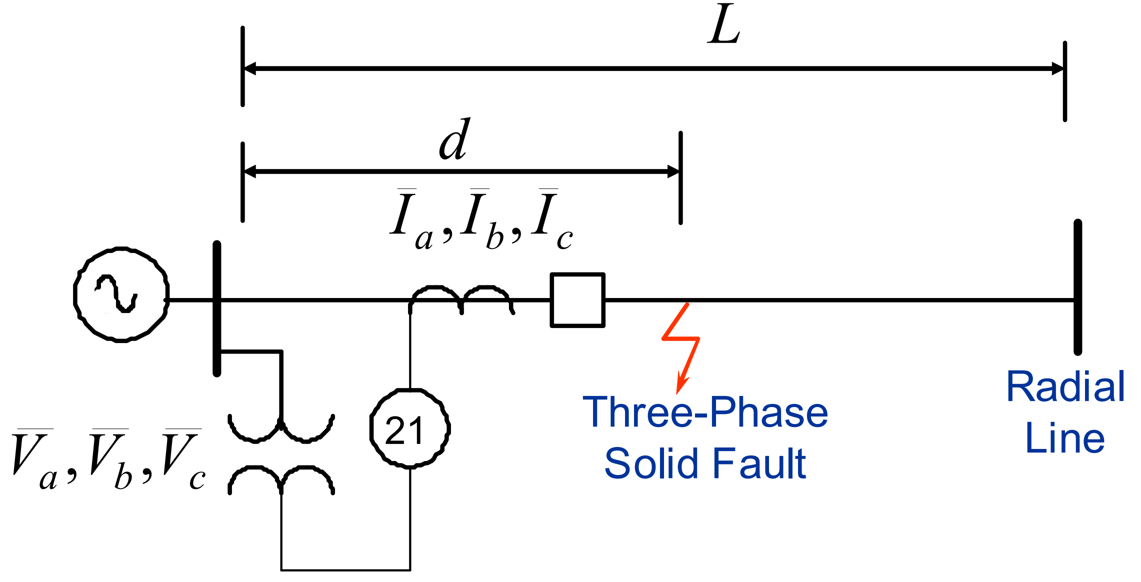
Distance Relay Principle

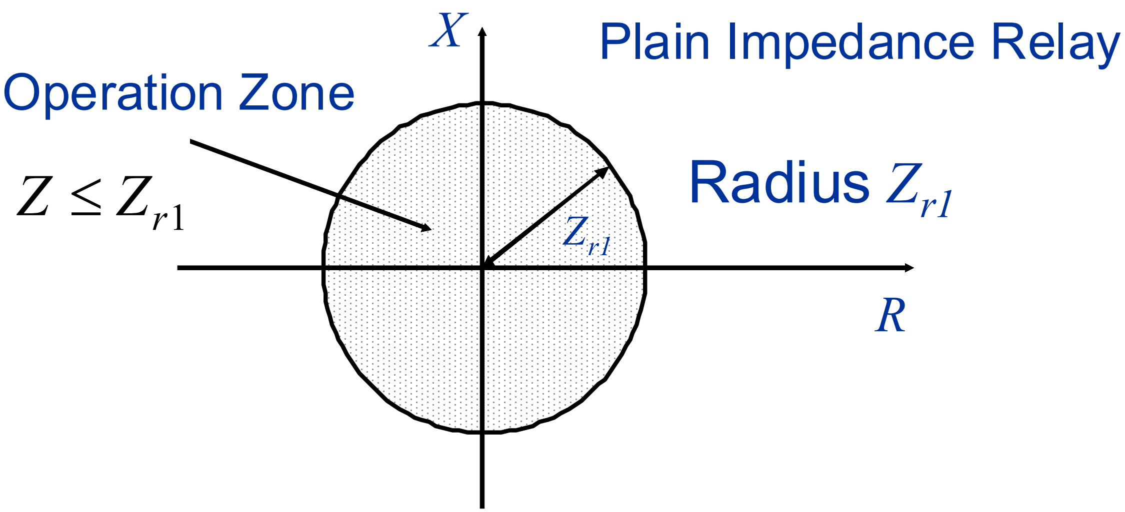


Suppose Relay Is Designed to Operate When:

