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FAULT LOCATION ON TRANSMISSION LINE USING TWO ENDED IMPEDANCE BASED ALGORITHM (A CASE STUDY OF OTUKPO 132KV TRANSMISSION LINES)

By

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Abstract

The rapid growth of the electric power system has in recent time resulted in an increase in the number of transmission lines and outages in Otukpo area. These lines experience various faults that lead to major disruptions and high operating costs of the transmission system. Fault location is an important task for power utility engineers as knowledge of accurate distance to fault assists in restoration of the power supply in the shortest possible time so as to avoid possible damages to consumers, property and environment. This paper proposed double-ended impedance-based algorithm for fault location using Otukpo 132kV transmission lines as a case study. The proposed algorithm measured fault current and voltage signals captured by digital fault record from both terminals of the line for estimation of the location of the fault, the lines was modeled in Matlab Simulink environment using distributed parameters of transmission lines data obtained for system operator in New Haven Substation. Five different faults namely; Single Line to Ground Fault (A-G), Double Line Fault (AB), Double Line to Ground Faults (AB-G), Three Phase Fault (ABC) and Three Phase Faults (ABC-G) were also modeled and applied one after the other on the transmission lines. The system was simulated for each faults cases at various distances namely; 50km to 120km .The simulated results system was able to detect A-G fault at 0.0219s, A-B faults at 0.024s, AB-G faults at 0.023s, ABC faults at 0.02s and ABC-G faults at 0.024s respectively, also clear the faults for A-G fault at 0.1057s, AB faults at 0.1065s, AB-G faults at 0.0125s, ABC faults at 0.185s and ABC-G faults at 0.1043s respectively. The simulation results proved the proposed algorithm to be fast, reliable, robust and accurate. The *result of this work will be of huge relevance to power utility operators and other industry practitioners especially those managing transmission lines in Nigeria particularly, the Transmission Company of Nigeria (TCN).*

Keywords: Fault location, transmission lines, impedance-based algorithm, single-ended algorithm, two-ended algorithm

I. INTRODUCTION

An overhead transmission line is one of the main components in every electric power system. Transmission lines connect the generating stations and load centers. As the generating stations are far away from the load centers, these power transmission lines run over hundreds of kilometers. Fault has higher possibility to occur at power transmission line because transmission line is exposed to harsh climate conditions and external contacts such as (lightning strikes during stormy weather conditions,, animal or tree contact with a transmission line, vehicles or aircraft colliding with the transmission towers or poles or insulation failure in power system equipment.), these faults result mostly from mechanical failures and have to be isolated immediately before the line can be manually re-energized. (Dine et.al, 2012). Therefore these faults can be classified into four main categories namely single line to ground faults, line to line faults, double line to ground faults and three phase faults. In the past fault location approach is conventional, thus, the locating process is time consuming and might expose additional stress to the equipment during the switching on/off of a section. Due to these problems, many automated fault location methods have been introduced by researches to expedite the process of locating faults (Mattias H., 2014). An important objective of all the power systems is to maintain a very high level of continuity of service, and when abnormal conditions occur, to minimize the outage times. It is practically impossible to avoid consequences of natural events, physical accidents, equipment failure or miss-operation which results in the loss of power, voltage dips on the power system (IEEE guide, 2014). Accurate fault location in transmission lines is highly required by operators and power utility engineers to know the exact fault location, to accelerate service restoration this way reducing outage time, operating cost, customer complaints and improving system reliability (Catarina, 2005).

II. MATERIALS AND METHOD

A. One-end Impedance-Based algorithms
B. Two-end Impedance Based algorithms
C. Transmission Line Model

One-end Impedance-Based Fault Location algorithms

One-ended impedance methods of fault location are a standard feature in most numerical relays. This algorithm is simple and straight forward to implement such that Communication channels and remote data are not required. One-ended impedance-based fault locators calculate the fault location from the apparent impedance seen by looking into the line from one end. To locate all fault types, the phase-to-ground voltages and currents in each phase must be measured. (Karl and David, 2010)

Two-end Impedance Based Fault Location algorithms

Two-ended methods can be more accurate but require data from both terminals. Data must be captured from both ends before an algorithm can be applied (Yelsin, 2013). Also, this data is collected and analyzed at a central location.

III. Transmission Line Model

The Enugu region substation is connected to the national grid via Onitsha TCN at a voltage of 330kv. This voltage is stepped down by T1-1x150MVA and T2-1x150MVA power transformers connected in parallel to a Bus Bar to a voltage level of 132kV and fed into the 132kv main bus bar, the voltage level is fed to the Otukpo Line, as shown in figure1below.

