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Overcurrent relays coordination using MATLAB model

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ABSTRACT

Proper coordination of protective relays at substation renders a significant part in the safe operation of power system. The principal aim of coordinating protective relays in a power system network is to obtain selectivity without sacrificing sensitivity and fast fault clearance time. In order to minimize outages, proper coordination of protective relays must be ensured. As a result of increased urbanization, a substantial increase in electric power demand has been recorded in recent years. But, owing to ineffective coordination of relay operation, there has been limited expansion in the system. This paper presents the design of a MATLAB Graphical User Interface (GUI) model of overcurrent relay (extremely inverse, standard inverse, and very inverse) using various characteristic equations in order to determine the parameters of the different relay. This paper further presents the relay coordination and setting for a 132/33 kV substation with a 3515.1 A short circuit current. The time multiplier setting (TMS), plug setting (PS) and actual operating time of the different relay was ascertained.

INTRODUCTION

According to Zoran and Milenko (2014), overcurrent protection represents one of the basic protections in every power system. Overcurrent and directional overcurrent relays are widely used for the protection of radial and ring sub transmission systems and distribution systems. They are also used as backup protection in transmission systems. The input signal for this protection is the root mean square (RMS) current of the protected element according to which tripping time of the relay is determined.

The problem of coordinating protective relays in power system networks consists of selecting their suitable settings such that their fundamental protective function is met under the requirements of sensitivity, selectivity, reliability and speed. In modern power system, abnormal condition such as short circuit can frequently occur, thereby causing interruption in power supply, and may damage the equipment connected to the power system, which allows us to think the importance of designing a reliable protective system (Vijayakumar and Neme, 2008). Relays are essential part of a power system protection and they are essential for isolating only the faulty section of the power system network, while preventing the tripping of healthy circuit and sections of the network (Reza et al., 2010). Proper coordination of protective relay plays an essential role with the power system protection scheme.

Akbar and Mohsen (2011) stated that short circuit study has to be carried out at critical points in the system before embarking on relay coordination. Akbar and Mohsen (2011) further suggested a method, named linear programming and particle swarm optimization (LP-LSO) that would help to provide favorable coordination between overcurrent relays and distance relays.

According to Javad et al. (2011), application of distance and overcurrent relay as main and backup relays are necessary to achieving optimal system protection in power transmission protection scheme.

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Javad et al (2011) proposed the use of hybrid algorithm and linear programming for obtaining the relay settings which are time multiplier setting (TMS) and current setting I_{set} for overcurrent relays and second zone time (T_{z2}) for distance relays.

This paper presents a study on the design of a MATLAB Graphical User Interface (GUI) model of overcurrent relay to ascertain the pick-up current, plug setting and the time multiplier setting protection coordination of over-current relays (OCRs) that will facilitate the calculation of the TMS. For an effective substation protection scheme, a time delay should be made to exist between the main and back up protection system.

METHODOLOGY

Overcurrent protection

The protection in which the relay picks up when the magnitude of current exceeds the expected pick-up value (setting value) is known as overcurrent protection. The occurrence of a short circuit in the system usually results to a reduction in the circuit impedance and therefore a fault is accompanied by large current. Overcurrent protection is the protection from overloads. Overloading of a power system equipment means that the equipment is taking more current than its rated current and is also associated with temperature rise of the equipment whose permissible limit is based on insulation class and material problems (Akbar and Mohsen, 2011). The basic element in overcurrent protection is the overcurrent relays.

