

# Modeling and Simulation of Overcurrent and Earth Fault Relay for Extra High Voltage Transmission Line

Han Su Yin\*, ShweZanAung\*\*

\*(Department of Electrical Power Engineering, Yangon Technological University/ Yangon, Myanmar)

\*\* (Project & System Design, Omega Integration Pte. Ltd)

\*\*\*\*\*

## Abstract:

The Electrical Power System consists of many vital components. Among them, the Transmission lines are one of the most important parts of the system. Faults occur in transmission lines have high impact on the electrical power system. The major fault in transmission line is single line to ground (L-G) fault, but, various types of faults also occur in transmission line, such as unsymmetrical faults which includes single line to ground (L-G) fault, double line to ground (L-L-G) fault and line to line (L-L) fault and symmetrical faults which are three phase fault. So, the protection relays are needed to protect transmission lines from various types of faults. Overcurrent and earth fault relay is normally used to protect transmission lines, distribution lines, transformers and bus coupler etc. Moreover, these relays can be used as main or backup protection. The modeling of protection relays is required to determine the effects of network parameters and configurations on the operation of these relays. This paper presents the modeling and simulation of standard inverse definite minimum time (IDMT) relay using MATLAB/SIMULINK software. The study of test system is Paunglaung – Pynmana High Voltage transmission line. The proposed model was tested for single line to ground (L-G) fault and three phase fault with a fault resistance (0.001  $\Omega$ ) at various locations. The simulation results obtained by MATLAB software show the feasibility analysis of High Voltage Transmission Line with Overcurrent and Earth Fault relay.

**Keywords —High Voltage Transmission line, Overcurrent and earth fault relay, MATLAB, Single line to ground (L-G) fault, Three Phasefault.**

\*\*\*\*\*

## I. INTRODUCTION

The electrical power system consists of many components such as generators, transformers, transmission lines and distributions lines, etc. Transmission lines are a vital part of electrical power system because they transmit energy from generation to load. When various faults occur in electrical power system, they cause significant changes in system like overcurrent, over or under voltage, power factor, impedance, frequency and power or current direction<sup>[1]</sup>. In EHV transmission lines, there are various type of faults occur in power system such as unbalanced faults: single line to ground (L-G) fault, double line to ground (L-L-G)

fault, line to line (L-L) fault and balanced faults: three phase fault.<sup>[2]</sup>

Transmission line protection is an important role in electrical power system because most of faults are occurring in transmission line. Transmission protection systems are designed to identify the location of faults and isolate the faulted section. An automatic protective relay is needed to isolate the faulty element as quickly as possible and keep the healthy section of the system to normal operation.<sup>[3]</sup> One of the protection relays used to protect the power system is overcurrent and earth fault relay.

These relays will detect and isolate the faulty section and it can be used main or backup

protection relay.<sup>[4]</sup> In overcurrent and earth fault relay, there are two types of operating time speed which are instantaneous time and delay time.<sup>[5]</sup> The weakness of instantaneous type is that it can't discriminate the operation when the fault current at two or more locations is the same.<sup>[6]</sup> In delay time type, there are definite time and inverse time. For definite time overcurrent and earth fault relay, the operating time is independent of current. For inverse time overcurrent and earth fault relay, if the fault current is high, the operating time will be fast. The fault current is measured in multiples of current setting or pickup current setting.<sup>[5]</sup>

In this paper, the test system is Paunglaung – Pyinmana, 230kV High Voltage Transmission Line. Using high voltage in transmission lines reduce line losses, voltage drop and size and volume of conductor for transmitting the same amount of power. This transmission line is modelled and simulated by using MATAB/SIMULINK Software. MATLAB/SIMULINK software is used to model Standard Inverse Definite Minimum Time (IDMT) overcurrent and earth fault relay which are digital signal processor (DSP) based relay. The performance of relay is investigated at normal condition in electrical power system. Then, the transmission line model was tested with single line to ground (L-G) fault and three phase fault with various fault location and fault resistance (0.001 Ω) by using the model of Standard Inverse Definite Minimum Time (IDMT) overcurrent and earth fault relay.

**II. THEORIES OF STANDARD IDMT RELAY**

Fig. 1 shows the characteristic curves of inverse time for overcurrent and earth fault relay. It shows four curves which each curve can be expressed by equations to calculate the operating time of overcurrent and earth fault relay. Fig. 2 shows the tripping characteristics for different time multiplier setting using standard inverse definite minimum time.

