Distance Protection

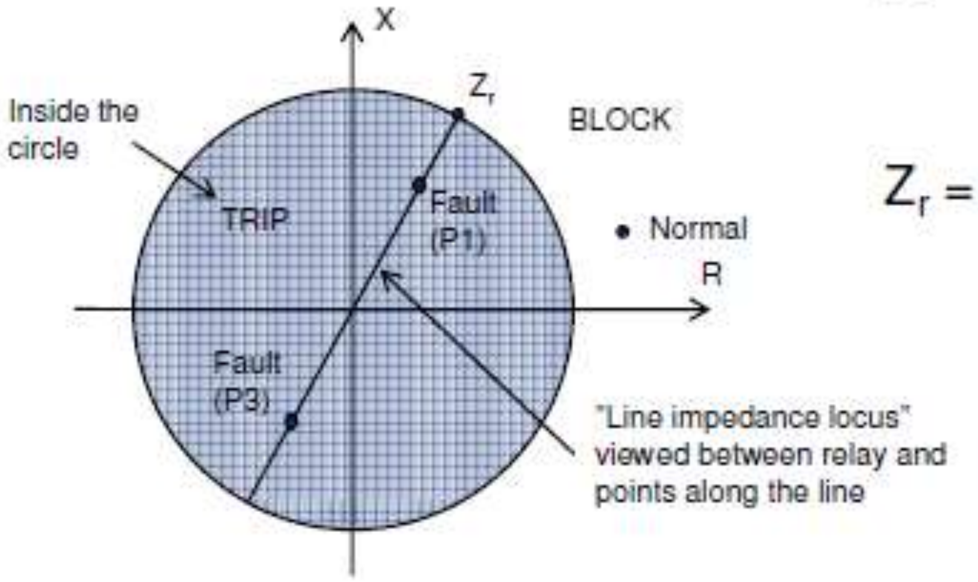
Power System Protection

Dr. Abdul Basit

Introduction to Distance Relaying

- Overcurrent protection is not suitable for
  - protection of meshed transmission systems where selectivity and sensitivity requirements are more strict
  - if fault current and load currents are comparable
- Distance protection provides the following features:
  - More accurate as more information is used for taking decision.
  - Directional, i.e. it responds to the phase angle of current with respect to voltage phasor
  - Fast and accurate.
  - Back-up protection.
  - Primarily used in transmission line protection. Also it can be applied to generator backup, loss of field and transformer backup protection

Block and trip regions



Z = voltage-to-current ratio at relay position

$$Z = \frac{V}{I} \text{ (phasor)}$$

Z_r = adjustable relay setting

TRIP: $|Z| < |Z_r|$

BLOCK: $|Z| > |Z_r|$

Impedance relay for breaker B12: $Z = \frac{V_1}{I_{12}}$

Normal operation: $|Z| >> |Z_r|$ → block

Fault at P1: $|Z| < |Z_r|$ → trip

↓

Z of line from relay to fault position

Fault at P3: $|Z| < |Z_r|$ → trip

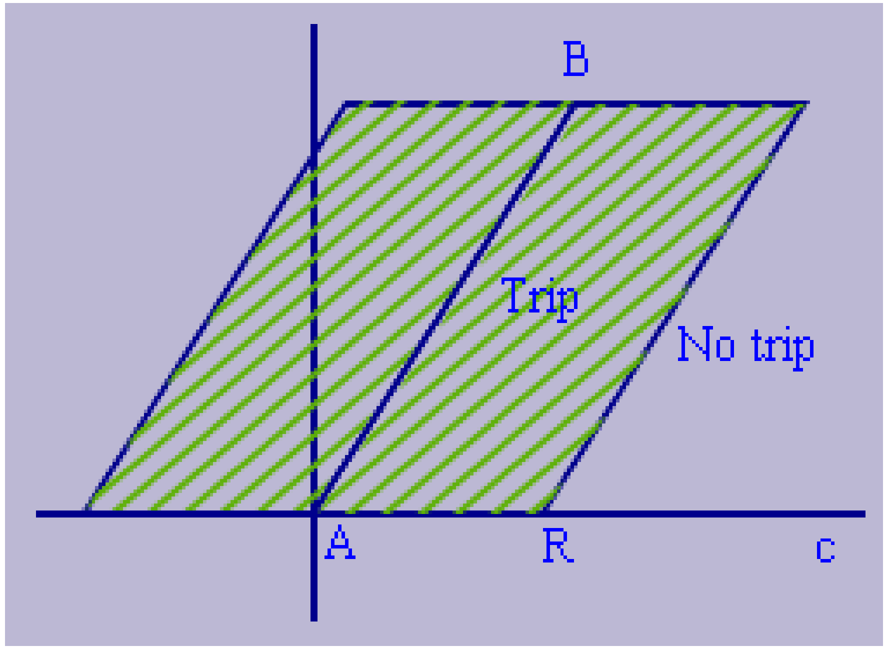
↓

Negative of Z of line from relay to fault position

Impedance relay not directional → MODIFIED

Introduction to Distance Relaying

- Apparent impedance seen by the relay will not exactly lie on transmission line AB impedance when the fault has some impedance Z_f.
  - Rather it would lie in a region shown by trapezoid.
  - Also, note that arcing faults are primarily resistive in nature.

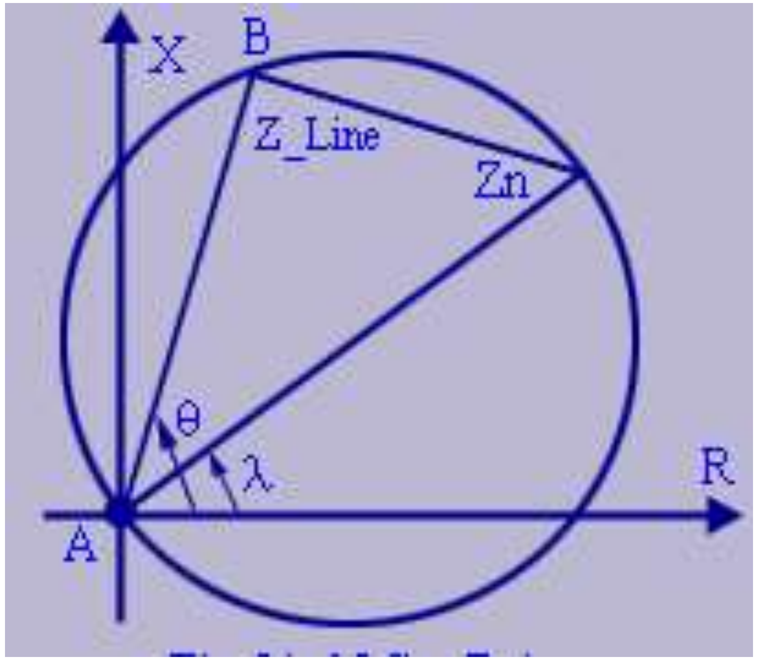


Introduction to Distance Relaying

- Distance relay characteristics are visualized by drawing the relay characteristics in R-X plane.
  - If the apparent impedance seen by the relay falls inside the trip region (enclosed region), then relay declares a fault and issues a trip decision.
  - This decision making can be done in about 1/2 - 1 cycle time, if no intentional time delays are introduced, e.g, for backup protection.
- While trapezoid or quadrilateral characteristics are quite popular with the numerical relays, previous generation of electromechanical and solid state relays used other characteristics like 'mho' characteristics, which were easier to derive.

