Optimal Coordination of Overcurrent Relay in IEEE 39 Bus System

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Abstract— Protection Relays and Circuit Breakers are the major devices for large interconnected power system. Proper protection is needed to isolate the faulted region from healthier network. When two protective Relays are installed in series with transmission line have certain features, which provide a specified operating sequence, they are said to be coordinated or selective. Relay coordination is an important portion in the protection system design as coordination schemes must be fast, selective, and reliable Relay operation. Learning and analysis of Relay coordination is performed to make sure that safety operation of the transmission system are functioning correctly and to avoid the unwanted tripping. The reason for unwanted tripping is variation in the Relay protection settings. In this project, Over current Relay is used for proper protection. The Relay protection is designed for IEEE 39 bus system using DIgSILENT and their coordination is achieved.

Key words: Overcurrent Relay, Relay Coordination, DIgSILENT, MATLAB

I. Introduction

Power-system protection deals with the protection of electrical power systems equipment from faults through the disconnection of faulted parts from the rest of the electrical network. The aim of a protection scheme is to keep the power system stable by isolating only the components that are under fault, whilst leaving as much of the network as possible still in operation. Thus, protection schemes must apply a very pragmatic and pessimistic approach to clearing system faults. The equipment that are used to protect the power systems from faults are called protection devices. Protection systems usually comprise five components such as i) Current and voltage transformers to step down the high voltages and currents of the electrical power system to suitable levels for the Relays to deal with ii) Protective Relays to sense the fault and start a trip, or disconnection iii) Circuit breakers to open/close the system based on Relay and autorecloser commands iv)Batteries to supply power in case of power disconnection in the system v) Communication channels to allow analysis of current and voltage at remote terminals of a line and to allow remote tripping of devices

Actually circuit breaker isolates the faulty section from rest of the healthy section and this circuit breakers open without human intervention during fault condition due to its trip signal comes from protection Relay. The main aim of the protection is that no protection of power system can prevent the flow of fault current through the system, it only can prevent the continuation of flowing of fault current by quickly disconnect the short circuit path from the electrical system.

The Relays reach point should be up to the end of the next protected zone. This is required to ensure the back-up protection. Whenever possible, use Relays with the same operating quality in series with each other and make sure that the Relay farthest from the source has current settings equal to or less than the Relays behind it. The Primary current necessary to operate the Relay in front is always equal to or less than the Primary current necessary to operate the Relay behind it. A detection method for hidden failure in smart grid is based on the features of Relay protection system. Directional Overcurrent Relay coordination problem is formulated as an Interval Linear Programming(ILP)[1]. In [2], simultaneous coordination of Distance and Directional Overcurrent Relays (D&DOCRs). User defined Time Inverse Overcurrent Relay is used for Zone 2 settings of distance Relay [3].Three different types of protection Overcurrent protection,Transformer protection and Differential protection are implemented in IEEE 9 and 14 bus electrical power system[4]. The Coordiantion of Directional Overcurrent Relays is formulated as a mixed-integer nonlinear programming problem [7] and is then solved by using new seeker optimization technique. Continuous Genetic Algorithm (CGA) technique is used for optimum coordination of OCR in a ring fed distribution system [6]. Particle swarm Optimization is used for optimal coordination of Overcurrent Relay [13]. A set of two algorithms named Opposition based Chaotic Differential Evolution (OCDE1 and OCDE2) has been developed and applied for the coordination of Directional Overcurrent Relay [9]. The application of swarm intelligence algorithms: Ant Colony Optimization and Firefly Algorithm in radial system are done in order to obtain the time multiplier settings of the Relays [12].

The Relay current setting is given by Plug Setting Multiplier (PSM) and the time settings are given by the Time Dial Settings. The plug-setting must not be less than the maximum normal load including permissible continuous overload unless monitor by under voltage Relay, otherwise the Relay will not allow the normal load to be delivered. In estimating the plug-setting, an allowance must be made for the fact that the Relay pick-up varies from 1.05 to 1.3 times plug settings, as per standards.

II. Overcurrent Relay

The Overcurrent Relay is the Relay, which operates only when the value of the current is greater than the Relay setting time. It protects the power system equipment from the fault current. Depending on the time of operation the Overcurrent Relay is classified into following types.

- Instanteneous Overcurrent Relay
- Inverse Overcurrent Relay
- Definite Time Overcurrent Relay
- Inverse Definite Time Overcurrent Relay
- Very Inverse Definite Time Overcurrent Relay
- Extremely Inverse Definite Time Overcurrent Relay
- Instantaneous Overcurrent Relay

The Relay nearer to the fault will act as the Primary Relay while the remaining Relays will act as

Backup[5].Relay coordination study and analysis is performed to make sure that safety operation of the system are operating correctly and to avoid the nuisance tripping. The cause for nuisance tripping is modification of protective devices and their settings at the time of upkeep without performing suitable study and analysis.

A. Relay current setting

The minimum current required for the Relay to control is known as Relay current setting. Determination of current setting should be in such a way that the Relay does not function for the maximum fault current level but does operate for a minimum fault current level. If the current setting is set for the maximum fault current level in the power system, an Overcurrent Relay can provide small degree of protection against overload and faulted condition. The main function of an Overcurrent Relay is to isolate Primary system faults not for the overload protection.

B. Relay time grading margin

The minimum time interval between the Primary and backup protective Relay is maintained to achieve proper discrimination between the Primary and back up Relay is known as the time grading margin. If the grading margin is not provided then more than one Relay will operate for the same fault leading to failure of the determination of fault location and occurrence of blackout in the power system.