The current setting multipliers of overcurrent relays generally range from 50 to 200% in steps of 25% which is referred to as plug setting (PS). Plug setting for each relay is determined by the fault current. Depending upon the time of operations, overcurrent relays may be classified as; standard inverse, very inverse and extremely inverse relay. Each characteristic can be calculated from the equation below:

$$t = \frac{K}{\left(\frac{I}{I_S}\right)^{\alpha} - 1} \text{ x TMS} \quad (1)$$

Where: t = Tripping time in (s)
I = Fault (actual) secondary CT current (A)
I_s = Relay pick-up current setting
TMS = Time Multiplier Setting

Standard inverse relay (SIR)

These are relay whose operating time of the standard inverse relay is almost inversely proportional to the fault current near the pick-up value and becomes considerably constant slightly above the relay pick-up value.

$$\text{SIR (t)} = \frac{0.14}{\left(\frac{I}{I_S}\right)^{0.02} - 1} \text{ x TMS} \quad (2)$$

Very inverse relay (VIR)

The very inverse types of relay are employed in feeders and long sub transmission lines protection. The relay time current characteristic is inverse over a significant time range and it tends to definite time after saturation. It is remarkably effective with ground faults due to its steep characteristics.

$$\text{VIR (t)} = \frac{13.5}{\left(\frac{I}{I_S}\right) - 1} \text{ x TMS} \quad (3)$$

Extremely inverse relay (EIR)

The operating time of these relay is approximately inversely proportional to the square of the current. It is often used when fault current is dependent on fault location.

$$\text{EIR (t)} = \frac{80}{\left(\frac{I}{I_S}\right)^{2.0} - 1} \text{ x TMS} \quad (4)$$

Coordination setting

The actual understanding of the fault current at each part of the power system is needed for accurate relay setting and application. Essential data needed for accurate setting of power system relay include the following; Maximum short circuit current, transformer impedance in p.u., single line diagram of the power system, and maximum peak load current. The time interval of operation between two adjacent relays depends upon a number of factors; the circuit breaker fault current interruption time, the overshoot time of the relay, variation in measuring devices errors, factors of safety.

System fault study

Figure 1 shows a simplified model of the system under review. The generator supplies active power P and reactive power Q to the network. A fault between all three

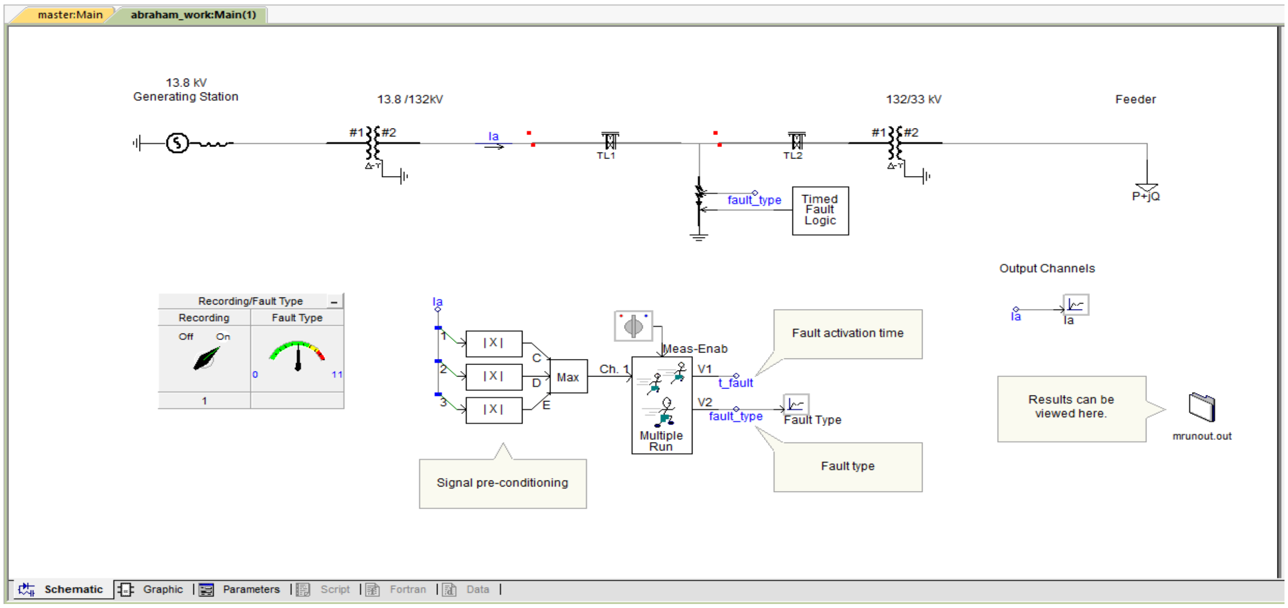

Figure 1. PSCAD model of 132/33 kV substation under review.

