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Optimal over Current Relay Coordination of IEEE 9 Bus System using Mipower

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Abstract: ***The protective system plays a major role which has great effect on the power system operation. The modern interconnected power system consists of large numbers of protective relays and circuit breakers which constitute an integral part of the protective scheme. The main function of the relay is to sense and locate the fault and sends a command to the breaker to isolate the faulty element. The objective of the relay coordination is to provide primary as well as backup protection from any fault that is likely to occur in the power system. In this paper, overcurrent relay coordination is implemented on an IEEE 9 Bus test system using MiPower software for phase and earth faults. The Load flow analysis and the short circuit analysis on the IEEE 9 Bus test system is initially done followed by relay coordination. Fault MVA and Fault current data obtained from short circuit analysis enables us to obtain operating time of the relays used in the test system. The calculated value of operating time gives the coordinated operation of all the relays. The MiPower software has unique feature which is very useful in proper coordination of overcurrent relays.***

Keywords : PSM (Plug Setting Multiplier), Relay coordination, Short circuit studies, three phase to ground fault, TMS (Time Multiplier Settings) MiPower simulation.

I. INTRODUCTION

In any power system network, the protection system should be designed in such a way that the protective relays isolate the unhealthy part of the network as quickly as possible as is of detecting faults and clearing the fault as early as possible to avoid damage for equipment, injury to operators and to ensure minimum system disruption enabling continuity of service to healthy portion of the network. Protection system consists protective relays, current transformers, circuit breakers, potential transformers and transducers. the most important part of a power system network is protective relay and it is necessary to coordinate them correctly so that the customers can get continue and reliable supply[1,2].

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In modern scenario, the demand for electrical power generally is increasing at a faster rate in economically emerging countries. So, the power network of electricity companies become very complex network. The exercise of load flow analysis, fault MVA and current calculations and listing the primary and back-up(secondary) pairs will be very tedious and number of iterations would be required to calculate TMS of relays so that minimum discrimination margin as required is found between a relay and all its back-up relays in large inter connected system. This is possible only through computer programming. Over current relay coordination can be done with utmost high accuracy and tolerance using the MiPower software. MiPower performs numerical calculations with very high speed, automatically applies industry accepted standards, and provides standard and customized output reports in easy way. MiPower, while capable of handling large number of buses, contains a load and reports the voltage and short-circuit current at the terminals of each load item. MiPower software is very interactive and has user friendly windows-based power system analysis package.[3] Load flow studies and short circuit analysis is done using the same software and the results of these analysis are used to have an optimal coordination of the relays. The protective devices are installed to protect the system from any fault that is likely to occur. This paper includes smart implementation of relay coordination using MiPower and protective relays having combined definite time and inverse time characteristics.

II. POWER SYSTEM MODEL UNDER STUDY

A single line diagram of the IEEE 9-bus standard system taken from [3] is shown in below figure. The system is delivering 315 MW to its loads fed from the three generators. There are 3 loads in the system totaling of 320 MW and 115 Mvar. The system comprises of 6 lines and three transformers. The transformer impedances and their MVA ratings shown in below figure.

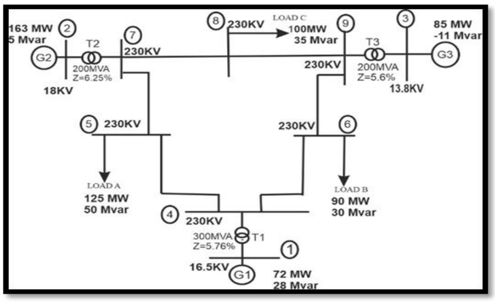

Fig. 1. IEEE 9 Bus Test Syst

III. RELAY COORDINATION

A. Concept of Relay Coordination

When a fault persists in the power system network it may cause vast damage to the network and the equipment. Therefore, there is a requirement of suitable protective device to protect the power system to prevent from any damage. The protective device should be selective enough that shall discriminate operation of the specific relay to cut off the unhealthy part from the healthy section of power system network and to reduce the interruption of healthy section of the power distribution system network. One such device is the protective relay. [4]A protective relay senses the fault and sends a command to the breaker. There is a primary relay installed in every zone of the system to protect the power system network. After the existence of fault, the primary relay senses the fault and identifies the location of the fault. The primary relay sends the command to the circuit breaker and the circuit breaker trips. If the primary relay flops to operate then there is a backup relay to clear the fault. Relay coordination is implemented to check if the relay is quick enough or reliable enough to identifies the fault at the proper time and send the signal to the supplementary devices. The relay co-ordination study of an electric power system comprises of an organized time-current study of all devices in series from utilization device to source[7]. The main motive of this study is to determine the ratings of the over current protective devices which will see that the minimum portion of the system is affected when the protective devices removes a fault in the system[5]. On other hand, it must provide protection to the equipment and remove short circuit conditions as quickly as possible. Coordination ensures that protective relays work properly to provide safe and reliable protection. IECN curve type is used for all relay calculation. The operating time of any protective relay depends on three important factors i.e. TMS, Fault current and plug setting.[6] The flowchart for the overcurrent relay coordination procedure is shown in fig.2. below