C. Grading

Grading of Overcurrent Relay is the adjustment of settings in the Overcurrent Relay to make certain discrimination and selectivity. When a radial feeder consist of multiple feeders in series, an Overcurrent protection Relay with same characteristics is installed at every breaker location. When a fault occurs at any given point in the system only the Relay closest to the fault should operate. This is called Grading. As per the standard the grading between the Relays should be less than 0.5s and 0.3s is used as the grading margin in the simulation.

III. METHODS OF RELAY COORDINATION

The aim of a coordination study is to decide the characteristics, ratings, and settings of Overcurrent protective device. A coordination study should be conducted in the early planning stages of a new system to tentatively select protection and utilization equipment or in the case where an existing system is modified and new loads are installed [14]. Directional Overcurrent Relay coordination problem is formulated as an interval linear programming (ILP) problem [1].

Discrimination by time, discrimination by current and discrimination both by current and time are the three methods used for the Relay coordination. Though the methods are different from each other but they follow the same plan of isolating only the faulty section of system and leaving the rest of the system undisturbed.

A. Discrimination by time

In this method, an suitable time setting keeping the same fault current level is given to each Relay controlling the circuit breakers in power system to ensure that the Relay nearest to the fault operates first. The Relay near the source will have the maximum time compared to the Relay far away from the source.

B. Discrimination by current

Discrimination by current relies on the fact that the fault current varies with the position of the fault because their impedance values differ from place to place between the source and the fault. Therefore the Relays controlling the various circuit breakers are set to operate at suitable values of current so that only the Relay nearest to the fault trips its breaker.

C. Discrimination by both time and current

In this method, the operation of time is inversely proportional to the current level and the actual characteristics is a function of both time and current settings. For a large difference in fault current between the two ends of the feeder, faster operating times can be achieved by the Relays nearest to the source, where the fault level is the highest.

IV. SIMULATION STUDIES AND RESULT

DIgSILENT stands for DIgital SImulation and Electrical Network. DIgSILENT Power Factory is a leading power system analysis software application for use in analysing generation, transmission, distribution and industrial systems. It covers the full range of functionality from standard features to highly sophisticated and advanced applications including wind power, distributed generation, real-time simulation and performance monitoring for system testing and supervision. Power Factory is easy to use, fully windows compatible and combines reliable and flexible system modeling capabilities with state-of-the-art algorithms and a unique database concept

For the load flow analysis, AC balanced, positive sequence calculation method was chosen and the formulation was done by using Newton-Raphson with power equations. This work consist of 4 section. They are i) Modelling of 39 bus system in DIgSILENT ii) Conducting load flow iii) Conducting Short Circuit Analysis iv) Choosing the Relay Setting for IEEE 39 Bus system using MATLAB.

Figure 1 shows the Implementation of IEEE 39 Bus system. It consists of 10 Generator and 49 lines. After modelling the 39 Bus system, load flow has to be conducted and their load flow results.

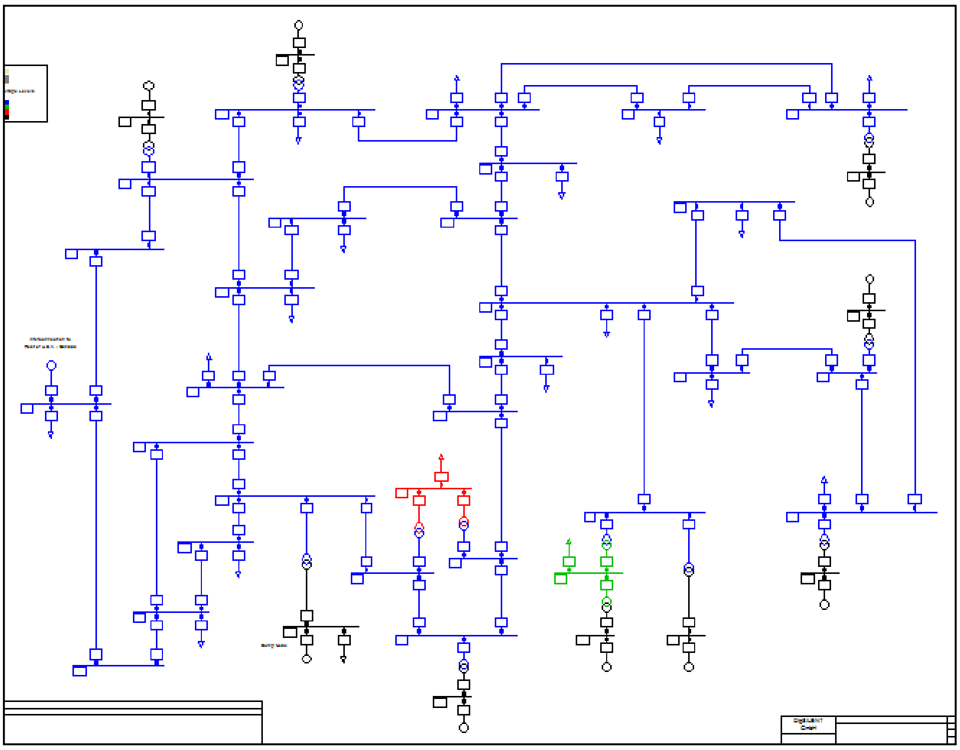

Fig. 1: Implementation of IEEE 39 bus system in DIgSILENT

Load Flow Calculation — Complete System Report: Substations, Voltage Profiles, Grid Interchange

