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Coordination of Overcurrent Relay in Distribution System

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Abstract: The overcurrent phenomena are dangerous conditions that can be occurred in the electrical system and equipment. The condition of the overcurrent will cause short-circuited current flows through the system and affect the other distribution line. The purpose of this study is to investigate the coordination of overcurrent relay in different types of the distribution network, which are radial, ring, and interconnected distribution system during line to ground fault occurrence at the bus. The generation of the overcurrent and directional overcurrent flow in the distribution network will damage the nearest equipment and reduce the power stability. The installation of the IDMT overcurrent relay in the distribution system will clear the faulty section from affecting the other distribution line. This protective device also operates to detect the abnormal condition with proper time current characteristic condition that involves the optimum time speed, accurate coordination, and sensitivity. The simulation of the IDMT overcurrent relay in the one-line diagram of the distribution network is executed by using ETAP software meanwhile the IDMT relay setting is calculated via MATLAB.

Keywords: IDMT, Distributed Generation, overcurrent relay, relay coordination.

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1. INTRODUCTION

Protection relay is a crucial engineering part of a power system from the generation, transmission until distribution, which requires proper understanding and analysis of the overcurrent to secure the electrical components. The fundamental target of the protective relay is to remove the fault current and isolate the faulty section from disturbing the other section in the power system network [1].

The protection relay is invented more than a century ago and the relay of inverse time started its operations in early 1909 [2]. This device is developed to detect the fault condition with appropriate torque value to trip the circuit breaker. The development of the relay is classified into three types which are electromechanical relay, static or electronic relays, and the latest invention is microprocessor-based relay [3]. The electromechanical relay is a conventional protection which involves overcurrent relay, differential relay, directional relay and distance relay [4].

In early 1920, the installation of the protective relay is challenging to analyse the relay setting by measuring the instrument with the magnetic cut-out and effective tripping torque at certain fault and the engineers also faced conflict to determine the sensitive relay operating time when high current flows through the system because the limitation of the available current transformer[5].

Nowadays, the protection engineer can use software to simulate the performance of relay operating time and analyse the coordination of the overcurrent relay accurately.

The overcurrent arises when the current in the distribution system exceeds the allowed current capacity at the bus or any electrical equipment. The current at the faulty section will interrupt the power system network and causes the upstream distribution to suffer a heavy breakdown. If the overcurrent remains longer in the system, it will damage the equipment and reduce the power stability. The overcurrent relay is required to isolate the fault area and protect the entire distribution network and trigger the circuit breaker to clear the fault. Besides, the protection relay might fail to trip or maltripping occur, if the optimum setting level of the protection device is not achieved. The improper relay setting parameters will interfere the coordination of the relay to follow the right sequence and cause the tripping time to become less effective. Hence, this study will overcome these problems by analyzing the optimum relay operating time and time multiplier setting to ensure the faulty section can be removed from the distribution network.

The primary objective of this paper is to analyse the relay operating time and time-current characteristics of the overcurrent relay in the different type of distribution system. The sub-objectives to support this study are to determine the relay operating time performance and minimize the duration of fault. Apart from that, this paper is also can identify the selectivity of the relay operation at specific fault location and specifically can analyse the time current characteristic of the IDMT relay. Generally, this study is focused on the protection devise setting at the distribution system. The scope of this paper will cover on the study of the overcurrent protection system of the IDMT relay and analysis of the protection coordination.

The one-line diagrams of the designed analysis for the distribution network are based on the previous research paper. The network topology of the distribution system is focussing on the radial distribution system, ring distribution system, and interconnected distribution system. The short-circuited condition that will be analysed in these network topologies are the Line-to-Ground Fault. The simulation of the IDMT relay coordination will be executed by using ETAP software. Meanwhile the mathematical calculation of the IDMT relay setting is calculated by using MATLAB.

2. COORDINATION OF OVERCURRENT RELAY

The relay coordination can be achieved by the discrimination in time, current and combination of both time and current.

2.1 IDMT Overcurrent Relay

The IDMT relay is widely used as the protection device in the distribution system. Inverse Definite Minimum Time relay is operating inversely changed with current whereas the relay will operate faster than the lower current once it detects the high fault current. The IDMT relay uses the electromagnetic core that wounded by a current coil which it can easily saturate when the current is larger than the pick-up current. When the high secondary current from the current transformer enters the relay and go through the current coil, it will reduce the time of operation in the relay. Therefore, the higher the fault current, the shorter the time to trip the circuit breaker. In IDMT relay setting, there will be five parameters to be considered which are PS (Plug Setting), RSI (Relay Setting Current), PSM (Plug Setting Multiplier), RCOT (Relay Characteristic Operating Time), ROT (Relay Operating Time), and TSM (Time Setting Multiplier) [8].

