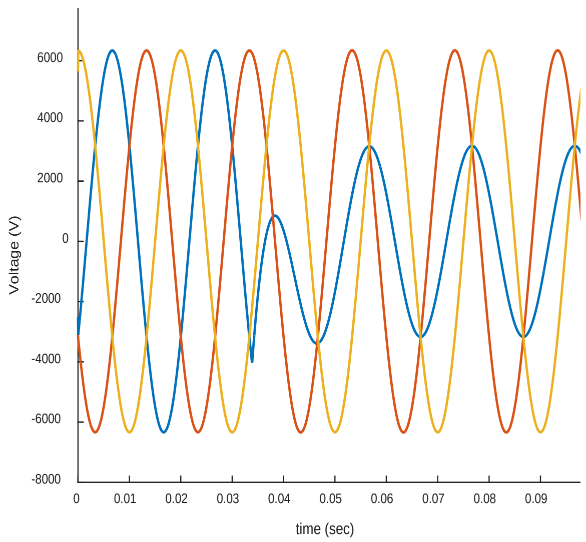

Fig.5: Voltage waveform during one phase open circuit fault.

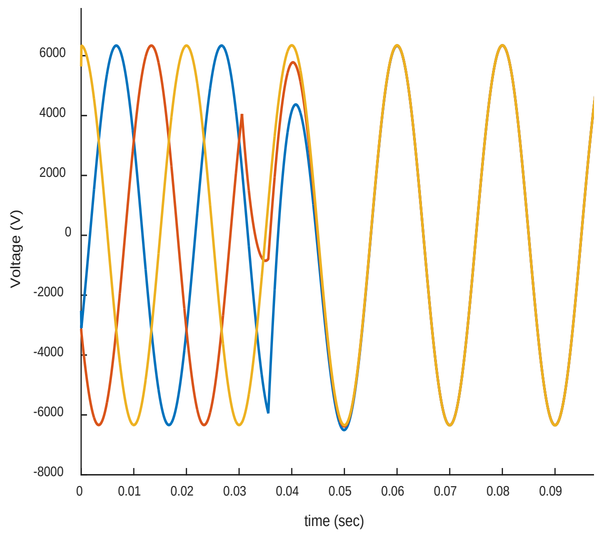

Fig.7: Voltage waveform during two phase open circuit fault.

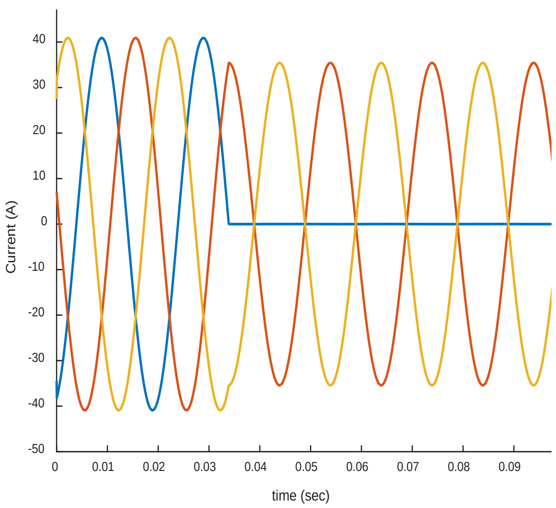

Fig.6: Current waveform during one phase open circuit fault.

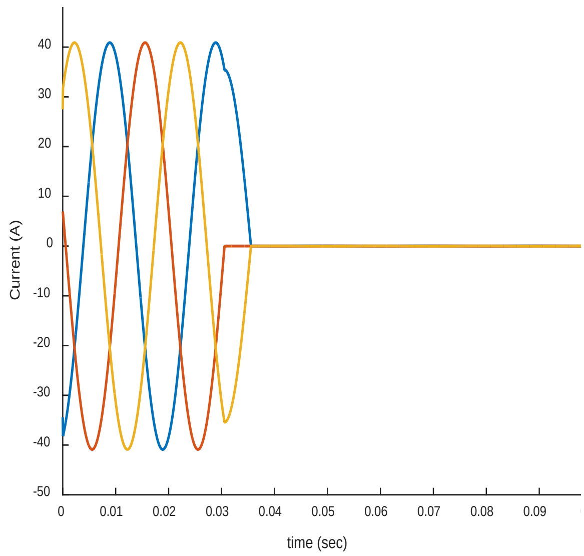

Fig.8: Current waveform during two phase open circuit fault.

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.

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.

