ASU – FOE
EPM 461s- Fall 2023
Distance Protection

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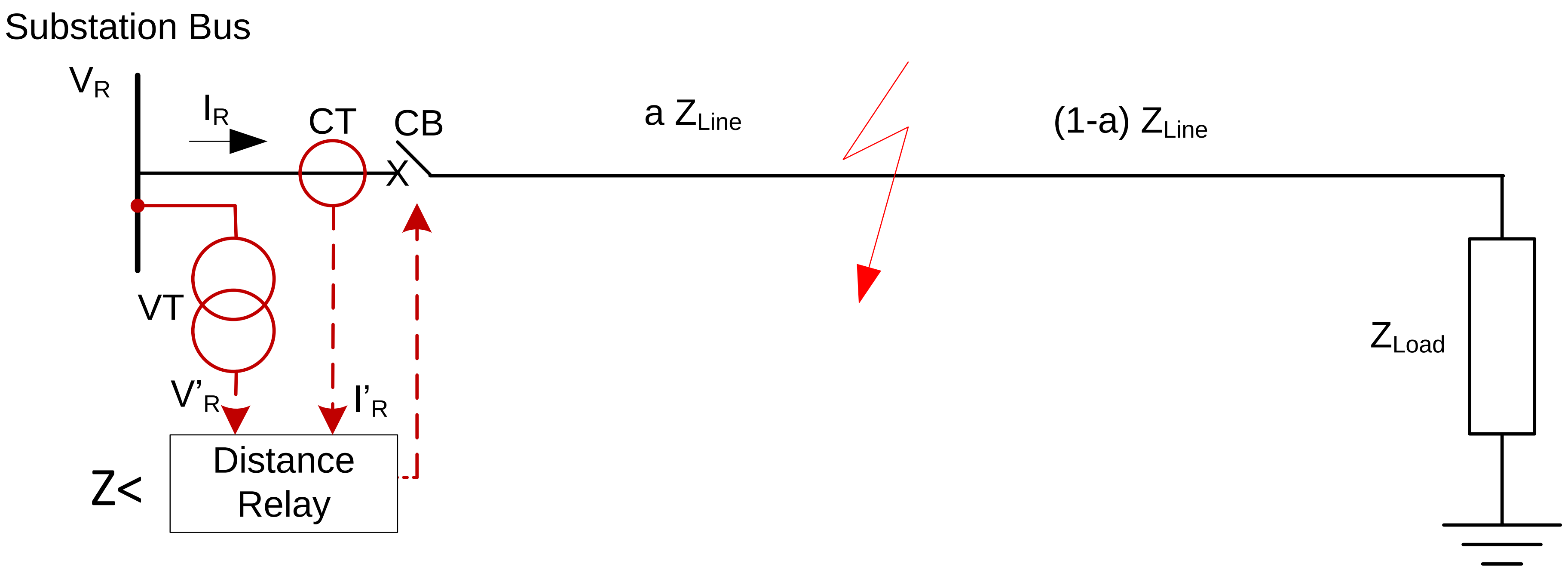
Contents

1. Principles of Distance Relay

ANSI Number	21
IEC Symbol	Z<

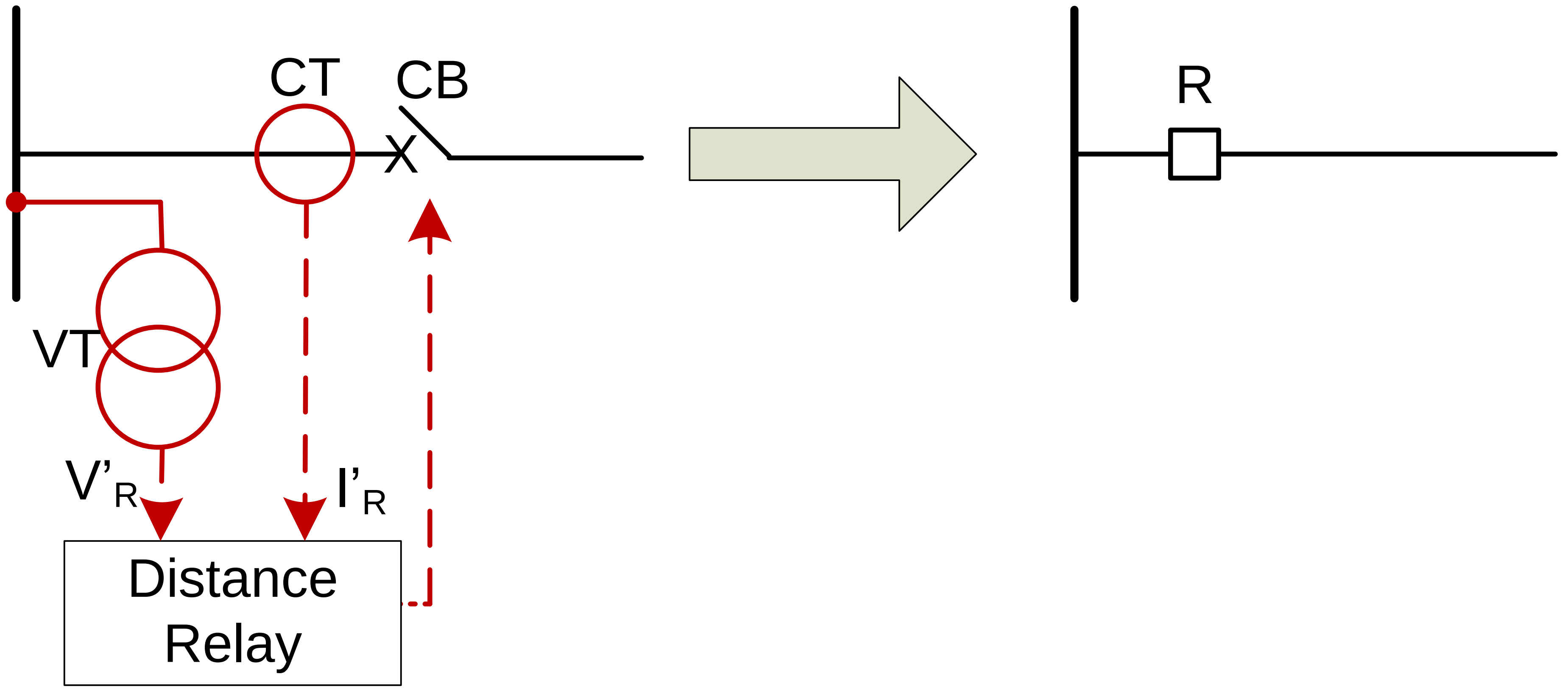
1.1 Concept of Distance Protection



Z_R at the relay location (primary circuit):

- During normal conditions: $Z_R = V_R \,/\, I_R = Z_{line} + Z_{load}$
- During 3-phase short circuit: $Z_R = a\ Z_{line}$, a is a fraction of the line length, e.g., a = 0.4 (40%), which is proportional to the fault location (distance to fault).

1.2 Simplified schematic of Distance Relay



1.3 Features of Distance Protection

- Distance protection is usually applied in sub-transmission (66 kV) and Transmission (220 kV) line protection as the primary protection.
- The task of each distance relay is to protect its line as a primary relay and to provide protection to all adjacent (next) lines as a backup relay.
- Distance relay is monitoring the line to be protected from one end only (like the overcurrent and unlike the differential).
- The reach and operating time of distance relay are independent of source impedance unlike the overcurrent relay.
- The distance protection must respect selectivity (Max service continuity with min system disconnection), this is due to the huge served area.
- The distance protection must be very fast to prevent stability problems.

1.4 Impedance Seen by the Distance Relay

Distance relay, which is connected to both CT and VT, is continuously calculating the equivalent impedance seen by the instrument transformers ($Z'_R = V'_R/I'_R$) and compare it to the reference (setting) impedance Z_r , where: $V'_R = V_R$ / VTR, $I'_R = I_R$ / CTR, i.e., $Z'_R = Z_R$ * CTR/VTR.

Example 1:

At a certain loading condition, the current in a 220 kV line is 1000 A $\angle -30^o$. Calculate the impedance seen by the distance relay if the CT is 1000: 1 A and the VT is 220 kV: 110 V.

Solution

CTR = 1000/1 = 1000, VTR = 220000/110 = 2000

$Z_R = V_R/I_R = 220000/\sqrt{3} /(1000 \angle -30^o) = 127\ \Omega \angle 30^o = 110 + j\ 63.5\ \Omega$

$Z'_R = (110 + j\ 63.5) * 1000/2000 = 55 + j\ 31.75\ \Omega = 63.5\ \Omega \angle 30^o$

1.5 R-X (Impedance) Diagram

Example 2

The line of example 1 has an overall impedance of 3 + j30 Ω. Locate the impedance seen by the relay for four conditions:

A- Loading condition of Example 1,

B- A bolted three-phase fault at the end of the line,

C- A bolted three-phase fault at the mid of the line, and

D- A three-phase fault at the end of the line through a fault resistance of 20 Ω.

