Module 5 : Directional Overcurrent Protection

Lecture 19 : Directional Overcurrent Relay Coordination (Tutorial)

Objectives

In this lecture we will solve a tutorial on directional relay coordination and see that

- In a mesh system both clockwise and anticlockwise loops have to be coordinated separately.
- Directional relay coordination in a mesh system is iterative.
- The relay setting converges after a couple of iterations.

19.1 Introduction

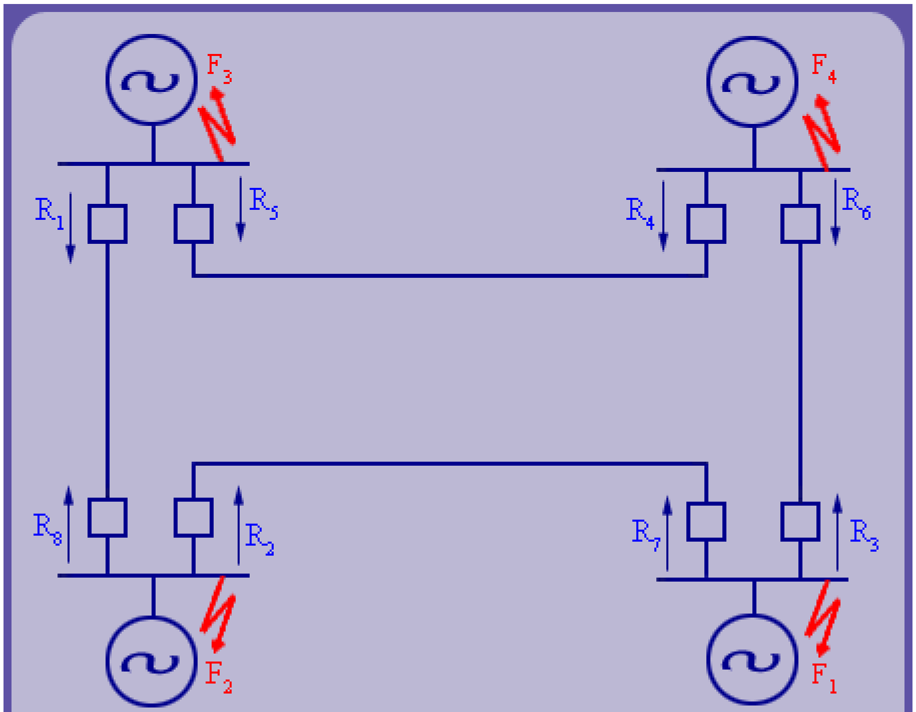

Fig 19.1 Relay Coordination in a Loop System

Coordination of directional overcurrent relays involves setting of relays one by one so that at each stage the relay coordinates with its primary relay. But in a loop as shown in fig 19.1, the last relay to be set is the very first, in which initial setting were assumed. This makes the relay coordination activity in a mesh system iterative. This should be contrasted with a radial system where the relay coordination is completed in one pass. The iterative nature of relay setting and coordination converges when on revisiting the same relay, if we do not have to change the relay settings and TMS.

As shown in fig 19.1, a typical transmission line is protected by directional relays at both ends. Hence we have to consider two loops, i.e. one loop formed in clockwise direction and the another in anticlockwise direction.

In this case clockwise loop is given by $R_5 \longrightarrow R_6 \longrightarrow R_7 \longrightarrow R_8 \longrightarrow R_5$ and anti clockwise loop is given by $R_1 \longrightarrow R_2 \longrightarrow R_3 \longrightarrow R_4 \longrightarrow R_1$ where arrow '$\longrightarrow$' should be read as 'backs up'.

Now, let us consider the anticlockwise loop for setting. We can start setting from any one of the four relays, i.e. R_1, R_2, R_3 and R_4. Let us start from R_2, i.e. setting in relay R_2 is assumed appropriately. Typically this implies that some value of TMS within the limits is taken. Limit points should be avoided at initial stage. PSM can be calculated using the guidelines outlined in the previous lectures. R_1 will be set to coordinate with R_2, since R_1 has to back up R_2. Now R_4 has to coordinate with R_1, R_3 with R_4 and R_2 with R_3. Thus we can see that the setting of R_2 has changed from what it was initially to coordinate with R_3. After first iteration, we update the setting of R_2 to the corresponding new setting, to coordinate with R_3, thus closing the loop. If the setting of the R_2 has changed significantly, then we repeat the above process by fine tuning the settings of all the relays in the loop again.

