Analysis of Relay Protection System Comparison for Better Identification of Faults in High Voltage AC Transmission Lines

Rimsha Fazal
UET
Arooj Aslam
UET
Habib Ullah Manzoor
University of Glasgow
Tareq Manzoor (tareqmanzoor@cuilahore.edu.pk)
COMSATS Institute of Information Technology - MA Jinnah Campus https://orcid.org/0000-0003-1719-4449

Research Article

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Abstract

A high voltage protection system is designed to protect the system against the hazards like instant high voltage condition like lightening voltage in the rain, power variation in the transmission lines etc. In these conditions, our system may face a voltage twice and thrice greater than its original nominal ratings. In this paper, performance of four different relays (overcurrent relay, over and under voltage relay, distance relay and differential relay) have been calculated based on operating time in 400KV high voltage AC transmission line of 80-250km under different faults, modeled on MATLAB for the identification of different types of faults in a transmission line. These relays can differentiate between the normal operating condition and fault conditions. In this paper simulation comparison of these four relays is presented by comparing their operating time in Single line to ground fault (LG), three phase fault (LLLG) and Double phase to ground fault (LLG). The output waveforms are observed under the normal condition or no-fault condition and in the fault condition and response time is calculated to operate a circuit breaker.

1. Introduction

For efficient electric supply from production site to consumer end, all major and minor components of transmission and distribution infrastructure are of key importance. However, among all transmission linecomponents, one of the most important and sensitive one is that used forthe protection of power system against faults.Faults can be of many types like phase-to-phase fault, two phase-to-ground fault, three phase faults, however, the most common type is single line to ground fault. All these fault types result in the disturbance of power supply to the consumer and lead to the inconvenience. Thesefaults in power system could causeeconomic losses. Economic losses could be due to either damage of power system orshortfall of electricity at consumer's side. It is important to protect the EHVtransmissionwhen fault is occurred [1].

Various types of fault can occur in a power systemare[2] :

- Single line to ground fault (LG).
- Three phase fault (LLLG).
- Double line to ground fault (LLG).

The values of current and voltage can be used to locate the presence of an error in the system in small transmission lines.While for the long transmission lines, distance relays are optimal option for transmissionlineprotection.

Different types of relays have been designed to protect the power system from different fault types which have various specific operating phenomena. Many relays have been tested for fault detection performance using different methods in past,and transmission lines are tested by using different methodologieslikean ANN based relay design for faults identification of 400kVAC Transmission Line.This technique is based on ANN software and elaborates the impedance relay protection in transmission lines [3]. Furthermore, a lot of work has been done on digital differential relays to show its performance and efficiency over the conventional differential relay,concluding that performance and operating time of digital differential relay is better than the conventional differential relay, however, the algorithm and structure of modern digital differential relay are complex than the conventional relays[4]. Numerical overcurrent relay is tested in operational prospective and on MATLAB/Simulink model for the discrete current input values, in this case numerical current inputs were obtained to check the operation overcurrent relay [5]. Distance relay (normally called as Impedance relays) can be designed on MATLAB/Simulink model [6, 7]. Over an under-voltage relay for non-sinusoidal voltage is designed where the microprocess based over and under voltage relay operates for the third fundamental harmonic of the disturbed system.If third harmonic affects the relay voltage limit then relay trips [8]. Furthermore, the over and under voltage relays are tested for the transmission line protection [9]. This analysis work has been done by choosing a single relay model for specific fault conditions in transmission line.

1.1. Relays

Differential relay is used to measure the current and/or voltage value at feeding and load end to determine the difference between any of two quantities, it works on the principal that the values of current and voltage at the feeding end must be equal to the values at the load end and if the values are not equal then the relay [10] will trip.Distance/Impedance relay works on the principle of impedance value where the relay is inserted and the fault occurs. Impedance value is measured by pointing the current and voltage as the fundamental quantities ($Z=V\times I$).If the values of any of current and/or voltage are deviated from their nominal rated values then the value of the impedance will be changed and the relay will get the signal to trip[11]. While over-current relay is used for current fault detection when current rises from a specific value. Over-current relay is an adjusted value relay in which a plug value is set as threshold. Plug value is a rated value for over-current relay operation if the value of the system exceeds from the plugged value then the relay will trip [12].Over and under voltage relay operates on the principle of specific voltage value detection when the value of voltage goes above or below the rated value, the over and under voltage relay trips [13].

Choice of a relay for power system is based on the point where the fault condition occurs. In a power system the protection is done either on the generating side which includes our grid station or at the transmission side which includes the protection of our generator system, transformer and transmission lines etc [14]. The protection is done by keeping the voltage and current values between a bearable range during power ($P=V*I$) transfer, for example maintaining a voltage level in the transmission system or current level [15]. In case of faults, a large amount of current will start to flow in power system line [16]. For the protection of such a scenario, over-current protection relay is inserted which will detect the fault and initiates the circuit breaker (CB) operation of cutting off the passage of power flow into the circuit. In case of voltage fault, under/ over voltage relays are used [17]. And when the fault occurs, system cuts the supply to the load and to provide continuous supply to the load radial networks are used [18].

This research is carried out to satisfy the curiosity that which relay has the shortest operating time under same fault conditions in a high voltage power system. The considered relay types for this study are: differential relay, distance/impedance relay, overcurrent relay, and under and over voltage relay.MATLAB Simulink models for the mentioned relay types aredesigned to check their operation in three-phase (LLLG), double line to ground (LLG), and single line to ground (LG)fault conditions in transmission lines and their operating time values are measured. A comparative analysis is also carried out on the basis of their measured operating time figures to conclude that which relay type is the best for high voltage transmission lines.