B. Relay Coordination Calculations

For instance, the overcurrent relay settings are shown for R_{12} if three phase to ground fault persists at Bus 8
Fault MVA = 828.9
Fault current =2080.72 Amps
Fault MVA and Fault current extracted from the short circuit studies
CT Ratio =250/1
Current setting -100%(1 Amps)

Secondary fault current $If_{12} = \frac{Fault\ Current}{CT\ Ratio}$ **(1)**

$$= \frac{2080.72}{250/1} = 8.32 \text{ Amps}$$

Pick up current = Current setting * CT secondary

=100% * 1 = 1 Amps

$$PSM = \frac{Secondary\ fault\ current\ seen\ by\ relay}{Pick\ up\ current} \quad \textbf{(2)}$$

= 8.32/1 = 8.23 Amps

IEC Normal Inverse Characteristics is used and the characteristic equation is mentioned below

For Normal Inverse Relay

Time of operation $(t_{12}) = \frac{0.14}{PSM^{0.02}-1}$ **(3)**

$$= \frac{0.14}{8.23^{0.02}-1} = 3.25 \text{ seconds}$$

Actual operation time (T_{12}) of R_{12} $T12 = TMS_{R12} * t_{12}$
= 0.15* 3.25 = 0.4577 seconds

Backup Calculation
Relay R14 will back up R12 for fault at Bus 8

CT ratio = 100/1

Current setting =100%

Hence time of operation of $TR_{14}=T_{12}+CTI$
=0.487 +0.3=0.787 Seconds
CTI= Coordination time Interval
Back up relay fault current =380.2 amps
PSM= 3.8

$$0.787 = \frac{0.14 * TMSR14}{PSM^{0.02}-1} \quad \textbf{(4)}$$

TMS_{R14} = **0.152 seconds**
The close in operating time for relay R_{14}
Fault current =2026 Amps

Time of operation $(t_{14}) = \frac{0.14 * TMSR14}{PSM^{0.02}-1}$ **(5)**

Time of operation (t_{14}) = **1.2468 seconds**

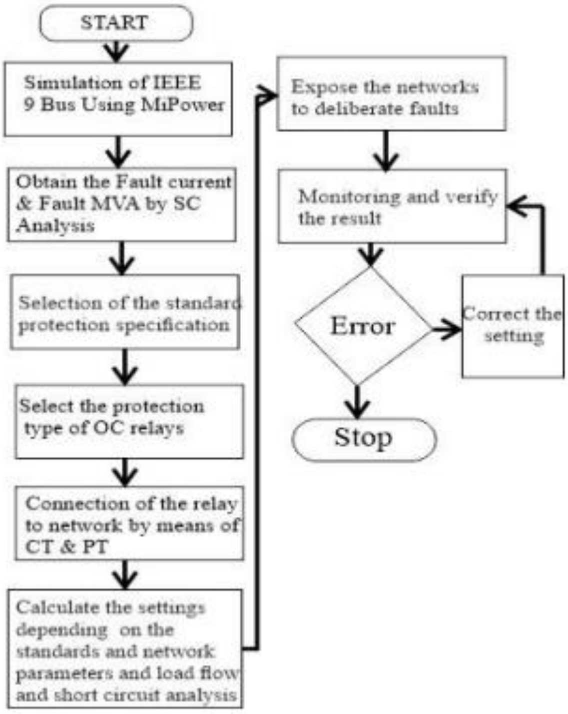

Fig.2. Flow chart for overcurrent relay coordination

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IV. SIMULATION AND RESULTS

A. Load Flow Studies

Load flow study provides the information about the optimal value of the voltage and the real and reactive power flowing in the line. The load flow analysis helps to minimize the transmission line losses and also reduces the cost of generation. The MiPower software indicates the power flows in blue under normal loading condition and in red for overloaded condition. The simulation is carried on the IEEE 9 Bus test system to give the load flow results as follows

Table 1. Load flow results

MW generation	322.5179
MVAR generation	62.8104
MW load	315.0000
MVAR load	115.0000
MW loss	7.5179
MVAR loss	-52.1896

B. Short Circuit Studies

Prior to relay coordination settings, we consider lad flow studies and short circuit studies which help us to know fault current, fault MVA and suitable develops a protection scheme for the power system. The fault current causes an extensive damage to the equipment if suitable protective scheme is not adopted in the power system. Short circuits are generally caused by failure of insulation or conducting path failures. There are three types of unsymmetrical faults. They are single line to ground (SLG), line to line fault (LL), double line to ground fault (LLG). In this paper, three phase to ground fault has been simulated as it forms a basis for the selection of the circuit breakers, relays and also of instrument transformers. Three phase to ground fault analysis is done on bus 8 of IEEE 9 Bus system and the following fault current, fault MVA and the post fault voltages are obtained.

