

# Modeling and Simulation of Inverse Time Overcurrent Relay using Matlab/Simulink

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**Abstract**—Overcurrent relay is an important relay used to protect transmission and distribution feeders, transformer, bus coupler etc. It can be used as main or backup protection relays. The modeling of overcurrent relay and other protection relays is important in the research on the effects of network parameters and configurations on the operation of these relays. This research deal with modeling and simulation of inverse time overcurrent relay using commonly used Matlab/Simulink software. The developed model was tested with single line to ground fault and phase to phase fault with various fault locations and fault resistances to evaluate phase and earth detectors in sensing the fault current. Simulations results show the feasibility of the software to be used to develop the relay.

**Index Terms**—Overcurrent relay, inverse time, Matlab, Simulation.

## I. INTRODUCTION

Protection relay is used to reduce harmful damage to both electrical equipment and personnel when an electrical fault occurs. Protection relay is designed based on the basis of selectivity, reliability, speed and sensitivity [1]. One of protection relays used to protect the circuits in power system is overcurrent relay. When there is a fault in power system, overcurrent relay will detects and isolate the faulty section from the rest of the system by measuring the value of current. It can be used as main or backup protection to protect the transmission or distribution feeders, transformers, bus coupler etc [2]. When it is used to protect the feeders and transformers, it normally will be coordinated in sequence so that the relay nearest to the fault location will operate first. There are two types of overcurrent relay operating speed which are instantaneous time and delayed time [3]. The weakness of instantaneous type is it can't discriminate the operation when fault current at two or more locations is the same [4].

For delayed time type, it can be divided into two categories which are definite time and inverse time. For definite time overcurrent relay, the operating time is independent of current where relay closest to the fault has shortest operating time. The problem with this type is the longest operating time is at the electrical source where the fault current is the highest. While for inverse time overcurrent relay, the higher the fault current level, the faster the operating time will be. Fault current is

measured in multiples of current setting or pickup current. When used in coordination with other overcurrent relays such as to protect radial feeders, it can be coordinated with upstream or downstream relays easily by the use of Time Multiplier Setting, TMS [3].

There are many works had been done to model and simulate protection relays using Matlab/Simulink software. As in [5], Matlab/Simulink was used to model Inverse Definite Minimum Time (IDMT) overcurrent relay which based on digital signal processor (DSP). After the developed Simulink model was tested using simulation, the developed model then was embedded in TMS320F2812 DSP board. Simulink also had been used to model overcurrent relay which used to protect the Photovoltaic (PV) system for irrigation [6]. The developed model was investigated at normal conditions, starting of the motor as well as at faulty conditions.

Graphical user interface (GUI) of distance relay was developed and linked with the model of distance relay created using Simulink [7]. The GUI was used to ease the understanding among electrical engineering students on the operation of distance relay. Finally, Matlab/Simulink was used to model the conventional distance relay as in [8]. The relay model then was simulated, analyzed and evaluated in real time using Opal-RT's Real-Time LABORatory (RT-LAB). The authors also successfully evaluated the effects of in feed current for protection at zones 1 and 2.

## II. SCOPES OF THE PROJECT

The purpose of this research is to model, simulate and evaluate inverse time overcurrent relay using Matlab/Simulink software. If the results prove the feasible use of the software to model and simulate the relay, the model can be extended to be used in further research in the future. Matlab/Simulink is chosen because of the widespread use of this software as research platform and its' capability to model power system components [9]. To ease the modeling of the relay, the model has been simplified and bounded by limitation where only standard inverse (SI) curve was modeled and simulated in this research.

## III. THEORIES OF INVERSE TIME OVERCURRENT RELAY

Figure 1 shows the characteristic curves of inverse time overcurrent relay. There are four curves in the figure where each curve can be expressed by an equation to calculate the operating time. Table I shows the equations of operating time which represent the characteristic curves of inverse time overcurrent relay. For the same multiples of current setting, long time inverse curve has the longest time to operate while extremely inverse curve has the fastest time to operate the relay [3]. The current setting (or the pickup current) for each curve is represented by Eq. (1).