2.2 Plug Setting

The plug setting indicates as the percentage or ratio to the pick-up value of the relay based on the rated Current Transformer ratio.

$$PS = \frac{Full\ load\ current}{CT\ ratio}\ 100\% \tag{1}$$

2.3 Relay Setting Current

Relay setting current is the parameter to let the relay operate at the proposed current value.

$$RSI = \frac{PS}{100} \times CT\ ratio \tag{2}$$

2.4 Plug Setting Multiplier

Plug setting multiplier is the ratio between the fault current and the pick-up current.

$$PSM = \frac{Fault\ Current}{RSI} \tag{3}$$

2.5 Relay Characteristic Operating Time

Relay current characteristics in IDMT is classified into three types which are standard inverse, very inverse, and extremely inverse[9].

Standard Inverse:
$$T = \frac{0.14}{PSM^{0.02} - 1} \tag{4}$$

Very Inverse:
$$T = \frac{13.5}{PSM^{1} - 1} \tag{5}$$

Extremely Inverse:
$$T = \frac{80}{PSM^{2} - 1} \tag{6}$$

Where T= Operating Time

2.6 Time Setting Multiplier

The Time Setting Multiplier is used to control the operation time of the relay. Most of the relays have time dial setting value from 0.1 and up to 1.0. TSM allows the adjustments between contacts in the relay with different tripping curves can be made based on the timing dial. Furthermore, the operating time of the IDMT relay can be improved by choosing proper time dial setting value.

3. METHODOLOGY

The flowchart of the research work is shown in Figure 1. This work begins with the literature review, find the IDMT relay formula and single line diagram of the radial distribution. Next, identify the fault current and full load current to determine the CT ratio. Based on these values, the parameters in the relay setting can be calculated and found by using the several formulas of the IDMT. Next, these parameters can be used to set the relay setting in the ETAP simulation. Then, simulate the one-line diagram in the ETAP to analyze the coordination of the relay setting and time-current characteristic. Lastly, repeat the same process for ring and interconnected distribution systems

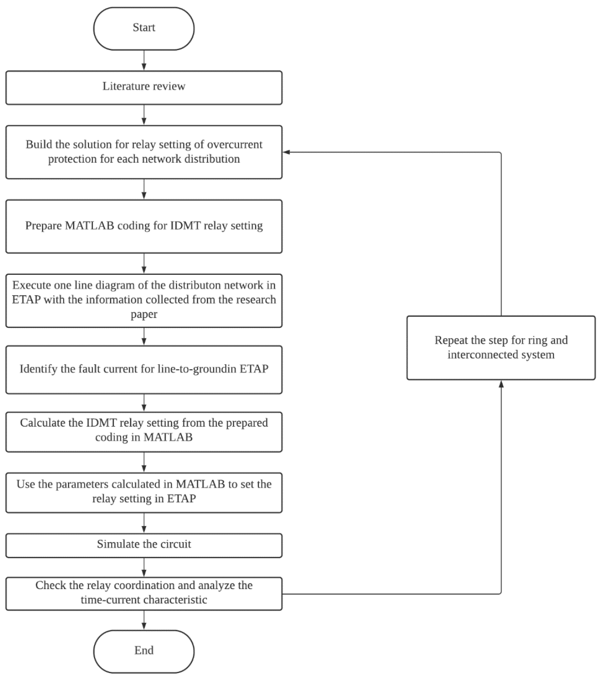

Figure 1. Flowchart of the work

The one-line diagram of the IEEE 6 bus distribution system is developed in ETAP software as illustrated in Figure 2. The data for the incomer and load are given by the Table 1.