AC Load Flow, balanced, positive sequence		Automatic Model Adaptation for Convergence	No
Automatic Tap Adjust of Transformers	No	Max. Acceptable Load Flow Error for	
Consider Reactive Power Limits	No	Nodes	1.00 kVA
		Model Equations	0.10 %

Grid: Grid | System Stage: Grid | Study Case: Power Flow | Annex: / 1

	rtd. V [kV]	Bus-voltage [p.u.]	Bus-voltage [kV]	Bus-voltage [deg]	Generation [MW]	Generation [Mvar]	Motor Load [MW]	Motor Load [Mvar]	Load [MW]	Load [Mvar]	Ext. Infeed [MW]	Ext. Infeed [Mvar]	Compensation [Mvar]
Bus 01	345.00	1.04	206.83	-30.92	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Bus 02	345.00	1.02	203.32	-31.69	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Bus 03	345.00	1.00	200.12	-30.93	0.00	0.00	0.00	0.00	322.00	2.40	0.00	0.00	0.00
Bus 04	345.00	0.97	194.14	-26.85	0.00	0.00	0.00	0.00	500.00	184.00	0.00	0.00	0.00
Bus 05	345.00	0.97	194.16	-22.73	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Bus 06	345.00	0.98	194.70	-21.34	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Bus 07	345.00	0.97	192.65	-24.32	0.00	0.00	0.00	0.00	233.80	84.00	0.00	0.00	0.00
Bus 08	345.00	0.97	192.56	-25.18	0.00	0.00	0.00	0.00	522.00	176.00	0.00	0.00	0.00
Bus 09	345.00	1.01	202.09	-28.40	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Bus 10	345.00	1.00	198.22	-20.40	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Bus 11	345.00	0.99	196.81	-20.75	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

	rtd. V [kV]	Bus-voltage [p.u.]	[kV]	[deg]	Generation [MW]	[Mvar]	Motor Load [MW]	[Mvar]	Load [MW]	[Mvar]	Ext. Infeed [MW]	[Mvar]	Compensation [Mvar]
Bus 12	138.00	0.98	77.72	-21.25	0.00	0.00	0.00	0.00	7.50	88.00	0.00	0.00	0.00
Bus 13	345.00	0.99	197.37	-21.63	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Bus 14	345.00	0.99	196.52	-24.65	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Bus 15	345.00	1.00	198.71	-27.47	0.00	0.00	0.00	0.00	320.00	153.00	0.00	0.00	0.00
Bus 16	345.00	1.02	202.67	-27.03	0.00	0.00	0.00	0.00	329.00	32.30	0.00	0.00	0.00

Grid: Grid System Stage: Grid | Study Case: Power Flow | Annex: / 2

	rtd. V [kV]	Bus-voltage [p.u.]	[kV]	[deg]	Generation [MW]	[Mvar]	Motor Load [MW]	[Mvar]	Load [MW]	[Mvar]	Ext. Infeed [MW]	[Mvar]	Compensation [Mvar]
Bus 17	345.00	1.01	202.06	-29.21	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Bus 18	345.00	1.01	201.03	-30.31	0.00	0.00	0.00	0.00	158.00	30.00	0.00	0.00	0.00
Bus 19	345.00	1.04	208.07	-21.81	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Bus 20	230.00	0.99	131.24	-22.81	0.00	0.00	0.00	0.00	628.00	103.00	0.00	0.00	0.00
Bus 21	345.00	1.02	203.51	-24.58	0.00	0.00	0.00	0.00	274.00	115.00	0.00	0.00	0.00
Bus 22	345.00	1.04	208.03	-20.08	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Bus 23	345.00	1.04	207.00	-20.28	0.00	0.00	0.00	0.00	247.50	84.60	0.00	0.00	0.00
Bus 24	345.00	1.02	204.02	-26.91	0.00	0.00	0.00	0.00	308.60	-92.20	0.00	0.00	0.00
Bus 25	345.00	1.01	202.03	-32.33	0.00	0.00	0.00	0.00	224.00	47.20	0.00	0.00	0.00
Bus 26	345.00	1.03	204.90	-30.49	0.00	0.00	0.00	0.00	139.00	17.00	0.00	0.00	0.00
Bus 27	345.00	1.02	202.45	-31.12	0.00	0.00	0.00	0.00	281.00	75.50	0.00	0.00	0.00
Bus 28	345.00	1.04	206.76	-26.91	0.00	0.00	0.00	0.00	206.00	27.60	0.00	0.00	0.00
Bus 29	345.00	1.04	207.48	-24.11	0.00	0.00	0.00	0.00	283.50	26.90	0.00	0.00	0.00
Bus 30	16.50	1.05	9.98	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Bus 31	16.50	0.98	9.35	0.00	1314.76	519.46	0.00	0.00	9.20	4.60	0.00	0.00	0.00
Bus 32	16.50	0.98	9.37	-12.23	650.00	307.29	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Bus 33	16.50	1.00	9.50	-16.58	632.00	144.41	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Bus 34	16.50	1.01	9.64	-17.62	508.00	181.74	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Bus 35	16.50	1.05	10.00	-15.09	650.00	251.14	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Bus 36	16.50	1.06	10.13	-12.39	560.00	123.14	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Bus 37	16.50	1.03	9.79	0.00	0.00	-0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Bus 38	16.50	1.03	9.78	-17.02	830.00	76.27	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Bus 39													

Fig. 2: Load Flow result

Figure 2 shows the Load Flow result for the IEEE 39 Bus system.