2. Methodology

Protection models are designed using four different relay types to achieve the aimed objective. The designed models are described as:

- Protection model using differential relay
- Protection model using distance/ impedance relay
- Protection model over and under voltage relay
- Protection model using over-current relay

2.1. Protection model using differential relay

By using differential relay protection scheme for transmission line protection a model of single-line diagram is designed with its certain characteristic value MATLAB Simulink model is designed to explain the working of differential relay at the fault conditions in [19].In transmission pi line model, three faults have been introduced in the zone of transmission line, generated faults are LLLG, LLG and LG faults. The results are obtained on the scope in form to waves to check the fault occurring condition and the operating time of the circuit breaker (CB). The MATLAB Simulink model designed to check the desired fault conditions and CB operating time in the transmission lines is shown in Fig. 2.

2.2. Protection model using distance/ impedance relay

Single line diagram of distance/ impedance relay is shown in Fig. 3.The distance relay is tested for pre-fault conditions, and after that faults have been generated in the transmission line. The transmission line model of distance/ impedance relay is designed on the MATLAB Simulink, shown in Fig. 4.When the fault is occurred, relay generates signal to operate circuit breaker and protects the circuit against fault. Conventional distance relay has been replaced with the modern digital relay which works faster than the conventional distance relay, here the MATLAB simulink models have been designed to study the behavior of relay when the fault occurs in the circuit as shown in Fig. 4.

2.3. Protection model using over and under voltage relay

Single-line diagram of under and over voltage relay is shown below in Fig. 5, and MATLAB Simulink based designed transmission line model for under and over voltage relay is shown in Fig. 6.In the case of over and under voltage relay, MATLAB simulink models have been designed which are given a rational operator for both over and under value conditions, and checked alternatively [21, 22, 23, 24]. The designed model is inserted in power transmission line for the protection purpose to check its operation.

2.4. Protection model using over-current relay

Single-line diagram of over-current relay is shown in Fig. 7, and the MTALABsimulink model for over-current relay designed to check the operating time under the fault condition in transmission line is shown in Fig. 8.

3. Results And Discussion

Reduction in operating time is calculated for four different transmission line protection relays using mathematical set of equations and developed simulation models (described in section 2). Calculated and simulation outcomes are discussed below.

3.1. Differential relay presence effect on power transmission line fault

Firstly, the operating time of the relay in single line to ground fault condition is calculated.For differential relay maximum driving voltage at load side is, Vd=30000V. At over-loading state in relay,the assumed current exceeds by 25%.The reduction in operating time delay is calculated using equation (1):

$$t_{R.B} = \frac{0.14\,(tsm)}{(psm^{0.02}) - 1}$$

1

Where

$psm = \frac{Vrelay}{ps}$

and$Vrelay = 300V, ps = 1V, Tcb = 0.5s, V\max fault = 300V$

$Ttotal = tcb + tcb$

$Ttotal = 0.5011s$

Thus operating time of differential relay for LG fault is 0.5s. Similarly, operating time of 0.5s have been calculated for LLLG and LLG respectively as shown in Table 1.

Figure 9 represents circuit breaker opreating time in seconds when LG, LLG and LLLG fault are generated respectively in the system. In all faults the realy triped as soon as fault is generated at 0.5s and value of voltages are droped to zero.

3.2. Distance/ impedance relay presence effect on power transmission line fault

In order to calculate operating time, let the value of the nominal current exceed up to 25% from rated value.By using equation (1), the reduction in operating timeis calculated for distance relay by changing certain parameters as I_{relay}=15A;ps=1A; I_{OC}=150A instead of using V_{relay}= 300V; and ps=1V, and total calculated operating time of distance/impedance relay is 0.525s.Here, MATLAB is also used for calculation of operating time of distance relay when LG, LLG and LLG faults are generated, as shown in figure 10.

From figure 10, In case of LLLG fault distance relay the relay operates exactly at 0.5sof the fault conditions while in case of LLG faultthe circuit breaker did not operates exactly at 0.5s but it takes a delay and operates at 0.5125sWhich means at this condition distancerelay do not operates instantly to remove the faul. In case of LG fault the CB operated at 0.52s in this case it took longer time to operate than two other faults when fault occurred at 0.5s. As the result types changes CB behaved differently for different faults and CB operating time changes.All the results are reported in table 1 for comparison.

3.3. Over and under voltage relay presence effect on effect on power transmission line fault

In case of manual calculation for over voltage condition for LLG fault, which most commonly occurs. Maximum driving voltage at load side=4000V.At overloading in relay let assume current exceed 25% of nominal value.By using equation (1) calculate the reduction in operating time for over and under voltage relay by changing certain parameters as V_{relay}=9.37V and ps=0.8V and total calculated operating time of over and under voltage relay 0.515s in case of LG fault.

MATLAB is also used to calculate operating time when LG, LLG and LLG faults are generated at 0.5s, as presented in figure 11.In figure 11 as the LLLG fault occurred, the relay trips and CB operate at 0.5s and protect the system without any delay in the system,in this case of LLG fault, the relay operates at 0.525s with a delay time of 0.025s and in case of LG fault the circuit breaker operates at 0.515s, with the delay of 0.015s.

In both cases when the relay operated as under voltage, it trips when the value of voltage gets down from rates value and in case of over voltage condition the relay trips when the value of voltage gets more than that of rated value of voltage.

3.4. Over-current relay presence effect on effect on power transmission line fault

Calculating operating time for of over-current relay in case of single line-to-ground (LG) fault. Maximum driving current at load side in system=80A. At overloading condition in the relay assume that the current value exceed by 25%.By using equation (1) calculate the reduction in operating time for distance relay by changing certain parameters such asI_{relay}=30A,ps=1A,tsm=0.01s instead of I_{relay}=15A ps=1A I_{OC}=150A and total calculated operating time of over and under current relay is 0.519s. Relay operating time of overcurrent relay in the case of LG fault= 0.519s

The results have been drawn with three phase faults (LLLG) and double phase to ground fault (LLG) in the system and checking the behavior with and without relay operations and operating time of 0.519s dedcued respectively. Here MATLAB is also used to calculate operating time of CB when LG, LLG, LLLG faults occurred at 0.5s, as presented in figure 12.