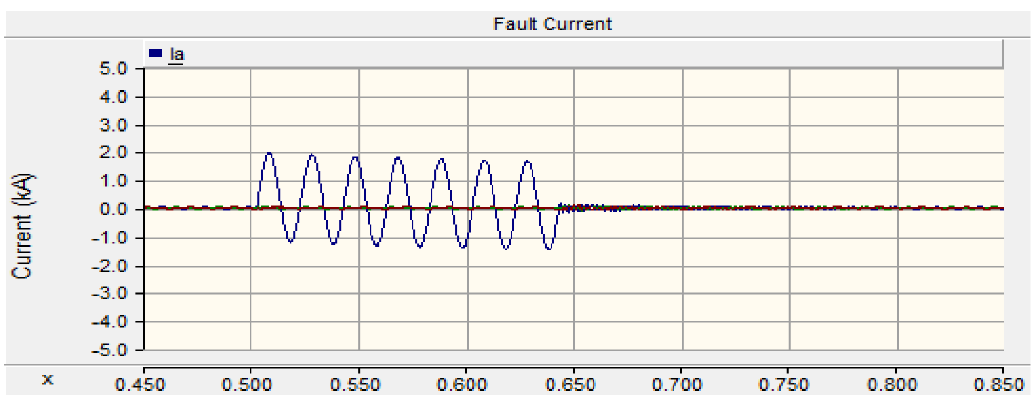

Figure 2. Result of a single phase-to-ground fault (A-G).

phases and ground (that is, ABC-G) shall be explored. The multiple-run component is used to activate the fault at different points on the voltage waveform.

From Figures 2, 3 and 4, it could be observed that a three phase-to-ground fault is the most severe fault. During a three phase-to-ground fault, the entire system is unbalanced. While this type of fault does not occur frequently, its results are used for protective device selection, because this fault type generally yields the maximum short circuit current values.

From Figure 4, a three phase-to-ground fault (ABC-G) of magnitude 3.5151 kA occurs at 0.51 s and last for 0.13 s. The simulation indicates the greatest fault current occurs on the 7th fault type (Table 1). This window indicates the fault type was 7 (ABC-G), and resulted in a peak fault current of 3.5151 kA.

Figure 5 shows the total fault extracted from the PSCAD multiple run output. This comprise of the following fault type; A-G, B-G, C-G, AB-G, AC-G, BC-G, ABC-G, AB, AC, and BC. It will be observed that the highest fault current of 3.515.1 kA occurred at the 7th fault type (ABC-G).

Algorithm for relay coordination setting

Step 1 Data extraction: line voltage, short circuit current, current transformer primary and secondary current (HV

