Modeling and Simulation of Overcurrent and Earth Fault Relay with Inverse Definite Minimum Time

Win Win Tun, Han Su Yin, Ohn Zin Lin

Abstract**—**Transmission networks are an important part of an electric power system. The transmission lines not only have high power transmission capacity but also they are prone of larger magnitudes. Different types of faults occur in transmission lines such as single line to ground (L-G) fault, double line to ground (L-L-G) fault, line to line (L-L) fault and three phases (L-L-L) fault. These faults are needed to be cleared quickly in order to reduce damage caused to the system and they have high impact on the electrical power system equipment's which are connected in transmission line. The main fault in transmission line is L-G fault. Therefore, protection relays are needed to protect transmission line. Overcurrent and earth fault relay is an important relay used to protect transmission lines, distribution feeders, transformers and bus couplers etc. Sometimes these relays can be used as main protection or backup protection. The modeling of protection relays is important to indicate the effects of network parameters and configurations on the operation of relays. Therefore, the modeling of overcurrent and earth fault relay is described in this paper. The overcurrent and earth fault relays with standard inverse definite minimum time are modeled and simulated by using MATLAB/Simulink software. The developed model was tested with L-G, L-L-G, L-L and L-L-L faults with various fault locations and fault resistance (0.001Ω). The simulation results are obtained by MATLAB software which shows the feasibility of analysis of transmission line protection with overcurrent and earth fault relay.

Keywords**—**Transmission line, overcurrent and earth fault relay, standard inverse definite minimum time, various faults, MATLAB Software.

I. Introduction

An electrical power system consists of many electrical components such as generator, transformer, transmission lines, distribution lines, current transformer, voltage transformer and lightning arrestor, etc. Transmission lines are an important part of electrical power system. They transport power at high voltage from generation to load and are the most significant component of electrical power system. When a short circuit occurs in transmission line, a sudden abnormal flow of current occurs in the transmission line of power system. When various faults occur in electrical power system, they cause significant changes in power system like overcurrent, over or under voltage, power factor, frequency and power or current direction, etc. There are various type of faults in power system such as L-G, L-L-G, L-L and L-L-L faults [1]. High voltage transmission lines have a high power transmission capacity and they occur in the faults of larger magnitudes. Therefore, the occurrence of such faults needs to be cleared as quickly as possible in order to reduce damage causing to the power system. The faults cannot be prevented but they can be interrupted to isolate the faulty section from the healthy system and equipment damage is minimized and reliability of power system is not decreased [2]. The importance of power system protection must be understood with operation conditions of electric power system. Therefore, power system stability can be maintained in part by protection and corrective actions taken by protective relays. That is why prevention of transmission system is needed in modern electrical power system. The protective equipment detects irregular power system state and initiates corrective actions as quickly as possible to return the system to normal condition [3].

Protection relays are used to mitigate damage to both electrical equipment's and personnel when electrical faults occur in power system. Protection relays are designed based on the basis of selectivity, reliability, speed and sensitivity [4]. Overcurrent and earth fault relay are of protection relays used to protect electrical power system. When a fault occurs in power system, overcurrent and earth fault relay will detect and isolate the faulty section from rest of the power system by sensing the value of current. Moreover, this relay can be used as main or backup protection to protect the transmission lines or distribution feeders, transformers, bus coupler, etc. [5]. There are two types of operating time speed for overcurrent and earth fault relay which are delayed time and instantaneous. In delayed time type, there are definite time and inverse time. For definite time, the operating time is independent of overcurrent where relay closest to the fault has the shortest operating time and relay away from fault has the longest operating time. For inverse time, if the fault current is very high, the operating will be fast. The fault current is measured in multiples of current setting or pick up current setting. When this relay is used in coordination with other overcurrent relays such as to protect radial feeders, it can be coordinated with upstream or downstream relays by the use of time multiplier setting, TMS [6]. The weakness of instantaneous type is that it cannot discriminate the operation when a fault current at two or more locations is the same [7].

A proper relay setting plays a crucial role in reducing unexpected effects of faults on electrical power system. Overcurrent relays normally have plug setting or pickup setting ranging from 50 to 200% in step of 25%. The plug setting or pickup setting is the current setting of overcurrent and earth fault relay. For each relay, current setting is determined by two parameters: the maximum load current and the minimum fault current. However, the important variety in

Win WinTun, Han Su, and OhnZin Lin are with the Electrical Engineering Department, Yangon Technological University, Myanmar (e-mail: wintun63@ gmail.com, hansuyin2009@gmail.com, ohnzinlin@ytu.edu.mm).

coordination of overcurrent and earth fault relay is TMS [8].

In this paper, the protection scheme of overcurrent and earth fault relay is presented and Meikhtila-Taungoo 500 kV Extra High Voltage Transmission Line is used for test system. This transmission line is modeled with standard inverse definite minimum time of overcurrent and earth fault relay to simulate the system and show the results. Therefore, overcurrent and earth fault relay is installed in this transmission line. And then, MATLAB/Simulink software is used to model standard inverse definite minimum time overcurrent and earth fault which based on digital signal processor. The performance of developed model is investigated at normal condition. That is why, the transmission line model with standard IDMT overcurrent and earth fault relay is tested with L-G fault, L-L-G fault, L-L fault and three phase (L-L-L) fault at various fault location and fault resistance (0.001Ω) by using MATLAB/ Simulink software. Then, the relay model is simulated, analyzed and evaluated by using real time laboratory in MATLAB software and the authors successfully evaluated the effects of in feed current for transmission line protection.

II. Theories of Standard Inverse Definite Minimum time Relay

Fig. 1 shows the characteristics of standard inverse definite minimum time overcurrent and earth fault relay. This figure shows four curves which each curve can be expressed by equations to calculate the operating time of relay. Fig. 2 shows the characteristics of standard inverse definite minimum time with different TMS.

The current setting or pick up current for each curve is (1):

$$I_s = PS \times CT_{sec} \tag{1}$$

where PS = Plug setting; CTsec = Rated secondary current of current transformer in ampere.

The mathematical formula of curves is (2):

$$t = T \times \left[\frac{K}{\left(\frac{I}{I_S} \right)^{\alpha} - 1} + L \right] \tag{2}$$

where t = Operation time; K = Factor 1; I = Value of measured current; I_S = Value of programmed threshold (pick-up value); α = Factor 2; L = Zero for IEC Standard; T = TMS.

