018 environment for four classes of faults, namely; Single line to ground fault, Line-to-Line fault, Double Line to ground fault and three phase fault.

SIMULATION AND PLOTS FOR SINGLE LINE TO GROUND FAULT

The model of Figure 3.6 represents the studied network that is subjected to a single line to ground fault. The test is conducted on transformer (TR2021) installed at utilities section of the complex where the red phase is faulted to ground with the help of Matlab/Simulink fault block and the fault signal is connected to the fuzzy controller and displayed on a scope. Figure 11 shows the voltage of the red phase that is faulted to ground and Figure 4.2 shows the fuzzy logic viewer for the single line to ground fault.

Looking at these values, the line-to-ground, fault is easily identified as single Red phase-to-ground fault, since fuzzy scope displays IR, and IN as high and VR as low, as against the conventional protection system in the study area which only displays earth fault but does not have the capability to differentiate it from Blue phase-to-ground fault (B-G), Yellow phase-to-ground (Y-G).

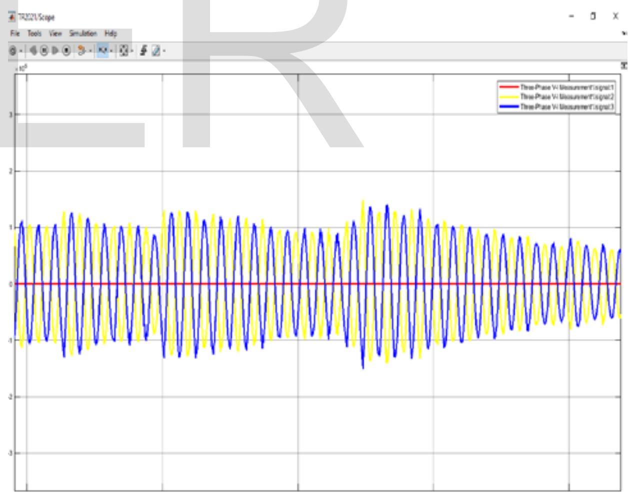


Figure 11: Single Line to Ground Fault

Figure 10: Fuzzy Logic Rule Viewer For Single Line To Ground

From Figure 10, Eight Plots of columns and ten plots of rows are displayed. The first seven columns from left are the inputs of the controller while the last and the eighth column from left is the output. The figures that appear across the top of the columns represent the antecedent and consequent of the rule for red to ground fault as seen by the controller. The eleventh plot in the eight column of plots represents the aggregate weighted decision for the given inference system. The defuzzified output is displayed as a bold vertical line on this plot. Thus, the rule for this fault condition is read as:

If (I(R) is 0.931) and (I(Y) is 0.5) and (I(B) is 0.5) and (I(N) is 0.9) and (V(R) is 0.2) and (V(Y) is 0.5) and (V(B) is 0.5) then (FAULT R-G is 0.0439)

SIMULATION AND PLOTS FOR DOUBLE LINE TO GROUND FAULT

The double line to ground fault model in Figure 3.7 was simulated on transformer (TR2231) installed at Demin section of the complex with total load capacity of 0.57MW. The yellow and blue phase are faulted to ground with the help of Matlab/Simulink fault block and the fault signal is connected to the fuzzy controller and displayed on a scope. Figure 4.3 shows the fuzzy logic viewer for the double line to ground fault.

In the case of double line-to-ground fault (D-L-G) the protection scheme in place (study area) does not have the capability to specify the very type of fault rather sees it as Earth fault. Fuzzy logic identifies it as double line-to-ground.

