Transmission Line Performance Analysis Under Unsymmetrical Faults Using Fuzzy Logic Techniqu

Bright Ekpe[1], Akaniyene Obot[2], Nsebong Okpura[3]
Department of Electrical /Electronic and Computer Engineering, University of Uyo P.M.B.1017 Uyo, Akwa Ibom State, Nigeria
Emails: Ekpebright47@gmail.com¹, Akaniyeneobot@uniuyo.edu.ng², Nseobongokpura@uniuyo.edu.ng³

Abstract— **This paper presents a scheme for transmission line performance analysis under unsymmetrical faults using fuzzy logic technique. When a fault occurs in a power system, the magnitude of the fault current, will be very high compared to the steady state current that flows in the power system. It is important that, unsymmetrical fault performance analysis of the transmission line be undertaken to determine the magnitude of these fault currents, so as to select adequate ratings of the power system protective devices such as circuit breakers, relays and fuses. During transmission some faults occur in the system, such as line to line (L-L), line to ground (L-G) and double line to ground (L-L-G). In this work, Afam-Alaoji Nigeria 330KV 25 km transmission line bus system was considered, using relevant data which was obtained from the National Control Center (NCC) Oshogbo. MATLAB fuzzy logic tool version R2018a was used to carry out the simulation analysis. Various types of unsymmetrical faults were simulated at bus 21(Afam) and bus 22 (Alaoji) close to the generator. Base MVA of 470 MVA and Base KV of 330 KV and fault time of 0.2 to 2.599 seconds were used. The result of various fault on the bus system are shown as current and voltage along with the positive, negative and zero sequence and effect on generator in waveforms. The results obtained show that line to ground (L-G) fault is the most severe kind of faults occurring very close to the synchronous generator.**

Keywords: Transmission line, Unsymmetrical faults, Fuzzy Logic, Waveform

1. Introduction

A fault is any abnormal condition in a power system [1]. The steady state operations of a power system is a balanced 3-phase alternating current (a.c). However, due to sudden external or internal changes in the system, this condition is disrupted. When the insulation of the system fails at one or more points or a conducting object comes into contact with a live point, a short circuit or a fault occurs which generates the abnormal condition in a power system. The various cases of abnormal condition such as natural events, physical accidents, equipment failure, and misoperation generate faults in the power system [2]. Power system faults are classified as symmetrical fault and unsymmetrical fault. Symmetrical faults displace current at 120 degree equally on phase. Unsymmetrical faults are single phase to ground, two phases to ground and phase to phase short circuits [3]. The consequences of fault are traumatic amplification of current flow, increasing heat produced in the conductors leading to the major causes of damage in power system [4].

Faults leads to cut of supply in areas beyond the fault point in a transmission and distribution networks leading to power blackouts. This interferes with industrial and commercial activities that supports economic growth, stalls learning activities in institutions, work in offices, domestic applications and creates insecurity at night. All the above results into retarded development due to low gross domestic product (GDP) realized. It is important therefore to determine the values of system voltages and currents during faulted conditions, so that protective devices may be set to detect and minimize the harmful effects of such contingencies [5,6].

In this study, various types of faults occurrence were identified and analyzed based on test carried out. The identification and prediction of different causes of fault in a transmission line was done and analysed with an intelligent model with the fault occurrence type outcome reported in this study. The causes of fault analysed in this study includes low impedance fault and different causes and identification of high impedance faults on the transmission line network that connects a generation station and a load station [7,8,9,10,11,12,13].

2. Review of Related works

When fault occur in the transmission line, it causes changes in electrical quantities (current and voltage), therefore analyzing the changes during unsymmetrical fault at the generating end, obtaining the waveforms showing the behavior of each unsymmetrical fault in the transmission line is very important. Aiming at the fault analysis on transmission line, certain scholars have made relevant researches and have achieved certain results.

Bhupendra and Anamika [14,15] presented the use of laboratory prototype model of thyristor controlled series compensator (TCSC) transmission line. Using TCSC to reduce some part of line reactance, thereby reducing the effective line impedance, causing increase in current signal and voltage decrease. TCSC was considered at load end, by this method they proposed a fuzzy logic system to detect and classify faults for laboratory prototype model of TCSC.

Oputa and Madueme [16] investigated the nature of the system when faults occur in buses 4, 16 and 22 corresponding to Niger, oshogbo and Alaoji respectively by simulating in ETAP (Electrical Transient and Analysis Program). They concluded that fault always results in reduction of voltage at three different location, as investigated shows that the network is mostly affected by unsymmetrical fault.

3. Materials and Method

(a) The material utilized in this study includes a laptop with Microsoft word and MATLAB R2018a Software

(b) Methodology

The summary of the research procedure is presented in the flow diagram shown in Figure 4. Double Circuit Line adopted for the study is shown in Figure 5. Transmission line of 25 km 330 KV. 3 phase source voltage system to simulate the proposed technique. The basic steps taken during the research work were:

Step 1: Acquisition of data.
Power system data of Nigeria 330 KV Afam-Alaoji 25 km short transmission line was obtained from the National Control Center Oshogbo as shown in Table 1. In this