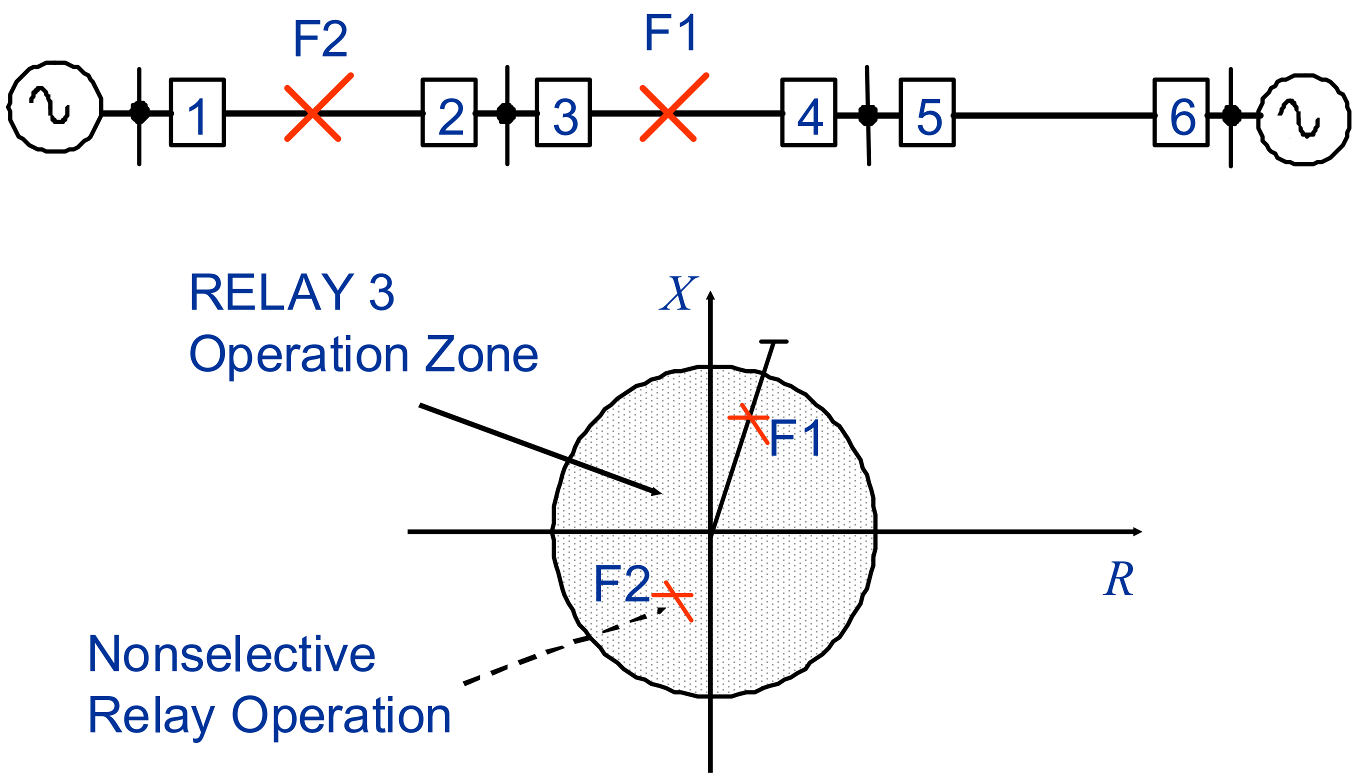
$$|\bar{V}_a| \leq (0.8)\,|\bar{Z}_{L1}|\,|\bar{I}_a|$$