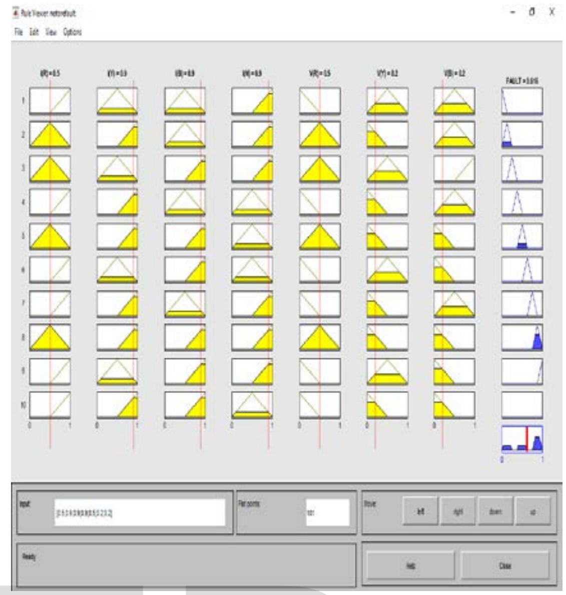


Figure 13: Fuzzy Logic Rule Viewer For Double Line to Ground Fault

From Figure 13, Eight Plots of columns and ten plots of rows are displayed. The first seven columns from left with the readings; [IR = 0.5, IY = 0.9, IB = 0.9, IN = 0.9, VR = 0.5, VY = 0.2, VB = 0.2] are the inputs of the controller while the last and the eight column from left with the reading; Fault = 0.616 is the output. The figures that appear across the top of the columns represent the antecedent and consequent of the rule for yellow and blue phases to ground fault as seen by the controller. The eleventh plot in the eight column of plots represents the aggregate weighted decision for the given inference system. The defuzzified crisp output is Fault = 0.616 and is displayed as a bold red vertical line on this plot. Thus, the rule for this fault condition is read as:

If (I(R) is 0.5) and (I(Y) is 0.9) and (I(B) is 0.9) and (I(N) is 0.9) and (V(R) is 0.5) and (V(Y) is 0.2) and (V(B) is 0.2) then (FAULT, Y-B-G is 0.616)

SIMULATION AND PLOTS FOR LINE TO LINE FAULT

The line to line fault model in Figure 3.8 was simulated on transformer (TR2031) installed at Utilities section of the complex with total load capacity of 0.3MW. The red and yellow phases are faulted in Matlab/Simulink fault block and the fault signal is connected through fuzzy logic controller and displayed on a scope. Figure 4.4 shows the voltage of the red and yellow phases that is faulted but clears of ground and Figure 4.5 shows the fuzzy logic viewer for the line to line fault.

This result indicates that, it is easy to identify this fault from fuzzy scope that Red and Yellow Phases are short circuited which clearly specified line-line fault (R-Y) as against the conventional protection system that displays this particular fault as over current fault.

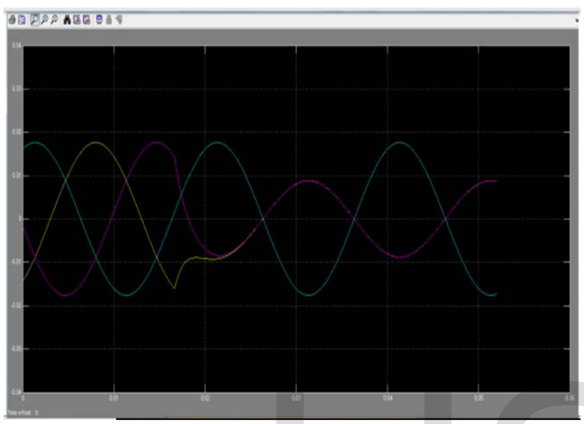


Figure 14: Line to Line Fault

Figure 15: Fuzzy Logic Viewer For Line To Line Fault

From Figure 15, Eight Plots of columns and ten plots of rows are displayed. The first seven columns from left with the readings; [IR = 0.9, IY = 0.9, IB = 0.5, IN = 0.5, VR = 0.2, VY = 0.2, VB = 0.5] are the inputs of the controller while the last and the eight column from left with the reading; Fault = 0.375 is the output. The figures that appear across the top of the columns represent the antecedent and consequent of the rule for red and yellow phases clear of ground fault as seen by the controller. The eleventh plot in the eight column of plots represents the aggregate weighted decision for the given inference system. The defuzzified crisp output is Fault = 0.375 and is displayed as a bold red vertical line on this plot. Thus, the rule for this fault condition is read as:

If (I(R) is 0.9) and (I(Y) is 0.9) and (I(B) is 0.5) and (I(N) is 0.5) and (V(R) is 0.2) and (V(Y) is 0.2) and (V(B) is 0.5) then (FAULT, R-Y is 0.375). This result agrees with electrical principle for red and yellow fault as V(R) and V(Y) voltage values are low while I(R) and I(Y) are high.