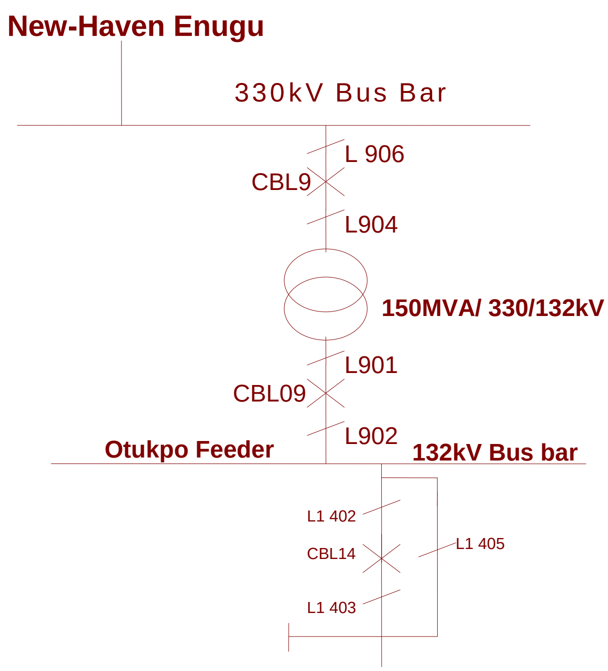

Figure 1: Single Line diagram of New Haven to Otukpo 330/132/33kV Network

Table.1 Line Parameters used for analysis

Parameters of Lines	**Value**
Total Length	160Km
Normal frequency	50 Hz
Voltage phase to phase	132 KV
Zero Sequence Resistance	0.210 Ω/Km
Positive Sequence Resistance	0.075 Ω/Km
Zero Sequence Inductance	0.001267 H/Km
Positive Sequence Inductance	0.003819 H/Km
Positive Sequence Capacitance	12.74e-0.0009 F/Km

A transmission line was modeled using MATLAB Simulink. The analysis of single line to ground fault location was performed, the SimPower System toolbox is used to perform the simulation. The study is tested with transmission line parameters as show in table 1, varying fault location and fault types.

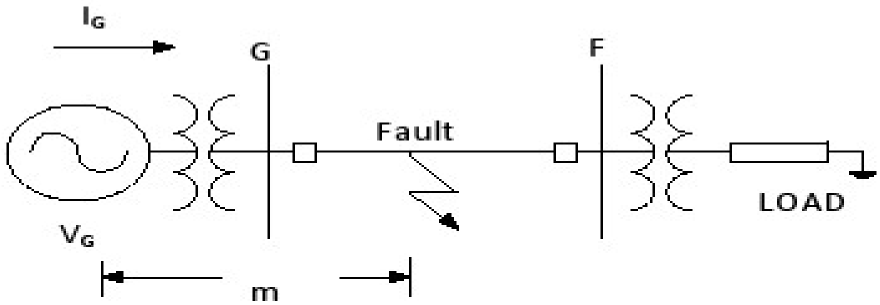

Figure 2: Single Line Diagram for Transmission Line Model with fault.

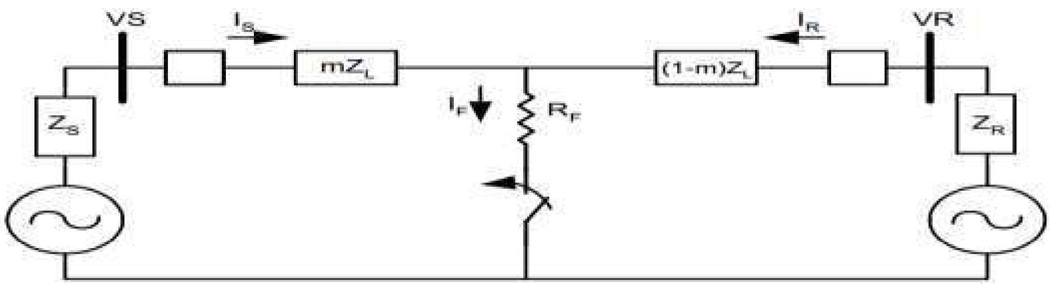

Figure 3: The equivalent circuit positive sequence of the symmetrical circuit

The current flowing through (R_F) is the sum of the local source (Is) and the remote source (I_R).

Where: V_S = voltage at terminal S, M = distance to the fault in per unit, I_S = line current from terminal S, I_F = the total fault current, Z_L = line impedance between terminals S and R

R_F = the fault resistance

Using the Kirchhoff voltage law along the transmission line with positive sequence whether the fault is symmetrical or unsymmetrical. Then at point of fault along phase 'a'

$$V_{a1S} - I_{a1S} m Z_L = V_{a1R} - I_R (1-m) Z_L \tag{1}$$

$$V_S - I_S m Z_L = V_R - I_R Z_L + I_R m Z_L \tag{2}$$

$$(I_S + I_R) m Z_L = V_S - V_R - I_R Z_L \tag{3}$$

$$\boldsymbol{m} = \frac{\boldsymbol{V_S - V_R - I_R Z_L}}{\boldsymbol{(I_S - I_R) Z_L}} \tag{4}$$

$\boldsymbol{m}\rightarrow$ is the fault distance.

$$\text{Error}(\%) = \frac{\text{calculated distance} - \text{actual distance}}{\text{total length of the line}} \text{ x } 100$$