The current setting for each curve is the following equation (1).

$$I_s = \text{PSM} \times I_{\text{Full Load}} \tag{1}$$

Where, PSM = Plug Setting Multiplier  
 $I_{\text{Full Load}}$  = Full Load Current

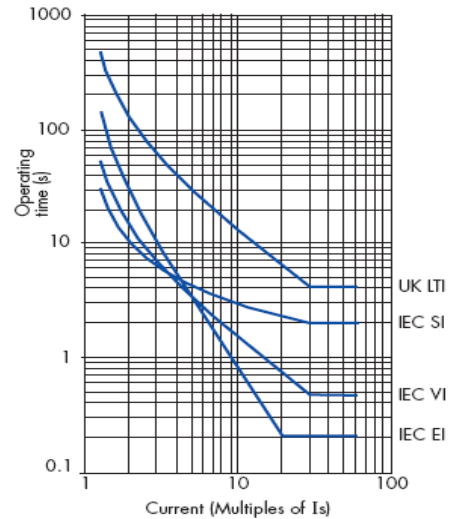


Fig. 1 Characteristics of Inverse Time Curve

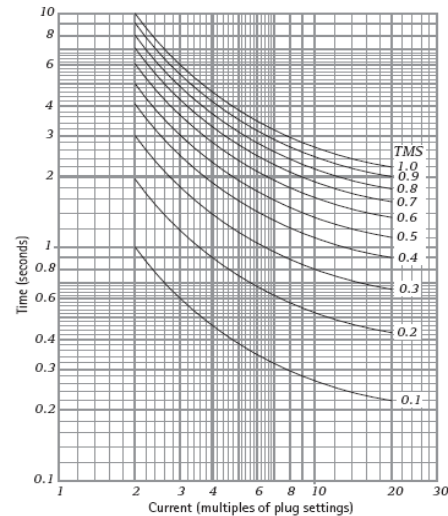


Fig. 2 Characteristic of Standard IDMT Curve with Different TMS Setting

TABLE 1  
OPERATION TIME EQUATION

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

Where,

t = Operating Time (s)

TMS = Time Multiplier Setting

I = Fault Current (A)

I<sub>s</sub> = Current Setting or Pickup Current (A)

Table 1 shows the equations of operation time which represent the characteristics curves of long time inverse, standard inverse, very inverse and extremely inverse of overcurrent and earth fault relay. For the same setting, long time inverse curve has the longest time to operate the relay and extremely inverse curve has the fastest time to operate the relay.

### III. MODELING AND SIMULATION

Table 2 shows overall parameters for power system network and Standard Inverse Definite Minimum Time overcurrent and earth fault relay. The current transformer (CT) ratio is chosen as 400/1 because the full load current is 96.82 A. The length of HV transmission is 13.36 km. The capacitance of transmission line is neglected. The plug setting for phase and earth are different where plug setting for phase fault set higher than full load current while plug setting for earth fault set lower than full load current to detect high impedance fault and ground fault which remain undetected by phase overcurrent relay.

The Time Multiplier Settings for phase and earth faults are set the same value. In proposed model, Standard inverse curve used to detect phase and earth fault. However, the model can be extended to other types such as Long Time Inverse, Very Inverse and Extremely Inverse.

TABLE 2  
SYSTEM AND RELAY PARAMETERS

No.	Parameters	Values
1	Source Short Circuit Level (MVA)	3694.591
2	X/R Ratio	6.3778
3	Source V <sub>LL</sub> (V)	230,000
4	Line CT Ratio (A)	400/1
5	Line Length (km)	13.36
6	Line Positive Sequence Resistance, R <sub>1</sub> (Ω/km)	0.04759
7	Line Zero sequence Resistance, R <sub>0</sub> (Ω/km)	0.31555
8	Line Positive sequence Inductance, L <sub>1</sub> (H/km)	0.000966
9	Line Zero sequence Inductance, L <sub>0</sub> (H/km)	0.003557
10	Line Full Load Current, I <sub>FL</sub> (A)	96.82
11	3 Phase Line Capacity (MVA)	298.78
12	Plug Setting (PS) for Phase	1.2
13	Time Multiplier Setting (TMS) for Phase	0.2
14	Plug Setting (PS) for Earth	0.4
15	Time Multiplier Setting (TMS) for Earth	0.2
16	Line V <sub>LL</sub> (V)	230,000
17	Nominal Frequency (HZ)	50
18	Type of Curve	SI Curve
19	Load Active Power (MW)	35.1

Fig. 3 shows overall diagram of simulation model for Paunglaung – Pyinmana High Voltage Transmission Line by using MATLAB/SIMULINK software. Fig 4 shows block inside overcurrent and earth fault relay subsystem. All phases and earth subsystem have their own curve to calculate the operating time and send the trip signal to the breaker. For earth fault subsystem, the input is the phasor summation of ‘A’ phase, ‘B’ phase and ‘C’ phase currents. When there is a ground fault, there will be unbalanced current flow to the earth. Subsystem from any phase or earth will send the trip signal faster than others when the current is higher than others.

