Open Circuit Fault Detection For 11kV Distribution Network using ANFIS

CHRYSOGONUS OGOMAKA[1], KINGSLEY UDOFIA[2], NSEOBONG OKPURA[3]
[1,2,3]Department of Electrical/Electronic and Computer Engineering,
University of Uyo, Nigeria
[1]chrysblaise1@gmail.com, [2]kingsleyudofia@uniuyo.edu.ng, [3]nseobongokpura@uniuyo.edu.ng

Abstract: - This research work made use of ANFIS to solve the problem of detecting open circuit fault in an 11kV distribution network. This work looked at improving the reliability and quality of power supply to by reducing the time it takes to detect, and clear open circuit fault in the network. The method adopted to solve the problem uses ANFIS to detect and determine the type of open circuit fault; to train the ANFIS system, Amaogugu 11kV distribution network is modelled on MATLAB/SIMULINK. Different types of open circuit fault conditions were initiated on the model network and simulate on MATLAB to generate fault condition data used to train ANFIS. ANFIS fault detector uses six inputs which are three phase voltages and their corresponding phase angles to detect and determine type of fault. Results show that when open circuit faults happens on one phase the voltage recorded at the primary terminals of substation transformers exhibit 50% voltage drop and 180˚ phase shift in phase angle for the affected phase; two phase open circuit fault caused the affected phases to bear the same voltage and phase angle as the healthy phase while during a three phase fault no voltage was read. The system accurately detected open circuit fault, determined the type of open circuit fault.

Key-Words:- open, circuit, Voltage, phase, MATLAB/SIMULINK, ANFIS, detect, fault, transformer.

1 Introduction

In an electrical power system made of generation, transmission and distribution, there is a greater probability that faults will occur on power lines. This high probability of fault occurrence on power lines is true because power lines are widely spread, have great lengths and are not housed in secured locations; the pass through many types of terrains and environment with different characteristics and challenges. Their exposure to conditions like high wind, rainfall, landslides, erosion, crossing vehicles and animals, vegetation falling trees and most times vandalism by humans lead to greater occurrence of fault on power lines. Faults that occur on power line ranges from short circuit faults (when two or more current carrying conductor come in contact with each other) and open circuit fault or loss of phase fault. Open circuit fault occur when a power line is ruptured and it can no longer deliver power to a load. Apart from ruptured lines, open circuit faults can still occur due to loose connections on terminals and contacts of circuit breakers or isolator that fail to close or make proper connection [1].

When an open circuit fault happens in one phase of a three phase distribution network power supply will not be interrupted, but there will be an unbalanced flow of current in the network which will lead to transformer losses that will cause loss in revenue for the distribution company [2; 3]. When the cable of an 11kV distribution network cuts and drops to surfaces having a very high resistances thereby triggering no ground fault over-current protective device; when left undetected and attended to it can cause fire outbreak and also has a high risk of causing electric shock to any person that comes in contact with it [1].

The detection of a short circuit fault can be done by over current relays and circuit breakers due to very large abnormal current that will flow during short circuit fault whereas an open circuit fault is most times very hard to detect especially in a distribution network. Open circuit faults do not cause high abnormal amount of current to flow through the power system, thereby making most current based protective schemes to be ineffective in detecting open circuit faults. Due to the nature and characteristics of open circuit fault, it is most times overlooked because of how hard it is to be detected. This act of not paying much attention to open circuit faults in a distribution network has made final users of electricity to be serviced with power that is below regulated specifications over a long period of time. This prolonged neglect or slow identification of open circuit fault in distribution network most time causes hidden damage to power equipment [4] and lead to loss of revenue [5].

There have been different methods tried previously to detect open circuit fault in an electrical power network. According to [1], open circuit fault was detected by using measuring the voltage at the substation terminals; an alarm was set to sound when the voltage drops below 80% of the initial voltage. Also under voltage sensing devices were implemented at the low voltage side of the transformers to detect open circuit fault [1]. According to [6], when an open circuit fault occurs the current flowing in that phase drops to zero.

Artificial intelligence will be employed to make the detection of the fault and determination of fault type possible and easier with improved accuracy. The Artificial intelligence tool to be used in this work is Adaptive network based fuzzy inference system (ANFIS). Adaptive network based fuzzy inference system (ANFIS) is a neuro-fuzzy technique where the fusion is made between the neural network and the fuzzy inference system.

