

Module 4 : Overcurrent Protection

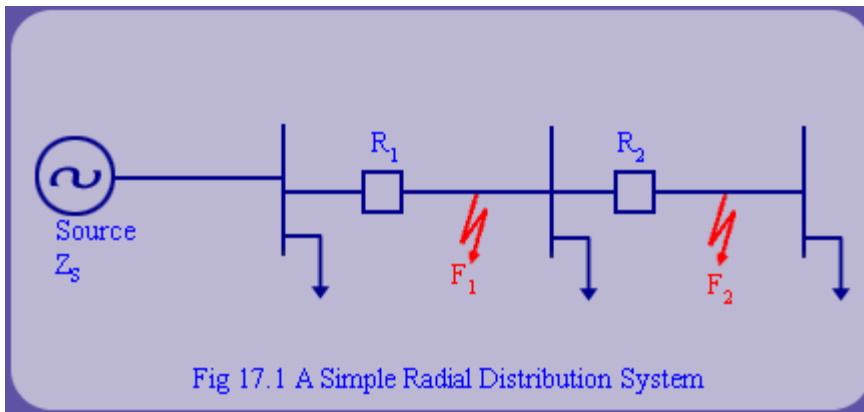
Lecture 17 : Earth Fault Protection using Overcurrent Relays

Objectives

In this lecture, we will learn

- Overcurrent protection against earth faults.
- Relay coordination for earth fault relays.
- Need for adaptive relaying.
- Automatic reclosing.

17.1 Earth-fault Relays



Earth-fault relay is used to protect feeder against faults involving ground. Typically, earth faults are single line to ground and double line to ground faults. For the purpose of setting and coordination, only single line to ground faults are considered.

Consider a radial system as shown in fig 17.1. For a fault near the source, the maximum fault current for a-g fault is given

$$\text{by } I_{Fa} = \frac{3E}{Z_{S1} + Z_{S2} + Z_{S0}}$$

If we model the utility system with identical values for all the sequence impedances then, $I_{Fa} = \frac{E_1}{Z_{S1}}$. This

value is identical to the bolted three phase fault current. If however, $Z_{S0} < Z_{S1}$ then the bolted single line to ground fault current can be higher than the three phase fault current. As we move away from the source, for a bolted fault, fault current reduces due to larger feeder impedance contribution to the denominator. Since, for a feeder, zero sequence impedance can be much higher than the positive or negative sequence impedance, it is apparent that fault current for bolted fault reduces significantly as we go away from source. Thus, as we go away from the source, the bolted three phase fault current will be higher than corresponding ground fault current as it does not depend upon zero sequence impedance of the feeder. In addition, if the single line to ground fault has an impedance Z_F , then the fault current can

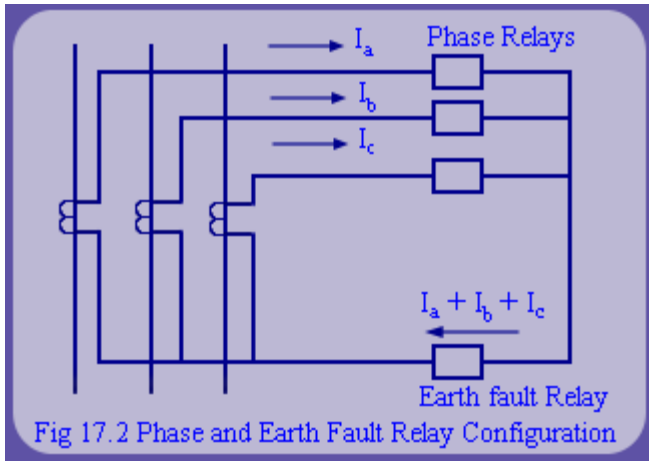
fall even below the bolted a-g fault value, $I_{Fa} = \frac{3E}{Z_{1eq} + Z_{2eq} + Z_{0eq} + 3Z_F}$. In contrast, for a balanced

system, three phase fault current is independent of the value of Z_F .

17.1 Earth-Fault Relays (contd..)

Thus, we conclude that there can be significant variation in the earth fault current values. They can be even below the load current due to large impedance to ground. Hence, to provide sensitive protection, earth fault relays use zero sequence current rather than phase current for fault detection. Note that the zero sequence component is absent in normal load current or

phase faults. Hence, pickup with zero sequence current can be much below the load current value, thereby providing sensitive earth fault protection. In what follows, we will discuss the setting and coordination of earth fault relays.