From figure 12, for LG, LLG and LLLG faultsCB operated at 0.519s, which the delay of 0.019s which means the overcurrent relay never operates instantly at fault condition (as fault condition is 0.5s). It will always take time delay to operate and clear the fault in all LLLG, LLG, and LG condition. This means overcurrent relay is less effective in clearing fault as soon.

3.5. Comparative analysis of four protection relay model

The operating time of four different relays are calculated and deducted by using the MATLAB models for all three Three-phase (LLLG), double line to ground (LLG) and single line to ground (LG) faults. Looking at a comparative prospective the differential relay operated at 0.5s for all fault conditions while the Distance/Impedance relay operated at different time for all three fault conditions with an average operating time of 0.5125s which is more than differential relay so differential relay is better than Distance/Impedance relay, 97.56% in operating time similarly over and under voltage relay operated at different operating time for all three faults and on an average it operates at 0.513s which is still higher than differential relay operating time and differential relay is 97.46% better in its operation from over and under voltage relay. At the end overcurrent relay which operated at similar delayed value for all three types of faults that is 0.519s which means overcurrent relay never operates instantly in any type of fault condition so differential relay is 96.34% better than overcurrent relay in its operating time. All the operating times of above mentioned four relays for all three types of fault (LLLG, LLG and LG) are given below in Table 1.

Table No. 1 Operating time of all relays

Relay protection Schemes	Circuit Breaker operating time for LLLG fault	Circuit Breaker operating time for LLG fault	Circuit Breaker operating time for LG fault
Differential relay scheme	0.5s	0.5s	0.5s
Distance or Impedance relay scheme	0.5s	0.5125s	0.525s
Over and under voltage relay scheme	0.5s	0.525s	0.515s
Over current relay scheme	0.519s	0.519s	0.519s

4. Conclusions

In this paper, circuit breaking time of four relays (Differential relay, Distance or Impedance relay, Over and under voltage relay, Over current relay) have been calculated in fault conditions and compared with each other for the better identification of relays. Considered faults are LG, LLG and LLLG fault. From the results of MATLAB simulations,for LLLG fault all the relays operated instantly at 0.5s of fault time (when fault is occurred at 0.05sec) except the overcurrent relay it took a time gap of 0.019sec, in case of LLG fault all the relays took a time delay in their operation except the differential relay which operated the CB at exact 0.5s, in the third case of LG fault again all the relays showed time delay in operating time except differential relay. It is concluded that differential relay performed betterthan Distance or Impedance relay, Over and under voltage relay, Over current relay, when circuit breaking time is considered. But there is a problem associated with the differential relay that is differential relay is not able to differentiate between the fault condition and the swung condition in transmission line. Sometimes a swing can occur the transmission lines at which the value of nominated current or voltage goes high from the rated value for nano seconds and then get back to the stable condition. Similar condition takes place when we start a motor in the beginning it takes higher current values and then get back to its nominal rated values as differential relay is an instantly operating relay so it will operate for swing condition as well to avoid this condition in differential relay we use to design a radial system which leads our system to the complications. On the other hand, overcurrent relay always operates with a time delay in its path which raises the percentage of risk in case if our system is highly sensitive towards the fault. Over and under voltage relay operated fast for LG fault as compare to LLG fault and distance/impedance relay operates fast for LLG fault as compare to LG fault.

Declarations

Conflict of Interest:

The authors declare that they have no conflict of interest in this submission . All organizations have worked in collaboration in it.