2 Open Circuit Fault

Open circuit fault or series fault is experienced in a distribution network when the series impedance in a distribution lines conductor is unbalanced [7]. An open circuit fault according to [8] is usually caused by a broken distribution line or change in impedance of the lines or equipment, open circuit fault is associated with an increase in frequency and voltage in the affected phase and consequently a decrease in the current flowing through the affected phase [8].

The occurrence of open circuit or open phase fault in a power system network is frequent in a medium voltage distribution network of 33kV and below voltage value [2]. Breakage of distribution lines, blown fuses and loose connections in remote or rural areas lead to open circuit fault, in some situation defective contacts of circuit breakers or isolators an also lead to open phase faults [1;2].

The occurrence of an open phase or circuit fault on a distribution line before a power transformer is very difficult to detect on the secondary side of the transformer [2]. Detection of this fault on the low side of the transformer in a distribution network can be made very difficult to detect depending on the configuration of the winding, transformer core and the level of loading on the transformer [2]. In lower loading of distribution power transformers in a medium voltage distribution system, there are cases where the three phase voltages and currents on the secondary side of the transformer will be fairly balanced that it will be hard for over current protection devices or negative sequence current elements to detect any fault [2]. During low loading even up to 50% loading of power transformers, the transformer may continue giving an output of normal operation for a very long period with an open phase fault on the primary side of the transformer [2].

2.1 Effects of Open Circuit Fault

Open circuit fault does not cause very large abnormal current like that of short circuit to flow in a distribution network causing over current protective devices used in the protection of distribution network to fail to detect this form of fault making it very difficult to detect when it occurs in a distribution network [6]. Combined with how difficult it is to detect this type of fault and the ability of power transformers to tend to operate for a long time normally under low load conditions [2], this will lead to negative effects of an open circuit faults to last for long unless it is quickly detected.

Once an open circuit fault occurs on an 11kV distribution network because of a downed conductor, blown fuse or loose contacts of a circuit breaker have the following effect on the distribution network;

According to [1], consumers on the low voltage section of the distribution network experience abnormal voltages on two or three phases due to an open circuit fault on the 11kV line [1]. There is a drop in the voltage across the coils that are connected to the phase that is open [2]. This is shown in figure 2.1. Where; A is the phase with an open circuit, B and C are the phases that do not have an open circuit.

The coils that have a link to the open circuit will have half of their initial voltage seen across them before the open circuit occurred, while the coil that is not directly connected to the faulted phase will not experience change in voltage [2].

3 Detection Method

Artificial intelligence (AI) when employed to help solve a problem in a system requires the use of data of different conditions in the system. The system conditions ranges from normal operation, fault condition on some parts of the system and full system fault condition.

During open circuit fault condition in a distribution network different network quantities change values different from that of normal network operation. In order to detect the occurrence of this fault these quantities are taken note of and recorded. The quantities that are measured are the line voltages with their phase angles and the current flowing into the primary terminals of the transformer. In order to get the required data for fault conditions on the network, a model of Amaogugu 11kV distribution network was simulated on MATLAB/SIMULINK to generate the data needed. The MATLAB/SIMULINK model of the network was created considering overhead distribution line parameters same as that of Amaogugu distribution network. Amaogugu 11kV feeder is one out of two feeders on the 7.5MVA 33/11 kV injection substation at Nkwoegwu under Umuahia District 11 kV network shown in appendix I. This 11 kV distribution network is managed by Enugu Electricity Distribution Company.

The network like most 11 kV in the district is a radial network making use of overhead distribution lines which runs into few kilometres when the length of the different branches are put together. The network makes use of Delta-Star transformers to step down voltages of 11 kV to 415V to consumers. The MATLAB model comprise of all the equipment found in the network and similar ratings.

During the simulation of fault conditions in the network model, different open circuit faults were initiated on different sections of the network. The types of open circuit faults initiated include;

a) one phase open circuit fault,
b) two phase open circuit fault and,
c) Three phase open circuit fault.

At the end of each simulation, the values of the voltage on the primary section of the transformer were recorded. The results taken are; peak phase to ground voltages and the phase angles of the different primary terminal voltages.