TABLE I
THE VALUE OF CURVES

Type of Curve	Standard	K factor	α Factor	L factor
Long Time Inverse	IEC	120	1	0
Standard Inverse	IEC	0.14	0.02	0
Very Inverse	IEC	13.5	1	0
Extremely Inverse	IEC	80	2	0

Table I shows the values to calculate the operation time of equation for various curve. Table II shows the equation of operation time which represents the characteristics of curves for long time inverse, standard inverse, very inverse and extremely inverse of overcurrent and earth fault relay. For same setting, extremely inverse curve has the fastest time and longtime inverse curve has the longest time to operate the protection relay.

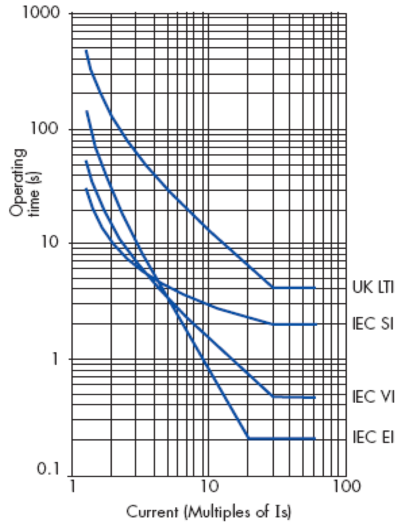

Fig. 1 Characteristics of Inverse Definite Minimum Time Curve

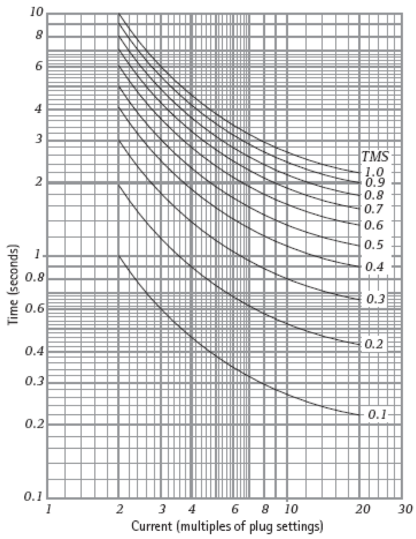

Fig. 2 Characteristic of Standard IDMT Curve with different TMS setting

III. Modeling and Simulation of Transmission Line

Table III is overall parameters for power system network and relay setting of standard inverse definite minimum time overcurrent and earth fault relay. The full load current is 577 A so that the current transformer (CT) ratio is chosen at 600/1 A. The line length of Extra High Voltage transmission line is 235 km. The capacitance of transmission line is neglected. The current setting or pick up setting for phase protection is higher than full load current and the current setting or pick up setting for earth protection is lower than full load current to detect ground fault and high impedance fault which undetected by phase protection. The TMS for phase is 0.3 and for earth is 0.2. In proposed model, standard inverse definite minimum time is used to detect overcurrent phase protection and earth protection. However, this model can be extended to use other type of curves such as long time inverse, very inverse and extremely inverse.

TABLE II
OPERATION TIME EQUATION

Type of curve	Equation of operation time (s)
Long time inverse	$t = TMS \times \frac{120}{\left[\frac{I}{I_s}\right] - 1}$
Standard inverse	$t = TMS \times \frac{0.14}{\left[\frac{I}{I_s}\right]^{0.02} - 1}$
Very inverse	$t = TMS \times \frac{13.5}{\left[\frac{I}{I_s}\right] - 1}$
Extremely inverse	$t = TMS \times \frac{80}{\left[\frac{I}{I_s}\right]^{2} - 1}$

Fig. 3 shows overall diagram of Simulink model for Meikhtila – Taungoo Extra High Voltage Transmission Line with standard inverse definite minimum time overcurrent and earth fault relay by using MATLAB/Simulink software. This power system network is simple and there phase power source is connected at one end while the other end is connected with three phase load. Fig. 4 shows the block inside the overcurrent and earth fault relay subsystem. All phase and earth subsystem have their own curve to calculate the operation time and send the trip signal to the trip coil of circuit breaker. The input current for earth fault is the phasor summation of R phase, Y phase and B phase currents. When there is a ground fault, the unbalanced current flows to earth. Therefore, phase fault does not happen and the trip signal of earth fault is sent to circuit breaker. When the fault current is higher than the others, the trip signal of the phase or earth is sent to circuit breaker. The phase or earth protection depends on the value of fault current and will calculate the operation time for trip signal of the phase or earth. Thus, the trip signals used 'OR' gate. The tripping time will be started when the fault current is higher than pick up current setting and then trip signal will be sent to circuit breaker. Fig. 5 is the block parameters for phase and earth system.

TABLE III
SYSTEM AND RELAY PARAMETERS

No	Parameters	Values
1	Source Short Circuit Level (MVA)	45000
2	X/R Ratio	33.33
3	Source V_{LL} (V)	500,000
4	Line CT Ratio (A)	600/1
5	Line Length (km)	235
6	Line Positive Sequence Resistance, R_1 (Ω/km)	0.01793
7	Line Zero sequence Resistance, R_0 (Ω/km)	0.14468
8	Line Positive sequence Inductance, L_1 (H/km)	0.00088694
9	Line Zero sequence Inductance, L_0 (H/km)	0.00240053
10	Line Full Load Current, I_{FL} (A)	577
11	3 Phase Line Capacity (MVA)	500
12	Plug Setting (PS) for Phase	1.0
13	TMS for Phase	0.3
14	Plug Setting (PS) for Earth	0.3
15	TMS for Earth	0.2
16	Line V_{LL} (V)	500,000
17	Nominal Frequency (HZ)	50
18	Type of Curve	SI Curve
19	Load Active Power (MW)	332

