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RESEARCH ARTICLE

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MATHEMATICAL AND SIMULINK ANALYSIS OF RELAY COORDINATION

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ABSTRACT

Power system required protection against various types of fault. Different relays are used for different kind of protection. Directional relay are widely used for Generator protection and Transmission line protection. Relay co-ordination is very important and challenging aspect of power system protection. In our analysis, the directional relay co-ordination will be done for the small system with mathematical analysis and MATLAB program. The system will be highly protected with back-up protection and proper co-ordination.We have shown here the example of the Six bus system with two generation and calculated Relay settings of all the primary and backup relays mounted on the system.

KEYWORDS: Relay coordination, MATLAB Program, POWER WORLD, Directional Relay

INTRODUCTION

Relay co-ordination plays an important role in the protection of power system. For proper protection, proper co-ordination of relays with appropriate relay settings is to be done. Relay settings are done in such a way that proper co-ordination is achieved along various series network. However the review of Co-ordination is always essential since various additions / deletion of feeders and equipments will occur after the initial commissioning of plants. As power can be received from generators of captive power plant, the analysis becomes complex.

Relay co-ordination can be done by selecting proper plug setting and time multiplication setting of the relay, considering maximum fault current at the relay location. After selecting the plug setting and time multiplier setting, the co-ordination can be checked graphically.

When plotting co-ordination curves, certain time intervals must be maintained between the curves of various protective devices in order to ensure the correct sequential operation of the devices when co-coordinating inverse time over current relays.

For a given fault current, the operating time of IDMT relay is jointly determined by its plug and time multiplier settings. Thus this type of relay is most suitable for proper coordination. Operating characteristics of this relay are usually The relay coordination is mainly based on the requirements imposed by case a) e.g. starting large motors direct-on-line, faults at switchboard busbars, faults at consumer terminal boxes. It is reasonable to assume that the plant will operate as in a) for 90% or more of its lifetime. However, the system must have satisfactory, not necessarily the best, coordination for start-up and light load operations as in case b). Operational restrictions at light load may assist the coordination calculations e.g. most large HV

- Operational restrictions at light load may assist the coordination calculations e.g. most large HV motors would not be running, hence their starting performances need not be considered, when switchboard feeder circuit breakers are being examined.
- When all the over current curves are plotted for the main generators, transformer feeders, large motors and downstream feeders, they tend to be located 'close together', and without much room for adjustment.

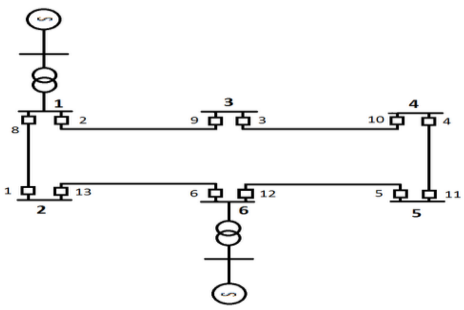
1. Radial System

- The specific protective relay as primary or backup is important in distribution system. When relay applied to protect its own system element it is thought of primary relay, when to backup other relays for fault at remote location, it is serving as backup relay.
- Providing both functions simultaneously; serving primary relay for its own zone protection and backup relay for remote zone of protection. The protective relay must be time-coordinated, so that the primary relay will always operate faster than the backup relay.
- So, the setting and coordination of the relay is the very important part to make sure which relay stands for primary and the other one for backup.

2. Ring Main System

- To setting relay, the same method is used for both ring and radial system. However, the circuit must be opened, start at the source point to form a two radial circuit before setting the relay. First, followed the clockwise.
- The relay setting start with R1 and the concept same like radial system. Second, followed the anticlockwise and the system will form a radial circuit.

SYSTEM ANALYSIS:



System

DIRECTION OF RELAY OPERATION:

Clockwise	1	2	3	4	5	6
Anticlockwise	8	13	12	11	10	9

Pair of relay operation:

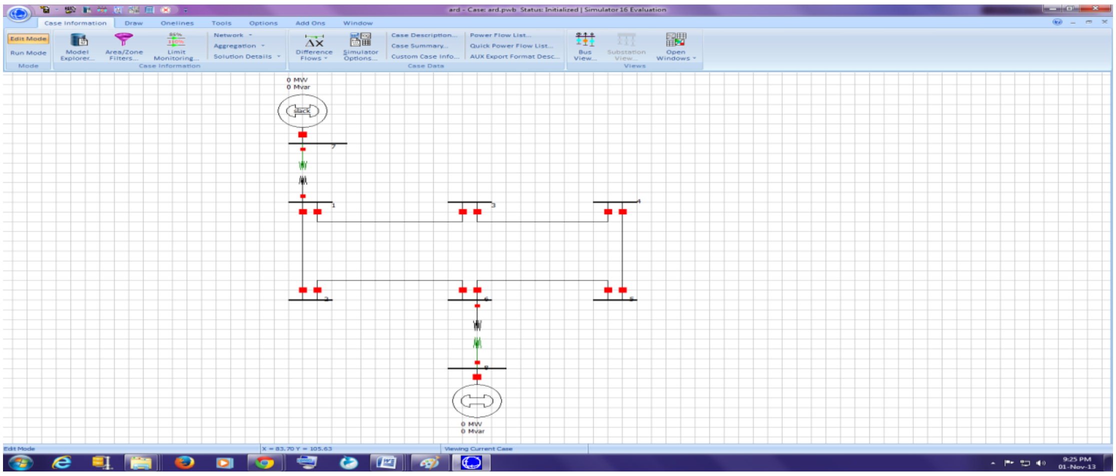
1. **For Clockwise Operation:**

Fault Current	Primary Relay	Backup Relay
F1	1	6
F2	6	5
F3	2	1
F4	3	2
F5	4	3
F6	5	4

2. **For Anticlockwise Operation:**

Fault Current	Primary Relay	Backup Relay
F1	9	10
F2	8	9
F3	10	11
F4	11	12
F5	12	13
F6	13	8

Fault Analysis:



The fault currents on each bus are calculated in power world software. The simulation and result obtained are as above.

FAULT CURRENT:

BUS NO.	FAULT CURRENT(A)
1	755.229
2	735.193
3	704.795
4	697.792
5	711.192
6	739.640

Fault current data

Calculation For Relay Coordination:

- **For Clockwise Operation:**

FIRST ITERARTION

Let TMS of R1=0.05

For Fault F1,Relays R1 act as primary and R6 as backup

PS of R6>1.3÷1.05 x PS of R1 > 1.3÷1.05x120

=148.571=61.9048% of 240

≈75% of 240

PSM of R1= F1÷(CTR1xPS of R1)

=755.229÷(240x0.5)=6.2936

PSM of R6= F1÷(CTR6xPS of R6

=755.229÷(240x0.75)=4.1957

Top R1=(TMS)R1 x 0.14÷((PSM of R1)^0.02-1)

=0.05x0.14÷((6.2936)^0.02-1) = 0.1868sec

Top R6=Top R1+0.3 = 0.1868+0.3 =0.4868sec

Top R6=(TMS)R6 x 0.14÷((PSM of R6)^0.02-1)

(TMS)R6=0.486x((4.1957)^0.02-1)÷0.14 =0.1

(TMS)R6=0.1012

For Fault F2,Relays R6 act as primary and R5 as backup

PS of R5>1.3÷1.05 x PS of R6 > 1.3÷1.05x180

=222.8571≈100% of 240

PSM of R6= F2÷(CTR6xPS of R6)

=735.193÷(240x0.75)=4.0844

PSM of R5= F2÷(CTR5xPS of R5)

=735.193÷(240x1)=3.0633

Top R6=(TMS)R6 x 0.14÷((PSM of R6)^0.02-1)

=0.1012x0.14÷((4.0848)^0.02-1) = 0.4962sec

Top R5=Top R6+0.3 = 0.4905+0.3 =0.7962sec

Top R5=(TMS)R5 x 0.14÷((PSM of R5)^0.02-1)

(TMS)R5=0.7962x((3.0633)^0.02-1)÷0.14 =0.1288

(TMS)R5=0.1288

For Fault F6,Relays R5 act as primary and R4 as backup

PS of R4>1.3÷1.05 x PS of R5 > 1.3÷1.05x240

=297.1429≈125% of 240

PSM of R5= F6÷(CTR5xPS of R5)

=739.640÷(240x1)=3.0818

PSM of R4= F6÷(CTR4xPS of R4)

=739.640÷(240x1.25)=2.4655

Top R5=(TMS)R5 x 0.14÷((PSM of R5)^0.02-1)

=0.1288x0.14÷((3.0818)^0.02-1) = 0.7919sec

Top R4=Top R5+0.3 = 0.7919+0.3 =1.0919sec

Top R4=(TMS)R4 x 0.14÷((PSM of R4)^0.02-1)

(TMS)R4=1.0919x((2.4655)^0.02-1)÷0.14 =0.1420

(TMS)R4=0.1420

For Fault F5,Relays R4 act as primary and R3 as backup

PS of R3>1.3÷1.05 x PS of R4 > 1.3÷1.05x300

=371.4286≈200% of 160

PSM of R4= F5÷(CTR4xPS of R4)

=711.192÷(240x1.25)=2.3706

PSM of R3= F5÷(CTR3xPS of R3)

=711.192÷(160x2)=2.2225

Top R4=(TMS)R4 x 0.14÷((PSM of R4)^0.02-1)

=0.1420x0.14÷((2.3706)^0.02-1) = 1.1420sec

Top R3=Top R4+0.3 = 1.1420+0.3 =1.4420sec

Top R3=(TMS)R3 x 0.14÷((PSM of R3)^0.02-1)

