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Modeling of Power System Protection Scheme by Distance Relay for Distribution Lines

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Abstract

In the power system protection of transmission and distribution lines from any faults or abnormal conditions is a very vital issue to ensure a safe and reliable electrical power supply to consumers. As the power system is a complex network with different equipment, there is a chance to happen a lot of danger due to sudden faults in a power system. Therefore, the development of a complete technological arrangement is necessary to prevent damage to types of equipment. Because due to faults in power system networks cause heavy current flow through the related equipment working in the system. Distance relays play a key role in the protection of transmission lines. It is relevant to highlight that conventional distance relays have limitations in detecting and classifying faults with high impedance. From this point of view, this work aims to design and modeling of a reliable protection scheme introducing a new algorithm for digital distance relay in the distribution area. This simulation model analyzes the line-to-line fault, line-to-ground fault, double-line-to-ground fault and triple-line-to-ground fault at different zones. Simulation results showed that voltage, current, and impedance of three phase lines were affected by any types of faults where voltages and impedances are decreased and line currents are increased. The fault location is also calculated by the new algorithm and the relay response is made faster by reducing its trip time from 20 ms to 6.778 ms.

Keywords

Distance relay, Relay box, Distribution line, Conventional relay, faults, MATLAB/SIMULINK

1. Introduction

In the power system network, several problem or abnormal conditions occurs which cause damage/failure to the pieces of equipment. Most of the equipment is very expensive, thus we need proper protective arrangements to protect those equipment [1, 2]. This provision consists of protective relays and circuit breakers to protect generators, transformers, reactors, capacitors and so on. The objectives of a power system fault analysis are to provide satisfactory information to identify the reasons for fault as soon as possible and restore the power to service people swiftly [3, 4]. The main goal of a power system is to identify any fault within a very short time to minimize damage to costly equipment and maintain the delivery of stable electrical energy to consumers. Many types of protective relays are used to protect power system equipment which are classified according to their operating principles; such as distance relay, over current relay, differential relay, impedance relay, etc [5, 6]. The performance of a relay depends on the following characteristics; dependability, security, selectivity, sensitivity, and speed [2-5]. Protective relaying is a vital part of any electric power system: unnecessary during normal operation but very important during trouble, faults, and abnormal disturbances [7]. Therefore, it is very important to choose an appropriate relay setting.

S. Seghir et al. compared the impedance calculation by the simulation model with reference impedance values to detect the faulty zone and to find the tripping time of the circuit breaker [8]. They found that the resistance was increased due to all types of fault causing a localization of error, which results in incorrect faulty zone identification. Also, the variation in fault resistance affects the performance of the distance relay. Y. Wang et al reported an FPGA-based low-latency high-resolution distance protective digital relay with both phasor-based and instantaneous-signal-based processing designed. With this low latency, a much higher sampling rate can be achieved and the fault detection time would be shortened [6]. They found the fault detection time was reduced at various conditions. A. S. Sampeallo et al explained how distance relay adjustment (Impedance Adjustment) affects the reading of the fault zone when there is a short circuit fault on the line [9]. They showed that the relay with new settings resulted in faster fault detection where the Bolok substation reads disturbances in zone 1, and the relay at Maulafa Substation reads disturbances in zone 2. Though conventional relays suffer from several problems such as under-reach, over-reach, delay, incorrect fault detection, inaccurate fault location, and impedance measurement [6-10]. So, further research is required in this aspect to reduce the aforementioned problems. The main objective of this work is to propose a new algorithm for digital distance relays using MATLAB/SIMULINK to improve the protection scheme in a distribution area by reducing relay tripping time and ensuring a continuous healthy electricity supply in the network.

2. Methods

Distribution lines are used for distributing power from a transmission system to the consumer. For a particular line when a voltage greater than 1 kilovolt and less than 40 kilovolts is used for a particular power distribution line. A substation of 33/11KV including three zones is selected as a model distribution system. The proposed simulation model for the advanced protection scheme of three-phase distribution lines with zones is shown in Fig. 1. This model consists of a generation station, distribution lines, transmission section, short circuit test, relay box, and load centers. Here distance display showed the distance from the feeder to the fault location under fault conditions and fault conditions were identified by a short circuit test.

For zone 1 the distance relay can detect and protect 80% between lines A and B and impedance is set aside as below 120 ohms. When the distance relay is measured below 120 Ω then it will send a signal from the impedance unit to the relay box that a fault is occurred at zone 1. For zone 2 the relay can detect and protect 100% between lines A and B and 20% between B and C which is between 60 Ω to 120 Ω. If the relay is measured between 60 Ω to 120 Ω then it will send a signal from the impedance unit to the relay box that a fault occurred at zone 2.

Finally, for zone 3, the relay can detect and protect 100% between lines A and B and between B and C, and 25% between C and D which is kept above 40 Ω. If the relay is measured above 40 Ω then it will send a signal from the impedance unit to the relay box that fault is occurred at zone 3. In this model, scopes are connected with three-phase V-I measurements to record temporal changes in the voltage and current waveforms during the tripping period of the relay.