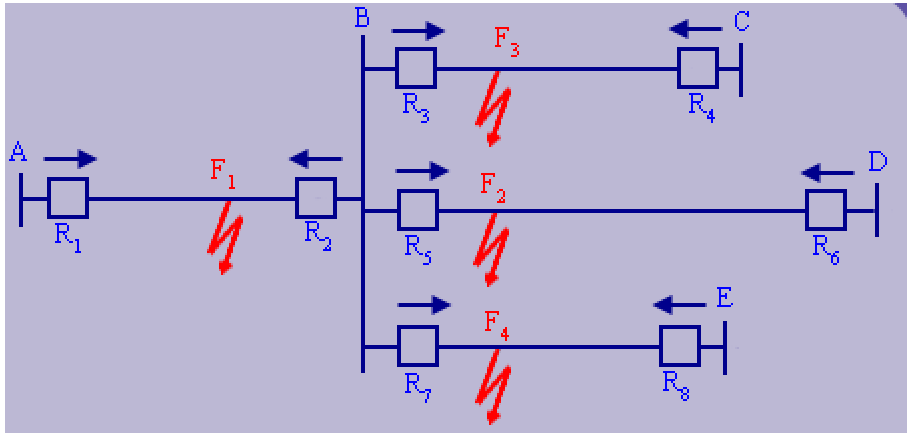
Introduction to Distance Relaying

- Mho relay circles usually enclosed a larger area than the quadrilateral characteristics for identical line impedance and arcing impedance parameters.
- More susceptible to nuisance tripping.
- These characteristics have been superseded by the trapezoidal characteristics.



Settings of Distance Relay

- 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).
- Just like an overcurrent relay, a distance relay also has to perform the dual task of primary and back up protection.
- Distance relay R1 has to provide primary protection to line AB and back up protection to lines BC, BD and BE.



Settings of Distance Relay

- 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.
- 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 Z1 and zones 2 & 3 by Z2 and Z3 respectively

Settings of Distance Relay

- 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 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 all of which are close to bus B.
  - In other words, if a fault is close to bus, one cannot as certain if it is on the primary line, bus or on back up line

Settings of Distance Relay

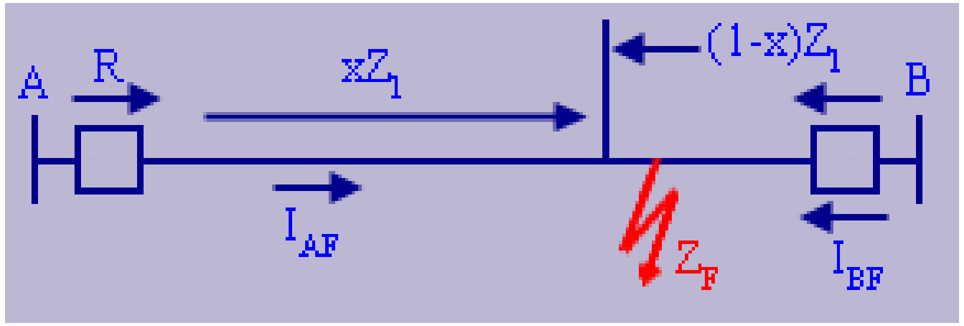
This is because of the following reasons:

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
   - 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 modeled as 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.

Settings of Distance Relay

3. With only local measurements, and a small time window, it is difficult to determine fault impedance accurately when ZF > 0. The impedance seen by the relay R1 for fault F also depends upon the current contribution from the remote end, thus