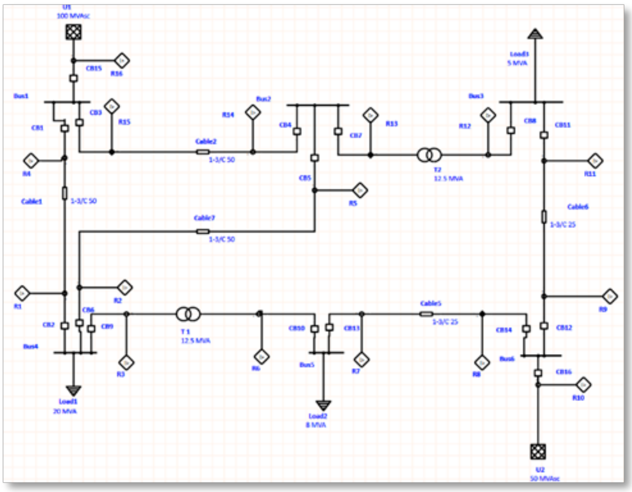

Figure 2. Single line diagram of IEEE 6 bus interconnected system

Table 1. System Data

Element	Power (MVA)
Power Incomer U1	100
Power Incomer U2	50
Load1	20
Load 2	8
Load 3	5

The short circuit analysis is conducted to investigates the various type of fault such as three phases, line to ground fault, line to line fault, and double line to ground fault. In this study, the fault involves is the line to ground fault by activating the fault conditions at each bus. Once the fault generated, the overcurrent fault will flow in the system.

4. RESULT AND ANALYSIS

In the interconnected distribution, the fault is placed at the Bus 1 where the Load 1 is connected at that bus. Table 2 shows the parameters after the short circuit and load flow simulation in ETAP. Next, these parameters will help in calculation of the relay setting in the MATLAB to obtain the ROT values as in highlighted column in Table 3. The ROT results in the simulation as in Figure 3 can be proven by the Table 3 for each relay. The directional overcurrent flows in the three configurations when Bus 1 is faulted which is Cable 1, Cable 7, and Transmission 1.

In order to isolate the fault current at Cable 1, R1 and R4 will be triggered at 0.477s meanwhile at Cable 7, R2 and R5 takes 0.406s to disconnect the fault current. At the Transmission 1, both Relay 3 and Relay 4 takes 0.529s to trip the circuit breaker. After all the downstream network is tripped, the relay at the power grid will be calculated by taking the longest ROT backup from the downstream distribution. For example, the R16 will take the value of ROT backup from the R15 compared to the R4 at that configuration to ensure all the fault current is cleared by the downstream distribution. It is because the worst-case scenario is being considered, if the directional fault current affected the downstream buses first before flowing to the power grid. Hence, R16 takes 1.722s to isolate the fault from effected the Power Grid 1 and the ROT for R10 needs 1.64s to disconnect the fault from the Power Grid 2.

Table 2. Current Data

	Configuration	If, kA	In, A	CT ratio
R10	Bus 6	2.178	418.8	500/5
R8	Bus 6-5	1.106	257.3	300/5
R9	Bus 6-3	1.072	161.5	200/5
R7	Bus 5-6	1.106	257.3	300/5
R6	Bus 5-4	1.106	264.3	300/5
R3	Bus 4-5	0.369	88.1	100/5
R2	Bus 4-2	0.815	124.8	150/5
R1	Bus 4-1	1.276	296.5	300/5
R12	Bus 3-2	1.072	167	200/5
R11	Bus 3-6	1.072	161.5	200/5
R13	Bus 2-3	0.357	55.7	100/5
R5	Bus 2-4	0.815	124.8	150/5
R14	Bus 2-1	0.461	172.8	200/5
R15	Bus 1-2	0.461	172.8	200/5
R4	Bus 1-4	1.276	296.5	300/5
R16	Bus 1	1.736	469.1	500/5

Table 4 represents the relay sequence in the interconnected system when the fault exists at the bus 1, the fault current will flow in three configurations. At the left configuration, the sequence of the relay tripping is R1-R4-R16 meanwhile at the middle sequence is R2-R5-R14-R15-R16 and R2-R5-R13-R12-R11-R9-R10. At the right sequence, it involves the relay coordination at R3-R6-R7-R8-R10. The relay operation is similar in the ring distribution where the relay at the same line will trip simultaneously to remove the faulty area.

The plug setting of relays can be expressed in percentage or in ampere of the relay pickup current. This subtopic will analyse the effect of the Plug Setting towards the Relay Operating Time in the Ring Distribution when the PS at 50%, 100%, and 125%. Table 4 shows the data for ROT on each bus by adjusting the Plug Setting. The basic parameters are maintained as previous setup such as the current transformer. The PS 50% gives much faster response of ROT compared to the PS 100%. It is because the lower the value of the plug setting, the higher the sensitivity of the relay to minimize the fault.

