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Relay Coordination using ETAP

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Abstract—Relays and circuit breakers are heart of the modern large interconnected power system. Proper coordination of relays is essential to minimize unnecessary outages.This paper presents short circuit analysis and relay coordination of overcurrent relays of a radial power system of 1218.5 MVAsc capacity of an industrial power plant using etap simulation and hand calculation and comparison of results by both the methods.

Index Terms— earth fault settings , etap simulation , hand calculation, over current relay settings, radial system, relay coordination, short circuit analysis.

1 INTRODUCTION

In any power system network, protection should be designed such that protective relays isolate the faulted portion of the network at the earliest, to prevent equipment damage, injury to operators and to ensure **minimum** system **disruption** enabling continuity of service to healthy portion of the network. In case of failure of primary relays, back up relays operate after sufficient time discrimination .

The protective relay should be able to discriminate between normal, abnormal and fault conditions.The term relay coordination covers concept of discrimination, selectivity and backup protection.

In modern era, the demand for electrical power generally is increasing at a faster rate in economically emerging countries. So the networks of electricity companies become very complicated. The exercise of load flow analysis, fault calculations and listing the primary and back-up pairs will be very tediousand several 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 electrical system. This is possible only through computer programming.

ETAP performs numerical calculations with tremendous speed, automatically applies industry accepted standards, and provides easy to follow output reports. ETAP, while capable of handling 1000 buses, contains a load schedule program which tracks up to 10,000,000 load items, and reports the voltage and short-circuit current at the terminals of each load item. 100% of the Top 10 electrical design firms rely on ETAP (ECM Magazine). This capability makes ETAP suitable for large industrial facilities, as well as utility systems[6],[3].

Thus our project includes smart implementation of relay coordination using ETAP and multifunction relays having combined definite time and inverse time characteristics**.**

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2 SHORT CIRCUIT ANALYSIS

2.1 Calculation of Transformer fault current & circuit breaker capacity

For a 1000KVA ,13.8KV – 480Y/277V, first you will need to know the transformer Full Load Amperes
Full Load Ampere = KVA / 1.73 x L-L KV
FLA = 1000 / 1.732 x 0.48
FLA = 1,202.85
The 1000KVA 480V secondary full load ampere is 1,202A.
When the secondary ampere meter reads 1,202A and the primary Voltage Meter reads 793.5V. The percent of impedance value is 793.5 / 13800 = 0.0575. Therefore;
% Z = 0.0575 x 100 = 5.75%
This shows that if there was a 3-Phase Bolted fault on the secondary of the transformer then the maximum fault current that could flow through the transformer would be the ratio of 100 / 5.75 times the FLA of the transformer, or 17.39 x the FLA = 20,903A
Based on the infinite source method at the primary of the transformer. A quick calculation for the Maximum Fault Current at the transformer secondary terminals is
FC = FLA / %PU Z
FC = 1202 / 0.0575 = 20,904A
This quick calculation can help you determine the fault current on the secondary of a transformer for the purpose of selecting the correct overcurrent protective devices that can interrupt the available fault current. The main breaker that is to be installed in the circuit on the secondary of the transformer has to have a KA Interrupting Rating greater then 21,000A. Be aware that feeder breakers should include the estimated motor contribution too. If the actual connected motors are not known, then assume the contribution to be 4 x FLA of the transformer. Therefore, in this case the feeders would be sized at 20.904 + (4 x 1202) = 25,712 Amps.

2.2 Assumptions

1. The reactance of all cables, circuit breakers, current transformers, and buses are neglected, as well as the resistance values of all the system components. The effect of these is usually small when compared to the effect of power company short circuit per-unit reactance and generator and transformer per-unit reactance.

2. All the faults are considered bolted, that is, the fault impedance is assumed to be zero.
3. Contribution of back emf of motors in feeding the fault current is neglected.

The short-circuit currents calculated with the preceding assumptions will be slightly higher, on the conservative side, than if the neglected values were used in the calculations.

2.3 Steps for hand calculation of 3 phase short circuit current

- MVAsc capacity of an equipment is obtained by dividing MVA of equipment with (%Z /100) of the equipment:

  MVAsc of an equipment = $\frac{MVA*100}{\%Z}$
- If the equipments lie in parallel feeders, simply add the MVAsc of the equipments to get resultant MVAsc.