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Figures

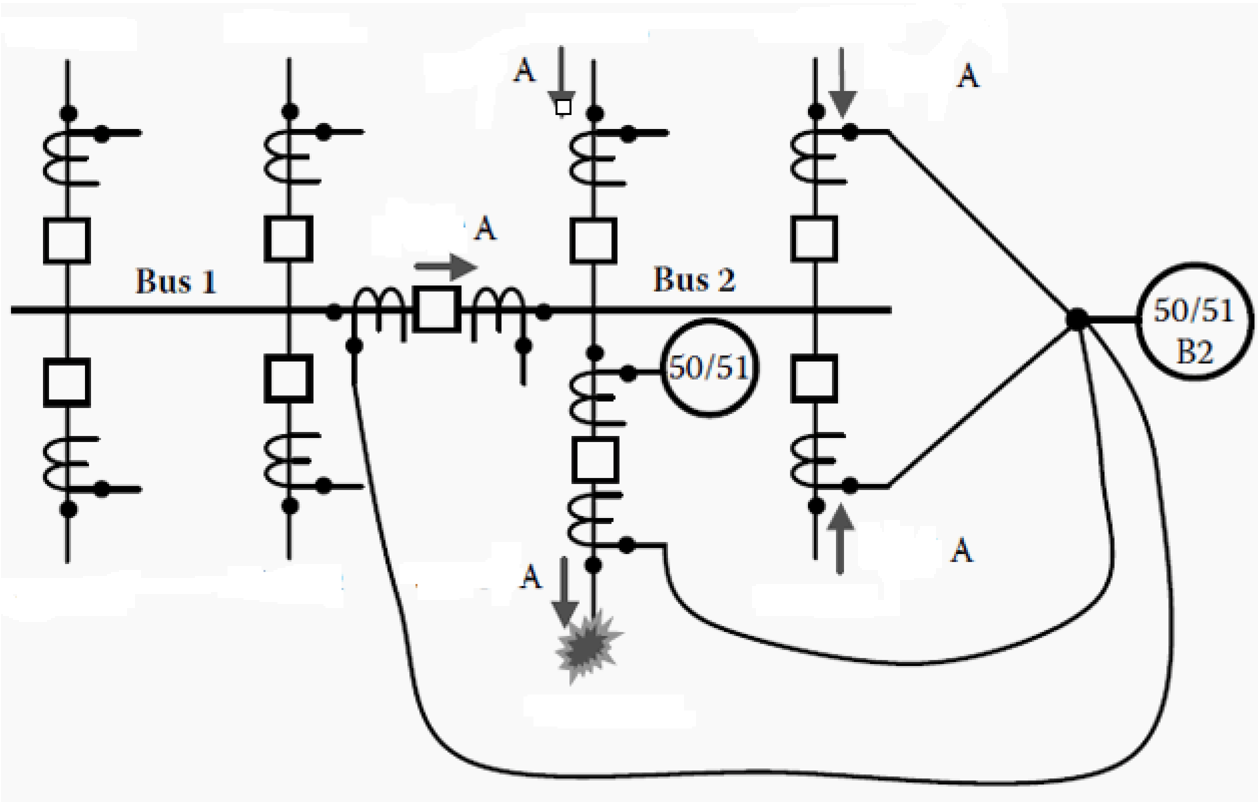

Figure 1

Single-line diagram of differential relay based transmission protection model

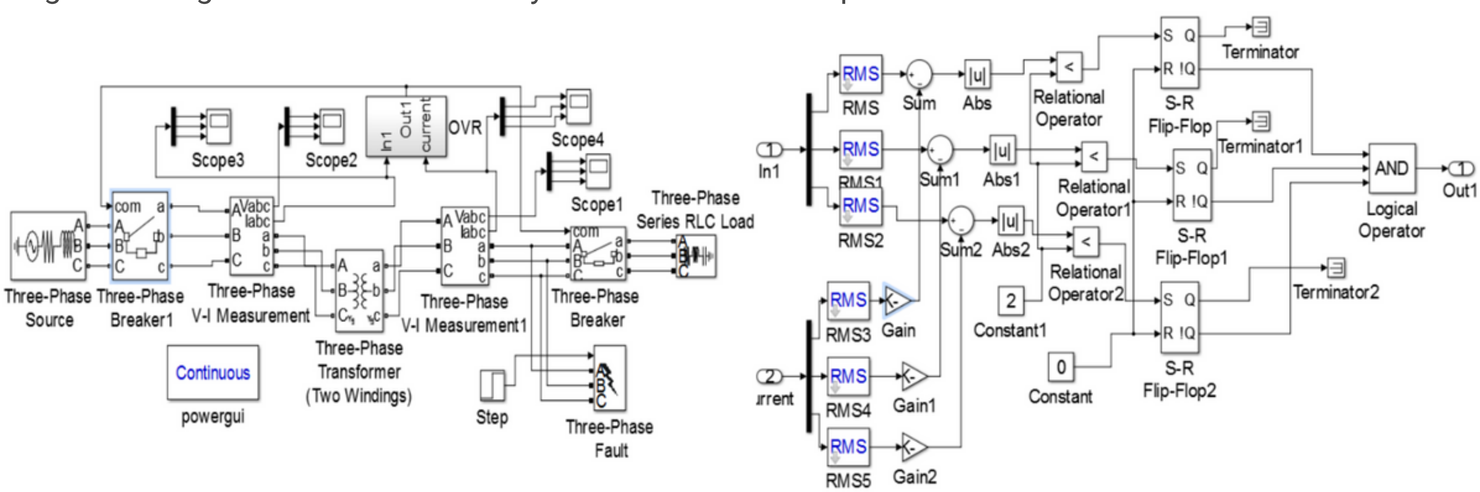

Figure 2

MATLAB simulink based Transmission line model for differential relay

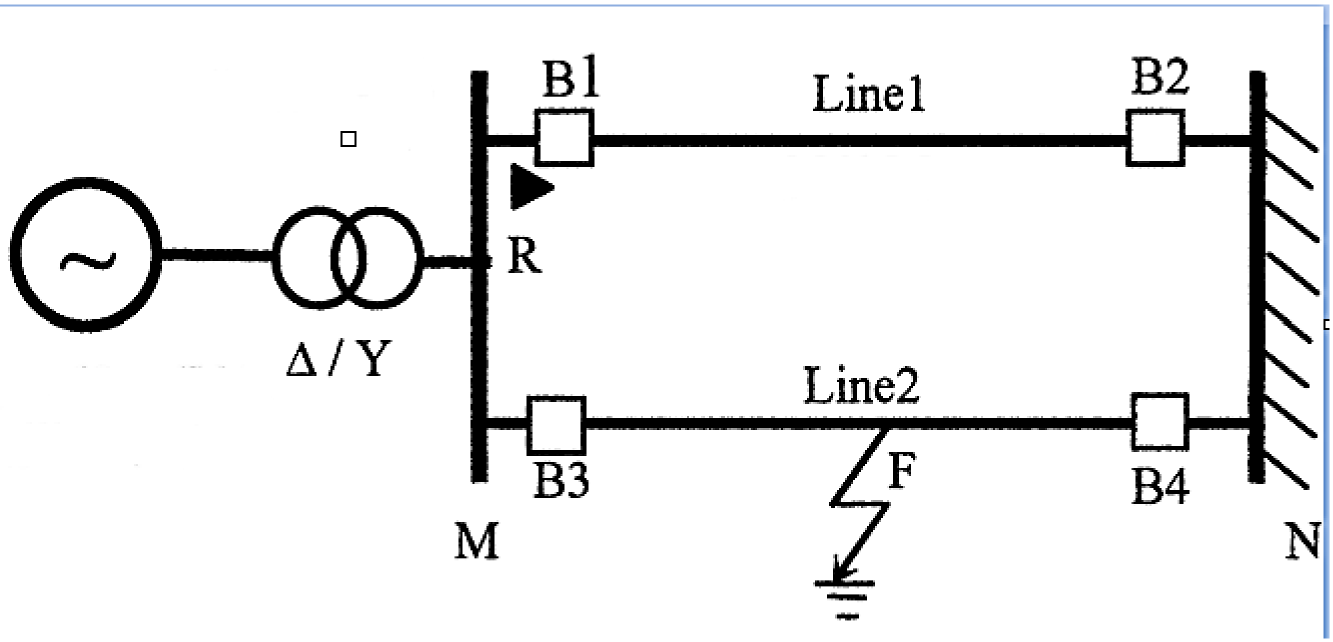

Figure 3

Single-line diagram of conventional distance/ impedance relay

