Module 4 : Overcurrent Protection

Lecture 16 : PSM Setting and Phase Relay Coordination (Tutorial)

Objectives

In this lecture we will solve tutorial problems for

- PSM setting and relay coordination for phase fault.
- Providing backup protection by time discrimination.
- Evaluating the performance of CTs and relays.
- Effect of fault type on CT burden.

16.1 PSM setting for primary and back-up protection

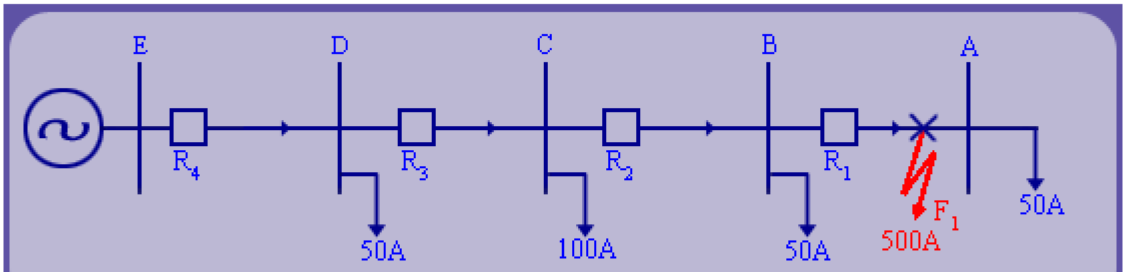

Fig 16.1 Radial system for Primary and Back up Overcurrent Protection

To explain intricacies of the problem, let us consider a radial system in the fig 16.1. Fault under consideration is a 3 - phase fault. Relays used have Normal Inverse, IEC standard characteristics. Coordination time interval CTI is 0.3sec. It is required that primary protection should fulfill its responsibility within 1.0sec of the occurrence of fault.

The relays along with Circuit Breaker are labeled as R_1, R_2, R_3, R_4. The bus loads and fault currents are tabulated in Table 1. It is obvious that pick up current settings for the relays should be above the feeder load currents and not the bus load currents. In fact, one should consider the maximum possible loading conditions, to decide conservatively pick-up current settings. A rule of thumb is to set the pick-up current at 1.25 times maximum load current. Another 'rule of thumb' is to limit pick-up current to $2/3^{rd}$ of the minimum fault current. This decides the range available for setting relay pick-up.

Table 2 details the calculations associated with setting of overcurrent relays. It shows both the minimum fault current and the maximum load current. Now ideally, one can set the pick up current of the overcurrent relay anywhere within the maximum feeder load current (column 2) and minimum fault current (column 3). However, as explained in the previous lecture, with electromechanical relays, we should not allow PSM to be below 1.5. Since $I_p = If_{min}/PSM$, upper limit on PSM sets lower limit on I_p, which is equal to $\left(\frac{2}{3}\right)\times If_{min}$ at PSM = 1.5. For example, pick up of relay R_1 can be set between 62.5 A to 167A. In this example, we choose pickup of R_1 to be 160A.

16.1 PSM setting for primary and back-up protection (contd..)

Table 1 : Data for Phase Relay Setting and Coordination			
Bus	Maximum Load	Minimum Fault Current	Maximum Fault Current
bus A	50	250	500
bus B	50	650	1200
bus C	100	1100	2000
bus D	50	1600	3500

Now to decide the pick-up current of relay R_2, it is not adequate to just look at the minimum fault current of section CB. This is because, relay R_2 also has to back up the section BA in case relay R_1 or the its CB or the associated circuitry fails. Hence, minimum fault current to be protected by relay R_2 is also 250 A. Now one can choose pick up current of R_2 to be equal to R_1. However, if we use same TMS setting for R_2 as R_1 then it leads to a serious conflict of interest between relays R_1 and R_2 with both of them competing to clear the fault. If R_1 clears the fault F_1 first, then there is absolutely no problem. But if R_2 clears the fault first then, there is an unwanted loss of service to load at node B. This brings out another additional requirement for relay R_2 *viz*. it should give preference to relay R_1 for faults on section BA. This can be achieved in two ways:

1. The relay R_1 sends a blocking signal to relay R_2.
2. Relay R_2 conservatively waits for a specified time for relay R_1 to act (time discrimination principle).

In the absence of the communication channel availability, alternative 2 is the only viable option.

16.2 Relay coordination for Phase fault Relay

In this example, we will use IEC - SI characteristic for all relays R_1 - R_4. Various steps of PSM setting are summarized in Table 2.

(1)	Used for evaluating TMS of R_2.
(2)	Used for evaluating TMS of R_3.
(3)	Used for evaluating TMS of R_4.

This interactive table works out the relay setting and coordination in fig 16.1. It is visualized by fig 16.2. The descriptive explanation of various steps follows:

Step 1

In this step, we will set relay R_1

Choose for relay R_1 TMS = 0.025. No intentional time delay is provided because R_1 does not have backup responsibility.

Relay 1 (R_1)

As explained before, pickup current of R_1 = 160A.