The ANFIS model was trained to detect and determine the type of fault using the data generated during fault simulation on MATLAB/Simulink. The data used to train ANFIS for fault detection were taken at:

(a) No fault condition.
(b) Different fault conditions (i.e. single phase open, two phase open and three phase open).

The ANFIS model has six input, these inputs are the voltage readings on the primary terminal of the transformer. The voltage readings comprise of three-phase maximum voltage and their three phase angles, which are inputs to the fault detector that gives out a single fault condition output shown in Figure 1.

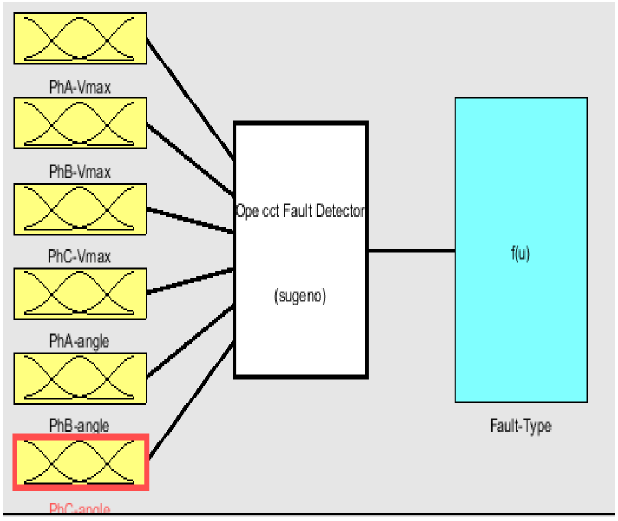

Fig.1: Fuzzy inference system for fault detector and type classifier.
Source: Researcher (2019).

The operation of the ANFIS fault detector is shown by the flowchart in Figure 2. The detector functions as follows:

a) It receives a normalized voltage data from the substations. The voltage data consists of the phase to ground voltage and the phase angle of the three phases
b) ANFIS detects the maximum voltage and phase angle for each phase.
c) ANFIS detector makes use of the data received to determine the type of fault.
d) Lastly, the type of fault detected is sent out in form of bar chart showing the substations and the type of faults that occurred in them.

The output of the model shows that there is a fault and the type of open circuit fault in the substation. The different types of open circuit fault results are represented with the following numbers;

(a) Phase A open circuit fault =1.
(b) Phase B open circuit fault =2.
(c) Phase C open circuit fault =3.
(d) Phase A and B open circuit fault =4.
(e) Phase A and C open circuit fault =5.
(f) Phase B and C open circuit fault =6.
(g) Phase A, B and C open circuit fault =7.

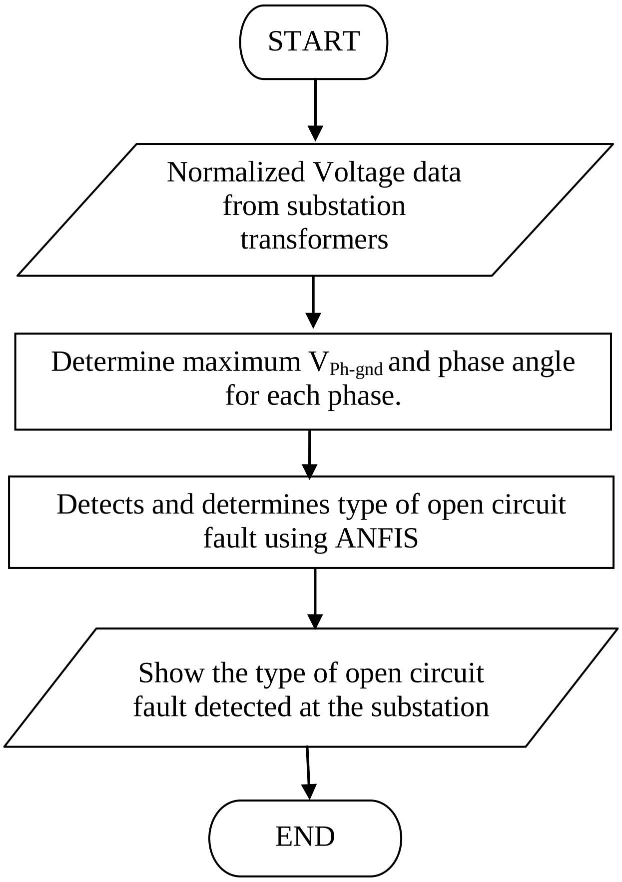

Fig.2: The ANFIS fault detectors flowchart.