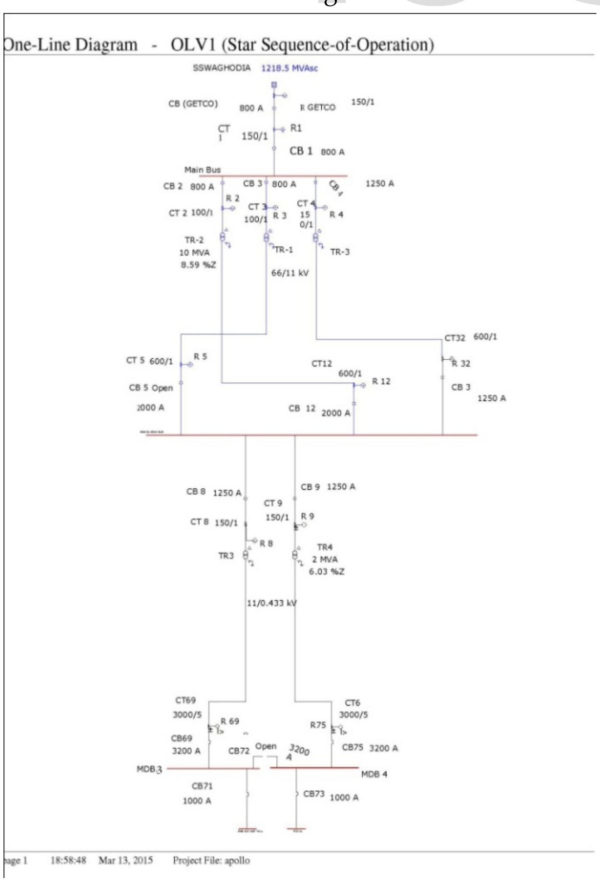
  MVAsc(res) = MVAsc1 + MVAsc2
- If the equipments lie on the same feeder, resultant MVAsc

  MVAsc(res) = $\frac{1}{\frac{1}{MVAsc1}+\frac{1}{MVAsc2}}$
- Now,for the MVAsc capacity of the point where the fault occurs in the system, consider the path from where the fault current flows, and find resultant MVAsc using above formulaes.
- Fault current at the point of fault=$\frac{MVAsc(res)}{\sqrt{3}*kV(L-L)of\ fault\ point}$

2.4 System Model

Here we have considered a part of 66 kV radial system of 1218.5 MVAsc capacity for relay coordination , which is as shown in fig. 1.

Figure 1



Scheme Of Operation Of SLD

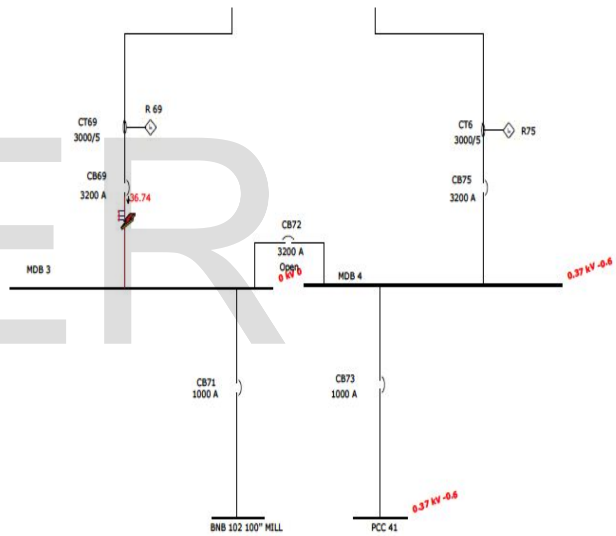
- TR-1 is a standby transformer (CB 5 is kept open) so that if either of TR-2 or TR-3 feeders fail, the stand by transformer can replace the faulty feeder and give continuous supply.
- Bus coupler is kept open

2.5 Calculation of 3 phase short circuit current of System Model

Consider the single line diagram in fig.2 which shows the values of current in the diagram obtained by performing Short Ciruit analysis when a 3 phase fault is inserted at load side in ETAP .

The fault current flows from grid through transformer 2(10MVA) & transformer 3(10MVA) (connected in parallel feeder) and transformer 3(2MVA) (fig. 1).

Figure 2



- MVAsc of grid= 1218.5MVA
- MVAsc of transformer 2 = MVAsc of transformer 3(10MVA) = $\frac{10*100}{8.59}$ = 116.4MVA
- MVAsc of transformer 3(2MVA) = $\frac{2*100}{6.11}$ =32.73MVA
- MVAsc(res) of transformer 2 & MVAsc of transformer 3(10MVA) =116.4 + 116.4 = 232.83MVA
- MVAsc (res)=$\frac{1}{\frac{1}{1218.5}+\frac{1}{232.83}+\frac{1}{32.73}}$ = $\frac{1}{0.03566}$ =28.04MVA
- Fault current at the point of fault=$\frac{28.04}{\sqrt{3}*0.433}$ = **37.3 kA**

HAND CALCULATION	ETAP RESULT
37.3 kA	36.74 kA

3 RELAY COORDINATION

Stage 51:

It involves the inverse time characteristic stage, required for coordination of relays.

