RESEARCH ARTICLE

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Location of Fault on Transmission Line using Traveling Wave Technique

John A. Atuchukwu, Obi K. Obinna, and Anionovo E. Ugochukwu

ABSTRACT

When a fault on a transmission line manifests itself, the reliability of the power system is often compromised. It is advantageous to be able to stop certain faults from happening or to identify their causes when they do. The system may be quickly returned to its regular functioning condition by knowing the location of any possible line faults. This study proposes a method for fault localization based on travelling waves. This technique makes use of the currents and voltages coming from the line, as well as the speed of propagation, capacitance, inductance, the length of the transmission line, and the change in time that the fault occurs, in order to locate the specific site of the problem. The Onitsha to New/Haven 96 km transmission line was employed as a case study, and Matlab/Simulink was used to model, simulate, and apply the travelling wave fault detection equation. After simulating several fault sequences, the locations of the single line to ground fault, double line to ground fault, line to line fault, and three phase fault were found to be 48.539625306645 km, 48.539625261133 km, 48.539624540792 km, and 48.539625285965 km, respectively.

Keywords: Fault, fault location, transmission line, traveling wave.

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I. Introduction

The term "power network" refers to the interconnected systems that produce, transmit, and distribute electricity [1]. An electric power system includes all the components involved in generating, transmitting, and delivering electrical power to consumers. Transmission lines provide electricity to distant large load centers [2]. Electric transmission lines are susceptible to both short and long-term defects since they are often above and exposed to things like birds, trees, storms, etc. Power outages, lost money, destroyed property, and sometimes even the deaths of people, animals, and birds may be brought on by errors in the electrical system. To hasten power restoration and component repairs, the locations of faults in the power system network must be properly and rapidly identified. System reliability is enhanced, and power outages are reduced. A prompt service restoration also lowers customer dissatisfaction, staff repair expenses, and revenue loss [3]. The rapid growth of the electric power infrastructure over the last several decades has resulted in a large rise in the number of working lines and their overall length. Lightning, short circuits, broken equipment, inappropriate usage, human mistake, overload, and ageing all put these lines at risk for issues. Electrical malfunctions usually result in mechanical damage, which must be repaired before the line can be utilized again. The repair procedure may be accelerated if the fault location is known or can be foreseen with reasonable certainty. Short- to long-term power outages are caused by faults, which may also lead to significant losses, especially for the industrial sector [4].

To keep a power system reliable, fault isolation, identification, localization, and repair must be done quickly. The voltage at the location of a transmission line failure decreases rapidly to a low value. This sudden transition generates a high frequency electromagnetic impulse known as the travelling wave. These waves leave the fault at almost the speed of light in both directions. To find the issue, the signal recorded from instrument transformers has to be filtered and evaluated using different signal processing methods. The filtered signal is then used to find and localize the fault. Quantifying the incoming wave's value, phase, polarity, and time lag is crucial for pinpointing the fault [5]. This work's main objective is to assess fault detection methods for high voltage transmission utilizing the travelling wave theory in a Matlab Simulink environment.

II. Traveling Wave

This technique is based on the idea of propagating waves. This proposal is based on the fact that any disturbance on a transmission line generates travelling waves that travel along the transmission line. These waves are the consequence of charging and discharging the line capacitance and line inductance of the transmission line. Each wave, with a frequency anywhere from a few kilohertz to several megahertz, travels at a rate that is almost as fast as the speed of light. Time-of-arrival measurements of surges induced by the fault at the terminals are required for fault location calculations utilizing travelling wave-based methodologies. You may track the wave's progress by keeping an eye on the transient voltage and current signal on a single bus. Current and voltage transformers that are already in use can be used to test the current and voltage of AC transmission lines [6].

On the notion of travelling waves, this approach is founded. Based on the observation that any disturbance on a transmission line causes travelling waves to propagate down the transmission line, this idea is put forward. The transmission line's line capacitance and line inductance are charged and discharged, resulting in these moving waves. The propagation speed of each wave, which ranges from a few kilohertz to several megahertz, is close to the speed of light. In order to calculate the distance to the fault using travelling wave-based techniques, measurements of the time at which surges caused by the fault arrive at the terminals are necessary. The transient voltage and current signal on one bus can be used to monitor the travelling wave. Traditional current and voltage transformers provide simple and cost-effective measurements in AC transmission lines [6].

III. Method

The gradual development of line voltage may be attributed to a voltage wave travelling from the supply source end to the far end, and the related current wave will be accounted for by progressive charging of the line capacitances. Assume that a current I and a voltage V are established over a length x of the line in a relatively short time t. The back emf created by the magnetic flux produced by the current in this length of the line balances the emf V. The inductance of the length δx is Lδx (L is line inductance per unit length), hence the flux built up is ILδx and the back emf is the rate of building viz. IL δx/δt.

So we have

$$V = IL\frac{\delta x}{\delta t} = ILv \tag{1}$$

where v represents the wave's propagation speed.