As every iteration improvises the relay settings (TMS), we expect the settings to converge in a few iterations. We have to repeat the same process with the clockwise loop also. Then all the relays will be set and relay coordination activity is complete.

19.2 Example

The following example will illustrate this process in detail. In the fig 19.1, the remote bus fault currents seen by each primary and back up relay pairs are tabulated below (Table 1).

Table 1 : Fault Current seen by Primary - Back up Relay Pairs				
	Anti clockwise loop		Clockwise loop	
Remote Bus Fault at	Current seen by primary relay	Current seen by back up relay	Current seen by primary relay	Current seen by back up relay
F_1	R_2 (639A)	R_1 (152A)	R_6 (1365A)	R_5 (272A)
F_2	R_1 (1652A)	R_4 (391A)	R_7(868A)	R_6 (240A)
F_3	R_4 (1097A)	R_3 (140A)	R_8 (1764A)	R_7 (287A)
F_4	R_3 (937A)	R_2 (142A)	R_5 (553A)	R_8 (197A)

For the relays in table 1, if the pick up values are as tabulated in table 2, find out the TMS.

Table 2 : Pick up Values of Relays								
Relay	R_1	R_2	R_3	R_4	R_5	R_6	R_7	R_8
Pick up setting (A)	60	80	60	160	80	160	128	100

19.2 Example (contd..)

Answer

We can assume relay setting for any one of the four relays. Let us start setting from relay R_2.

Iteration 1

For relay R_2, assume a TMS of 0.05 (Normal range is 0.025 to 1.2). The reason to initialize TMS to 0.05 and not the minimum value i.e. 0.025 is that further iterations may reduce TMS. If to begin with 0.025 then the problem becomes infeasible.
For fault at F_1 where R_2 acts as primary,

Time of operation of standard inverse relay, $t_{R_2} = \dfrac{TMS_{R_2} \times 0.14}{\left(I/_{Is}\right)^{0.02} - 1}$ (where Is = 80A, I = 639A)

$$= \frac{0.05 \times 0.14}{\left(639/_{80}\right)^{0.02} - 1}$$ = 0.165sec

For fault at F_1, R_1 will back up R_2.

Hence time of operation R_1 = t_{R_2} + CTI (where CTI is the coordination time interval and CTI = 0.3sec.)

= 0.165 + 0.3 = 0.465sec

i.e. $0.465 = \dfrac{TMS_{R_1} \times 0.14}{\left(I/_{Is}\right)^{0.02} - 1}$ (where I = 152A, Is = 60A)

$$= \frac{TMS_{R_1} \times 0.14}{\left(152/_{60}\right)^{0.02} - 1}$$

TMS_{R_1} = 0.0623

For fault at F_2, where R_1 acts as primary,

$$t_{R_1} = \frac{0.0623 \times 0.14}{\left(\frac{I}{Is}\right)^{0.02} - 1}$$ (where I = 1652A, Is = 60A)

= 0.127sec

19.2 Example (contd..)

Answer

Iteration 1 (contd..)

Relay R_4 will back up R_1 for fault at F_2. Hence, time of operation of R_4 = t_{R_1} + CTI = 0.127 + 0.3 = 0.427sec

i.e., $$0.427 = \frac{TMS_{R_4} \times 0.14}{\left(\frac{I}{Is}\right)^{0.02} - 1}$$ (where I = 391A, Is = 160A)

Then, TMS_{R_4} = 0.055

For fault at F_3, where R_4 acts as primary relay, we have

$$t_{R_4} = \frac{TMS_{R_4} \times 0.14}{\left(\frac{I}{Is}\right)^{0.02} - 1}$$ (where I = 1097A, Is = 160A)

= 0.196sec

Since relay R_3 has to back up R_4, time of operation of relay R_3 = t_{R_4} + CTI = 0.496sec