Solution

$ZA = Z'_{line} + Z'_{load} = 55 + j\ 31.75 = 63.5\ \Omega\ \underline{/30^o}$

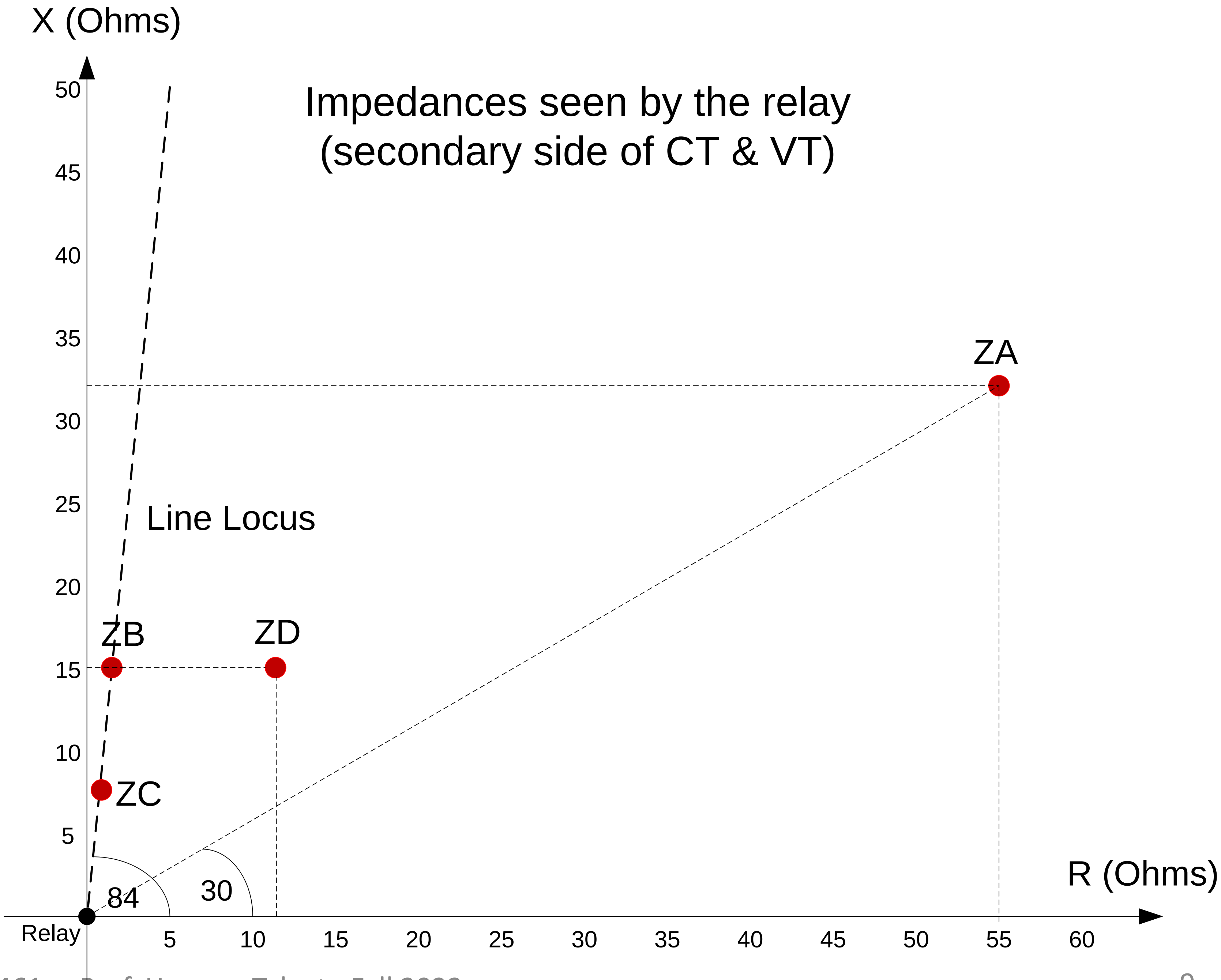
$Z'_{line} = (3 + j\ 30) * 1000/2000 = 1.5 + j\ 15 = 15.07\ \Omega\ \underline{/84^o}$

$ZB = Z'_{line} = 15.07\ \Omega\ \underline{/84^o}$

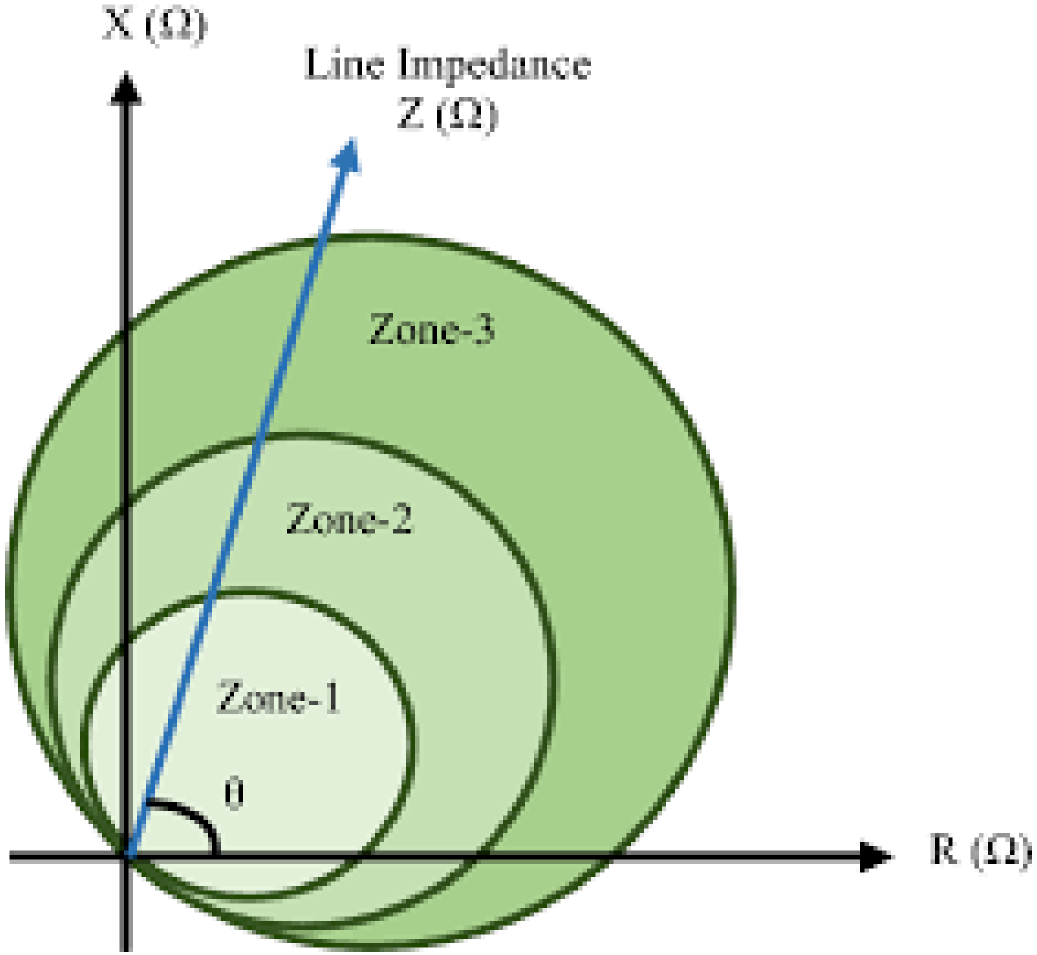
$ZC = Z'_{line} / 2 = (1.5 + j\ 15) * 1000/2000 = 0.75 + j\ 7.5 = 7.54\ \Omega\ \underline{/84^o}$

$ZD = Z'_{line} + R'_F = [(3 + j\ 30) + 20\ ]* 1000/2000 = 11.5 + j\ 15 = 18.9\ \Omega\ \underline{/53^o}$

R-X (Impedance) Diagram



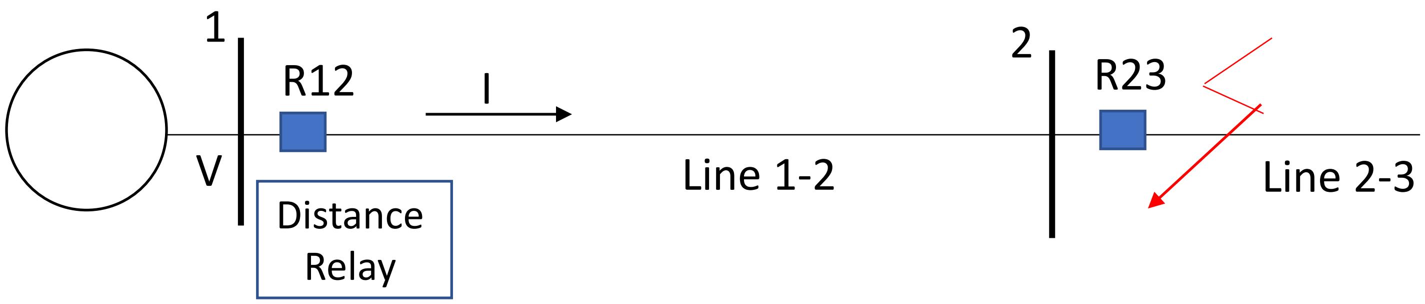
2. Stepped (3-Zone) Distance Relay



2.1 3-Zone Distance Relay, why?

Tasks:

- Relay R12 is to protect Line 1-2 as a primary relay and to assist in protecting line 2-3 as a backup relay.
- Relay R23 is to protect Line 2-3 as a primary relay.