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

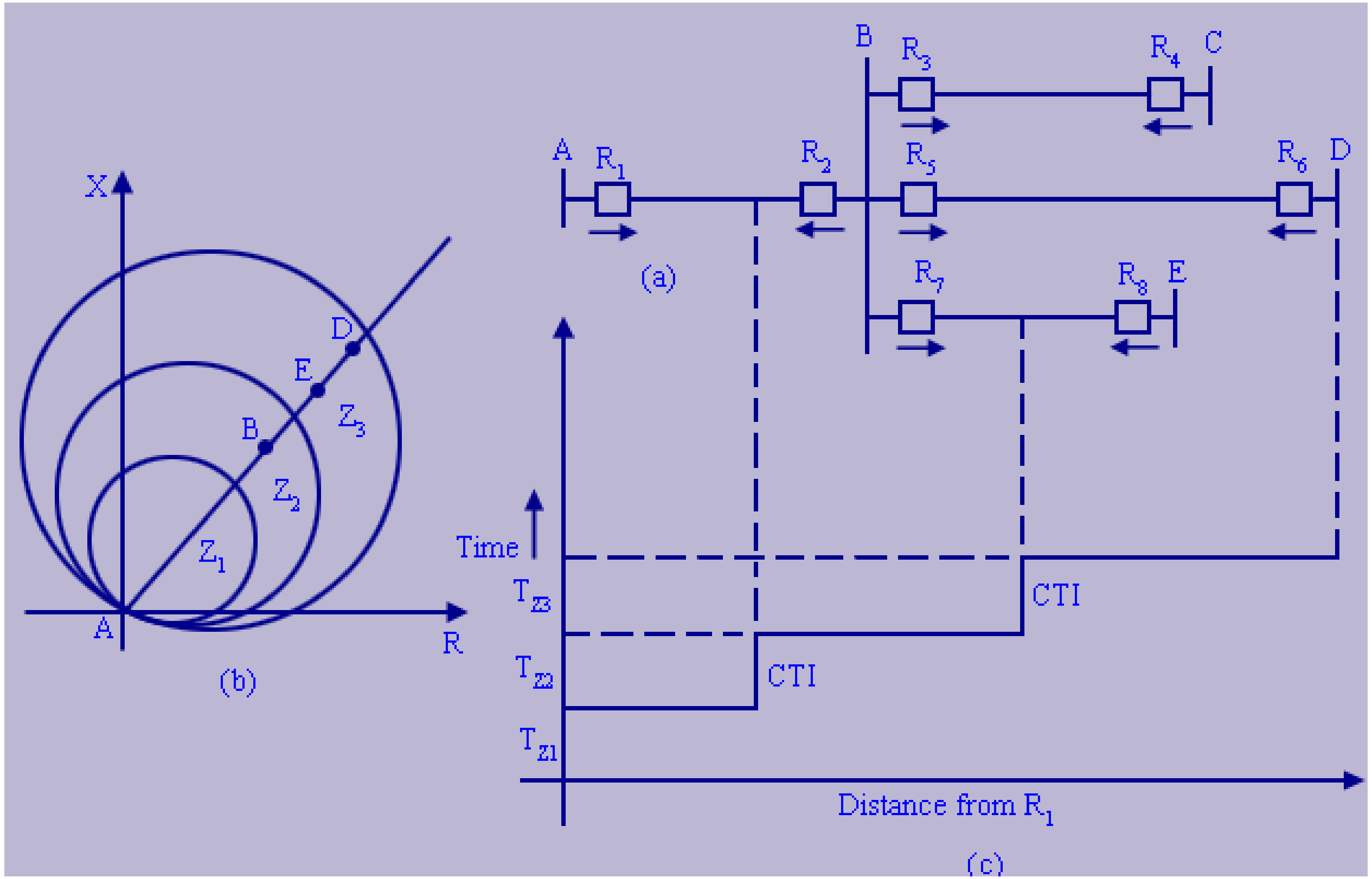


4. There are infeed and outfeed effects associated with working of distance relays. Recall that a distance relaying scheme uses only local voltage and current measurements for a bus and transmission line. Hence, it cannot model infeed or outfeed properly.

Settings of Distance Relay

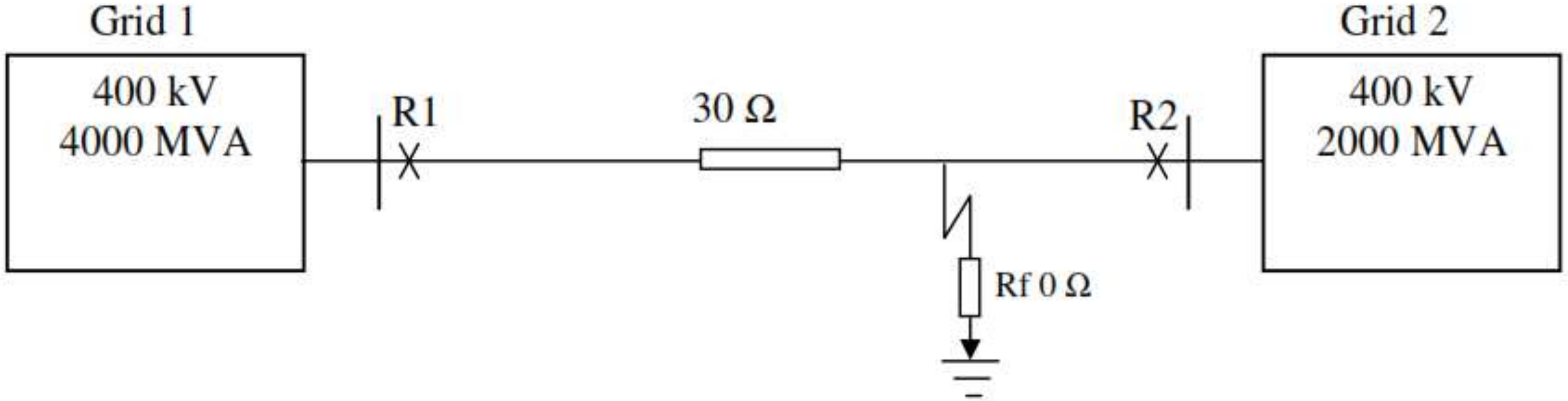
- Usually zone 2 is set to 120% of primary line impedance Z1, providing sufficient margin to account for non-zero fault impedance and other errors in relaying.
    - Z2 also provides back up protection to a part of the adjacent line; therefore, Z2 should be extended to cover as large a portion of adjacent line as possible.
- Typically, Z2 is set to reach 50% of the shortest back up line provided that ZP + 0.5ZB > 1.2 ZP; where ZP and ZB 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 ZP + 0.5ZB will be less than 1.2ZP. In such a case, Z2 is set to 1.2ZP.
    - Since, back up protection has to be provided for entire length of remote line, a third zone of protection, Z3 is used.

- Z3 is set to cover the farthest (longest) remote lines for relay R1 acting as a back up relay.
  - Since its operation should not interfere with Z2 operation of relays R1/R3/R5/R7, it is set up to operate with a time delay of 2 CTI where CTI is the coordination time interval.



Example 1

- Two independent networks Grid 1 and Grid 2 are interconnected as shown in Figure 1. At terminals 1 and 2, distance relays with the characteristics shown in Figure 2 are installed. Relays R1 and R2 have two zones. Zone 1 includes 80% of the line and Zone 2 includes 100% of the line, considering a fault impedance of 0 ohm (zero ohm). Assume that the systems and line impedances have angle of 70°
  - Determine the parameters of relay R2 (Z1, Z2).



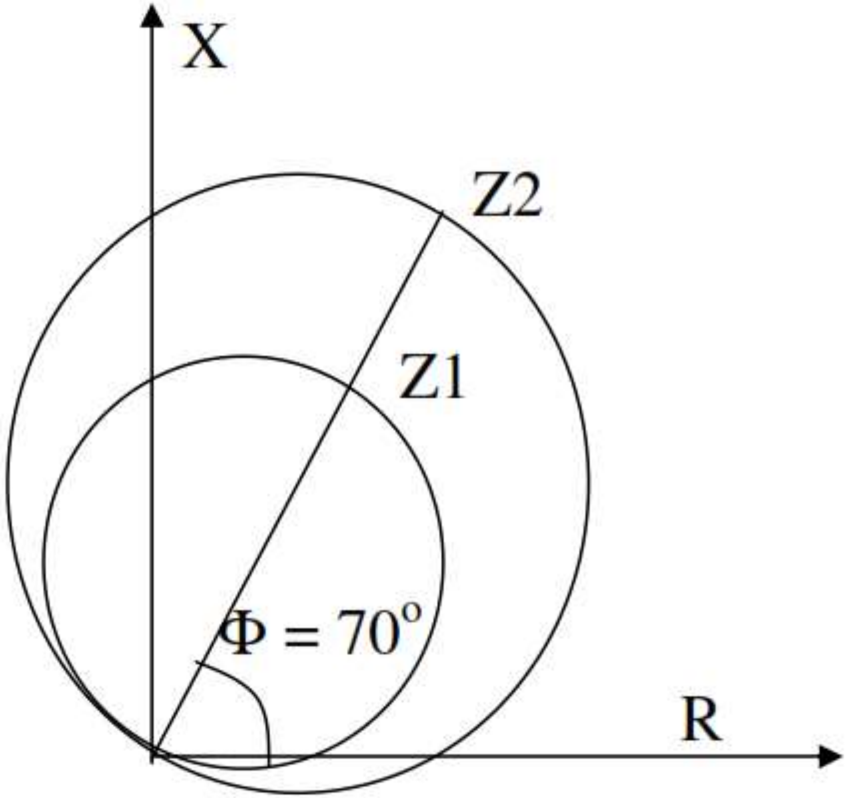


Figure 2: Characteristics of relays R1 and R2

Example 2

- Two independent networks named Grid 1 and Grid 2 are interconnected as shown in Figure 1. At terminals 1 and 2, distance relays R1 and R2 with characteristics given in Figure 2 are installed. Relay R1 has to protect 80% of the line, considering a pure resistive fault impedance of 10 ohms (ten ohms). Relay R2 has two protection zones: Zone-1 includes 80% of the line and Zone-2 includes 100% of the line, considering a fault impedance of 0 ohm (zero ohm).
  - Set the parameters of relays R1 and R2 (X1, Rb, Z1, Z2) such that the relays can perform the intended protection.
  - Assume that the systems and line impedances have angle of 70º