For a fault at F_3

i.e., $$0.496 = \frac{TMS_{R_3} \times 0.14}{\left(\frac{I}{Is}\right)^{0.02} - 1}$$ (where I = 140A, Is = 60A)

TMS_{R_3} = 0.0605

Now for fault at F_4, where R_3 acts as primary,

$$t_{R_3} = \frac{TMS_{R_3} \times 0.14}{\left(\frac{I}{Is}\right)^{0.02} - 1}$$ (where I = 937A, Is = 60A)

= 0.15sec

19.2 Example (contd..)

Answer

Iteration 1 (contd..)

For fault F_4, R_2 has to back up R_3

i.e., Time of operation of R_2 = t_{R_3} + CTI = 0.45sec

$$0.45 = \frac{TMS_{R_2} \times 0.14}{\left(\frac{I}{Is}\right)^{0.02} - 1}$$ (where I = 142A, Is = 80A)

TMS_{R_2} = 0.037

We had assumed a value of 0.05 for TMS_{R_2}, but now the value has changed to 0.037. Therefore, let us update the TMS of R_2 to 0.037.

Iteration 2

Repeating the same process as above,

For fault at F_1, time of operation $t_{R_2} = \dfrac{0.037 \times 0.14}{\left(639/80\right)^{0.02} - 1}$

= 0.122sec

Time of operation of R_1 = t_{R_2} + CTI

= 0.3 + 0.122 = 0.422sec

i.e., $0.422 = \dfrac{TMS_{R_1} \times 0.14}{\left(152/60\right)^{0.02} - 1}$ or TMS_{R_1} = 0.0565

For fault at F_2, where R_1 acts as primary,

$t_{R_1} = \dfrac{0.0565 \times 0.14}{\left(1652/60\right)^{0.02} - 1}$ = 0.1154

R_4 backs up R_1 for fault at F_2

19.2 Example (contd..)

Answer

Iteration 2 (contd..)

Time of operation of R_4 = t_{R_1} + CTI = 0.1154 + 0.3

= 0.4154

i.e. $0.4154 = \dfrac{TMS_{R_4} \times 0.14}{\left(391/160\right)^{0.02} - 1}$

TMS_{R_4} = 0.0535

Now, for fault at F_3, where R_4 acts as primary,

$t_{R_4} = \dfrac{0.0535 \times 0.14}{\left(1097/160\right)^{0.02} - 1}$ = 0.191sec

Since, relay R_3 backs up R_4, time of operation of relay R_3 = t_{R_4} + CTI = 0.191 + 0.3 = 0.491

i.e. 0.491 = $\dfrac{TMS_{R_3} \times 0.14}{\left(140/60\right)^{0.02} - 1}$

TMS_{R_3} = 0.0599

For fault at F_4, where R_3 acts as primary,

Time of operation $t_{R_3} = \dfrac{0.0599 \times 0.14}{\left(937/60\right)^{0.02} - 1}$ = 0.1484sec

R_2 backs up R_3; Therefore,

Time of operation of R_2 = t_{R_3} + CTI = 0.3 + 0.1484

= 0.4484sec

i.e. $0.4484 = \dfrac{TMS_{R_2} \times 0.14}{\left(142/80\right)^{0.02} - 1}$

TMS_{R_2} = 0.0369

Now, let us update the TMS of R_2 to this new value, i.e., 0.0369 and repeat iteration.

19.2 Example (contd..)

Answer

Iteration 3

For fault at F_1, $t_{R_2} = \frac{0.0369 \times 0.14}{\left(639/80\right)^{0.02} - 1}$

= 0.1217sec

For relay R_1, which has to back up R_2

Time of operation = 0.3 + 0.1217 = 0.4217sec

i.e. $0.4217 = \frac{TMS_{R_1} \times 0.14}{\left(152/60\right)^{0.02} - 1}$

TMS_{R_1} = 0.0565

Then for fault at F_2, $t_{R_1} = \frac{0.0565 \times 0.14}{\left(1652/60\right)^{0.02} - 1}$ = 0.1154sec

Since R_4 backs up R_1, time of operation of R_4

= 0.1154 + 0.3 = 0.4154sec

i.e. $0.4154 = \frac{TMS_{R_4} \times 0.14}{\left(391/160\right)^{0.02} - 1}$

TMS_{R_4} = 0.0535

For fault at F_3, where R_4 acts as primary, we have

$t_{R_4} = \frac{0.0535 \times 0.14}{\left(1097/160\right)^{0.02} - 1}$ = 0.191sec

19.2 Example (contd..)

Answer

Iteration 3 (contd..)