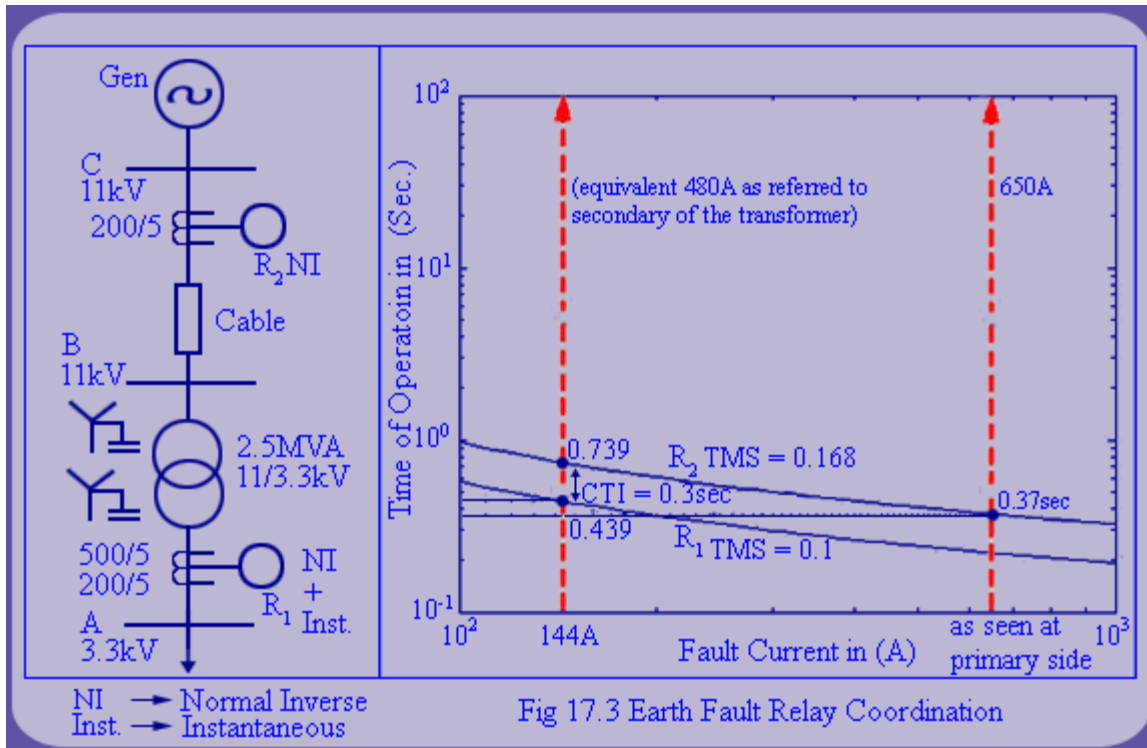
In practice, distribution systems are inherently unbalanced. Thus, load current would also have a small percentage of zero sequence due to unbalance. Hence, it is mandatory to keep the pick up current above the maximum unbalance expected under normal conditions.

A rule of thumb is to assume maximum unbalance factor to be between 5 to 10%.

It should be also observed that earth fault relays will not respond to the three phase or line to line faults. One earth fault relay is adequate to provide protection for all types of earth fault (a-g, b-g, c-g, a-b-g etc). Three phase relays are required to provide protection against phase faults (three phase, a-b, b-c, c-a). Thus with four relays as shown in fig 17.2 complete overcurrent protection can be provided.

17.2 Relay Co-ordination for Earth-fault Relay

Example



Consider a feeder as shown in fig 17.3 with earth fault relays R_1 and R_2 . Relay R_1 is used for providing protection against earth fault at the secondary side of 2.5MVA, 11/3.3kV transformer, whereas, relay R_2 has to provide protection at bus B. Two CTs are used for protection. 200:5 CT is connected to instantaneous relay and 500:5 is connected to inverse current characteristic relay.

Compute the setting of instantaneous and standard inverse units at relay at R_1 . Assume that

- 1) maximum system unbalance is 20% and
- 2) SLG fault current at bus A is 480 A and at bus B it is 650A.
- 3) Compute the time required by relay R_2 to clear SLG fault at bus B.

Use coordination time interval (CTI) of 0.3sec.

17.3 Relay Co-ordination for Earth-fault Relay (contd..)

Example

a) Setting of Relay R₁

Since the relay is on secondary side of transformer, our calculations will be referred to secondary side. From fig 17.3,

Full load secondary current of 2.5MVA transformer = $\frac{2.5 \times 10^6}{\sqrt{3} \times 3300} = 437A$. Earth fault relay should not

pick up for the unbalance current 20% of 437A = 87.47A. Hence choose a pick up value of 100A. Thus, instantaneous relay will pick up at $100 \times 5 / 200 = 2.5A$

Typical range available for setting is 1-4A. We choose the pick up at 3A.