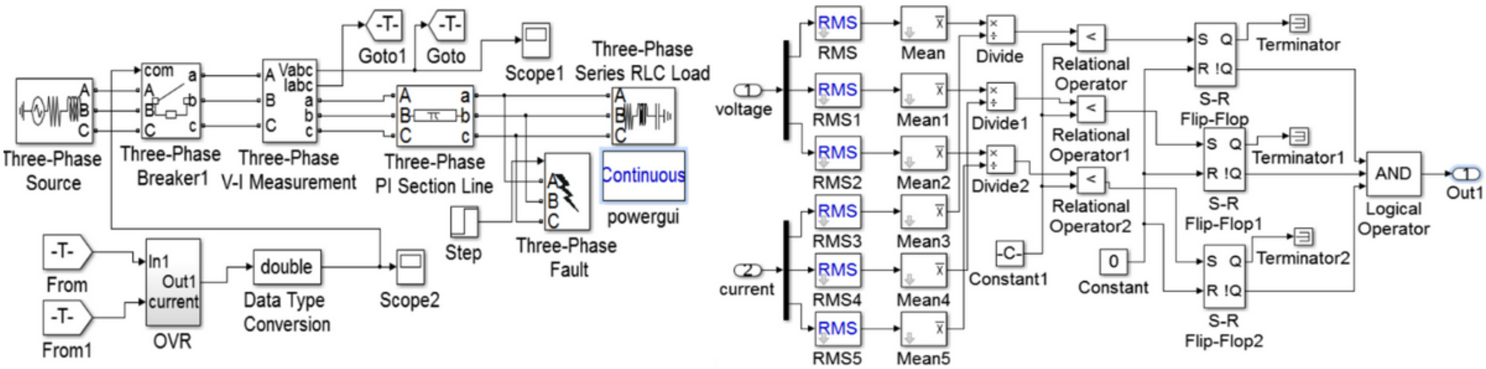

Figure 4

MATLAB simulink based transmission line model for distance/ impedance relay

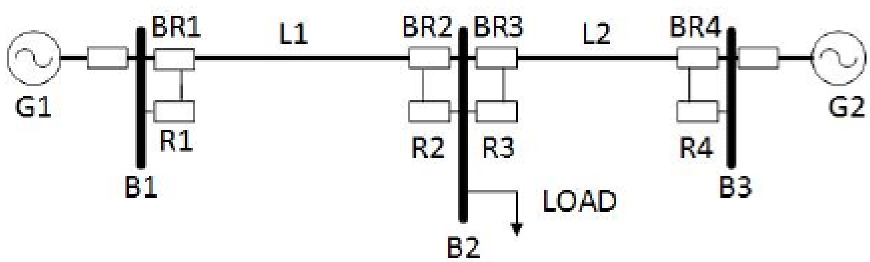

Figure 5

Single-line diagram of over and under voltage relay

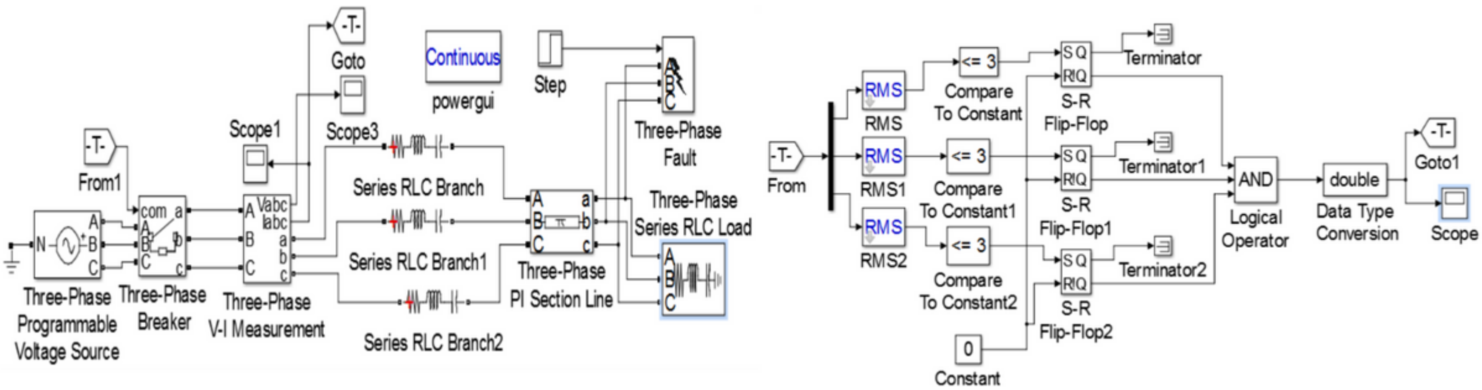

Figure 6

MATLAB simulink based transmission line model for over and under voltage relay

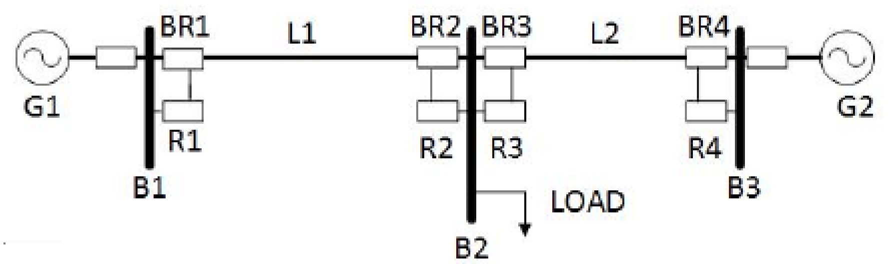