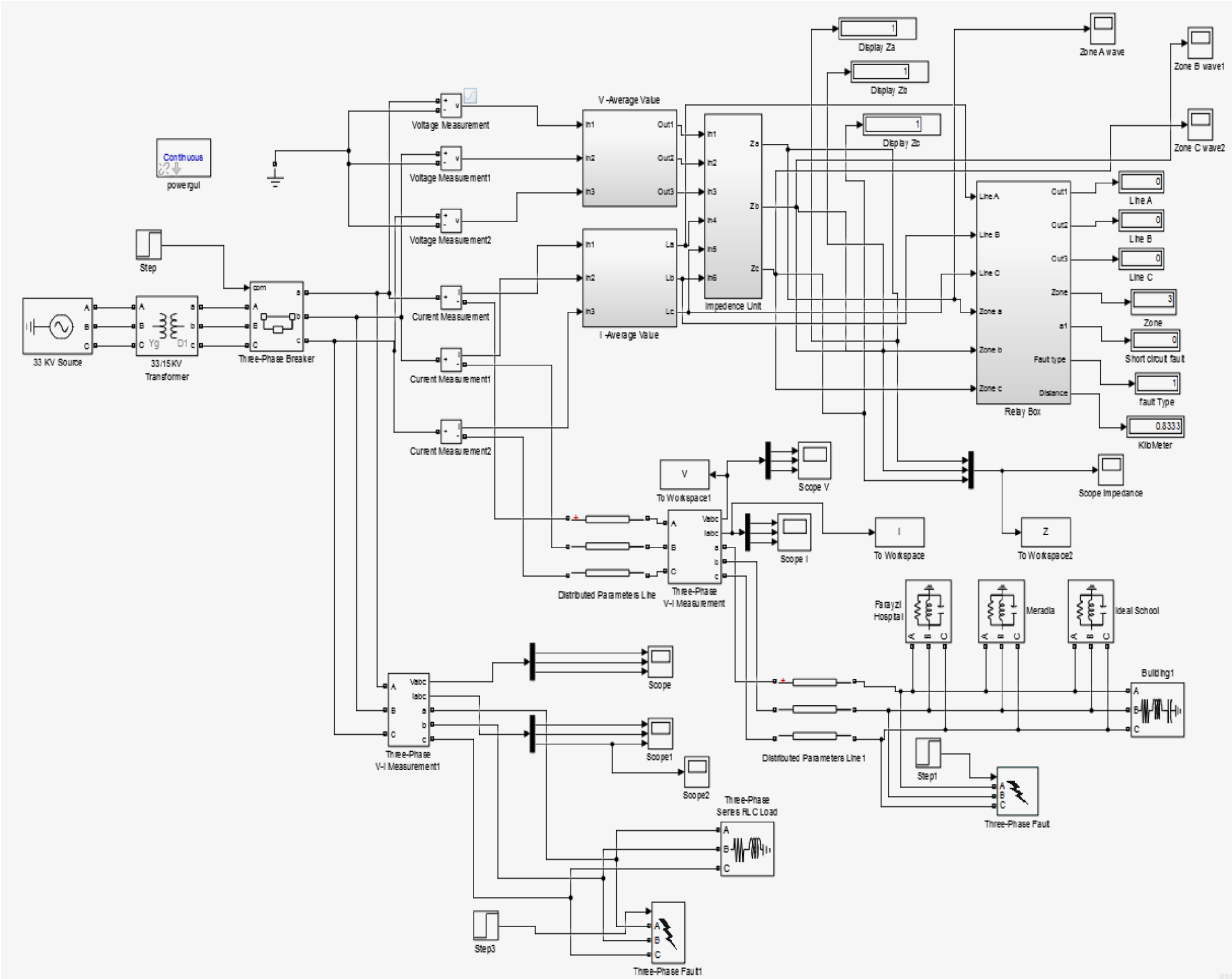

Figure 1. Proposed model of protection scheme for distribution lines.

3. Simulation Results

3.1 Output results of distribution line at normal condition

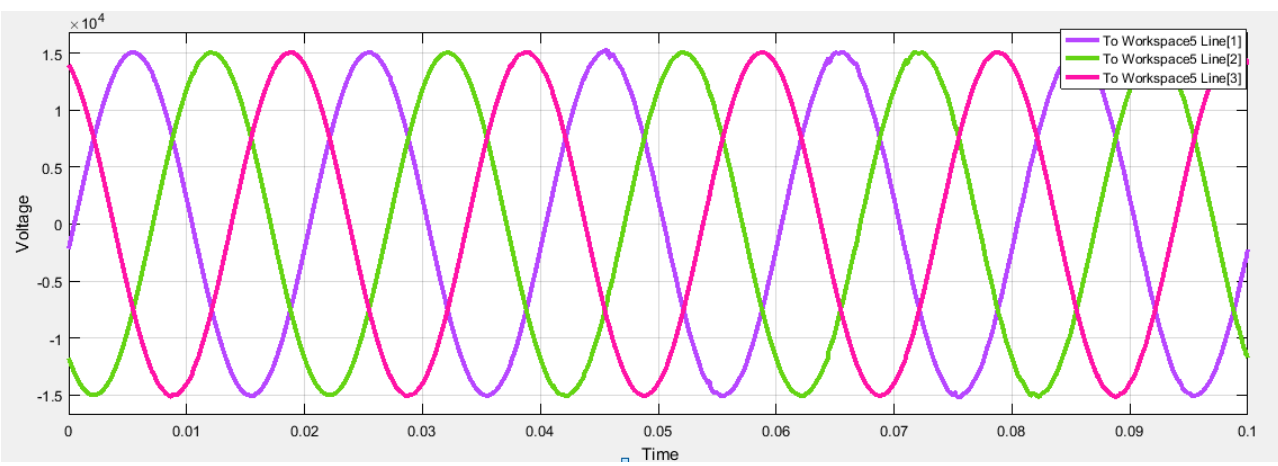

Figure 2. Three-phase voltage wave diagram of distribution line at normal condition.