The current I carries a charge Iδt in time δt, and this charge remains on the line to charge it up to the potential of V. Since the capacitance of length δx of the line is Cδx (C is the capacitance of the line per unit length), its charge is VCδx, so we have

$$I\delta t = VC\delta x \tag{2}$$

Or

$$I = VC\frac{\delta x}{\delta t} = VCv \tag{3}$$

The switching of an emf V on to the line results therefore in a wave of current I and velocity v are given by equations (1) and (3). Dividing (1) by (3), we have

$$\frac{V}{I} = \frac{ILv}{VCv} = \frac{I}{V}.\frac{L}{C} \tag{4}$$

Or

$$\frac{V^2}{I^2} = \frac{L}{C} \tag{5}$$

Or

$$\frac{V}{I} = \sqrt{\frac{L}{C}} = Z_n \tag{6}$$

The expression is a ratio of voltage V and current I which has the dimensions of impedance and is therefore here designated as surge impedance of the line. It is also called natural impedance because this impedance has nothing to do with the load impedance, but depends only on the line constants.

From (5) surge impedance Zn which is the ratio of voltage and current having the dimension of impedance is thus:

$$Z_n = \frac{V^2}{I^2} = \frac{L}{C} \tag{7}$$

Inductance

$$L = \frac{V^2 C}{I^2} \tag{8}$$

Capacitance

$$C = \frac{I^2 L}{V^2} \tag{9}$$

IV. Propagation Velocity V of Travelling Wave

To get velocity of travelling wave, multiply (1) and (3)

$$VI = ILv \times VCv \tag{10}$$

$$VI = VILCv^2 \tag{11}$$

Or

$$v^2 = \frac{1}{LC} \tag{12}$$

$$v = \sqrt{\frac{1}{LC}} \tag{13}$$

Where L is inductance of the line and C is the capacitance of the line v is the propagation velocity.

V. Two Ended Fault Location on the Transmission Line Based on Travelling Wave

Some of the most common and reliable defect detection techniques use a travelling wave based on a two-ended concept, as seen in the image below.

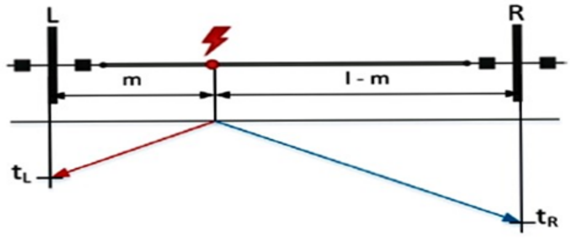

Fig. 1. Two ended fault location based on time difference of first arrival times [7].

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The arrival times of the traveling waves on both ends of the line are compared and the fault location m is calculated according to the following formula:

$$m = \frac{((l + (tL - tR)\, v))}{2} \tag{14}$$

Where
L = length of the line
t_L = Arrival time at the local end
t_R = Arrival time at the remote end
v = propagation velocity

VI. Simulink Modeling Of The Traveling Wave Fault Location Equation

Recall from (14),

$$m = \frac{(l+(t_L - t_R)v)}{2} \tag{15}$$

Propagation velocity from (13)

$$v = \sqrt{\frac{1}{LC}} \tag{16}$$

But
Surge impedance from (7)

$$Z_n = \frac{V^2}{I^2} = \frac{L}{C} \tag{17}$$

Inductance from (8)

$$L = \frac{V^2 C}{I^2} \tag{18}$$

Capacitance from (9)

$$C = \frac{I^2 L}{V^2} \tag{19}$$

Therefore propagation velocity

$$v = \sqrt{\frac{1}{\left(\frac{V^2C}{I^2}\right)\times\left(\frac{I^2L}{V^2}\right)}} \tag{20}$$

From (13),

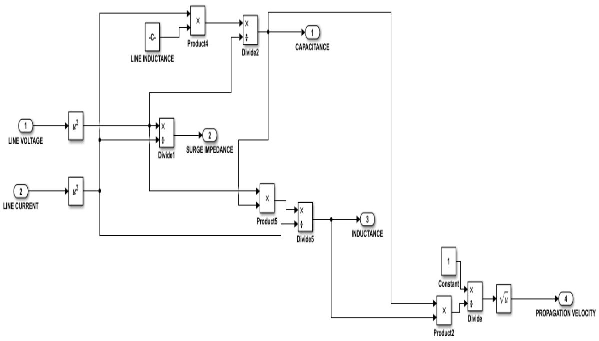

Fig. 2. Simulink model of travelling wave propagation equation (21).

$$m = \frac{(l+(t_L - t_R)v)}{2} \tag{21}$$

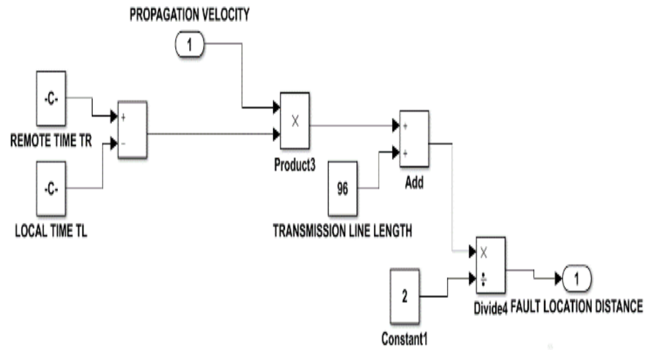

Fig. 3. Simulink model of travelling wave fault location equation model

The fault distance (m) can be calculated using the following expression.

$$m = \frac{\left(l+(t_L-t_R)\sqrt{\frac{1}{\left(\frac{V^2C}{I^2}\right)\times\left(\frac{I^2L}{V^2}\right)}}\right)}{2} \tag{22}$$