Example 2

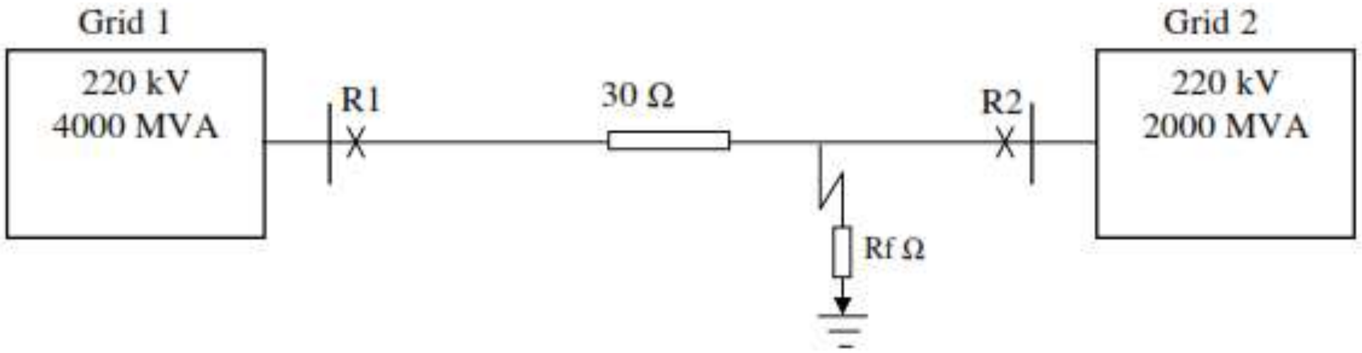


Figure 1: System

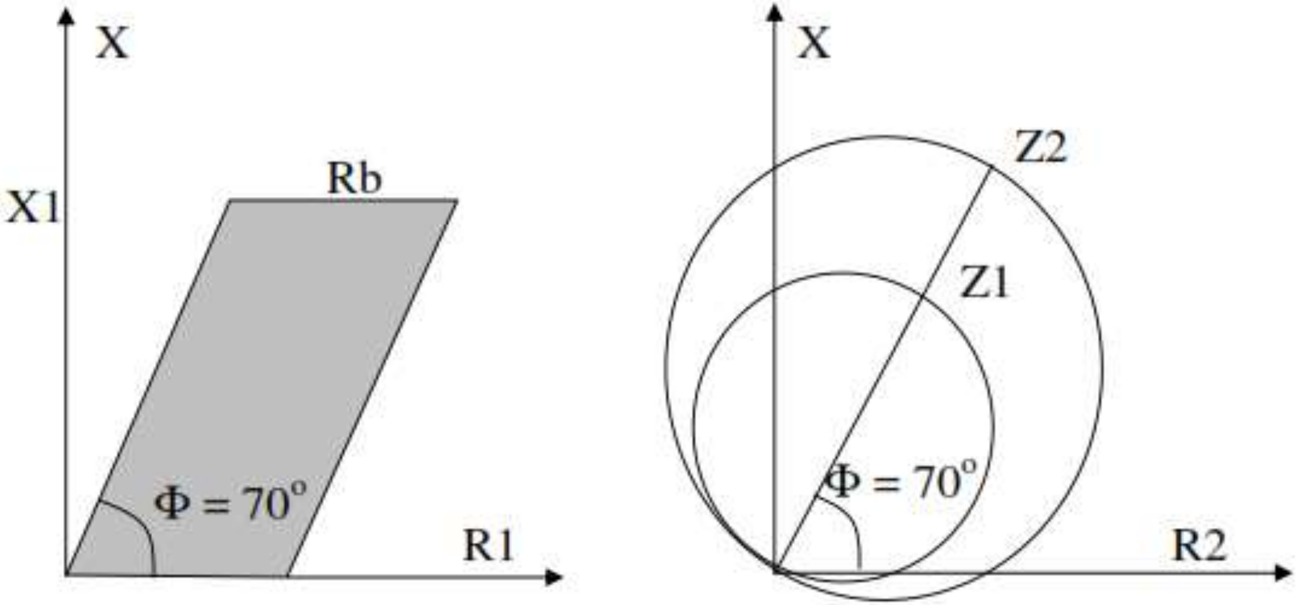
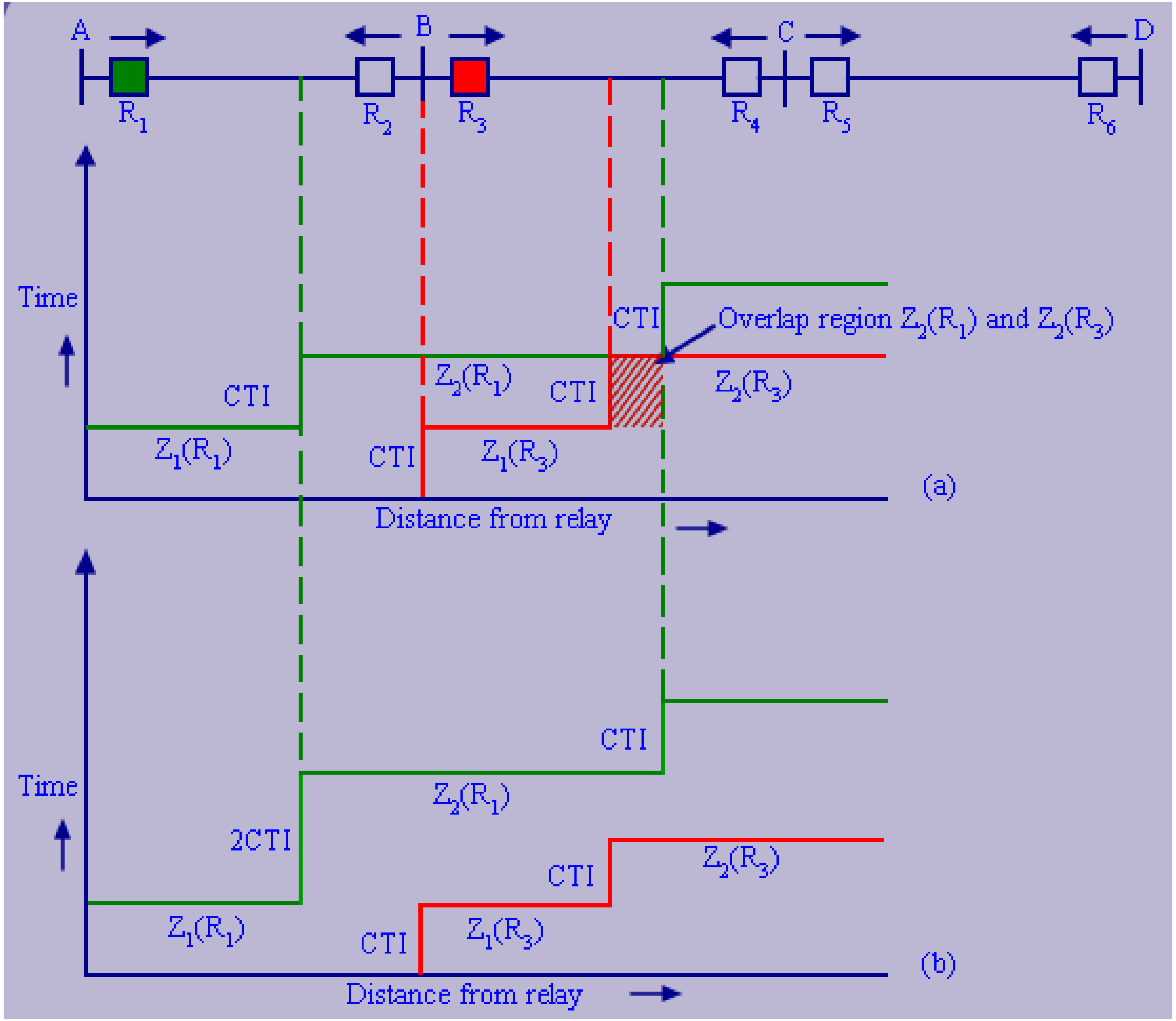


