Module 6 : Distance Protection

Lecture 22 : Setting of Distance Relays

Objectives

In this lecture we will explain

- Setting of distance relays
- Zone 1 setting and the reason for keeping zone 1 setting at 80% of primary line length.
- Zone 2 and zone 3 setting.
- Outfeed and Infeed effect.
- Load encroachment.

Zone 1 of Protection

Distance relays can be classified into phase relay and ground relays. Phase relays are used to protect the transmission line against phase faults (three phase, L-L) and ground relays are used to protect against ground faults (S-L-G, L-L-G). In this lecture, we will learn the ways to set distance relay. Just like an overcurrent relay, a distance relay also has to perform the dual task of primary and back up protection. For example, in fig 22.1, the distance relay R_1 has to provide primary protection to line AB and back up protection to lines BC, BD and BE.

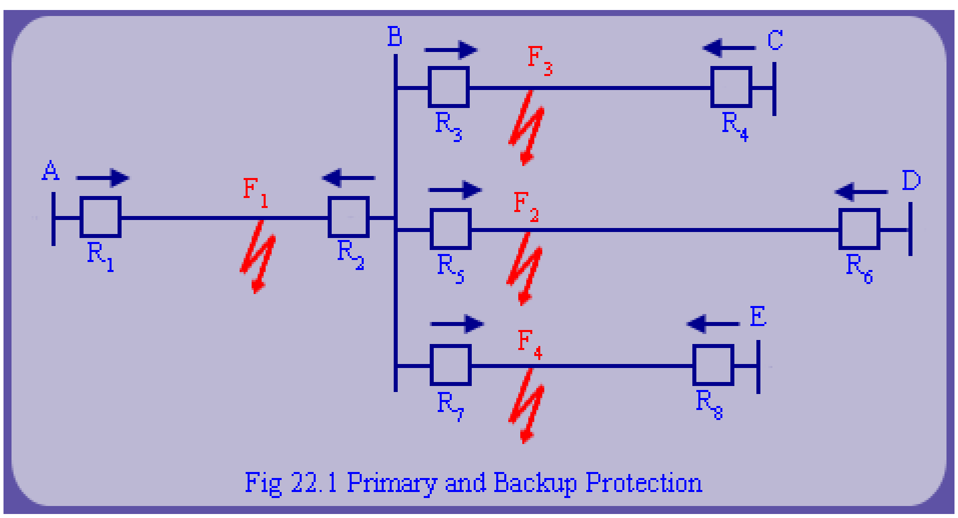

Fig 22.1 Primary and Backup Protection

The primary protection should be fast and hence preferably it should be done without any intentional time delay, while back up protection should operate if and only if corresponding primary relay fails. In fig 22.1, R_1 backs operation of relays R_3, R_5 and R_7. Typically, distance relays are provided with multiple zones of protection to meet the stringent selectivity and sensitivity requirements. At least three zones of protection are provided for distance relays.

Zone 1 is designated by Z_1 and zones 2 and 3 by Z_2 and Z_3 respectively. Zone 1 is meant for protection of the primary line. Typically, it is set to cover 80% of the line length. Zone 1 provides fastest protection because there is no intentional time delay associated with it. Operating time of Z_1 can be of the order of 1 cycle. Zone 1 does not cover the entire length of the primary line because it is difficult to distinguish between faults at F_1 *and* $F_2 / F_3 / F_4$ all of which are close to bus B. In other words, if a fault is close to bus, one cannot ascertain if it is on the primary line, bus or on back up line. This is because of the following reasons:

1. CTs and PTs have limited accuracy. During fault, a CT may undergo partial or complete saturation. The resulting errors

in measurement of apparent impedance seen by relay, makes it difficult to determine fault location at the boundary of lines very accurately.