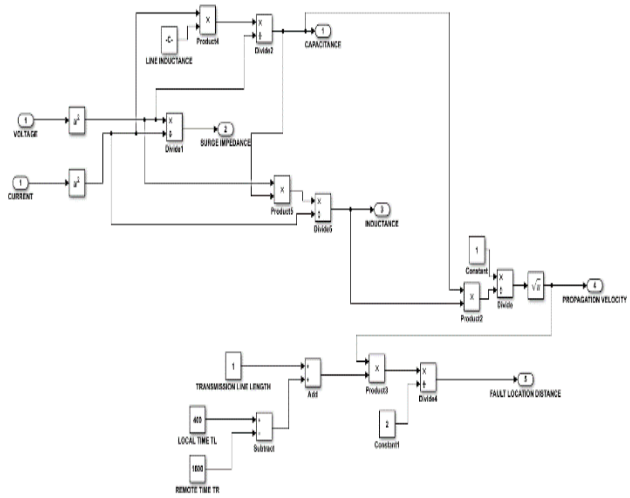

Fig. 4. Simulink model of travelling wave fault location equation model with propagation velocity equation.

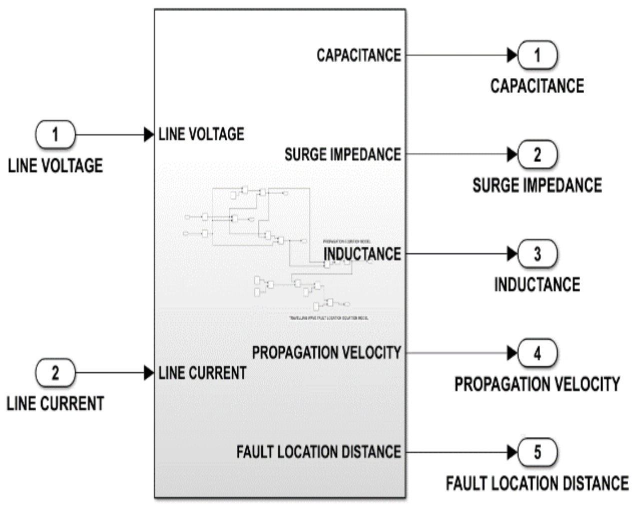

Fig. 5. Travelling wave fault location Simulink subsystem.

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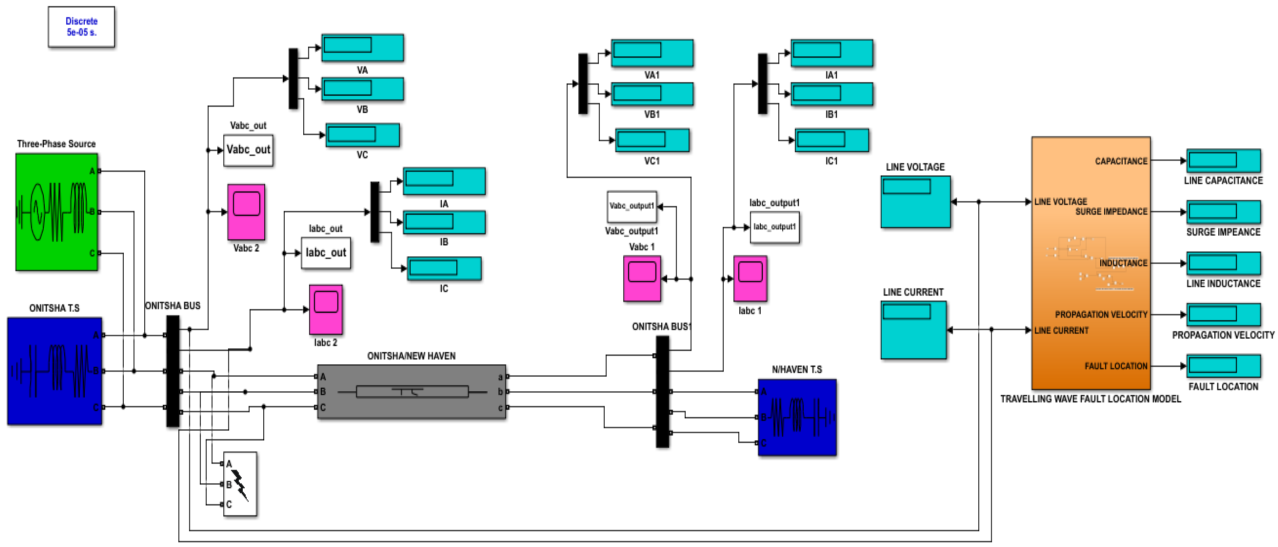

Fig. 6. Fault detection and location models linked to the Onitsha to New/Haven transmission line network.

VII. Result

The Results Obtained Through Simulation of the Nigerian Network Utilizing the Onitsha–New Haven 330KV Transmission Line as a Case Study.

In this section, the results that were produced by following the methods presented in the study were discussed. When the Time-Frequency (S-Transform) model was simulated in its entirety, the following findings emerged as a consequence of the process.