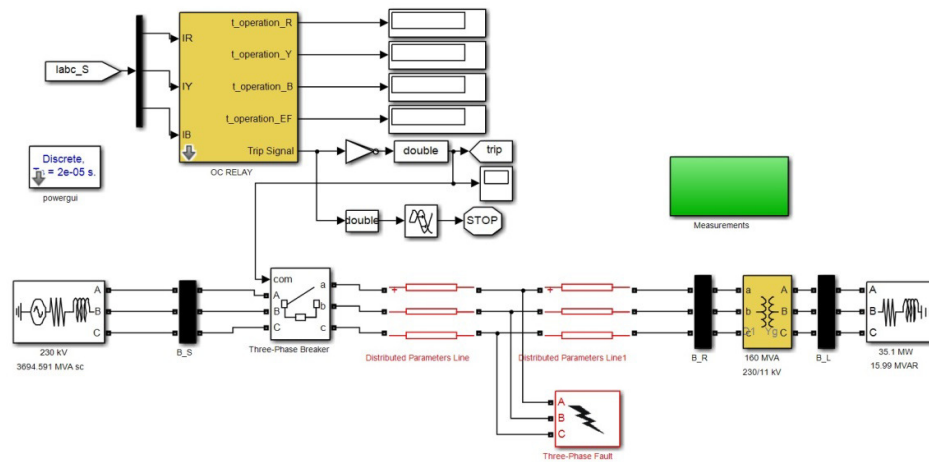


Fig. 3 Overall Diagram of Simulink Model

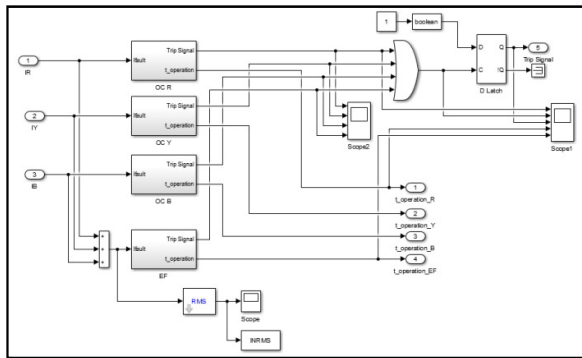


Fig. 4 Overcurrent and Earth Fault Relay subsystem

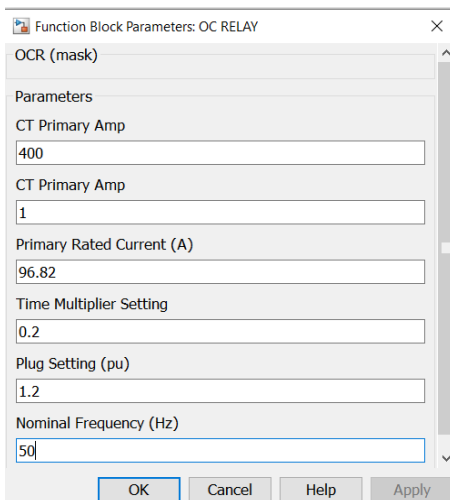


Fig.5 Block Parameters for Phase and Earth System

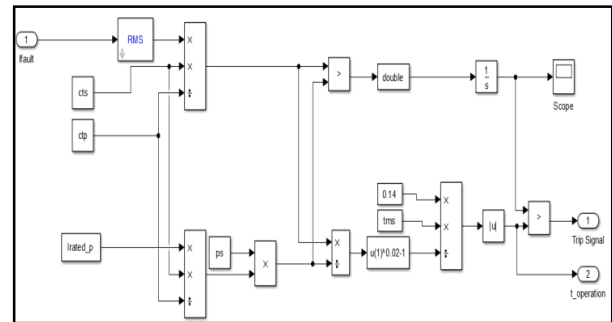


Fig. 6 Phases Subsystem

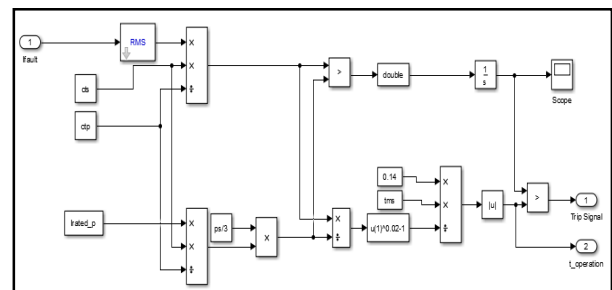


Fig. 7 Earth Subsystem

Thus, all the trip signal use “OR” gate. All subsystem will compute the operating time depending on the value of fault current and then the relay will trip the breaker when the operating time reach in pickup setting time. Fig. 5 shows the block parameters for phase and earth System. Fig. 6

shows block inside phase subsystem and Fig. 7 shows block inside earth subsystem.

All blocks represent the equation for standard inverse definite minimum time (IDMT) curve. The tripping time will be started when the fault current is higher than pickup current setting. When the tripping time more than calculated operating time, the trip signal will be sent to the circuit breaker.

#### IV. SIMULATION RESULTS

This section discusses the results from the simulation. From the model, all faults were initiated at 0.1 s. Two types of faults which are single line to ground (L-G) fault and three phase faults were taken to be studied. Faults were simulated at different locations (3.36 km, 7 km and 10 km) and fault resistance is 0.001  $\Omega$ . The results are the operation times (top) for three phase and earth detectors. The fault currents for three phase and earth are higher than the pickup current for three phase and earth faults. From the relay setting parameters  $I_p$  for each phase and earth were calculated as follows:

- I. Phase,  $I_p = 1.2 \times 96.82 = 116.184$
- II. Earth,  $I_p = 0.4 \times 96.82 = 38.728$

Table III shows the results of fault current, operation time and trip signals for faults at different locations (3.36 km, 7 km and 10 km) and fault resistance (0.001  $\Omega$ ). Cases 1 to 3 are single line to ground (SLG) faults at different locations and Cases 4 to 6 are three phase faults at different locations.