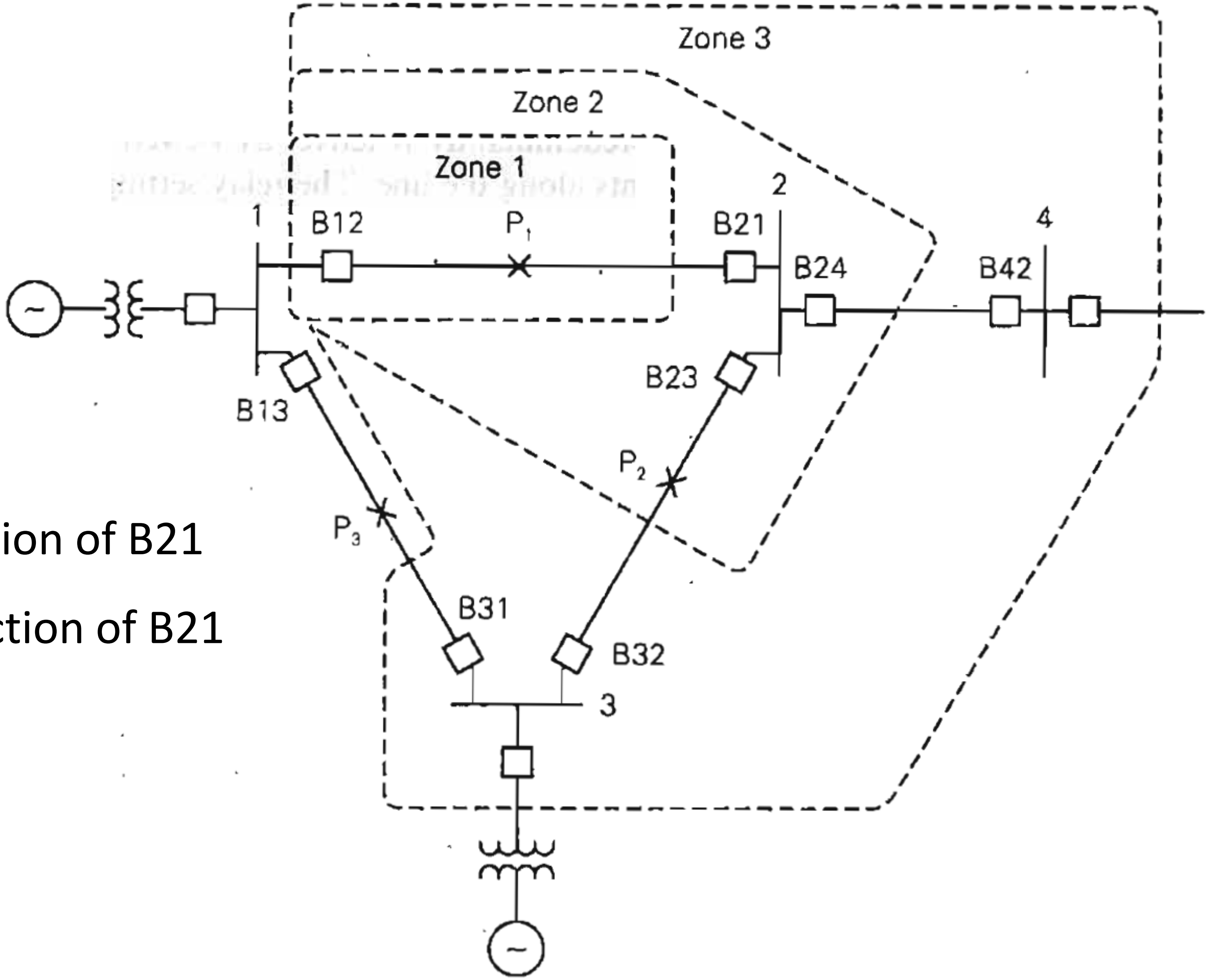
➢A fault at Line 2-3 close to bus#2 may be seen by R12 as a fault at the end of Line 1-2 (due to errors in calculating Z'_R) => Selectivity problem.

➢The errors are mainly due to transients and dc component in current and CT error.

2.2 Purpose of each zone

- Zone-1: is typically to cover 80-90% of the line (accounts for 10-20% error) without intentional delays (almost instantaneous) => primary protection.
- Zone-2: is typically to cover 120-150% of the line with a time delay = coordination margin (0.3-0.5 s) => complement to the primary protection of the line.
- Zone-3: backups the next line (s), it is typically to cover with a time delay = 2* coordination margin (0.6-1 s).

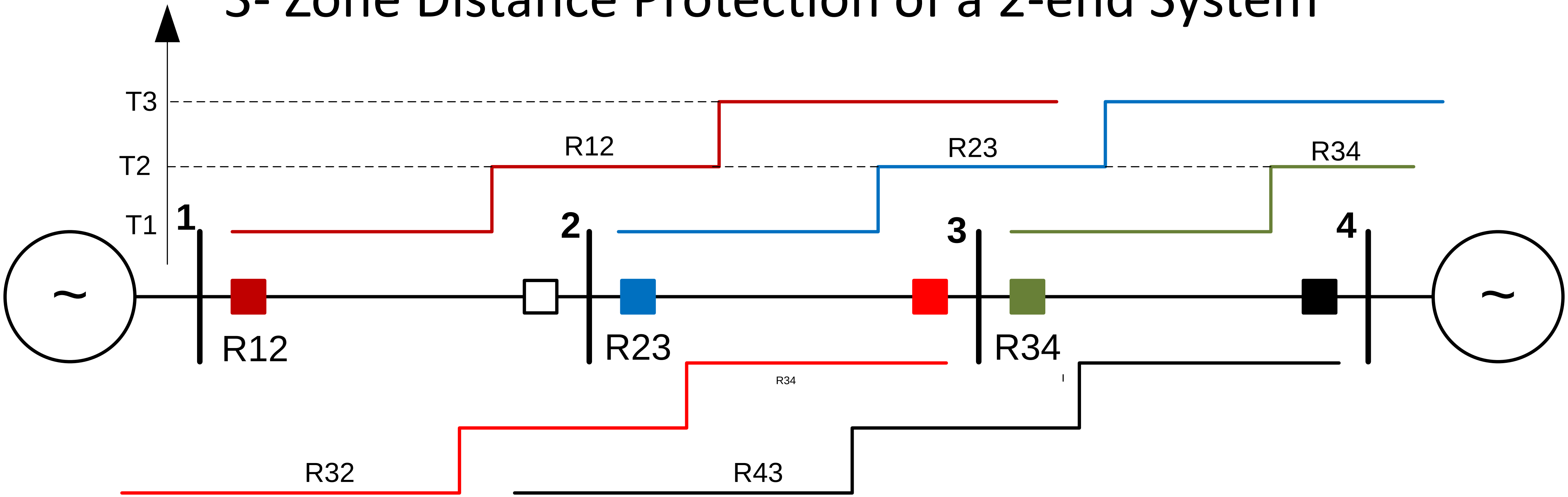
Example:
3 zones of B12



P1 is on the forward direction of B21

P2 is in the backward direction of B21

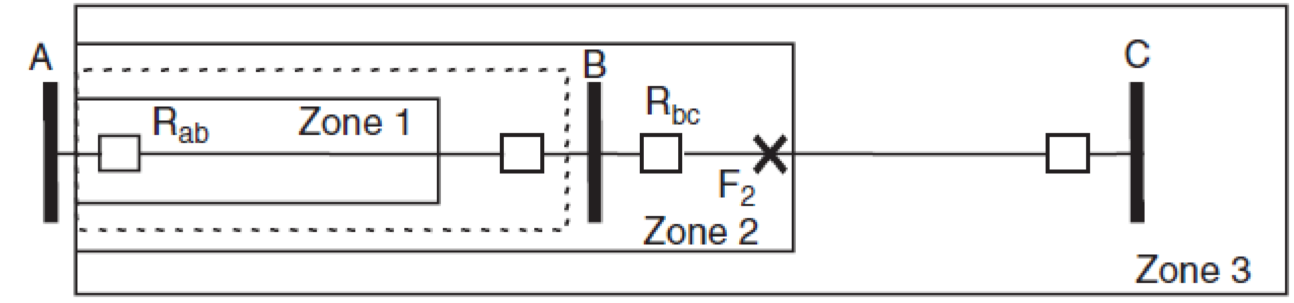
3- Zone Distance Protection of a 2-end System



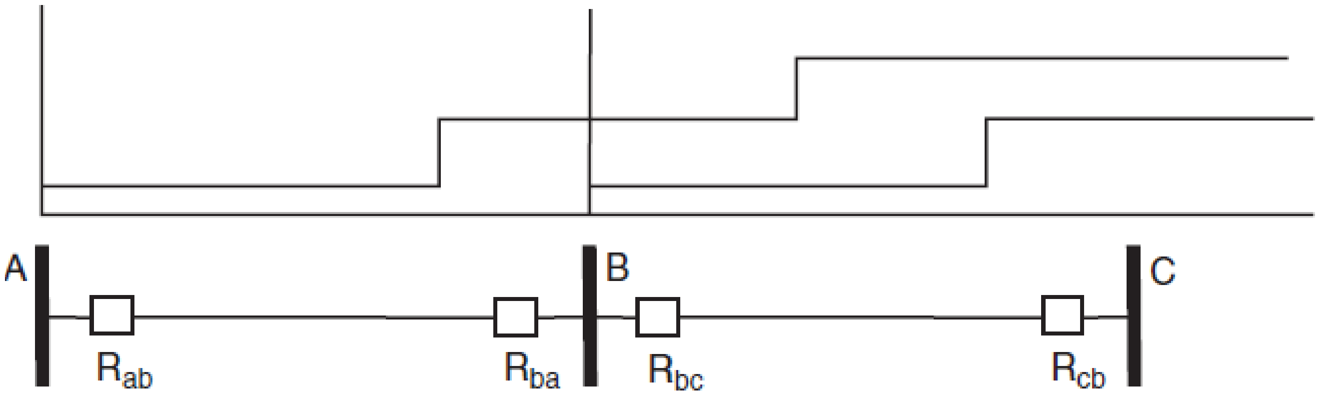
2.3 Primary Protection of the Line

Primary protection of line 1-2 is carried out using 2 steps:

- Instantaneous operation on 80-90% of the line (Zone 1).
- Delayed operation on the remaining of the line plus a part of the next line (zone 2)



(a)



2.4 Constraints to Reach Setting of Zones 2& 3

1. The reach (setting) of Zone 2, Z_{r2}, must cover the protected line plus a reasonable margin

   $Z_{r2} \geq$ 115% - 120% of line

1. Z_{r2} must not overlap with zone 2 of the next line, therefore,

   $Z_{r2} \leq$ 100% of line + 50% of the shortest next line

2. The reach (setting) of Zone 3 (Z_{r3}) must cover all the next lines, therefore,

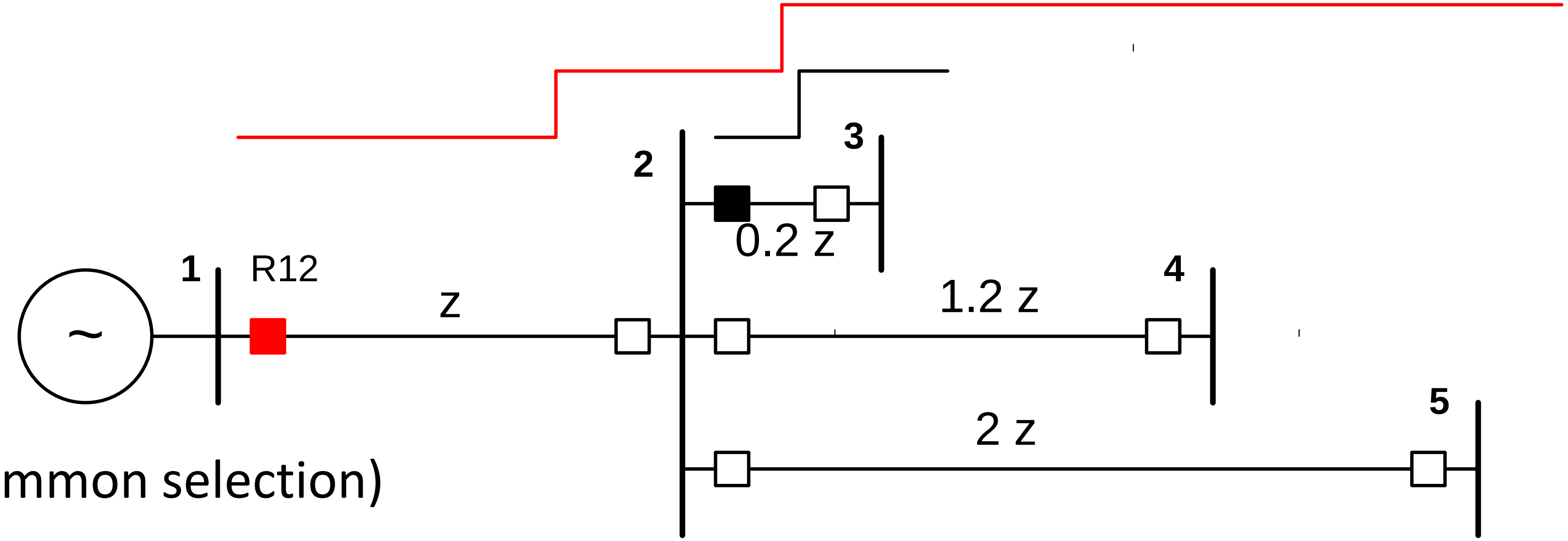
   $Z_{r3} \geq$ 100% of line + 120% of the longest next line

3. The reach (setting) of Zone 3 (Z_{r3}) must not exceed emergency loading impedance, therefore,

   $Z_{r3} \leq \min(Z_{load}) = Z_{emergency}$

Example 3

Select suitable reach settings for the 3-zone distance relay R12 in the following network.



Solution

1. Z_{r1} = 0.8 Z (common selection)
2. Taking Z_{r2} = 1.2 Z will cover the entire line 2-3, therefore,

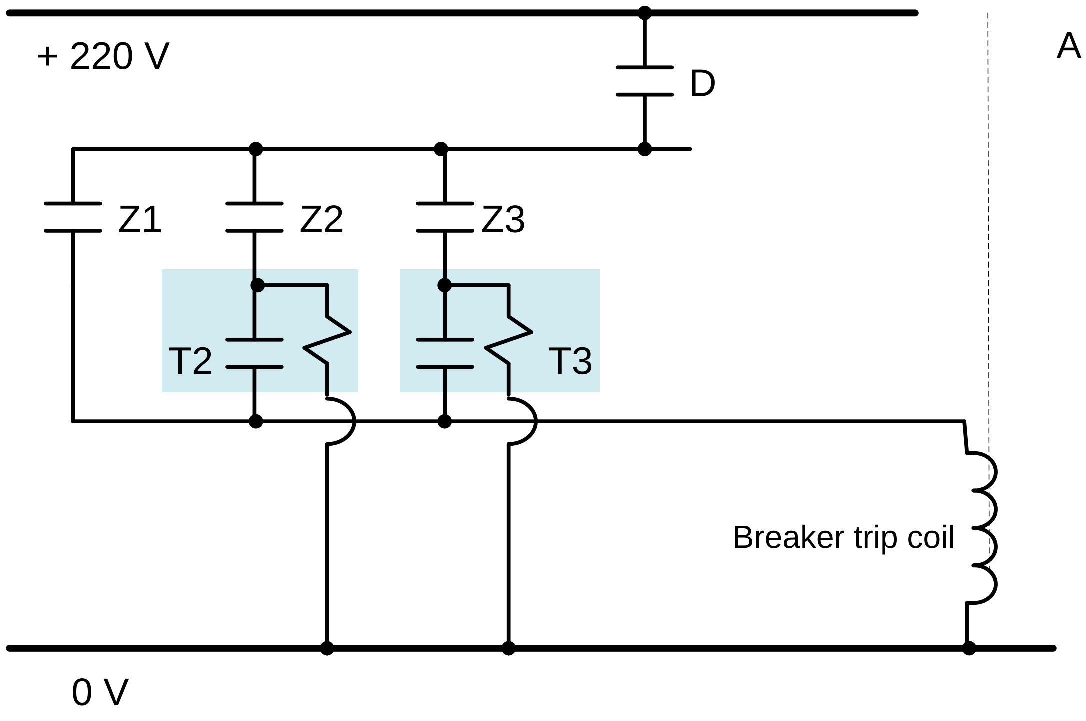
   Z_{r2} = Z + 0.5 (0.2 z) = 1.1 Z (110% of line to prevent the overlap of zone 2 of 2 lines)

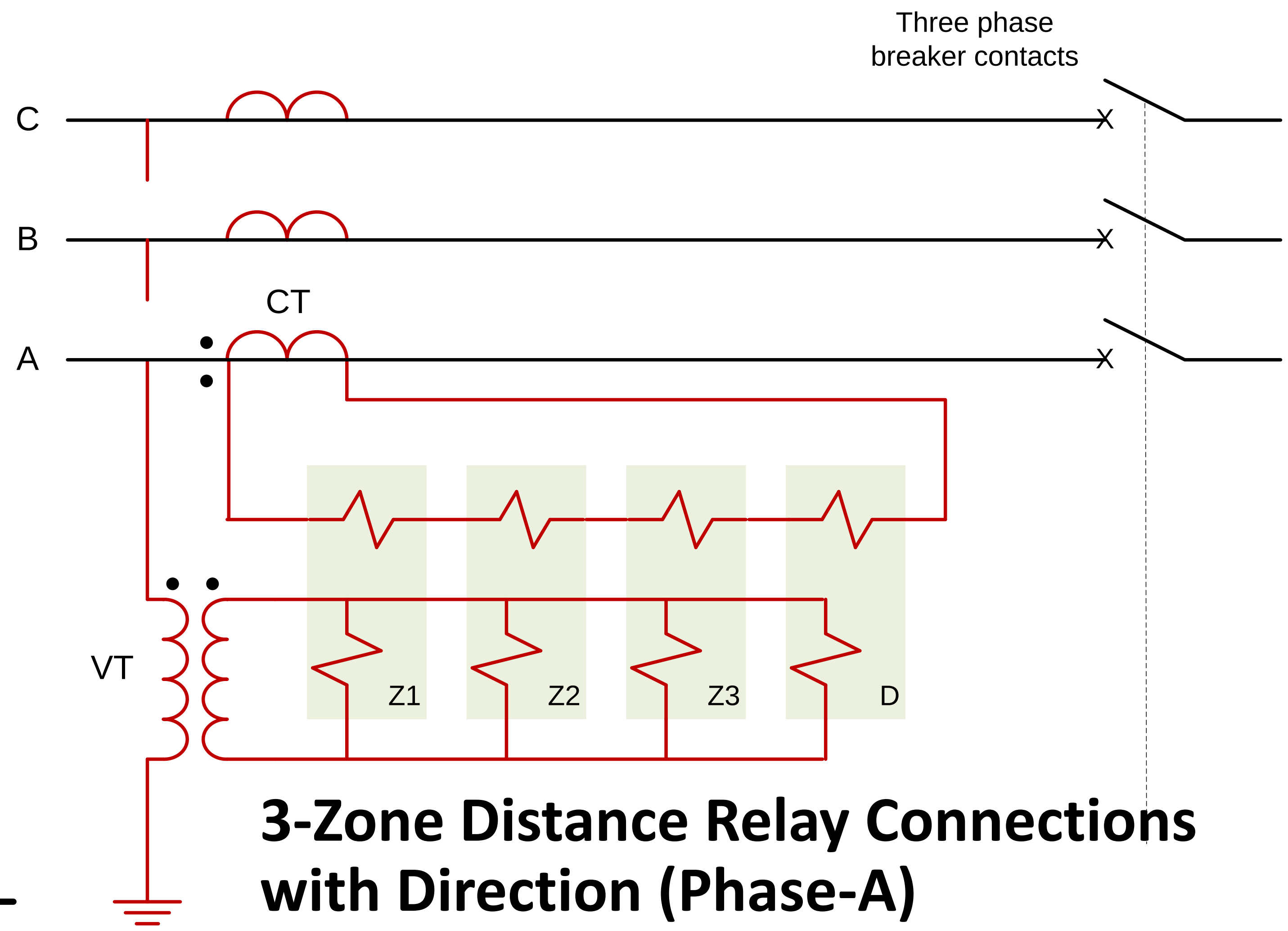
3. Taking Z_{r3} = 2.4 Z will cover only 70% of line 2-5, therefore,