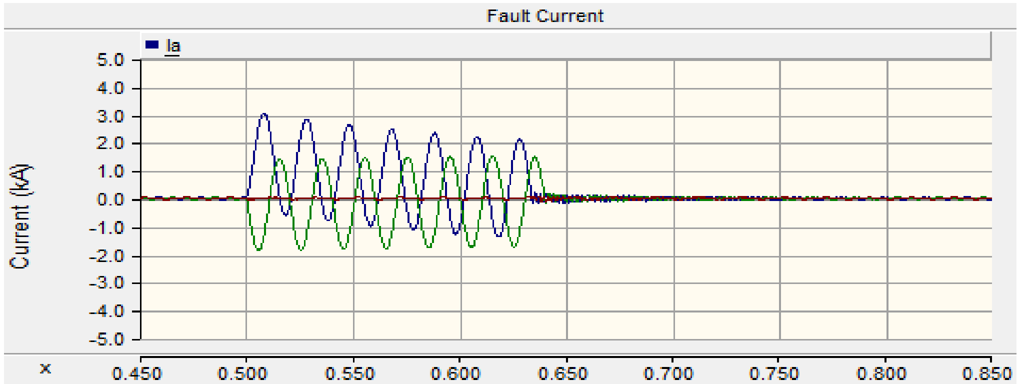

Figure 3. Result of two phase-to-ground fault (AC-G).

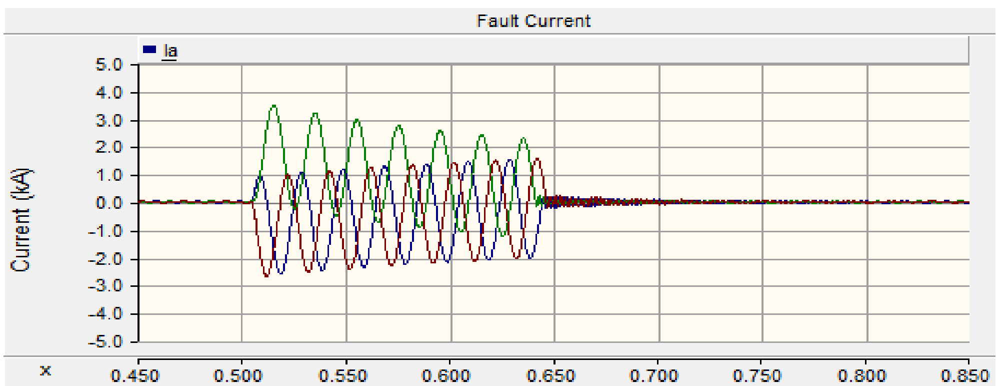

Figure 4. Result of three phase-to-ground fault (ABC-G).

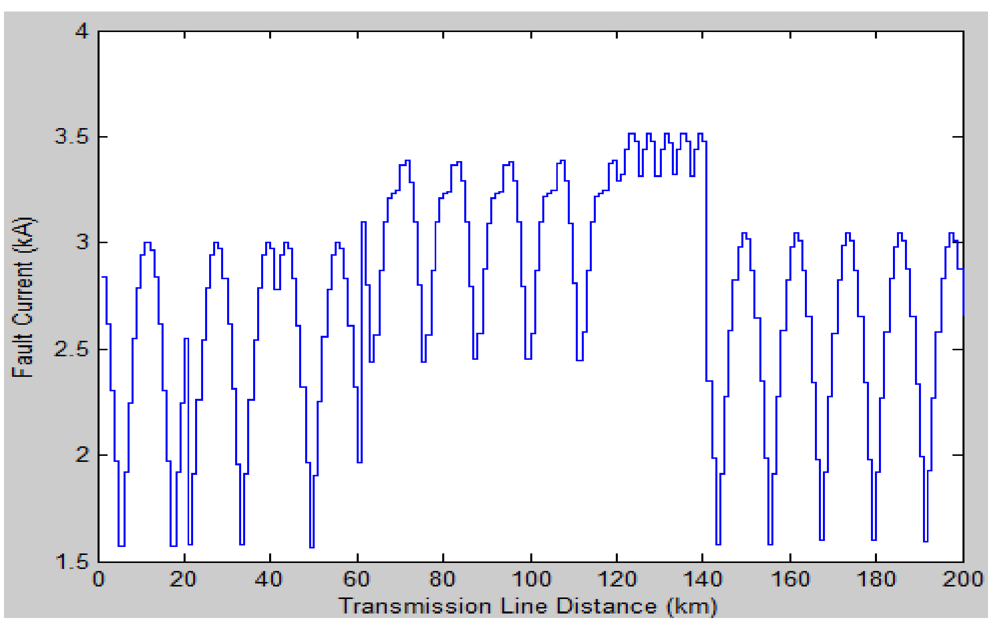

Figure 5. Total fault current extracted using MATLAB.