The Impedance Relay Characteristic

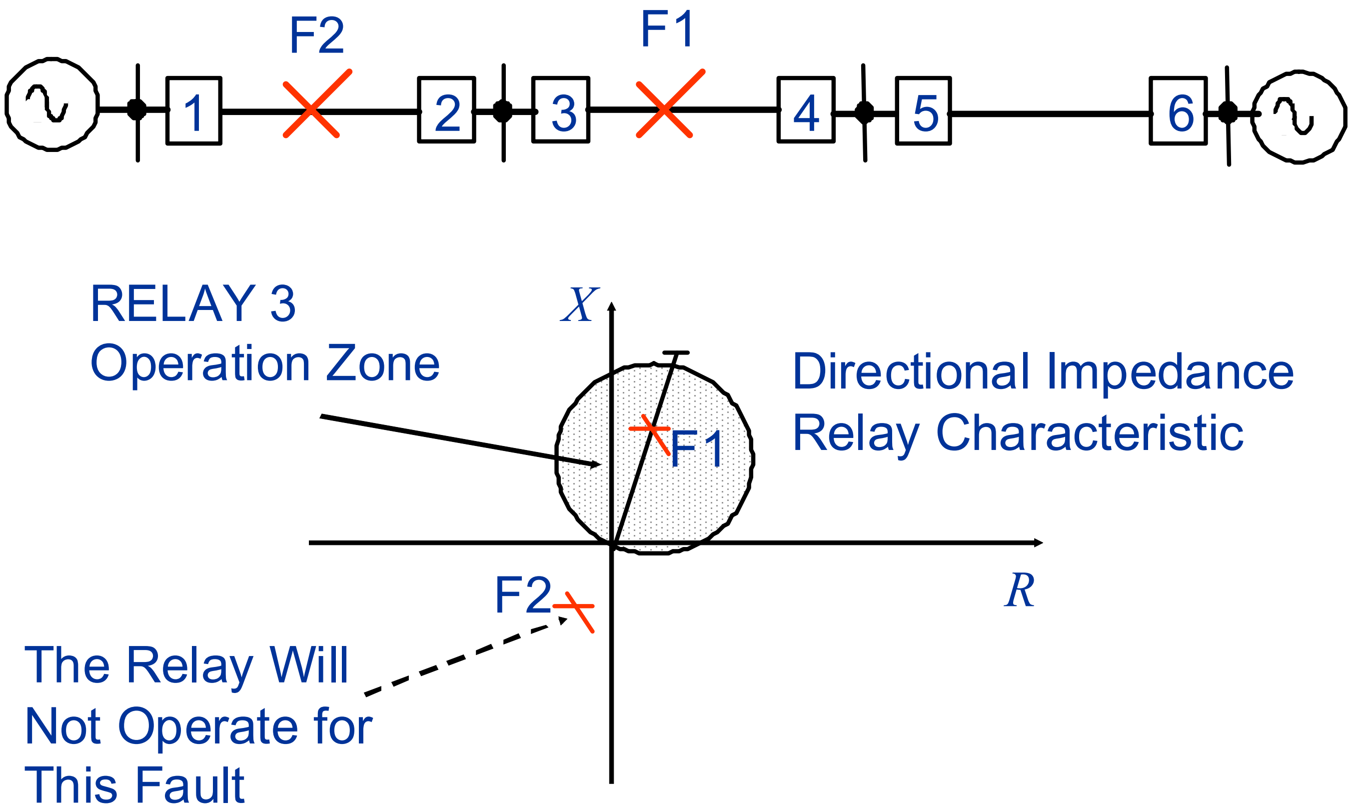
$$R^2 + X^2 \leq Z_{r1}^2$$



Need for Directionality