Figure 2: Characteristics of Relay R1 and R2

Overlap Problem for Z2

- If Z_2 is set to reach beyond 50% of the shortest remote line, it can overlap with the Z2 of the relay R3.
- Under such a situation, there exists following conflict.
  - If the fault is on line BC (and in Z2 of R3), relay R3 should get the first opportunity to clear the fault. Unfortunately, now both R1 and R3 compete to clear the fault. This means that Z2 of the relay R1 has to be further slowed down by CTI.



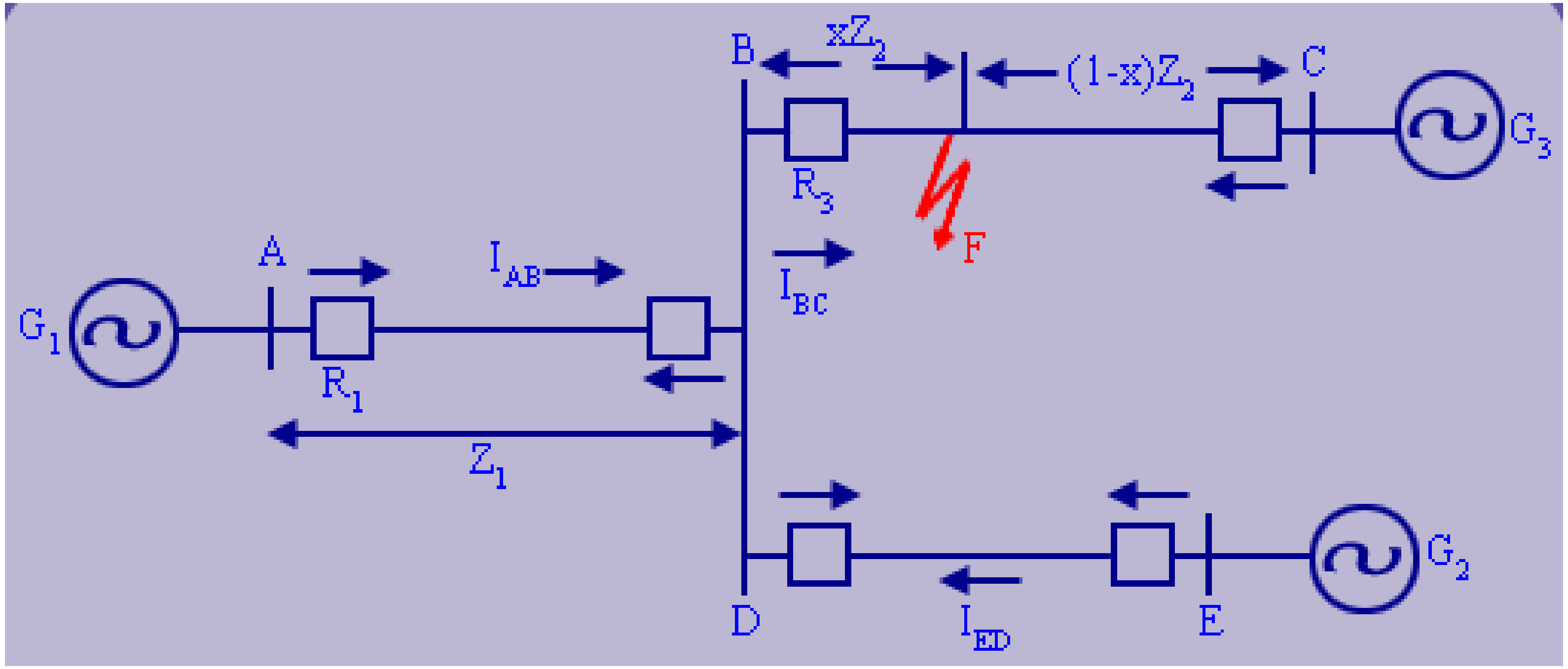
A
B
C
D
R1
R2
R3
R4
R5
R6
Time
CTI
CTI
Overlap region Z2(R1) and Z2(R3)
Z2(R1)
CTI
Z2(R3)
CTI
Z1(R1)
CTI
Z1(R3)
(a)
Distance from relay
Time
CTI
Z2(R1)
2CTI
CTI
Z2(R3)
Z1(R1)
CTI
Z1(R3)
(b)
Distance from relay

Overlap Problem for Z2

- Fault clearing time in 20% region of line AB is delayed a bit too much, thereby degrading performance of Z2 of relay R1.
  - Conscious effort is made to avoid overlaps of Z2 of relay R1 and R3.
  - Setting back zone Z2 of R1 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 Z2 without getting into Z2 overlap problem.
- However, under certain conditions, when the shortest line to be backed up is too short, it may not be possible to avoid Z2 overlap.
- Similarly, one may even encounter Z3 overlap problem.
- On small line segments, alternative way to improve speed characteristic of relay is to use pilot relaying.