   Z_{r3} = Z + 1.2 (2 Z) = 3.4 Z (340% of line to cover line 2-5)

3. Schematic Diagrams for Relay and Trip Circuit Connections

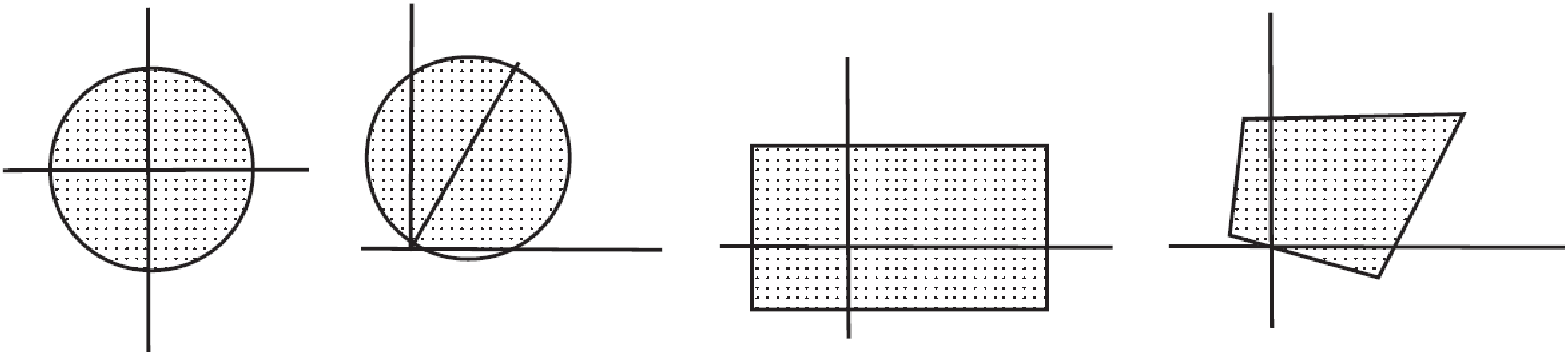
Schematic Trip Circuit Connections





3-Zone Distance Relay Connections with Direction (Phase-A)

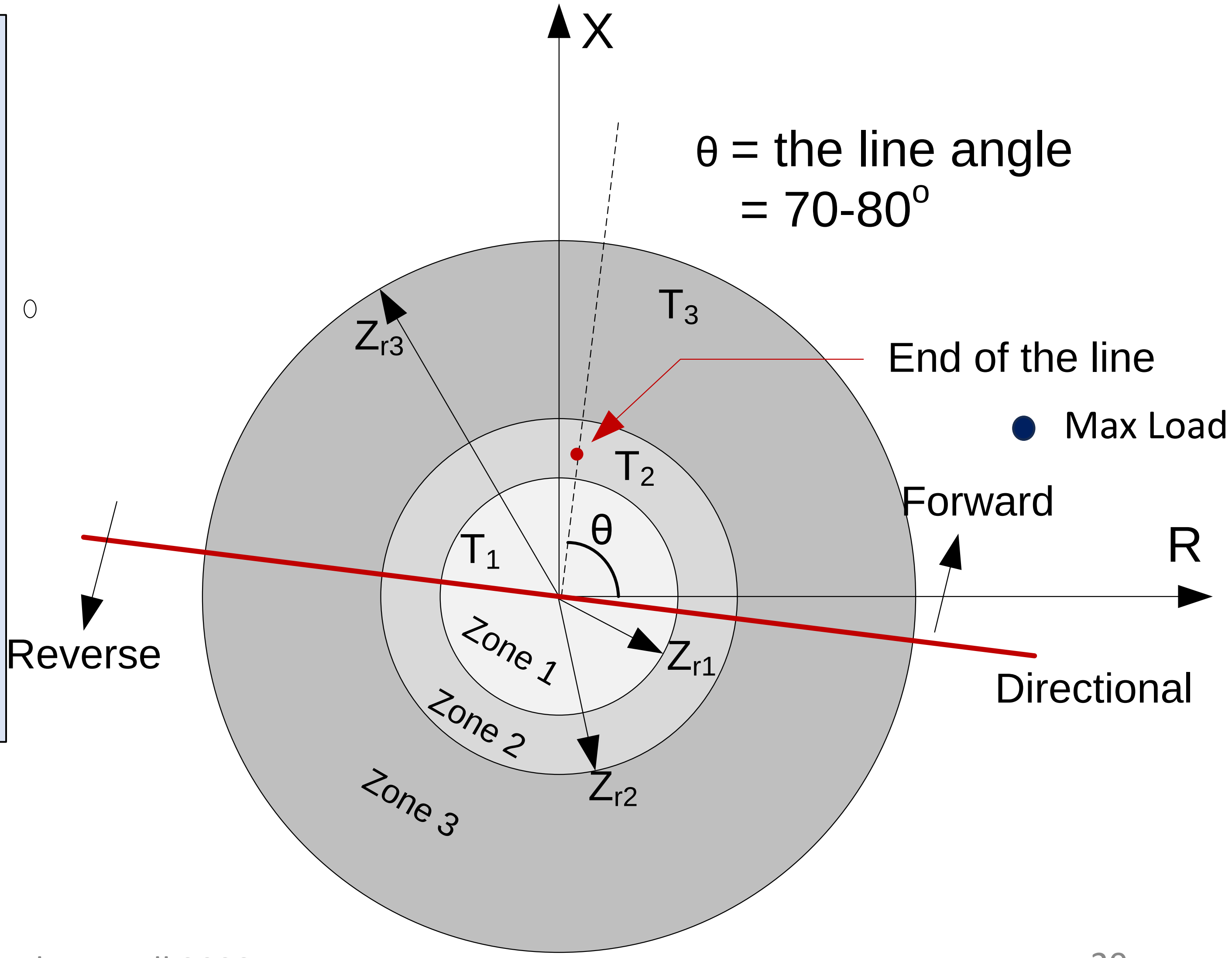
4. Types (Characteristics) of Distance Relays