Table 2. Fault Current (Amp/deg) at Bus 8

Sequence (1,2,0)		Phase (A,B,C)	
Mag	Ang	Mag	Ang
2081	-85.95	2081	-85.95
0	-90.00	2081	154.05
0	-90.00	2081	34.05
R/X Ratio of the short circuit path: 0.0707			
Peak Asymmetrical Short-Circuit Curren:5435 Amps			
PASCC = k x sqrt(2) x If , k = 1.847			

Table 3. Three phase fault levels

BUS NAME	BUS kV NOMINAL	3PH-f MVA	FAULT IN kA
Bus1	16.5	0.7	0.023
Bus2	18.000	0.5	0.017
Bus3	13.800	0.6	0.024
Bus4	230.000	0.6	0.001
Bus5	230.000	0.5	0.001
Bus6	230.000	0.5	0.001
Bus7	230.000	0.3	0.001
Bus8	230.000	828.9	2.081
Bus9	230.000	0.4	0.001

Fig.3 shows the phase A fault current at bus 8 when a three phase to ground fault is applied at bus 8. This graph shows the superimposition of dc offset current with the ac current to give the total asymmetrical (ac+dc) current.

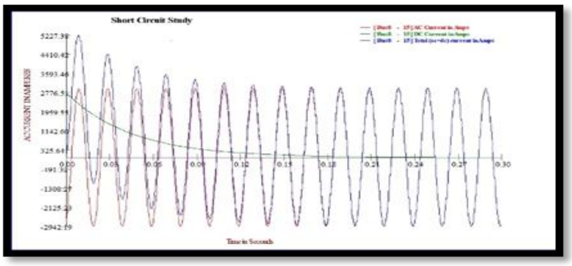

Fig 3. Wave form of Three phase symmetrical fault at bus 8

C. Operating time of Primary and Back up Relays

Table 4. operating time of relays

Fault Point	Primary Relay	Operating time of primary relay in seconds	Back up Relay	Operating time of Back up relay in seconds
Bus 1	R_1	0.3864		
Bus 2	R_9	0.3225		
Bus 3	R_{16}	0.2569		
Bus 4	R_2	0.5746	R_4	0.9854
	R_2	0.5746	R_6	0.9151
	R_3	0.3745	R_1	0.7494
	R_3	0.3745	R_6	0.9854
	R_5	0.3745	R_4	0.9854
	R_5	0.3745	R_1	0.7494
Bus 5	R_4	0.5738	R_8	0.9913
	R_7	0.461	R_3	0.8889
Bus 6	R_6	0.6863	R_{17}	0.8879
	R_{18}	0.6862	R_5	1.383
Bus 7	R_8	0.4242	R_9	0.936
	R_8	0.4242	R_{12}	0.9371
	R_{11}	0.4115	R_9	1.8154
	R_{11}	0.4115	R_7	1.7904
	R_{10}	0.4951	R_{12}	0.8175
Bus 8	R_{10}	0.4951	R_{12}	R_{10}
	R_{12}	0.4577	R_{14}	1.2468
	R_{13}	0.764	R_{11}	1.61208
Bus 9	R_{14}	0.4316	R_{16}	0.9378
	R_{14}	0.4316	R_{18}	0.9678
	R_{15}	0.3447	R_{18}	0.9678
	R_{15}	0.3347	R_{13}	0.9767
	R_{17}	0.4516	R_{13}	0.9767

The fig.4. shows the online diagram of simulation of over relay coordination using MiPower