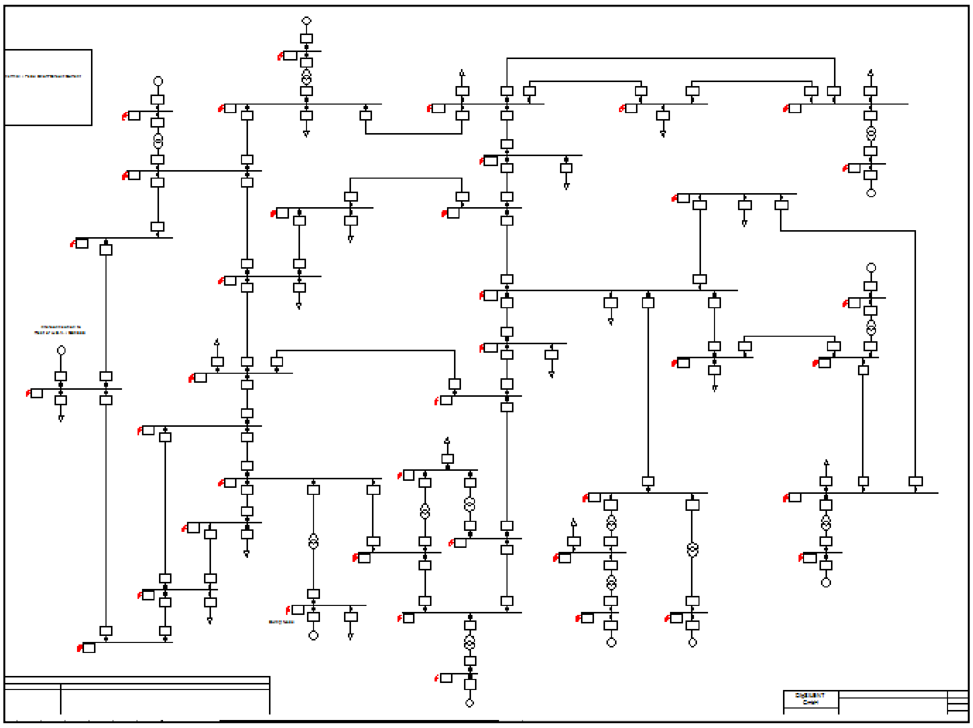

Fig. 3: Short Circuit Analysis for IEEE 39 Bus System

Figure 3 shows the Short Circuit Analysis for IEEE 39 Bus system. Red colour at each bus indicates the short Circuit are induced at each bus and their results are shown below.

Fault Locations with Feeders
Short-Circuit Calculation / Method : VDE 0102 — 3-Phase Short-Circuit / Max. Short-Circuit Currents

Asynchronous Motors: Always Considered
Decaying Aperiodic Component (idc): Using Method B
Grid Identification: Automatic
Conductor Temperature: User Defined No
Short-Circuit Duration: Break Time 0.10 s; Fault Clearing Time (Ith) 1.00 s
c-Voltage Factor: User Defined No

Grid: Grid | System Stage: Grid | Annex: / 1

	rtd.V. [kV]	Voltage [kV]	[deg]	c-Factor	Sk" [MVA/MVA]	Ik" [kA/kA]	[deg]	ip [kA/kA]	Ib [kA]	Sb [MVA]	Ik [kA]	Ith [kA]
Bus 01	345.00	0.00	0.00	1.10	5635.28 MVA	9.43 kA	-86.89	24.73 kA	9.43	5635.28	9.43	9.68
Line 01 - 39	Bus 39				4067.92 MVA	6.81 kA	92.33	17.85 kA				
Line 01 - 02	Bus 02				1568.73 MVA	2.63 kA	95.14	6.88 kA				
Bus 02	345.00	0.00	0.00	1.10	5467.42 MVA	9.15 kA	-84.97	22.99 kA	9.15	5467.42	9.15	9.30
Trf 02 - 30	Bus 30				0.00 MVA	0.00 kA	0.00	0.00 kA				
Line 02 - 03	Bus 03				2619.75 MVA	4.38 kA	93.44	11.02 kA				
Line 01 - 02	Bus 01				1602.03 MVA	2.68 kA	93.85	6.74 kA				
Line 02 - 25	Bus 25				1251.44 MVA	2.09 kA	99.87	5.26 kA				
Bus 03	345.00	0.00	0.00	1.10	6399.81 MVA	10.71 kA	-86.03	27.52 kA	10.71	6399.81	10.71	10.93
Line 03 - 04	Bus 04				2348.82 MVA	3.93 kA	92.98	10.10 kA				
Line 02 - 03	Bus 02				1827.34 MVA	3.06 kA	95.58	7.86 kA				
Line 03 - 18	Bus 18				2224.75 MVA	3.72 kA	93.71	9.57 kA				
Bus 04	345.00	0.00	0.00	1.10	7181.23 MVA	12.02 kA	-86.73	31.37 kA	12.02	7181.23	12.02	12.31
Line 04 - 14	Bus 14				2370.43 MVA	3.97 kA	93.34	10.36 kA				
Line 03 - 04	Bus 03				2006.11 MVA	3.36 kA	93.92	8.76 kA				
Line 04 - 05	Bus 05				2804.94 MVA	4.69 kA	92.75	12.25 kA				

Bus 05		345.00	0.00	0.00	1.10	7832.36 MVA	13.11 kA	-87.03	34.46 kA	12.94	7730.20	13.11	13.46
Line 05 - 08	Bus 08					1270.05 MVA	2.13 kA	92.97	5.59 kA				
Line 05 - 06	Bus 06					4281.23 MVA	7.16 kA	92.80	18.84 kA				
Line 04 - 05	Bus 04					2281.14 MVA	3.82 kA	93.30	10.04 kA				
Bus 06		345.00	0.00	0.00	1.10	8195.63 MVA	13.72 kA	-87.14	36.16 kA	13.43	8022.63	13.72	14.10
Trf 06 - 31	Bus 31					2217.85 MVA	3.71 kA	91.53	9.78 kA				
Line 05 - 06	Bus 05					2521.90 MVA	4.22 kA	93.32	11.13 kA				