Outfeed and Infeed Effect

- Consider the operation of distance relay R1 for a fault F close to remote bus on line BC



Outfeed and Infeed Effect

- Due to the configuration of generators and loads, we see that

$$\vec{I}_{BF} = \vec{I}_{AB} + \vec{I}_{ED}$$

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

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

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

Thus, we see that the distance relay at R_1 does not measure impedance $(Z_1 + x Z_{l2})$.

Outfeed and Infeed Effect

- If there is an equivalent generator source at bus E, then it feeds the fault current.
- Thus I_{AB} and I_{ED} are approximately in phase, known as infeed effect.
  - infeed causes an equivalent increase in apparent impedance seen by the relay R1.
- From the relay's perspective, the fault is pushed beyond its actual location.
  - fault in zone-2 may be pushed into zone-3, thereby compromising selectivity of zone-2.
- Infeed effect does not compromise selectivity of zone-1.

Outfeed and Infeed Effect

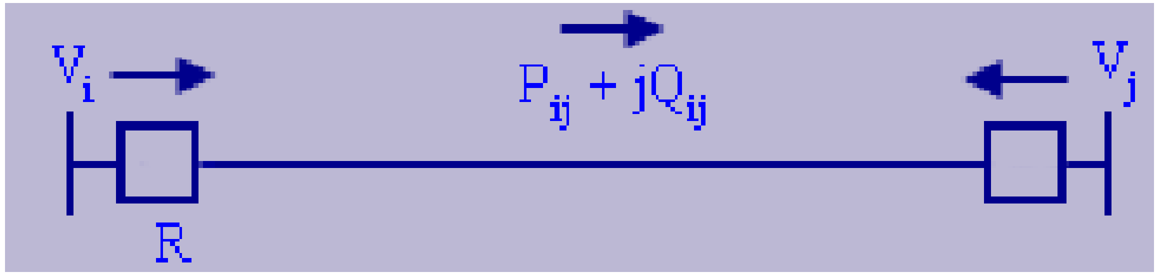
- If there is an equivalent load at bus E, then IAB and IEB are in phase opposition, causing an apparent reduction in the impedance seen by the relay R1.
- Relay R1 then perceives fault to be at a point closer than its actual location.
  - If this perceived point falls well in the section AB, the relay R1 will operate instantaneously for a fault on the back up line, thereby compromising selectivity.
  - Hence, instantaneous primary protection zone (Z1) of distance relay is always set below 100% line impedance.

Outfeed and Infeed Effect

- Typically, zone 1 is set to cover 0.8 to 0.9 times the primary line length as 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 Z2. The zone 2 protection is delayed at least by the coordination time interval, CTI to give first opportunity to relays to clear a close in fault if it falls into its primary protection zone.
- Relay R3 is immune to infeed or outfeed effect for fault F.

Problem of Load Encroachment

Apparent impedance of a steady state positive sequence model of a transmission line is given by



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

Problem of Load Encroachment

From equation:

1. Quadrant of ZR in the R - X plane correspond to the quadrant of apparent power (Sij) in (Pij - Qij) 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 ZR 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%.

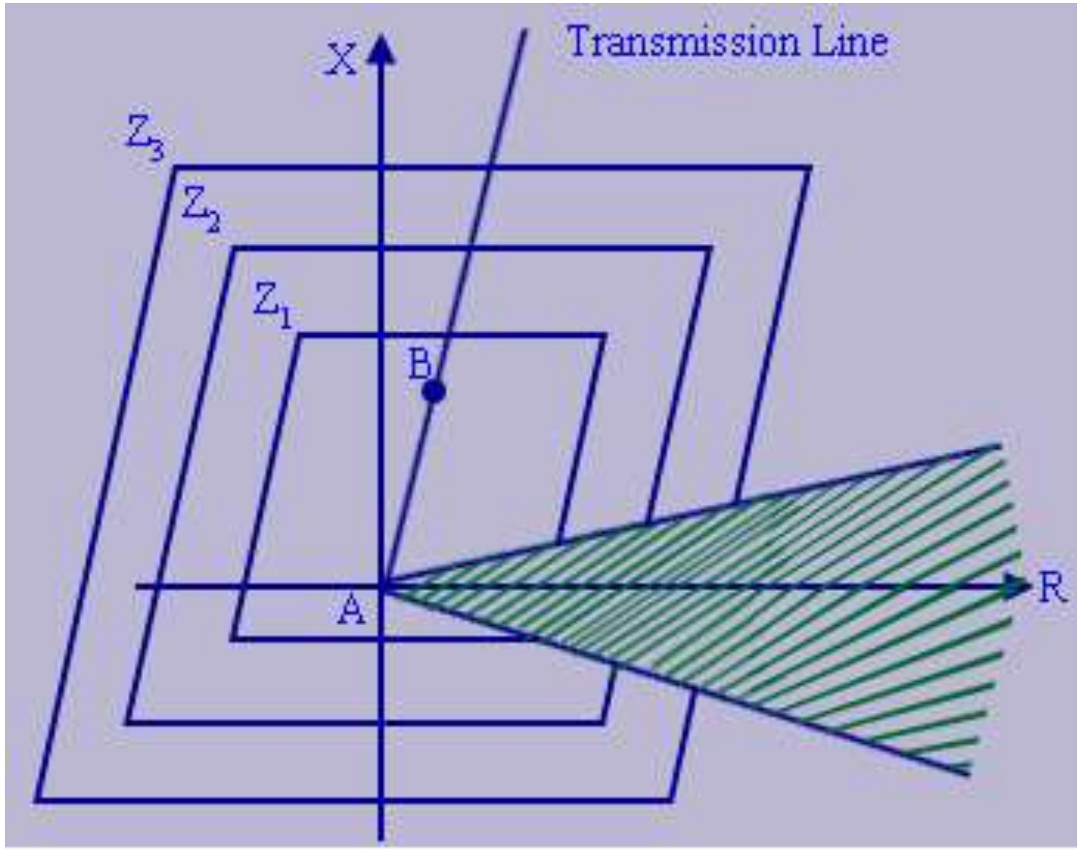
Problem of Load Encroachment

- 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 Z2 or Z3 characteristic.

Case when relay backing up a very long line.

- In such a case, Z3 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.