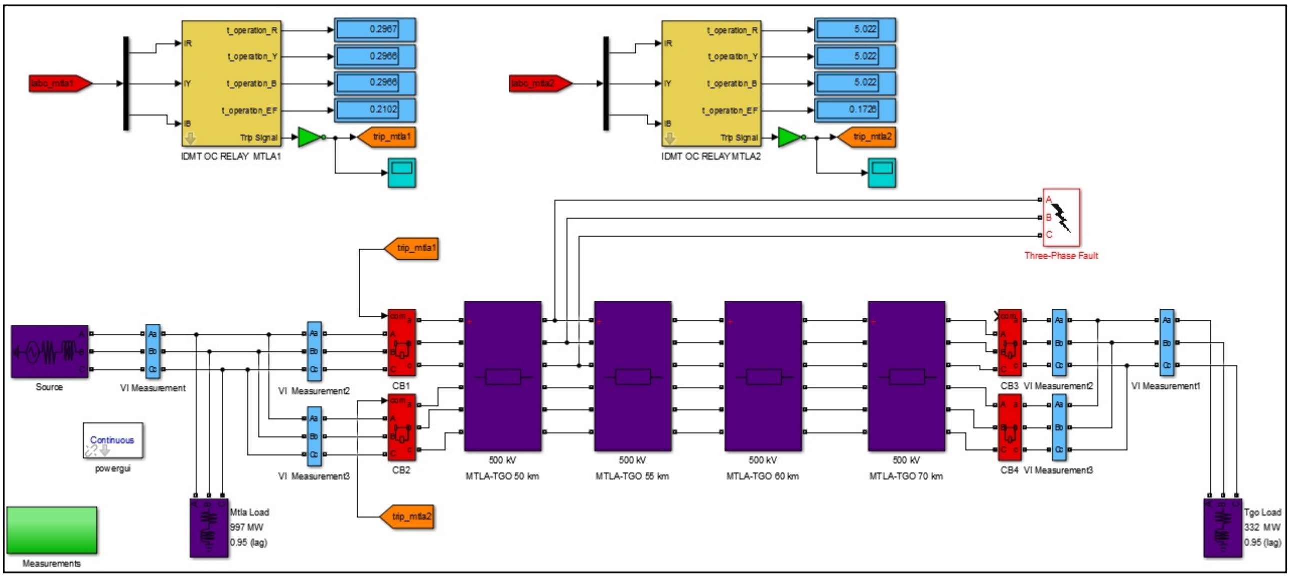

Fig. 3 Overall diagram of Simulink model

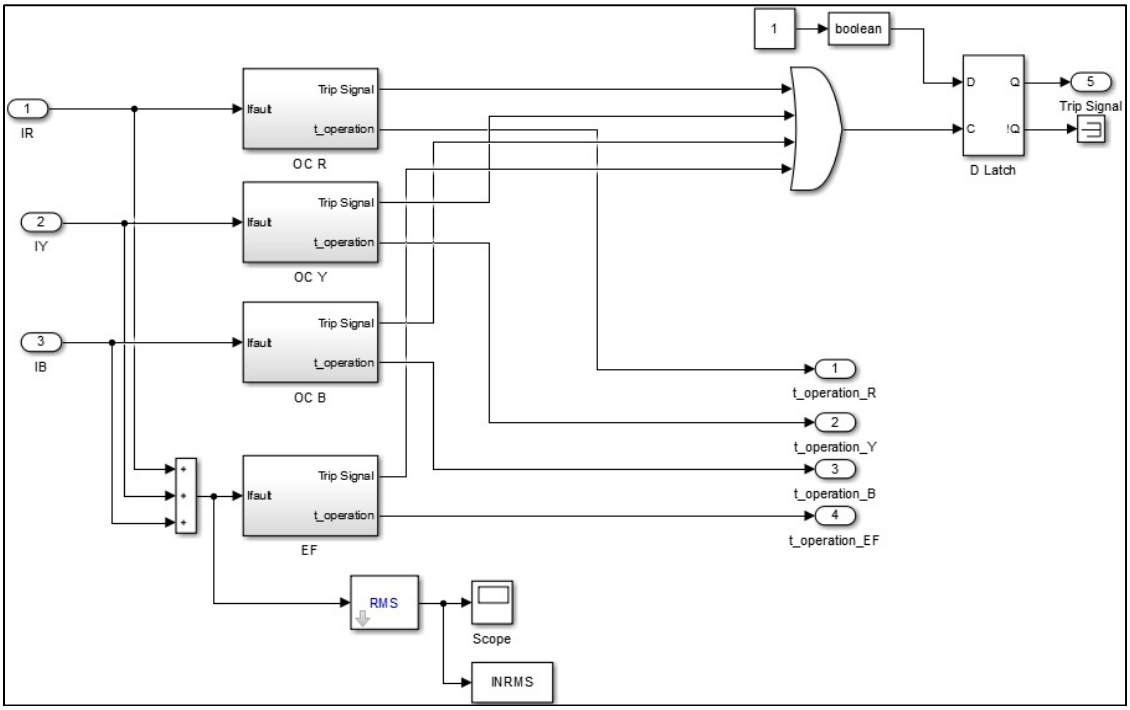

Fig. 4 Overcurrent and earth fault relay subsystem

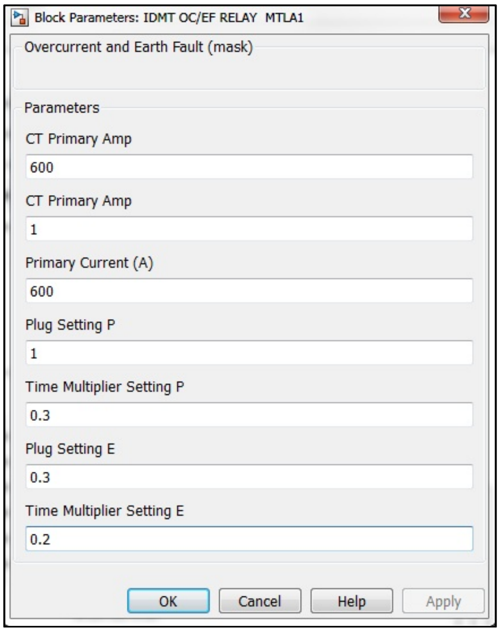

Fig. 5 Block parameters for phase and earth system

IV. Simulation Results

In this section, the results are discussed from the simulation of model. In model, the initial time of faults is started at 0.2 s. The faults such as L-G fault, L-L-G fault, L-L fault and L-L-L fault were simulated at different locations 50 km, 105 km, 165 km and 235 km and the fault resistance is selected at 0.001Ω. The results from simulation model focused on the operation time (sec) for phase and earth detector when four types of faults were simulated in this model. The fault currents for L-L-L and earth protection are higher than the current setting or pick up current setting for L-L-L fault and earth fault. The relay setting for each phase and earth were calculated as:

- Phase, IP = 1.0 x 600 = 600 A
- Earth, IP = 0.3 x 600 = 180 A

Table IV shows the simulation results of L-G fault at different distances. The results are fault currents, operation time and signal for faults at different locations 50 km, 105 km, 165 km and 235 km and fault resistance is 0.001. Case 1 to case 4 are L-G fault at different locations with resistance 0.001Ω. For case 1, the results are R phase, Y phase, B phase and Earth at location 50 km. In this case, the fault current for R phase, Y phase, B phase and earth are higher than pick up setting. However, the operation time of earth was faster than the operation time of phase because the multiple earth fault current (9990/180 = 55.5) was higher than for phase fault current (9911/600 = 16.51). Therefore, the circuit breaker was separated and tripped at 0.536 sec (≈0.2 + 0.335 = 0.535 sec). Figs. 6 and 7 show rms R phase current and rms return earth current for case 1 and Fig. 8 is the trip signal which was sent to the circuit breaker at the operation time 0.535 sec.

For case 2, the results can be seen that the fault currents for R phase, Y phase, B phase and earth were smaller than case 1 because the fault location for case 2 (105 km) was greater than the location of case 1 (50 km) at the same resistance so that the impedance of case 2 was higher than case 1. In that case, the fault current of R phase, Y phase, B phase and earth was still higher than pick up current of phase and earth. Therefore, the circuit breaker was tripped by trip signal of earth sensor at

0.607 sec (≈0.2 + 0.405 = 0.605 sec).

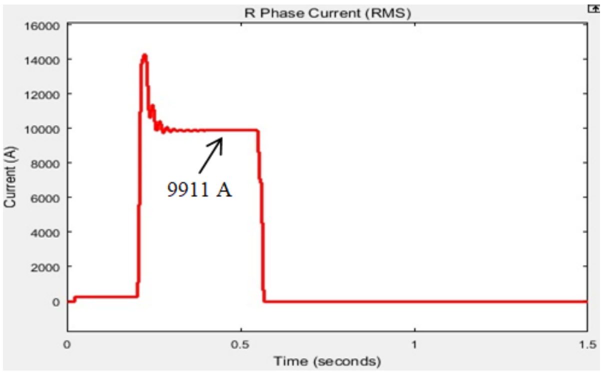

Fig. 6 RMS R phase Current for Case 1

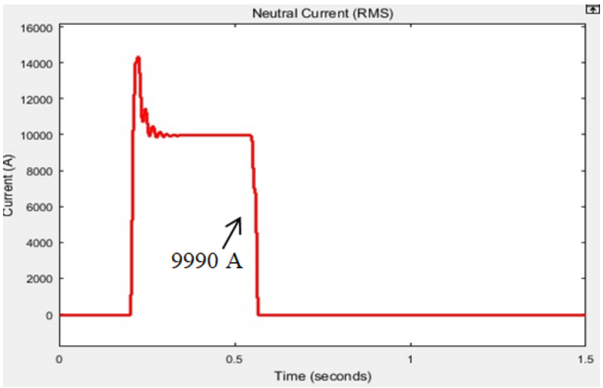

Fig. 7 RMS Earth Return Current for Case 1

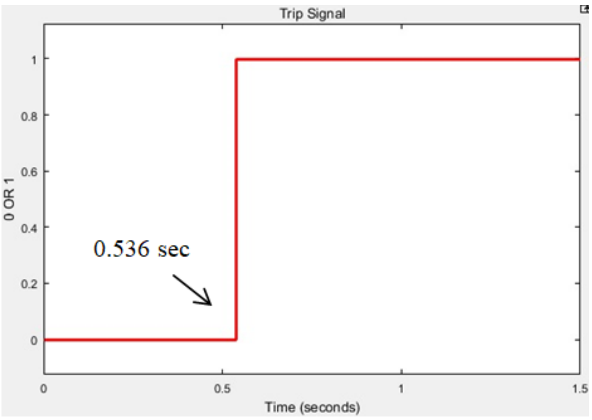

Fig. 8 Trip Signal for Case 1

For case 3, the fault currents for R phase, Y phase, B phase and earth were smaller than case 1 and case 2 because the fault location for case 3 (165 km) was greater than case 1 (50 km) and case 2 (105 km) at same resistance. Therefore, the impedance for case 3 was greater than the impedance of case 1 and case 2. The trip signal of earth sensor was sent to the circuit breaker at 0.678 sec (≈0.2 + 0.476 = 0.678 sec).

For case 4, at location (235 km), the fault currents of R phase, Y phase, B phase and earth for case 4 were smaller than the fault currents of case 1 (50 km), case 2 (105 km) and case 3 (165 km) at the same resistance because the impedance was higher than other cases. The circuit breaker was tripped by the trip signal of earth sensor at 0.771 sec (≈0.2 + 0.568 = 0.768 sec). The operation of line to ground (L-G) of each case is same.

Table V shows the simulation results of L-L-G fault at different locations. The fault currents, operation time and signals for faults are the results at location 50 km, 105 km, 165 km and 235 km and resistance is 0.001Ω. Case 5 to case 8 are L-L-G fault at different locations with resistance 0.001Ω. For case 5, the results can be seen that R phase, Y phase and earth fault current are the results at 50 km. The fault currents for R phase, Y phase and earth are greater than pick up current setting of phase and earth. In this case, the operation time of earth fault current is higher than the operation time of phase currents. Therefore, the operation time of earth sensor is faster than the operation time of R phase and Y phase sensors. The trip signal of earth sensor is sent to the circuit breaker at 0.559 sec (≈0.2 + 0.359 = 0.559 sec). Figs. 9-11 are rms R phase, rms Y phase and rms earth fault currents. Fig. 12 shows the trip signal which the breaker was tripped by the trip signal of earth sensor.

For case 6, the fault current for R phase, Y phase, B phase and earth are smaller than case 5. This is that the fault location for case 6 (105 km) is greater than case 5 (50 km). Therefore, the impedance of case 6 is higher than case 5 at same fault resistance. In this case, the fault current for R phase, Y phase, B phase and earth was still higher than pick up current setting. However, the circuit breaker was tripped by the trip signal of earth sensor at 0.607 sec (≈0.2 + 0.405 = 0.605 sec).