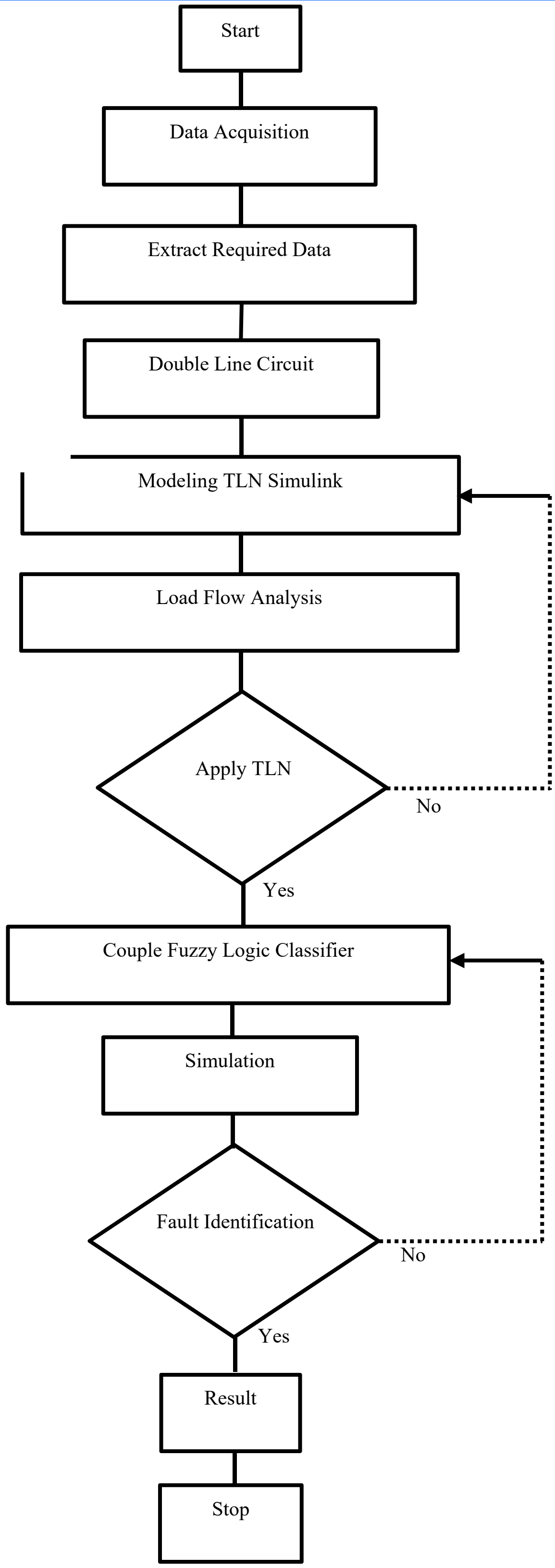

Figure 4: Flow diagram of the research methodology

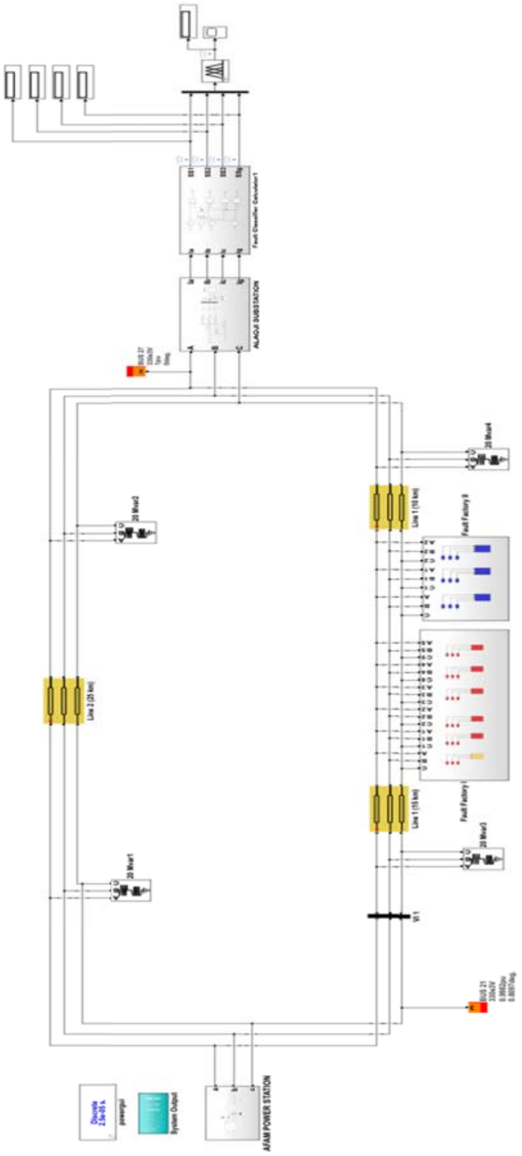

Figure 5: SIMULINK model of 330KV Afam-Alaoji transmission line

study the buses are identified and specified. The power plant and transmission line data with positive and Zero sequence are described in Table 1.

Table 1:Bus name, number and rating

Bus Name	Bus Number	Rating (MVA/MW)	KV	Frequency
Alaoji	**22**	**150/-161 - j83**	**330**	**50**
Afamm	**21**	**+470/162/ 138e3**		

Table 1 continuation

Bus No/Name From	Bus No/Name To	Length (km)	R (Ω/km)	L (mH/km)	XL (Ω/km)	C (μF/km)
21 Afam	**22Alaoji**	**25**	**0.009 0.007**	**$0.9337e^{-3}$ $4.1264e^{-3}$**	**6.92 75**	**$12.74e^{-9}$ $7.751e^{-9}$**

Step 2: Selection of the case study location

For the fault analysis to be effectively actualized, a location comprising of power generation station and transmission (load) station was considered. Hence, Afam-Alaoji was selected as the case study.

Step 3: The selected location was modelled in the power system tool in fuzzy logic with the current signals of various faults obtained.