R_3 backs up R_4

Time of operation of R_3 = 0.3 + 0.191 = 0.491sec

i.e. 0.491 = $\frac{TMS_{R_3} \times 0.14}{\left(140/60\right)^{0.02} - 1}$

TMS_{R_3} = 0.0599

For fault at F_4, $t_{R_3} = \frac{0.0599 \times 0.14}{\left(937/60\right)^{0.02} - 1}$

= 0.1484sec

Now R_2 backs up R_3

i.e. time of operation of R_2 = 0.3 + 0.1484 = 0.4484 $= \frac{TMS_{R_2} \times 0.14}{\left(142/80\right)^{0.02} - 1}$

TMS_{R_2} = 0.0369 which is same as the result of iteration 2.

Therefore no more iteration is required. Hence, setting and coordination of all the four anticlockwise relays are complete.

Coordination of all primary and back up relay pairs R_2 - R_1, R_1 - R_4, R_4 - R_3 and R_3 - R_2 for faults at F_1, F_2, F_3 and F_4 respectively are visualized in fig 19.2.

19.2 Example (contd..)

Answer

Iteration 3

For fault at F_1, $t_{R_2} = \dfrac{0.0369 \times 0.14}{\left(639/80\right)^{0.02} - 1}$

= 0.1217sec

For relay R_1, which has to back up R_2

Time of operation = 0.3 + 0.1217 = 0.4217sec

i.e. $0.4217 = \dfrac{TMS_{R_1} \times 0.14}{\left(152/60\right)^{0.02} - 1}$

TMS_{R_1} = 0.0565

Then for fault at F_2, $t_{R_1} = \dfrac{0.0565 \times 0.14}{\left(1652/60\right)^{0.02} - 1}$ = 0.1154sec

Since R_4 backs up R_1, time of operation of R_4

= 0.1154 + 0.3 = 0.4154sec

i.e. $0.4154 = \dfrac{TMS_{R_4} \times 0.14}{\left(391/160\right)^{0.02} - 1}$

TMS_{R_4} = 0.0535

For fault at F_3, where R_4 acts as primary, we have

$t_{R_4} = \dfrac{0.0535 \times 0.14}{\left(1097/160\right)^{0.02} - 1}$ = 0.191sec

19.2 Example (contd..)

Answer

Iteration 3 (contd..)

R_3 backs up R_4

Time of operation of R_3 = 0.3 + 0.191 = 0.491sec

i.e. 0.491 = $\dfrac{TMS_{R_3} \times 0.14}{\left(140/60\right)^{0.02} - 1}$

TMS_{R_3} = 0.0599

For fault at F_4, $t_{R_3} = \dfrac{0.0599 \times 0.14}{\left(937/60\right)^{0.02} - 1}$

= 0.1484sec

Now R_2 backs up R_3

i.e. time of operation of R_2 = 0.3 + 0.1484 = 0.4484 $= \dfrac{TMS_{R_2} \times 0.14}{\left(\frac{142}{80}\right)^{0.02} - 1}$

TMS_{R_2} = 0.0369 which is same as the result of iteration 2.

Therefore no more iteration is required. Hence, setting and coordination of all the four anticlockwise relays are complete.
Coordination of all primary and back up relay pairs R_2 - R_1, R_1 - R_4, R_4 - R_3 and R_3 - R_2 for faults at F_1, F_2, F_3 and F_4 respectively are visualized in fig 19.2.

19.2 Example (contd..)

19.2 Example (contd..)

Answer

Setting and Coordination of Clockwise Relays

Iteration 1

Now let us start setting all the clockwise relays. Let us start from relay R_5 for fault at F_4.