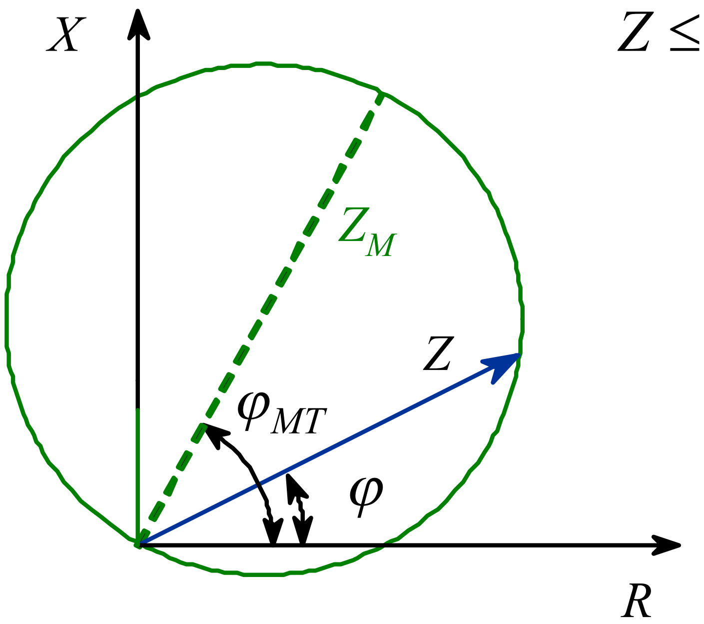
Directionality Improvement



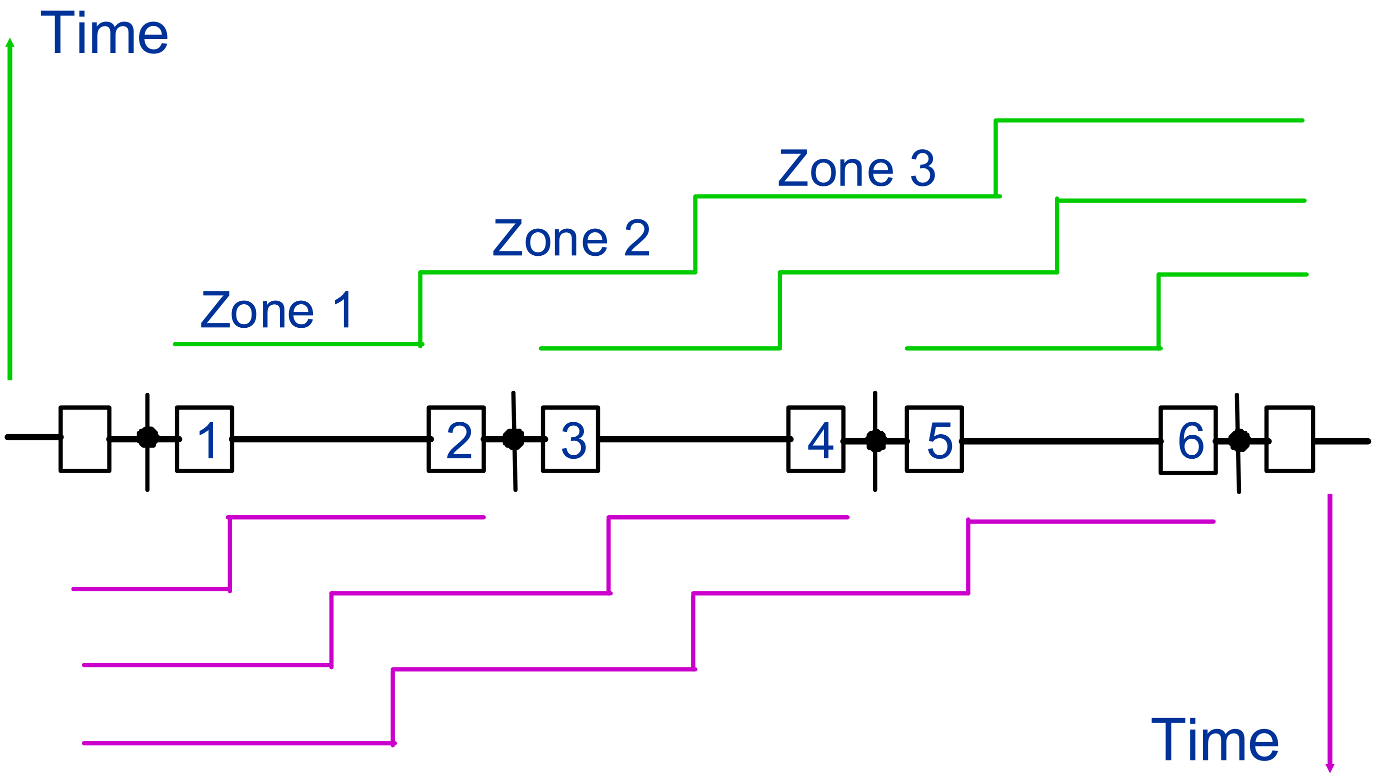
Mho Element Characteristic (Directional Impedance Relay)