4 Results and Discussion

4.1 Results

The open circuit fault waveform of voltages and currents on the primary side of the distribution network transformer was obtained by running a simulation of the MATHLAB/Simulink model of the network at different open circuit fault conditions including a no fault condition. The waveform of the parameters was taken when a no fault condition was initiated and the simulation was also carried out when various types of open circuit faults were initiated in the network. All voltage readings at the substation primary terminals are normalised and sent to the ANFIS model for fault detection and determination of type of open circuit fault. The waveforms during no fault condition are shown in Figures 3 and 4.

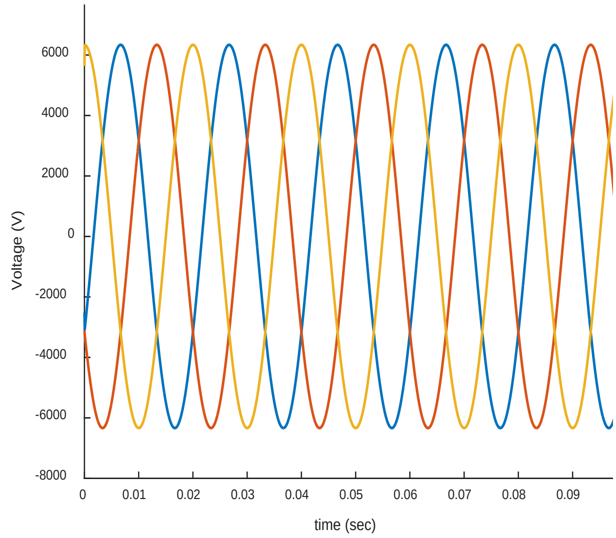

Fig.3: Voltage waveform during no fault condition.

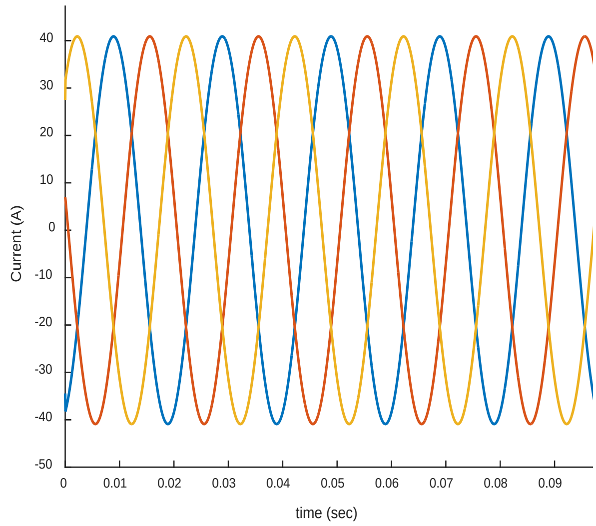

Fig.4: Current waveform during no fault condition.

Single phase open circuit fault

The voltage and current waveforms when an open circuit condition is initiated on only one phase before the primary terminals of the transformer are shown in figure 5 and 6.

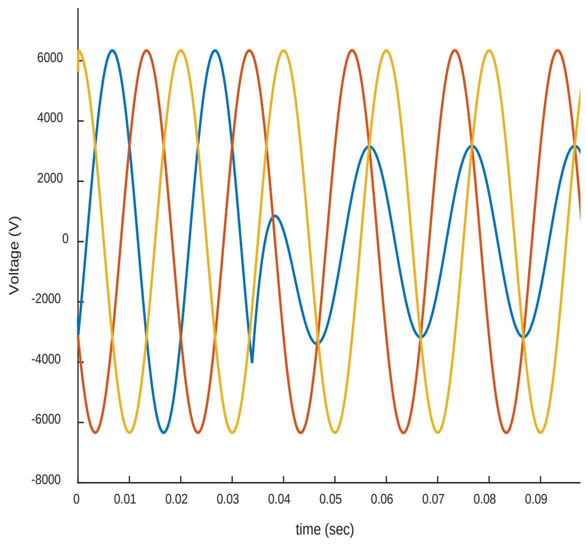

Fig.5: Voltage waveform during one phase open circuit fault.