Figure 7

Single-line diagram of over-current relay

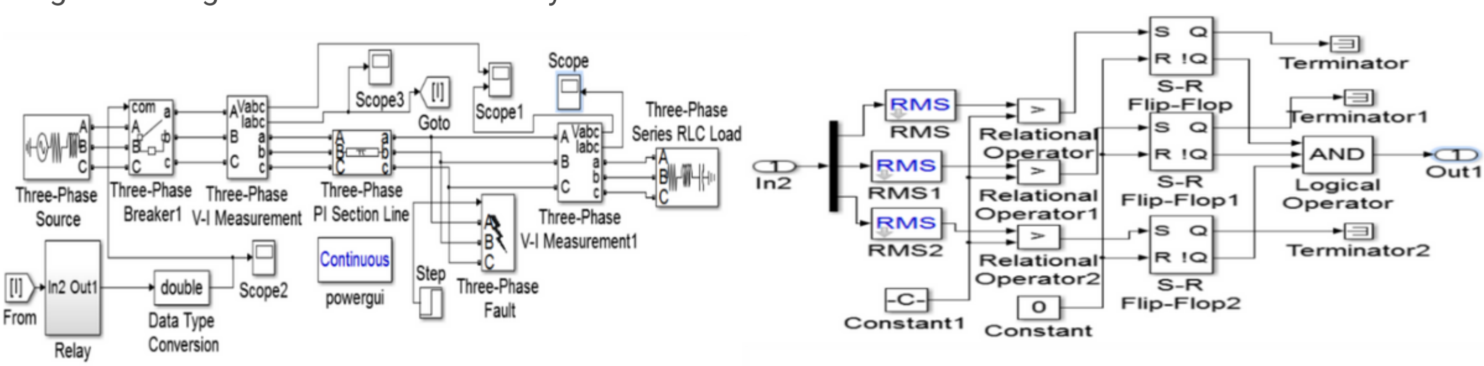

Figure 8

MATLAB simulink based transmission line model for over-current relay

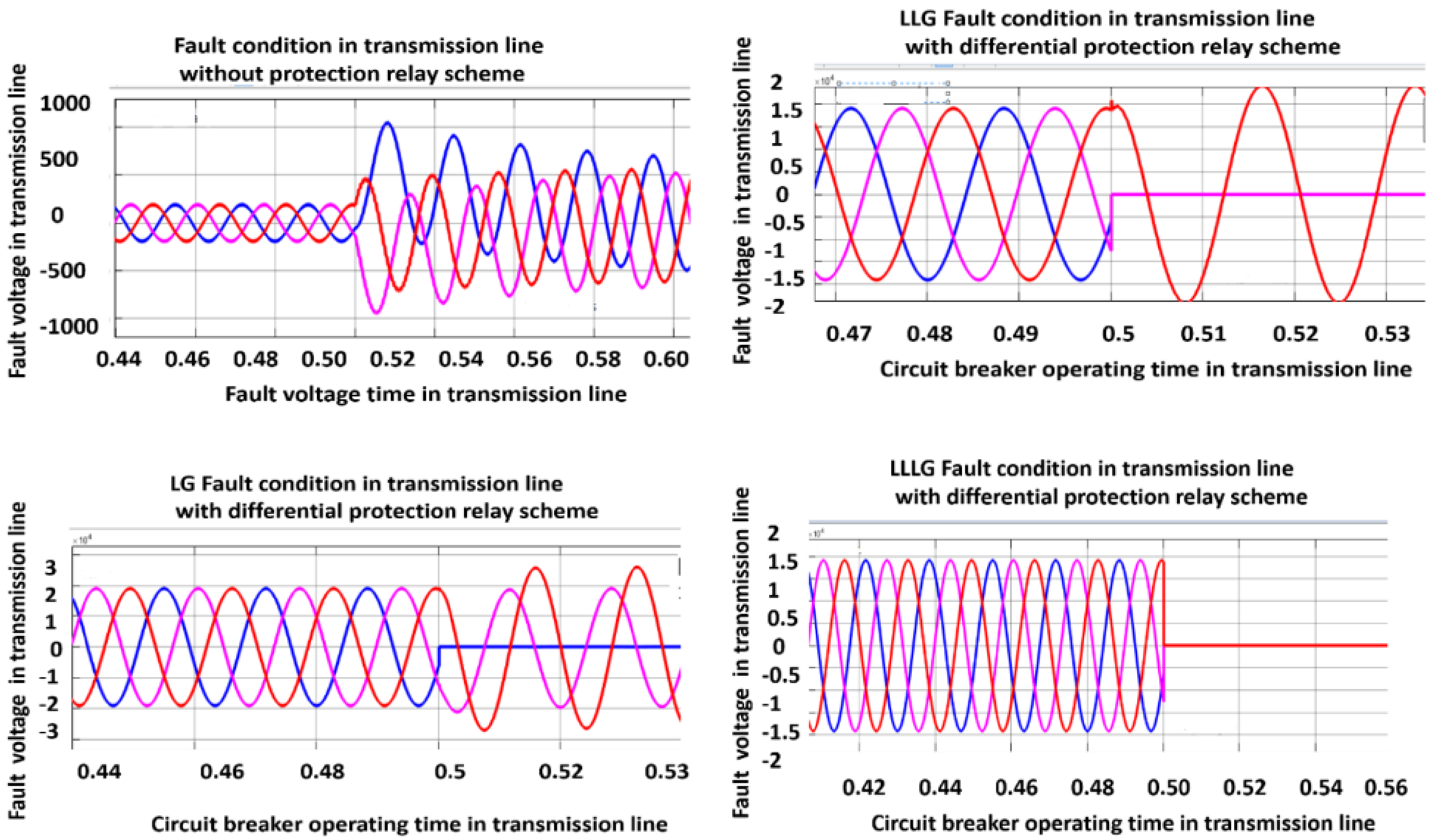

Figure 9

Fault current analysis in transmission line without and with differential protection scheme (here blue line represents phase I; red line represents phase II; purple represents phase III)