Grid: Grid | System Stage: Grid | Annex: / 2

		rtd.V. [kV]	Voltage [kV]	Voltage [deg]	c-Factor	Sk" [MVA/MVA]	Ik" [kA/kA]	Ik" [deg]	ip [kA/kA]	Ib [kA]	Sb [MVA]	Ik [kA]	Ith [kA]
Line 06 - 07	Bus 07					940.58 MVA	1.57 kA	93.18	4.15 kA				
Line 06 - 11	Bus 11					2516.13 MVA	4.21 kA	93.46	11.10 kA				
Bus 07		345.00	0.00	0.00	1.10	6389.10 MVA	10.69 kA	-86.84	27.99 kA	10.66	6369.37	10.69	10.96
Line 07 - 08	Bus 08					3025.49 MVA	5.06 kA	93.49	13.25 kA				
Line 06 - 07	Bus 06					3363.71 MVA	5.63 kA	92.86	14.74 kA				
Bus 08		345.00	0.00	0.00	1.10	6613.91 MVA	11.07 kA	-86.86	28.99 kA	11.04	6595.93	11.07	11.35
Line 08 - 09	Bus 09					1723.46 MVA	2.88 kA	93.07	7.55 kA				
Line 07 - 08	Bus 07					2293.77 MVA	3.84 kA	93.15	10.05 kA				
Line 05 - 08	Bus 05					2596.69 MVA	4.35 kA	93.17	11.38 kA				
Bus 09		345.00	0.00	0.00	1.10	5925.09 MVA	9.92 kA	-87.32	26.25 kA	9.92	5925.09	9.92	10.21
Line 08 - 09	Bus 08					1858.78 MVA	3.11 kA	93.45	8.23 kA				
Line 09 - 39	Bus 39					4066.55 MVA	6.81 kA	92.33	18.01 kA				
Bus 10		345.00	0.00	0.00	1.10	7700.31 MVA	12.89 kA	-86.99	33.85 kA	12.55	7501.18	12.89	13.23
Trf 10 - 32	Bus 32					2640.22 MVA	4.42 kA	91.59	11.61 kA				
Line 10 - 13	Bus 13					2234.01 MVA	3.74 kA	94.07	9.82 kA				
Line 10 - 11	Bus 11					2827.38 MVA	4.73 kA	93.51	12.43 kA				
Bus 11		345.00	0.00	0.00	1.10	7426.28 MVA	12.43 kA	-86.87	32.55 kA	12.23	7305.87	12.43	12.75
Trf 11 - 12	Bus 12					256.24 MVA	0.43 kA	90.62	1.12 kA				
Line 06 - 11	Bus 06					3535.83 MVA	5.92 kA	93.20	15.50 kA				
Line 10 - 11	Bus 10					3634.47 MVA	6.08 kA	93.24	15.93 kA				
Bus 12		138.00	0.00	0.00	1.10	3177.04 MVA	13.29 kA	-87.53	35.37 kA	13.29	3177.04	13.29	13.72
Trf 11 - 12	Bus 11					1601.66 MVA	6.70 kA	92.42	17.83 kA				
Trf 13 - 12	Bus 13					1575.38 MVA	6.59 kA	92.51	17.54 kA				
Bus 13		345.00	0.00	0.00	1.10	7091.63 MVA	11.87 kA	-86.69	30.96 kA	11.72	7005.17	11.87	12.16
Trf 13 - 12	Bus 12					303.53 MVA	0.51 kA	90.32	1.32 kA				
Line 13 - 14	Bus 14					2714.82 MVA	4.54 kA	93.95	11.85 kA				
Line 10 - 13	Bus 10					4073.88 MVA	6.82 kA	93.11	17.78 kA				
Bus 14		345.00	0.00	0.00	1.10	7149.30 MVA	11.96 kA	-86.52	31.08 kA	11.94	7136.07	11.96	12.24
Line 04 - 14	Bus 04					2397.98 MVA	4.01 kA	92.82	10.43 kA				
Line 14 - 15	Bus 15					2102.22 MVA	3.52 kA	94.34	9.14 kA				
Line 13 - 14	Bus 13					2649.49 MVA	4.43 kA	93.40	11.52 kA				
Bus 15		345.00	0.00	0.00	1.10	6716.93 MVA	11.24 kA	-85.98	28.84 kA	11.24	6716.93	11.24	11.47
Line 15 - 16	Bus 16					4435.82 MVA	7.42 kA	94.16	19.04 kA				
Line 14 - 15	Bus 14					2281.15 MVA	3.82 kA	93.74	9.79 kA				
Bus 16		345.00	0.00	0.00	1.10	9283.30 MVA	15.54 kA	-86.53	40.37 kA	15.52	9272.89	15.54	15.90