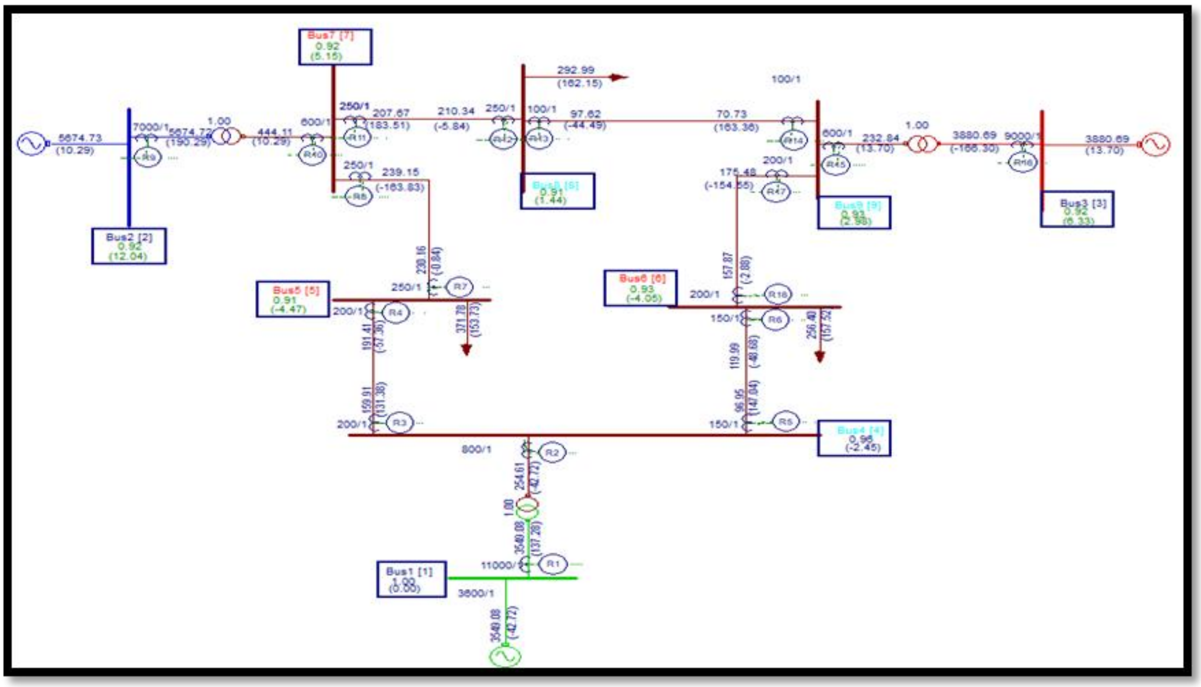

Fig.4. Relay Coordination simulation in Mipower

D. Relay Characteristic Curve

In this paper, the over current relay characteristic curves of all the R13, R11, R9 have been plotted in graphical form. If there is no intersection of two curves each other within the maximum fault current point, then relay coordination can be achieved even for high impedance faults. In order to obtain to the actual coordination in case of systems having multiple fault feeds curves can also be normalise by using this tool. The relay coordination for the IEE 9 Bus test case System for the fault at bus 8 is as shown in fig 5

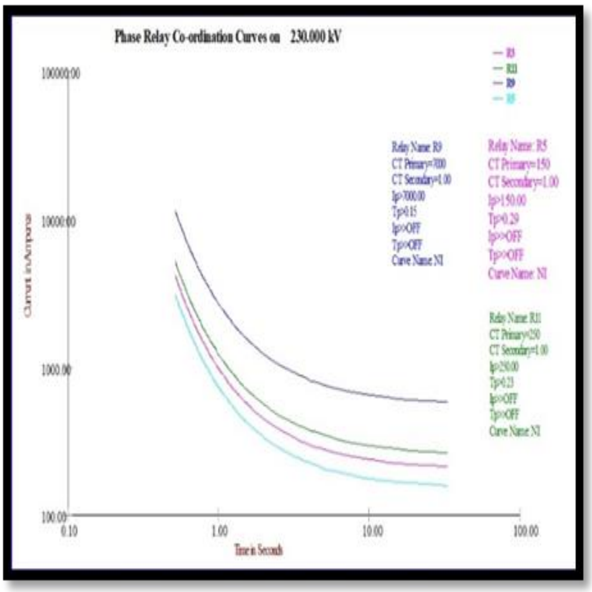

Fig.5. overcurrent relay characteristics

V. CONCLUSION

This paper presents the power flow studies, short circuit analysis and relay coordination of an IEEE 9 Bus test case. Load flow studies shows the correct power flow in the power system. Short circuit studies is done on bus 8 which gives fault current of 2089Amperes and fault MVA of 829. Fault current obtained is thereby by the operating time is obtained for R13, R11, R9, R5, R3 relays connected between lines such that their operation is properly coordinated without any maloperation of relays. Hence in this paper the overcurrent relay coordination for phase faults using the GUI of MiPower tool is clearly depicted.

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Pasala Naresh, received his Bachelor's degree in Electrical and Electronics Engineering, M.Tech degree in Power System Engineering from Visvesvaraya Technological University, Belagavi, Karnataka, India in 2012 and 2015 respectively. He, pursuing his Ph.D. degree from Visvesvaraya Technological University, Belagavi, Karnataka, India. Currently he is working as assistant professor in department of Electrical and Electronics Engineering in Jain college of Engineering,Belagavi, Karnataka. He is having 5 years of teaching experience and he was published various international and national conferences and journals. His current research areas include intelligent techniques for power system operational planning, Optimal protection coordination of relays,smart grid,AI techniques,Machine learning.

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