If standard inverse relay is also set to pick up at the same current in primary, which is 100A, then with 500:5 CT, pick up current of relay R₁ referred to secondary is 1A.

Since R₁ has no back up responsibility, we choose its TMS to minimum, i.e. 0.1.

Now, for a L-G fault current of 480A at bus A,

PSM for R₁ = fault current / actual pick up = 480/100 = 4.8.

From standard inverse TCC,

Time of operation of earth fault relay R₁, $TR_1 = TMS \times \frac{0.14}{(PSM)^{0.02} - 1} = 0.439\text{sec.}$

b) Setting of Relay R₂

The coordination time interval, CTI = 0.3 sec.

Then time of operation of earth fault relay R₂, which has to provide back up protection to bus A = 0.439 + 0.3 = 0.739sec

Since this relay is on primary side of transformer, our calculations will be now referred to primary side.

Full load current at primary side of transformer = $\frac{2.5 \times 10^6}{\sqrt{3} \times 11000} = 131.2A$

R₂ should not trip for the unbalance current. i.e. 20% of full load current = 26A.

Let us, choose safely the pick up value to be 30A.

Pick up current of R₂ referred to secondary of 200:5 CT = $30 \times 5 / 200 = 0.75A$.

Fault current of 480A referred to 11kV side = $480 \times 3.3/11 = 144A$.

PSM for NI current = 144/30 = 4.8.

Desired time of operation of earth fault relay R₂, $TR_2 = TR_1 + CTI = 0.439 + 0.3 = 0.739\text{sec}$

Substituting in equation, $TR_2 = TMS \times \frac{0.14}{(PSM)^{0.02} - 1}$, we will get TMS of relay R₂ = 0.168.

PSM for a fault current of 650A at bus B = 650/30 = 21.67.

Substituting in equation, $TR_2 = TMS \times \frac{0.14}{(PSM)^{0.02} - 1}$, time of operation for relay R₂ = 0.37sec.

The results are visualized in fig 17.3.

17.3 Adaptive Relaying in Overcurrent Protection

We now briefly introduce the concept of adaptive relaying. Adaptive relaying is a protection scheme in which settings can adapt to the system conditions automatically, so that relaying is tuned to the prevailing power system conditions. Traditionally, relaying settings are computed conservatively. For example, in overcurrent fault protection, one would like to choose pick-up current to be above the maximum possible load current and below minimum possible fault current. Sometimes, it may be quite difficult to obtain such 'comfort zones' for relay settings. If one accepts that load currents vary significantly from 'light loads' to 'peak load' conditions, one can increase 'sensitivity' of an overcurrent relay under light load conditions by safely reducing corresponding overcurrent pick up value. Such adjustments makes relaying 'adaptive'.

