International Journal of Control and Automation
Vol.9, No.1 (2016), pp.371-386
http://dx.doi.org/10.14257/ijca.2016.9.1.32

Application of Differential Protection Technique of Domestic Solar Photovoltaic Based Microgrid

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Abstract

The microgrid systems play a vital role in reducing the impact of renewable generation effect on the main grid. Microgrid systems can achieve grid-tied operation and isolated operation modes with fast switching and isolation functions. The reliability of power supply can be further achieved through the microgrid by reforming a mesh configuration. However, the protection of the network is a challenging task due to the bi-directional power flow and the change of the network structure. In this paper, an adaptive -model and simulation of the solar photovoltaic microgrid differential current protection scheme -are presented. Differential scheme denotes a very credible method to secure the protection zone. The protection system that is under consideration behaves the most important part of the power system. Current protection relay scheme plays an important role in the protection of transmission lines, because it is sufficient and reliable. This paper discusses (dual slope) differential relay parameters of the system with various fault situation states. Therefore, the protection scheme must identify the fault zone for rapid separation to reduce the damage of equipment. Our simulation results show that the proposed method is effective and can reduce the percentage of errors.

***Keywords**: Microgrid protection, Solar PV Array, Differential relays, Relay model.*

1. Introduction

Protection is one of the most important challenges for the deployment of Microgrids (MGs). Microgrid is used efficiently for the resources allocated to provide economic, reliable electricity to our customers. Islanded operation, during the disturbance main grid must be continuous power supplied to the load. Reliability of the microgrid can be further improved by the formation of a network structure. However, the protection of the microgrid is a challenging task [1, 2]. In this paper, the protection scheme using current differential protection for the microgrid is discussed. Problems related to the protection are the bi-directional power flow, reticular structure and the fault current level. The microgrid is designed to run in the operation mode of the power grid connection or separation. When the power source is in the damaged part of the distributed generator, the main grid continues to supply the island. Therefore, the island allows benefits to customers to reduce power outages [3-4].

Power system must operate at any time in a safe manner, however, even with the perfect design, it may fail. Failure can cause partial or complete blackouts. In order to prevent the interference to the system, the protection system is necessary. There are a lot of ways to solve this problem. The main requirements of relay protection in a power system include speed, selectivity, sensitivity, safety, reliability, and dependability. Selective protection system must reliably determine its protected area of failure. Sensitivity is the smallest possible malfunction that the relay can pick up. Security is an ability to express tripping or protecting the system to avoid running the property.

ISSN: 2005-4297 IJCA

Reliability is the degree of certainty that the relay will operate correctly. The reliability requirement for the protection system is to ensure the appropriate and operable protective action, even when some parts of the protection device may have failed. High-quality equipment's and necessary routine testing can ensure that the equipment's still operate well, and the redundancy protection system design is feasible [5].

The disadvantages of distance and directional over current relay on the transmission line are :(1) relays cannot disconnect instantly on both ends of the line if a fault occurs at the end of the line. (2) Coordination is achieved by adjusting the time delay of the relay mounted on a channel next to the main and backup protection. As a result, termination disturbance will be slow in line with the delay time of the relay that works on each protection zone [6].

2. Differential Protection of Transmission Line Model

Differential Protection principle is based on Kirchhoff current law which has been widely used in main equipment protection of power systems. The fault current is proportional to the internal fault, and must be close to zero under normal condition [7].

2.1. Differential Protection Criterion

For the ratio differential protection, the multi-slope feature as shown in Figure 1 is introduced to the modern relay due to its excellent compromise between reliability and sensitivity. Differential components compare the differential current (also called operating current) with restraining current. Differential current I_{diff} and Restraining current I_{bias} are expressed as [8-9]:

$$I_{diff} = |I'_{As} + I'_{Bs}| \tag{1}$$

$$I_{bias} = (|I'_{As}| + |I'_{Bs}|)/2 \tag{2}$$

I'_{As} and I'_{Bs} are secondary CT phase current. The relay may have two stages (low and high) in tripping characteristic to provide a flexible and a secure operation. A typical characteristic of differential protection is shown in Figure 1.

For : $|I_{bias}| < I_{bias1}$

$$|I_{diff}| > K_1 * |I_{bias}| + I_o \tag{5}$$

$for \quad |I_{bias}| \geq I_{bias1}$

$$|I_{diff}| > \mathrm{K}_2 * |\mathrm{I}_{bias}| - (\mathrm{K}_2 - \mathrm{K}_1)\mathrm{I}_{bias1} + \mathrm{I}_o \tag{4}$$

Where:

I_o: the pick – up setting of the differential relay
K_1: the slope of the first part of the characteristic
K_2: the slope of the second part of the characteristic

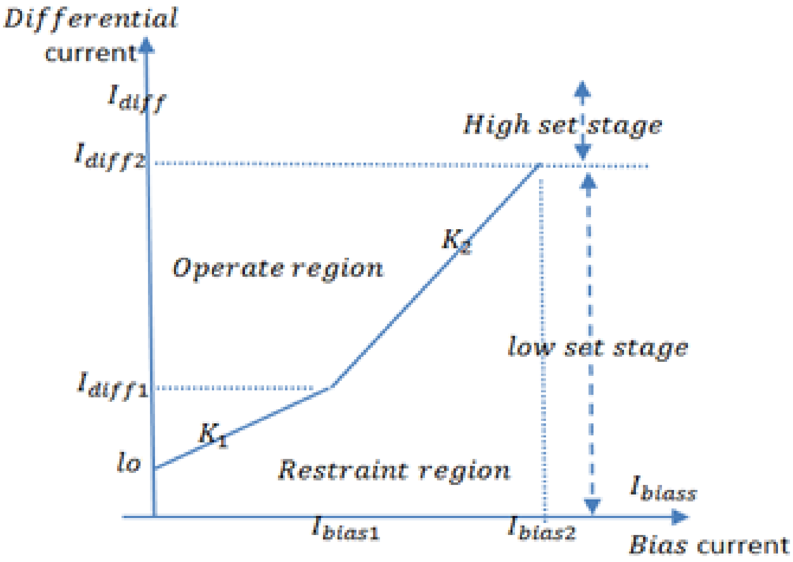

Figure 1. Differential Relay Characteristic

2.2 Current Differential Protection Principle

Figure 2 shows one phase current differential protection system. Clearly, the protected area is enclosed by a pair of current transformers. Because it's a natural tendency, differential protection does not provide backup protection for adjacent system equipment's or transmission lines. , For this reason, this type of protection is famous for the unit protection scheme. As shown in Figure 2, in case of no fault, the current input protection unit I_p is the same as the current going out from the protected zone at all times. By considering current transformer A, the current that the pilot wire is carrying from CT_A is equal to

$$I_{AS} = a_A I_p - I_{Ae} \tag{5}$$

Where, a_A is the conversion ratio for CT_A

I_{Ae} is the secondary excitation current for CT_A

Similarly for current transformer B, the equation is as follows:

$$I_{BS} = a_B I_p - I_{Be} \tag{6}$$

Where, a_B is the conversion ratio for CT_B

I_{Be} is the secondary excitation current for CT_B

Considering the equal ratio, $a_A = a_B = a$, the operating current of relay I_{op} is

$$I_{op} = I_{Ae} - I_{Be} \tag{7}$$

For the normal operation or the external fault situations, the relay's operating current Iop is very small, but it never tends to zero. But within the time of the internal fault, the current input the protection unit is no longer equal to the outgoing current.