Table 1. Simulation results.

Multiple run output			
Run	**Fault current**	**Fault type**	**Maximum fault**
1	0.5000000000	1	2.837832029
2	0.5008333000	1	2.614030347
3	0.5016666000	1	2.305496062
4	0.5024999000	1	1.968979813
5	0.5033332000	1	1.570025179
6	0.5000000000	4	3.100306356
7	0.5016666000	4	2.435044486
8	0.5024999000	4	2.565988118
9	0.5033332000	4	2.871236302
10	0.5041665000	4	3.098755873
11	0.5091663000	7	3.471576280
12	0.5099996000	7	3.319696126
13	0.5108329000	7	3.439127165
14	0.5116662000	7	3.515149294
15	0.5124995000	7	3.475403754

and LV; CT), time graded margin and TMS.

Step 2 Compute relay current (I_{R1}) using Equation 1

$$I_{R1} = \frac{\text{Fault Current}}{\text{CT Ratio}} \quad (1)$$

Step 3 Compute the pickup value of relay 1 (PU_1) using Equation 2

$$PU_1 = \frac{\text{Current Setting} * \text{Rated Current of Secondary CT}}{100} \quad (2)$$

Step 4 Compute the plug setting multiplier (PSM_1) using Equation 3

$$PSM_1 = \frac{I_{R1}}{PU_1} \quad (3)$$

Step 5 Determine relay type and calculate the time of operation using the following Equations 4, 5 and 6

$$\text{Standard Inverse Relay} = \frac{0.14}{PSM^{0.02} - 1} \quad (4)$$

$$\text{Very Inverse} = \frac{13.5}{PSM^{1} - 1} \quad (5)$$

$$\text{Extremely Inverse} = \frac{80}{PSM^{2} - 1} \quad (6)$$

Step 6 Compute the actual operation time (T_1) of relay 1 using Equation 7

$$T_1 = t * TMS \quad (7)$$

Step 7 Compute the fault current in relay (I_{FR2}) in relay 2 using Equation 8

$$I_{FR2} = \frac{\text{Fault Current} * \text{LV}}{\text{HV}} \quad (8)$$

Step 8 Compute relay current (I_{R2}) in relay 2 using Equation 9

$$I_{R2} = \frac{I_{FR2}}{\text{Relay\_2 CT Ratic}} \quad (9)$$

Step 9 Compute pick up setting multiplier of relay_2 (PU_2) using Equation 10

$$PU_2 = \frac{\text{Current Setting} * \text{Rated CT Secondary Current}}{100} \quad (10)$$

Step 10 Compute Plug Setting Multiplier (PSM) of relay_2 (PSM_2) using Equation 11

$$PSM_2 = \frac{I_{R2}}{PU_2} \quad (11)$$

Step 11 Determine time of operation using Step 5
Step 12 Compute the actual operating time of relay_2 (T_2) using Equation 12

$$T_2 = t * TMS + T_1 \quad (12)$$

Step 13 Relay coordination setting data (See Figure 6 for the protection algorithm).