- Loads having large power factor leads to apparent impedance with large R/X ratio. In contrast, faults are more or less reactive in nature and the ratio is quite high X/R
- To prevent tripping on load encroachment, the relay characteristic are modified by excluding an area in R – X plane



Pilot Protection with Distance Relays

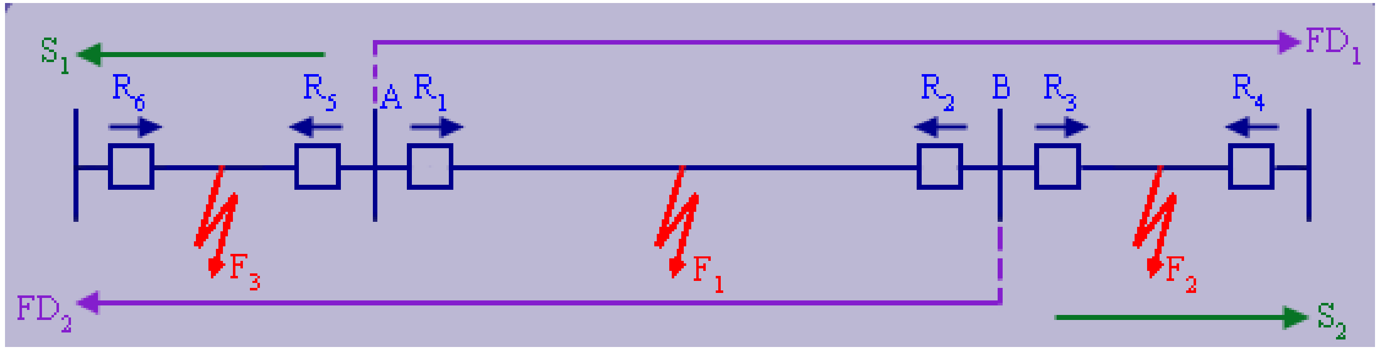
- Distance relays provide fast protection up to 80% of the primary line length.
  - for remaining 20% is deliberately slowed down by coordination time interval.
- Pilot protection is used for lines to provide the high speed simultaneous detection of phase and ground faults for 100% of the primary line.
- Distance relays are directional relays, the corresponding schemes are known as
  1. Directional comparison blocking.
  2. Directional comparison unblocking.
  3. Overreaching transfer trip.
  4. Under reaching transfer trip:
     a) Non-permissive. b) Permissive.

Directional Comparison Blocking

Basic Principle

1. Use directional fault detectors to detect faults in the direction of primary line.
2. Use blocking signal from the remote end in case the fault is not on the primary line.

Consider the requirement of protecting line AB.



Directional Comparison Blocking

- If the fault is at F1 (anywhere on the line AB), fast protective action is required from relays R1 and R2.
- To achieve this action, relays R1and R2 are enabled with two units each called **fault detectors** (FD1 and FD2) and **carrier starts** S1 and S2.
- Typically, the fault detectors correspond to Z2 of distance relays at respective locations as shown in figure.
  - They overreach the primary line.
- The carrier start relays look for fault in opposite sense to respective FD. They are called carrier starts because the channel signals between A and B are initiated by them.

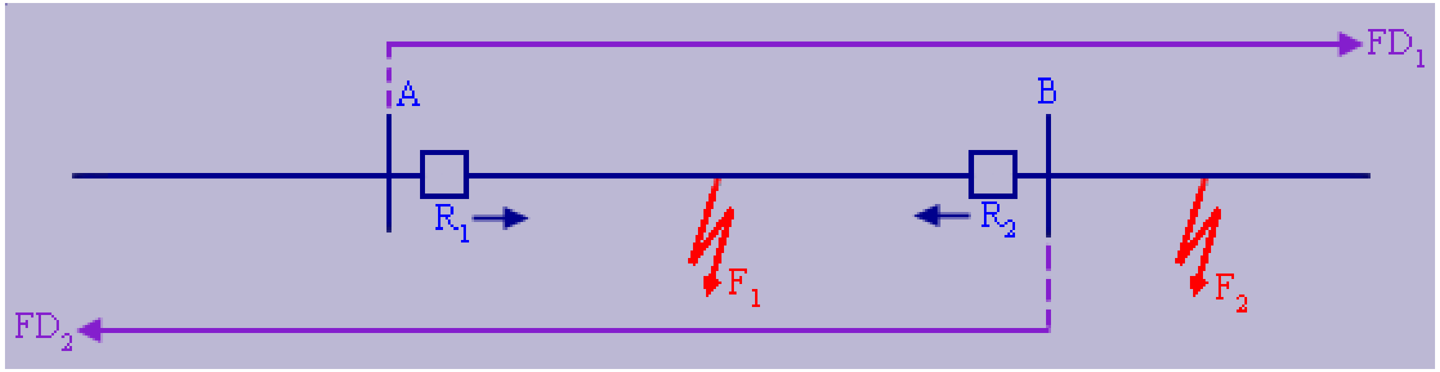
Directional Comparison Blocking

- Imagine a scheme where FD issues a trip signal after identifying a fault unless it is quickly blocked by an external agent (carrier starters).
  - For example, if the fault is in F1, both FD1 and FD2 will pick up. Since neither carrier starts S1 nor S2 will pick up, fault F1 will be cleared quickly.
  - In contrast, suppose that fault is at F2. Then FD1 will pick up and so will S2. The S2 will initiate channel and send blocking signal to FD1. The FD1 will be blocked from tripping action until its timer runs out. In this interval, either the primary relay R3 will clear the fault or else it is cleared by R1 as a back up measure.
- In other words, in this scheme, the relays are set for fast clearing action. They do not care whether the fault is in primary line or the back up line. Blocking from the other end is used to prevent fast tripping for faults on backup line.

Directional Comparison Unblocking Pilot System

Basic Principle

1. After detecting a fault in the right direction, put the relays in ‘block mode' for CTI.
2. Use unblock signals from the remote if the fault is on the primary line.



Directional Comparison Unblocking Pilot System

- Z2 of R1and R2 remain in ‘block mode' for a specified time after seeing the fault.
  - In case, relay R2 observes a fault in the direction of bus A, it sends an unblock signal to relay R1 (and vice- versa). If the fault is in the primary line AB (F1), both R1and R2 detect the fault, and also receive unblock signal from the opposite end. The unblocking signal helps in immediate action of both relays R1 and R2 leads to fast tripping of line.
  - In case, the fault is at F2, then the relay R2 will not send unblock signal to R1. While relay R1 sees the fault, its FD also initiates a down counter set to CTI. If the FD detects fault even after counter has run down, then a trip signal is issued by R1 for back up fault clearing action in the adjacent line.