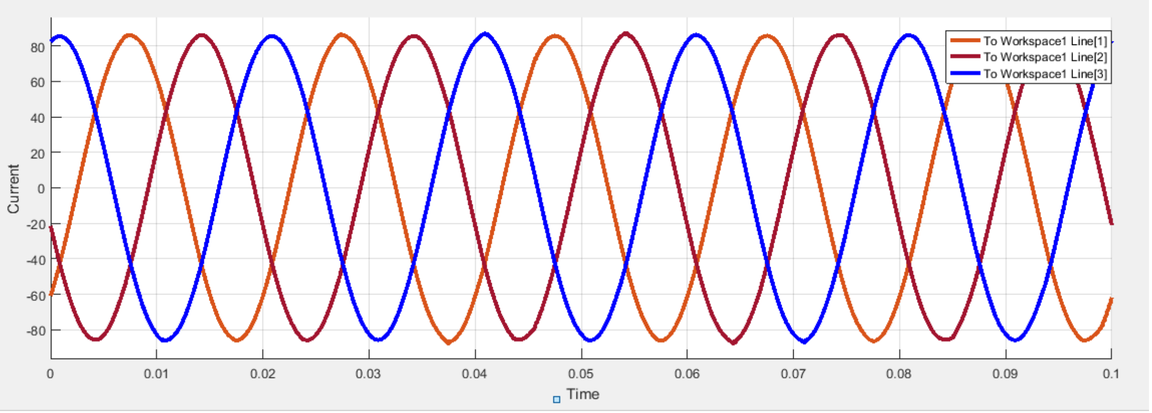

Figure 3. Three-phase current wave diagram of distribution line at normal condition.

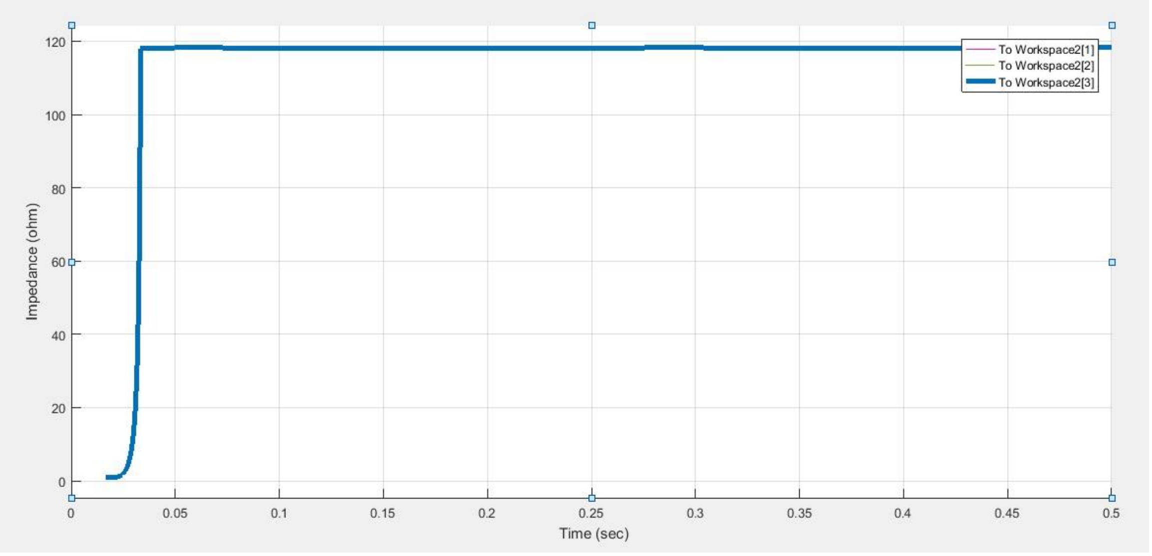

Figure 4. Three-phase impedance wave diagram of distribution line at normal condition.

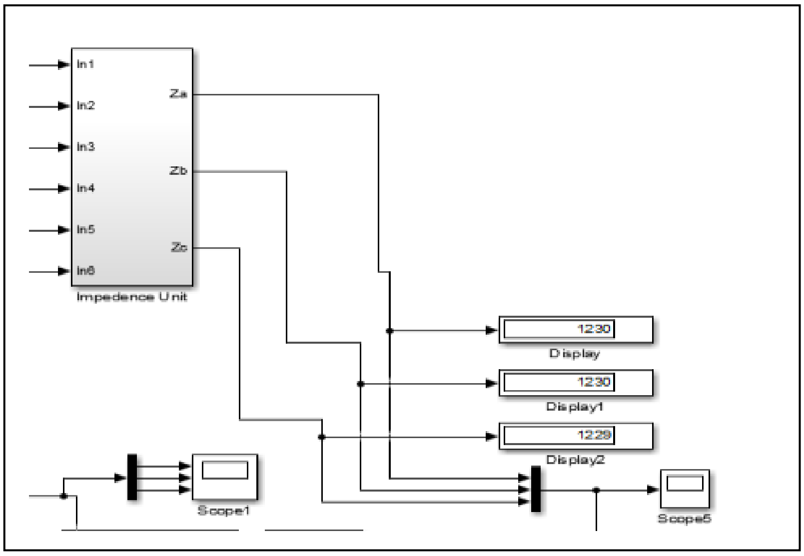

Figure 5. Resultant values at the normal condition.