4.1 3-Zone Impedance / Directional Impedance Relay

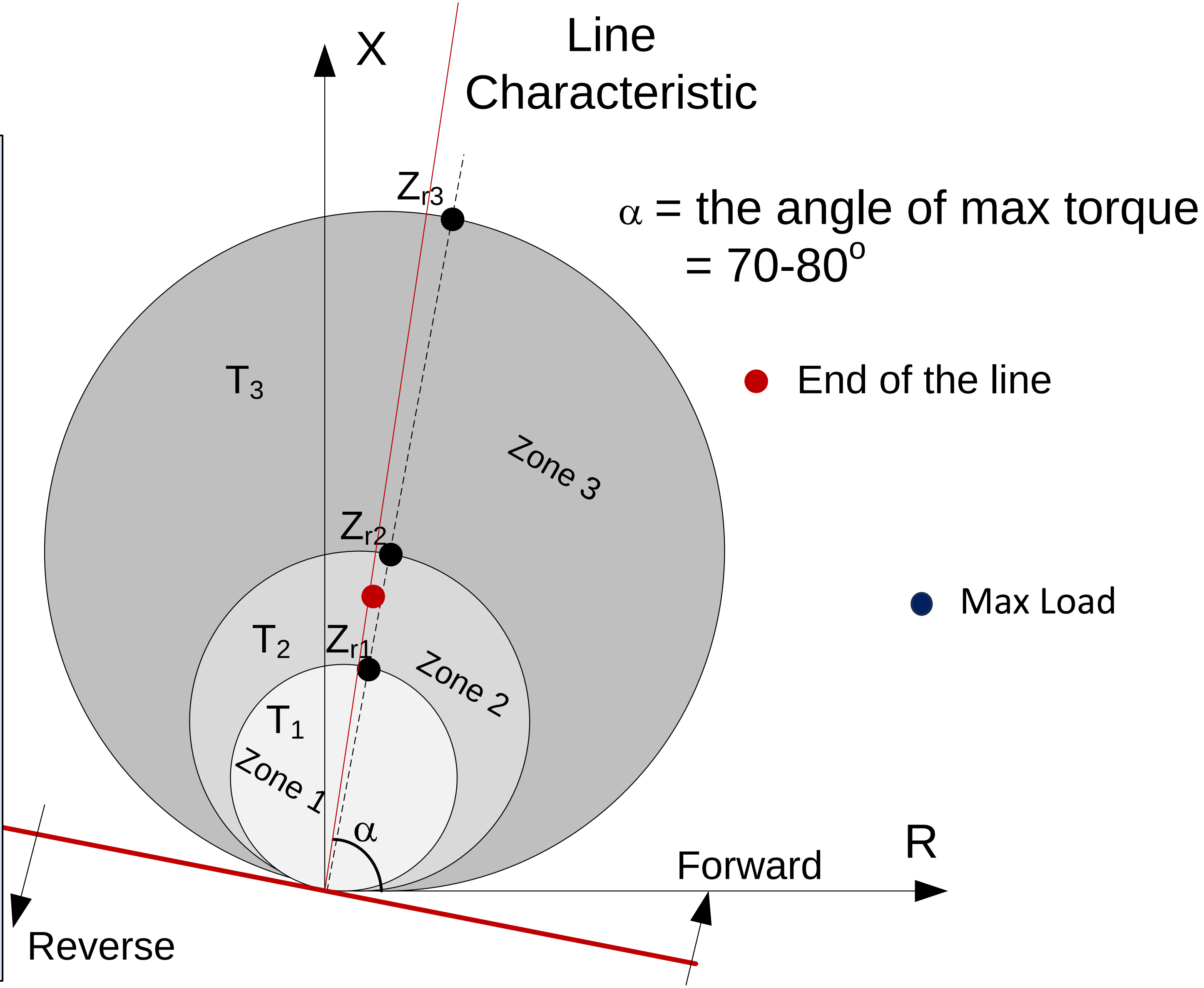
- The most elementary c/c.
- It is non-directional and may need a direction unit.
- Settings: Z_{r1}, Z_{r2}, Z_{r3}, and α.
- The shape is a result of the torque equation of an electromechanical relay
- Trip Condition:

$|V'_R/I'_R| = |Z'_R| < Z_r$

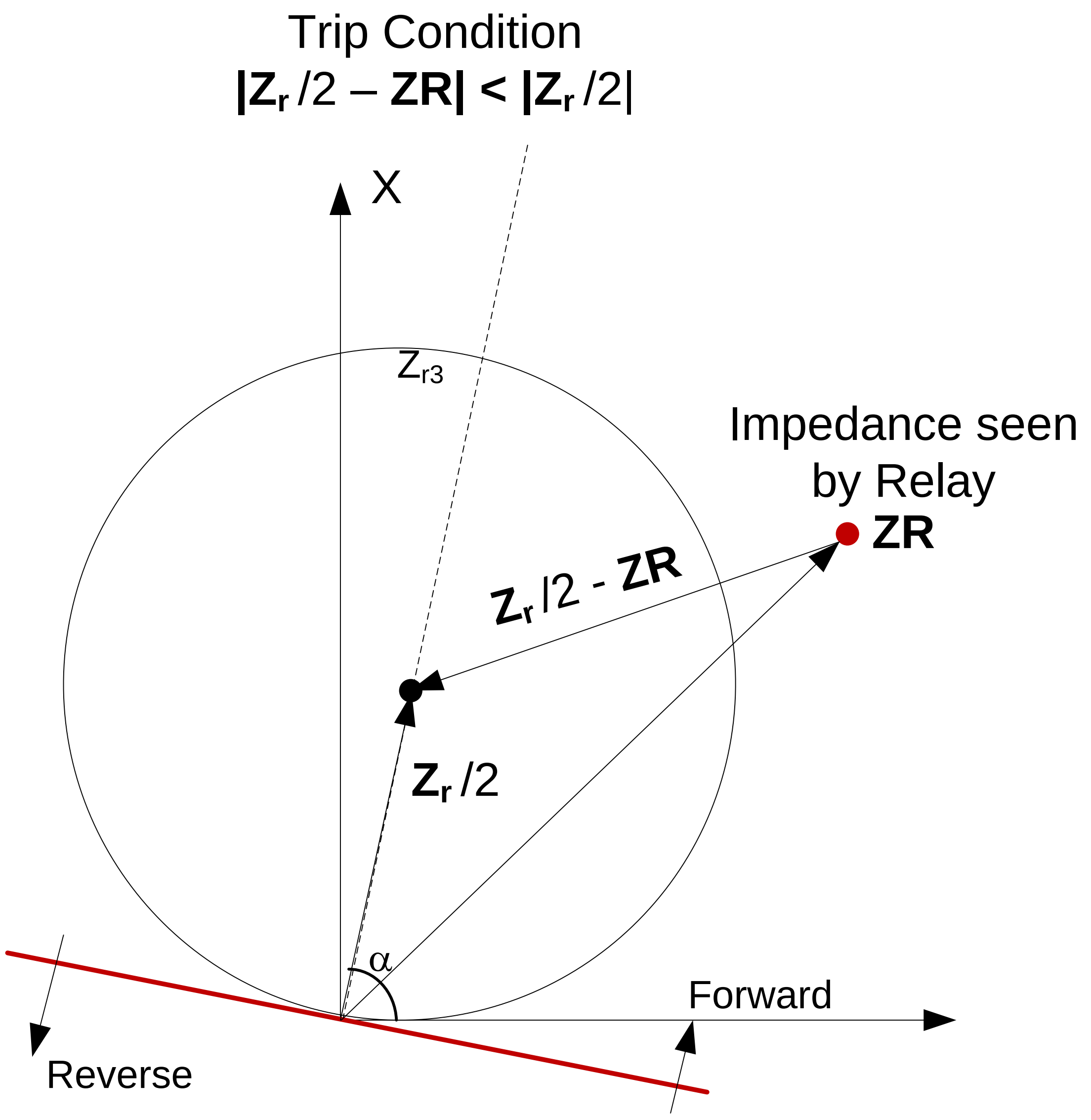


4.2 3-Zone MHO (Admittance) Relay

- An improved version of impedance relay
- Inherently directional.
- Settings: Z_{r1}, Z_{r2}, Z_{r3}, and α.
- The shape is a result of the torque equation of an electromechanical relay.
- Better security compared to impedance relay
- For best performance Max torque angle α = line angle θ