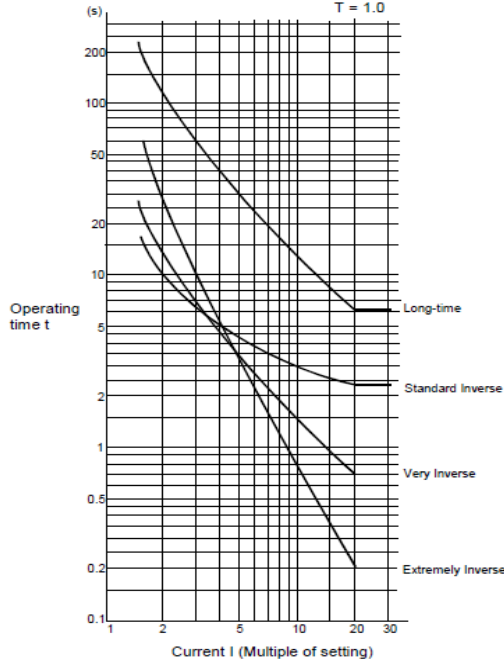


Fig. 1. Characteristics of inverse time overcurrent relay [3]

$$I_p = PS \times CT_{sec} \quad (1)$$

Where;

PS = Plug Setting (% or pu)

$CT_{sec}$  = Rated Secondary Current of Current Transformer (CT) in Ampere (A).

TABLE I. OPERATING TIME EQUATIONS [3]

Type of curve	Equation for operating time (s)
Long time inverse	$t_{op} = TMSx \frac{120}{\left(\frac{I_r}{I_p}\right) - 1}$
Standard inverse	$t_{op} = TMSx \frac{0.14}{\left(\frac{I_r}{I_p}\right)^{0.02} - 1}$
Very inverse	$t_{op} = TMSx \frac{13.5}{\left(\frac{I_r}{I_p}\right) - 1}$
Extremely inverse	$t_{op} = TMSx \frac{80}{\left(\frac{I_r}{I_p}\right)^2 - 1}$

Where;

$t_{op}$  = Operating Time (s)

TMS = Time Multiplier Setting (% or pu)

$I_r$  = Fault Current (A)

$I_p$  = Current Setting or Pickup Current (A)

#### IV. MODELING AND SIMULATION

Table II shows the overall parameters used for the power system network and relay setting. The CT ratio been chosen is 1200/1 A depending on the value of calculated full load current. The length of the line is 50 km. The capacitance of the line is neglected. The PS parameters for phase and earth faults are different where PS for phase fault normally set higher than full load current while PS for earth fault normally set lower than full load current to detect high impedance fault when involving ground fault which normally undetected by phase overcurrent relay. The TMS for both phase and earth faults are set to the same value. In this model, only Standard Inverse (SI) curve used to detect phase and earth faults. However, the model can easily be extended to other types of curve.

TABLE II. NETWORK AND RELAY SETTING PARAMETERS

Parameters	Values
Source Short Circuit Level (VA)	500,000,000
X/R Ratio	5
Source $V_{LL}$ (V)	132,000
Line CT Ratio	1200/1 A
Line Length (km)	50
Line Positive Sequence Resistance, $R_1$ ( $\Omega$ /km)	0.045531917
Line Zero Sequence Resistance, $R_0$ ( $\Omega$ /km)	0.151489359
Line Positive Sequence Inductance, $L_1$ (H/km)	0.0006176566224
Line Zero Sequence Inductance, $L_0$ (H/km)	0.001533982723
Line Full Load Current, $I_{FL}$ (A)	1233 A
3 Phase Line Capacity (VA)	282,000,000
Plug Setting (PS) for Phase	1.2
Time Multiplier Setting (TMS) for Phase	0.35
Plug Setting (PS) for Earth	0.4
Time Multiplier Setting (TMS) for Earth	0.35
Line $V_{LL}$ (V)	132,000
Network Frequency (Hz)	50
Type of Curve	Standard Inverse
Load Active Power (W)	175,000,000

Figure 2 shows the overall model for the network and relay which was created using Matlab/Simulink software. The network chosen is a simple spur transmission line which is connected to a Thevenin equivalent three phase power source at one end while the other end is connected to a three phase load. Figure 3 shows the blocks inside OC Relay Subsystem.