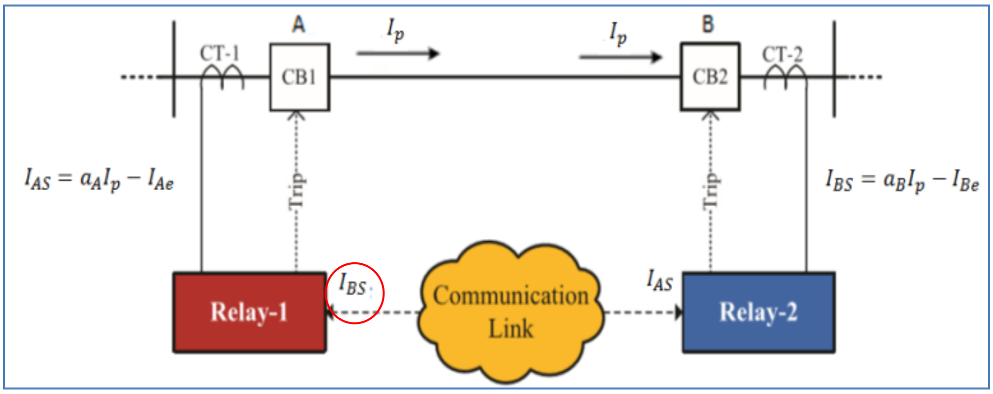

Figure 2. Differential Relay Currents at the External Fault

The operating current of the differential relay is nothing more than an increase of the input current as the same as the feed fault as shown in Figure 3.

$$I_{op} = a(I_{f1} + I_{f2}) - I_{Ae} - I_{Be} \tag{8}$$

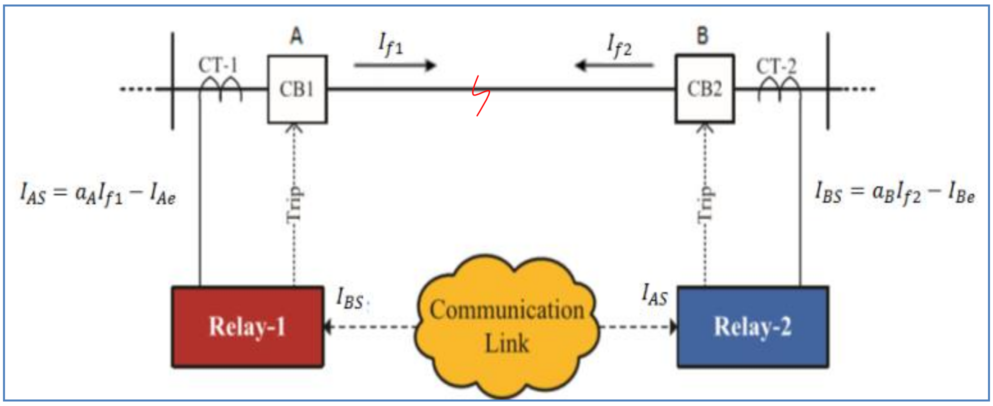

Figure 3. Differential Relay Currents at the Time Internal Fault

The following equations are for the uniform distribution transmission line, where, c_o is shunt capacitance (F/km), g_o is the shunt leakage conductance (S/km), l_o is series inductance (H/km) and r_o is a series resistance (Ω/km).The distribution of current and voltage along the transmission line is given by equations below[10].:

$$-\frac{\partial u}{\partial x} = r_o i + l_o \frac{\partial i}{\partial t} \tag{9}$$

$$-\frac{\partial i}{\partial x} = g_o u + c_o \frac{\partial i}{\partial t} \tag{10}$$

By transferring equation (9) and (10) to its frequency domain:

$$\begin{bmatrix} U_m \\ I_m \end{bmatrix} = \begin{bmatrix} ch(\gamma l_{nm}) & -Z_c sh(\gamma l_{nm}) \\ sh(\gamma l_{nm})/Z_c & -ch(\gamma l_{nm}) \end{bmatrix} \begin{bmatrix} U_n \\ I_n \end{bmatrix} \tag{11}$$

Where, $sh(.)\ and\ ch(.)$ are Hyperbolic functions. Zc is the characteristic impedance, and γ is the propagation constant. Both are of frequency dependent. And l_{nm} is the distance from end n to end m.

3. System Modeling

The simulation of line differential protection is presented in Simulink / Matlab Environment, as shown in Figure 4. It simulates a three-phase, two sources, 60 Hz, 25 kV transmission line, with 22 kilometers in length used in the system. The detailed design of each block is shown separately from Figures 4 to 6. To get right settings, characteristics of the relay must be considered. The proposed settings of the protection scheme for transmission lines from bus A to bus B and the information corresponding to the lines are listed in Table 1, where $I_n$is the rated secondary current. In this work, $I_n$is taken to be 1 Amp. According to this value of I_n , the following constants are:

$$I_0 = 0.3 \ , \ \ I_{S2} = 2.0 \ , \ \ K_1 = 0.35 \ \ , K_2 = 1.2$$

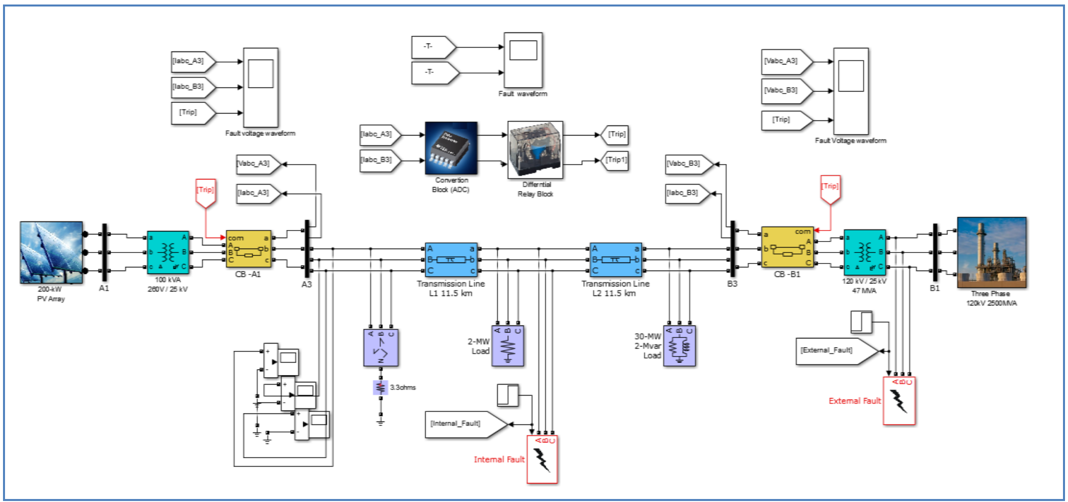

Figure 4. Matlab /Simulink Representation of the Differential Line Protection Schemes for Microgrid