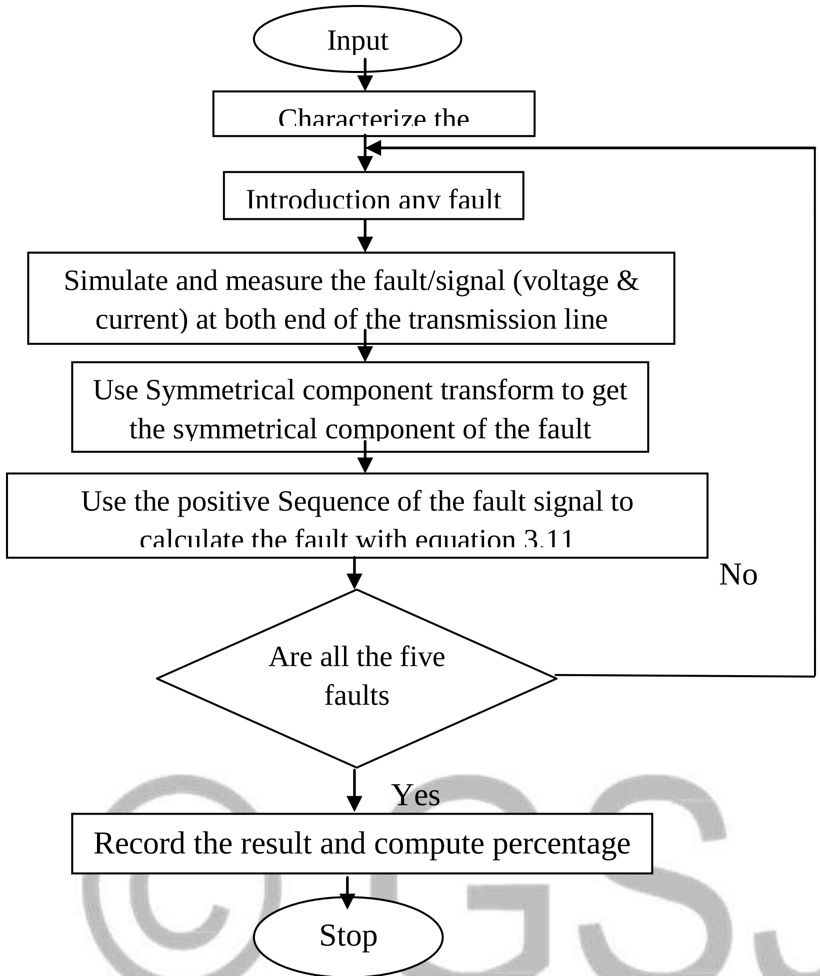

Figure 4: The Flowchart of Impedance based Algorithm

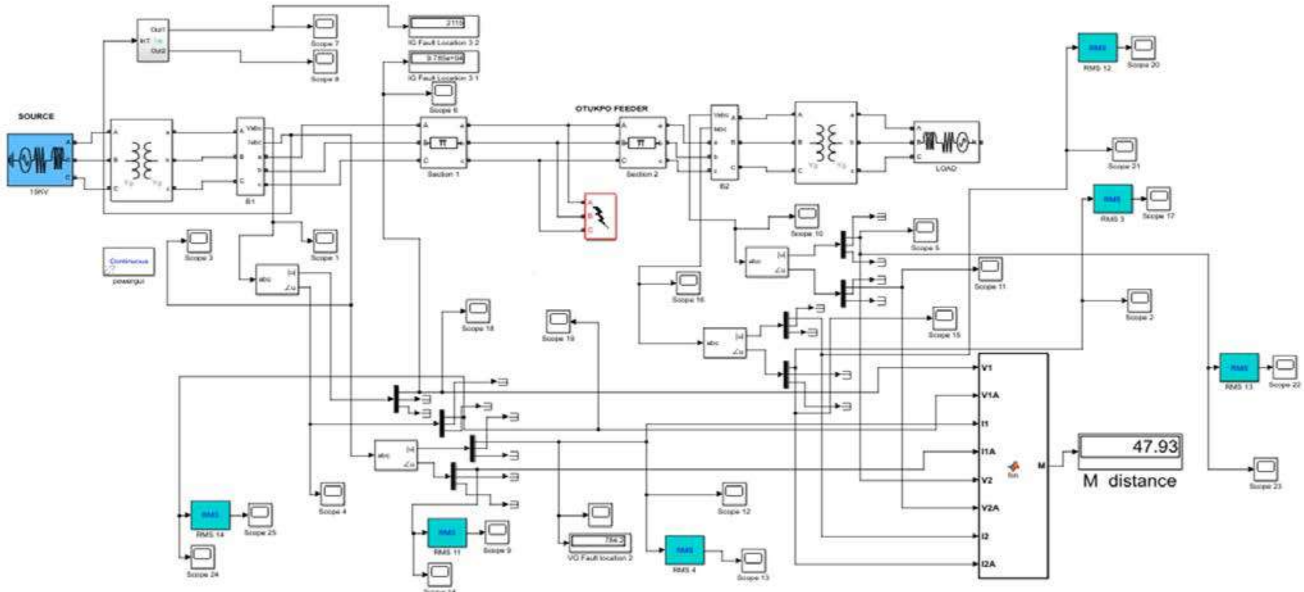

Figure 5 Simulation model for Otukpo 132kV Transmission line using two-ended algorithms

Figure 6: (Relay 1) measured quantity at the remote side (Enugu) of the transmission line for fault current on single phase to ground (A-G) @ 50km.

Figure 7: (Relay 1) measured quantity at the remote side (Enugu) of the transmission line for fault voltage on single phase to ground (A-G) @ 50km.

Figure 8: Positive sequence current for Relay 1 at the remote side (Enugu) of the transmission line.