SIMULATION AND PLOTS FOR THREE PHASE FAULT

From Figure 16, simulation was carried out on the transformer (TR2631) installed at General workshop and Admin section of the complex with total load capacity of 0.02MW. The Red, yellow and blue phases were faulted with the help of Matlab/Simulink fault block and the fault signal is connected to the fuzzy controller and displayed on a scope. Figure 4.6 shows the voltages of the red, yellow and blue phases that is faulted but clear of ground and Figure 4.7 shows the fuzzy logic viewer for the three phase fault.

The conventional protection scheme in Notore fertilizer plant (case study) identifies three phase fault as over current fault whereas fuzzy specifies it as a three phase fault (R-Y-Bfault)

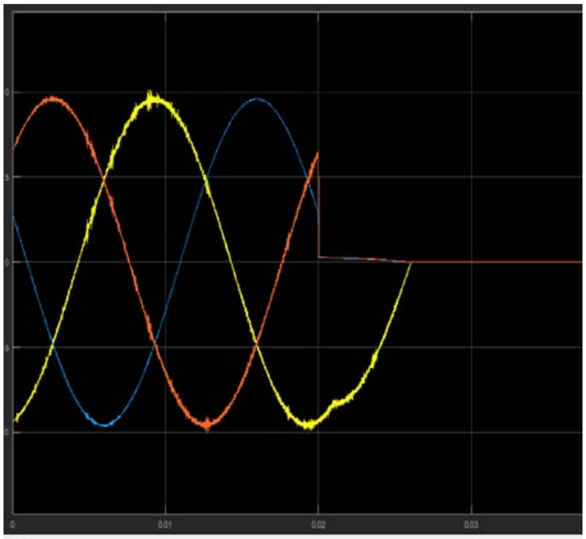


Figure 16: Three Phase Fault

Figure 17: Fuzzy Logic Viewer for Three Phase Fault

From Figure 17, Eight Plots of columns and ten plots of rows are displayed. The first seven columns from left with the readings; [IR = 0.9, IY = 0.9, IB = 0.9, IN = 0.5, VR = 0.2, VY = 0.2, VB = 0.2] are the inputs of the controller while the last and the eight column from left with the reading; Fault = 0.5 is the output. The figures that appear across the top of the columns represent the antecedent and consequent of the rule for three phase fault as seen by the controller. The eleventh plot in the eight column of plots represents the aggregate weighted decision for the given inference system. The defuzzified crisp output is Fault = 0.5 and is displayed as a bold red vertical line on this plot. Thus, the rule for this fault condition is read as:

If (I(R) is 0.9) and (I(Y) is 0.9) and (I(B) is 0.9) and (I(N) is 0.5) and (V(R) is 0.2) and (V(Y) is 0.2) and (V(B) is 0.2) then (FAULT, 3phase is 0.5). This result agrees with three phase fault condition as the voltages V(R), V(Y) and V(B) values are low while the currents I(R), I(Y) and I(B) are high.

5. Conclusions

In this research work, fuzzy logic controller was developed to detect, single line to ground fault, double line to ground fault, line to line fault and three phase fault on Notore 11KV Line and Substations in Rivers State, Nigeria as case study. The proposed fuzzy logic controller takes neutral, phase currents (IR, IY, IB, IN) and phase voltages (VR, VY, VB) as inputs. The inputs are assigned three linguistic variables (Low, Normal and High) with some degrees of triangular membership function. Also a single output (Fault) was assigned to the controller with ten linguistic variables [(R-G), (Y- G), (B-G), (R -Y), (R - B), (Y-B), (RY- G), (RB-G), (YB-G), 3-Ø] with varying degree of triangular membership function. Additional, the mamdani expert system was used for the implementation and the output of the ten rules are aggregated to form a defuzzified output with the help of Centre of gravity method. This result is displayed on a scope at every instant that fault occurred on the network. The results of defuzzified output from the controller using single line to ground fault, double line to ground fault, line to line fault and three phase fault are 0.0439, 0.616, 0.375 and 0.5 respectively. These results are within the range of zero to one (0 – 1) that the controller configured to operate. This shows that the result from the proposed fuzzy logic is optimal.