All phases and earth subsystems have their own curve to calculate the operation time and send the trip signal. For EF subsystem, the input to it is the phasor summation of red, yellow and blue currents where when there is a ground fault, there will be residual or imbalanced current flow to the earth. This will not happen for phase to phase fault. Subsystem from any phase or earth will send the trip signal faster than others when the current to it is higher than others. This is why all the trip signals is 'OR' gated. All phases and earth subsystems will compute the operation time depending on the value of fault

current entering them. Figure 4 shows the block properties developed for the phase and earth subsystems.

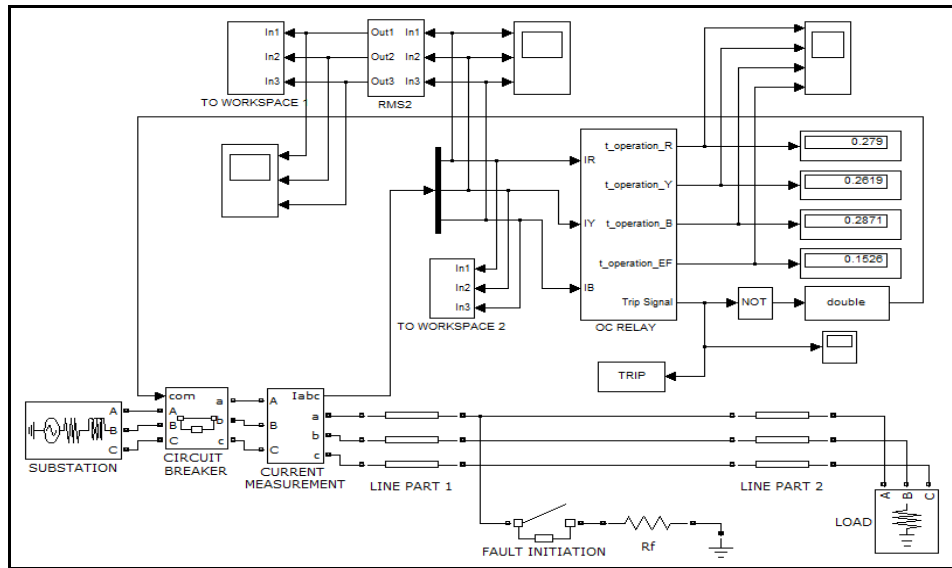


Fig. 2. Overall diagram of Simulink model

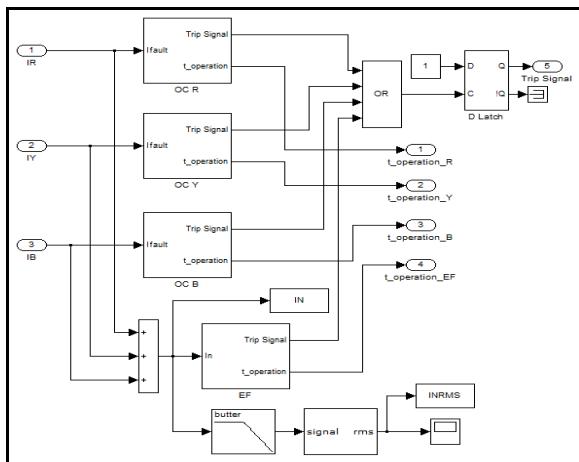


Fig. 3. OC relay subsystem

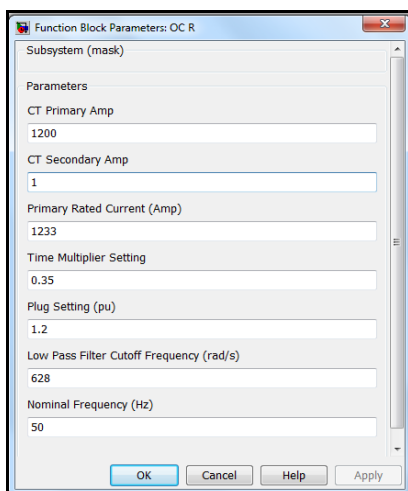


Fig. 4. Block properties for phase and earth subsystems

Figure 5 shows the blocks inside each phase and earth subsystem. All these blocks represent the equation for SI curve. It can be seen that, the timer only will be started when the fault current is higher than the pickup current. When the timer elapse (more than) the calculated operation time, trip signal will be sent.

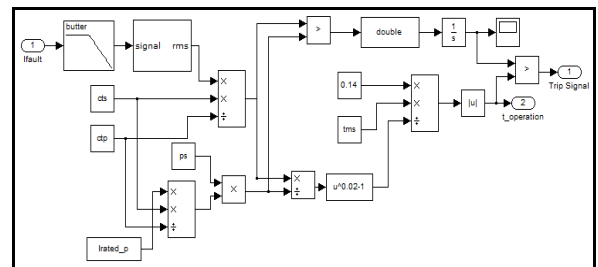


Fig. 5. Phases and earth subsystems