For case 7, the fault current for R phase, Y phase, B phase and earth are smaller than case 5 and case 6 because the fault location for case 7 (165 km) is greater than case 5 (50 km) and case 6 (105 km). Therefore, the impedance of case 7 is higher than case 5 and case 6 at same fault resistance. The fault current for R phase, Y phase, B phase and earth was still higher than pick up current setting. But, the circuit breaker was tripped by the trip signal of earth sensorat 0.678 sec (≈0.2 + 0.476 = 0.676 sec).

For case 8, the results can be seen that the fault current for R phase, Y phase, B phase and earth are smaller than case 5, case 6 and case 7 because the fault location for case 8 (235 km) is greater than case 5 (50 km), case 6 (105 km) and case 7 (165 km). The impedance of case 8 is higher than other cases at the same fault resistance. So, the fault current for R phase, Y phase, B phase and earth was higher than pick up current setting. The trip signal of earth sensor is sent to circuit breaker to isolate the healthy section at 0.771 sec (≈0.2 + 0.568 = 0.768 sec). The operation of double line to ground fault (L-L-G) of each case is equal to the values (0.771, 0.771 and 0.771 sec).

TABLE IV
SIMULATION RESULTS OF L-G FAULT AT DIFFERENT DISTANCES

Case no	Length (km)	Fault Type	Resistance (Ω)	Fault Current for Phase (A)	Fault Current for Earth (A)	$I_F > I_P$	Operating time for phase	Operating time for Earth	Trip Signal (S)
1	50 km	RG	0.001	9911	9990	Phase: Yes Earth: Yes	0.728	0.335	0.536
		YG	0.001	9911	9990	Phase: Yes Earth: Yes	0.728	0.335	0.535
		BG	0.001	9911	9990	Phase: Yes Earth: Yes	0.728	0.335	0.535
2	105 km	RG	0.001	5006	5079	Phase: Yes Earth: Yes	0.969	0.405	0.607
		YG	0.001	5006	5079	Phase: Yes Earth: Yes	0.969	0.405	0.607
		BG	0.001	5006	5079	Phase: Yes Earth: Yes	0.969	0.405	0.607
3	165 km	RG	0.001	3078	3139	Phase: Yes Earth: Yes	1.263	0.476	0.678
		YG	0.001	3078	3139	Phase: Yes Earth: Yes	1.263	0.476	0.676
		BG	0.001	3078	3139	Phase: Yes Earth: Yes	1.263	0.476	0.676
4	235 km	RG	0.001	1947	1991	Phase: Yes Earth: Yes	1.763	0.568	0.771
		YG	0.001	1947	1991	Phase: Yes Earth: Yes	1.763	0.568	0.771
		BG	0.001	1947	1991	Phase: Yes Earth: Yes	1.763	0.568	0.771