- Pickup
- Time Dial

Stage 50 allows us with:

- o Instantaneous operation of relay
- o Definite time operation of relay (delay)
- Pickup
- Delay

3.1 Stage 51 Setting

1) **Curve type:** IEC Normal Inverse
2) **Pickup setting(Amp):** For all relays, pickup for 51 = rated current through the relay

$$\text{Pick up} = \frac{\frac{transformerMVA*1000}{\sqrt{3}*Ratedvoltage(L-L)}}{CTRATIO}$$

3) **Decide required time of operation for each relay:**

First of all, we consider the PSM & TMS settings of GETCO Relay, provided by GETCO .We insert 3phase fault at load side & note down its stage 51 tripping time.(We got 700ms). Now taking this time as reference,we decide the tripping times for the rest keeping <u>150ms</u> difference as follows:

- R1 should trip at 600 ms(before R-GETCO).
- R2 & R12 both should trip at 550 ms (as there is no other feeder or bus connected between them).
- R8 & R69 both should trip at 400 ms.

4) **Time Dial (TSM):**

Insert a 3 phase fault between MDB3 & CB69 and note down reflected currents through all the relays for 51 stage calculation:

- ❑ **R69 Setting (400ms) (CT Ratio-3000/5):**

Pickup: Relay Pickup= $\frac{\frac{transformerMVA*1000}{\sqrt{3}*Ratedvoltage(L-L)}}{CTRATIO} = \frac{\frac{2000}{0.433*\sqrt{3}}}{600}$ = **4.45A**

Time Dial:

- Reflected current at R69 due to 3 phase fault on load side = 36.739 kA
- WithTMS=1,

$$Timeofoperation = \frac{0.14}{PSM^{0.02} - 1}$$

$$= \frac{0.14}{\left(\frac{36.79*10^3}{4.4*600}\right)^{0.02} - 1}$$

= 2.58 sec

- *$ForTimeofoperation$ = 0.4s ;* ***TMS=0.4/2.54=0.15***

Similarly we calculated pickup & TMS for rest of the relays as shown below:

STAGE 51			
Relay	**Pick up(amp)**	**Time dial (TMS)**	**Expected Time(ms)**
R-69	4.45	0.15	400
R-8	0.7	0.15	400
R-75	4.45	0.15	400
R-9	0.7	0.15	400
R-12	0.87	0.025	550
R-2	0.87	0.025	550
R-32	0.87	0.025	550
R-4	0.58	0.025	550
R-1	1	0.04	700

3.2 Stage 50 Setting (Instantaneous or definite time)

1) **Pickup setting(Amp):**

- For all outgoing feeder relays, we insert a 3 phase fault on LT side of transformer & note down reflected fault current on HT side through the relay.

Pickup= $\frac{1.3 * \text{reflected primary fault current on HT side of transformer}}{\text{CT ratio}}$

The factor of 1.3 is multiplied so as to avoid pickup of the relay for fault on LT side of transformer i.e. for a fault out of its voltage level reach.

- For all incomer relays,

Pickup = $\frac{1.3 * \text{primary pickup of immediate down relay}}{\text{CT ratio}}$

The factor of 1.3 is multiplied so thatthe settings must be high enough to avoid relay operation with the maximum probable load, a suitable margin being allowed for large motor starting currents or transformer inrush transients.

2) **Delay setting (sec):**

- For all feeder relays,

Delay= 0 sec (instantaneous) or (0.04 to 0.06 s)

- For all incomer relays,

Delay=0.2 sec(to allow feeder relay to trip first)

Going from load side to upstream and applying above two points,

- For **R69 & R75** (load side relays) , we set fixed delay (300/400 ms), as we want the relays to trip in 400ms or less anyways for a fault at loadside.