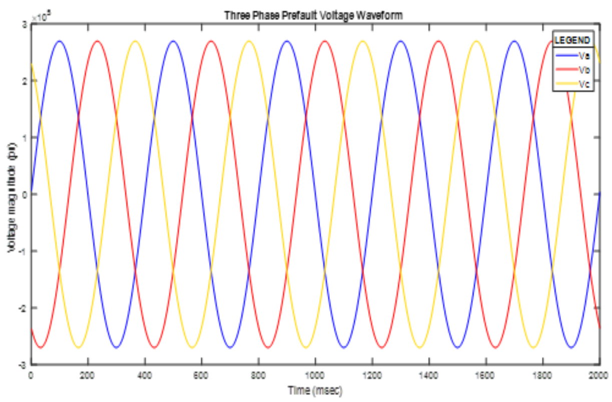

Fig. 7. Three Phase Pre-fault Voltage Waveform.

Fig. 7 illustrates the pre-fault voltage waveform that resulted from simulating the system with no faults present. This result was obtained before the fault occurred. One can see that the voltage waveform for the three phases before to the fault is moving in a sinusoidal uniform shape, which results in a pattern that is identical to a pure sine wave. In the absence of a problem in the system, the magnitude is about 2.8 X 10e-5 on the logarithmic scale, and the Gaussian window widths are likewise unaltered.

In the same manner, it can be seen from the waveform of the three-phase pre-fault current, which can be found in Fig. 8 up top, that when there is no fault current, the current magnitudes of each of the lines are relatively the same at a value of 200pu. This is something that can be observed in the absence of fault current. This also results in a pure sine wave pattern that has a Gaussian window length that is consistent throughout.

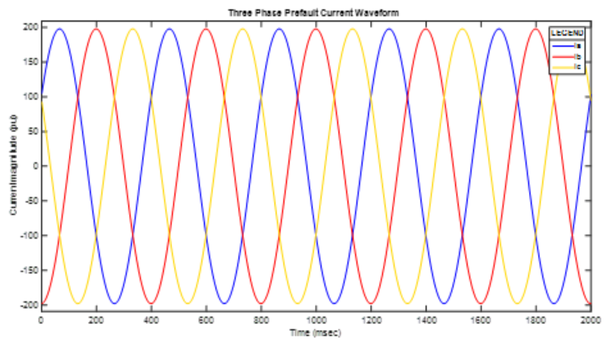

Fig. 8. Three Phase Pre-fault Current Waveform.

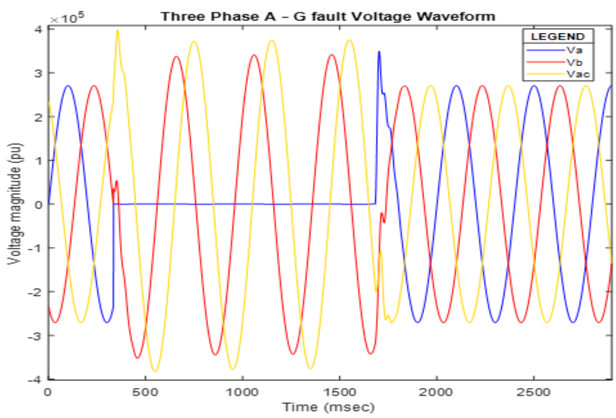

Fig. 9. Three Phase A – G fault Voltage Waveform.

When a line to ground fault occurred on line A, the voltage in the defective phase dropped until it reached zero, but the voltage on the healthy phases increased by a little amount, reaching a value of around 4 x 10e5pu in magnitude at the moment the fault occurred. According to the voltage waveform for a three-phase A-G fault, which can be seen above in Fig. 9, the fault started at a time of 400 milliseconds and continued until it was cleared at 1750 milliseconds. As soon as the fault occurred, the waveform of the voltage, which had previously been travelling in a sinusoidal manner, became erratic and distorted. After the problem was fixed, this pattern of sinusoidal waveform was brought back into existence.

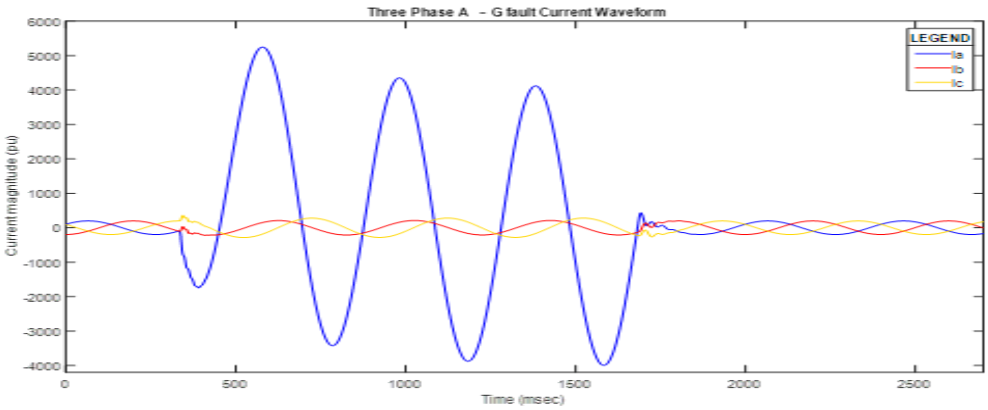

Fig. 10. Three Phase A – G fault Current Waveform.