3.2 Output results of single line to ground (L-G) fault at Zone 1

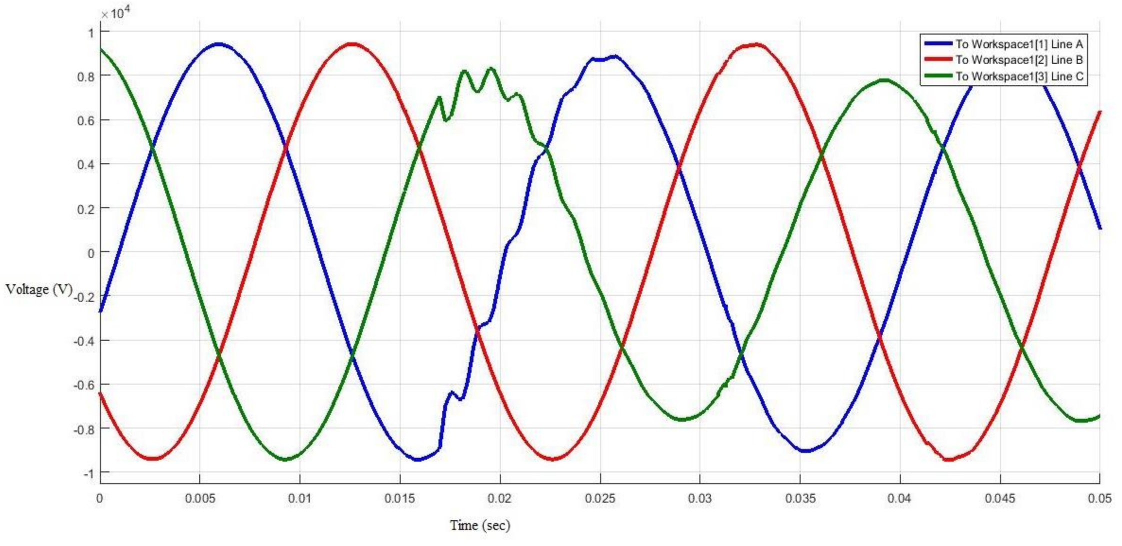

Figure 6. Three-phase voltage wave diagram of the distribution line for the Line A to Ground (L-G) fault at zone 1.

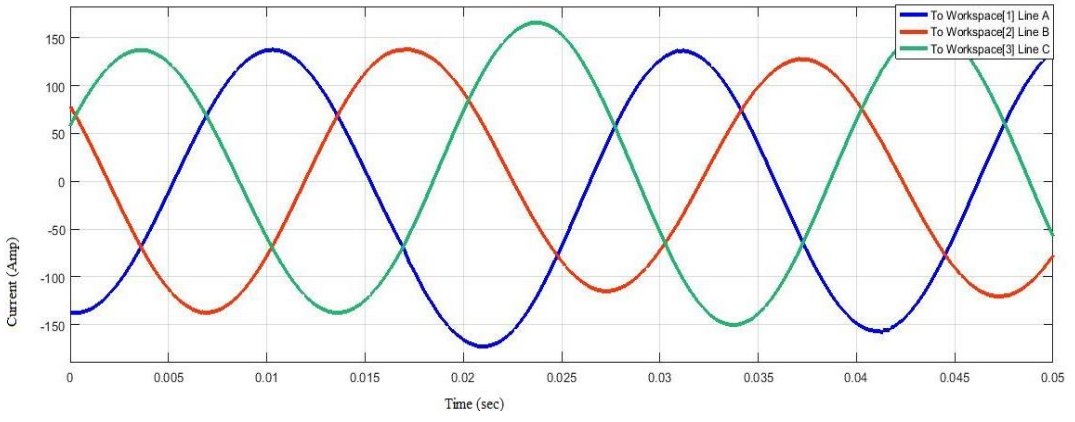

Figure 7. Three-phase current wave diagram of distribution line during Line A to Ground (L-G) fault at zone 1.

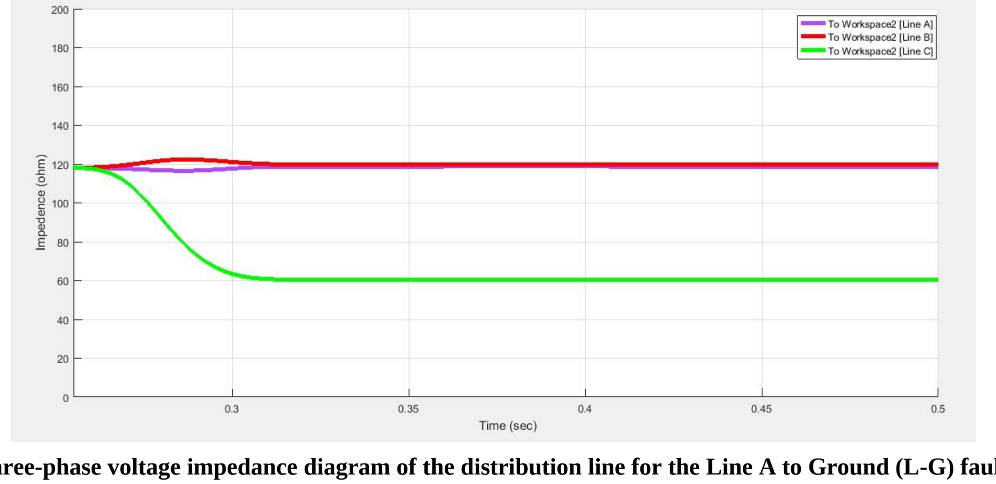

Figure 8. Three-phase voltage impedance diagram of the distribution line for the Line A to Ground (L-G) fault at zone 1.