## V. SIMULATION RESULTS

This section discusses the results from the simulation. From the model, all faults were initiated at 0.5 s. Two types of fault which are single line to ground (SLG) fault and line to line (LL) fault were taken to be studied. Faults were simulated at different locations,  $F_L$  and with different fault resistances,  $R_f$  to vary the value of fault current. The results which were focused are the operation times,  $t_{op}$  for all phases and earth detectors and whether the fault current,  $I_f$  for each phase and earth is higher than the pickup current,  $I_p$  or not. From the relay setting parameters,  $I_p$  for each phase and earth were calculated as follows:

- i. Earth,  $I_p = 0.4 \times 1200 = 480 \text{ A}$
- ii. Phase,  $I_p = 1.2 \times 1200 = 1440 \text{ A}$

Table III shows the results of fault current, operation time and trip signal for faults at different locations and different fault resistances. Case 1 to 3 are for SLG faults (RG) while case 4 to case 6 are for LL faults (RY). For case 1, it can be seen that both red phase and earth detected the fault due to low fault resistance (1 Ω) and both fault currents exceeded the pickup currents. However, the operation time was faster for earth detector compared with phase detector because the

multiple of earth's fault current over pickup current ( $2061/480 = 4.294$ ) was higher than for phase ( $2604/1440 = 1.808$ ). Thus, the breaker was isolated and tripped at 2.204 s ( $\approx 0.5 \text{ s} + 1.692 \text{ s} = 2.192 \text{ s}$ ). Figure 6 and 7 show the rms red phase current and rms earth return current for case 1 respectively while Fig. 8 shows the trip signal which was sent to trip the breaker after the operation time 1.692 s had been elapsed.