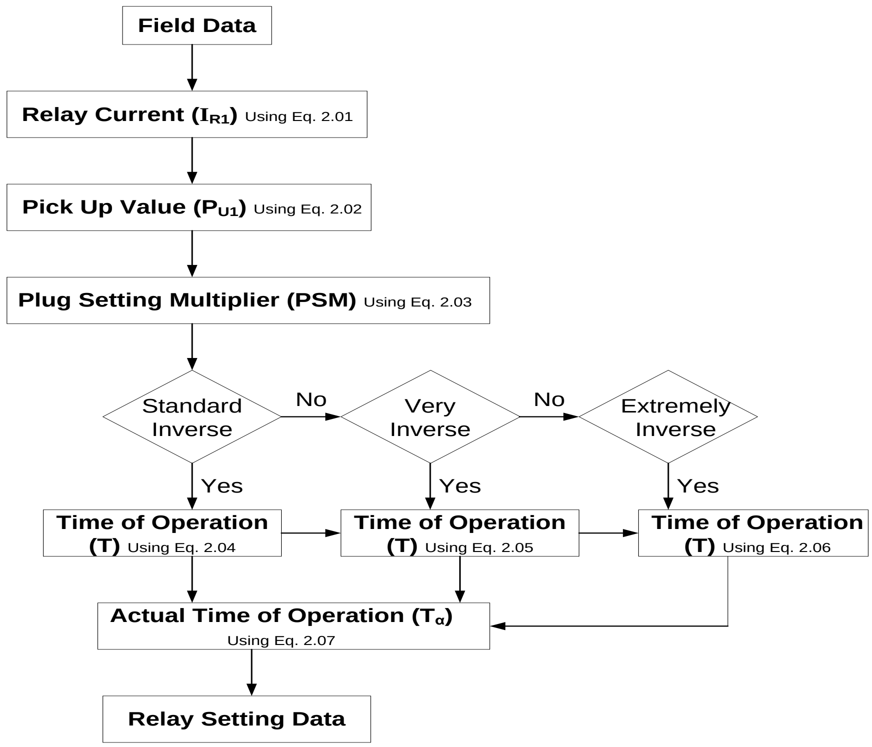

Figure 6. Protection algorithm implemented in the overcurrent relay model.

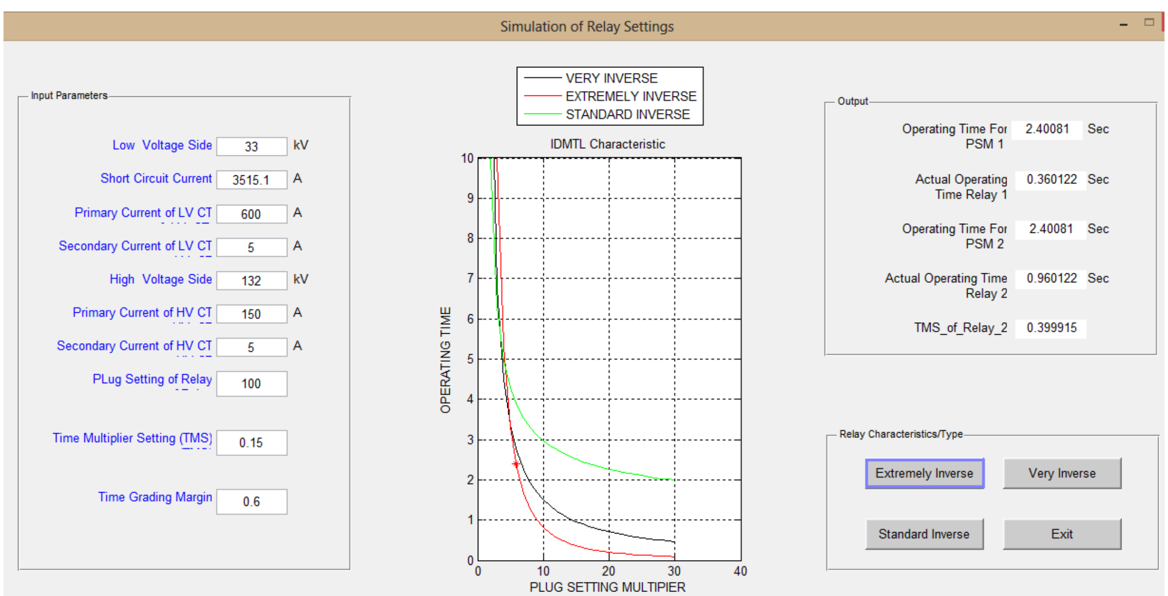

Figure 7. Extremely inverse relay co-ordination setting.