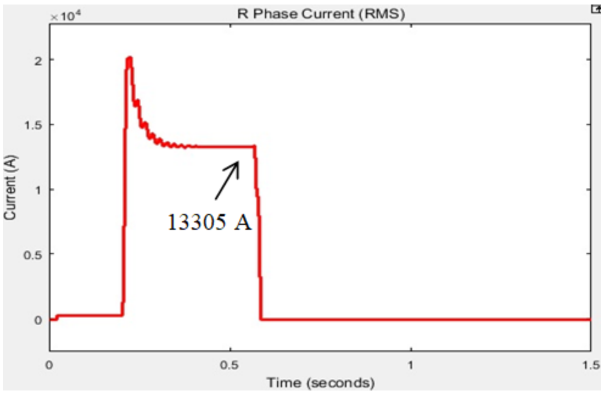

Fig. 9 RMS R phase Current for Case 5

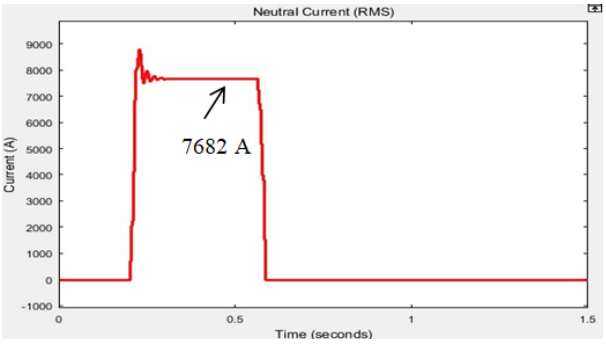

Fig. 11 RMS Earth Return Current for Case 5

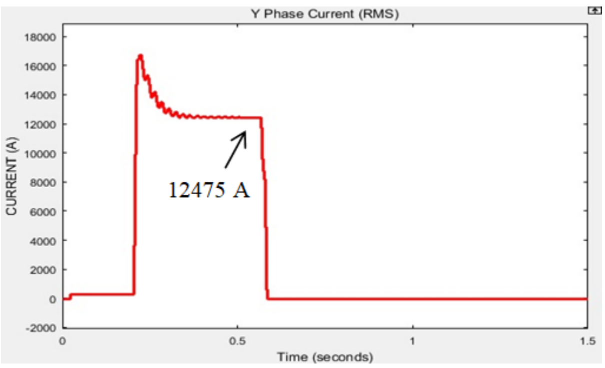

Fig. 10 RMS Y phase Current for Case 5

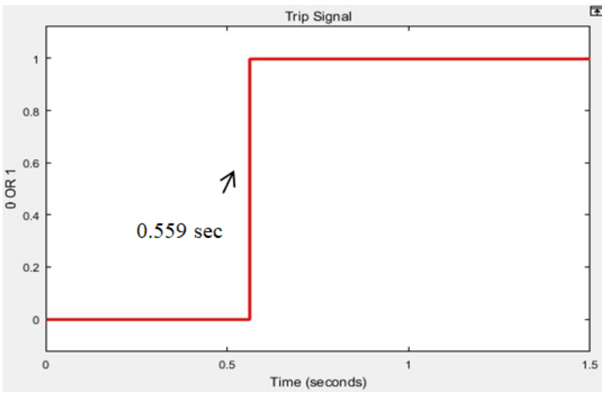

Fig. 12 Trip Signal for Case 5

TABLE V
SIMULATION RESULTS OF L-L-G FAULT AT DIFFERENT DISTANCES

Case no	Length (km)	Fault Type	Resistance (Ω)	Fault Current for Phase (A)	Fault Current for Earth (A)	$I_F > I_P$	Operating time for phase	Operating time for Earth	Trip Signal (S)
5	50 km	RYG	0.001	13305	7682	Phase: Yes	0.656	0.359	0.559
				12475		Phase: Yes	0.671		
						Earth: Yes			
		RBG	0.001	12475	7682	Phase: Yes	0.671	0.359	0.559
				13305		Phase: Yes	0.656		
						Earth: Yes			
		YBG	0.001	13305	7682	Phase: Yes	0.656	0.359	0.560
				12475		Phase: Yes	0.671		
						Earth: Yes			
6	105 km	RYG	0.001	7297	3750	Phase: Yes	0.819	0.447	0.648
				6763		Phase: Yes	0.846		
						Earth: Yes			
		RBG	0.001	6763	3750	Phase: Yes	0.846	0.447	0.648
				7297		Phase: Yes	0.819		
						Earth: Yes			
		YBG	0.001	7297	3750	Phase: Yes	0.819	0.447	0.649
				6763		Phase: Yes	0.846		
						Earth: Yes			
7	165 km	RYG	0.001	4832	2250	Phase: Yes	0.985	0.540	0.741
				4429		Phase: Yes	1.029		
						Earth: Yes			
		RBG	0.001	4429	2250	Phase: Yes	1.029	0.540	0.741
				4832		Phase: Yes	0.985		
						Earth: Yes			
		YBG	0.001	4832	2250	Phase: Yes	0.985	0.540	0.743
				4429		Phase: Yes	1.029		
						Earth: Yes			
8	235 km	RYG	0.001	3393	1376	Phase: Yes	1.191	0.674	0.876
				3081		Phase: Yes	1.262		
						Earth: Yes			
		RBG	0.001	3081	1376	Phase: Yes	1.262	0.674	0.876
				3393		Phase: Yes	1.191		
						Earth: Yes			
		YBG	0.001	3393	1376	Phase: Yes	1.191	0.674	0.877
				3081		Phase: Yes	1.262		
						Earth: Yes			