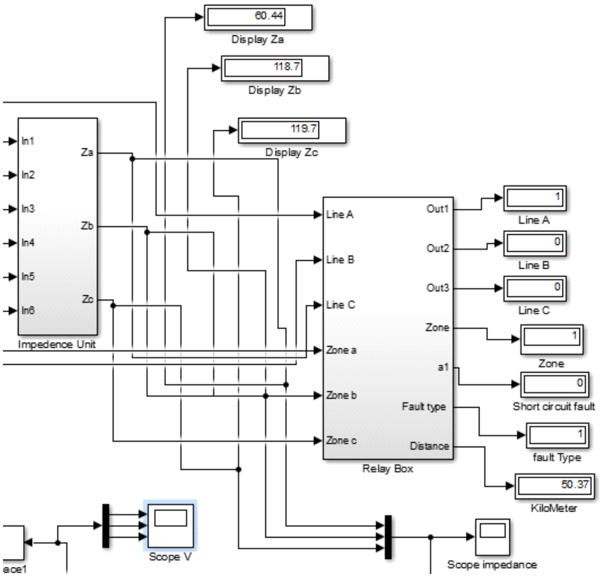

Figure 9. Resultant value for Line A to Ground (L-G) fault at zone 1.

3.3 Output results of Double Line to Ground (L-L-G) fault at Zone 2

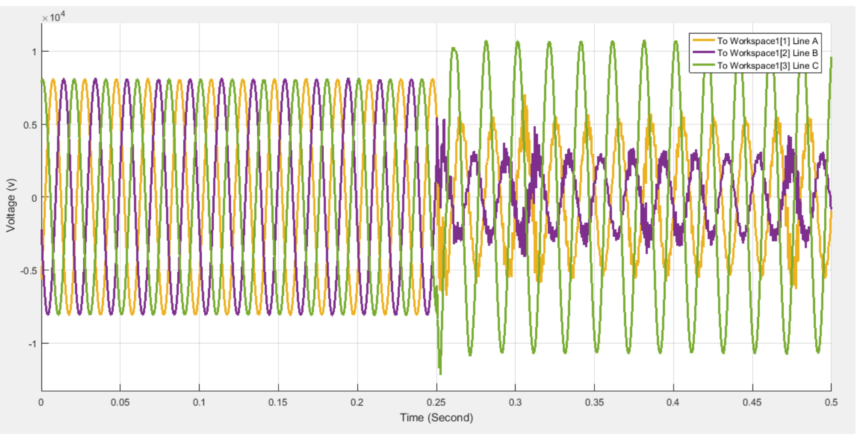

Figure 10. Three-phase voltage wave diagram of distribution line for the L-L-G fault at zone 2.

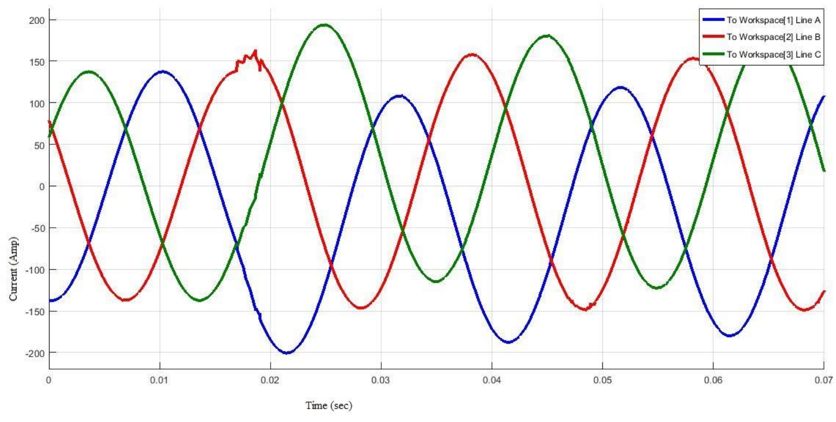

Figure 11. Three-phase current wave diagram of distribution line for the L-L-G fault at zone 2.

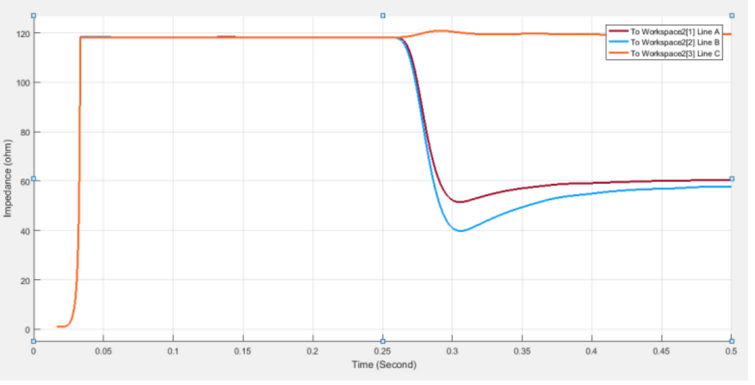

Figure 12. Three-phase impedance wave diagram of distribution line for the L-L-G fault at zone 2.