Operates when: $V \le I\,Z_M \cos(\varphi - \varphi_{MT})$

$$Z \le Z_M \cos(\varphi - \varphi_{MT})$$

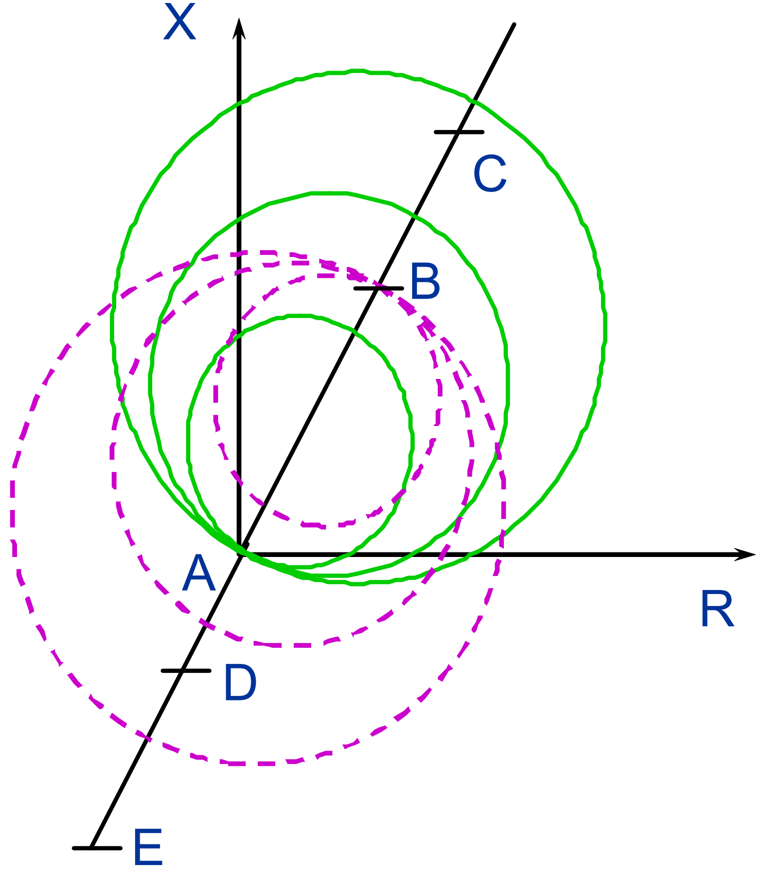


Three-Zone Distance Protection

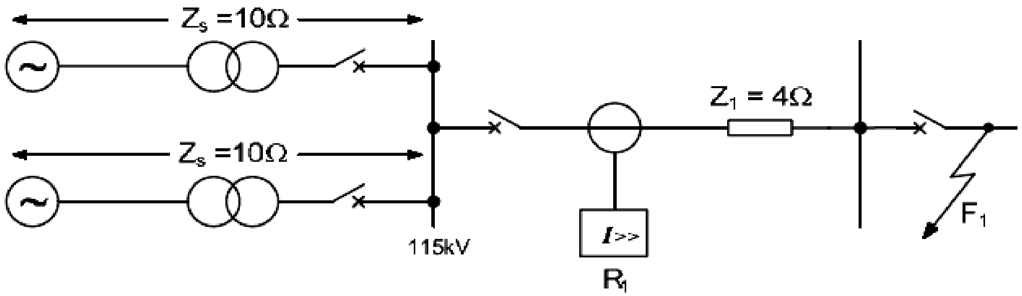


Zone 1 Is Instantaneous

Line Protection With Mho Elements



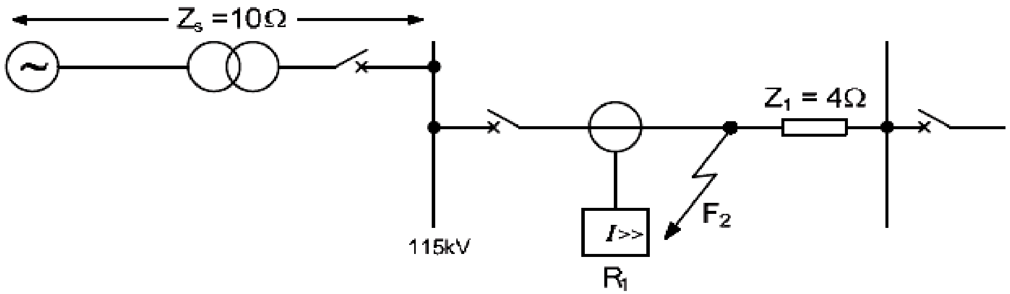
حفاظت دیستانس



$$I_{F1} = \frac{115 \times 10^3}{\sqrt{3} \times (5+4)} = 7380\,A$$

Relay R1 setting >7380A

(a)



$$I_{F2} = \frac{115 \times 10^3}{\sqrt{3} \times 10} = 6640\,A$$

(b)