For fault on section AB (If_{max} = 500 A):

PSM = Fault Current / Actual Pick up = 500/160 = 3.125

TMS = 0.025

Operating time using IEC SI TCC.

$$t = 0.025\frac{(0.14)}{\{(3.125)^{0.02} - 1\}} = 0.15\text{sec}$$

The corresponding point 'a' is marked on fig 16.2 (step 1). Now, the back-up protection for section AB is given by relay 2. Setting of relay -2 is explained in the next step.

16.2 Relay coordination for Phase fault Relay (contd..)

Step 2

Relay 2 (R_2)

Let, Actual Pick up = 167 A. The PSM setting of R_2 has been already explained and summarized in row 2 of table 2.

We co-ordinate R_2 with R_1 for close in fault for relay R_1. This leads to large PSM. Other alternative would be to perform relay co-ordination at minimum fault current on remote feeder (If_{min}). However, co-ordination at If_{max} of remote feeder is preferred because it is observed that TCC for say TMS_1 and TMS_2 ($TMS_2 > TMS_1$) tend to come closer for large PSM. Conversely, as PSM reduces, they separate out. Thus, if we co-ordinate relays at large PSM, then co-ordination at lower values is automatically ascertained.

PSM = Fault Current / Actual Pick up = 500/167 = 2.99

Expected operating time for relay 2 = Operating time of relay 1+ CTI

= 0.15 + 0.3 = 0.45sec.

$$0.45 = TMS\frac{(0.14)}{\{(2.99)^{0.02} - 1\}}$$

TMS = 0.07

Now for maximum fault current on section BC (1200A)

PSM = Fault Current / Actual Pick up = 1200/167 = 7.185

with TMS = 0.07 operating time of relay 2

$$t = 0.07\frac{(0.14)}{\{(7.185)^{0.02} - 1\}}$$

Operating time of relay 2 = 0.24sec.

In the similar way all relays can be coordinated. Details of PSM setting are given in Table 1. Reader, should in an interactive mode single-step through the example in Table - 1. Similarly for TMS, readers should single step through fig 16.2.

It is clear that slowest relay in the system is R_4. To compute its worst case performance, we should evaluate its fault clearing time with minimum fault current at remote bus D for primary protection and bus C for backup protection.

Time of operation for fault current of 1600A (bus D) = 0.82sec.

Time of operation for fault current of 1100A (bus C) = 1.5sec.

Since primary protection is always cleared within 1sec, we can consider the protection system to be satisfactory.

16.2 Relay coordination for Phase fault Relay (contd..)

We have emphasized earlier that CT and PT play a critical role in determining performance of relaying system. We now evaluate their effect in performance of overcurrent relaying application.

16.3 Fault Type and CT burden

In the previous lectures on CT, we have discussed the effect of CT burden on the performance of CTs. But in real life application, in three phase CT connection, the burden on individual CTs will vary with the type of connection and the type of fault. This is summarized in Table 3.

Table 3 : **Fault Type and Its Effects on CT burden**

	Type of fault	
Connection	**3 - Phase or Phase to Phase**	**Phase to Ground**
Wye (connected at CT)	$Z = R_S + R_L + Z_R$	$Z = R_S + 2R_L + Z_R$
Delta (connected at CT)	$Z = R_S + 3R_L + 3Z_R$	$Z = R_S + 2R_L + 2Z_R$
Z	is the effective impedance seen by the CT	
R_S	is the CT secondary winding resistance and CT lead resistance; also includes any relay impedance that is inside the delta connection (ohms)	
R_L	is the circuit one-way lead resistance (ohms)	
Z_R	is the relay impedance in the CT secondary current path (ohms)	

Consider a three phase fault in Wye connected CT. For a three phase fault as shown in fig 16.3. $I_A + I_B + I_C = 0$, hence the current does not require an explicit return path. Therefore, only single lead wire resistance R_L is taken into account. Then effective impedance seen by CT, $Z = R_S + R_L + Z_R$.

Now, take the case of a phase to ground fault. Here, the fault current requires an explicit return path and hence the lead wire resistance R_L has to be doubled. Then the effective impedance seen by the CT, $Z = R_S + 2R_L + Z_R$.

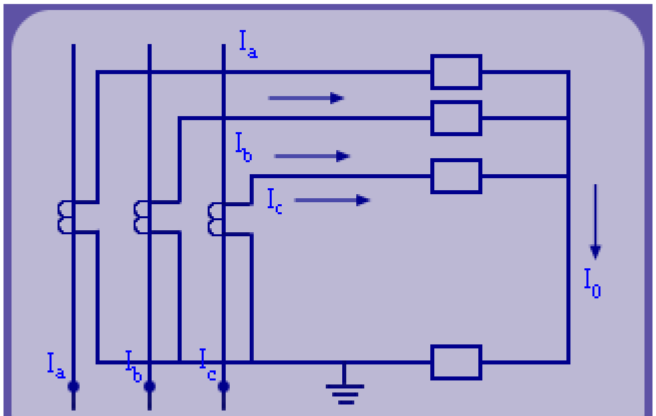

Fig 16.3 Three Phase Fault with Y Connected CT

Similar calculations for delta connected CTs are also shown in Table 3.