Grid: Grid | System Stage: Grid | Annex: / 3

		rtd.V. [kV]	Voltage [kV]	Voltage [deg]	c-Factor	Sk" [MVA/MVA]	Ik" [kA/kA]	Ik" [deg]	ip [kA/kA]	Ib [kA]	Sb [MVA]	Ik [kA]	Ith [kA]
Line 16 - 19	Bus 19					2573.97 MVA	4.31 kA	93.70	11.19 kA				
Line 16 - 21	Bus 21					1681.34 MVA	2.81 kA	92.46	7.31 kA				
Line 16 - 24	Bus 24					1133.07 MVA	1.90 kA	92.62	4.93 kA				
Line 16 - 17	Bus 17					2217.49 MVA	3.71 kA	94.02	9.64 kA				
Line 15 - 16	Bus 15					1678.00 MVA	2.81 kA	93.96	7.30 kA				
Bus 17		345.00	0.00	0.00	1.10	7361.23 MVA	12.32 kA	-86.19	31.75 kA	12.32	7361.23	12.32	12.58
Line 17 - 18	Bus 18					1792.88 MVA	3.00 kA	93.56	7.73 kA				
Line 17 - 27	Bus 27					1258.42 MVA	2.11 kA	94.69	5.43 kA				
Line 16 - 17	Bus 16					4310.11 MVA	7.21 kA	93.66	18.59 kA				
Bus 18		345.00	0.00	0.00	1.10	6151.95 MVA	10.30 kA	-86.05	26.45 kA	10.30	6151.95	10.30	10.51
Line 17 - 18	Bus 17					3694.25 MVA	6.18 kA	93.98	15.88 kA				
Line 03 - 18	Bus 03					2457.71 MVA	4.11 kA	93.90	10.57 kA				
Bus 19		345.00	0.00	0.00	1.10	7805.08 MVA	13.06 kA	-86.66	34.04 kA	12.39	7404.88	13.06	13.38
Trf 19 - 20	Bus 20					1718.12 MVA	2.88 kA	92.87	7.49 kA				
Trf 19 - 33	Bus 33					3028.29 MVA	5.07 kA	92.85	13.21 kA				
Line 16 - 19	Bus 16					3059.11 MVA	5.12 kA	94.09	13.34 kA				
Bus 20		230.00	0.00	0.00	1.10	5672.60 MVA	14.24 kA	-86.91	37.33 kA	13.66	5442.87	14.24	14.61
Trf 19 - 20	Bus 19					3502.49 MVA	8.79 kA	93.23	23.05 kA				
Trf 20 - 34	Bus 34					2170.14 MVA	5.45 kA	92.86	14.28 kA				
Bus 21		345.00	0.00	0.00	1.10	6492.05 MVA	10.86 kA	-86.88	28.46 kA	10.82	6467.40	10.86	11.14
Line 16 - 21	Bus 16					3621.27 MVA	6.06 kA	93.52	15.88 kA				
Line 21 - 22	Bus 22					2870.99 MVA	4.80 kA	92.60	12.59 kA				
Bus 22		345.00	0.00	0.00	1.10	7448.35 MVA	12.46 kA	-87.35	33.02 kA	11.97	7151.22	12.46	12.84
Trf 22 - 35	Bus 35					2883.27 MVA	4.83 kA	91.82	12.78 kA				
Line 22 - 23	Bus 23					2427.56 MVA	4.06 kA	92.89	10.76 kA				
Line 21 - 22	Bus 21					2138.07 MVA	3.58 kA	93.49	9.48 kA				
Bus 23		345.00	0.00	0.00	1.10	6774.84 MVA	11.34 kA	-87.25	29.96 kA	11.08	6623.67	11.34	11.67
Trf 23 - 36	Bus 36					1980.76 MVA	3.31 kA	91.98	8.76 kA				
Line 22 - 23	Bus 22					3242.31 MVA	5.43 kA	92.85	14.34 kA				
Line 23 - 24	Bus 24					1552.11 MVA	2.60 kA	93.55	6.86 kA				
Bus 24		345.00	0.00	0.00	1.10	6978.80 MVA	11.68 kA	-86.73	30.49 kA	11.68	6978.80	11.68	11.97
Line 16 - 24	Bus 16					5474.26 MVA	9.16 kA	93.34	23.92 kA				
Line 23 - 24	Bus 23					1504.57 MVA	2.52 kA	92.99	6.57 kA				