Step 4: Load flow analysis was carried out to ascertain the reliability system design and data obtained through Newton-Raphson method.
Step 5: Fault identification indices was used, to calculate the input variables using current at one end of the system with the post fault current.
Step 6: load flow analysis was applied on the transmission line network.
Step 7: Integration of Fuzzy logic classifier (FLC) which contains Mandani (FIS), input and outputs, membership functions (MFs) and Rule based formulation
Step 8: At this point the system was ready for simulation, fault was introduced at distance of 10 km with time of 0.2 to 2.599 seconds. Breakers were switched open and closed.
Step 9: Fault bank was obtained with result. It was observed during the analysis, depending on the type of unsymmetrical fault line to ground, line-line to ground or line to line fault, the waveform changes accordingly. It was crystal clear to mention that during fault the voltage tends to reduce to zero while current rise.

(i) Fault Identification Indices

The S_1, S_2, S_3 and S_g are inputs to the fuzzy system. The calculations of the input variables using currents at one end of the system are given. The ratio SS_1, SS_2, SS_3 and SS_g are calculated using post –fault current as follows:

$$SS_1 = \frac{Ia}{\text{Max}\,\{abs(Ia), abs(Ib), abs(Ic)\ abs(Ig)\}} = \frac{Ia}{IABCG} \quad (1)$$

$$SS_2 = \frac{Ib}{\text{Max}\,\{abs(Ia), abs(Ib), abs(Ic)\ abs(Ig)\}} = \frac{Ib}{IABCG} \quad (2)$$

$$SS_3 = \frac{Ic}{\text{Max}\,\{abs(Ia), abs(Ib), abs(Ic)\ abs(Ig)\}} = \frac{Ic}{IABCG} \quad (3)$$

$$SS_g = \frac{Ig}{\text{Max}\,\{abs(Ia), abs(Ib), abs(Ic)\ abs(Ig)\}} = \frac{Ig}{IABCG} \quad (4)$$

where Ia, Ib, Ic represent the sample of the three phase current, Ig and I are Zero sequence and Positive sequence current. Fuzzy rule based method for fault classification is developed on the basis of SS_1, SS_2, SS_3 and SS_g. Zero sequence current, Ig has been taken into account to detect the presence of ground fault and S_g represent the ground fault detection. The differences of P_1 (n), P_2 (n), P_3(n) and Pg(n) calculated as follows:

$$SS_1 = P_{1(n)} - P_{2(n)}, \quad (5)$$

$$SS_2 = P_{2(n)} - P_{3(n)}, \quad (6)$$
$$SS_3 = P_{3(n)} - P_{g(n)}, \quad (7)$$
$$SS_g = P_{g(n)} - P_{1(n)}, \quad (8)$$

Applying the general configuration of fuzzy logic based fault classification as shown in Figure 6.

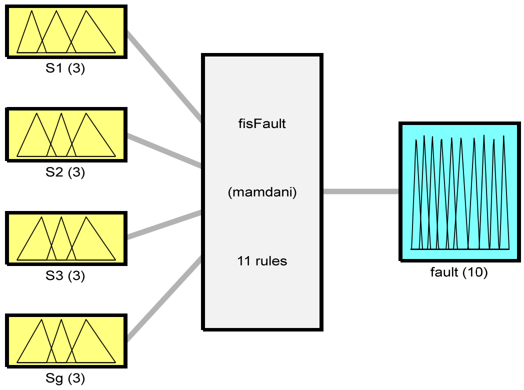

Figure 6: Fuzzy inference system.

(ii) Implementing Fuzzy Logic Technique

The four inputs values S_1, S_2, S_3, and S_g values are used to classify nature of fault through the general structure of fuzzy inference system (FIS). To map these input variables with the output of the FIS, Mamdani type with triangular membership function is used accompanied with a different rule base as presented in Figure 6.

(iii) Fuzzy Classifier

Fuzzy rule base to find the values for S_1 S_2 S_3 and S_g

i. (S1==High) & (S2==Low) & (S3==Low) & (Sg==High) => (fault=AG) (1)
ii. (S1==Low) & (S2==High) & (S3==Low) & (Sg==High) => (fault=BG) (1)
iii. (S1==Low) & (S2==Low) & (S3==High) & (Sg==High) => (fault=CG) (1)
iv. (S1==High) & (S2==High) & (S3==Low) & (Sg==Low) => (fault=AB) (1)
v. (S1==Low) & (S2==High) & (S3==High) & (Sg==Low) => (fault=BC) (1)
vi. (S1==High) & (S2==High) & (S3==Medium) & (Sg==Low) => (fault=ABC) (1)
vii. (S1==High) & (S2==High) & (S3==Low) & (Sg==High) => (fault=ABG) (1)
viii. (S1==Low) & (S2==High) & (S3==High) & (Sg==High) => (fault=BCG) (1)
ix. (S1==High) & (S2==High) & (S3==High) & (Sg==High) => (fault=ABCG) (1)
x. (S1==High) & (S2==High) & (S3==High) & (Sg==Low) => (fault=NF) (1)
xi. (S1==Medium) & (S2==Medium) & (S3==Medium) & . (Sg==Medium) => (fault=NF) (1)

Triangular membership functions are chosen for each input with 3 triangles identify as low, medium and high. The ranges for input membership functions are, value between 0 and 0.37 for low, values between 0.27 and 0.67 for medium and value between 0.6 and 1.2 for high.

Figure 7 shows the membership functions of input and outputs of unsymmetrical faults. Table 2 shows the output of classifier result.

