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Optimum Overcurrent Relay Coordination of a Power Grid

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ABSTRACT
Protective system plays a pivotal role in any power system operation. In a typical power system there are large numbers of circuit breakers and relays installed which constitute an integral part of the protective scheme. Relay is a device that senses and locates the fault and sends a command to the circuit breaker to disconnect the faulty element. Relay coordination is done to provide primary as well as back up protection from any fault that is likely to occur in the system. In this paper, overcurrent relay coordination is implemented on a 72 bus 220 KV substation. Load flow studies and the short circuit analysis on the test system is initially done followed by relay coordination. Fault current data obtained from short circuit studies enables us to obtain operating time of the relays used in the test system. The simulated value of operating time provides the coordinated operation of all the relays connected from 220kV to 33kV line thereby protecting the equipment of the test system.
Keywords-PSM (Plug Setting Multiplier), Relay coordination, Three phase to ground fault, TMS (Time Multiplier Settings)

I. INTRODUCTION

Protection system does the function of detecting the faults and clearing the fault as quickly as possible. Protection system includes circuit breakers, relays, current transformer, potential transformers and transducers. A protective relay is one of the most important part of a power system network and it is necessary to coordinate them properly so that the customers can get undisturbed supply. Over current relay coordination can be done with utmost accuracy and tolerance using the MiPower software. MiPower software is very interactive and has user friendly windows based power system analysis package. 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. The quantities that may change due to occurrence of fault are current, voltage, phase angle and frequency. A power system is mainly divided into a number of protective zones so that no part of the system is left unprotected. The protective devices in each zone isolate the faulty part from the healthy part as soon as possible to avoid further damage to equipment .If the fault is not cleared, then the system voltage will reduce and the generators will lose synchronism. Several methods are there to provide relay coordination. One such method is linear programming which is used to optimize the time multiplier setting of the relays [1]. Another method is to apply linear programming technique to minimize the operating time [2]. Therefore relay coordination is the most important part of a protective system design.

II. Case study: 220 kv Masudpur substation

Relay coordination is done on 220 KV Masudpur Substation. This substation is located in Hisar, Haryana. It is a 72 bus system receiving an incoming of 220 KV double circuit line and delivers two 220 KV double circuit line to 400 KV Kirori Substation and Samain Substation respectively. It has two step down transformers of 220/132 KV and 220/33KV which steps down the 220KV to 132KV and 33KV respectively. In total there are 23 breakers and 66 isolators. There are 4 loads in the system which sums up to 12.41 MW.132KV subsystem and capacitor banks are currently not in use in the existing substation operation.Fig.1 shows the pictorial view of the 220Kv Masudpur substation. From the Fig.1 we can see that there are three different voltage levels i.e. 220Kv, 132Kv, 33Kv in this substation. For 220 Kv and 33 Kv voltages level, main bus-1 is working. All the outgoing feeders are connected are 33Kv voltage level.

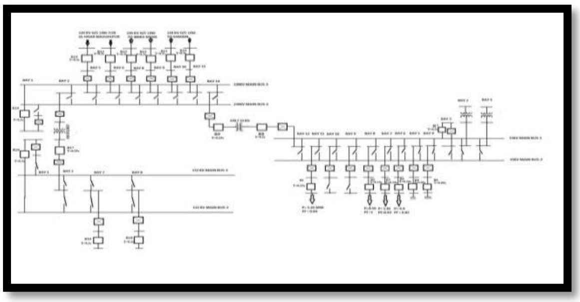

Fig.1:220 kv Masudpur Substation, Hisar, Haryana

III. System Data

1.Bus Data

Table 1: Bus voltages

Bus Number	Bus(KV)
1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,22,23,24,27,38	220
25, 26, 28, 29, 30, 31, 32, 33, 34, 35, 36, 37	132
39, 40, 41, 42, 43, 44, 45, 46, 47, 48, 49, 50, 51, 52, 53, 53, 54, 55, 56, 57, 58, 59, 60, 61, 62, 63, 64, 65, 66, 67, 68, 69, 74	33
72,73	0.4

2.Transformer Data

Table 2: Transformer Ratings

From	To	POSITIVE		ZERO	
Bus Name	Bus Name	R(P.U) TAP	X(P.U) PHASE	R(P.U) FB-MVA	X(P.U) TB-MVA
27	28	0.00501 1.00000	0.10027 0.000	0.00501 10000	0.10027 5000
38	39	0.00501 1.00000	0.10027 0.000	0.00501 10000	0.10027 1500
53	72	0.00294 1.05000	0.05883 0.000	0.00294 1500	0.05883 0
52	73	0.00294 1.05000	0.05883 0.000	0.00294 1500	0.05883 0