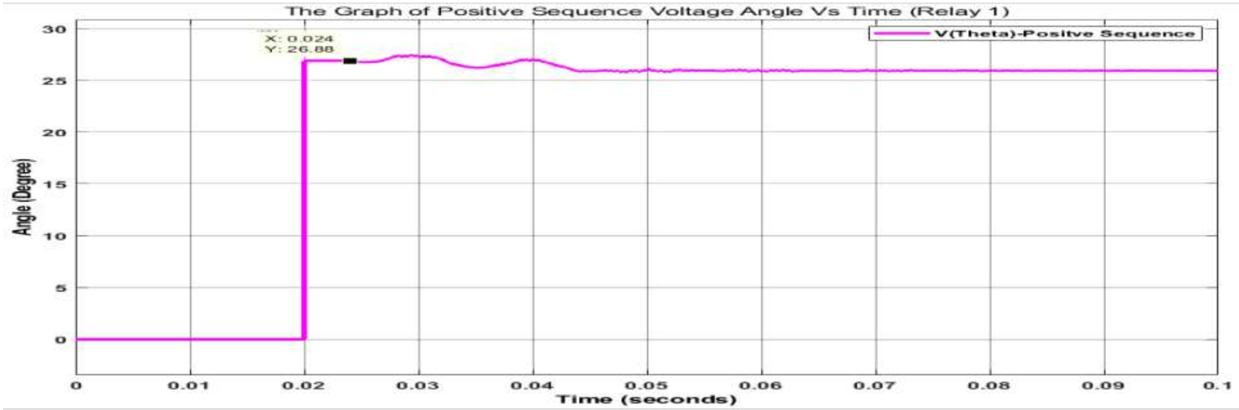

Figure 9: Positive sequence voltage angle for Relay 1 at the remote side (Enugu) of the transmission line.

IV. SIMULATION RESULT

Table 2

Summary of Fault Analysis under Varying Fault Distances and Fault Resistances

Single Phase to Ground Fault						
Fault type	**Fault location (km)**	**Fault resistance**	**fault inception time(s)**	**Measuring Time**	**Calculated fault location (km)**	**Fault location % Error**
A-G	50	5	0.02	0.07	47.98	1.2
	50	5	0.025	0.07	47.92	1.3
	50	5	0.027	0.069	47.93	1.3
	50	10	0.02	0.068	47.91	1.2
	50	10	0.025	0.072	47.97	1.3
	50	10	0.027	0.071	47.99	1.3
	50	100	0.02	0.072	50.06	0.2
	50	100	0.025	0.079	50.09	0.5
	50	100	0.027	0.081	50.11	0.6
A-G	90	5	0.02	0.073	91.44	0.9
	90	5	0.025	0.078	91.46	0.3
	90	5	0.027	0.079	91.49	0.9
	90	10	0.02	0.07	91.46	0.3
	90	10	0.025	0.075	91.48	0.3
	90	10	0.027	0.079	91.5	0.3
	90	100	0.02	0.045	91.25	0.7
	90	100	0.025	0.065	91.31	0.8
	90	100	0.027	0.068	91.35	0.8
A-G	120	5	0.02	0.066	126.9	4.3
	120	5	0.025	0.068	126.8	4.2
	120	5	0.027	0.070	127	4.3
	120	10	0.02	0.071	126.9	4.3

	120	10	0.025	0.074	126.8	4.2
	120	10	0.027	0.081	127	4.3
	120	100	0.02	0.062	124.6	2.4
	120	100	0.025	0.071	124.7	2.3
	120	100	0.027	0.072	124.8	3.0

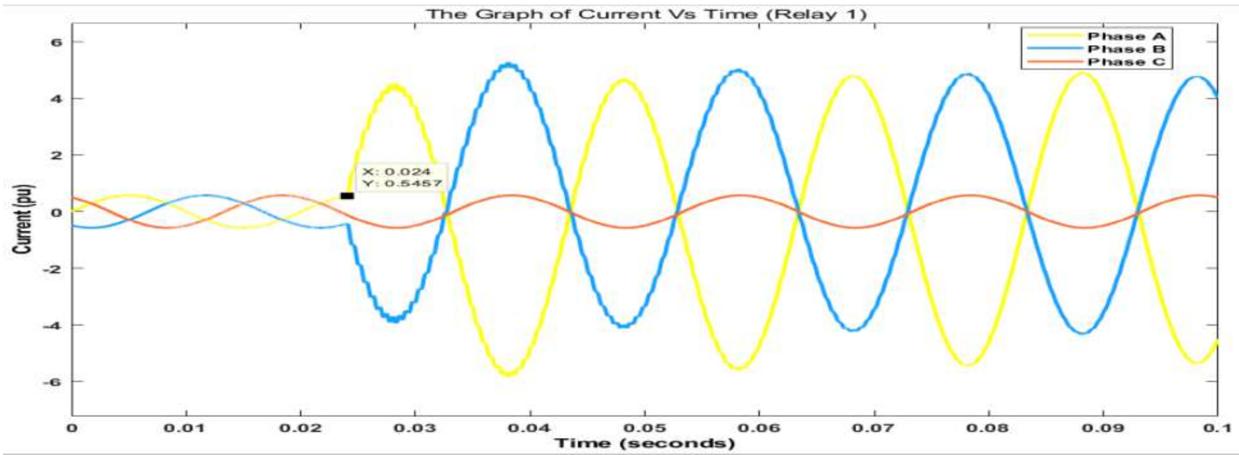

Figure 10: (Relay 1) measured quantity at the remote side (Enugu) of the transmission line for fault current on phase to phase (AB) @ 50km.