16.4 Example

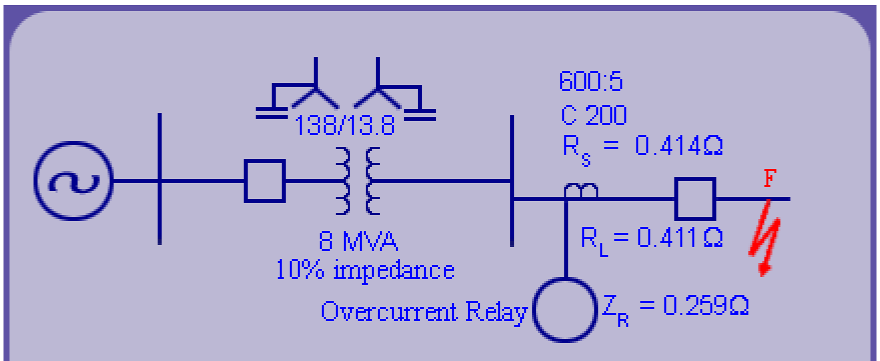

Fig 16.4 Bolted Three Phase Fault

1. A 8 MVA, 138/13.8 KV transformer is connected to an infinite bus. If a bolted three phase fault occurs at F, find out the fault current. The impedance of the transformer is 10% and location of the fault is close to the bus as shown in fig 16.4.
2. If the distribution feeder has 600/5 C 200 CT with a knee point 100 Volt, calculate the voltage developed across CT and comment on its performance. CT secondary resistance is 0.414 Ω.

Assume that (1) CTs are star connected (2) Lead wire resistance is 0.411 Ω and relay impedance is 0.259 Ω.

3. If the existing 8 MVA transformer is replaced with a new 28 MVA transformer with 10% leakage impedance, find out the
new fault current. Will this new fault current lead to CT saturation?
4. In case CT saturates, comment on the performance of
(a) Primary relay (b) back up relay (c) co-ordination between primary and back up relay pair.

Solution:

1. With 8 MVA transformer, Full load current $I_L = \dfrac{8000}{\sqrt{3}\times 13.8}$

= 334.7A
% Impedance of transformer X = 10

Fault current $I_{FL} = \dfrac{I_L}{\%X} = \dfrac{I_L \times 100}{10}$

$= \dfrac{334.7}{10}\times 100$
= 3347A

16.4 Example

Solution:

2. CT secondary current $= \dfrac{3347}{120} = 27.89A$ ($\because$ CT turns ratio = 600/5 = 120)

To obtain conservative estimate of CT performance we will use this value. This amounts to assuming bolted SLG fault current to be comparable to bolted 3 phase fault current. In comparison to three phase fault, CT phases larger burden with S-L-G fault.

CT burden for three phase fault,
Z_B = 0.414 + 0.414 + 0.259 = 1.084 Ω
For S-L-G fault it is
= 0.414 + (0.411 + 0.259) + (0.411 + 0.259) = 1.754 Ω
Effective impedance seen by the CT, Z = $R_S + 2R_L + Z_R$
= 0.414 + 2(0.411) + 0.259
= 1.495 Ω

$V_S = I_S \times Z$

$= 27.89 \times 1.495 = 41.7V$

Since the secondary voltage, V_S is less than knee point voltage the CT will not saturate.

3. When the 8 MVA transformer is replaced with similar 28 MVA transformer

Full load current = $\dfrac{28000 \times 10^3}{\sqrt{3} \times 13.8 \times 10^3} = 1171.5\text{A}$

New Fault current = 11715 A

CT secondary current $= \dfrac{11715}{120} = 97.6A$

$V_S = I_S \times Z$

= 97.6 × 1.754 = 171.19 V

Since, the knee point is 100 V the CT will saturate at 171.19 V.

4. Because of CT saturation, the secondary current will be clipped. Thus, CT secondary current will reduce. Hence, PSM will reduce and primary relay operation time will increase. This will slow down the operation of primary overcurrent relay. But typically, the back up relays in a radial system will have higher ratio CTs than the primary. Consequently, knee point voltage is also higher. This implies that the back up relay, which does not saturate can act before the primary since, these CTs are generally less likely to saturate. Hence, relay co-ordination may be lost.

This can be minimized by one of the following methods.

a. Additional co-ordination time can be included in the settings.
b. Set the instantaneous relay units below the current at which saturation begins.
c. Relays with less inverse time characteristics can be used upstream from the relay which has saturated CTs. This
ensures a greater time margin at high currents when saturation is more likely.

Review Questions

1. In a radial system if minimum fault current is less than or equal to maximum load current, can overcurrent relay be used?

Why?

2. How does CT saturation affect the performance of an overcurrent relay?

3. Calculate the burden on a delta connected CT for a three phase fault and S-L-G fault.

Recap

In this lecture we have learnt the following:

- Setting and coordination of relays in a radial system for phase faults.
- Effect of CT saturation on relay coordination.

- Fault type effects on CT burden.