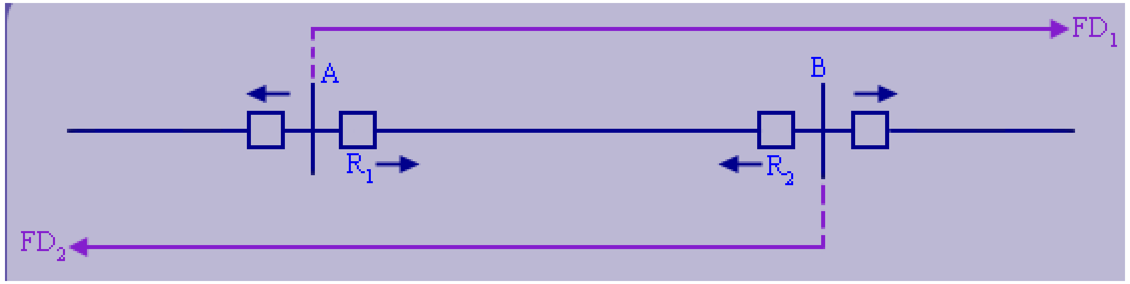
Directional Comparison Unblocking Pilot System

- The advantage of directional comparison unblocking pilot system is that it eliminates need of carrier starts S1 and S2.
- To summarize, the relays or more appropriately their fault detectors detect fault in the appropriate direction. Unblock signal from the remote end is used to quickly clear the faults on the primary line

Directional Comparison Overreaching Transfer Trip Pilot System

Basic Principle

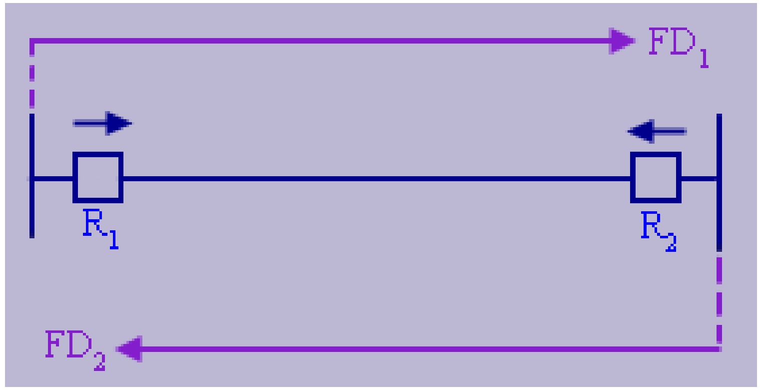
1. If fault is detected from both ends of the line, initiate trip.
2. Else, initiate back up protection



For internal fault both FD1 and FD2 operate to shift respective transmitters to trip mode. A logical ANDing of trip of both FD1 and FD2 provides the trip output at both ends of the line. In case of external fault either FD1 or FD2 will not pick up and hence relays R1and R2 will not operate.

Directional Comparison under Reaching Transfer Trip Pilot System

- Directional comparison under reaching transfer trip pilot system implies that the FDs are to be set so as always to overlap but not over reach any remote terminal under all operating condition.

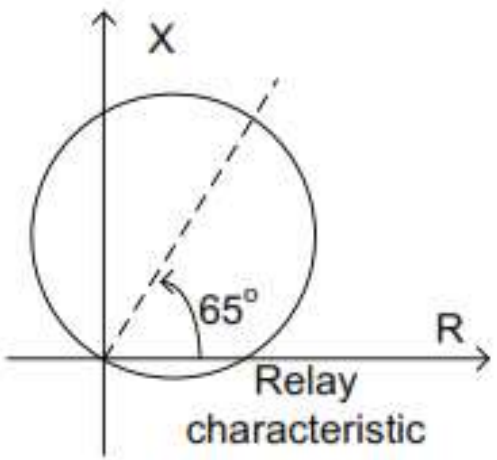


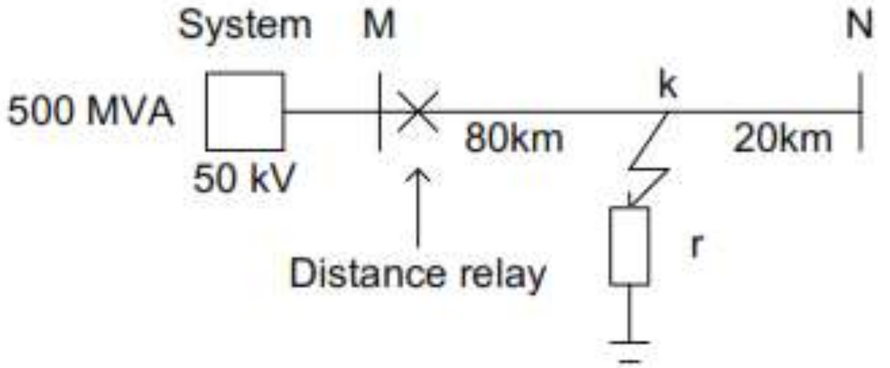
Two types of implementation exist, known as a) non permissive b) permissive. With external faults, neither FD1 nor FD2 picks up. For internal faults in the overlap area of FD1 and FD2 both FD1 and FD2 pick up. To clear internal faults quickly which are not in the overlap region, OR-ing of the trip decision of FD1 and FD2 is used at both ends. This system is not very much in use.

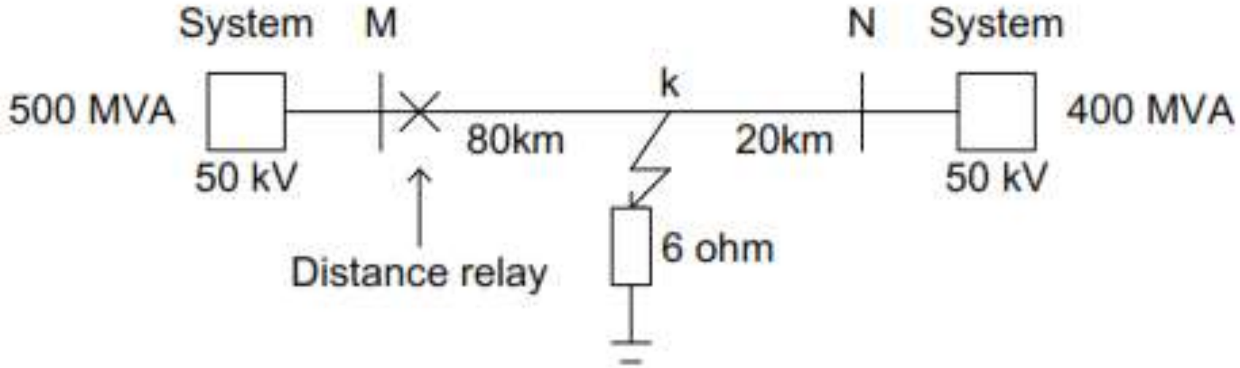
Example 3

The characteristic of a distance relay is shown in the figure. It is installed at busbar M to protect line MN in a power system. Line impedance value is 0.4 ohm/km. Assume that all the system and line impedance have an angle of 80º A three-phase to-ground fault occurs at fault point K with a fault resistance r.

1. Assume there is no system source or load attached at busbar N (see the middle figure). What is the maximum value of r, for which such three-phase-to-ground fault at K can be detected by the relay M.
2. Now there is another system source attached at busbar N (see the bottom figure). What is the detected value of Z by the relay at M when r =6 ohm? Will the relay operate?


X
65°
R
Relay characteristic


System
M
N
k
500 MVA
50 kV
80km
20km
Distance relay
r


System
M
N
System
k
500 MVA
50 kV
80km
20km
400 MVA
50 kV
Distance relay
6 ohm