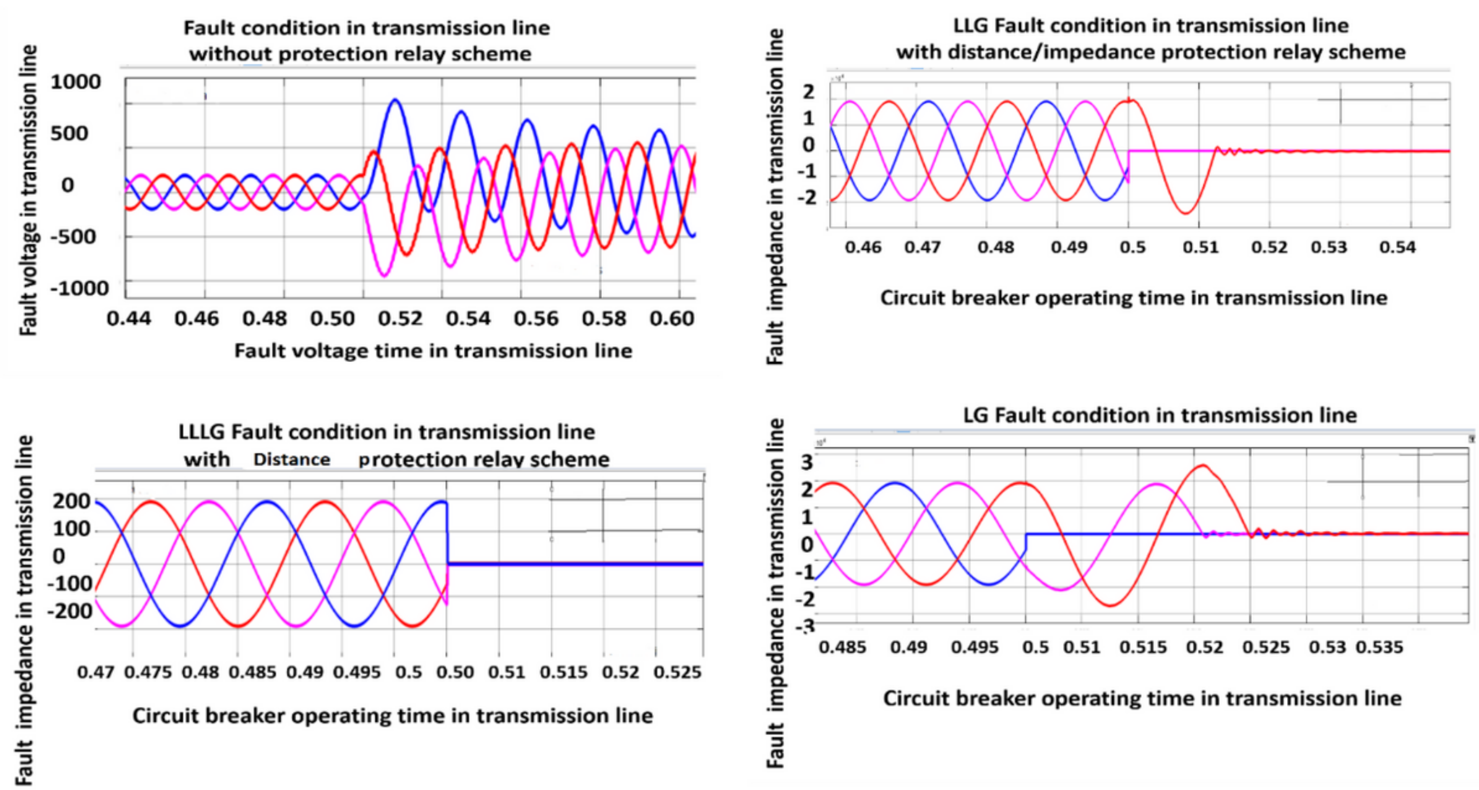

Figure 10

Fault current analysis in transmission line without and with distance/ impedance protection scheme (blue line for phase I; red line for phase II; purple line for phase III)