2. Derivations for equations of distance relays made some assumptions like neglecting capacitance of line, unloaded

system transposed lines and bolted faults. In practice none of these assumptions are valid. Fault on a line will also destroy effect of transposing. Such factors affect accuracy of distance relaying. Further, algorithms for numerical relays may use a specific transmission line model. For example, a transmission line may be modeledas a series R – L circuit and the contribution of distributed shunt capacitance may be neglected. Due to model limitation and because of transients accompanied with the fault, working of numerical algorithm is prone to errors.

Zone 1 of Protection (contd..)

3. With only local measurements, and a small time window, it is difficult to determine fault impedance accurately. For

example, if the fault has an impedance ($Z_f \neq 0$), then the derivations of previous lectures are no more exact. The impedance seen by the relay R_1 (fig 22.2) for fault F also depends upon the current contribution from the remote end, thus

$$Z_R = xZ_l + Z_F + Z_F \frac{I_{BF}}{I_{AF}}.$$

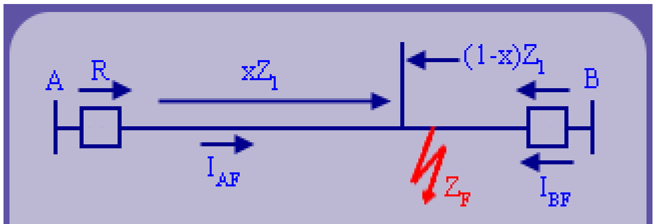

Fig 22.2 A Fault with Impedance Z_F

4. There are **infeed and outfeed effects** associated with working of distance relays. Recall that a distance relaying

scheme uses only local voltage and current measurements for a bus and transmission line. Hence, it cannot model infeed or outfeed properly.

Zone 2 and Zone 3 for Protection

Usually zone 2 is set to 120% of primary line impedance Z_1. This provides sufficient margin to account for non-zero fault impedance and other errors in relaying. Also one should note that Z_2 also provides back up protection to a part of the adjacent line. Therefore, one would desire that Z_2 should be extended to cover as large a portion of adjacent line as possible.

Typically, Z_2 is set to reach 50% of the shortest back up line provided that $Z_P + 1.5Z_B > 1.2Z_P$ where Z_P and Z_B are the positive sequence impedance of primary and the shortest back up line respectively. If the shortest back up line is too short then, it is likely that $Z_P + 1.5Z_B$ will be less than $1.2Z_P$. In such a case, Z_2 is set to $1.2Z_P$. Since, back up protection has to be provided for entire length of remote line, a third zone of protection, Z_3 is used.

Zone 2 and Zone 3 for Protection (contd..)

It is set to cover the farthest (longest) remote lines (BD in fig 22.3(a) for relay R_1 acting as a back up relay). Since its operation should not interfere with Z_2 operation of relays $R_1 / R_3 / R_5 / R_7$, it is set up to operate with a time delay of 2 CTI where CTI is the coordination time interval. The settings of relay R_1 on an R-X plane is visualized in fig 22.3(b). The timing diagrams are shown in fig 22.3(c).