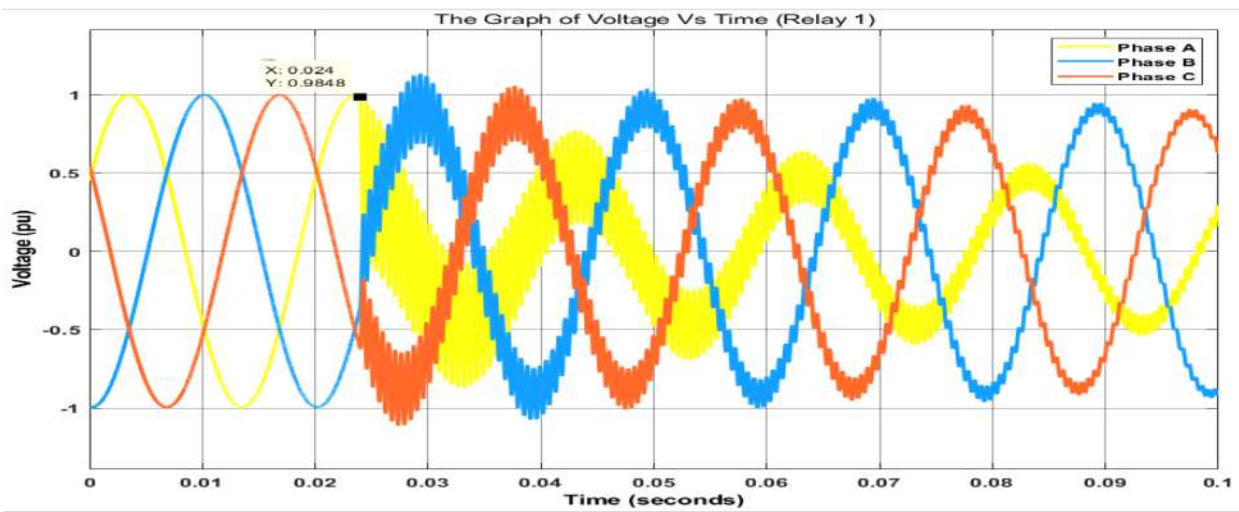

Figure 11: (Relay 1) measured quantity at the remote side (Enugu) of the transmission line for fault voltage on phase to phase (AB) @ 50km.

Table 3
Summary of Fault Analysis under Varying Fault Distances and Fault Resistances

Phase to Phase Fault						
Fault type	**Fault location (km)**	**Fault resistance**	**fault inception time(s)**	**Measuring Time**	**Calculated fault location (km)**	**Fault location % Error**
A-B	50	5	0.02	0.07	49.38	0.3

	50	5	0.025	0.073	49.5	0.3
	50	5	0.027	0.076	49.65	0.2
	50	10	0.02	0.077	49.45	0.3
	50	10	0.025	0.078	49.52	0.3
	50	10	0.027	0.08	49.6	0.2
	50	100	0.02	0.041	50.33	0.2
	50	100	0.025	0.051	50.38	0.2
	50	100	0.027	0.052	50.4	0.2
A-B	90	5	0.02	0.07	90.16	0.1
	90	5	0.025	0.071	90.55	0.3
	90	5	0.027	0.072	90.81	0.5
	90	10	0.02	0.07	90.3	0.1
	90	10	0.025	0.076	90.48	0.3
	90	10	0.027	0.08	90.62	0.3
	90	100	0.02	0.042	90.49	0.2
	90	100	0.025	0.051	90.53	0.3
	90	100	0.027	0.051	90.57	0.3
A-B	120	5	0.02	0.066	121.1	0.6
	120	5	0.025	0.068	121.7	1.0
	120	5	0.027	0.070	121.9	1.1
	120	10	0.02	0.071	121.3	0.8
	120	10	0.025	0.074	121.6	1
	120	10	0.027	0.081	121.7	1.0
	120	100	0.02	0.062	121.1	0.6
	120	100	0.025	0.071	121.2	0.7
	120	100	0.027	0.072	121.3	0.8

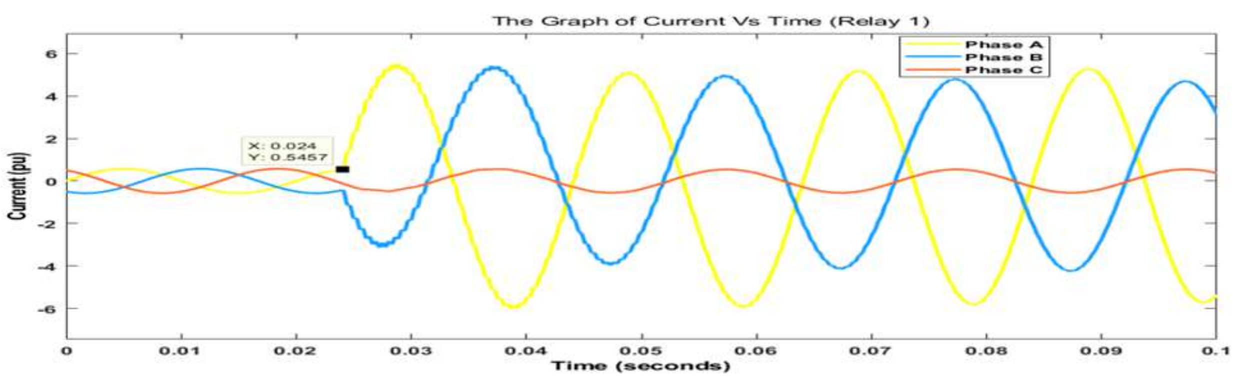

Figure 12: (Relay 1) measured quantity at the remote side (Enugu) of the transmission line for fault current on AB-G @ 90km.