Assume a TMS of 0.05 for relay R_5. Then, time of operation of relay R_5, $t_{R_5} = \dfrac{0.05 \times 0.14}{\left(\frac{553}{80}\right)^{0.02} - 1} = 0.1775$

i.e. Time of operation of back up relay R_8 = t_{R_5} + CTI

= 0.1775 + 0.3
= 0.4775sec

Now, 0.4775 = $\dfrac{TMS_{R_8} \times 0.14}{\left(\frac{197}{100}\right)^{0.02} - 1}$

= 0.04656

TMS_{R_8}

For a fault at F_3, where R_8 acts as primary,

$$t_{R_8} = \frac{0.0465 \times 0.14}{\left(1764/100\right)^{0.02} - 1} = 0.11\text{sec}$$

Now relay R_7 will back up R_8. Then time of operation of R_7 = 0.11 + 0.3 = 0.41sec

i.e., $0.41 = \dfrac{TMS_{R_7} \times 0.14}{\left(287/128\right)^{0.02} - 1}$

TMS_{R_7} = 0.0477

R_7 acts as primary relay for fault at F_2.

$$t_{R_7} = \frac{0.0477 \times 0.14}{\left(868/128\right)^{0.02} - 1} = 0.1711\text{sec}$$

19.2 Example (contd..)

Answer

Setting and Coordination of Clockwise Relays

Iteration 1 (contd..)

R_6 backs up R_7,
i.e. Time of operation for R_6
= 0.1711 + 0.3 = 0.4711

i.e. $0.4711 = \dfrac{TMS_{R_6} \times 0.14}{\left(240/160\right)^{0.02} - 1}$

TMS_{R_6} = 0.0274

For fault at F_1, R_6 acts as primary,

i.e., $t_{R_6} = \dfrac{0.0274 \times 0.14}{\left(1365/160\right)^{0.02} - 1}$ = 0.0875sec

R_5 backs up R_6
i.e. Time of operation of R_5 = 0.0875 + 0.3 = 0.3875

i.e., $0.3875 = \dfrac{TMS_{R_5} \times 0.14}{\left(272/80\right)^{0.02} - 1}$

TMS_{R_5} = 0.0686

i.e. after 1st iteration TMS of R_5 has been changed from 0.05 to 0.0686. Let us update TMS of R_5 to 0.0686 and begin iteration 2.

19.2 Example (contd..)

Answer

Setting and Coordination of Clockwise Relays

Iteration 2

TMS_{R_5} = 0.0686

For fault F_4, = 0.2436

$$t_{R_5} = \frac{0.0686 \times 0.14}{\left(553/80\right)^{0.02} - 1}$$

For fault at F_4, R_8 backs up R_5

i.e. Time of operation of R_5 = t_{R_5} + CTI = 0.2436 + 0.3

= 0.5436sec

i.e. 0.5436 = $\frac{TMS_{R_8} \times 0.14}{\left(197/100\right)^{0.02} - 1}$

TMS_{R_8} = 0.053

For fault F_3, where R_8 acts as primary,

$t_{R_8} = \frac{0.053 \times 0.14}{\left(1764/100\right)^{0.02} - 1}$ = 0.1256sec

Relay R_7 backs up R_8

Time of operation of R7 = 0.1256 + 0.3 = 0.4256sec

i.e. 0.4256 $= \frac{TMS_{R_7} \times 0.14}{\left(287/128\right)^{0.02} - 1}$

TMS_{R_7} = 0.0495

19.2 Example (contd..)

Answer

Setting and Coordination of Clockwise Relays

Iteration 2 (contd..)

For fault at F_2, R_7 acts as primary,

i.e. $t_{R_7} = \frac{0.0477 \times 0.14}{\left(868/128\right)^{0.02} - 1}$ = 0.1776sec

R_6 backs up R_7,

i.e. Time of operation for R_6 = 0.1776 + 0.3 = 0.4776sec

i.e. 0.4776 $= \frac{TMS_{R_6} \times 0.14}{\left(240/160\right)^{0.02} - 1}$

TMS_{R_6} = 0.0278

For fault at F_1, R_6 acts as primary,

i.e. $t_{R_6} = \frac{0.0278 \times 0.14}{\left(1365/160\right)^{0.02} - 1}$ = 0.0888sec

R_5 backs up R_6,

i.e. Time of operation of R_5 = 0.0888 + 0.3

= 0.3888sec

i.e. 0.3888 $= \frac{TMS_{R_5} \times 0.14}{\left(272/80\right)^{0.02} - 1}$

TMS_{R_5} = 0.0688

Now let us set TMS of R_5 to 0.0688 and repeat iteration.