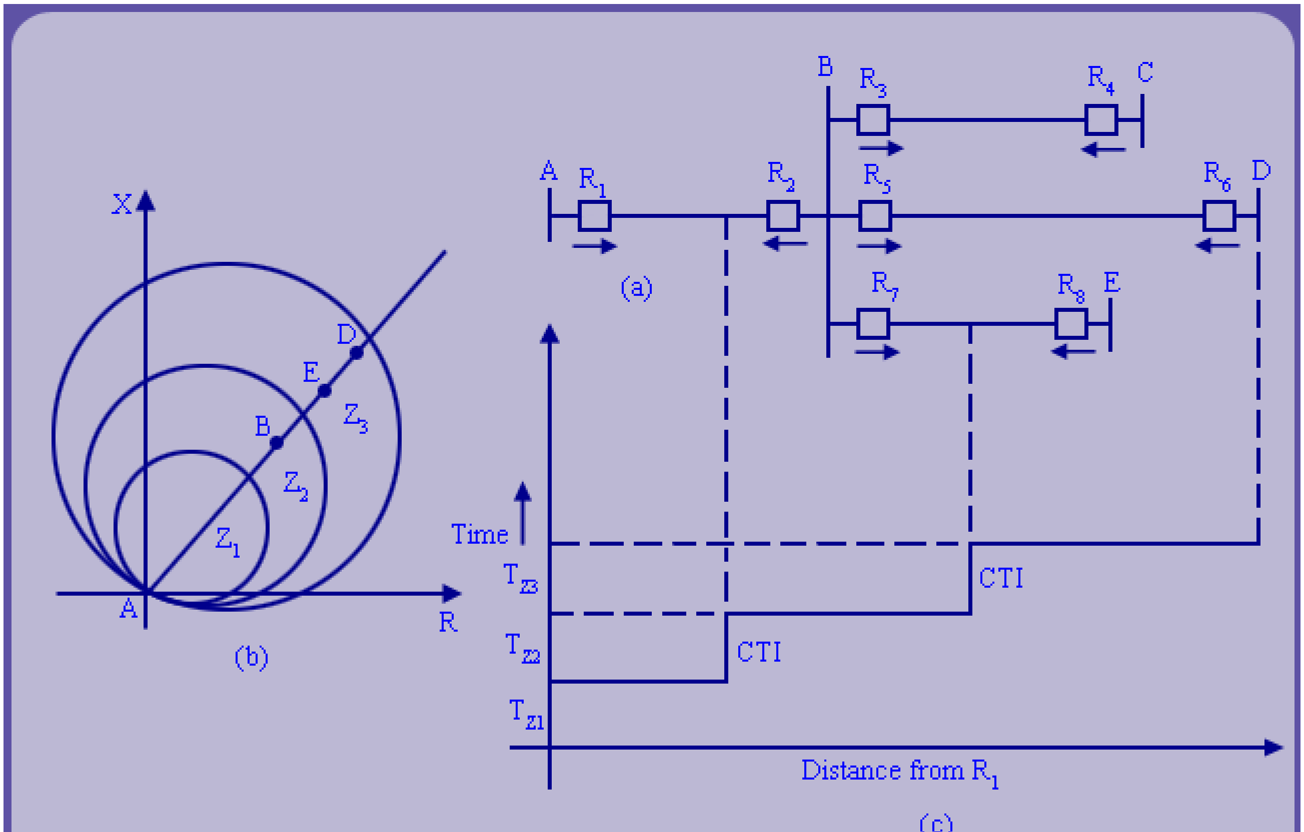

Fig 22.3 a, b, c: Three Zones of Protection

Overlap Problem for Z_2

There is a specific reason as to why Z_2 is not set to reach beyond 50% of the shortest remote line. As shown in fig 22.4 (a), if the reach of Z_2 of a relay R_1 is extended too much, then it can overlap with the Z_2 of the relay R_3.

Under such a situation, there exists following conflict. If the fault is on line BC (and in Z_2 of R_3), relay R_3 should get the first opportunity to clear the fault. Unfortunately, now both R_1 and R_3 compete to clear the fault. This means that Z_2 of the relay R_1 has to be further slowed down by CTI. This leads to timing diagram (fig 22.4 (b)).