For case 1, the results can be seen that 'A' phase and earth detected the fault at location (3.36 km) and fault currents exceeded the pickup currents. Phase fault current and earth fault current are the same (657000A), and consequently, secondary fault currents for phase and earth are also the same (65700/400=164.25A). However, operation time was faster for earth detector compared with phase detector because the multiple of pickup for earth fault current (164.25/38.728) higher than the multiples of pickup for phase (164.25/116.184). Therefore, the breaker was isolated and tripped at 0.275s ( $\approx 0.1 + 0.1746 = 0.2746$  s). Fig. 8 and Fig. 9 show 'A' phase (RMS) current and earth (RMS)

current for case 1. Fig. 10 shows trip signal which was sent to trip the breaker after the operation time 0.275 s had been elapsed.

For case 2, the fault currents both B phase and earth detectors were smaller compared with case 1 because the fault location for case 2 (7 km) was greater than case 1 (3.36 km) while fault resistance value (0.001  $\Omega$ ) was the same but the impedance between the fault and generation point for case 2 was higher than case 1. However, B phase and earth fault currents are still greater than each pickup current and the breaker was tripped at 0.2950s ( $\approx 0.1 + 0.1949 = 0.2949$  s) by the trip signal of earth fault detector.

For case 3, the C phase and earth fault currents were smaller than case 1 and case 2 because the fault location for case 3 (10 km) was greater than case 1 (3.36 km) and case 2 (7 km) at the same fault resistance (0.001  $\Omega$ ). Therefore, the impedance between fault and generation point for case 3 was greater than the impedance for case 1 and case 2. However, both fault currents were greater than the pickup currents for A phase and earth fault and the breaker were tripped at 0.3070s ( $\approx 0.1 + 0.2065 = 0.3065$  s).

For case 4, a fault occurs between 'A' phase, 'B' phase and 'C' phase of the HV transmission line. From the results, fault currents at each phase are the same, but, the earth fault current is almost zero ( $5 \times 10^{-11}$ A). So, the earth fault current is lower than the pickup current. Therefore, the breaker was not tripped by trip signal of earth fault. However, the breaker was tripped at 0.262s ( $\approx 0.1$  s + 0.187 s = 0.287 s) by trip signal of three phase fault detectors. Fig. 11, Fig. 12, Fig. 13 and Fig. 14 show 'A' phase, 'B' phase, 'C' phase and earth return current for case 4 respectively while Fig. 15 shows the trip signal for three phase.