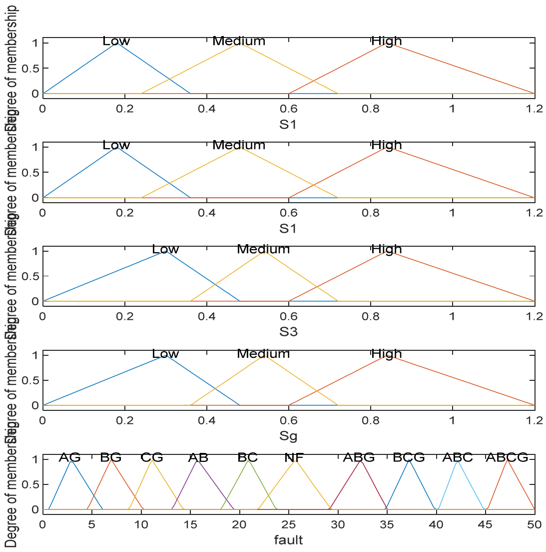

Figure 7: Triangular membership function for input and output.

Table 2: shows the Classifier result

Faults	SS1	SS2	SS3	SSG	FLC
AG	1	0.001	0	1	3.5
BG	0	1	0	1	7.5
CG	0	0	1	1	11.5
AB	1	1	0.000200000	0.0028	18.962199999999999
BC	0	1	0.0000000001	0.003000000	22.9116
ABG	1	1	1	1	34.427999999999997
BCG	0	1	0	1	37.351300000000002

Source: Researcher's field work (2021)

4. Results and Discussion

The waveforms obtain from the result of all the unsymmetrical fault will be analized in the sub section below.

Line-Ground Fault (L-G)

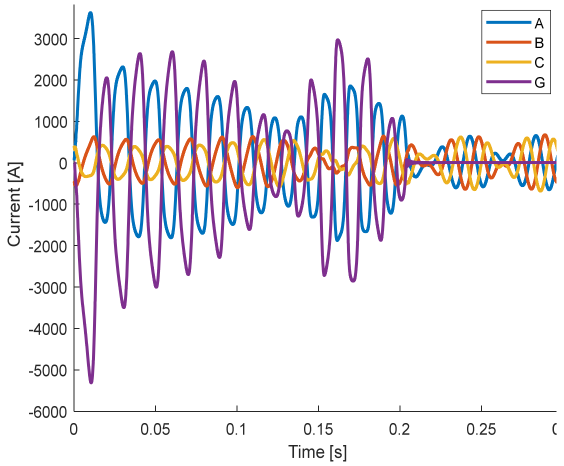

Figure 8: Current performance during AG fault

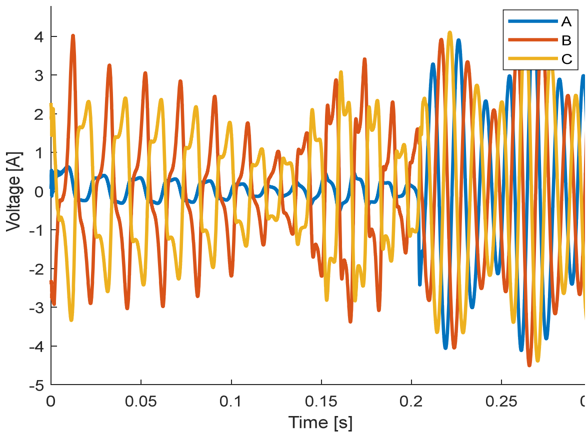

Figure 9: Voltage performance during AG fault

When AG fault is switch into the network from 0.0002 (0.01/50) to 0.2 (10/50) seconds on the positive sequence, A-phase has maximum current of 3700 amps minimum of 1000 amps, G-phase has a maximum current of 3000 amps minimum of 800amps inter changing half-circle of each circles. On the negative sequence A-phase has maximum current of -2000amps minimum of -1200 amps, G-phase has maximum current -5300amps minimum of -800amps. B-phase and C-phase current were not affected, as the voltage on A-phase drop almost to Zero. At the end of 0.2 seconds 0.1second time lap was introduce as shown in Figure 8 and 9 respectively.

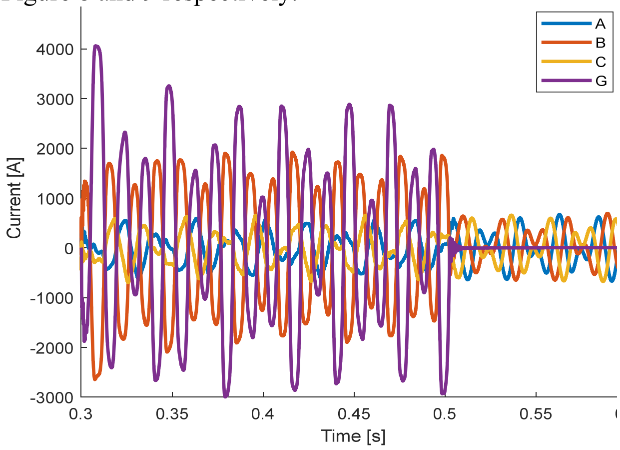

Figure 10: Current performance during BG fault. Source: MATLAB output result(2021).

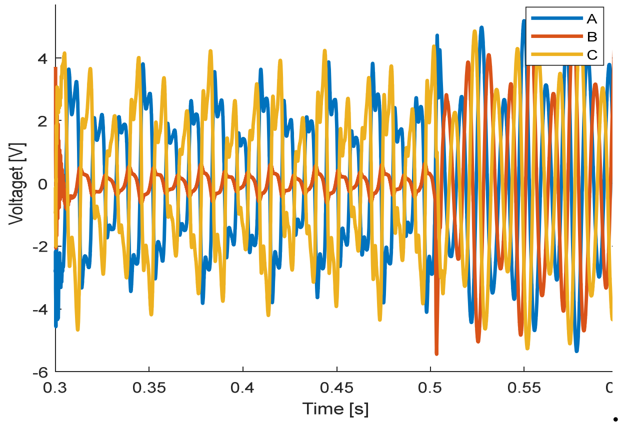

Figure 11: Voltage performance during BG fault . Sources: MATLAB output result(2021).