RESULTS AND DISCUSSION

Relay co-ordination settings are generally based on their characteristic curve, which indicates the speed of operation. The characteristics are: (1) Standard Inverse (2) Very Inverse and (3) Extremely Inverse.

From Figure 7, it is observed that the operating time for PSM-1 is 2.40081 sec., operating time for PSM-2 is

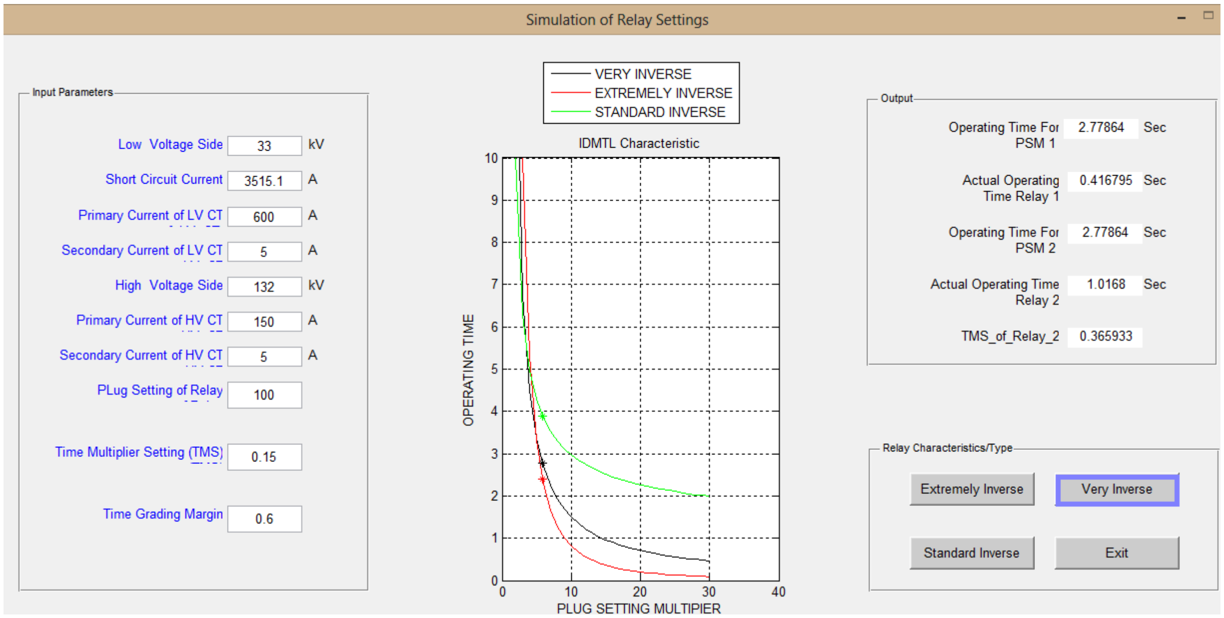

Figure 8. Very inverse relay co-ordination setting.