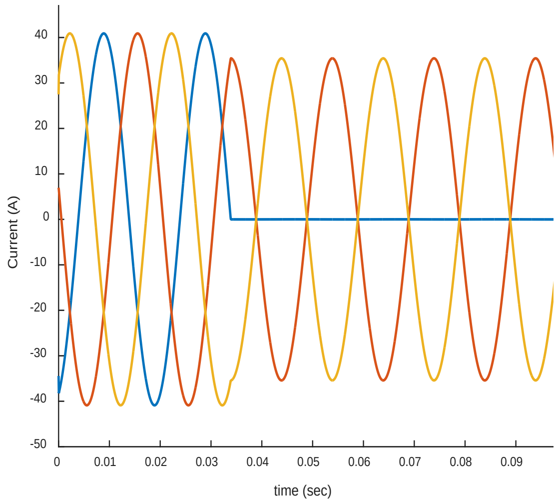

Fig.6: Current waveform during one phase open circuit fault.

Double phase open circuit fault

The waveforms showing phase to ground voltage and current of the three phases in the primary side of the distribution substation when two phase open circuit fault were initiated while running the network simulation are shown in Figures 7 and 8.

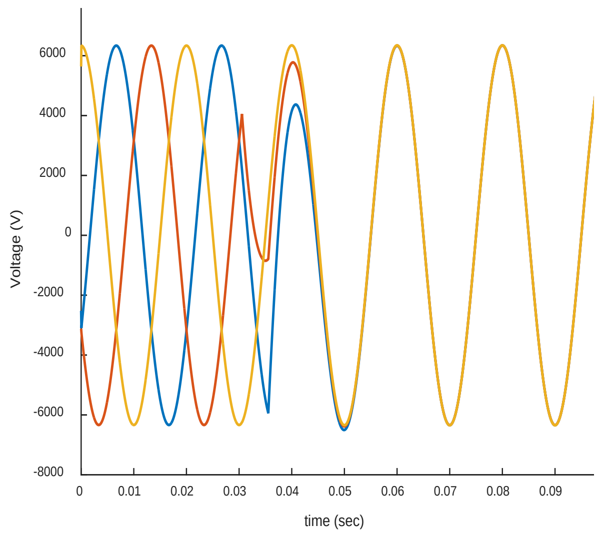

Fig.7: Voltage waveform during two phase open circuit fault.

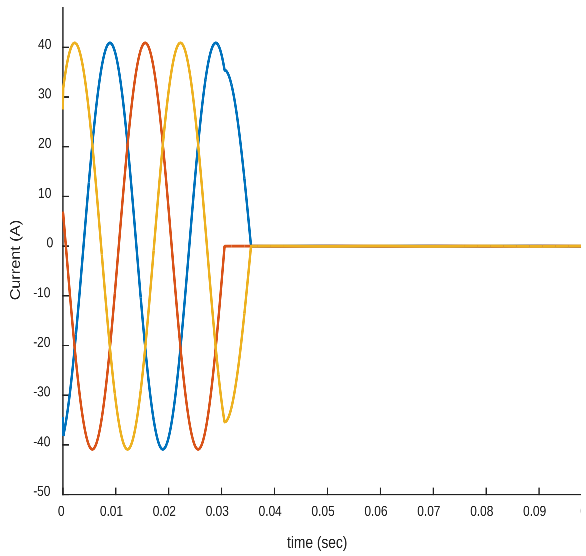

Fig.8: Current waveform during two phase open circuit fault.

Three phase open circuit fault

The waveforms showing phase to ground voltages and current of the three phases in the primary side of the distribution substation when three-phase open circuit fault condition is initiated while running the network simulation is shown in Figure 9 and Figure 10.

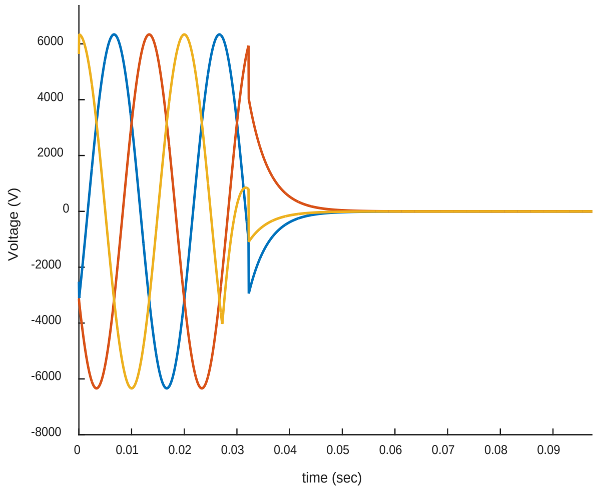

Fig.9: Voltage waveform during three phase open circuit fault.