Table 1.Relay Setting Ranges

Relay Setting	Range
Differential current setting I_o	(0.2-2.0I_n)
Bias current threshold setting I_{S2}	(1-30I_n)
Lower percentage bias setting K_1	(0.3-1.5)
Higher percentage bias setting K_2	(0.2-2.0I_n)

4. Matlab/Simulink Representation

In the local (A3) and remote side (B3), CTA and CTB are respectively installed to measure current and voltage per phase. The current and voltage of each phase of the analog signal are converted into digital data by using analog-to-digital converter (ADC) block, as shown in Figure5.

The local side is directly connected to the relay while the faraway side is connected to the transmission delay block. The function of this block is to delay the channel time (propagation) factor into the remote signal. Channel time delayed setting 27 msec, as shown in Figure 5.

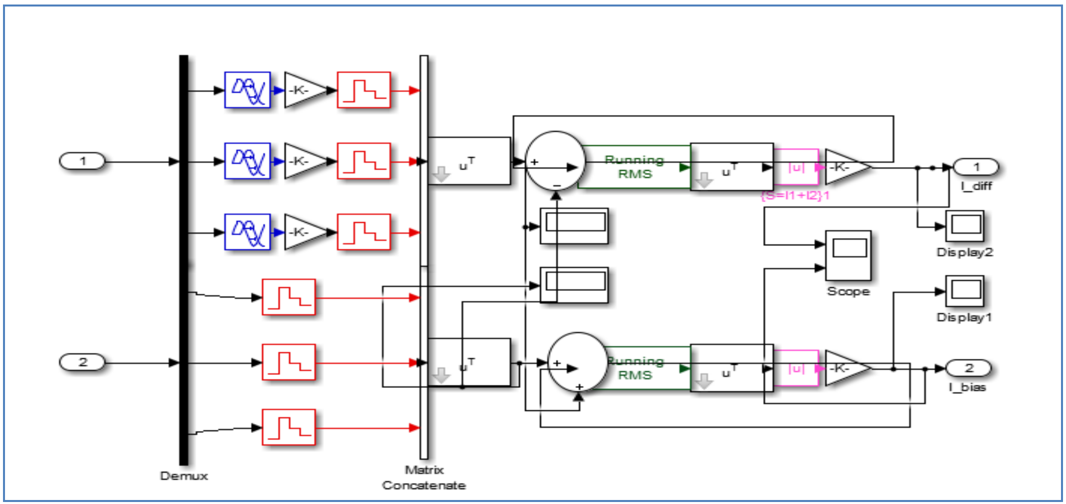

Figure 5. ADC and Comparative Block

In the three-phase differential blocks, the feature is distinguished by the current both (local and remote) amplitude, as shown in Figure 6.

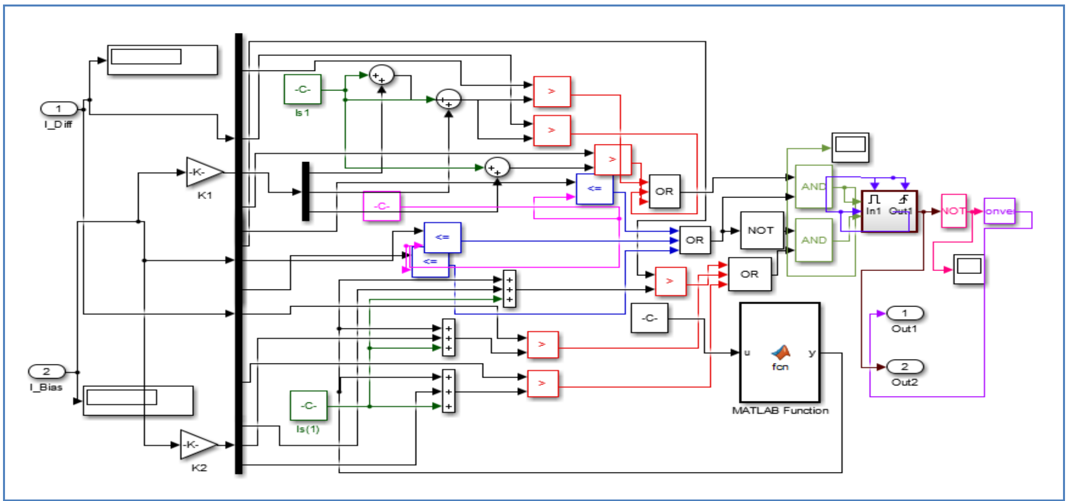

Figure 6. Differential Block

The output of the three-phase differential relay block is binary (0, 1). When disturbances happen in the protected region, there will be a current difference between the two channels (local and remote). Thus, the relay is set to provide tripping signal when there is a difference in the current or the voltage across each phase. In this paper, we proposed that the fault will occur in the middle of the line starting at 0.3 msec. In the fault parameter block, the fault type is simulated separately by using MATLAB.

5. Simulation Results and Discussion

In this part, we consider two fault situations (External and Internal faults), and for each situation we considered five cases .The five cases are as follows; Case 1, Single Line to Ground Fault (SLGF); Case 2, Line to Line Fault (LLF); Case 3, Double Line to Ground Fault (2LGF); Case 4, Three Line Fault (3LF); Case 5, Three Line to Ground Fault (3LGF).

The main principle of the differential relay should be compared for both ends protected area. Modeling for each case was made in a similar form, comparing the current at both ends. All used cases results are indicated from Figures 7 to 22.There are three diagrams in every figure: Remote, Local and Differential. Remote and local measurements are done separately; each color in this diagram represents one phase such as red, green and blue colors for phase A, B and C respectively. The difference diagram is represented as a binary (0, 1) measurement, which is the difference between the signals of the two ends and is then sent as the signal trip., represents the difference between the current and voltage magnitude of the two ends.

The Figures 7 to 22 has two types of status: one is for current differential and the other is for the voltage differential. When the fault occurred at t = 0.3msec, a current value decreased significantly (almost zero) at the remote end, .while voltage on the remote side is increased nearly five times of the normal state. The simulation is done for 400 kW of photovoltaic array, connecting the microgrid.