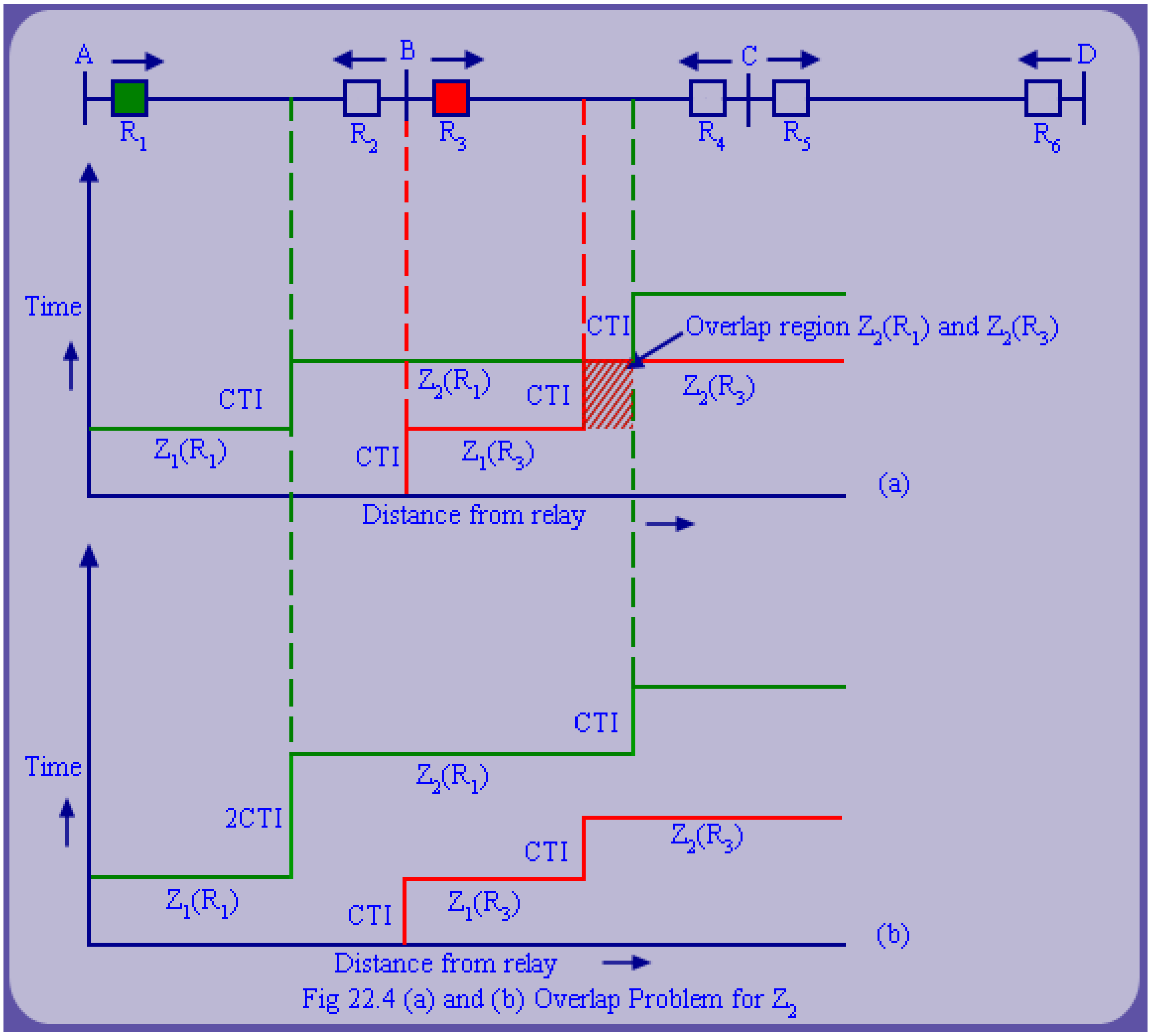

Fig 22.4 (a) and (b) Overlap Problem for Z_2

Overlap Problem for Z_2 (contd..)

Thus, it is clear that fault clearing time in 20% region of line AB is delayed a bit too much, thereby degrading performance of Z_2 of relay R_1. Hence, a conscious effort is made to avoid overlaps of Z_2 of relay R_1 and R_3. Setting back zone Z_2 of R_1 to maximum of 120% of primary line impedance or primary line impedance plus 50% of smallest back up impedance usually works out as a good compromise to reach as much of back up lines by Z_2 without getting into Z_2 overlap problem.

However, under certain conditions, when the shortest line to be backed up is too short, it may not be possible to avoid Z_2 overlap. Similarly, one may even encounter Z_3 overlap problem. On such small line segments, alternative way to improve speed characteristic of relay is to use pilot relaying. This aspect will be discussed in later lectures.