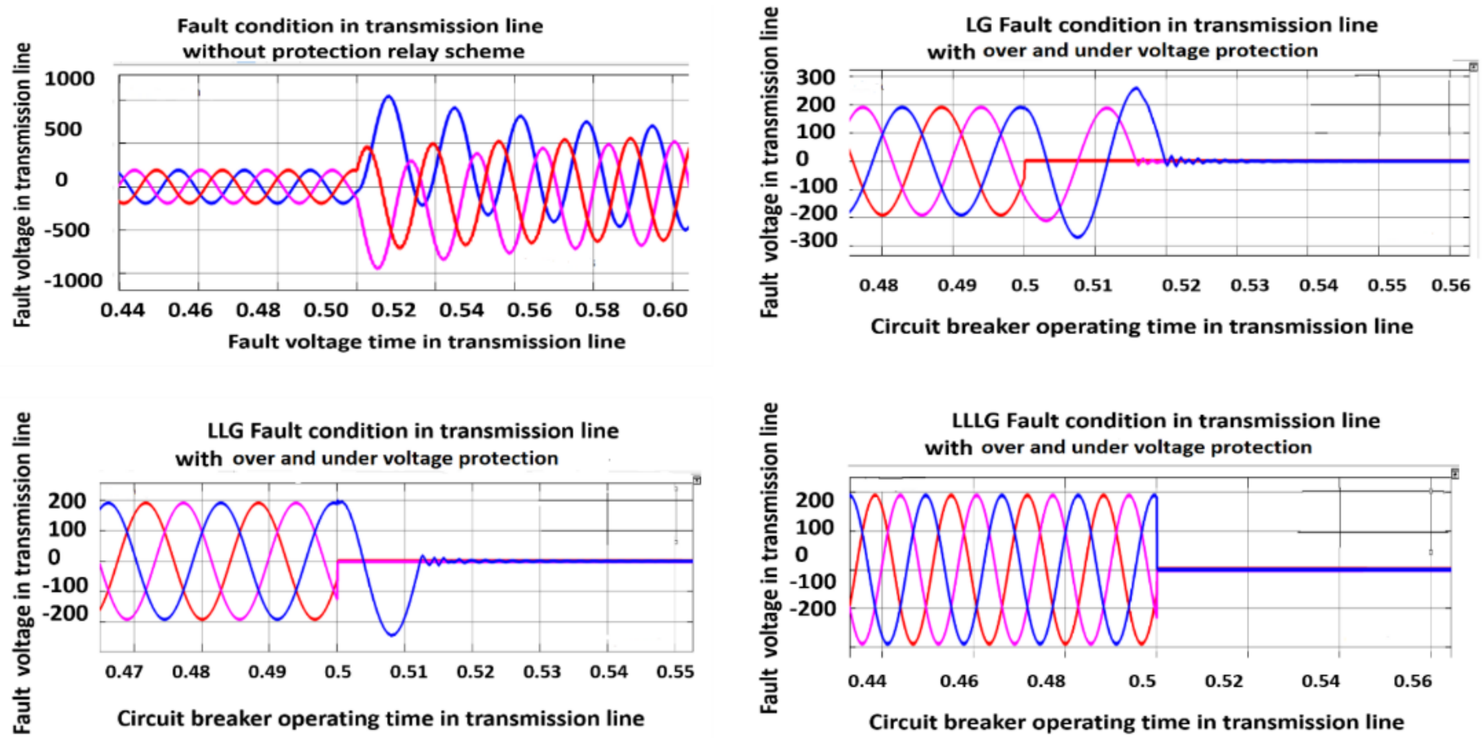

Figure 11

Fault current analysis in transmission line without and with over and under voltage protection scheme (blue line represents phase I; red line represents phase II; purple represents phase III)

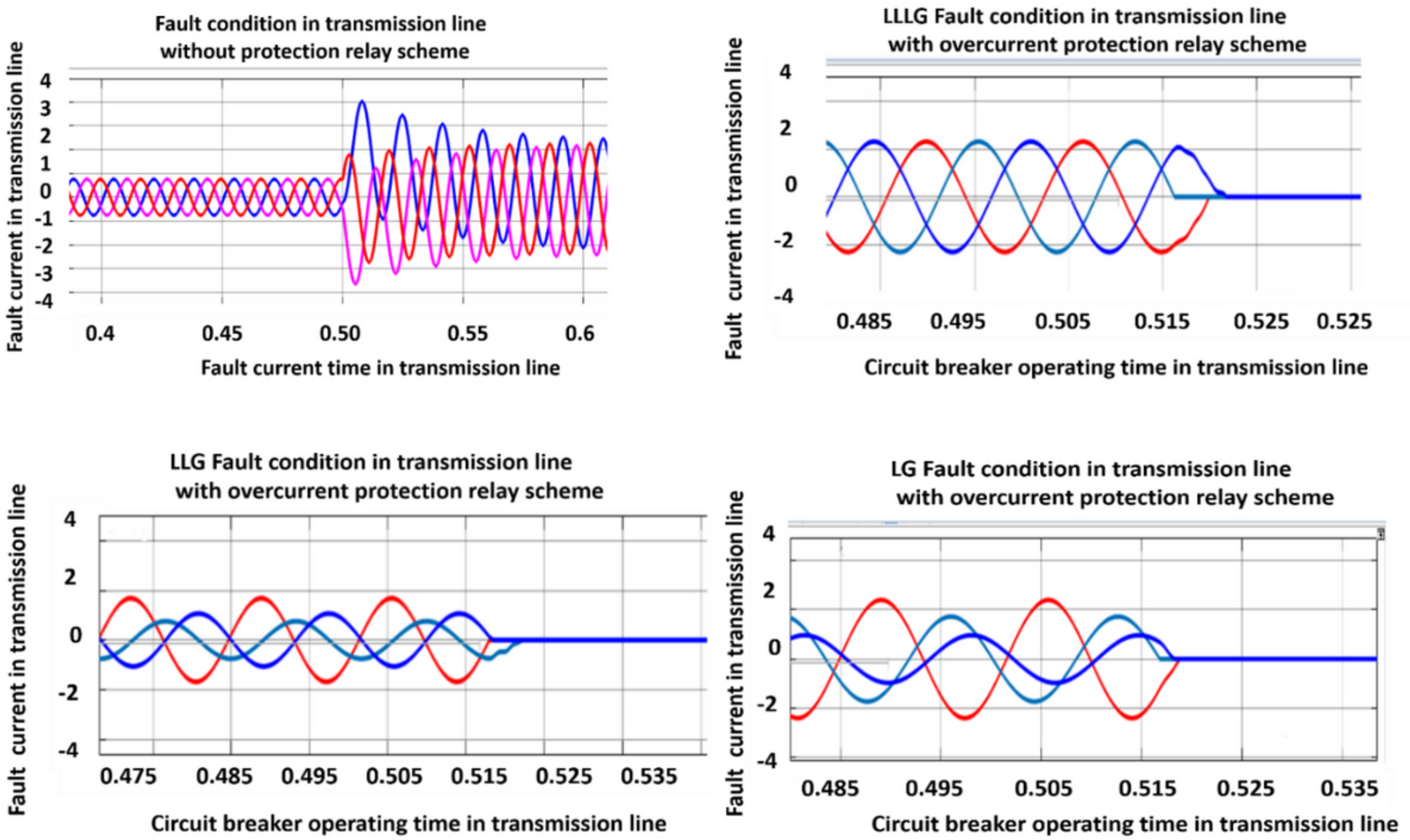

Figure 12

Fault current analysis in transmission line without and with overcurrent protection scheme (blue line represents phase I; red line represents phase II; purple represents phase III)