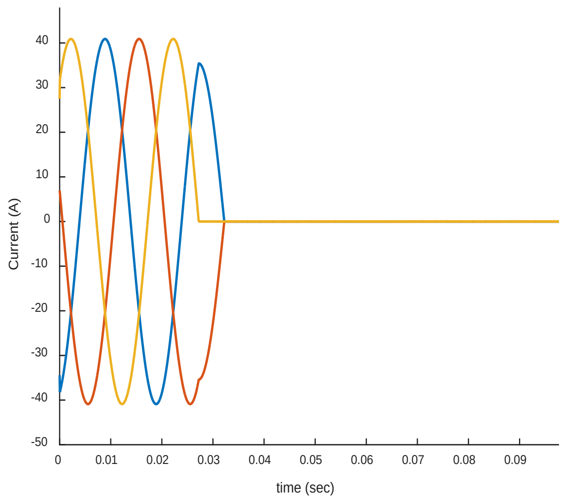

Fig.10: Voltage waveform during three phase open circuit fault.

Fault detection and fault type result.
The output result by ANFIS showing the type of open circuit fault that occurred in the network when different types of open circuit fault are initiated in the network are shown in Figures 11, 12 and 13.

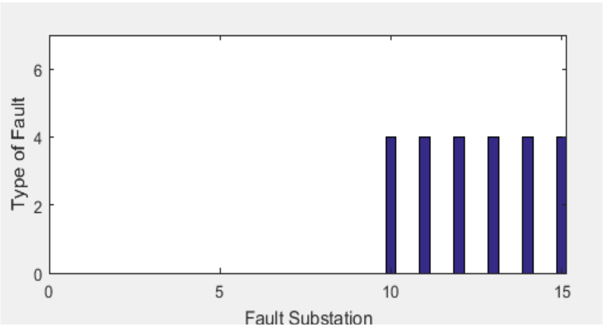

Fig.11: ANFIS output when there is an open circuit fault on phase AB on substations 10 to 15.

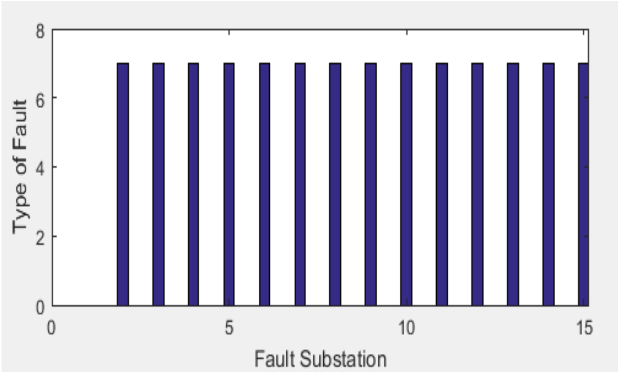

Fig.12: ANFIS output when there is an open circuit fault on phase A, B and C on substations 2 to 15

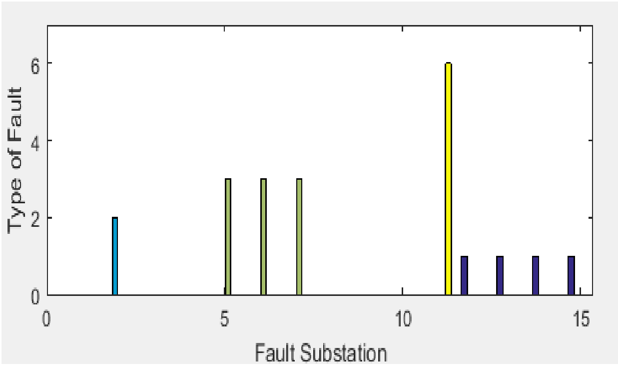

Fig.13: ANFIS output when multiple types of open circuit fault in different substations.