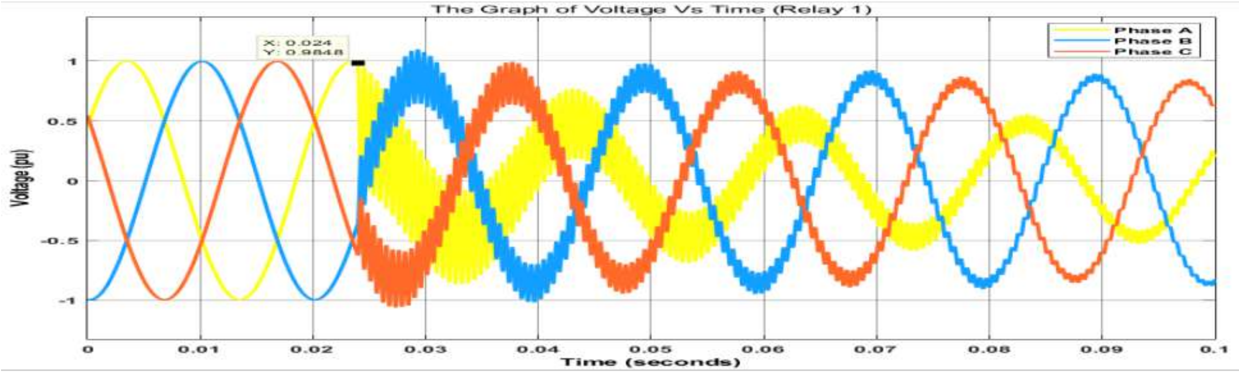

Figure 13: (Relay 1) measured quantity at the remote side (Enugu) of the transmission line for fault voltage on AB-G @ 90km.

Table 4

Summary of Fault Analysis under Varying Fault Distances and Fault Resistances

Two Phases to Ground						
Fault type	**Fault location (km)**	**Fault resistance**	**fault inception time(s)**	**Measuring Time**	**Calculated fault location (km)**	**Fault location % Error**
AB-G	50	5	0.02	0.08	49.48	0.1
	50	5	0.025	0.081	49.62	0.2
	50	5	0.027	0.082	49.79	0.1
	50	10	0.02	0.06	49.55	0.2
	50	10	0.025	0.062	49.63	0.2
	50	10	0.027	0.065	49.73	0.2
	50	100	0.02	0.05	50.12	0.2
	50	100	0.025	0.052	50.16	0.1
	50	100	0.027	0.054	50.17	0.1
AB-G	90	5	0.02	0.07	90.16	0.1
	90	5	0.025	0.071	90.5	0.3
	90	5	0.027	0.078	90.73	0.4
	90	10	0.02	0.068	90.29	0.2
	90	10	0.025	0.07	90.43	0.3
	90	10	0.027	0.071	90.55	0.3
	90	100	0.02	0.054	90.46	0.2
	90	100	0.025	0.056	90.53	0.3
	90	100	0.027	0.065	90.56	1.3
AB-G	120	5	0.02	0.07	121	0.2
	120	5	0.025	0.071	121.6	1
	120	5	0.027	0.078	121.8	1.1
	120	10	0.02	0.075	121.1	1.1
	120	10	0.025	0.078	121.5	0.3
	120	10	0.027	0.08	121.6	1
	120	100	0.02	0.05	121.3	0.3
	120	100	0.025	0.051	121.4	0.2
	120	100	0.027	0.058	121.4	0.2

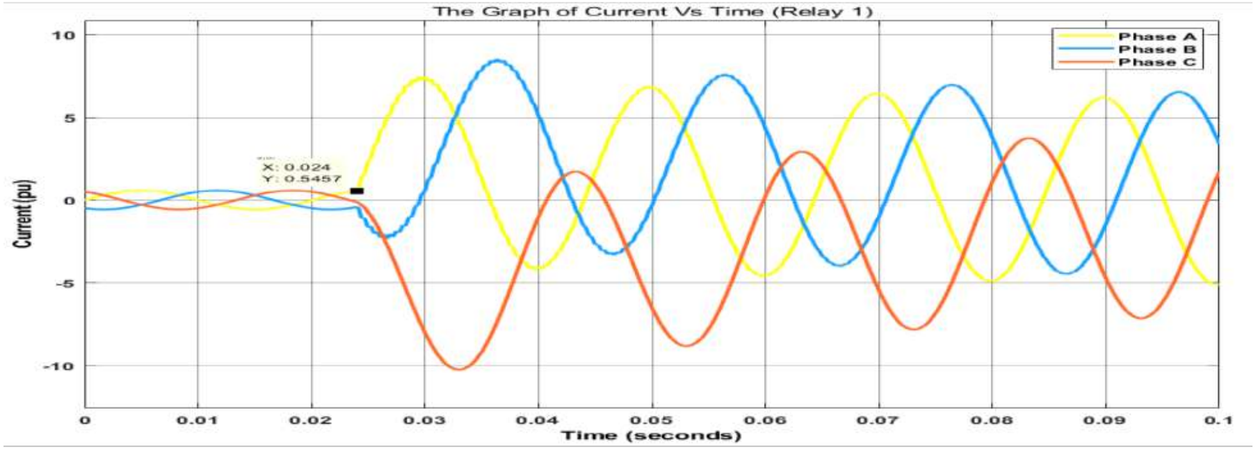

Figure 14: (Relay 1) measured quantity at the remote side (Enugu) of the transmission line for fault current on ABC @ 120km.