For case 5, fault location was changed from 3.36 km to 7 km with the same fault resistance (0.001  $\Omega$ ). The fault currents for 'A' phase, 'B' phase and 'C' phase decrease but the fault currents are still more than pickup current for three phase fault. Therefore, the breaker was tripped at 0.2874s ( $\approx 0.1$  s + 0.210 = 0.310 s) by trip signal of three phase detectors.

TABLE 3  
 SIMULATION RESULTS

Case No.	Fault Type	F <sub>L</sub> (km)	R (Ω)	I <sub>F</sub> FOR FAULTED PHASE (A)	I <sub>F</sub> FOR EARTH(A)	I <sub>F</sub> > I <sub>p</sub>	T <sub>OP</sub> FOR FAULTED PHASE(S)	T <sub>OP</sub> FOR EARTH(S)	TRIP SIGNAL(S)
1	AG	3.36	0.001	65700	65700	PHASE: YES EARTH: YES	0.2072	0.1746	0.275
2	BG	7	0.001	31810	31850	PHASE: YES EARTH: YES	0.2357	0.1949	0.2950
3	CG	10	0.001	22320	22360	PHASE: YES EARTH: YES	0.2525	0.2065	0.3067
4	ABC	3.36	0.001	A=124400 B=124400 C=124400	0	PHASE: YES PHASE: YES PHASE: YES EARTH: NO	0.1870 0.1870 0.1870	0.06646	0.2620
5	ABC	7	0.001	A=60610 B=60890 C=60730	0	PHASE: YES PHASE: YES PHASE: YES EARTH: NO	0.2100 0.2100 0.2100	0.07757	0.2874
6	ABC	10	0.001	A=42730 B=42730 C=42730	0	PHASE: YES PHASE: YES PHASE: YES EARTH: NO	0.2233 0.2233 0.2233	0.07355	0.2983

Finally, for case 6, fault location was changed from 7km to 10km at the same fault resistance (0.001 Ω). The fault currents for three phase less than case 4 and case 5 but fault currents greater than pickup current of three phase. Thus, the phase detectors sensed the fault and the breaker was tripped at 0.2983s ( $\approx 0.1 \text{ s} + 0.2233 = 0.3233 \text{ s}$ ) by trip signal of three phase detectors.