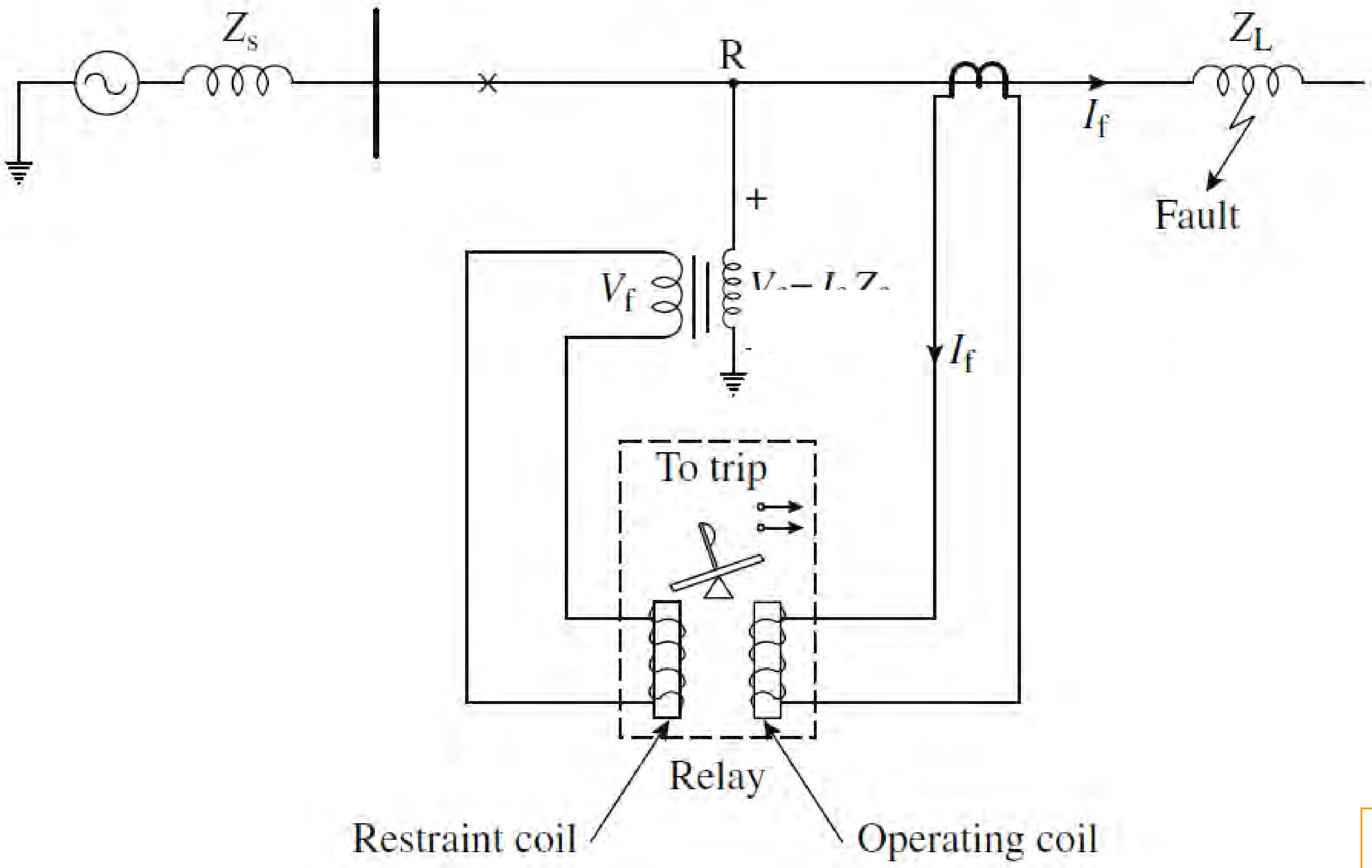
Therefore, for relay operation for line faults,
Relay current setting <6640A and >7380A
This is impractical, overcurrent relay not suitable.
Must use Distance or Unit Protection

Figure 11.1: Advantages of distance over overcurrent protection

مزیت عمده حفاظت دیستانس بر حفاظت اضافه جریان:

مستقل بودن محدوده حفاظتی از تغییرات امپدانس منبع

Relay based on an amplitude comparator:



It operates when the ampere-turns of the current circuit are greater than the ampere-turns of the voltage circuit.

$$\frac{V}{I} \le Z_R \Rightarrow I \ge \frac{V}{Z_R} \; or$$

$$(S_o = IZ_R) \ge (S_r = V)$$

The following analysis shows that for two signals, S_0 and S_r , which are to be compared in magnitude, there exist two other signals S_1 and S_2 that can be compared by phase.