- ❑ **R8(outgoing feeder relay)(CT Ratio-150:1):**

Pickup:

- Reflected fault current on HT side of transformer=1.45 kA
- Primary Pickup = 1.3 * 1.45 = 1.885 kA
- Pickup= 1885/150 =**12.57 A**

Delay: 0 sec (instantaneous)

- **R12(incomer relay)(CT Ratio-600:1):**

Pickup:

- Primary pickup of immediate down relay = 1.885 kA
- Pickup = 1.3 * 1885 / 600 = **4.1 A**

Delay: 0.2 sec

STAGE 50		
Relay	**Pick up (Amp)**	**Delay (s)**
R-8	12.57	0
R-9	12.57	0
R-12	4.1	0.2
R-32	4.1	0.2
R-2	11.2	0
R-4	11.2	0
R-1	14.56	0.15
R(GETCO)	25	0.2

3.3 Simulation results and Comparison

Entering the pickup and time setting of the relays obtained from calculations in chapter 4 of overcurrent (50 and 51 stage) and earth fault (50 and 51 stage) relays, we can simulate the system tripping and coordination of relays incase of any kind of fault occurring at any point on the system considered.
The results in sequence viewer of 3 phase faults at different locations are attached hereby:Similarly we calculated pickup & delay for rest of the relays as shown below:

Figure 3

Project:
Location:
Contract:
Engineer:
Filename: apollo

ETAP
12.6.0C

Study Case: SM

Page: 1
Date: 03-14-2015
SN: EXPELPRO3
Revision: Base
Config.: Normal

Sequence of Operation Event Summary Report

Symmetrical 3-Phase Fault between MDB 3 and CB69 Adjacent to MDB 3

Time (ms)	ID	If (kA)	T1 (ms)	T2 (ms)	Condition
390	R 8	1.446	390		Phase - OC1 - 51
390	R 69	36.739	390		Phase - OC1 - 51
450	CB 8		60.0		Tripped by R 8 Phase - OC1 - 51
450	CB69		60.0		Tripped by R 69 Phase - OC1 - 51
533	R 4	0.121	533		Phase - OC1 - 51
533	R 32	0.724	533		Phase - OC1 - 51
538	R 2	0.120	538		Phase - OC1 - 51
538	R 12	0.722	538		Phase - OC1 - 51
573	CB 4		40.0		Tripped by R 4 Phase - OC1 - 51
573	CB 32		40.0		Tripped by R 32 Phase - OC1 - 51
578	CB 2		40.0		Tripped by R 2 Phase - OC1 - 51
578	CB 12		40.0		Tripped by R 12 Phase - OC1 - 51
588	R1	0.241	588		Phase - OC1 - 51
648	CB 1		60.0		Tripped by R1 Phase - OC1 - 51
704	R (GETCO)	0.241	704		Phase - OC1 - 51
714	CB (GETCO)		10.0		Tripped by R (GETCO) Phase - OC1 - 51

Project:
Location:
Contract:
Engineer:
Filename: apollo

ETAP
12.6.0C

Study Case: SM

Page: 1
Date: 02-18-2015
SN: EXPELPRO3
Revision: Base
Config.: Normal

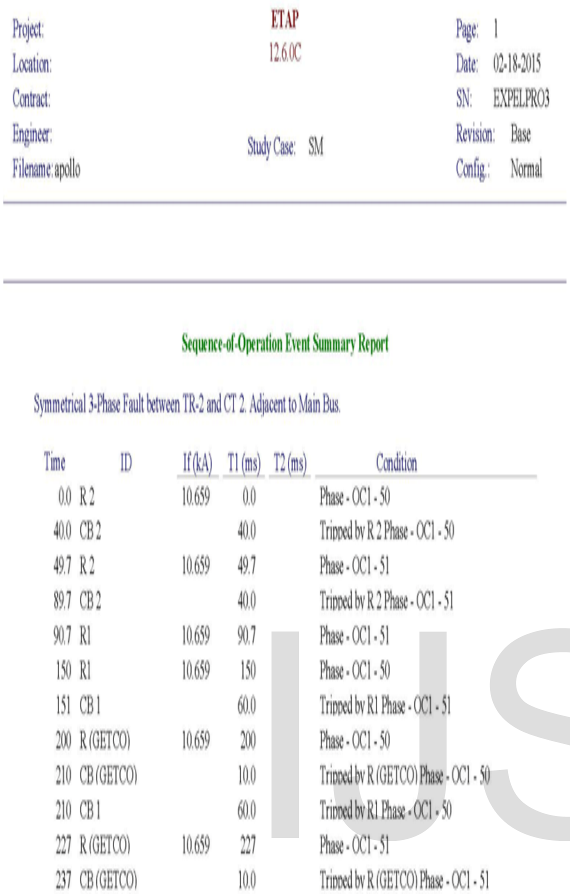
Sequence-of-Operation Event Summary Report

Symmetrical 3-Phase Fault between MDB 4 and CB75.