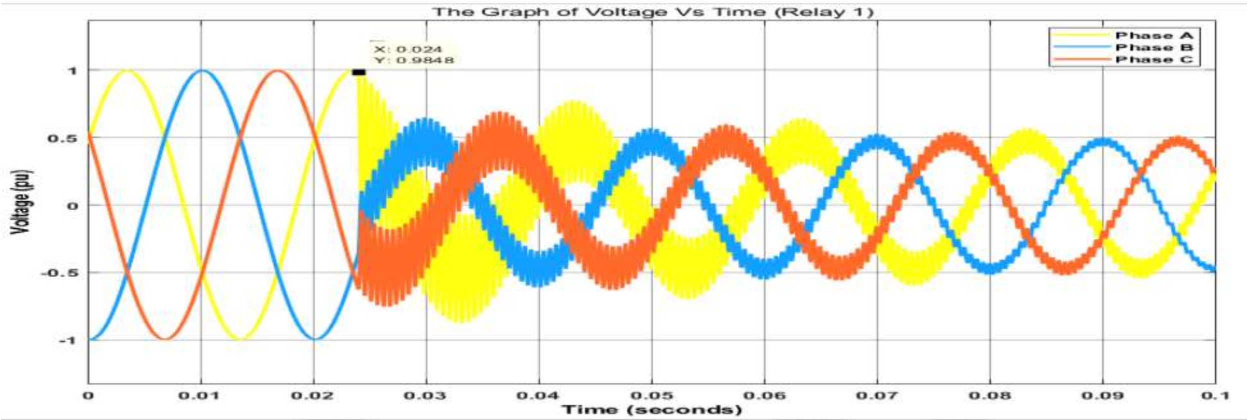

Figure 15: (Relay 1) measured quantity at the remote side (Enugu) of the transmission line for fault voltage on ABC @ 120km.

Table 5

Summary of Fault Analysis under Varying Fault Distances and Fault Resistances

Three Phases Fault						
Fault type	**Fault location (km)**	**Fault resistance**	**fault inception time(s)**	**Measuring Time**	**Calculated fault location (km)**	**Fault location % Error**
ABC	50	5	0.02	0.07	49.99	0.2
	50	5	0.025	0.071	50.09	0.5
	50	5	0.027	0.075	50.08	1.1
	50	10	0.02	0.07	49.97	0.1
	50	10	0.025	0.072	50.02	0.1
	50	10	0.027	0.072	50.02	0.1
	50	100	0.02	0.048	50.24	1.2
	50	100	0.025	0.051	50.26	0.1
	50	100	0.027	0.053	50.28	0.5

ABC	90	5	0.02	0.08	90.09	0.3
	90	5	0.025	0.082	90.49	0.2
	90	5	0.027	0.081	90.44	0.1
	90	10	0.02	0.07	90.17	0.1
	90	10	0.025	0.076	90.31	0.1
	90	10	0.027	0.077	90.31	0.2
	90	100	0.02	0.05	90.25	0.1
	90	100	0.025	0.023	90.29	0.1
	90	100	0.027	0.053	90.31	0.1
ABC	120	5	0.02	0.07	120.5	0.5
	120	5	0.025	0.075	121.3	0.6
	120	5	0.027	0.076	121.5	0.5
	120	10	0.02	0.077	121.6	1
	120	10	0.025	0.078	121.3	0.6
	120	10	0.027	0.079	121.4	0.7
	120	100	0.02	0.065	121.2	0.7
	120	100	0.025	0.065	121.5	0.5
	120	100	0.027	0.069	121.6	1

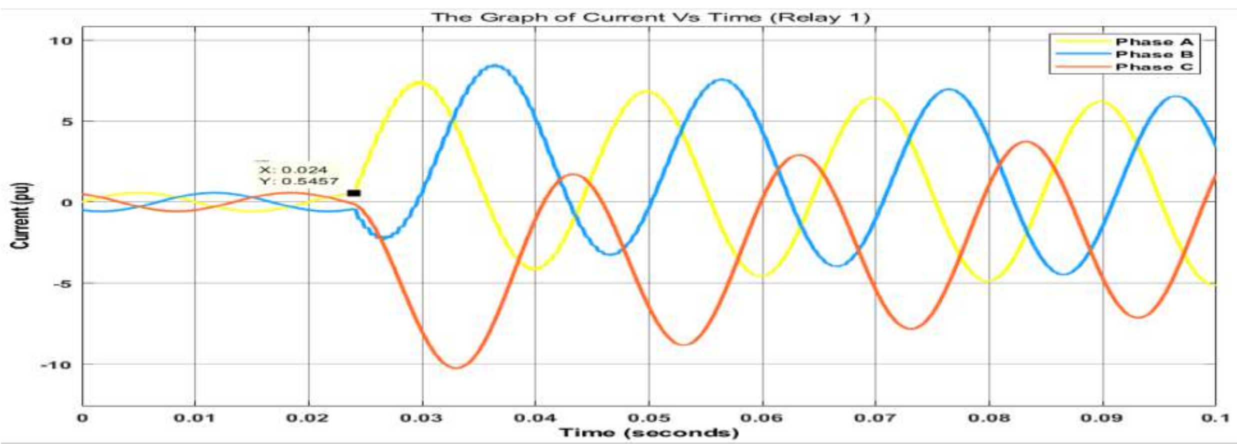

Figure 16: (Relay 1) measured quantity at the remote side (Enugu) of the transmission line for fault current on ABC-G fault @ 120km