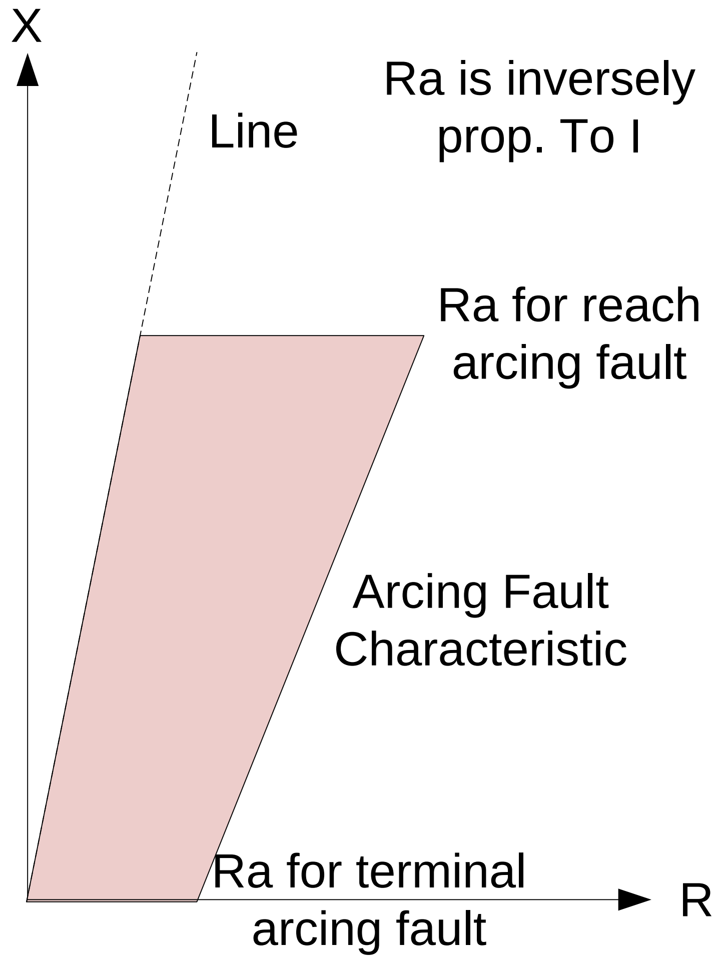
Trip Condition of MHO Relay



Trip Condition

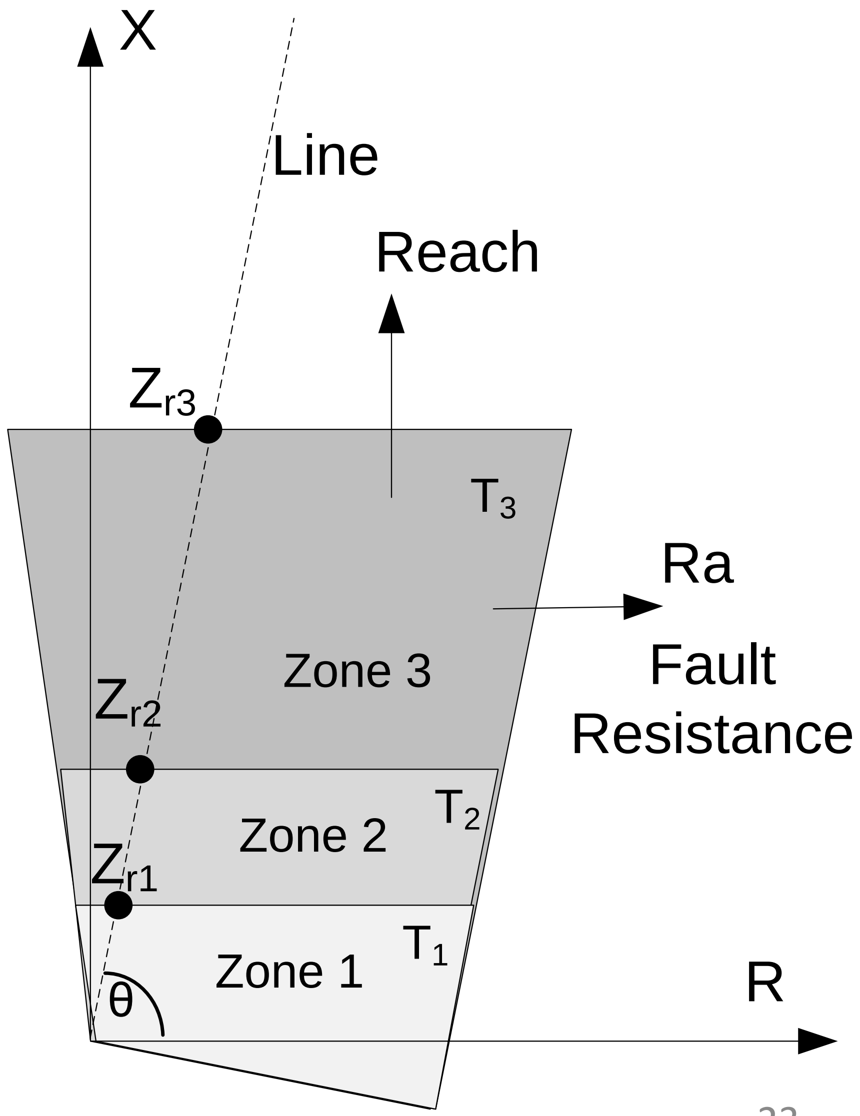
$$|Z_r/2 - \mathbf{ZR}| < |Z_r/2|$$

4.3 Quadrilateral Relay (Digital Only)

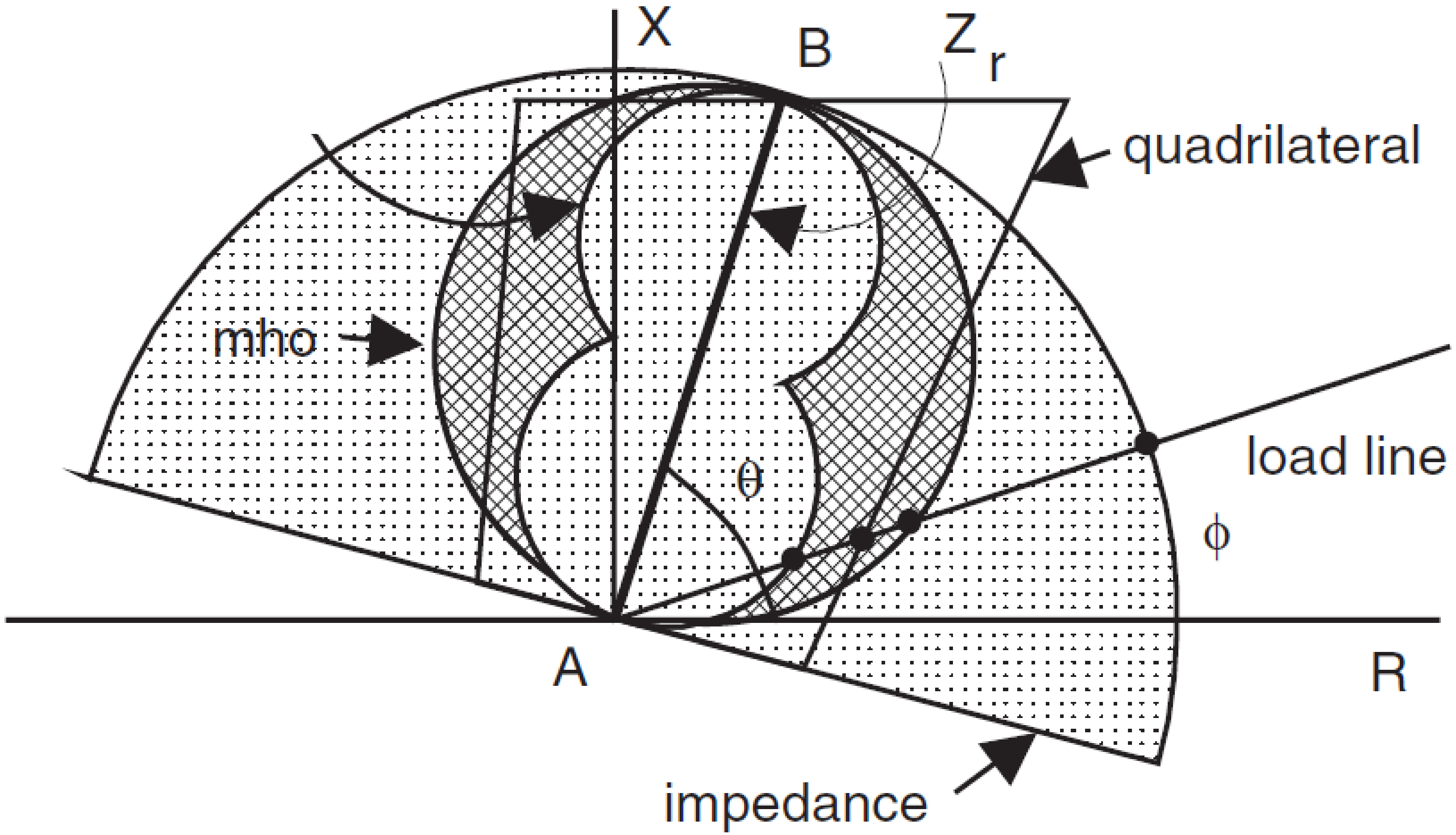


- Implemented using microprocessor
- Inherently directional.
- Settings: Z_{r1}, Z_{r2}, Z_{r3}, θ, and Ra.
- No underreach with arcing fault
- For best performance Max torque angle α = line angle θ

Quadrilateral Characteristics



4.4 Reach of the Three Characteristics



5. Challenges of Distance Relay

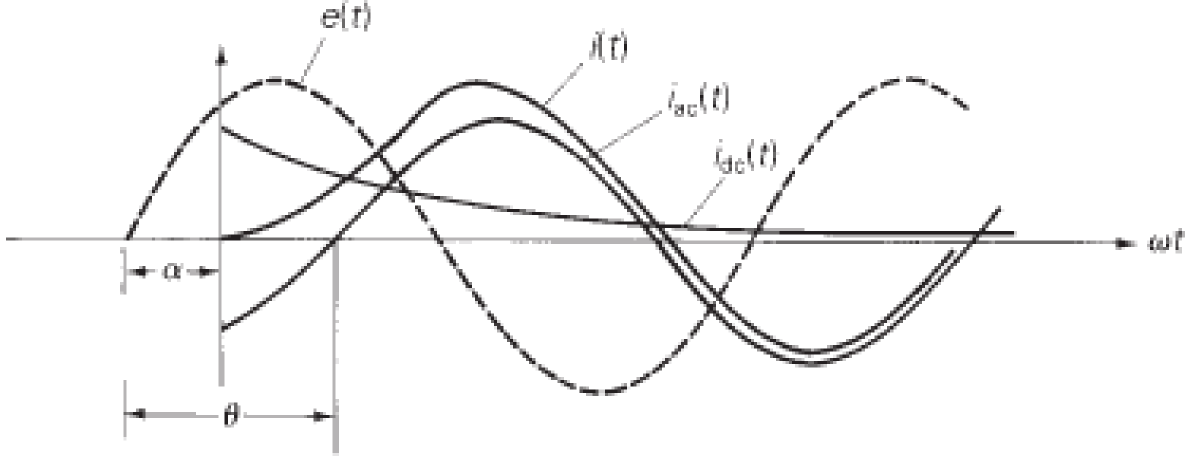
1. Transient Overreach
2. Infeed Underreach
3. Arcing fault Underreach

Terminology

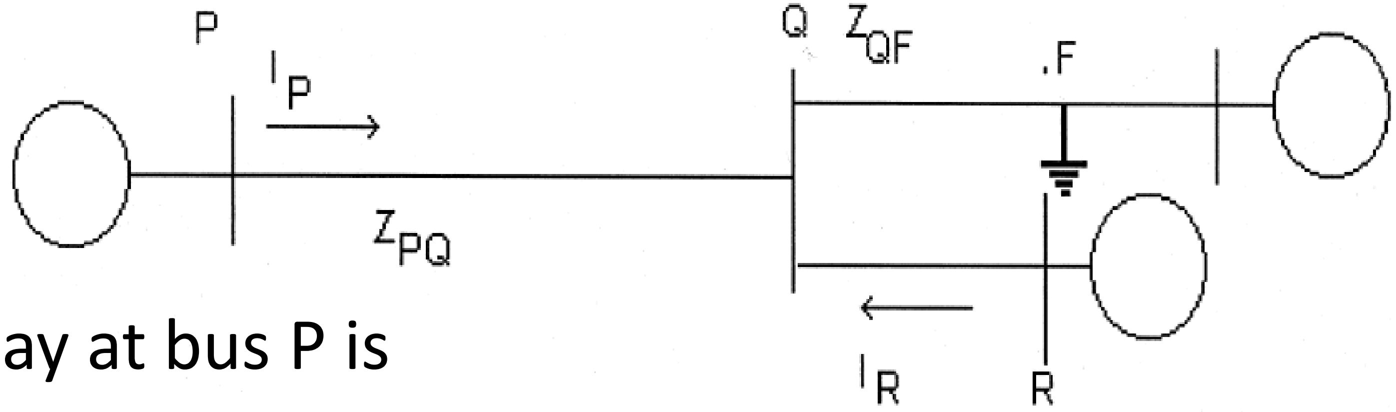
- ***Reach:*** It is the impedance of the transmission line upto which the distance relay protects the line from fault.
- **Underreach**: The Impedance seen by the relay due to fault is more than the actual impedance proportional to distance to fault, leading to operate for a lower value of impedance than that for which they are adjusted to.
- **Overreach**: The impedance measured by the relay is less than the actual impedance proportional to distance to fault, leading to operate for a larger value of impedance than that for which they are adjusted to.