5.1 Simulation Results under External Fault

Figures 7-8 show results of an external L-G fault on system, differential circuit breaker relays give no tripping signal. Similarly, Figures 9-12 show results of external fault on system in various fault conditions, relay send a signal to the circuit breaker.

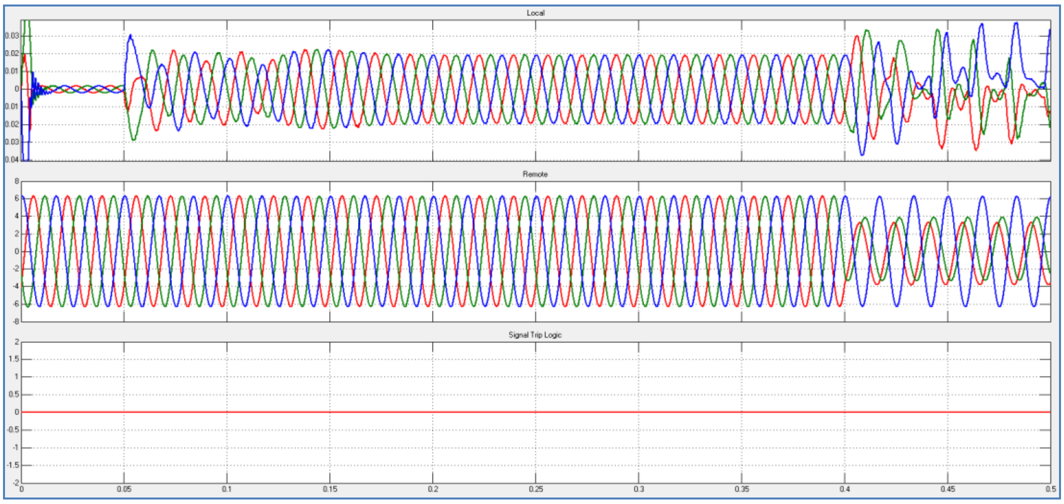

Figure 7. Single Line to Ground Fault Currents Waveform

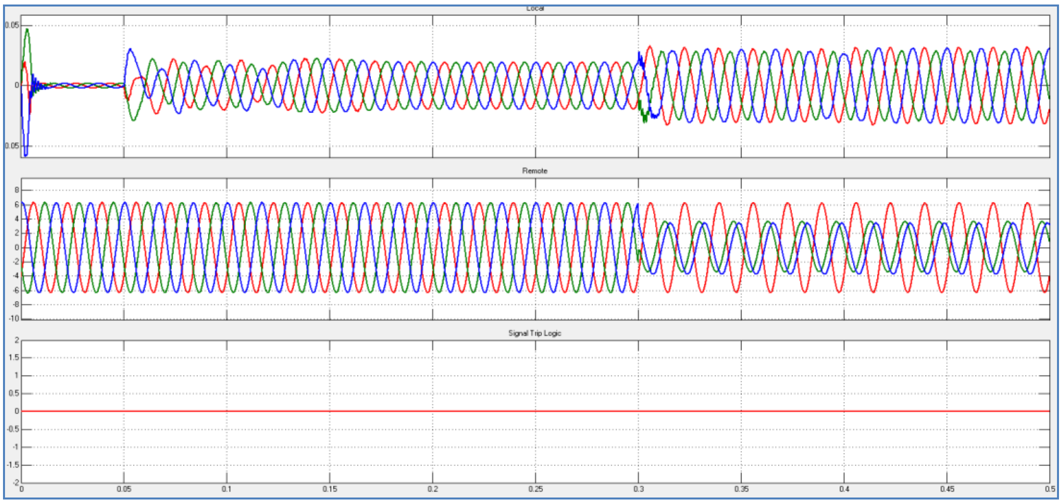

Figure 8.Single Line to Ground Fault Voltage Waveform

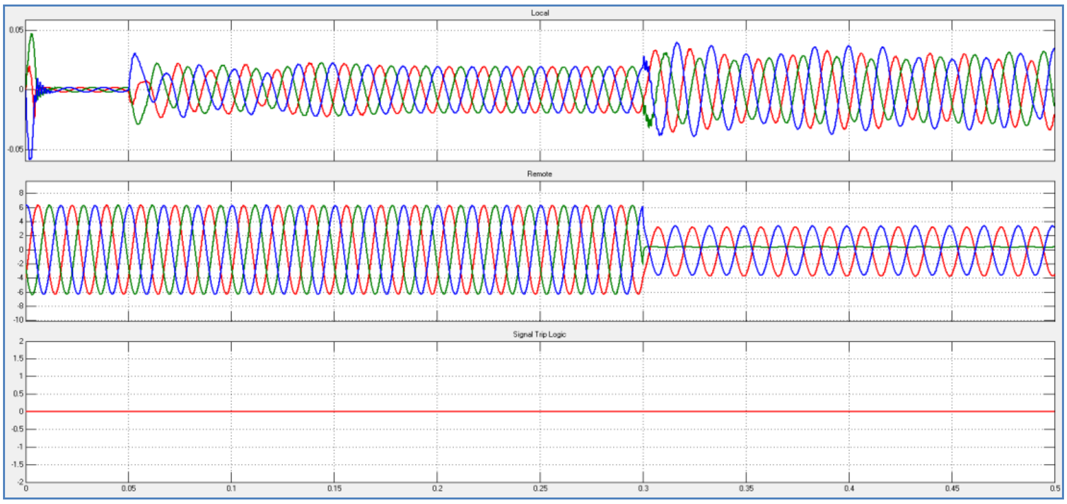

Figure 9. Double Line to Ground Fault Currents Waveform

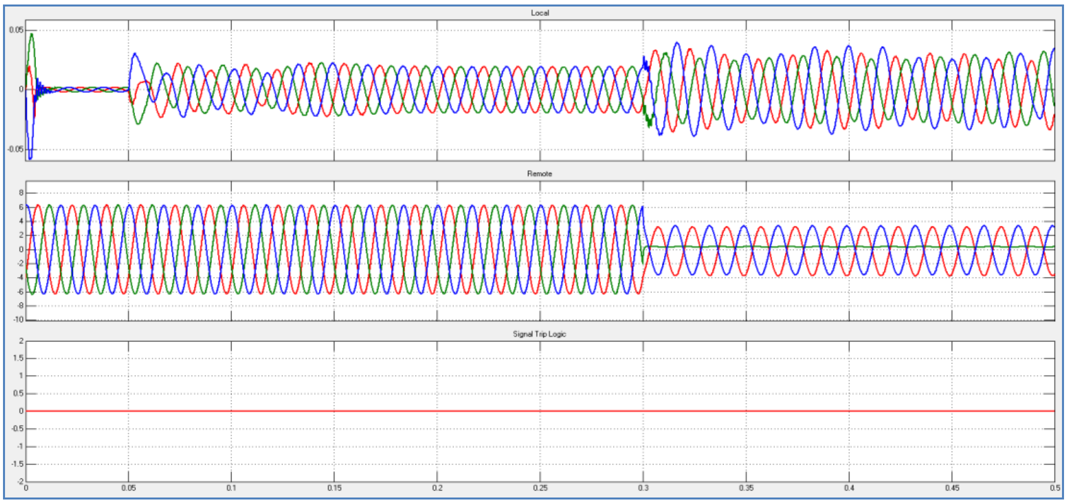

Figure 10. Double Line to Ground Fault voltage waveform