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|Bus 25             345.00   0.00    0.00  1.10   4516.61 MVA    7.56 kA  -79.25   17.04 kA   7.56  4516.61     7.56    7.62 |
|    Trf 25 - 37    Bus 37                           0.00 MVA    0.00 kA    0.00    0.00 kA                                    |
|    Line 25 - 26   Bus 26                        1558.97 MVA    2.61 kA   93.04    5.88 kA                                    |
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□------------------------------------------------------------------------------------------------------------------------------
| Grid: Grid                System Stage: Grid             |                                    | Annex:            / 4       |
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|                     rtd.V.   Voltage      c-       Sk"              Ik"             ip       Ib      Sb        Ik     Ith |
|                     [kV]    [kV]   [deg] Factor  [MVA/MVA]     [kA/kA]   [deg]    [kA/kA]   [kA]    [MVA]     [kA]    [kA] |
-------------------------------------------------------------------------------------------------------------------------------
|    Line 02 - 25   Bus 02                        2979.05 MVA    4.99 kA  104.77   11.24 kA                                    |
|                                                                                                                             |
|Bus 26             345.00   0.00    0.00  1.10   4990.08 MVA    8.35 kA  -84.51   20.78 kA   8.35  4990.08     8.35    8.48 |
|    Line 25 - 26   Bus 25                        1370.85 MVA    2.29 kA  100.14    5.71 kA                                    |
|    Line 26 - 27   Bus 27                        1957.61 MVA    3.28 kA   93.50    8.15 kA                                    |
|    Line 26 - 28   Bus 28                         833.94 MVA    1.40 kA   94.00    3.47 kA                                    |
|    Line 26 - 29   Bus 29                         833.94 MVA    1.40 kA   94.00    3.47 kA                                    |
|                                                                                                                             |
|Bus 27             345.00   0.00    0.00  1.10   4940.25 MVA    8.27 kA  -85.43   20.97 kA   8.27  4940.25     8.27    8.41 |
|    Line 26 - 27   Bus 26                        2011.13 MVA    3.37 kA   96.07    8.54 kA                                    |
|    Line 17 - 27   Bus 17                        2930.29 MVA    4.90 kA   93.53   12.44 kA                                    |
|                                                                                                                             |
|Bus 28             345.00   0.00    0.00  1.10   3670.06 MVA    6.14 kA  -85.45   15.58 kA   6.12  3659.64     6.14    6.25 |
|    Line 26 - 28   Bus 26                        1224.53 MVA    2.05 kA   95.42    5.20 kA                                    |
|    Line 28 - 29   Bus 29                        2445.75 MVA    4.09 kA   94.11   10.38 kA                                    |
|                                                                                                                             |
|Bus 29             345.00   0.00    0.00  1.10   4885.09 MVA    8.18 kA  -86.11   21.06 kA   7.82  4671.45     8.18    8.35 |
|    Trf 29 - 38    Bus 38                        3180.48 MVA    5.32 kA   92.89   13.71 kA                                    |
|    Line 26 - 29   Bus 26                         852.99 MVA    1.43 kA   95.74    3.68 kA                                    |
|    Line 28 - 29   Bus 28                         852.99 MVA    1.43 kA   95.74    3.68 kA                                    |
|                                                                                                                             |
|Bus 30              16.50   0.00    0.00  1.10   5519.89 MVA  193.15 kA  -87.14  509.01 kA 143.52  4101.75    88.82  153.98 |
|    Trf 02 - 30    Bus 02                           0.00 MVA    0.00 kA    0.00    0.00 kA                                    |
|    G 10                                          5519.89 MVA  193.15 kA  -87.14  509.01 kA                                    |
-------------------------------------------------------------------------------------------------------------------------------
|Bus 31              16.50   0.00    0.00  1.10   6399.12 MVA  223.91 kA  -87.71  598.27 kA 189.29  5409.77   223.91  231.73 |
|    Trf 06 - 31    Bus 06                        2535.69 MVA   88.73 kA   91.42  237.07 kA                                    |
|    G 02                                          3863.92 MVA  135.20 kA  -87.14  361.25 kA                                    |
|                                                                                                                             |
|Bus 32              16.50   0.00    0.00  1.10   7052.89 MVA  246.79 kA  -87.48  655.71 kA 207.21  5921.91   246.79  254.62 |
|    Trf 10 - 32    Bus 10                        2637.19 MVA   92.28 kA   91.96  245.18 kA                                    |
|    G 03                                          4415.91 MVA  154.52 kA  -87.14  410.55 kA                                    |
|                                                                                                                             |
|Bus 33              16.50   0.00    0.00  1.10   7369.39 MVA  257.86 kA  -86.95  676.55 kA 218.26  6237.76   257.86  264.64 |
|    Trf 19 - 33    Bus 19                        2953.54 MVA  103.35 kA   93.34  271.15 kA                                    |
|    G 04                                          4415.91 MVA  154.52 kA  -87.14  405.40 kA                                    |
|                                                                                                                             |
|Bus 34              16.50   0.00    0.00  1.10   5537.36 MVA  193.76 kA  -87.04  509.50 kA 164.06  4688.71   193.76  199.01 |
|    Trf 20 - 34    Bus 20                        2225.44 MVA   77.87 kA   93.10  204.76 kA                                    |
|    G 05                                          3311.93 MVA  115.89 kA  -87.14  304.73 kA                                    |
|                                                                                                                             |
|Bus 35              16.50   0.00    0.00  1.10   7281.81 MVA  254.80 kA  -87.48  677.05 kA 215.22  6150.82   254.80  262.89 |
|    Trf 22 - 35    Bus 22                        2866.10 MVA  100.29 kA   91.99  266.48 kA                                    |
|    G 06                                          4415.91 MVA  154.52 kA  -87.14  410.58 kA                                    |