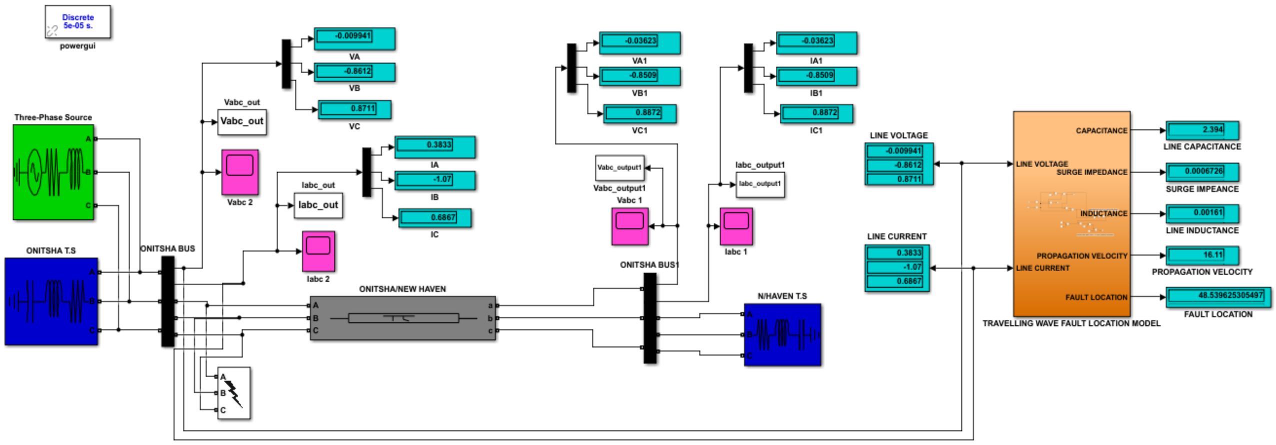

Fig. 11. The travelling wave model was used to pinpoint the single line to ground fault on the transmission line at a distance of 48.539625305497Km.

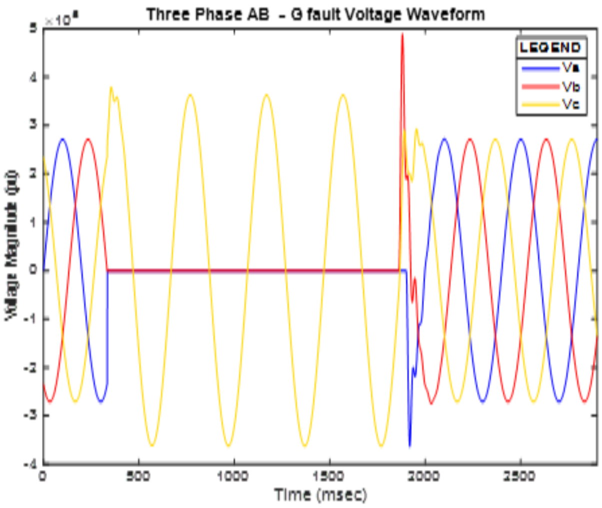

Fig. 12. Three Phase AB – G fault Voltage Waveform.

During the time of the fault, which lasts approximately 400 milliseconds, there is a spike in the magnitude of current in the faulty phase A. As the voltage drops to zero, the current in the faulty phase increases to approximately 5000pu, whereas the current in the healthy phases does not change at all. The current amplitude of the defective phase becomes uniform with the current magnitude of the healthy phases at the moment when the phase A to ground fault is cleared. The aforementioned Fig. 10 makes this quite clear.

Location of line A-G fault

Between stages AB and G, the double line to ground fault was simulated. The magnitude of the resulting voltage waveform versus time is shown in Fig. 12. Fig. 12 shows that the voltage magnitude of the defective phases A and B decreases throughout the fault state and follows the same pattern. This double line to ground fault occurs at a period of about 400 ms. During the period of the fault, the voltage magnitude in the healthy phase C spikes and rises to around 1.9x105pu. When the fault state was resolved at 1750 milliseconds, the voltages of phases A and B returned to normal and were consistent with the healthy phase. The waveform pattern takes on a sinusoidal shape as a result.

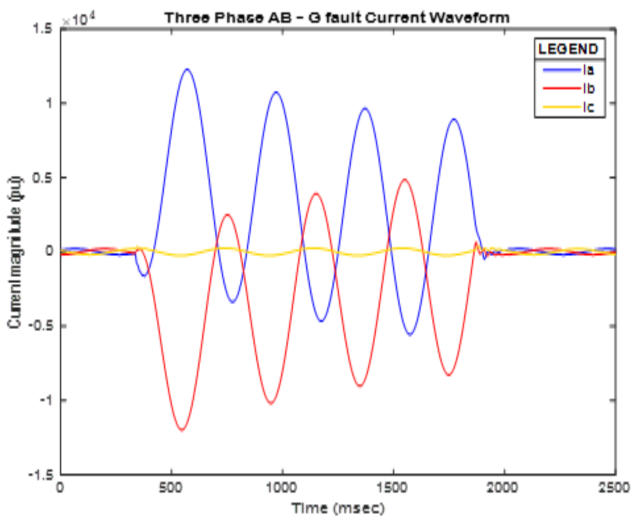

Fig. 13. Three Phase AB – G fault Current Waveform.