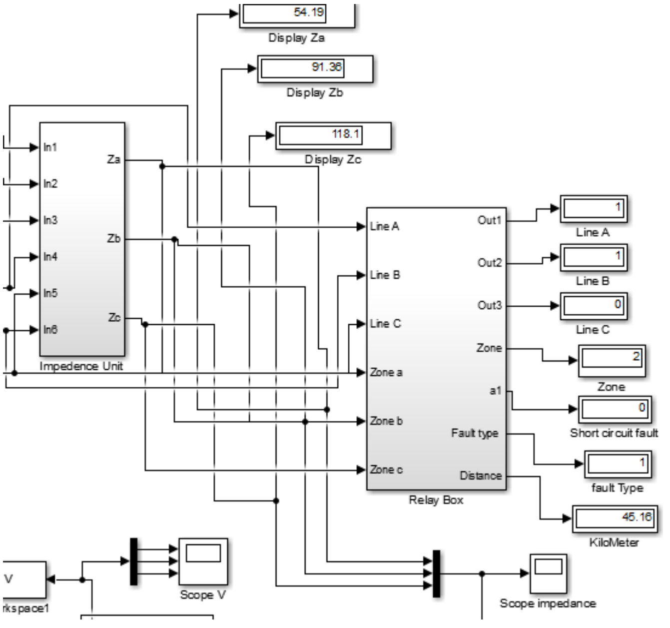

Figure 13. Resultant value for L-L-G fault at zone 2.

3.4 Output results of Triple Line to Ground (L-L-L-G) fault at Zone 3

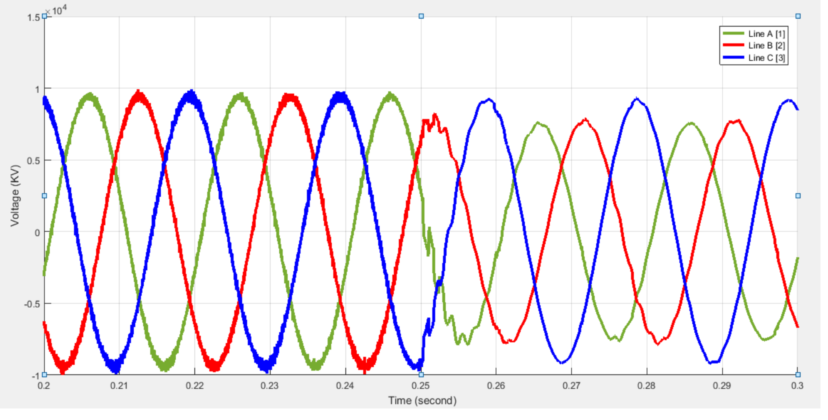

Figure 14. Three-phase voltage wave diagram of distribution line for the L-L-L-G Ground fault at zone 3.

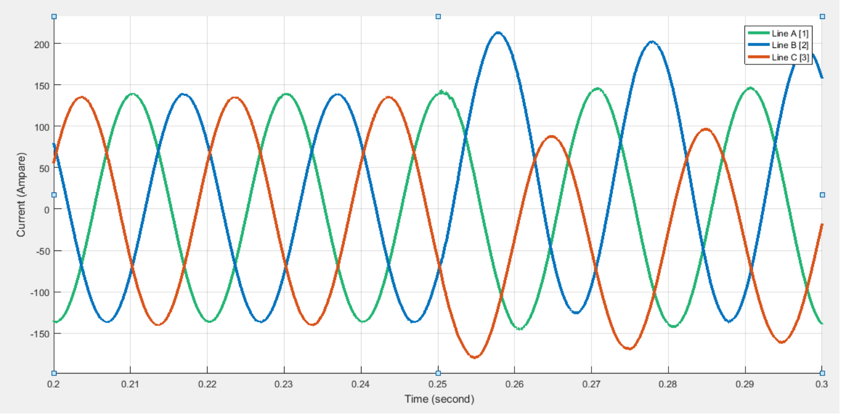

Figure 15. Three-phase current wave diagram of distribution line for the L-L-L-G fault at zone 3.

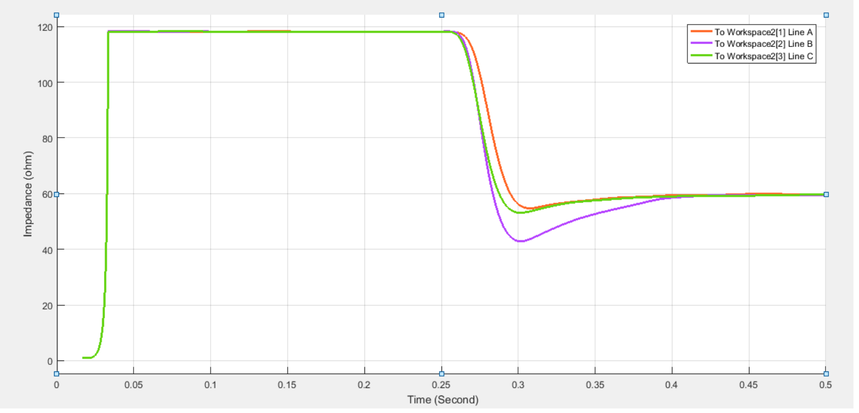

Figure 16. Three-phase impedance wave diagram of distribution line for the L- L-L-L-G fault at zone 3.