Time (ms)	ID	If (kA)	T1 (ms)	T2 (ms)	Condition
390	R 9	1.446	390		Phase - OC1 - 51
390	R 75	36.739	390		Phase - OC1 - 51
450	CB 9		60.0		Tripped by R 9 Phase - OC1 - 51
450	CB75		60.0		Tripped by R 75 Phase - OC1 - 51
533	R 4	0.121	533		Phase - OC1 - 51
533	R 32	0.724	533		Phase - OC1 - 51
538	R 2	0.120	538		Phase - OC1 - 51
538	R 12	0.722	538		Phase - OC1 - 51
573	CB 4		40.0		Tripped by R 4 Phase - OC1 - 51
573	CB 32		40.0		Tripped by R 32 Phase - OC1 - 51
578	CB 2		40.0		Tripped by R 2 Phase - OC1 - 51
578	CB 12		40.0		Tripped by R 12 Phase - OC1 - 51
588	R1	0.241	588		Phase - OC1 - 51
648	CB 1		60.0		Tripped by R1 Phase - OC1 - 51
704	R (GETCO)	0.241	704		Phase - OC1 - 51
714	CB (GETCO)		10.0		Tripped by R (GETCO) Phase - OC1 - 51

Figure 4

Figure 5



Project: ETAP 12.6.0C Page: 1
Location: Date: 02-18-2015
Contract: SN: EXPELPRO3
Engineer: Study Case: SM Revision: Base
Filename: apollo Config.: Normal

Sequence-of-Operation Event Summary Report

Symmetrical 3-Phase Fault between TR-2 and CT 2. Adjacent to Main Bus.

Time	ID	If (kA)	T1 (ms)	T2 (ms)	Condition
0.0	R 2	10.659	0.0		Phase - OC1 - 50
40.0	CB 2		40.0		Tripped by R 2 Phase - OC1 - 50
49.7	R 2	10.659	49.7		Phase - OC1 - 51
89.7	CB 2		40.0		Tripped by R 2 Phase - OC1 - 51
90.7	R1	10.659	90.7		Phase - OC1 - 51
150	R1	10.659	150		Phase - OC1 - 50
151	CB 1		60.0		Tripped by R1 Phase - OC1 - 51
200	R (GETCO)	10.659	200		Phase - OC1 - 50
210	CB (GETCO)		10.0		Tripped by R (GETCO) Phase - OC1 - 50
210	CB 1		60.0		Tripped by R1 Phase - OC1 - 50
227	R (GETCO)	10.659	227		Phase - OC1 - 51
237	CB (GETCO)		10.0		Tripped by R (GETCO) Phase - OC1 - 51

Comparison of Stage 51		
Relay	Expected Time(ms) set by **hand calculation**	Time(ms) obtained in **Simulation**
R-69	400	390
R-8	400	390
R-75	400	390
R-9	400	390
R-12	550	538
R-2	550	538
R-32	550	533
R-4	550	533
R-1	600	588

3.4 Methodology for Earth Fault Setting

The pickup and time settings for both 51 and 50 stage for earth fault, can be calculated in a similar way as we calculated for over current relay, except the following differences :-

- Pickup: The overcurrent relay pickup are set at rated current while the overcurrent earth fault relay pickup is set at 0.2 times of rated current in IDMT stage(51) , while pickup=0.4*rated current in high set stage(50).
- Transformer connection : The 51 stage time setting of earth fault relay is increased upstream in the same way as 51 stage setting of overcurrent. But if the transformer is delta-star(neutral grounded) connected, the fault at star side does not reflect any unbalance in line current of delta side . So instead of continuing the increase in time moving upstream (along the line) , we start again from instantaneous tripping from delta side. And go on increasing the time upstream till next such delta star transformer is encountered (that is when unbalance in line currents due to fault current is not reflected on the other side).

4 CONCLUSION

Thus, in this report, we have presented methodology of hand calculation and results of short circuit analysis and relay coordination of a part of 66kV electrical system of 1218.5 MVAsc capacity industrial plant.
The short circuit analysis methodology presented here is the method used generally in industries with reference to ect 158 of Schneider Electric.The relay coordination methodology used in this report, is based on industrial guides(Alstom protection guide) and IEEE papers.Simulation results are obtained using Electrical Transient Analyzer Program (ETAP).
The overcurrent relays (phase and earth fault) are the major protection devices in a distribution system.The overcurrent relay coordination in radial network is highly constrained optimization problem. 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 mal function and hence avoid the unnecessary outage of healthy part of system.
In this paper, hand calculation of relay settings is presented. But, if the network is very large and complicated and the calculations need to be performed again and again to get best coordination, then it becomes very tedious so using software like ETAP is helpful to reduce the chances of malfunction and increase the speed. Thus ETAP software provides efficient tool to solve the coordination problem of overcurrent relays in radial system.
Thus it can be concluded that the results obtained by both the methods i.e. hand calculation and simulation are almost same.

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