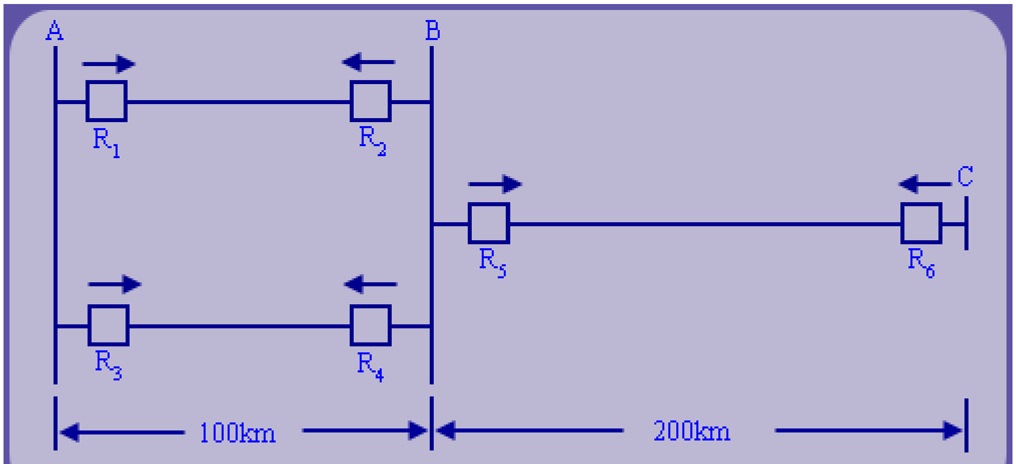

Fig 22.5 Example Problem on Setting Distance Relays

Example

1. Consider a protection system shown in fig 22.5. Identify the primary relays for back up relay R_1.

Ans: Relay R_1 not only backup's line BC but also parallel line AB. Therefore, for relay R_1 acting as back up, the primary relays
are R_5 and R_4.

2. Now assuming that pu impedance of all transmission lines in above fig 22.5 is α pu Ω/km, determine the setting of

zone 1, zone 2 and zone 3 relays of R_1.

Ans: $Z_1(R_1) = 0.8\alpha \times 100\, pu\Omega = 80\alpha pu\Omega$

$Z_2(R_1) = 100\alpha + 50\alpha = 150\alpha pu\Omega$ [because BA is the shortest back up line]

$Z_3(R_1) = 100\alpha + 200\alpha = 300\alpha pu\Omega$ [because BC is the longest back up line]

This approach for setting of distance relays presented is known as kilometric distance approach because the set values of impedances are proportional to lengths. In doing so, we have neglected effect of load currents and as well as the effect of change in operating condition in the system. More accurate settings can be computed by evaluating fault impedance seen by the relay for a fault by using short circuit analysis programs.

Outfeed and Infeed Effect

Consider the operation of distance relay R_1 for a fault F close to remote bus on line BC (fig 22.6).