REFERENCES

[1.] Abdel-Akler, M. (2010). Fault analysis of multiphase distribution system using symmetrical components. IEEE Transaction on Power Delivery 25(4), 2931-2939

[2.] Anthapol, et al. (2017). Behaviour analysis of winding to ground fault in transformer using high and low frequency components from discrete wavelet transform 2017 Int. conference on Applied Syst. Innovation (ICASI) (Sapporo) 1102-1105

[3.] Atthapol, Ngaopitakkul et al., (2011). Behaviour of interturn fault in power transformer using sequence components of discrete wavelet transform 2012 15th International Conference on Electrical Machines and system (ICEMS) Sapporo). 1-6

[4.] Binh,.&,,Tuyen, N.D (2006). Fault Diagnosis of Power System Using NeuralPetri Net and Fuzzy ,Neural Petri Nets, *Power India Conference*, IEEE, Delhi, India, 5

[5.] Brown, R. E. (1996). Reliability Assessment and Design Optimization for Electric power distribution systems, Ph.D Dissertation, University of Washington, Seatle, WA

[6.] Deliver,y Sekine, Y., Akimonto,Y, Kunugi, M. and Fukui, C. (1992). Fault Diagnosis of Power ,System, Proceeding of the IEEE, Vol. 80, No.5, Pg 673 – 683

[7.] Fathabadi, H., (2016). Novel Filter base ANN approach for short Circuit faults detections classification and location power transmission lines. *Intr. J. Electr. Power Energy Syst.*

[8.] Frantisek, Janicek et al., (2007). Digitalization in power distribution systems: Stoak University of Technology , 2018, 89-94 ISBN 978-80-89983-00-1

[9.] Jalali, D. & Moslemi, N. (2005). Fault location for Radia Distribution systems using fault generated high frequency transient and wavelet analysis. 18th *International Conference on Electricity Distribution*, Turn 6-9 June,1-4, date of current of version 11th March 2010, TEE Publisher.

[10.] Magnago, F. H. and Abur, (1999). Htts://booksgoogle.com.ng/book. Advance techniques for transmission and distribution system fault location.

[11.] Mamdani, E. H. (2008). Application of fuzzy logic to approximate reasoning using linguistic synthesis. www.google.com

[12.] Math Works, Matlab/Simulink R2008 (B) software, www.mathworks.com

[13.] Mohammed Abdul Baseer (2013). Transient Stability Improvement of Multi-machine Power system using fuzzy logic controlled TCSC MA- Baseer – IOSR *Journal of Electrical and Electronics Engineering*, 2014.

[14.] Mohammed, and Mazumder, A (1999), A Neural Network Approach to Fault Diagnosis in a Distribution System, *International Journal of Power and Energy Systems*, Vol.19, No.2, Pg 129-134

[15.] Mokhlis, H. (2018). High Impedance fault detection and identification based on pattern recognition of phase displacement computation.

http://www.electrical4u.com/protection.syst-in-power-system

https://en.wikipedia/powersystem_protection

www.electrical-engineering-portal.com.protection-and-switchgear-by-U.A.Bakshi-and-MVBaskhi

[16.] Notore Chemical Industries Plc. Control room data for the substation in Onne, River State.

[17.] Ningkang, et al., (2010). Computer Architecture: A quantitative approach, Fifth Edition

[18.] Onojo, Ondoma James et al., (2012). *Asian Journal of Natural and Applies Sciences (AJSC)*. ISSN: 2186-8476, ISSN: 2186-8468 print 1(2).

[19.] Oysal, Y. (2005). Comparative study of adaptive load frequency controller designs in a power system with dynamic neural network models, Energy convers. Manage, 46(15-16), 2656-2668

[20.] Ogujor, E. A. et al. (2006). Optimization models for hybrid energy system-A review

[21.] Pothiya, S., Ngamroo, I., Runggeratigal, S. & Tantaswadi, P. (2006). Design of optimal fuzzy logic based pi controller using multiple tabu search algorithm for load frequency control, *Int. J. Confr. Automation, Syst.* 4(2), 155-164

[22.] Samantaray, A. K. (2006). Bond graph in modeling, simulation anf fault identification (CRC Press USA). ISBN: 978 -8188237

[23.] Sarvi, S. et al., (2012). Gravitational Search algorithm based optimal reactive porous dispatch for voltage stability enhancement, Electric power components and systems, 40(9), 956-976

[24.] Zamanan et al., (2011). Lane Department of Computer Science and Electrical Engineering: Computer Forensice certificate, http://www.csee.wvu.edu