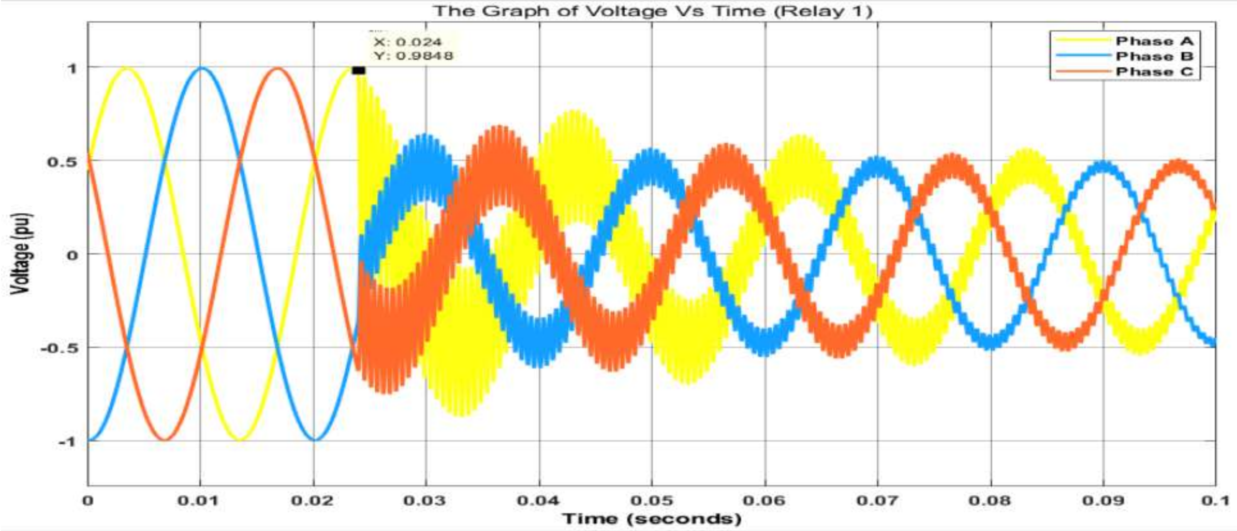

Figure 17: (Relay 1) measured quantity at the remote side (Enugu) of the transmission line for fault voltage on ABC-G fault @ 120km.

Table 6
Summary of Fault Analysis under Varying Fault Distances and Fault Resistances

Three Phases to Ground						
Fault type	**Fault location (km)**	**Fault resistance**	**fault inception time(s)**	**Measuring Time**	**Calculated fault location (km)**	**Fault location % Error**
ABC-G	50	5	0.02	0.07	50.11	0.3
	50	5	0.025	0.076	50.09	0.2
	50	5	0.027	0.085	50.08	1.1
	50	10	0.02	0.07	49.97	0.1
	50	10	0.025	0.072	50.02	0.1
	50	10	0.027	0.078	50.02	0.1
	50	100	0.02	0.05	50.24	1.2
	50	100	0.025	0.054	50.26	0.1
	50	100	0.027	0.055	50.28	0.5
ABC-G	90	5	0.02	0.081	90.01	0.1
	90	5	0.025	0.085	90.51	0.3
	90	5	0.027	0.087	90.41	0.3
	90	10	0.02	0.07	90.15	0.1
	90	10	0.025	0.08	90.32	0.2
	90	10	0.027	0.07	90.31	0.2
	90	100	0.02	0.043	90.25	0.1
	90	100	0.025	0.048	90.29	0.2
	90	100	0.027	0.05	90.31	0.2
ABC-G	120	5	0.02	0.08	120.5	0.3
	120	5	0.025	0.089	120.9	0.5
	120	5	0.027	0.09	120.9	0.5
	120	10	0.02	0.07	120.5	0.3

	120	10	0.025	0.078	120.7	0.4
	120	10	0.027	0.079	120.7	0.4
	120	100	0.02	0.042	120.5	0.3
	120	100	0.025	0.045	120.5	0.3
	120	100	0.027	0.05	120.6	0.4

Table 2 to Table 6 shows the accuracy of the fault location algorithms for different type of faults at various locations, with varied fault resistance and fault inception time(s) using two-end methods. The proposed method detects faults within 0.07ms for all types of faults. Fault-location accuracy is within 3%.

V. CONCLUSIONS

The formulated algorithm is tested for several simulated cases on lines 50km to 120km in Otukpo transmission line. The line length is 160km. The test system is modeled in MATLAB R2018a Simulink software and different types of faults namely; (L-G, L-L, LL-G LLL and LLL-G) at difference location by varying fault distance, fault resistance, and fault inception angle are simulated at both ends of the line are used to verify the algorithm. The fault inception time is 0.024ms and with fault resistance of 5Ω. The results of the algorithm proof that single line to ground fault occurred at a distance of 47.92km which have an error of 1.2%.fault from A bus bar, in Eziama Village, 9mile Enugu State as a result of heavy wind. Test results have shown that formulated algorithm for two- ended impedance is able to provide more accurate results compared to one-ended method with excellent robustness to voltage and current measurement, because the algorithm not affected by fault resistance and reactance. This algorithm has huge potential for power utility in both distribution and transmission system application.

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