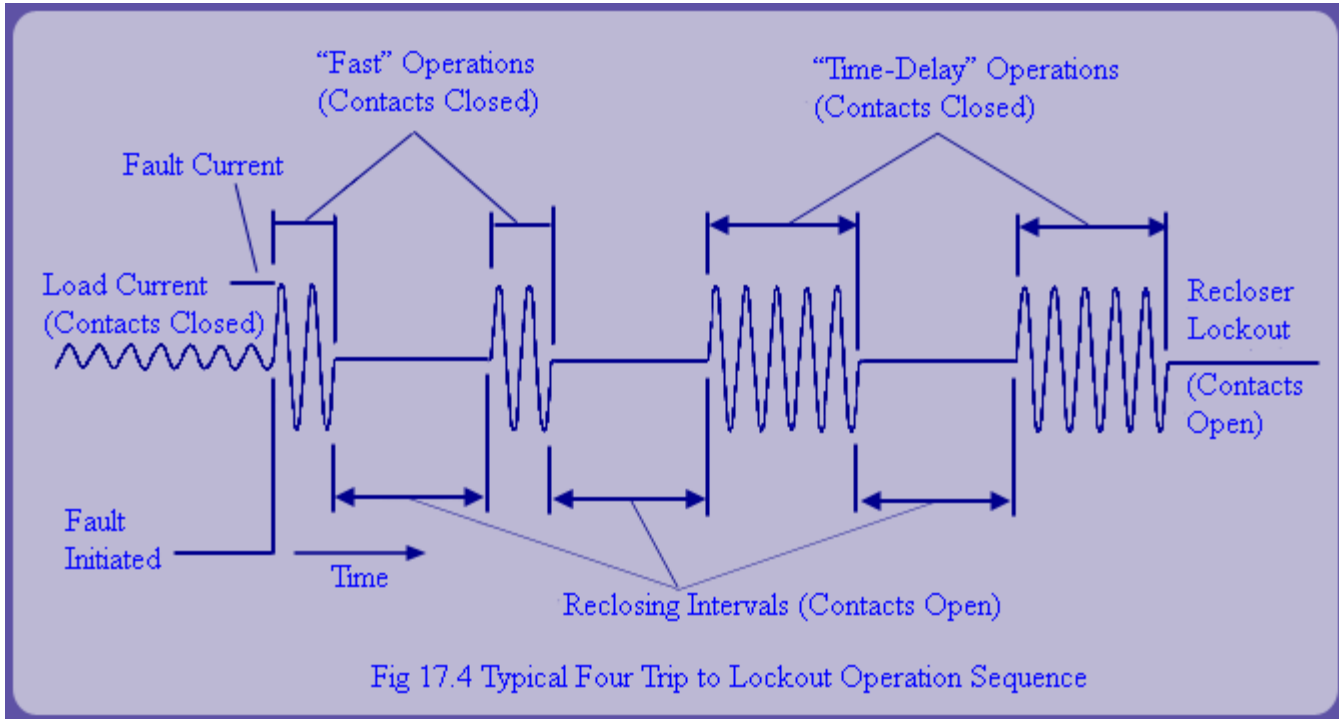
In the present era, generation is being added to the distributed system directly. This also changes the fault level in the system directly. Presence or absence of grid and/or distributed generator will alter fault current levels drastically, and it would be impossible to achieve a single acceptable setting for distributed generators. However, if for example, overcurrent relay could be made aware through communication that grid and/or DG is connected, it could choose the settings from a set of present values and 'adaptive' to new load condition. Adaptive protection has not yet realized its full potential, and hence provides new

opportunities for bright and innovative research in relaying.

17.4 Automatic Reclosing

Many faults (80-90%) in the overhead distribution system like flash over of insulators, crow faults, temporary tree contacts, etc are temporary in nature. Thus, taking a feeder or line permanent outage may lead to unnecessary long loss of service to customers. Hence, many utilities use fast automatic reclosers for an overhead radial feeder without synchronous machines or with minimum induction motor load. Presence of synchronous machines will require additional problem of synchro-check to be addressed. The almost universal practice is to use three and occasionally four attempts to restore service before lock out (see fig 17.4).

17.4 Automatic Reclosing (contd..)



Subsequently, energization is by manual intervention. The initial reclosure can be high speed (0.2 - 0.5sec) or delayed for 3 - 5 seconds. This allows for de-ionization time for fault arc. If the temporary fault is cleared, then the service is restored. Otherwise, the relay again trips the feeder. Then one or two additional time delayed reclosures are programmed on the reclosing relay. Typical schedule might be instantaneous, followed by 30sec, or 35sec, followed by 15sec. If the circuit still continues to trip, the fault is declared as permanent and the recloser is locked out. Reclosers use three phase and single phase oil or vacuum circuit breakers for overhead distribution lines.

With underground network, faults tend to be more often permanent and reclosers are not recommended. In case of large synchronous motors, distributed generators or induction motor loads, it is recommended that sufficient time is allowed for underfrequency relays to trip these sources of back emf out-of-the-circuit.

17.4 Automatic Reclosing (contd..)

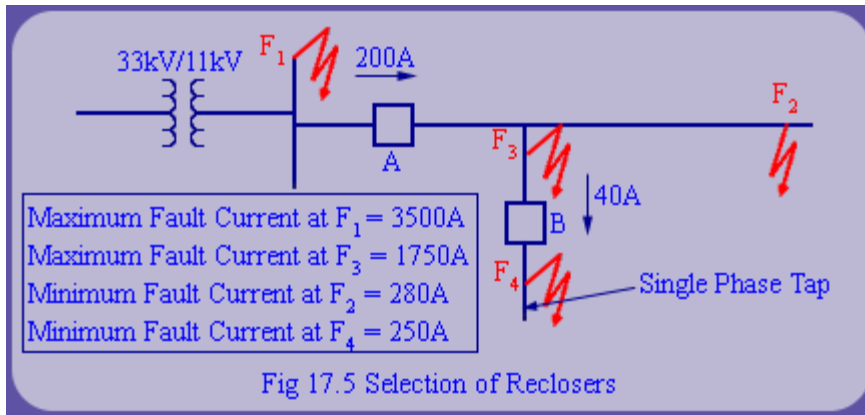
Application of reclosers in distribution systems requires selection of its ratings such as minimum trip current, continuous current, symmetrical interrupting current etc.