A self-tuning fuzzy PI controller for TCSC to improve power systems Research (E/Sevier), 78 (No-10), 1926-1735

[25.] Salman Hameed, B. Das (2010) Power System stability enhancement using reduced rule base self-turning fuzzy PI controller for TCSC. *Journal Proceedings of 2010 IEEE PES Transmission and distributes conference and exposition publication data 2010*

[26.] Shaik, V. A., Pulipaka, R. R. V. (2006). A new wavelet based fault detection, classification and location in transmission lives. *Int. J. Electr. Power Energy System.* 64, 114-118

[27.] Sadeh, J. and Afradi, H. (2009). A New and Accurate Fault Location Algorithm for Combined Transmission Lines Using Adaptive Network Based Fuzzy Inference System, *Journal of Electric Power System Research*, Vol.79, No.11, 15338 -1545

[28.] Saha, M,M., Izykowski, J. and Rosolowski, E. (2010) Fault Location on Power Networks, Berlin Springer.

[29.] Salim, R. H., M. Resener, A.D. Filomena, K.R. Caino De Oliviera, A.S. Bretas, (2009), “Extended Fault-Location Formulation for Power Distribution Systems”, *IEEE Transactions on Power*, Vol 24, No 2.April 508-516. IEEE Press.

[30.] Uhunmwa,ngho, R. & Omorogiuwa E. (2014). “Detection and Analysis of Faults in Power Di,stribution Network Using Artificial Neural Network”, International *Journal of Scientific &, Engineering Research*, Volume 5, Issue 10, 955 ISSN 2229-5518, 2014

[31.] Walid, G. M., Tarlochau, S. S. (2016). A new harmony search approach for optimal wavelets applied to fault classification. IEEE Trans. Smart Grid

[32.] Zadeh, L. A . (1965). Fuzzy sets. *Journal of Information and control*, 8, 338-353 USA

[33.] Alsafasfeh, Q., I. Abdel-Qader and A. Harb, 2010. Symmetrical pattern and PCA based framework for fault detection and classification in power systems. IEEE International Conference on Electro/Information Technology (EIT). 1-5.

[34.] Dustegor, D., S.V. Poroseva, M.Y. Hussaini and S. Woodruff, 2010. Automated graph-based methodology for fault detection and location in power systems. IEEE Transactions on power delivery, 25(2): 638-646.

[35.] Ghorbani, J., M.A. Choudhry and A. Feliachi, 2012. Real-time multi agent system modeling for fault detection in power distribution systems. North American Power Symposium (NAPS). 1-6

[36.] Sujatha, M.S., Dr. M. Vijay Kumar, 2011. On-Line Monitoring and analysis of Faults In Transmission and Distribution Lines using GSM technique. Journal of Theoretical and Applied Information Technology, 33(2)

[37.] Soumyadip Jana and Gaurab Dutt, 2012.Wavelet Entropy and Neural Network Based Fault Detection on A Non Radial Power System Network. IOSR Journal of Electrical and Electronics Engineering (IOSRJEEE), 2(3): 26-31.

[38.] Faig, J., J. Melendez, S. Herraiz and J. Sánchez, 2010. Analysis of Faults in Power Distribution Systems With Distributed Generation, International

ISSN 2229-5518

Conference on Renewable Energies and Power Quality (ICREPQ'10) Granada (Spain)

[39.] Jingbo, Huang & Mu, Longhua. (2006). Fault Diagnosis of Substation Based on Petri Nets Technology. 10.1109/ICPST.2006.321717.

[40.] Zhisheng Zhang and Yarning Sun, 2007. Assessment on fault-tolerance performance using neural network model based on ant colony optimization algorithm for fault diagnosis in distribution systems of electric power systems. The 8th International Conference on Software Engineering, Artificial Intelligent, Networking and Parallel Distributed Computing.

[41.] Silva, K.M., B.A. Souza &N.S.D. Brito,2006. Fault detection and classification in transmission lines based on wavelet transform and ANN. IEEE Transaction on Power Delivery, 21: 2058-2063.

[42.] Souza, J.C.S., E.M. Meza, M.T. Sebilling andM.B.Do Corato,2004. Alarm processing in electrical power systems through a Neuro-Fuzzy approach. IEEE Transaction on Power Delivery, 19(3): 537-544