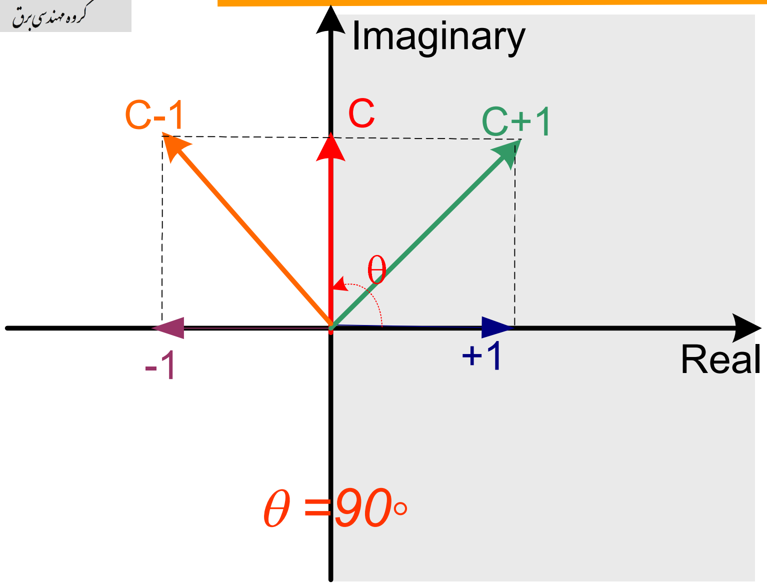
$$S_o = S_1 + S_2$$
$$S_r = S_1 - S_2$$

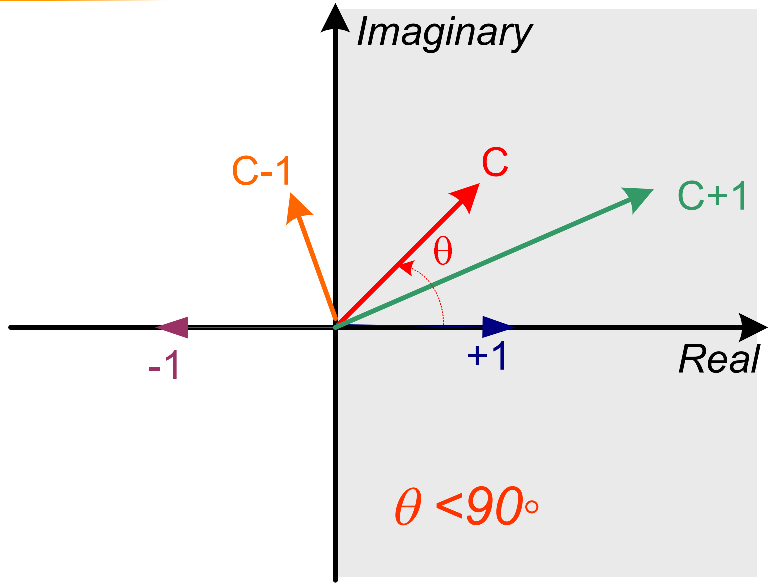
$$\Rightarrow \quad S_1 = \frac{S_o + S_r}{2} \qquad S_2 = \frac{S_o - S_r}{2}$$

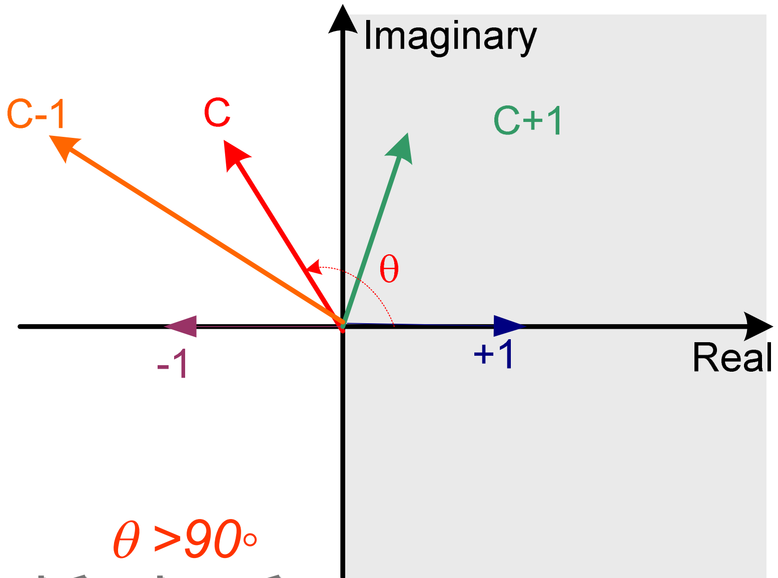
$$|S_0| \geq |S_r|$$
$$|S_1 + S_2| \geq |S_1 - S_2|$$
$$S_1 / S_2 = C$$

$$\Rightarrow \quad |C + 1| \geq |C - 1|$$

حفاظت دیستانس







$C\angle\theta = (S1\angle\alpha)/(S2\angle\beta)$ ⇨ $-90^\circ \le \theta \le +90^\circ$.