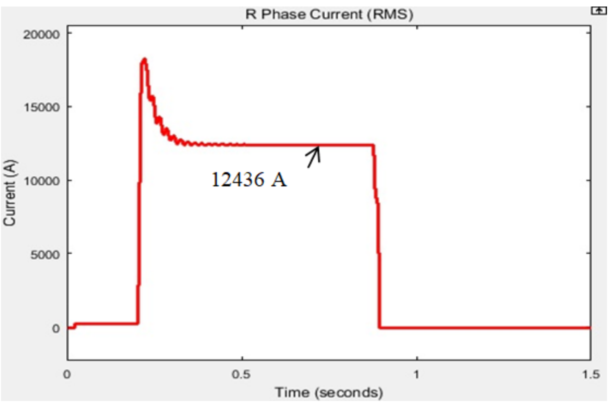

Fig. 13 RMS R phase Current for Case 9

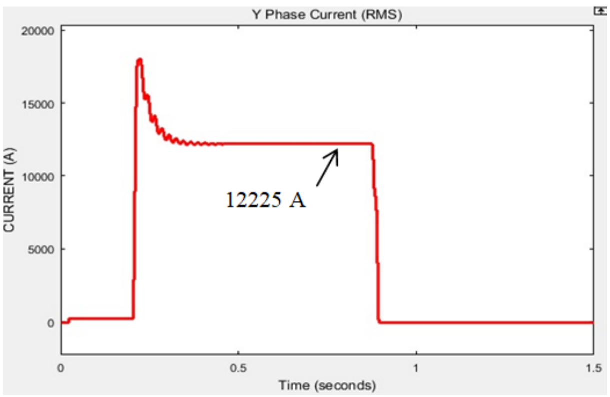

Fig. 14 RMS Y Phase Current for Case 9

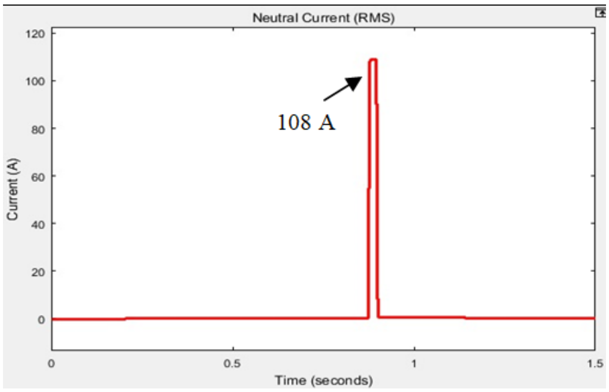

Fig. 15 RMS Earth Return Current for Case 9

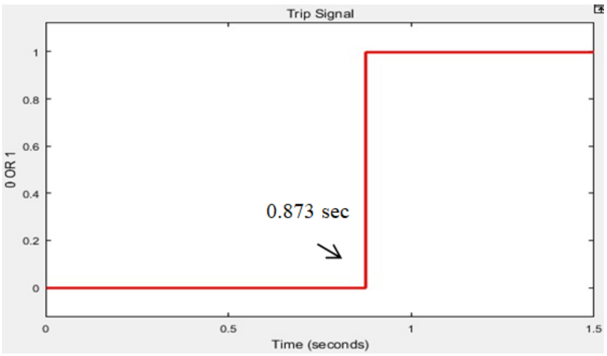

Fig. 16 Trip Signal for Case 9

TABLE VI
SIMULATION RESULTS OF L-L FAULT AT DIFFERENT DISTANCES

Case no	Length (km)	Fault Type	Resistance (Ω)	Fault Current for Phase (A)	Fault Current for Earth (A)	$I_F > I_P$	Operating time for phase	Operating time for Earth	Trip Signal (S)
9	50 km	RY	0.001	12436	108	Phase: Yes	0.672		0.873
				12225		Phase: Yes	0.676		
						Earth; No			
		RB	0.001	12225	35	Phase: Yes	0.676		0.873
				12436		Phase: Yes	0.672		
						Earth; No			
		YB	0.001	12436	35	Phase: Yes	0.672		0.872
				12225		Phase: Yes	0676		
						Earth; No			
10	105 km	RY	0.001	6904	35	Phase: Yes	0.838		1.040
				6693		Phase: Yes	0.849		
						Earth; No			
		RB	0.001	6693	35	Phase: Yes	0.849		1.043
				6904		Phase: Yes	0.838		
						Earth; No			
		YB	0.001	6904	108	Phase: Yes	0.838		0.039
				6693		Phase: Yes	0.849		
						Earth; No			
11	165 km	RY	0.001	4617	35	Phase: Yes	1.008		1.210
				4406		Phase: Yes	1.032		
						Earth; No			
		RB	0.001	4406	35	Phase: Yes	1.032		1.213
				4617		Phase: Yes	1.008		
						Earth; No			
		YB	0.001	4617	108	Phase: Yes	1.008		1.209
				4406		Phase: Yes	1.032		
						Earth; No			
12	235 km	RY	0.001	3285	35	Phase: Yes	1.214		1.416
				3074		Phase: Yes	1.264		
						Earth; No			
		RB	0.001	3074	35	Phase: Yes	1.264		1.419
				3285		Phase: Yes	1.214		
						Earth; No			
		YB	0.001	3285	35	Phase: Yes	1.214		1.415
				3074		Phase: Yes	1.264		
						Earth; No			

Table VI shows the simulation results of L-L fault at different location. The fault currents, operation time and trip signals for various faults occurred at different locations (50 km, 105 km, 165 km and 235 km) and fault resistance is 0.001. Case 9 to case 12 are L-L fault at different locations with resistance 0.001Ω. For case 9, the results are R phase, Y phase and Earth at location 50 km. The fault current for R phase and Y phase are higher than pick up setting. However, the operation time of R phase was faster than the operation time of Y phase because the multiple of R phase fault current (12436/600 = 20.72) was higher than for Y phase fault current (12225/600 = 20.37). Therefore, the circuit breaker was separated by the faulty section and tripped at 0.873 sec (≈0.2 + 0.672 = 0.872 sec). Figs. 13-15 show rms R phase current, rms Y phase current and rms earth current for case 9 and Fig. 16 is the trip signal which was sent to trip the circuit breaker at the operation time 0.876 sec. The earth fault current is lower than pick up current and it is not ground fault.

For case 10, the fault current for R phase, Y phase, B phase and earth were smaller than case 9 because the fault location for case 10 (105 km) was greater than the location of case 9 (50 km) at the same resistance so that the impedance of case 10 was higher than case 9. In this case, the fault current of R phase and Y phase was still higher than pick up current of phase. Therefore, the circuit breaker was tripped by the trip signal of R phase sensor at 1.040 sec (≈0.2 + 0.838 = 1.038 sec).

For case 11, the fault current for R phase, Y phase, B phase and earth were smaller than case 9 and case 10 because the fault location for case 11 (165 km) was greater than case 9 (50 km) and case 10 (105 km) at same resistance. Therefore, the impedance for case 11 was greater than the impedance of case 9 and case 9. The circuit breaker is tripped by trip signal of R phase sensor at 1.210 sec (≈0.2 + 1.008 = 1.208 sec).

For case 12, at location 235 km, the fault current of R phase, Y phase, B phase and earth for case 12 were smaller than the fault currents of case 9 (50 km), case 10 (105 km) and case 11 (165 km) at the same resistance because the impedance was higher than other cases. The trip signal of R phase sensor was sent to trip circuit breaker at 1.416 sec (≈0.2 + 1.214 = 1.414 sec). The operation of line to line fault (L-L) of each case is nearly equal the values (1.416, 1.419 and 1.415).

TABLE VII
SIMULATION RESULTS OF THREE PHASE FAULT AT DIFFERENT DISTANCES

Case no	Length (km)	Fault Type	Resistance (Ω)	Fault Current for Phase (A)	Fault Current for Earth (A)	$I_F > I_P$	Operating time for phase	Operating time for Earth	Trip Signal (S)
13	50 km	RYB	0.001	14238	387	Phase: Yes	0.642	1.814	0.843
				14238		Phase: Yes	0.642		
				14238		Phase: Yes	0.642		
						Earth: Yes			
14	105 km	RYB	0.001	7849	348	Phase: Yes	0.7959	2.109	0.996
				7849		Phase: Yes	0.7959		
				7849		Phase: Yes	0.7959		
						Earth: Yes			
15	165 km	RYB	0.001	5208	350	Phase: Yes	0.951	2.091	1.152
				5208		Phase: Yes	0.951		
				5208		Phase: Yes	0.951		
						Earth: Yes			
16	235 km	RYB	0.001	3670	304	Phase: Yes	1.138	2.657	1.340
				3670		Phase: Yes	1.138		
				3670		Phase: Yes	1.138		
						Earth: Yes			

Table VII shows the simulation results of three phase fault at different locations. The results can be seen that the fault currents, operation time and signals for faults are the results at location 50 km, 105 km, 165 km and 235 km and resistance is 0.001Ω.

Case 13 to case 16 are three phase (L-L-L) faults at different locations with resistance 0.001Ω. For case 13, the results can be seen that R phase, Y phase, B phase and earth fault current are the results at location 50 km. The fault current for R phase, Y phase, B phase and earth are greater than pick up current setting of phases and earth. In this case, the operation time of phase and earth fault current are higher than pick up current setting. However, the operation time of phase is faster than the operation time of earth. The trip signal of phase is sent to the circuit breaker at 0.843 sec (≈0.2 + 0.642 = 0.842 sec). Figs. 17-20 are rms R phase, rms Y phase, rms B phase and rms earth fault currents. Fig. 21 shows the trip signal which the breaker was tripped by the trip signal of phase sensor.

For case 14, the fault current for R phase, Y phase, B phase and earth are smaller than case 13. The fault location for case 14 (105 km) is greater than case 13 (50 km). Therefore, the impedance of case 14 is higher than case 13 at same fault resistance. In this case, the fault current for R phase, Y phase, B phase and earth were still higher than pick up current setting. However, the circuit breaker was tripped by trip signal of phase sensor at 0.996 sec (≈0.2 + 0.795 = 0.995 sec). The operation time of earth does not reach to pick up setting.