When BG fault is switch into the network from 0.3(15/30) to 0.5(25/50) seconds, on the positive sequence B-phase has maximum current of 2000 amps minimum 1000amps G-phase has maximum of 4100 amps minimum of 1900 amps . On the negative sequence B-phase has maximum current of -2700amps minimum -1200 amps, G-phase maximum of -3000amps and minimum of -900amps. A-phase and C-phase has normal current flow. Voltage on B-phase dropped .At end of 0.2seconds 0.1 time lap is introduce as shown in Figure 10 and 11 respectively.

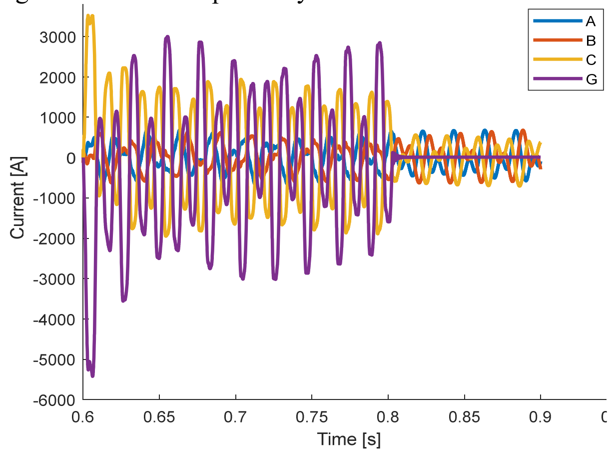

Figure 12: Current performance during CG fault.

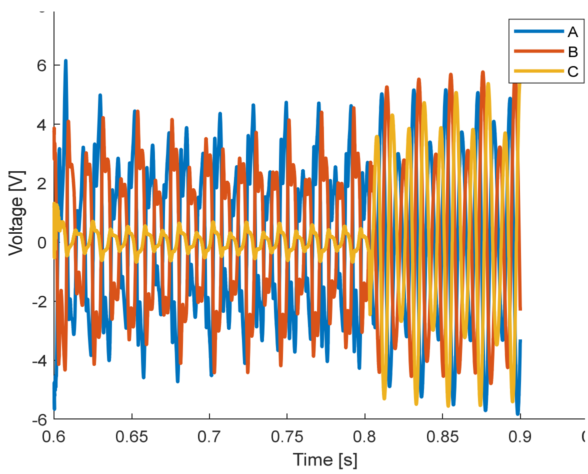

Figure 13: Voltage performance during CG fault

When CG fault is switch into the network from 0.6(30/50) to 0.8(40/50) seconds on the positive sequence C-phase has 3600 amp maximum current and 1200 amp minimum, G-

ISSN: 2632-1017
Vol. 6 Issue 10, October - 2022

phase has maximum current of 3000 amp and minimum of 900 amp. On the negative sequence C-phase has maximum current of -2000 amp, minimum of -1000 amps, G-phase has maximum of -5400 amp and minimum of 1000 amp. A-phase and B-phase has normal current flow while the opposite reaction applies on the voltage. At the end of running time 0.1 second time lap is introduce as shown in Figure 12 and 13.

Line-Line- Fault (L-L)

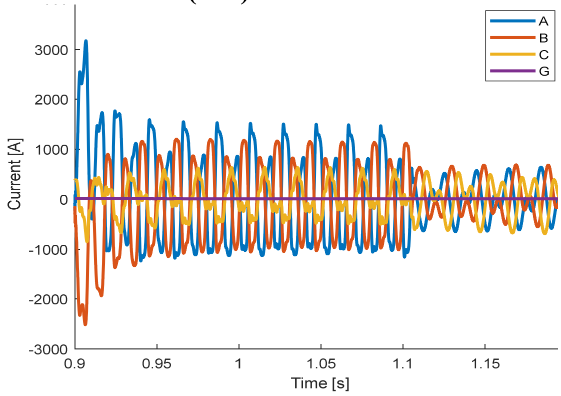

Figure 14: Current performance during AB fault.

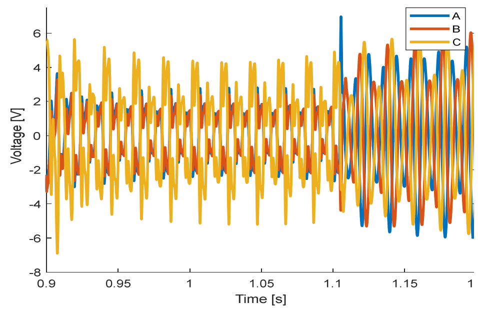

Figure 15: Voltage performance during AB fault.

When AB fault is introduce into the network from 0.9(45/50) to 1.1(55/50) seconds, current on A-phase positive sequence at first shoot has a maximum current of 3200amp and steady fluctuating minimum of 900amp, B-phase at first shoot has a maximum current of 1300 amp and 800 amp minimum. On the negative sequence, A-phase has a maximum current of -1200amp and -900 amp minimum, B-phase has a maximum of -2500 amps and -1100 amp minimum. C-phase has a normal current flow while G-phase at zero current. Opposite reaction applies on the voltage waveform and time lap of 0.1 second is introduce as shown in Figures 14 and 15.