19.2 Example (contd..)

Answer

Setting and Coordination of Clockwise Relays

Iteration 3

TMS_{R_5} = 0.0688

For fault at F_4 $t_{R_5} = \dfrac{0.0688 \times 0.14}{\left(553/80\right)^{0.02} - 1}$ = 0.2443

R_8 backs up R_5,

i.e. Time of operation of R_8 = t_{R_5} + CTI = 0.2443 + 0.3

= 0.5443sec

$$0.5443 = \frac{TMS_{R_8} \times 0.14}{\left(197/100\right)^{0.02} - 1}$$

i.e. TMS_{R_8} = 0.0531

For fault at F_3, R_8 acts as primary,

Then $t_{R_8} = \dfrac{0.0531 \times 0.14}{\left(1764/100\right)^{0.02} - 1}$ = 0.1258sec

Relay R_7 backs up R_8

i.e. Time of operation of R_7 = 0.3 + 0.1258 = 0.4258sec

$$0.4258 = \frac{TMS_{R_7} \times 0.14}{\left(287/128\right)^{0.02} - 1}$$

TMS_{R_7} = 0.0495

19.2 Example (contd..)

Answer

Setting and Coordination of Clockwise Relays

Iteration 3 (contd..)

For fault at F_2, R_7 acts as primary,

i.e. $t_{R_7} = \dfrac{0.0495 \times 0.14}{\left(868/128\right)^{0.02} - 1}$ = 0.1776sec

R_6 backs up R_7, Time of operation of R_6,

= 0.3 + 0.1776 = 0.4776sec

i.e. $0.4776 = \dfrac{TMS_{R_6} \times 0.14}{\left(240/160\right)^{0.02} - 1}$

TMS_{R_6} = 0.0278

For fault at F_1, R_6 acts as primary,

$t_{R_6} = \dfrac{0.0278 \times 0.14}{\left(1365/160\right)^{0.02} - 1}$ = 0.0888sec

Since R_5 backs up R_6 for fault at F_1, time of operation of R_5 = 0.3 + 0.0888sec = 0.3888sec i.e., $0.3888 = \frac{TMS_{R_5} \times 0.14}{\left(272/80\right)^{0.02} - 1}$

TMS_{R_5} = 0.0688.

Since, the result of iterations 2 and 3 are the same, the iteration is complete. Thus, all the clockwise relays are set. The settings are tabulated in table 3. Coordination of all clockwise relay pairs R_6 - R_5, R_7 - R_6, R_8 - R_7 and R_5 - R_8 for faults at F_1, F_2, F_3 and F_4 are visualized in fig 19.3.

19.2 Example (contd..)

19.2 Example (contd..)

Answer

Setting and Coordination of Clockwise Relays

Table 3 TMS Setting for Relay

Relay	1st Iteration	2nd Iteration	3rd Iteration
R_1	0.623	0.0565	0.0565
R_2	0.05	0.0369	0.0369
R_3	0.0605	0.0599	0.0599
R_4	0.055	0.0535	0.0535
R_5	0.05	0.0686	0.0688
R_6	0.0274	0.0278	0.0278
R_7	0.0477	0.0495	0.0495
R_8	0.04656	0.053	0.0531

Review Questions

1. Explain the process of the directional relay coordination in a mesh system.

2. In the given example if the standard inverse relays are replaced with very inverse relays. Find out whether relay coordination is achievable and comment on the selection of relays.

3. Develop a program for the given example.

Recap

In this lecture we have learnt the following:

- The directional relay coordination problem in a meshed system.

- In a meshed system both clockwise and anticlockwise loops have to be considered separately.