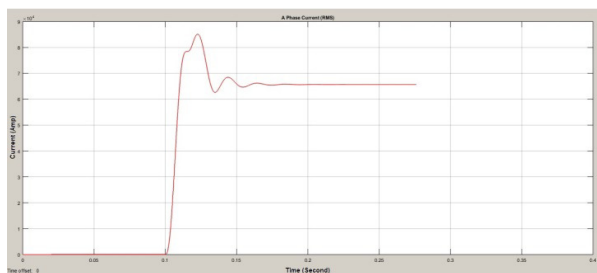


Fig. 8 A Phase Current for Case 1

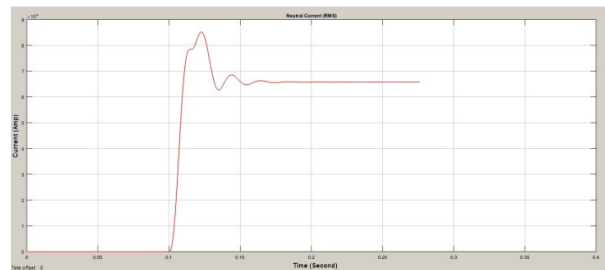


Fig. 9 RMS Earth Return Current for Case 1

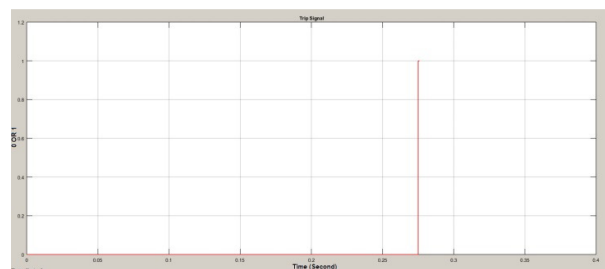


Fig. 10 Trip Signal for Case 1

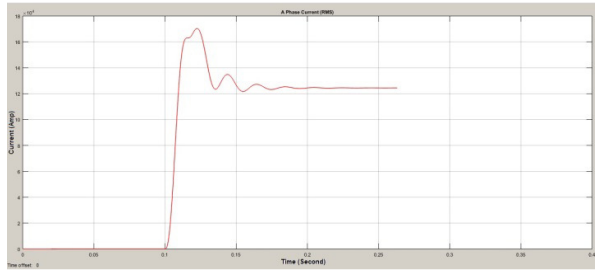


Fig. 11 A Phase Current for Case 4

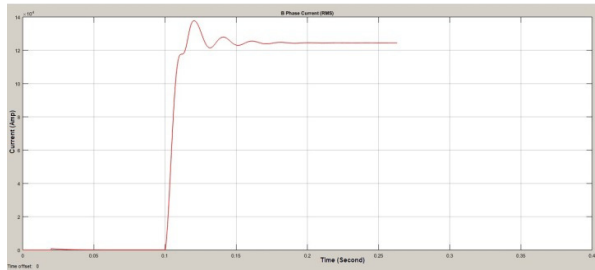


Fig. 12 B Phase Current for Case 4

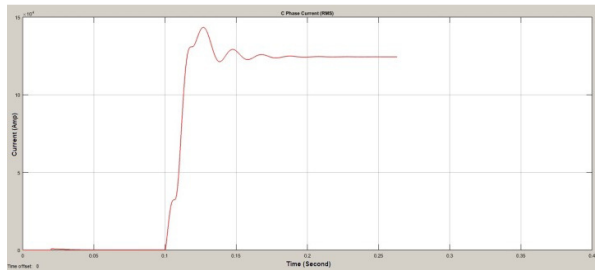


Fig. 13 C Phase Current for Case 4

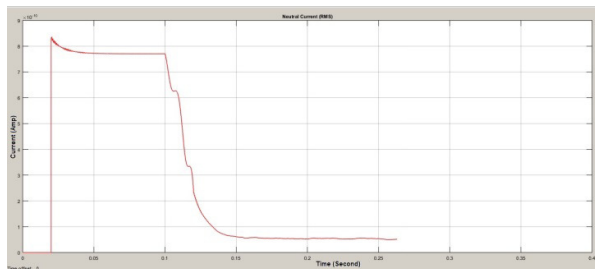


Fig. 14 RMS Earth Return Current for Case 4

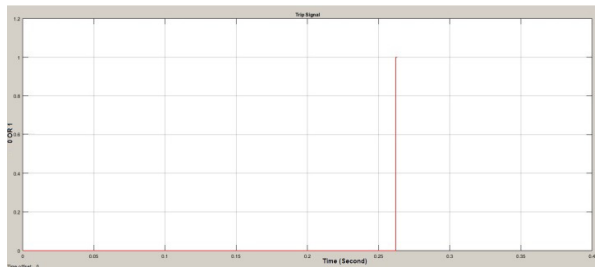


Fig. 15 Trip Signal for Case 4

## V. CONCLUSION

The standard IDMT overcurrent and earth fault relay was successfully modeled and simulated by using MATLAB/Simulink software. The model in this paper can be extended to other types of curve such as long time inverse, very inverse and extremely inverse. In future, distance relay and differential relay will be modeled and simulated in HV transmission line. As the faults are cleared by protective device more quickly, the transmission capacity of a power system can be maintain more sufficiently.

## ACKNOWLEDGMENT

I would like to express my sincere appreciation to the Paunglaung and Pyinmana Substations for their supports on data collecting. I also would like to acknowledge special thanks to all of my teachers, my seniors and colleagues from Department of Electrical Power Engineering for their help, support and encouragement towards this paper.

## REFERENCES

- [1] HimanMahajan, Ashish Sharma: Various Techniques used for Protection of Transmission line A Review, International Journal of Innovations in Engineering and Technology, Vol. 3 Issue 4 April 2014.
- [2] Blackburn, J. Lewis; Domin Thomas J. Protective Relaying, Principles and applications, 4<sup>th</sup> Edition, 2014
- [3] Usman I. Abubakar: A Design of Protection Achemes for AC Transmission Lines Considering A Case Study, 2nd International Conference on Science Technology and Management, University of Delhi (DU), Conference Center, Delhi (India), 27 September 2015.
- [4] P. R. Subcommittee: Protective Relaying Philosophy and Design Guidelines PJM Relay Subcommittee, 2013.
- [5] Fecime, Chapter 9: Overcurrent Protection for Phase and Earth Faults, Network Protection and Automation Guide, pp. 123-151, 2008.
- [6] Z. Wang, J. Li, W. Yang, and Z. Shi: Impact of Distributed Generation on the Power Supply Reliability, IEEE PES Innovative Smart Grid Technologies, 2012.