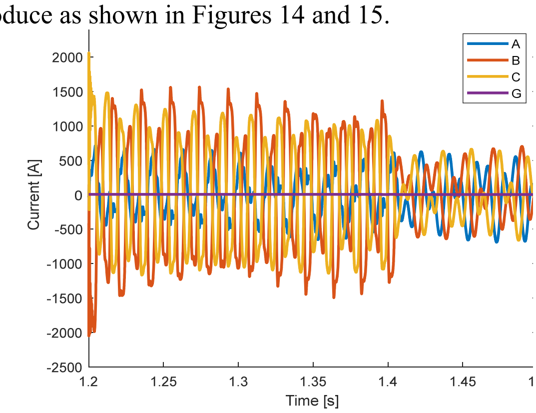

Figure 16: Current performance during BC fault.

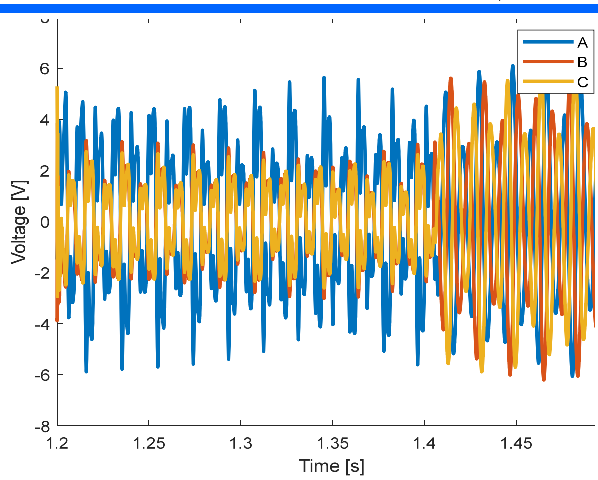

Figure 17: Voltage performance during BC fault

When BC fault is introduce into the network from 1.2 (60/50) to 1.4 (70/50) seconds on the positive sequence B-phase is 1600 amp maximum current 800 amp minimum and on negative sequence -2000 amp maximum current and -800 amp minimum while current on C-phase positive sequence is 2000 amp maximum, 800 amps minimum and on negative sequence -1200 amp maximum and 700 amp minimum. G-phase is zero current and A-phase at normal current flow. Opposite reaction on voltage waveform and time lap of 0.1second introduce as shown in Figures 16 and 17.

Line-Line-Ground Fault (L-L-G)

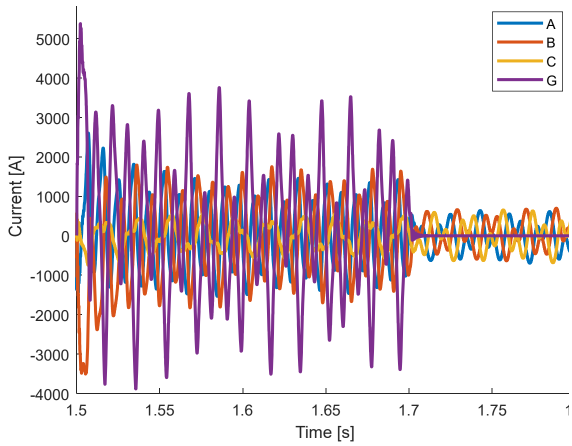

Figure 18: Current performance during ABG fault.

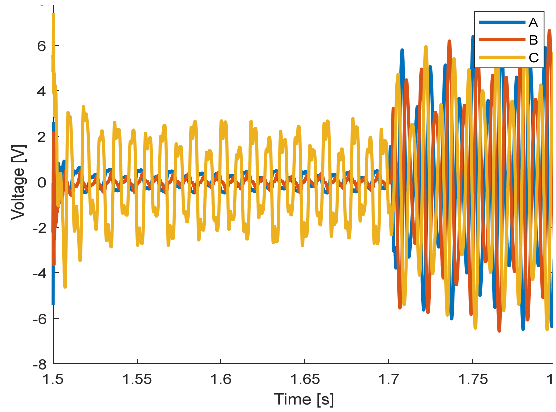

Figure 19: Voltage performance during ABG fault.

Science and Technology Publishing (SCI & TECH)
ISSN: 2632-1017
Vol. 6 Issue 10, October - 2022

When ABG Fault is switch into the network from 1.5(75/50) to 1.7(85/50) seconds , on the positive sequence G-phase has a maximum current of 5400 amp and 900 amps minimum A-phase has maximum of 2700 amp and minimum 900 amp and B- phase has a maximum current of 1800 amp minimum of 900 amp. On the negative sequence G-phase has a maximum of -3998 amps and minimum -700 amps, A-phase has maximum current of -1500 amps and minimum of -700 amps and B-phase has a maximum current of -3600 amps and minimum of -800 amps. C-phase is at normal current flow, opposite reactions seen on the voltage waveform. Time lap of 0.1 second introduce as shown in Figures 18 and 19.

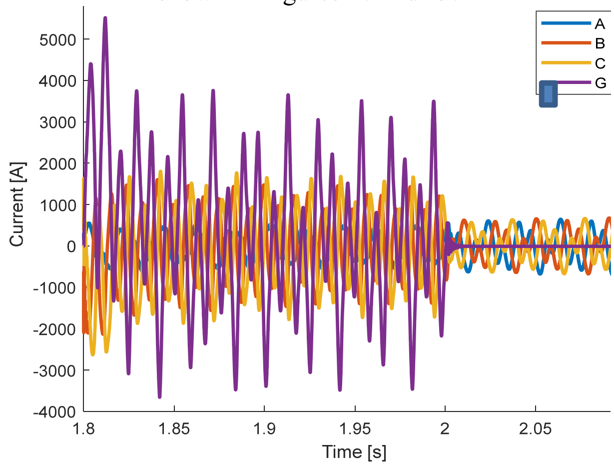

Figure 20: Current performance during BCG fault.