TABLE III. SIMULATION RESULTS

Case No.	Fault Type	$F_L$ (km)	$R_f$ (Ω)	$I_f$ for Faulted Phase (A)	$I_f$ for Earth (A)	$I_f > I_{pic}$ (Yes/No)	$t_{op}$ for Faulted Phases (s)	$t_{op}$ for Earth (s)	Trip Signal (s)
1	RG	10	1	2604	2061	Phase: Yes Earth: Yes	4.335	1.692	2.204
2	RG	40	1	1907	1356	Phase: Yes Earth: Yes	9.809	2.487	3.0041
3	RG	40	40	1374.6	533.15	Phase: No Earth: Yes	53.889	22.831	23.4691
4	RY	10	1	R = 2590 Y = 1920	$\approx 0$	Phase: R = Yes, Y = Yes Earth: No	R = 4.132 Y = 8.504	0.1252	4.5068
5	RY	40	1	R = 2130 Y = 1480	$\approx 0$	Phase: R = Yes, Y = Yes Earth: No	R = 6.352 Y = 88.235	0.132	6.8849
6	RY	40	20	R = 1890 Y = 1395	$\approx 0$	Phase: R = Yes, Y = No Earth: No	R = 8.992 Y = 78.705	0.122	9.5475

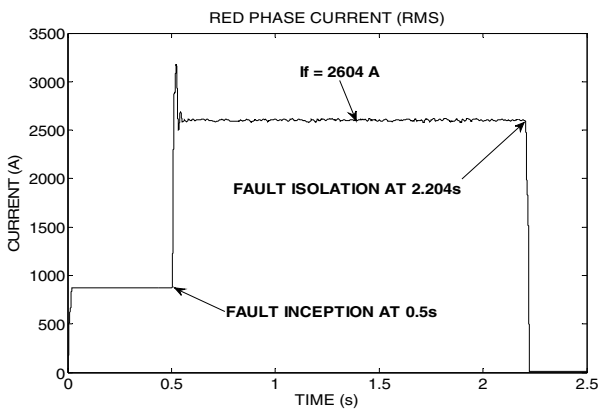


Fig. 6. Rms red phase current for case 1

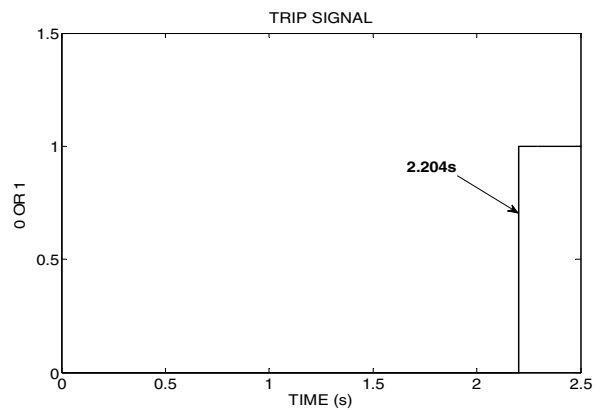


Fig. 8. Trip signal for case 1

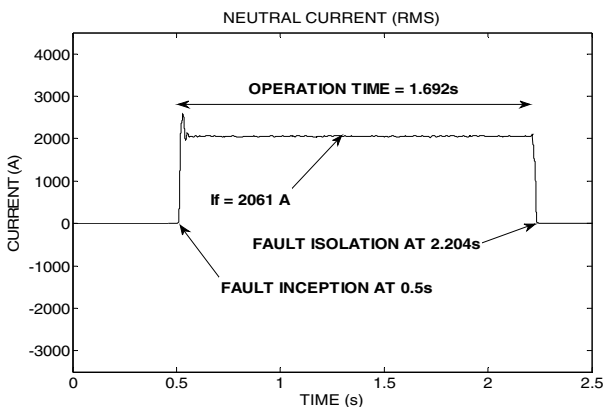


Fig. 7. Rms earth return current for case 1

For case 2, the fault currents for both red phase and earth detectors were smaller compared with case 1. This was because the fault location for case 2 (in km) was greater than case 1 although the fault resistance value was the same, thus the impedance for the fault current to flow was higher. However, both phase and earth fault currents still greater than each pickup current and the breaker was tripped at 3.0041 s ( $\approx 2.487 + 0.5 \text{ s} = 2.987 \text{ s}$ ) by the trip signal sent by the earth fault detector. For case 3, the fault location was still the same with case 2. However, the fault resistance was increased to 40 Ω. It can be seen that, fault currents for both phase and earth detectors dropped significantly. Only the earth detector sensed the fault because the fault current was still greater than pickup current. The breaker was tripped at a very long time which was 23.4691 s ( $\approx 22.831 \text{ s} + 0.5 \text{ s} = 23.331 \text{ s}$ ).