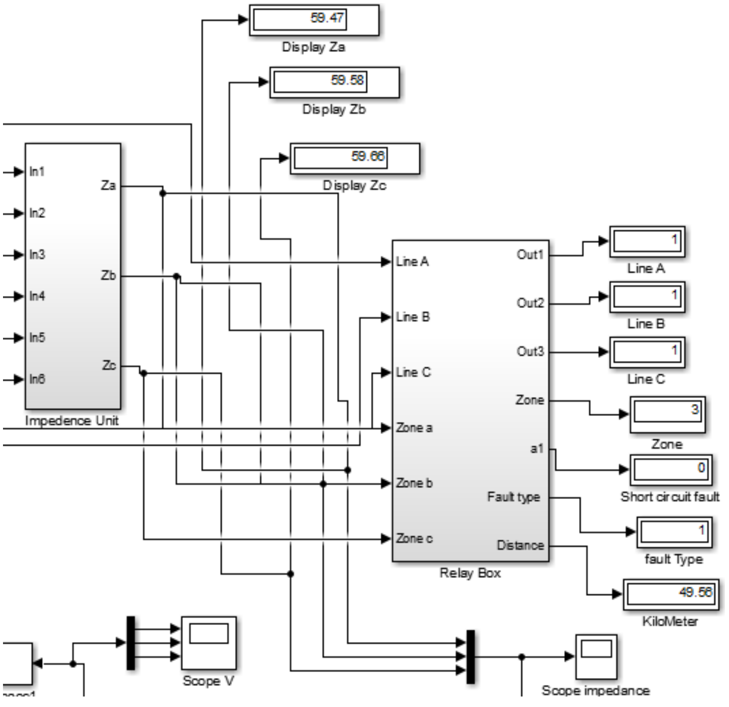

Figure 17. Resultant value for L-L-L-G fault at zone 3.

3.5 Simulation result of updated tripping signal

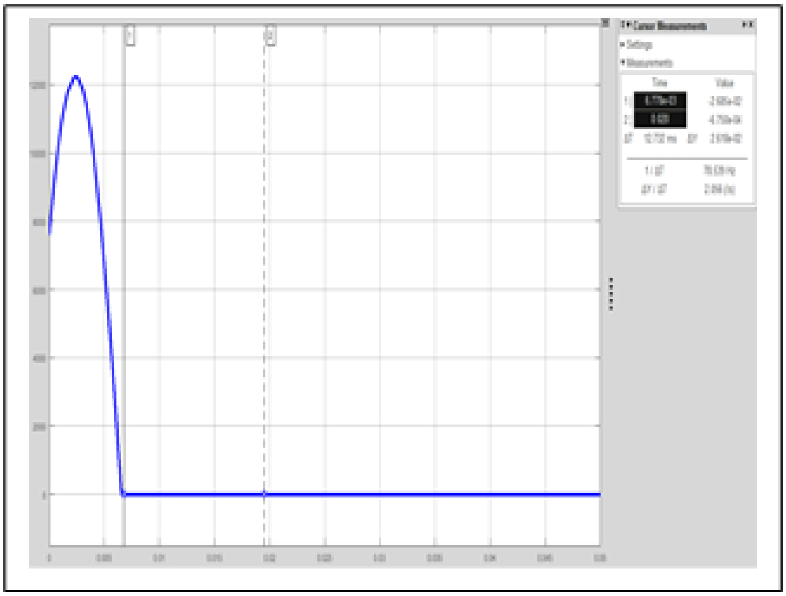

Figure 18. Updated tripping signal output for the Protection Scheme of the distribution network

4. Discussion

4.1 At Normal condition

After completing the design of the proposed model all values of network parameters are set according to the selected substation and run for normal condition. Under this condition, the amplitude of the voltage is 15000 V and the current is 80 A in all phases and a 120º phase difference is maintained among them. Typical voltage and current diagrams are shown in Figs. 2 and 3, respectively. For the three-phase distribution line, the impedance wave diagram and their resultant values are shown in Figs. 4 and 5, respectively. It is observed that the impedance of all lines is almost the same and there is no change. Therefore, it has been concluded that at the normal condition, all values are kept indistinguishable which means the lines are healthy and secure. Table 1 shows the relay output at normal conditions.

Table 1. Relay output at normal condition

Name of line	Output	Description
Line A	0	Line is healthy
Line B	0	Line is healthy
Line C	0	Line is healthy
Zone #	0	No fault occurs in the zone
Circuit breaker (CB)	1	Send a tripping signal to the CB

4.2 Line to the ground (L-G) fault at Zone 1

During line A-to-Ground fault, the wave diagram of the voltage and current are shown in Figs. 6 and 7. In three three-phase distribution line, when the line to ground fault is occurred at zone 1, the amplitude of voltage of line A declined from 10 kV to 8 kV and at the same time the amplitude of current jumped up from 100 A to 155A. During this fault, the values of other lines remained unaffected. The impedance diagram in Fig. 8 expresses the impedance of line A which went down from 120 Ω to 60 Ω. The other two lines, B and C remained healthy and safe with their impedance of 120 Ω for each. The relay box presents the line fault and the distance during the fault period. The resultant value for Line A to Ground fault at zone 1 is shown in Fig. 9. The description of all line conditions for Line A to Ground fault is given in Table 2.