|                                                                                                                             |
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□------------------------------------------------------------------------------------------------------------------------------
| Grid: Grid                System Stage: Grid             |                                    | Annex:            / 5       |
-------------------------------------------------------------------------------------------------------------------------------
|                     rtd.V.   Voltage      c-       Sk"              Ik"             ip       Ib      Sb        Ik     Ith |
|                     [kV]    [kV]   [deg] Factor  [MVA/MVA]     [kA/kA]   [deg]    [kA/kA]   [kA]    [MVA]     [kA]    [kA] |
-------------------------------------------------------------------------------------------------------------------------------
|Bus 36              16.50   0.00    0.00  1.10   6057.59 MVA  211.96 kA  -87.46  562.91 kA 177.33  5067.96   211.96  218.64 |
|    Trf 23 - 36    Bus 23                        2193.83 MVA   76.76 kA   91.98  203.87 kA                                    |
|    G 07                                          3863.92 MVA  135.20 kA  -87.14  359.06 kA                                    |
|                                                                                                                             |
|Bus 37              16.50   0.00    0.00  1.10   3863.92 MVA  135.20 kA  -87.14  356.31 kA 100.47  2871.23    62.18  107.79 |
|    Trf 25 - 37    Bus 25                           0.00 MVA    0.00 kA    0.00    0.00 kA                                    |
|    G 08                                          3863.92 MVA  135.20 kA  -87.14  356.31 kA                                    |
|                                                                                                                             |
```

Fig. 4: Short Circuit Analysis Result for IEEE 39 Bus System

Figure 4 shows the Circuit Analysis Result for IEEE 39 Bus System. Ip in the tabulation represents the peak fault current, Ik`` represents the Sub Synchronous fault Current, Sk`` represents the Sub Synchronous MVA. Ip is taken as fault current for calculating the Relay operating time.

A. Calculation of Relay Operating Time

The Calculation Relay Operating time involves 5 steps. They are

1) STEP 1: Selection of CT ratio=100/1A
2) STEP 2: Current setting for Relay=150%
   Ipick-up=1*1.50=1.5
3) STEP 3: Calculation of fault current in Secondary side ISC=Fault Current*(1/CT ratio)
4) STEP 4: PSM= ISC/Pick up current.
5) STEP5: Time of operation=TDS*(A/(ISC/Ipick-up)^B-1)

These calculations are done by using MATLAB so that each bus has a Primary as well as backup Relay. Some buses doesn't has Primary as well as backup Relay because that bus consist of generator and transformer. This paper only concentrates on the Overcurrent Relay. For Transformer and Generator Differential Relay is used for protection. The operation of Differential Relay is based on the difference in the current of Primary and Secondary winding. The time of operation is calculated for only Overcurrent Relay.(PSM-Plug Setting Multiplier)

Fault location at different Buses (B)	OPERATING TIMES OF RELAYS IN SEC.(p=Primary, b=backup, R=Relay)				
	P	b1	b2	b3	b4
BI	R in line1-39 0.0678	R in line 1-2 0.0739	-	-	-

B2	R in line 2-25 0.0716	R in line 2-3 0.0717	R in line 1-2 0.0765	-	-
B3	R in line 2-3 0.0693	R in line 3-18 0.0725	R in line 3-18 0.0725	-	-
B4	R in line 4-5 0.0709	R in line 3-4 0.0719	R in line 4-14 0.0721	-	-
B5	R in line 5-6 0.0673	R in line 4-5 0.0717	R in line 5-8 0.0782	-	-
B6	R in line 5-6 0.0711	R in line 6-11 0.0715	R in line 6-7 0.0812	-	-
B7	R in line 6-7 0.0691	R in line 7-8 0.07	-	-	-
B8	R in line 5-8 0.0712	R in line 7-8 0.0724	R in line 8-9 0.0754	-	-
B9	R in line 9-39 0.0677	R in line 8-9 0.0743	-	-	-
B10	R in line 10-11 0.0705	R in line 10=13 0.0723	-	-	-
B11	R in line 10-11 0.0685	R in line 6-11 0.0687	-	-	-
B12	R in line 13-12 0.0678	-	-	-	-
B13	R in line 10-13 0.0677	R in line 13-14 0.0707	-	-	-
B14	R in line 13-14 0.0713	R in line 4-14 0.0715	R in line 14-15 0.073	-	-
B15	R in line 15-16 0.0669	R in line 14-15 0.0725	-	-	-
B16	R in line 16-17 0.0710	R in line 15-16 0.0750	R in line 16-21 0.0756	R in line 16-24 0.0797	R in line 16-19 0.0981
B17	R in line 16-17 0.0674	R in line 17-18 0.0726	R in line 17-27 0.0763	-	-
B18	R in line 17-18 0.0682	R in line 3-18 0.0960	-	-	-
B19	No lines are presents, Only transformer are presents				
B20	No lines are presents, Only transformer are presents				
B21	R in line 16-21 0.0684	R in line 21-22 0.0706	-	-	-
B22	R in line 22-23 0.0719	R in line 21-22 0.0728	-	-	-
B23	R in line 22-23 0.0695	R in line 23-24 0.0759	-	-	-
B24	R in line 16-24 0.0651	R in line 23-24 0.0766	-	-	-
B25	R in line 17-27 0.0685	R in line 25-26 0.0773	-	-	-
B26	R in line 26-27 0.0737	R in line 25-26 0.0732	R in line 26-28 0.0834	R in line 26-29 0.0834	-
B27	R in line 17-27 0.0701	R in line 26-27 0.0725	-	-	-
B28	R in line 28-29 0.0722	R in line 26-28 0.0781	-	-	-
B29	R in line 26-29 0.0816	R in line 28-29 0.0816	-	-	-
B30	No lines are presents, Only Generator and transformer are presents				
B31	No lines are presents, Only Generator and transformer are presents				
B32	No lines are presents, Only Generator and transformer are presents				
B33	No lines are presents, Only Generator and transformer are presents				
B34	No lines are presents, Only Generator and transformer are presents				

B35	No lines are presents, Only Generator and transformer are presents
B36	No lines are presents, Only Generator and transformer are presents
B37	No lines are presents, Only Generator and transformer are presents
B38	No lines are presents, Only Generator and transformer are presents
B39	No lines are presents, Only Generator and transformer are presents

All the Relays are operating in the appropriate sequence within the defined coordinated margin for respective fault location. Thus, it can minimize the amount of damage to the system during a fault.

V. Conclusion

The prime aim of Relay Coordination and Grading is to identify and clear the fault as fast as possible. Different types of Relays are discussed So that it can prevent the devices from the high fault current. Various types of Relay coordination are discussed and in this thesis discrimination by time is used. The Relay nearer to the fault will act first and the remaining Relays will act as backup. Finally the Relay coordination is implemented in IEEE 39 bus system.

In the future plan, by using the dual setting directional Overcurrent Relays that are capable of operating in both forward and reverse directions, with different settings so that the remarkable reduction in both the Primary and backup Relay operating times can be achieved.

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