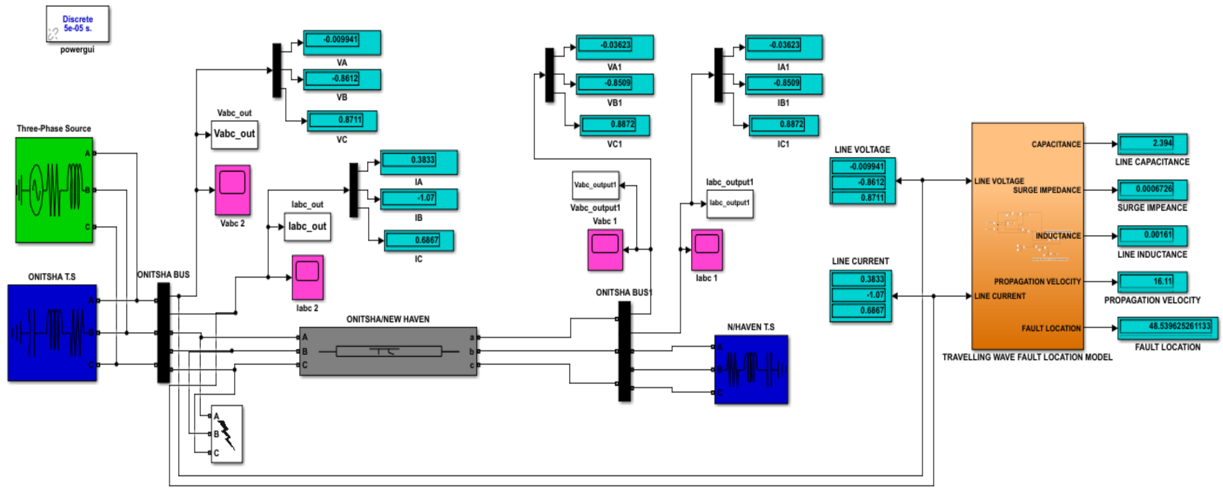

Fig. 14. The travelling wave model was used in order to pinpoint the location of the line AB-G fault on the transmission line at a distance of 48.5396261133 kilometres.

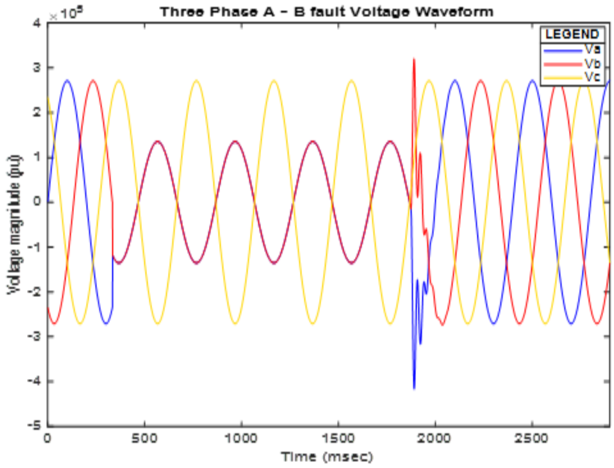

Fig. 15. Three Phase A – B fault Voltage Waveform.

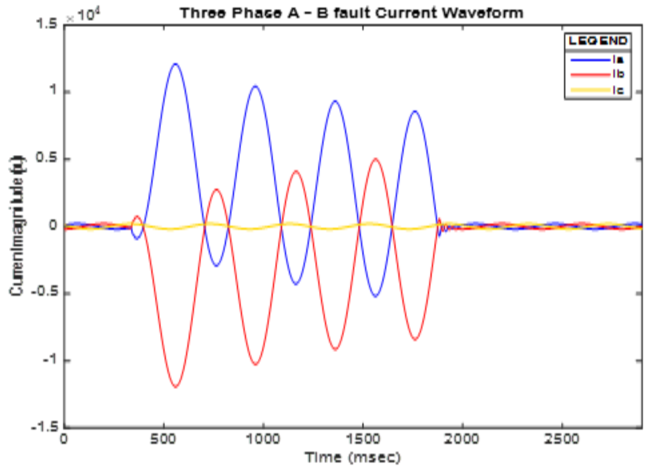

Fig. 16. Three Phase A – B fault Current Waveform.

The current magnitudes of the faulty phases A and B grow during the occurrence of a double line to ground fault. The current in the healthy phase drops to almost nothing at the period of fault at a time of 450 ms, whereas the values of current magnitude of these faulty phases, which are represented in Fig. 13, climbed to nearly 1.4x10e4pu. This pattern keeps on until the issue is fixed at around 1750 milliseconds.

Location of line AB-G fault

Fig. 15 depicts the outcome of the simulation that took place after a three phase double line fault occurred at a time of about 400 milliseconds. It has been discovered that the magnitude of the voltage in the defective phases A and B has been changed, and it has been lowered to around 1.5e5pu. When the line to line fault occurred at roughly 400 milliseconds, there was a corresponding reduction in the amplitude of the voltage across these defective phases. It is also important to observe that the voltage magnitude of the healthy phase C does not change and keeps the same value of roughly 2.8e5pu throughout the whole experiment. This decline in voltage magnitudes in the faulty phases continued until the faulty was cleared at a time of 1750 milliseconds. When these faults were fixed, the voltage magnitude waveform returned to its normal, uniform state, indicating that the system was once again in good condition.