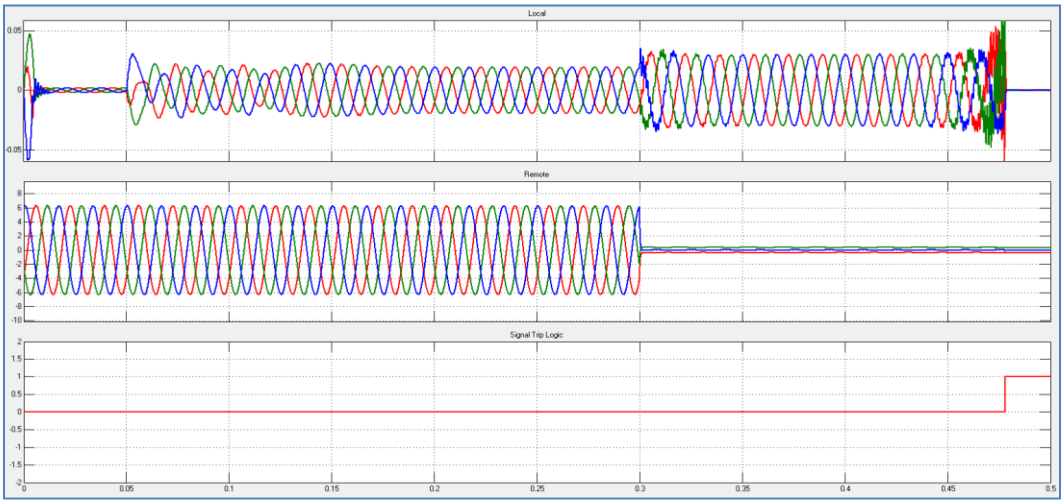

Figure 11. Three Line Fault Currents Waveform

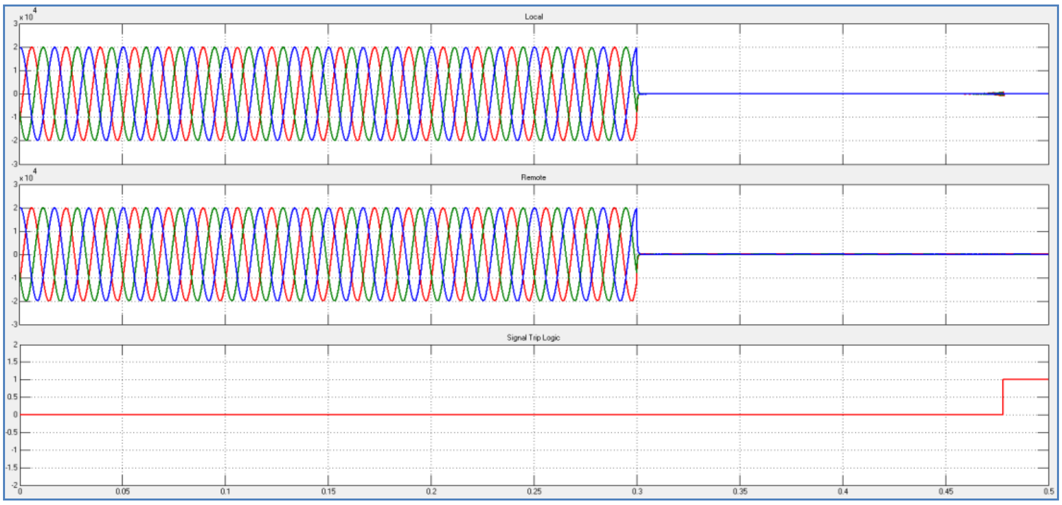

Figure 12. Three Line Fault Voltage Waveform

5.2 Simulation Results under Internal Fault

Figures 13-14 show internal L-G results of fault in the system, internal fault means relay sends a tripping signal to the circuit breaker inside the protected zone, which is clearly shown in differential diagrams of Figure13.

Similarly, figures 14-22 show results of internal fault in the system .The relay sends a trip signal to circuit breaker under faulty condition, and circuit breaker isolates the zone relay from the system.