5.1 Transient Overreach

- Transient fault which contains dc offset may cause relay overreach for zone 1, where:
- $I_f = \sqrt{{I_{ac}}^2 + {I_{dc}}^2}$ => $I_f > I_{ac}$
- Assuming I_{dc} = 0.5 I_{ac}
- I_f= 1.12 I_{ac}
- ZR without dc offset = V/ I_{ac}
- ZR with dc offset = V/ (1.12 I_{ac}) = 0.893 V/ I_{ac} which gives 11% overreach
- Setting zone 1 at 80-85 % to compensate for overreach
- e.g., the fault at 90% of the line is seen to be at 70%.



5.2 Infeed Underreach



- The impedance measured by relay at bus P is

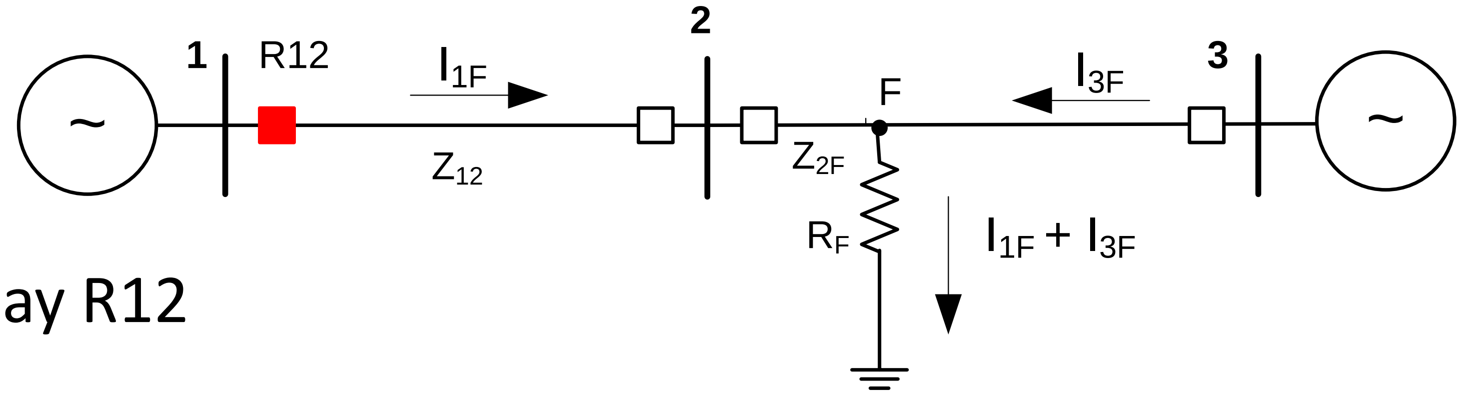
  $Z_P = V_P / I_P$

  $V_P = Z_{PQ} I_P + Z_{QF} (I_P + I_R)$

  $Z_P = Z_{PQ} + Z_{QF} (1 + I_R/I_P)$

- The measured impedance > actual impedance
- The fault at F therefore appears to be further away than it actually is.
- It may lead to uncomplete coverage of the next line (underreach of Zone-3)

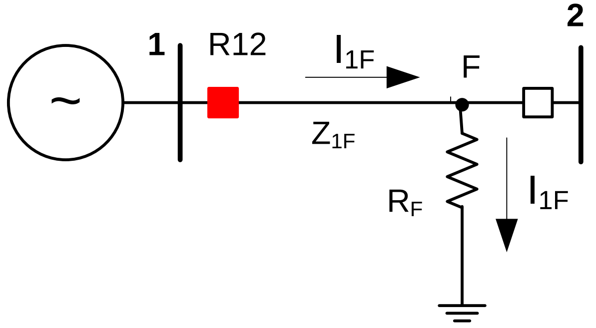
5.3 Underreaching on Arcing Faults



For the upper figure

- The impedance measured by relay R12

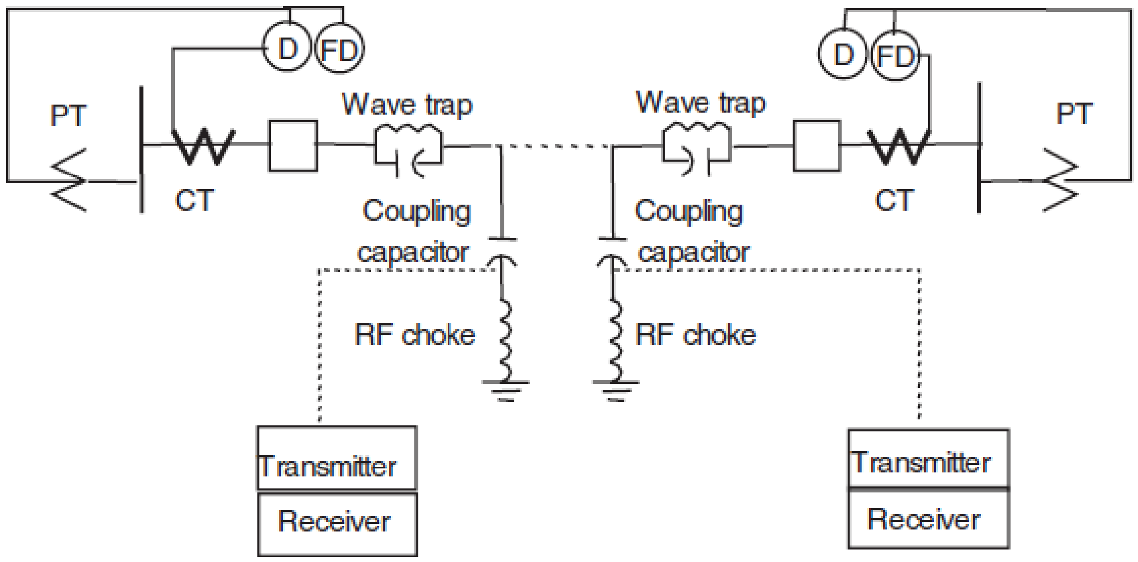
  $$Z_R = V_1 / I_{1F}$$
  $$V_1 = Z_{12}\, I_{1F} + Z_{2F}\, I_{1F} + R_F\,(I_{1F} + I_{3F})$$
  $$Z_R = Z_{12} + Z_{2F} + R_F\,(1 + I_{3F}/I_{1F})$$



- The measured impedance > actual impedance = $Z_{12} + Z_{2F}$
- The fault at F therefore appears to be further away than it is.
- It may lead to uncomplete coverage of the protected line or the next line (underreach of the 3 Zones).
- It is Max for MHO, Moderate for Impedance and None for Quadrilateral.

6. Pilot Protection

- The nonpilot distance protection provides fast protection (instantaneous) for only 60 % of the line (20% from each end is covered by zone-2 to compensate for measured impedance errors).
- Communication between the two ends is used to ensure fast operation on the whole line.



7. Example of a Commercial Distance Relay

Protection Functions Overview					
ANSI	**IEC 61850**	**Features**	**P441**	**P442**	**P444**
21P	PDIS	Quadrilatéral full scheme phase distance (6 zones)	•	•	•
21G	PDIS	Quadrilatéral full scheme ground distance (6 zones)	•	•	•
50/51/67	OcpPTOC / RDIR	Directional / non-directional phase overcurrent (2 stages)	•	•	•
50N / 51N / 67N	EfdPTOC / RDIR	Directional / non-directional stand by earth fault (2 stages)	•	•	•
67N	EfaPSCH	Channel aided directional earth fault protection (DEF)	•	•	•
32N		Directional zero sequence power protection	•	•	•
67/46	NgcPTOC / RDIR	Directional / non-directional negative sequence overcurrent	•	•	•
27	PTUV	Undervoltage (4 stages, 1st stage DT and IDMT)	•	•	•
59	PTOV	Overvoltage (4 stages, 1st stage DT and IDMT)	•	•	•
37		3-phase undercurrent (2 stages)	•	•	•
81U		Underfrequency (4 stages)	•	•	•
81O		Overfrequency (2 stages)	•	•	•
49	PTTR	Thermal overload protection	•	•	•
50 / 27	PSOF	Switch on to fault / trip on reclose (SOTF/TOR)	•	•	•
78 / 68	RPSB	Power swing blocking & Out of step tripping (using PSL)	•	•	•