Table 2. Relay output for Line A to Ground fault

Name of line	Output	Description
Line A	1	Fault Occurs in Line A
Line B	0	Line is healthy
Line C	0	Line is healthy
Zone #	1	Faults occur in Zone 1
Circuit breaker (CB)	1	Send a tripping signal to the CB

4.3 Double Line to Ground (L-L-G) fault at Zone 2

In this section, a double line to ground is considered between lines A and B to the ground at zone 2. The voltage of lines A and C reduced from 10,000 V to 2000 V and line B has an amplitude of 2000V as shown in Fig. 10. The current of faulty lines increases from 100 A to 150 A which is shown in Fig. 11. The impedance of the faulty lines decreased to inferior values 40 Ω and 50 Ω individually and the distance from 45 km to 60 km during the fault as shown in Fig. 12. From Fig. 13, it is seen that the impedance of the affected lines A and B reduced from 120 Ω to the lower value 54.19 Ω. The other line C is healthy and safe. The relay box also showed the line fault and the distance during the fault period. The description of all line conditions for line A and line B to Ground fault is given in Table 3.

Table 3. Relay output for Line A-Line B to Ground fault

Name of line	Output	Description
Line A	1	Fault occurs in Line A
Line B	1	Fault occurs in Line B
Line C	0	Line is healthy
Zone #	2	Fault occurs in Zone 2
Circuit breaker (CB)	1	Send a tripping signal to the CB

4.4 Triple Line to Ground (L-L-L-G) fault at Zone 3

Similarly, when faults take place in all three lines with respect to the ground, the voltages of lines A, B, and C have been reduced to 10000 V from 15000 V and to a lower value which is shown in Fig. 14. From the current wave diagram in Figure 15, it can be seen that the line currents of lines A, B, and C have been increased from 80 A to 140 A continuously, though the current is increased more after 0.25 seconds in line A. It is observed that the impedance of all lines falls to a lower value as shown in Fig. 16. Fig. 17 shows the faults occurred at zone 3 at about 49.56 Km. Moreover, the conditions of all lines under this L-L-L-G fault are shown in Table 4.

Table 4. Relay output for L-L-L to Ground fault

	Output	Description
Line A	1	Fault Occurs in Line A
Line B	1	Fault Occurs in Line B
Line C	1	Fault Occurs in Line C
Zone #	3	Fault occurs in Zone 3
Circuit breaker(CB)	1	Send tripping signal to the CB

4.5 Simulation result of update tripping signal

The faster response of a digital distance relay is mostly depending on the tripping time of a relay system of the distribution network. The performance time of the conventional relay system is longer for isolating a typical faulty section from a healthy section which is about 40 ms. Generally, relays are used in a substation to draw the tripping signal from 20 to 40 ms for isolating the faulty section. To overcome such problems, we develop a model that can carry out faster response than the typical distance relay, so that the relay can isolate the faulty section within 7 ms. During the analysis, we tried to reduce the trip signal time so that the relay could isolate the faulty section from the healthy section. To reduce the trip time another three-phase measurement is used from a three-phase circuit breaker and we have made a new three-phase section for finding the perfect trip signal. The breaker resistance is set at 0.001Ω at the close position, V-I measurement at Phase to phase and current measurement at the yes position, Step time at 0.1 Second, and Simulating the circuit at 0.3 Sec Scale. The faster-tripping signal resulting from the simulation of the proposed relay model is shown in Fig. 18. It is observed that the new trip time is 6.778 ms which is much smaller than the conventional relay system.

5. Conclusion

Transmission lines play a pivotal role in transmitting power from generation to distribution points, underscoring the necessity of safeguarding them and their components from disruptions. This thesis investigates the fundamental faults within a 33/11kV distribution network and endeavors to develop protection mechanisms using Matlab/Simulink software. Emphasis is placed on analyzing power system instabilities to enhance overall system protection and reliability. Various types of relays are employed in the protection system to facilitate the seamless transfer of power between distribution and transmission lines. These relays, in conjunction with breakers and other protective devices, serve to isolate faulty sections swiftly, thereby preventing system-wide failures. This work introduces a distance relay protection scheme tailored for distribution lines. While distance protection and fault detection are essential, they can also influence power system stability. To address this, we propose measures to enhance performance by combining new relay criteria with traditional impedance characteristics. This proposed method approach aims to fortify the distribution line's protection system against faults through the utilization of distance relays.

Various fault scenarios, including line-to-line, line-to-ground, double-line-to-ground, and triple-line-to-ground faults, are examined at the output of the relay box. Protection schemes are refined using a novel algorithm implemented in Matlab/Simulink software. Under normal conditions, voltage amplitude registers at 15 kV, current at 80 A, and impedance at 120 Ω. However, in the event of faults, voltage and impedance values decrease while current values increase compared to normal conditions across different fault zones. Fault location was also calculated and it is varied from 45 to 60 Km depending on the impedance at different zones. Initially, the relay response time for any fault ranged from 20 to 15 ms. Through algorithm enhancements and simulation modeling, we achieve a substantial reduction in relay response time to 6.778 ms, significantly faster than conventional relay systems. In conclusion, this proposed method effectively improves protection performance by minimizing relay response delay. Consequently, the overall protection scheme for distribution lines within the power system is enhanced, ensuring satisfactory service delivery to customers.

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