The result, which is provided in Fig. 15, demonstrates that the current magnitude of the defective phases increased to 1.4 x 10e4pu throughout the period of the fault, which was around 400 milliseconds. This happened when a three phase line to line fault occurred between line A and line B. During the period of the fault, it was observed that the amplitude of the current flowing through the healthy phase C did not change. This pattern carried on until the fault that connected line A to line B was cleared at 1750 milliseconds.

Fault location of A-B line fault

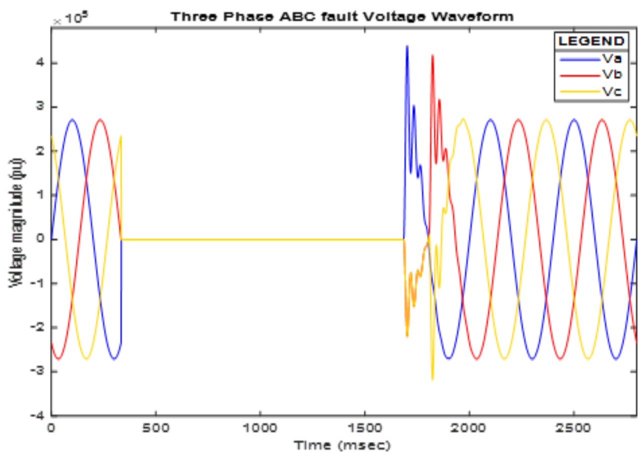

Fig. 18. Three Phase ABC fault Voltage Waveform.

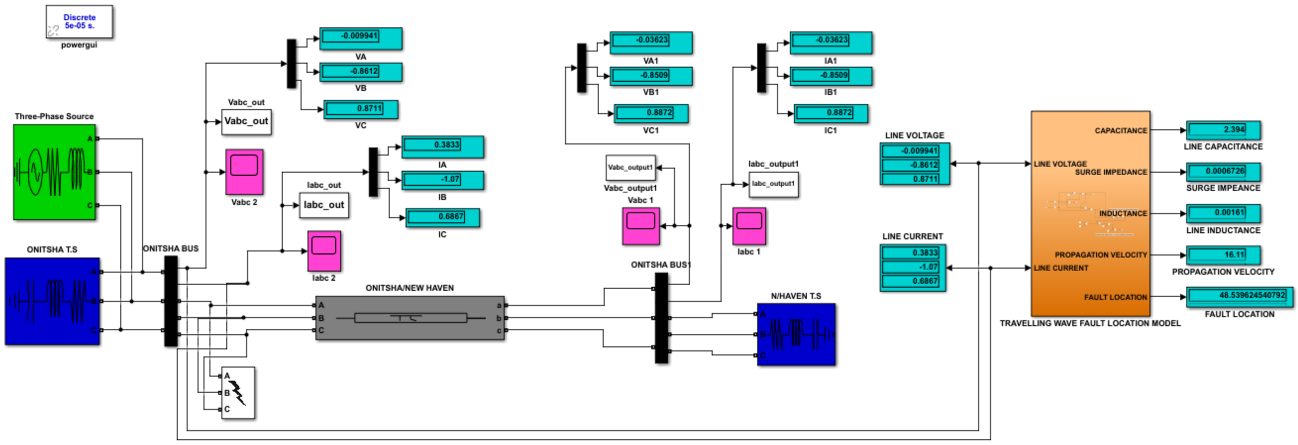

Fig. 17. The travelling wave model was utilized in order to pinpoint the location of the line A-B fault on the transmission line at a distance of 48.539624540792 kilometers.

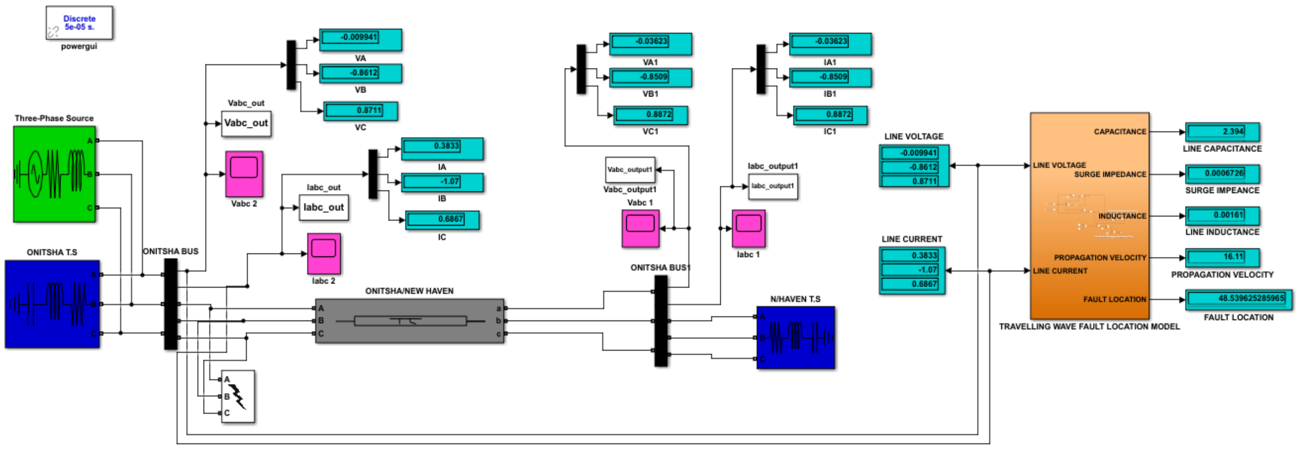

Fig. 20. The travelling wave model was used to pinpoint the location of the line ABC-G fault on the transmission line at a distance of 48.539625285965 kilometers.