3.Load Data

Table 3: Loads connected to 33Kv Bays

Bus Number	Real Power (MW)	Reactive Power (MVAR)
55	1.61	1.04
65	4.59	0
66	1.81	1.22
67	4.4	3.07

IV. Implementation: Simulation And Results

1.Load Flow Studies

Load flow studies forms the basis for any further analysis done in power system. This gives an idea to power engineers about the actual power flows both real and reactive power taking place in the system. Load flow analysis is important for planning future expansions of the power system networks and determining the best operation of the existing equipment. Load flow study gives the optimal value of the voltage and the real and reactive power flowing in the line. The load flow study helps to minimize the transmission line losses and also reduces the cost of generation. Fig 2 shows load flow simulation circuit of 220 KV Masudpur substation. It can be seen from the Fig.2 that system is under loaded as the real and reactive power flows are indicated in green. The software indicates the power flows in blue under normal loading condition and in red for overloaded condition. The simulation is carried on the test system to give the load flow data as follows:

Table 4: Load Flow Results

MW generation	12.4312
MVAR generation	5.525
MW load	12.41
MVAR load	5.3725
MW loss	0.212
MVAR loss	0.1975

Table 4 shows the real power (MW) generation, MW loss and MW load. It also shows the reactive power (MVAR) generation, MVAR loss and MVAR load.

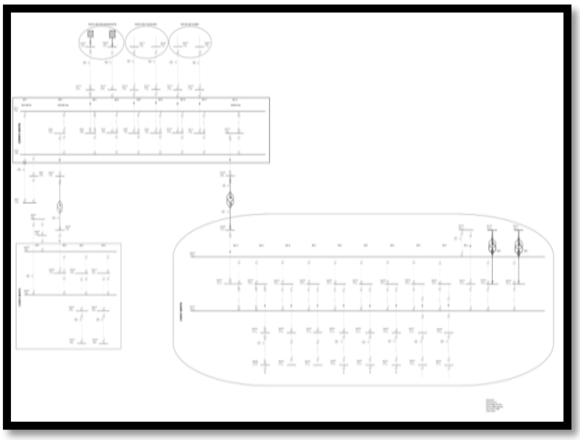

Fig.2: load flow simulation circuit of 220 kv Masudpur substation

2.Short Circuit Analysis

Prior to relay coordination, we consider short circuit studies which help us to know fault current, fault MVA and suitable develops a protection scheme for the grid. Devices like Generators, Transformers and Motors which are integral part of the power system should have their rating which exceeds the maximum fault current level and fault MVA value. So short circuit studies helps us to get values of fault current, fault MVA which helps us in designing proper protection scheme. The huge fault current causes an extreme damage to the equipment if suitable protective scheme is not incorporated in the power system. Short circuits are generally caused by insulation failures or conducting path failures. Short circuits on the transmission and the distribution lines are caused by over voltages due to lightning or switching surges. Faults can be classified as series and shunt faults. Series faults are also known as symmetrical faults. Three phase to ground fault comes under symmetrical faults and they are the most severe fault. They occur rarely in the power system. Shunt faults are also known as unsymmetrical faults and they are very common in the power system. 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 performed 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 65 and the following fault current, fault MVA and the post fault voltages are obtained.

Table 5: Fault Current (Amp/deg) at Bus 65

Sequence(1,2,0)		Phase (A,B,C)	
Mag	Ang	Mag	Ang
14310	-82.47	14310	-82.47
0	-90.00	14310	157.53
0	-90.00	14310	37.53
R/X Ratio of the short circuit path =0.1321			
Peak Asymmetrical short circuit current* = 34694 Amps			
*pascc = k X sqrt(2) X If , k=1.7144			

Table 6: Fault contribution from shunt connection

BUS NAME	CURRENT (AMPS/DEFREE)				MVA
	SEQUENCE (1,2,0)		PHASE (A,B,C)		PHASE (A,B,C)
	Mag	Ang	Mag	Ang	MAG
19	2146	97.53	2146	97.53	818
	0	-90.00	2146	-22.47	818
	0	-90.00	2146	-142.47	818
55,65, 66,67	0	-90.00	0	-90.00	0
	0	-90.00	0	-90.00	0
	0	-90.00	0	-90.00	0