For a single phase system, single phase reclosers can be used whereas for a three phase system, one three phase recloser or three single phase reclosers can be used. Reclosers have to be selected by considering the following factors.

- Voltage Rating.
- Continuous current Rating : This is the maximum load current the recloser has to carry.
- Maximum Symmetrical Interrupting Rating: The maximum symmetrical fault current should not exceed this rating.
- Minimum Tripping current : This is the minimum fault current that a recloser will clear. It is equal to two times the continuous current rating. Usually tolerance is $\pm 10\%$. This decides the sensitivity of the recloser.

The following example will explain the selection of reclosers in a simple distribution system.

Example



Consider a three phase distribution system with a single phase tap as shown in fig 17.5. Maximum load on this single phase line is 40A and that on three phase line is 200A. Fault currents at F_1, F_2, F_3 and F_4 are also shown in the fig 17.5. Table 1 shows the available standard rating of single phase and three phase reclosers. Select the ratings of reclosers at A and B.

17.4 Automatic Reclosing (contd..)

Example

Answer

Recloser at B

Maximum load current on this single phase line = 40A.

Continuous current rating of this recloser must be 1.25 - 1.5 times the maximum load current to account for anticipated load growth.

i.e. Continuous current rating of this recloser at B = $40 \times 1.5 = 60A$.

From the table 1, any recloser with continuous current rating of 100A and above is acceptable.

Maximum fault current at B = 1750A.

Interrupting current rating must be greater than 1750A. From the table 1, we see that recloser with 100A continuous current rating has 2000A symmetrical rms short circuit current rating. Hence, we can choose this recloser.

Minimum tripping current = Continuous current rating $\times 2 \pm 10\%$ tolerance
 = $100 \times 2 \pm 10\%$ of 100 = 220A

Since the minimum trip current 220A is less than the minimum fault current 250A at the line end, it can protect the entire line.

Voltage rating of the line is 11kV. So we can select the maximum voltage rating of 15.5kV (from the table).

Recloser at A

This recloser has to protect the three phase line. Hence a three phase recloser can be used here.

Maximum load current in this line = 200A.

Hence continuous rating of recloser at A = $200 \times 1.25 = 250A$.

From the table let us choose recloser with a continuous rating of 280A.

Maximum fault current at A = 3500A.

From the table, symmetrical interrupting capability of recloser A with 280A continuous rating is 4000A which is more than maximum fault current of 3500A. Hence, this recloser meets our requirements.

Minimum tripping current = Continuous current rating $\times 2 \pm 10\%$ tolerance
 = $280 \times 2 \pm 10\%$ of 560 = 616A.

Since the minimum fault current at the end of this line is 280A, recloser at A cannot protect the entire line. Hence, in order to increase sensitivity ground relay can be added here.

17.4 Automatic Reclosing (contd..)

Example

Answer

Table 1 (Source : IEEE Tutorial Course 80EH0157 - 8 - PWR)

	Rated Maximum Voltage kV rms	Current Rating (Amperes)	
		Continuous Current Rating	Symmetrical Interrupting Rating at Maximum Volts
Single Phase Reclosers	15.0	50	1250
	15.5	100	2000
	15.5	280	4000
	15.5	560	8000
	27.0	100	2500
	27.0	280	4000
	38.0	560	8000
Three Phase Reclosers	15.0	50	1250
	15.5	100	2000
	15.5	280	4000
	15.5	400	4000
	15.5	560	8000
	15.5	560	16000

Review Questions

1. Give reasons:
 - (a) The magnitude of earth fault current can vary over a wide range.
 - (b) The fault current for bolted S-L-G fault reduces as we go away from source.
2. What is meant by adaptive relaying?
3. Describe the role and action of auto reclosers.

Recap

In this lecture we have learnt the following:

- Earth fault can be detected by the presence of zero sequence component.
- Earth fault current can vary over a wide range.
- Setting and coordination of earth fault relays.
- Adaptive relaying in overcurrent protection.
- Role and action of autoreclosers.

Congratulations, you have finished Lecture 17. To view the next lecture select it from the left hand side menu of the page