(TMS)R3=1.4420x((2.2225)^0.02-1)÷0.14 =0.1658

(TMS)R3=0.1658

For Fault F4,Relays R3 act as primary and R2 as backup

PS of R2>1.3÷1.05 x PS of R3 > 1.3÷1.05x320

=396.1905≈175% of 240

PSM of R3= F4÷(CTR3xPS of R3)

=697.792÷(160x2)=2.1806

PSM of R2= F4÷(CTR2xPS of R2)

=697.792÷(240x1.75)=1.6614

Top R3=(TMS)R3 x 0.14÷((PSM of R3^0.02-1)

=0.1658x0.14÷((2.1806)^0.02-1) = 1.4774sec

Top R2=Top R3+0.3 = 1.4774+0.3 =1.7774sec

Top R2=(TMS)R2 x 0.14÷((PSM of R2)^0.02-1)

(TMS)R2=1.4774x((1.6614)^0.02-1)÷0.14 =0.1296

(TMS)R2=0.1296

For Fault F3,Relays R2 act as primary and R1 as backup
PS of R1>1.3÷1.05 x PS of R2 > 1.3÷1.05x420
=216.6667≈200% of 240
PSM of R2= F3÷(CTR2xPS of R2)
=704.795÷(240x1.75)=1.6781
PSM of R1= F3÷(CTR1xPS of R1)
=704.795÷(240x2)=1.4683
Top R2=(TMS)R2 x 0.14÷((PSM of R2)^0.02-1)
=0.1296x0.14÷((1.6781)^0.02-1) = 1.7430sec
Top R1=Top R2+0.3 = 1.7430+0.3 =2.0430sec
Top R1=(TMS)R1 x 0.14÷((PSM of R1)^0.02-1)
(TMS)R1=2.0430x((1.4683)^0.02-1)÷0.14 =0.1125

(TMS)R1=0.1125

Similarly, We can calculate PSM and TMS of relays which are operating in the anticlockwise direction .And by solving the iterations as above, we can get the true value of TMS of all the relays acting as a primary and backup for clockwise and anticlockwise direction.

MATLAB PROGRAMMING:

MATLAB program Clockwise Operation:

1. **M-FILE:**

```
F1=755.229;
F2=735.193;
F3=704.795;
F4=697.792;
F5=711.190;
F6=739.640;
CTR1=240;
CTR2=240;
CTR3=160;
CTR4=240;
CTR5=240;
CTR6=240;
F=[F1;F2;F6;F5;F4;F3];
P=[CTR1;CTR6;CTR5;CTR4;CTR3;CTR2];
B=[CTR6;CTR5;CTR4;CTR3;CTR2;CTR1];
PSra= (50*CTR1)/100;%value
b=1;
TMSb=0.05;
for i=1:6
  PSRa=0.5;
  for a=1:6
     b=a;
    PSrb=1.3/1.05*(PSRa*(P(a,1))) %value
    PSRb=(100*PSrb)/(B(b,1)) %percentage
```

```
        f=PSRb;
        for p=2:1:8
          q=f/(p*25);
           if q<1
           break
           end
        end
        f=p*0.25
        PSMRa=(F(a,1))/((P(a,1))*PSRa)
        PSMRBb=(F(a,1))/((B(b,1))*f)
        PSRa=f
        topa=(TMSb*0.14)/(((PSMRa)^0.02)-1)
        topb=topa+0.3
        TMSb=topb*(((PSMRBb)^0.02)-1)/0.14
        TMSa=TMSb
        disp(TMSb)

    end
    TMSb=TMSa
end
```

2. OUTPUT:

(TMS)R1=0.1301

Similarly we can generate MATLAB Program for anticlockwise operation by changing the operating sequence of the relay in P and B matrixes shown in above program.

CONCLUSION

By solving the calculation as described above, we can get the true value of TMS of all the relays acting as a primary and backup for clockwise and anticlockwise direction. The MATLAB program shown here is the general program for n bus system. If any bus is added or removed from the system then only fault current value,C.T ratio and direction of relay operation will change and the values of PSM and TMS of the all the relays are directly calculated by this MATLAB program.

Future Scope: In future we do the link net structure of our above system and find the result on ETAP software.

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APPENDIX:

LINE CHARACTERISTICS

NODES	R1(Ω/km)	X1(Ω/km)	Length(km)
1-2	0.004	0.05	100
1-3	0.0057	0.0714	70
3-4	0.005	0.0563	80
4-5	0.005	0.045	100
5-6	0.0045	0.0409	110
2-6	0.0044	0.05	90
1-6	0.005	0.05	100

TRANSFORMER DATA

NODES	Sa(MVA)	Vp(kV)	Vi(kV)	X(%)
7-1	150	10	150	4
8-6	150	10	150	4

GENERATOR DATA

NODE	Sa(MVA)	Vp(kV)	X(%)
7	150	10	15
8	150	10	15

CT RATIO

RELAY NO.	RATIO
1	240
2	240
3	160
4	240
5	240
6	240
7	240
8	240
9	160
10	240
11	240
12	240
13	240