Table 7: Three phase fault level

BUS NAME	BUS kV NOMINAL	3PH-fMVA	FAULT I kA
1,3,6,7,8,9,10, 11,12,13,14,16 ,17,18,19,21,2 2,23,24,27,38	220.000	0.3	0.001
2,4,14,20	220.000	0.4	0.001
25,26,30,31,32 ,33,34,35,36,3 7	132.000	0.2	0.001
39,40,41,42,43 ,44,45,46,47,4 8,49,50,51,52, 53,54,55,56,57 ,58,59,60,61,6 2,63,64,66,67, 68,69,74	33.000	0.0	0.000
65	33.000	817.9	14.310
72,73	0.400	0.0	0.000

Table 8: Fault MVA at bus 65

FAULT MVA	
SEQUENCE (1,2,0)	PHASE (A,B,C)
MAGNITUDE	MAGNITUDE
818	818
0	818
0	818

Table 9(a): Post fault voltages after creating fault at bus 65

Post Fault Voltages					
Bus Name	Sequence Current (1,2,0)		Phase (A,B,C)		Line-Line Mag
	V	Ang	V	Ang	Pu on L-L base
1,3,5,7,8, 9,10,11,1 5,16,17,1 8,21,22,2 3,24,27,2 8,29	0.88	1.14	0.88	1.14	0.88
	0	-90	0.88	-118.86	0.88
	0	-90	0.88	121.14	0.88

Table 9(b): Post fault voltages after creating fault at bus 65

Bus Name	Sequence Current (1,2,0)		Phase (A,B,C)		Line-Line Mag
	V	Ang	V	Ang	Pu on L-L base
2,4,14,20, 25,26,30,3 1,32,33,34 ,35,36,37	1	0	1	0	1
	0	-90	1	-120	1
	0	-90	1	120	1

Table 9(c): Post fault voltages after creating fault at bus 65

Bus Name	Sequence Current (1,2,0)		Phase (A,B,C)		Line-Line Mag
	V	Ang	V	Angle	Pu on L-L base
Bus 65	0	-90	0	-90	0
	0	-90	0	150	0
	0	-90	0	30	0

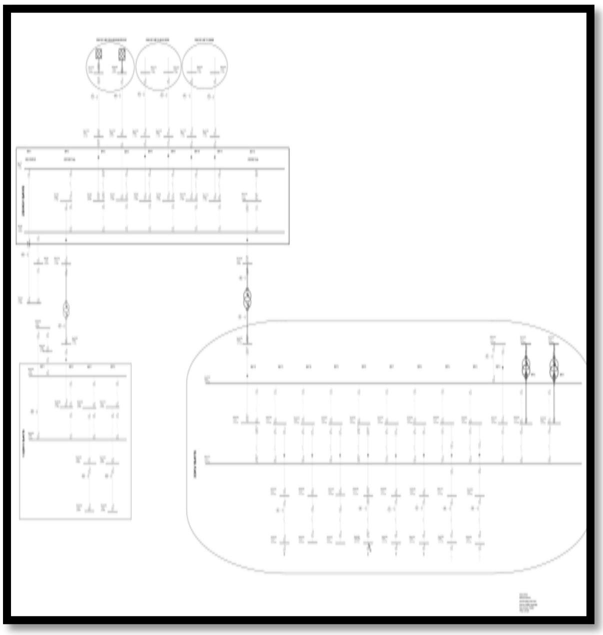

Fig.3: Three phase fault created at bus 65

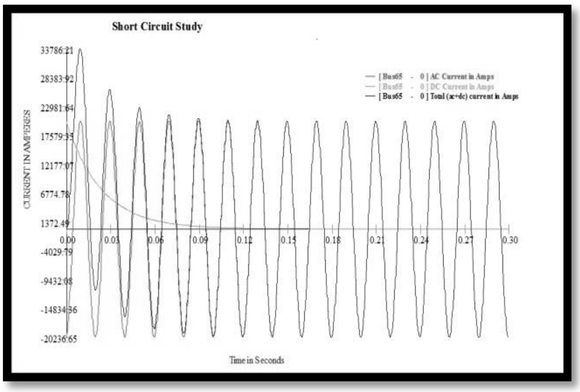

Fig.4: Waveform of Three phase symmetrical fault at bus 65

Fig.4 shows the phase A fault current at bus 65 when a three phase to ground fault is applied at bus 65.This graph shows the superimposition of dc offset current with the ac current to give the total asymmetrical (ac+dc) current.