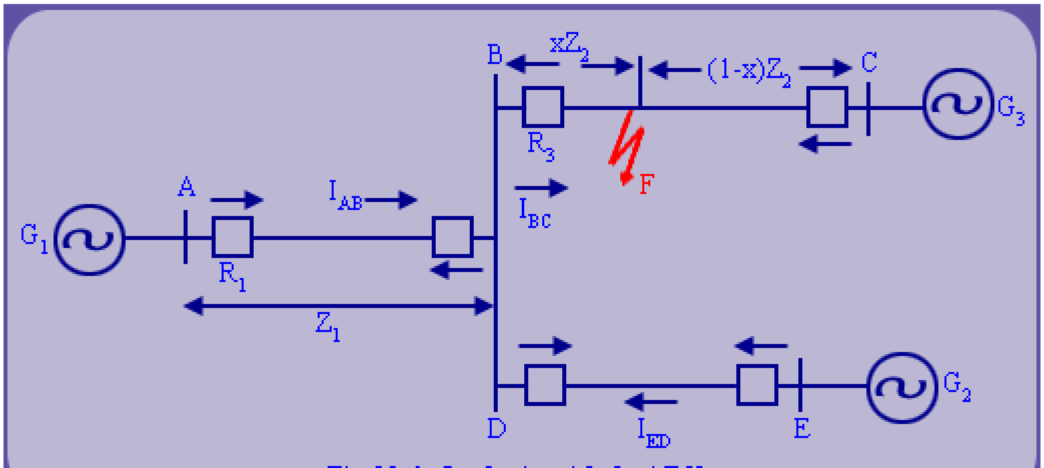

Fig 22.6 Outfeed and Infeed Effect

Due to the configuration of generators and loads, we see that $\vec{I}_{BF} = \vec{I}_{AB} + \vec{I}_{ED}$

Hence,

$$V_{R1} = \overrightarrow{I_{AB}} Z_1 + x Z_2 \overrightarrow{I_{BF}}$$

$$= (Z_1 + x Z_{l2}) \vec{I}_{AB} + x Z_{l2} \vec{I}_{ED}$$

$$\frac{V_{R1}}{\vec{I}_{AB}} = Z_1 + x Z_{l2} + x Z_{l2} \frac{\vec{I}_{ED}}{\vec{I}_{AB}} \qquad (1)$$

Thus, we see that the distance relay at R_1 does not measure impedance $(Z_1 + x Z_{l2})$. If there is an equivalent generator source at bus E, then it feeds the fault current. Thus $\overrightarrow{I_{AB}}$ and $\overrightarrow{I_{ED}}$ are approximately in phase. This is known as **infeed effect**. From equation (1), it is clear that infeed causes an equivalent increase in apparent impedance seen by the relay R_1.

From the relay's perspective, the fault is pushed beyond its actual location. Thus, a fault in zone-2 may be pushed into zone-3, thereby compromising selectivity of zone-2. However, infeed effect does not compromise selectivity of zone-1. In other words, relay R_1 perceives fault to farther away from than its actual location.

However, if there is an equivalent load at bus E, then I_{AB} and I_{EB} are in phase opposition. This causes an apparent reduction in the impedance seen by the relay R_1. In other words, the relay R_1 perceives fault to be at a point closer than its actual location. If this perceived point falls well in the section AB, the relay R_1 will operate instantaneously for a fault on the back up line, thereby compromising selectivity. Hence, instantaneous primary protection zone (Z_1) of distance relay is always set below 100% line impedance. Typically, zone 1 is set to cover 0.8 to 0.9 times the primary line length. In other words, we expect errors in measurements of fault impedance to be within 10-20% accuracy. The remaining portion of the primary line is provided with a time delayed protection known as Z_2. The zone 2 protection is delayed at least by the coordination time interval, CTI to give first opportunity to relays $R_3 / R_5 / R_7$ to clear a close in fault if it falls into its primary protection zone. Note that, relay R_3 in fig 22.6 is immune to infeed or outfeed effect for fault F.

Problem of Load Encroachment

Consider the steady state positive sequence model of a transmission line shown in fig 22.7.
Then, it can be shown that apparent impedance seen by relay R is given by,

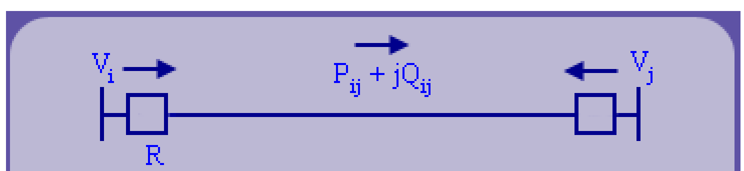

Fig 22.7 Power Flow on Transmission Line

$$Z_R = \frac{|V_i|^2}{P_{ij} - jQ_{ij}} = \frac{|V_i|^2}{P_{ij}^2 + Q_{ij}^2}(P_{ij} + jQ_{ij}) \qquad (2)$$

Thus from equation (2), we can derive following conclusions;

1. Quadrant of Z_R in the R - X plane correspond to the quadrant of apparent power (S_{ij}) in (P_{ij} - Q_{ij}) plane.

2. The apparent impedance seen by the relay is proportional to square of the magnitude of bus voltage. If the bus voltage

   drops say to 0.9 pu from 1 pu, then Z_R reduces to 81% of its value with nominal voltage. Further, if the bus voltage drops to say 0.8 pu, then the apparent impedance seen by the relay will drop to 64% of its value at 1 pu.