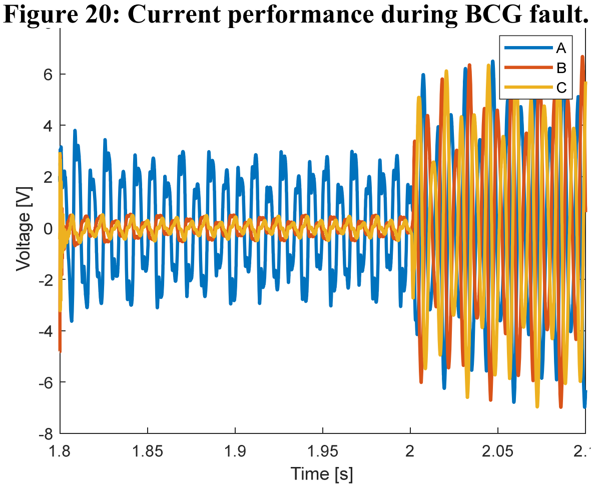

Figure 21: Voltage performance during BCG fault.

When BCG fault is switch into the network from 1.8(90/50) to 2.0(100/50) seconds, on the positive sequence G-phase has a maximum current of 5600 amp, minimum of 900 amps. C-phase has a maximum of 1800 amps and minimum of 900 amps, B-phase has a maximum current of 1600 amps and minimum of 800 amps, A-phase on a normal current flow. On negative sequence G-phase has a maximum current of -3700 amps, minimum of -800 amps, C-phase has a maximum current of -2700 amps minimum of -800 amps. B-phase has a maximum of -2000 amps and minimum of -1000 amps. A-phase has a normal flow, opposite reaction on voltage waveform. Time lap of 0.1 second introduce as shown in Figures 20 and 21.

Generator End

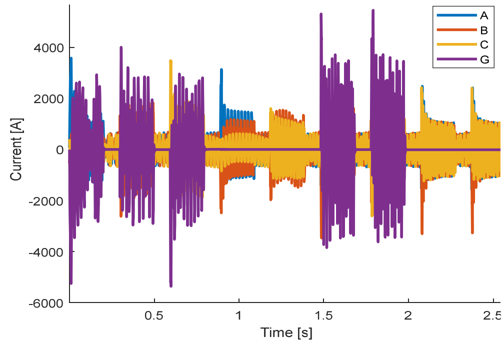

Figure 23: Line current at generator during fault

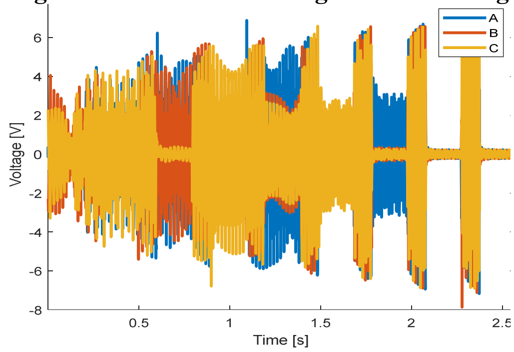

Figure 23: Line voltage at generator during fault.

The current and voltage waveform of all unsymmetrical faults at a glance are shown in Figure 22 and 23.

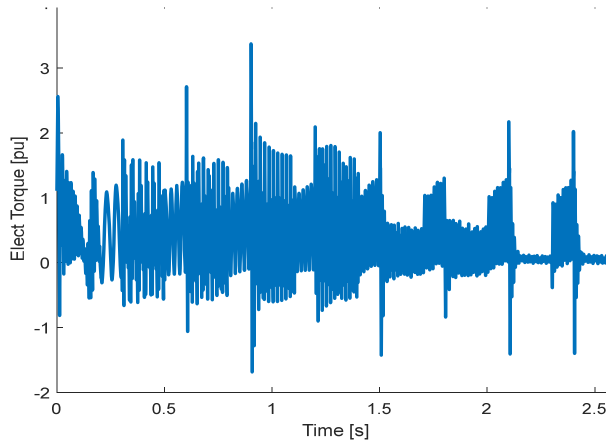

Figure 24: Electromagnetic torque generator during fault.

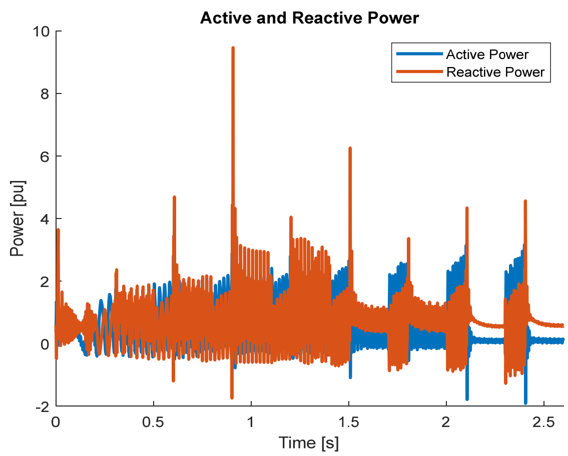

Figure 25: Active and reactive power at generator during fault.

Torque is the turning and twisting force acted over a shaft or rotor. When fault occur on transmission line, voltage and current variation occur on the electrical terminal of the generator, this variation introduces Electromagnetic torque reducing or increasing the frequency as shown in Figure 24. The variation increases the reactive power as shown in Figure 25, affecting the rotor causing non-harmonic oscillation as shown in Figure 26.