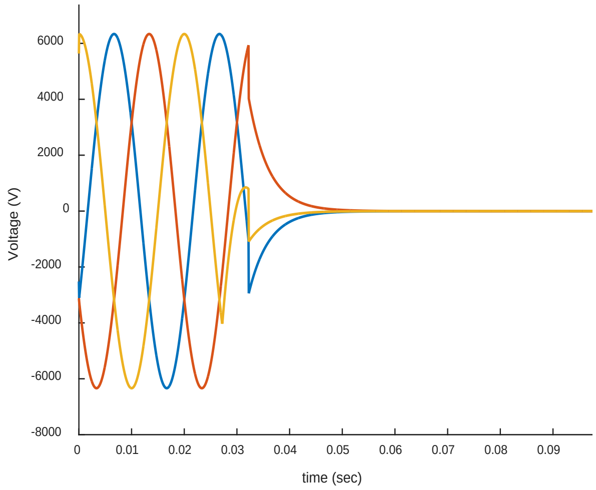

Fig.9: Voltage waveform during three phase open circuit fault.

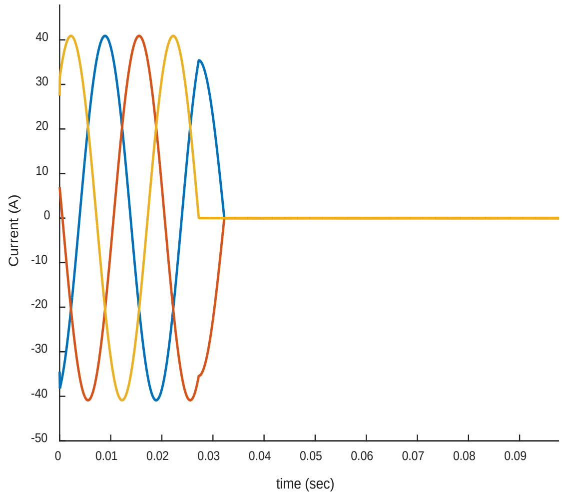

Fig.10: Voltage waveform during three phase open circuit fault.

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.

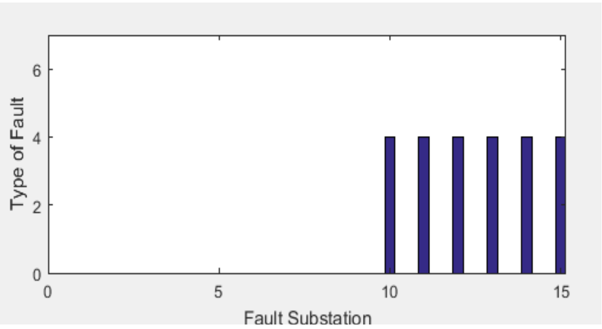

Fig.11: ANFIS output when there is an open circuit fault on phase AB on substations 10 to 15.

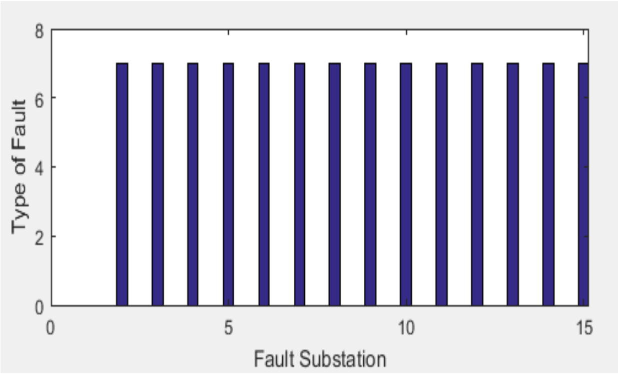

Fig.12: ANFIS output when there is an open circuit fault on phase A, B and C on substations 2 to 15

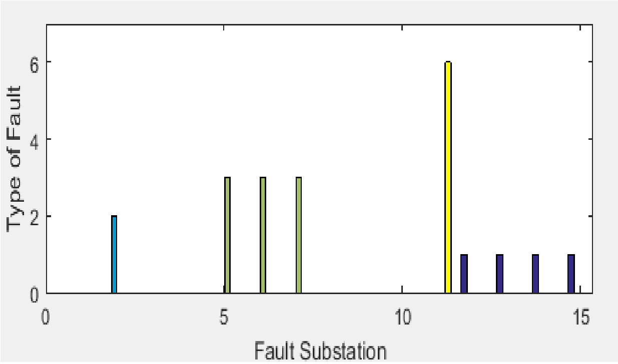

Fig.13: ANFIS output when multiple types of open circuit fault in different substations.

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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