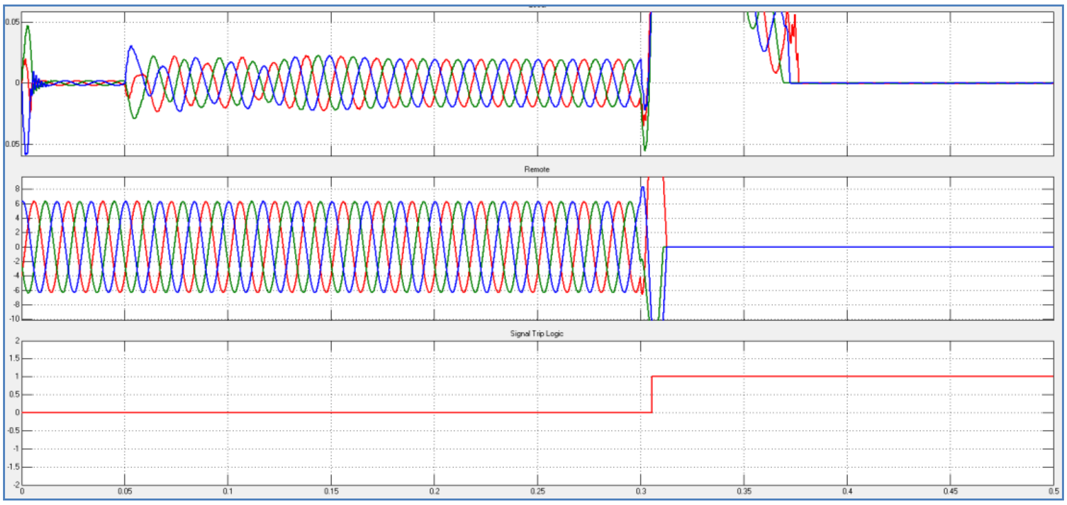

Figure 13. Single Line (A) to Ground Fault Currents Waveform

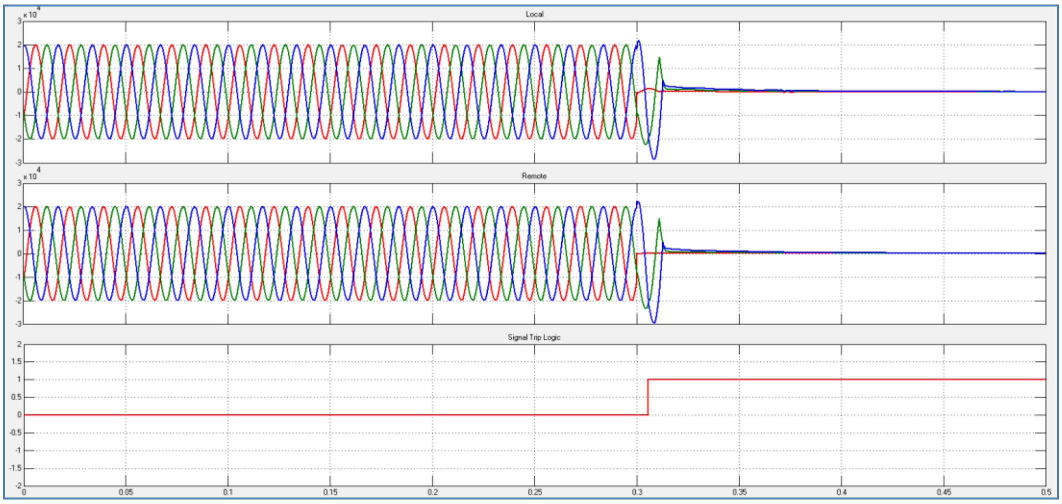

Figure 14. Single Line(A) to Ground Fault Voltage Waveform

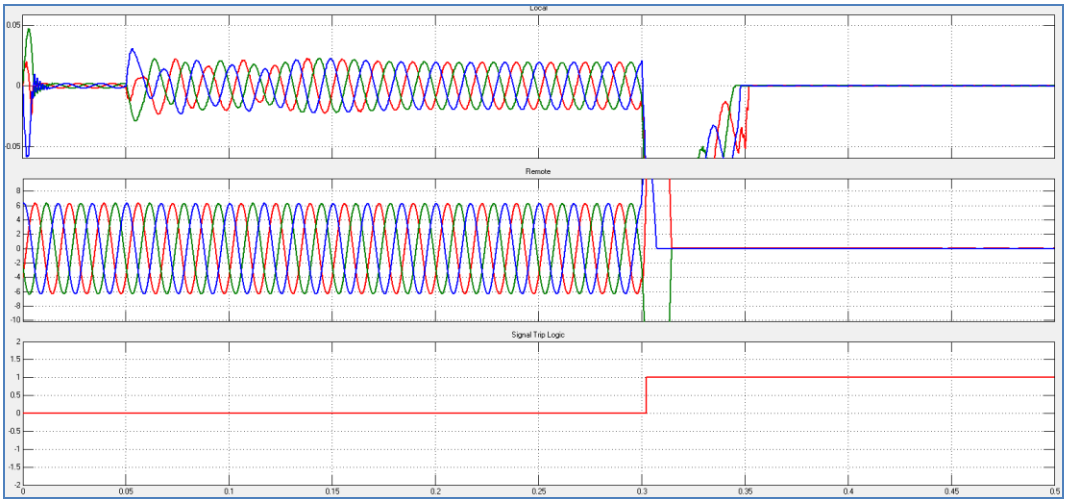

Figure 15. Double Line (A&B) Fault Currents Waveform

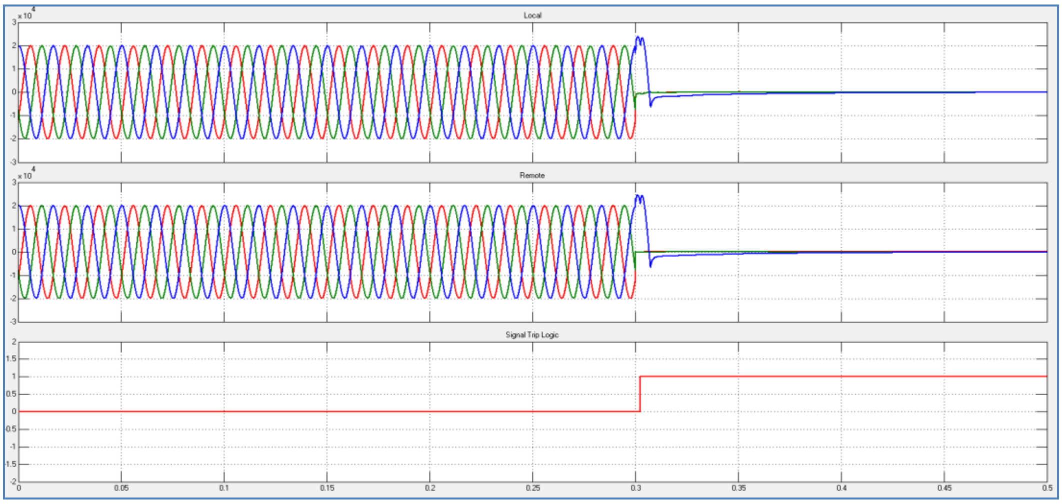

Figure 16. Double Line (A&B)Fault Voltage Waveform

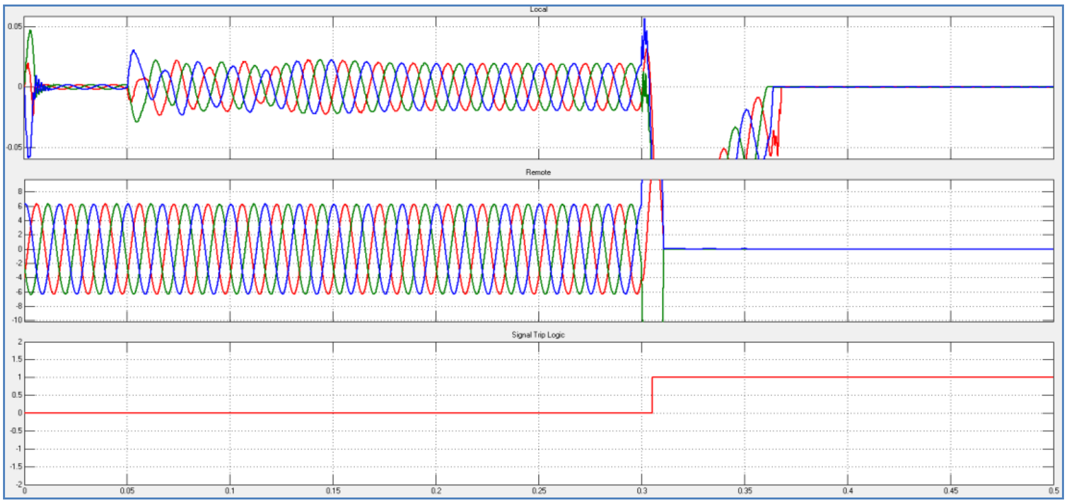

Figure 17. Double Line(B&C) to Ground Fault Currents Waveform

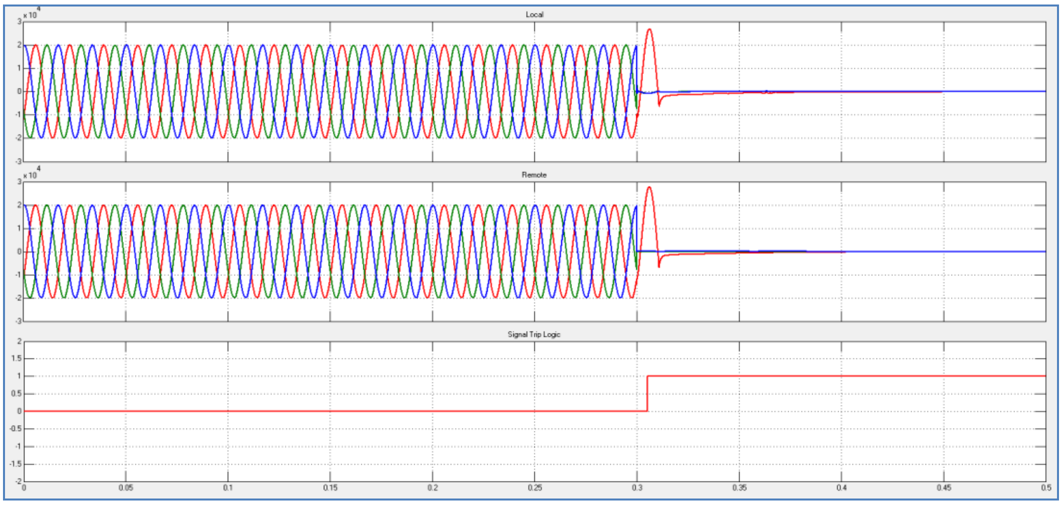

Figure 18. Double Line (B&C) to Ground Fault Voltage Waveform

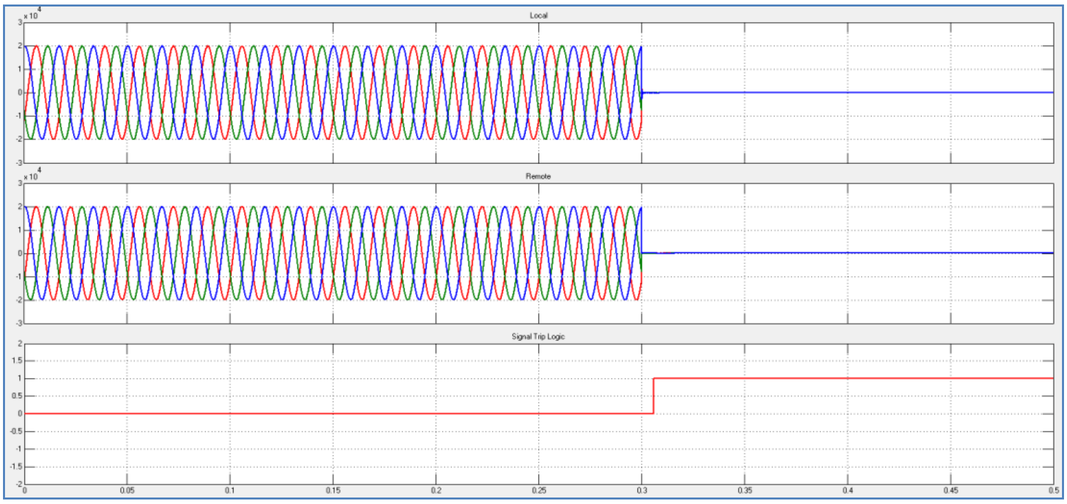

Figure 19. Three Line Fault Currents Waveform

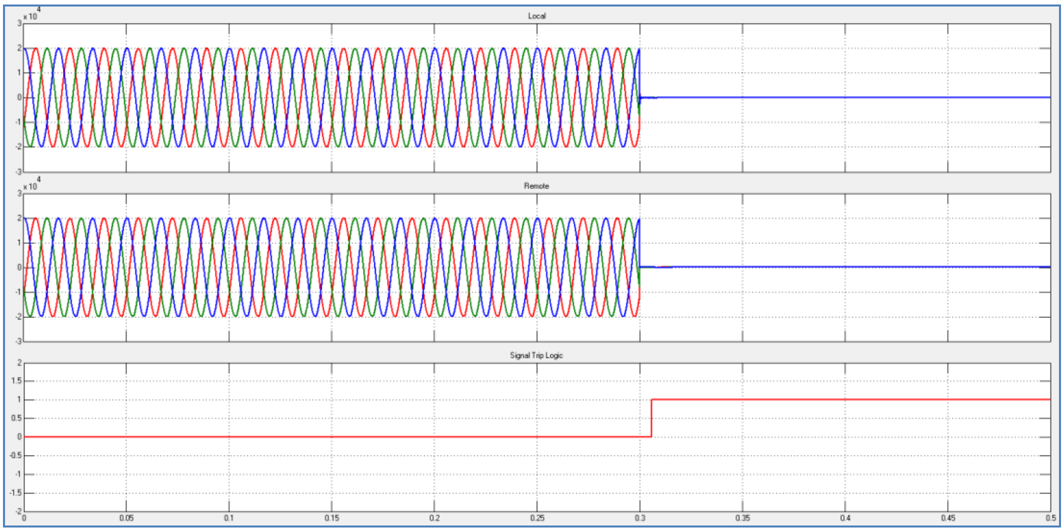

Figure 20. Three Line Fault Voltage Waveform

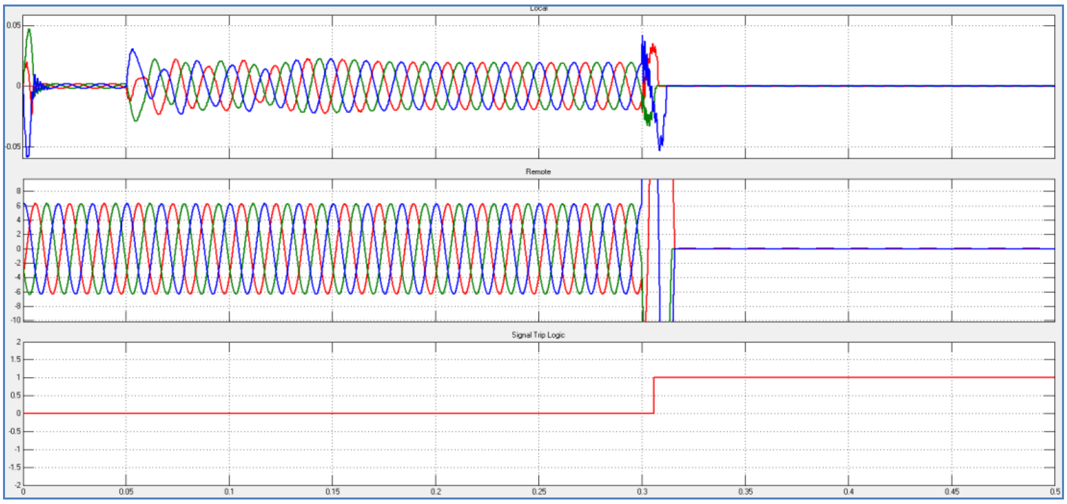

Figure 21. Three Line to Ground Fault Currents Waveform

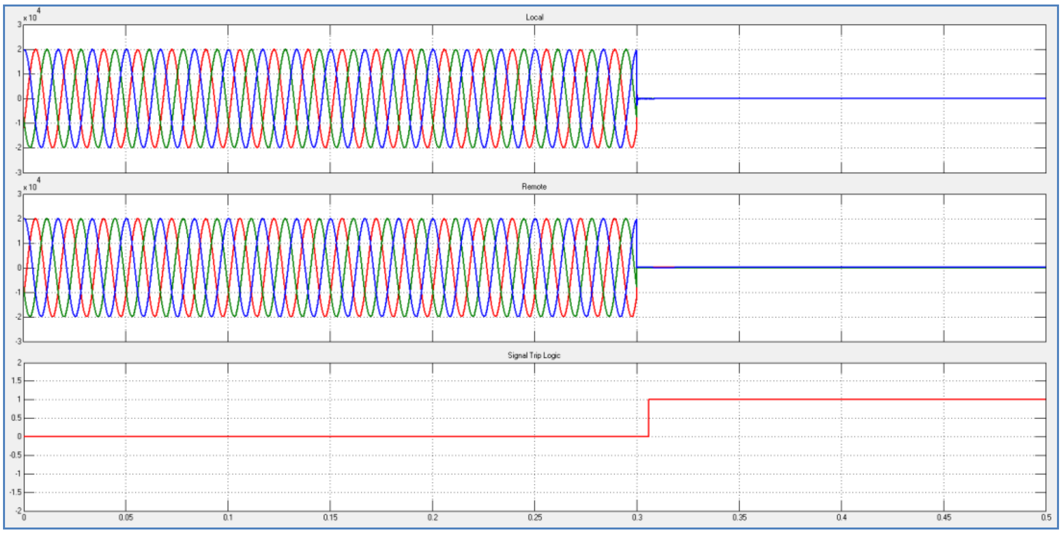

Figure 22. Three Line to Ground Fault Voltage Waveform

Figure 23 shows the main signal trip of the breaker a moment after the fault occurred. When fault have been recovered, the signal trip is also close to the breaker the moment after fault recovery.

Table 2 behaves the output of our proposed relay measurements, so we can show that comparing with the traditional behavior of normal operation, the speed of our proposed scheme is less than one cycle.

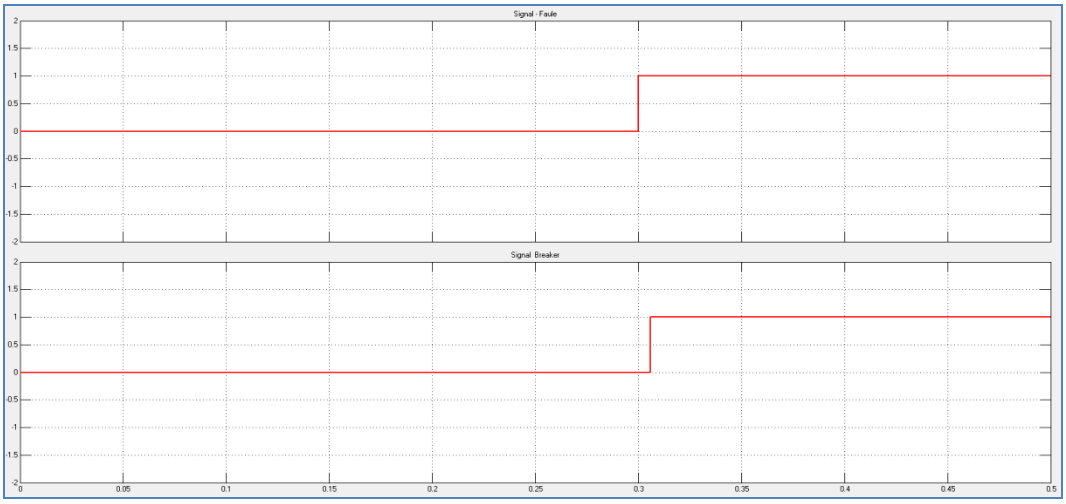

Figure 23. Main Signal Trip Logic