3. Relay Coordination

When a fault occurs it may cause heavy damage to the power system and the equipment. Therefore, a suitable protective device is needed to protect the system from any damage. The protective device should be selective enough to distinguish between normal condition and faulty condition. One such protective device is the relay. A relay senses the fault and sends a signal to the circuit breaker to trip. There is a primary relay installed in every zone of the system to protect the system. After the occurrence of fault, the primary relay senses the fault and locates the fault. The primary relay sends the alarm to the circuit breaker and the circuit breaker trips. If the primary relay fails to operate then there is a backup relay to clear the fault. Relay coordination is done to check if the relay is fast enough or reliable enough to detect the fault at the proper time and send the signal to the auxiliary devices. Relays can be classified into different types. One such type is the over current relay. For over current protection different types of relays are used like electromagnet relay, induction disc type relay and static relay. The over current relay shows the relation between relay operating time in terms of TMS (Time Multiplier Setting) and actuating current in terms of PMS(Plug SettingMultiplier). The core of the relay is made to saturate for a given actuating current. The minimum time for relay to operate is the current setting or settling time. Relay shall not operate at a time less than the settling time. The settling time depends on X/R ratio between fault location and source and the ratio of the impedance between fault and source and the impedance of zone. The relay co-ordination study of an electric power system consists of an organized time-current study of all devices in series from utilization device to source. It is a study of organized time – current of all the equipment connected from the load to source. 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 effected when the protective devices removes a fault in the system. 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.In 220KV Masudpur substation, ABB manufactured REF 615 relay is used.REF615 relays are generally used for feeder protection. IECN curve type is used for all relay calculation. Operating time of any relay depends on three factors i.e. TMS, Fault current and plug setting. Different relays used and their respective TMS and plug settings are as follows:

Table 10: Relay Settings

Sn no.	CT ratio	Overcurrent setting			Earth fault setting		
		Plug Set in % Ip>	TMS (Tp> sec)	Ins Set (Ip >> in % &Tp>> in sec)	Plug Set in % Ie>	TMS (Te> Sec)	Ins Set (Ie>> in % &Te>> in sec)
R1 - R4	300 / 5	100	0.15	Ip >> 500 &Tp>> 0	20	0.15	Ie>> 200& Te>> 0
R5 - R6	400 / 5	100	0.05	Ip >> 500 &Tp>> 0	20	0.05	Ie>> 200 &Te>>0
R7	2000 / 5	100	0.2	Dis	20	0.2	Dis
R8	2000 / 5	100	0.2	Dis	20	0.2	Dis
R9	300 / 1	100	0.25	Ip >> 850 &Tp>> 0	Dis	0	Dis
R10-R16	1200 / 1	100	0.3	Dis	20	0.3	Dis
R17	500 / 1	100	0.25	Dis	20	0.25	Dis
R1 - R20	600/ 1	100	0.2	Dis	20	0.2	Dis

Overcurrent relay coordination studies done at bus 65 gives the following results:

Table 11: 3 Phase to ground fault is created at bus Bus65

Relay name	Phase a fault current	Operating time
R2	14309	Inst(0.00)
R8	14309	0.7021
R9	2146	0.8776
R15	2146	3.5638

Table 11 shows the operating time of the relays when a three phase to ground fault occurs at bus 65. Relay R2 acts instantaneously after the occurrence of fault. This can also be seen from Fig.5 which shows the overcurrent graphs of relays used in the test system. The relay R2 is provided with instantaneous settings as it is present closest to the feeder bus 65. It acts as a primary defense to any fault occurring at bus 65. If this relay fails to operate then the remaining relays R8, R9 and R15 will act according to their respective operating time.

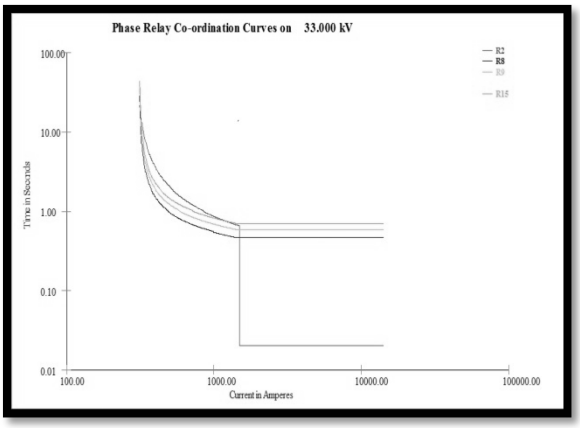

Fig.5: Relay coordination graph at bus 65

V. Conclusions

This paper presents the load flow studies, short circuit analysis and relay coordination of a 220 Kv Masudpur substation. Load flow studies show the proper power flow in the power system. It also shows that system is under loaded with 132 KV subsystem being non-operative. Short circuit studies is done on bus 65 which gives fault current of 14310 Amperes and fault MVA of 818. Fault current obtained is thereby utilized to determine the operating time for all the four relays connected between 220kV and 33 kV line such that their operation is properly coordinated. This ensures system protection scheme is adequate under existing working condition.

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