TABLE I: THREE PHASE PRE-FAULT AND FAULT VOLTAGE AND CURRENT FOR THE SYMMETRICAL AND UNSYMMETRICAL FAULTS

S/N	V_a	V_b	V_c	I_a	I_b	I_c	Fault conditions	Fault Distance (Km)
1	2.8e5	2.8e5	2.8e5	200	200	200	No fault	-
2	0	4e5	3.5e5	5000	100	100	A-G	48.539625305497
3	0	0	3.9e5	1.4e4	1.4e4	0.01e4	AB-G	48.539625261133
4	1.5e5	1.5e5	2.8e5	1.4e4	1.4e4	0.01e4	A-B	48.539624540792
5	0	0	0	1.2e4	1.2e4	1.5e4	ABC	48.539625285965

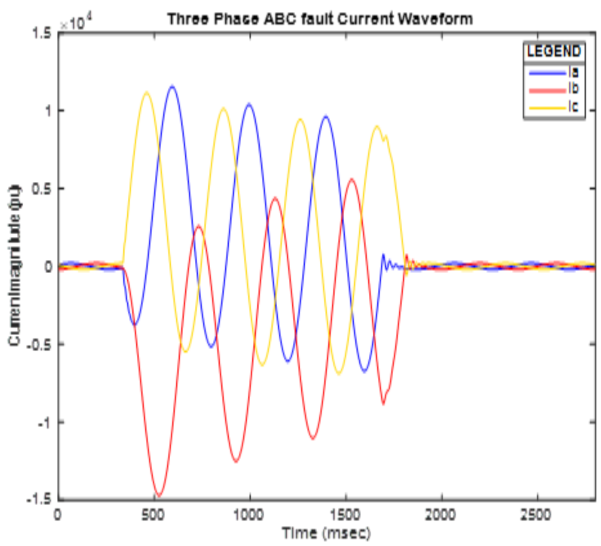

Fig. 19. Three Phase ABC fault Current Waveform.

The voltage waveform seen in Fig. 18 is the product of a simulation of a three-phase ABC failure, which was performed. It is clear that at the time of the fault, at a period of around 400 milliseconds, the voltage magnitude of all three phases drops to zero. This occurs during the fault. The magnitude of the voltage across phases ABC returns to its pre-fault state at the moment of fault clearing, which occurs at 1750 milliseconds, when it has increased to a high value of 2.7pu. This value was its initial state before the fault occurred.

The three phase ABC faults that were introduced and used to simulate the transmission line happened at time (400 msecs) and were cleared at time (1800 msecs) respectively. The result of the current magnitude of the three phase ABC fault is shown in Fig. 19, and it demonstrates that when the fault occurs at a time interval of 400 milliseconds, the current magnitudes of the three phases ABC increase to approximately 1.4pu. This pattern keeps repeating itself until the fault was repaired at 1750 milliseconds and the current waveform returned to its zero-point starting point.

Fault location of ABC-G fault

The pre-fault, fault, and current magnitude of the case study transmission line are shown in Table I. These values were obtained by simulating the line under the following fault conditions. no fault, A–G fault, AB–G fault, A–B fault, and ABC fault. It can be seen from Table I that when there is no fault condition, the values of the voltages in each phase stay the same at 2.8e5 pu, and the values of the currents stay the same at 200 pu. These values are maintained even when there is no fault situation. Whenever there was a failure between lines A-G that included a line to ground connection, the voltage on the affected phase-A went down to zero, and the current magnitude on that phase-A went up to a value of 1.5e5 pu. The results of the double line to ground fault reveal that the magnitude of the voltage on the defective phases AB fell to zero, while the magnitude of the current on the AB-G fault rose to 1.4e2 for both of them. When there was a failure between line A and line B, the voltages between the two lines dropped to 1.5e5 of their original levels. During the time when the A-B fault was active, it was observed that the magnitude of both A and B had climbed to 1.4e4 pu. The results of the three-phase ABC fault are tabulated in Table I. The table reveals that the magnitude of the voltage on line ABC decreased all the way to zero, while the magnitude of the current on line ABC increased to 1.2e4, 1.2e4, and 1.5e4 accordingly. The pre-fault voltage waveforms shown in Fig. 7 and Fig. 8 correspond to the following fault conditions. no fault, A–G fault, AB–G fault, A–B fault, and ABC fault.

VIII. Conclusion

The subject of fault localization is one that is investigated in this research utilizing travelling wave voltage and current signals that are collected at the terminals of a transmission network. This study work details a double-ended fault location detection approach of the travelling wave system that may be used to precisely locate the fault spot in the event that a defect in a transmission line is identified. It was shown that the modelling simulations and scenarios that were carried out with the help of the MATLAB/SIMULINK program were accurate and reliable. This technique can measure the position where the fault occurred by utilizing the distance of the line, capacitance of the line, inductance of the line, and propagation velocity, among other things. The research has suggested an automated travelling wave technique as an efficient way to locate faults.

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