Table 2.Specifications of Proposed Relay

Measurements	zone relay
Relay output	Trip or No Trip
Threshold of operation	t = 0.3 msec
Decision Speed	Less than one cycle

6. Proposed Protection Scheme vs. Distance Relay Protection Scheme

The basic principle of distance protection is to compare the apparent impedance (ZA) with the line impedance (ZR). If the measured impedance is less than the point of the line impedance, then the boundary of the relay and contact points are assumed to be faulty [11]. The design operation of distance relay is only for fault location, so that discrimination may occur between selected ranges of relay for different segments of fault points. Within the most common fault (phase to ground fault), -fault resistance problem increases, the calculation depending on the value of the impedance is greater than that of the high impedance fault resistance (RF) and the distance relay is not operating in this case. On the contrary, our proposed scheme will overcome this problem. The results show that any differential method can detect any internal faults. So the proposed scheme is not affected by the fault resistance, which will be more sensitive whenever the fault resistance increases.

7. Conclusions

Transmission line protection is necessary for maintaining and improving the stability of a power system. The differential protection is widely used in the optimization of the fault protection solution, and the time delay planning for multi-terminal system must be fast cleared. Differential protection is popularly used as the preferred solution; fault protection becomes very difficult time delays planning for multi-terminal system. This paper presents a different solution for transmission line protection and it discusses the design of a line current differential protection scheme for 25 kV transmission line. This method is better than the distance protection because the differential protection requires less input data, and reduces the computation time. Moreover, it covers any fault resistance values within the range of all regional lines. The performance of the algorithm under the condition of high fault resistance is more efficient than distance relay protection since the distance relay is unable to detect internal faults while the proposed scheme overcomes this problem.

Acknowledgements

I am heartily thankful to my supervisor, Professor Shaorong Wang for his encouragement, guidance and support through all stages of this work. Also special thanks to my friend Dr. Dheyaa Jasim Kadhim for his suggestions and help.

I also offer my regards and blessings to all of those who supported me especially studying in Southern Technical University, Technical College of Basrah, Iraq.

Last but not the least, my family and the one above all of us, the omnipresent God, for answering my prayers for giving me the strength, thank you so much my God.

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