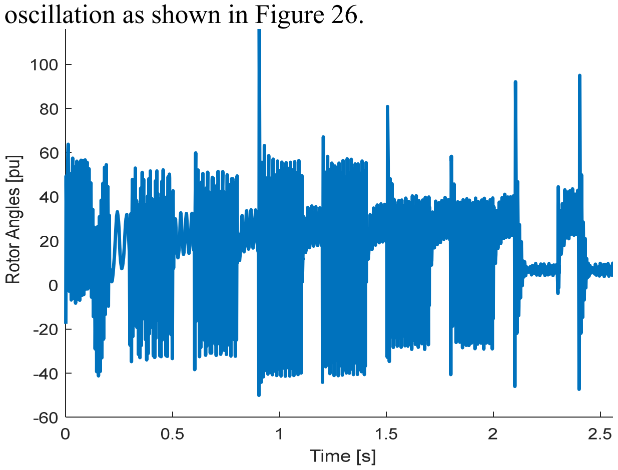

Figure 26: Rotor load angle on generator during fault

5. Conclusion

Fuzzy Logic technique for analyzing performance of unsymmetrical Fault conditions on transmission line is found to be very effective and efficient, since it requires behavioral rules. The research results, have shown that when unsymmetrical faults occur in a transmission line, current signal increases as voltage signal reduces to almost zero, using fuzzy logic technique in a real time performance analysis proved that line to ground (L-G) fault is the most serve kind of fault occurring close to the generator and having the highest reactive power and rotor angle during L-L (AB) fault on the generator. Results of different research have shown increase in current and decrease in voltage during unsymmetrical fault. In these research work, MATLAB results also show that every fault has effect on the generator as seen on the waveform in Figures 24, 25 and 26 respectively.

This technique can also determine real time automatic protection apart from detecting and classifying faults. The operation of this system is reliable and secure as shown by the proposed technique results.

REFERENCES

[1] Saravanan, N. and Rathinam, A. (2012). A Comparative Study on ANN Based Fault Location and Classification Technique for Double Circuit Transmission Line IEEE Conference Publication, pp. 824-830.

[2] Jain, A., Thoke, A. S. and Patel, R. N. (2008). Fault classification of double circuit transmission line using artificial neural network. *World Academia Science Engineering Technology*, 2: 750 – 755.

[3] Avagaddi, P., Edward, J. B., Roy, C. S., Divyansh, G. and Kumar, A. (2015). Classification of Faults in Power Transmission Lines using Fuzzy-logic Technique. *Indian Journal of Science and Technology*, 8 (30): 1 – 6.

[4] Das, B. and Vittal Reddy, J. (2005). Fuzzy logic based fault classification scheme for digital distance protection. *IEEE Transmission Power Delivery*, 20: 609–616.

[5] Ogbuefi, U. C., Ugwu, C. L. and Ogbogu, N. O. (2018). Analysis of Nigeria Power System Voltage Collapse Incidences from 2000 to 2017. *IOSR Journal of Electrical and Electronic Engineering*, 13(2): 28 – 34.

[6] Cecati C, Razi K. Fuzzy-logic-based high accurate fault classification of single and double- circuit power transmission lines. Sorrento: International Symposium on Power Electronics, Electrical Drives, Automation and Motion, IEEE Conference Publications. 2012 Jun 20-22. p. 883–889.

[7] Torres, V., Guardado, J. L., Ruiz, H. F., & Maximov, S. (2014). Modeling and detection of high impedance faults. *International Journal of Electrical Power & Energy Systems*, *61*, 163-172.

[8] Prasad, A., Edward, J. B., Roy, C. S., Divyansh, G. and Kumar, A. (2015). Classification of Fault in Power Transmission Lines using Fuzzy Logic Technique. *Indian Journal of Science and Technology*, 5: 185 – 192.

[9] Lee, C. (1990). Fuzzy Logic Systems: Fuzzy Logic Controller Part 1. IEE Transactions on Systems. *Man and Cybernetics*, 20(2): 9 – 10.

[10] Zadeh, L. A. (1973). Outline of a New Approach to the Analysis of Complex Systems and Decision Processes. *IEE Transaction on Systems, Man and Cybernetics*, 3(5): 28-44.

[11] Nagrath, I. J. and Gopal, M., (2007). *Control System Engineering* (5th Edition). New Delhi: New Age International Publishers, 799p.

[12] Burns, R. S. (2001). Advanced Control Engineering. Oxford: A Division of Reed Educational and Professional Publishing Limited, 300p.

[13]Gupta, M. M. and Tsukamato, Y. (1980). Fuzzy Logic Controllers: A perspective. A paper presented at the Proceedings of Joint Automatic Control Conference, FA10-C, held at the San Francisco, 3-4 August

[14]Bhupendra, K. and Anamika, Y. (2019). A fuzzy logic system to detect and classify faults for laboratory prototype model of TCSC compensated transmission line. *Journal of Power Technologies,* 99: 1 – 49.

[15] Tripathi, P., Sharma, A., Pillai, G. N. and Gupta, I. (2011). Accurate fault classification and Section Identification Scheme in (TCSC) Compensated Transmission Line using SVM. *International Science Index Journal,* 5(12): 1023–1029.

[16] Oputa, O. and Madueme, T. C. (2019) Fault Analysis on Nigeria 330kv Transmission System Using ETAP. *Nigerian Journal of Technology*, 5: 190 – 202.

[17] Izuegbunam, F. I., Ubah, C. B. and I. O. Akwukwaegbu (2012) "Dynamic security Assessment of 330kv Nigeria Power System" Academic Research international, Vol. 3, No. 1, pp 456 – 466

[18] Adebayo, I. Aborisade, D. and Akinola, I. (2020). Performance Evaluation of ANN Based Fault Classifier on Nigerian 330KV Transmission System. *International Journal of Scientific and Engineering Research,* 8(2): 67 – 90.