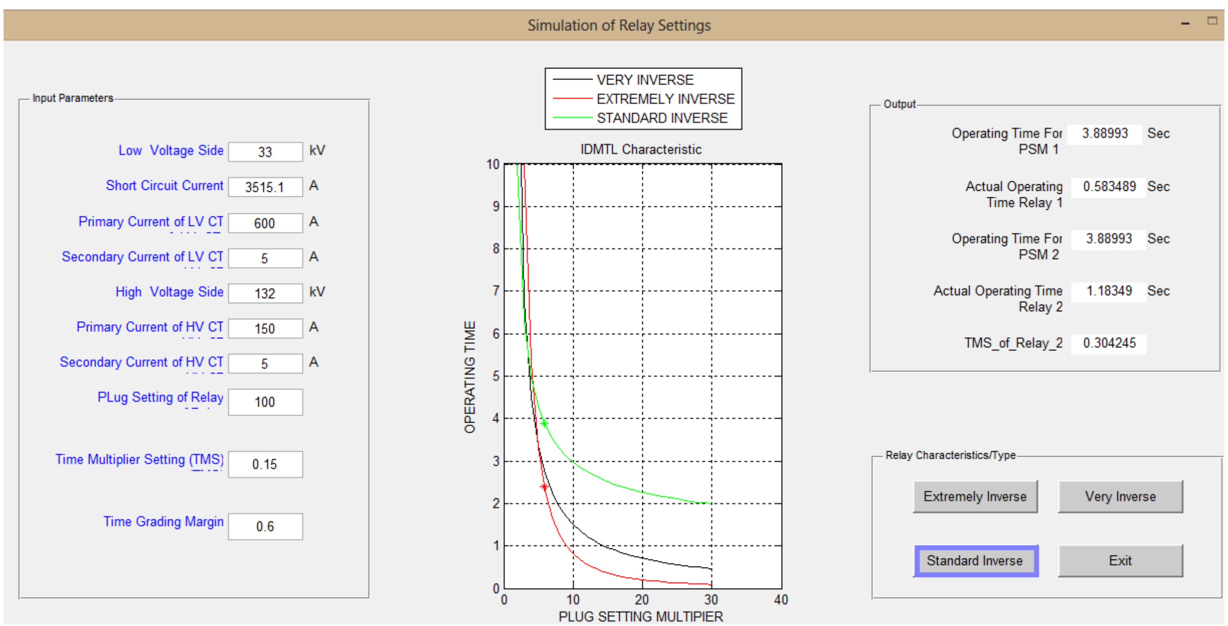

Figure 9. Standard inverse relay co-ordination setting.

2.40081 sec., and the actual operating time of relay-1 is 0.36012 sec, actual operating time of relay-2 is 0.96012 sec., and the TMS for relay-2 is 0.399915.

From Figure 8, it is observed that the operating time for PSM-1 is 2.77864 sec., operating time for PSM-2 is 2.77864 sec., and the actual operating time of relay-1 is 0.41679 sec, actual operating time of relay-2 is 1.01680 sec., and the TMS for relay-2 is 0.36593.

From Figure 9, it is observed that the operating time for PSM-1 is 3.88993 sec., operating time for PSM-2 is 3.88993 sec., and the actual operating time of relay-1 is 0.58348 sec, actual operating time of relay-2 is 1.18349 sec., and the TMS for relay-2 is 0.30424.

The respective values of actual operating time and time

Table 2. Overcurrent relay characteristics.

Characteristics	Standard inverse	Very inverse	Extremely inverse
Actual operating time of relay_2 (sec)	1.18349	1.01680	0.96012
PSM (sec)	3.88993	2.77864	2.40081
TMS (sec)	0.30424	0.36593	0.39991

multiplier settings recorded from the simulation of the different overcurrent relay characteristics are shown in Figures 7-9 and Table 2.

The time of operation of these relays varies, with the extremely inverse relay the smallest, followed by the very inverse and standard inverse. It would be observed that the three relay characteristics must be considered during the relay setting. The standard inverse characteristic takes care of faults within the utility substation. The very inverse characteristic takes care of fault at the mid-point of the feeder while the extremely inverse characteristic takes care of fault at the far end of the feeder.

Conclusion

The relays in the power system are to be coordinated properly so as to provide primary as well as back up protection, and at the same time avoid malfunction and hence avoid the unnecessary outage of healthy part of system. In this paper, the operating time of the relays was determined using a MATLAB GUI model. Thus it can be concluded that the results obtained showed the proper coordination of the different overcurrent relay characteristics.

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