In case 4, a fault was introduced which connected between red and yellow phases of the line. From the results, fault current at red phase was higher than yellow phase. No fault current flow to the earth because it was not a ground fault. Breaker was tripped at 4.5068 s ( $\approx 4.132 \text{ s} + 0.5 \text{ s} = 4.632 \text{ s}$ ) by the red phase detector. Although there was operation time calculated by earth detector, the trip signal was not sent by earth detector because the fault current was too low ( $\approx 0$ ) compared with its pickup current. Figure 9 shows the red phase, yellow phase and earth return currents for case 4 while Fig. 10 shows the red phase trip signal.

With the same fault resistance as case 4, fault location was changed to 40 km for case 5. It can be seen that both fault currents at red and yellow phases decreased. However, both red and yellow phase detectors still can detected the fault currents because both fault currents more than pickup current for phase detector. The breaker was tripped at 6.8849 s by red phase detector ( $\approx 6.352 \text{ s} + 0.5 \text{ s} = 6.852 \text{ s}$ ). Finally for case 6, fault location was maintained at 40 km but fault resistance was increased to 20  $\Omega$ . It can be seen that fault currents for both red and yellow phases dropped quite significantly. Fault current for yellow phase dropped below the pickup current for phase fault. Thus, only red phase detector sensed the fault and sent the trip signal.

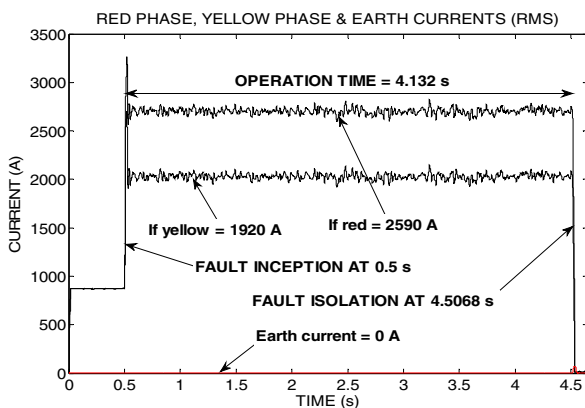


Fig. 9. Red phase, yellow phase and earth return currents for case 4

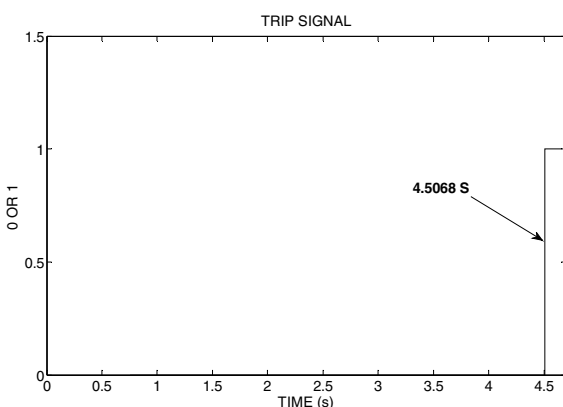


Fig. 10. Trip signal for case 4

## VI. CONCLUSION

The inverse time overcurrent relay was successfully modeled and simulated using Matlab/Simulink software. This shows that the software is capable to be used to model any type of relays. However, because Matlab is equation solver based software, the simulation time is depending on the complexity of the model. Higher complexity of the model will take longer time for the simulation to finish. Appropriate simulation solver must be chosen to reduce the simulation time. The model developed in this research can easily be extended to other types of curve such as extremely inverse, very inverse, and long time inverse. Besides that, definite time feature also can be added to cater for saturated current transformer when the fault current is too high.

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