Time (...	ID	If (kA)	T1 (ms)	T2 (ms)	Condition
406	R2	0.815	406		Phase - OC1 - 51
406	R5	0.815	406		Phase - OC1 - 51
426	CB5		20.0		Tripped by R5 Phase - OC1 - 51
426	CB6		20.0		Tripped by R2 Phase - OC1 - 51
477	R1	1.276	477		Phase - OC1 - 51
477	R4	1.276	477		Phase - OC1 - 51
497	CB1		20.0		Tripped by R4 Phase - OC1 - 51
497	CB2		20.0		Tripped by R1 Phase - OC1 - 51
529	R6	1.106	529		Phase - OC1 - 51
529	R3	0.369	529		Phase - OC1 - 51
549	CB10		20.0		Tripped by R6 Phase - OC1 - 51
549	CB9		20.0		Tripped by R3 Phase - OC1 - 51
814	R13	0.357	814		Phase - OC1 - 51
820	R12	1.072	820		Phase - OC1 - 51
834	CB7		20.0		Tripped by R13 Phase - OC1 - 51
840	CB8		20.0		Tripped by R12 Phase - OC1 - 51
953	R7	1.106	953		Phase - OC1 - 51
953	R8	1.106	953		Phase - OC1 - 51
973	CB13		20.0		Tripped by R7 Phase - OC1 - 51
973	CB14		20.0		Tripped by R8 Phase - OC1 - 51
1230	R9	1.072	1230		Phase - OC1 - 51
1230	R11	1.072	1230		Phase - OC1 - 51
1250	CB11		20.0		Tripped by R11 Phase - OC1 - 51
1250	CB12		20.0		Tripped by R9 Phase - OC1 - 51
1331	R14	0.461	1331		Phase - OC1 - 51
1331	R15	0.461	1331		Phase - OC1 - 51
1351	CB3		20.0		Tripped by R15 Phase - OC1 - 51
1351	CB4		20.0		Tripped by R14 Phase - OC1 - 51
1640	R10	2.178	1640		Phase - OC1 - 51
1660	CB16		20.0		Tripped by R10 Phase - OC1 - 51
1722	R16	1.736	1722		Phase - OC1 - 51
1742	CB15		20.0		Tripped by R16 Phase - OC1 - 51

Figure 3. The IDMT relay coordination in Interconnected system

Table 3. IDMT Relay Setting

	PS %	RSI	PSM	RCOT	ROT (ms)	ROT Backup	TSM
R2	100	150	5.4333	4.0662	406	0.80662	0.1
R5	100	150	5.4333	4.0662	406	0.80662	0.1
R1	100	300	4.2533	4.7656	477	0.87656	0.1
R4	100	300	4.2533	4.7656	477	0.87656	0.1
R3	100	300	3.6867	5.2954	529	0.92954	0.1
R6	100	100	3.69	5.2917	529	0.92917	0.1
R13	100	100	3.57	5.431	814	1.2146	0.15
R12	100	200	5.36	4.0996	820	1.2199	0.2
R7	100	300	3.6867	5.2954	953	1.3532	0.18
R8	100	300	3.6867	5.2954	953	1.3532	0.18
R9	100	200	5.36	4.0996	1229	1.6299	0.3
R11	100	200	5.36	4.0996	1229	1.6299	0.3
R14	100	200	2.305	8.3126	1331	1.73	0.16
R15	100	200	2.305	8.3126	1331	1.73	0.16
R10	100	500	4.356	4.6872	1640	2.0405	0.35
R16	100	500	3.472	5.554	1722	2.1217	0.31

Table 4. IDMT Relay Coordination

Fault Configuration	Relay Coordination
Bus 4/ Load 1	R1-R4-R16
	R2-R5-R14-R15-R16
	R2-R5-R13-R12-R11-R9-R10
	R3-R6-R7-R8-R10

5. CONCLUSION

This paper has successfully determine the relay operating time and minimize the duration of fault of the system by using simulation in ETAP. The result for both calculations in MATLAB and simulation of the relay operating time in ETAP for each relay is similar and can be proven. This research work also able to identify the selectivity of the relay operation at specific fault location in interconnected system. The analysis of the tripping sequence for interconnected distribution must be installed with the directional relay to overcome the directional current in the system and gives more advantage in the tripping sequence if the faults are changing to the other locations. The assessment of this IDMT relay in the interconnected system will act as a backup protective relay for the directional relay in case the relay fails to trip the circuit breaker. Therefore, the faulty area can be disconnected from the system quicker and avoid the heavy breakdown occur in the electrical power system.

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