4.2 Discussion

Figure 3 shows the voltage waveform of the substation primary terminals during no fault condition. The figure shows the three phase's maximum voltage and their phase angles. The maximum voltage is 6337V phase to ground voltage for the three phases and the phase angles are <0˚, <120˚ and <240˚ for Phase A, B and C respectively. The maximum voltage is 99.78% of the network voltage. The voltage drop can be attributed to voltage drop on the lines, which is within the allowable range. Figure 4 shows the current waveform on the primary terminal of the substation transformer. The current waveform during no fault condition was normal with current in all phases having 120˚ phase sequence between phase A, B and C.

The waveforms for a single-phase open circuit fault as shown in Figure 5 show the change of the phase to ground voltage and phase angle at 0.032 seconds. Open circuit fault on one of the phases was initiated to occur at 0.032 seconds during simulation. In Figure 5 when fault occurred on phase A; it can be noticed that after 0.032 second the maximum voltage of the phase fell to 3.308V which is 50% of the initial voltage. In addition, the waveform for phase A had 180˚ phase angle phase shift to <180˚ from the initial <0˚. Figure 6, shows that the current flowing in the faulted phase dropped to 0. The result shown in Figure 6 supports the work done by [6] which says that the current flowing on an open phase is zero.

This voltage drop of up to 50% from the initial value and the phase angle shifting by 180˚ is used in detecting a single-phase open circuit fault. Using 50% voltage fall and 180˚ as criteria for open circuit fault gives a more accurate result than the 80% voltage drop used by [1] in their work. Adopting only the 80% voltage drop as a means of detecting open circuit fault as used by [1], cannot differentiate voltage drops caused open circuit fault and other conditions in the network like; poor joints, hot spots, undersize conductors and non-uniform conductor.

The waveform shown in Figure 7 show that when a two phase open circuit fault occurs the voltages on the affected phases will be equal to the voltage on the third phase but their phase angles will shift and assume that of the healthy phase. This goes a step further to make the detection of open circuit fault possible on double phases by making use of the phase to ground voltage value on the primary winding of the transformer as against using current readings used by [6]. Figure 8 shows that current reading on the three phases during double phase open circuit fault is zero; this makes it impossible to know the phases that are open.

The waveform shown in Figure 9 shows that when a three phase open circuit fault occurs the voltage recorded on the three phases at the primary side of the distribution transformer is 0V.While from Figure 10, when there is a three-phase open circuit fault on three phases the current flowing into the transform is 0A. The similarity of the current waveform during double phase as shown in Figure 8 and three-phase open circuit fault make it impossible to differentiate between the two types of open circuit fault. Therefore, to detect open circuit fault the values of the phase to ground voltage and the phase angles of the phases is used instead of the current values.

The result in Figure 11 shows the ANFIS output when open circuit fault is detected on Phases A and B in substations 10, 11, 12, 13, 14 and 15. The result shown in Figure is the ANFIS output when there is a total outage seen on substations 2 to 15 as a result of a three phase open circuit fault affecting them.

The result in Figure 12 shows the ANFIS output when different types of open circuit fault occur at different substations in the network. From figure 12 it can be started that the following faults occurred in the network and was detected by ANFIS;

- Single phase (phase B) open circuit fault on substation 1.
- Single phase (phase C) open circuit fault on substations 5, 6 and 7.
- Double phase (phase B and C) open circuit fault on substation 11.
- Single phase (phase A) open circuit fault on substations 12, 13, 14 and 15.

These results from ANFIS eliminate the need for the operator to manually interpret the voltage waveforms of different substations before an open circuit fault is detected and the type determined.

5 Conclusion

The detection of open circuit fault in a distribution network was successfully carried out in this study. The results gotten at the study showed that when an open circuit fault occurs on only one phase, the peak voltage of the affected phase drops by about 50% and the phase angle voltage will experience a nearly 180˚ shift, a two phase open circuit fault causes the affected phases to take the peak voltage and phase angle of the healthy phase, while during a three phase fault no voltage was seen on any of the phases. While current values for double and three phase open circuit fault is the same making it impossible to utilize the current as a parameter to detect or determine type of open circuit fault. The value of the peak voltage and phase angle shift is used to detect and determine the type of open circuit fault that occurred in the network by ANFIS.

The results from ANFIS eliminate the need for an operator to manually interpret voltage waveforms of different substations before an open circuit fault is detected and the type determined. This will greatly reduce time it takes to detect open circuit fault and increase the networks reliability.

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