3. The apparent impedance seen by the relay is inversely proportional to the apparent power flowing on the line. If the

apparent power doubles up, the impedance seen by relay will reduce by 50%.

During peak load conditions, it is quite likely that combined effect of (2) and (3) may reduce the apparent impedance seen by the relay to sufficiently small value so as to fall in Z_2 or Z_3 characteristic. This is quite likely in case of a relay backing up a very long line. In such a case, Z_3 impedance setting can be quite large. If the impedance seen by relay due to large loads falls within the zone, then it will pick up and trip the circuit after its time dial setting requirement are met. Under such circumstances, the relay is said to trip on ***load encroachment*** . Tripping on load encroachment compromises security and it can even initiate cascade tripping which in turn can lead to black outs.

Thus, safeguards have to be provided to prevent tripping on load encroachment. A distinguishing feature of load from faults is that typically, loads have large power factor and this leads to Z_{app} with large R/X ratio. In contrast, faults are more or less reactive in nature and the X/R ratio is quite high.

Thus, to prevent tripping on load encroachment, the relay characteristic are modified by excluding an area in R – X plane, which corresponds to high power factor. A typical modified characteristic to account for load encroachment is shown in fig 22.8.

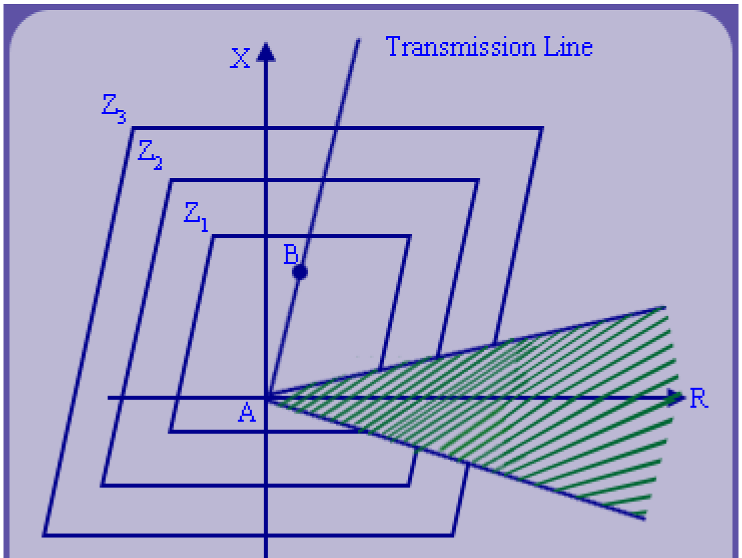

Fig 22.8 Distance Relay Characteristics Modified for Load Encroachment

The conditions of low value of Z_R discussed in (1) and (2) can also arise due to voltage instability or transients associated with electromechanical oscillations of rotors of synchronous machines after a major disturbance like the faults. This can also induce nuisance tripping. Such tripping is known as “tripping on power swings” and it will be studied in the later lectures.

Review Questions

1. Why is zone 1 protection of distance relays always set below 100% line length?
2. What is meant by infeed effect? How will it affect the performance of a distance relay?
3. What is the effect of overlap in Z_2 of relay?
4. How can the relay overlap problem in Z_2 be solved?
5. What is meant by load encroachment?
6. How can tripping of a relay on load encroachment be prevented?

Recap

In this lecture we have learnt the following:

- Setting of distance relays for zone 1 protection.

Zone 2 and zone 3 settings.

- Overlapping problem.
- Outfeed and Infeed effects.
- Solution for load encroachment.