For case 15, the fault current for R phase, Y phase, B phase and earth are smaller than case 13 and case 14 because the fault location for case 15 (165 km) is greater than case 13 (50 km) and case 14 (105 km). Therefore, the impedance of case 15 is higher than case 13 and case 14 at same fault resistance. The fault current for R phase, Y phase, B phase and earth were still higher than pick up current setting. But, the circuit breaker was tripped by phase trip signal at 1.152 sec (≈0.2 + 0.951 = 1.151 sec). The operation time of earth is greater than the operation time of phase.

For case 16, the fault current for R phase, Y phase, B phase and earth are smaller than case 13, case 14 and case 15 because the fault location for case 16 (235 km) is greater than case 13 (50 km), case 14 (105 km) and case 15 (165 km). The impedance of case 16 is higher than other cases at the same fault resistance. Therefore, the fault current for R phase, Y phase, B phase and earth were higher than pick up current setting. However, the trip signal for three phase faults is sent to circuit breaker to isolate the healthy section at 1.340 sec (≈0.2+1.138=1.338 sec) because the operation time of phase is lower than the operation time of earth. The operations of three phase fault (L-L-L) for cases 14, 15 and 16 operate correctly like the operation of three phase fault (L-L-L) for case 13.

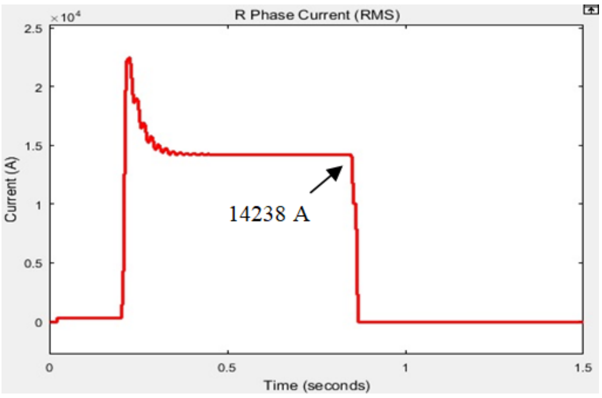

Fig. 17 RMS R phase Current for Case 13

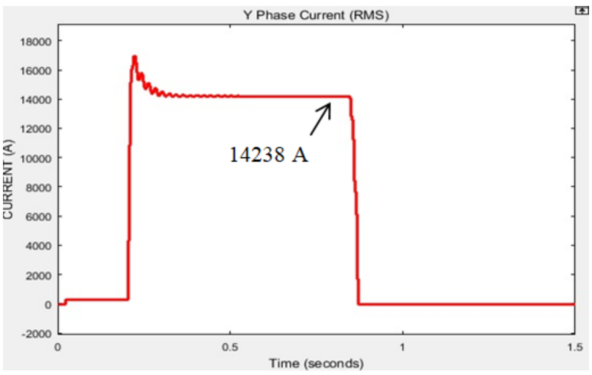

Fig. 18 RMS Y phase Current for Case 13

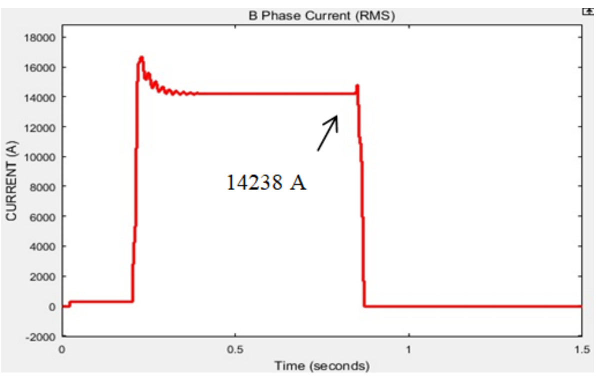

Fig. 19 RMS B phase Current for Case 13

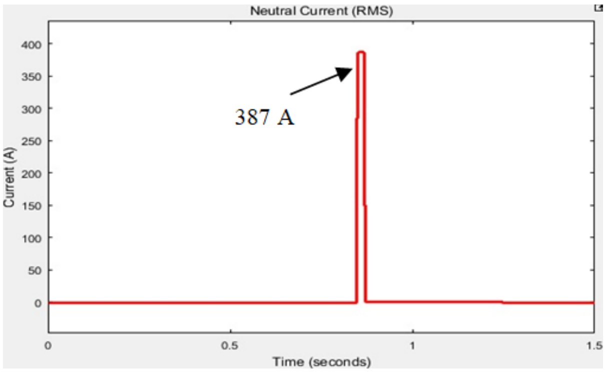

Fig. 20 RMS Earth Return Current for Case 13

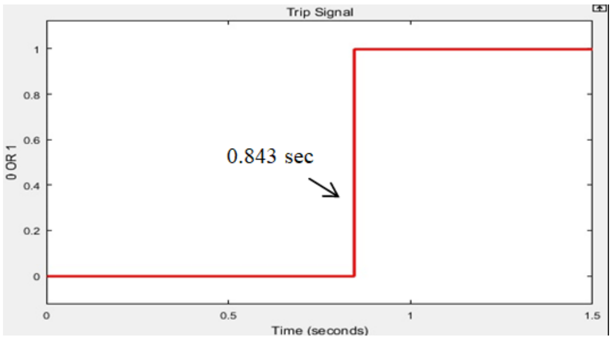

Fig. 21 Trip Signal for Case 13

V. Conclusion

The standard inverse definite minimum time overcurrent and earth fault relay is successfully modeled and simulated by using MATLAB/Simulink software. In according to simulation results, this software is capable to be used to model and simulate any type of relay such as step distance relay, over or under voltage relay and line current differential relay, etc. However, MATLAB software is the equation solver based software so that simulation time is depending on the complexity of the model. If the model is complex, the simulation time will take longer to finish. Therefore, the simulation time must be reduced by choosing appropriate simulation solver. The model in this paper can easily be used to other types of curve such as long time inverse, very inverse and extremely inverse curve. Moreover, the function of instantaneous overcurrent and earth fault relay can be added to model and simulate when the fault current is very high in transmission line. As the faults are cleared by protective device as possible as quickly, the transmission capacity of a power system can be maintained more sufficiently.

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