$-90^\circ \le \alpha-\beta \le +90^\circ$

⇕

$|S_0| \ge |S_r|$

Impedance relay

$$S_0 = I Z_R$$

$$S_r = K V$$

The constant K takes into account the transformation ratios of the CTs and VTs

$$S_1 = K V + I Z_R$$

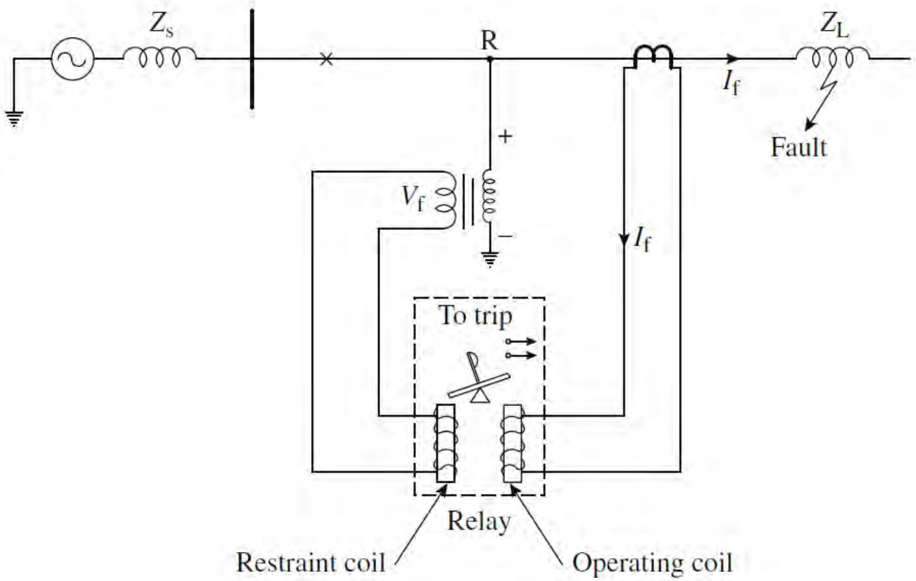
$$S_2 = -K V + I Z_R$$

Dividing by K*I* , gives:

$$S_1 = Z + Z_R / K$$

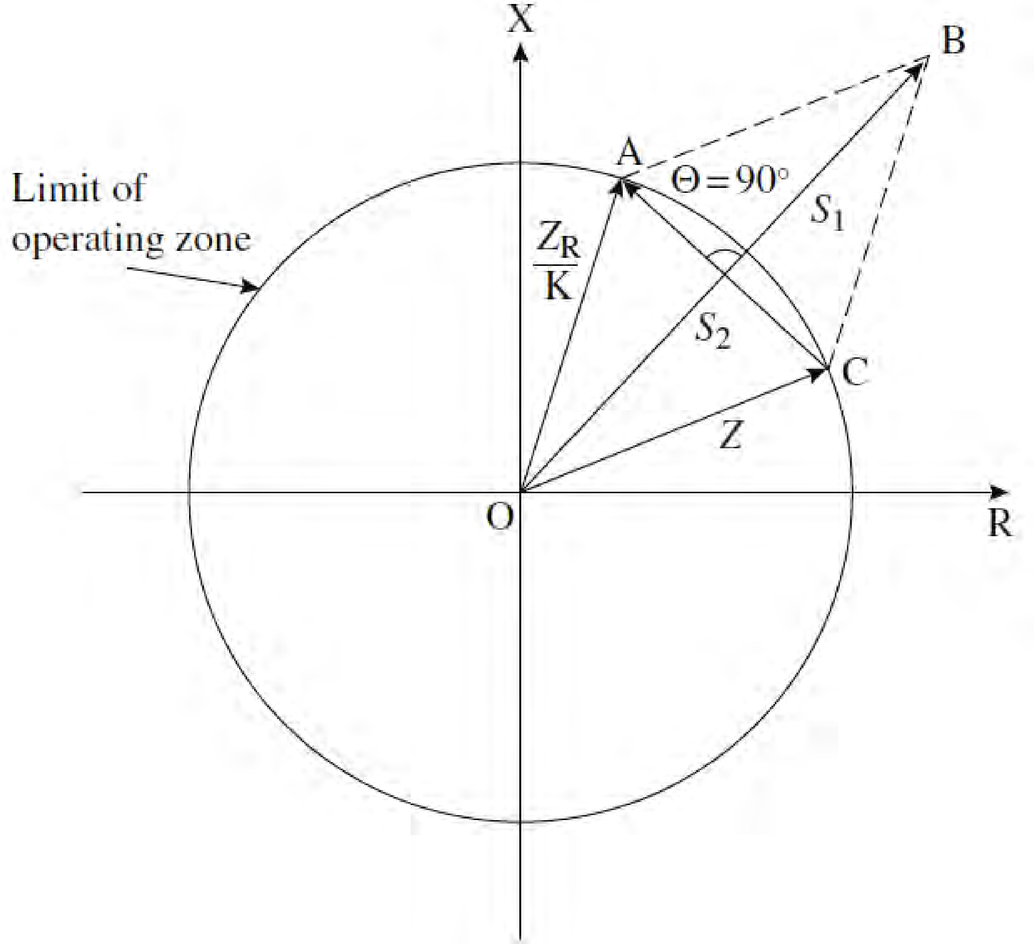
$$S_2 = -Z + Z_R / K$$

$$Z = V / I$$

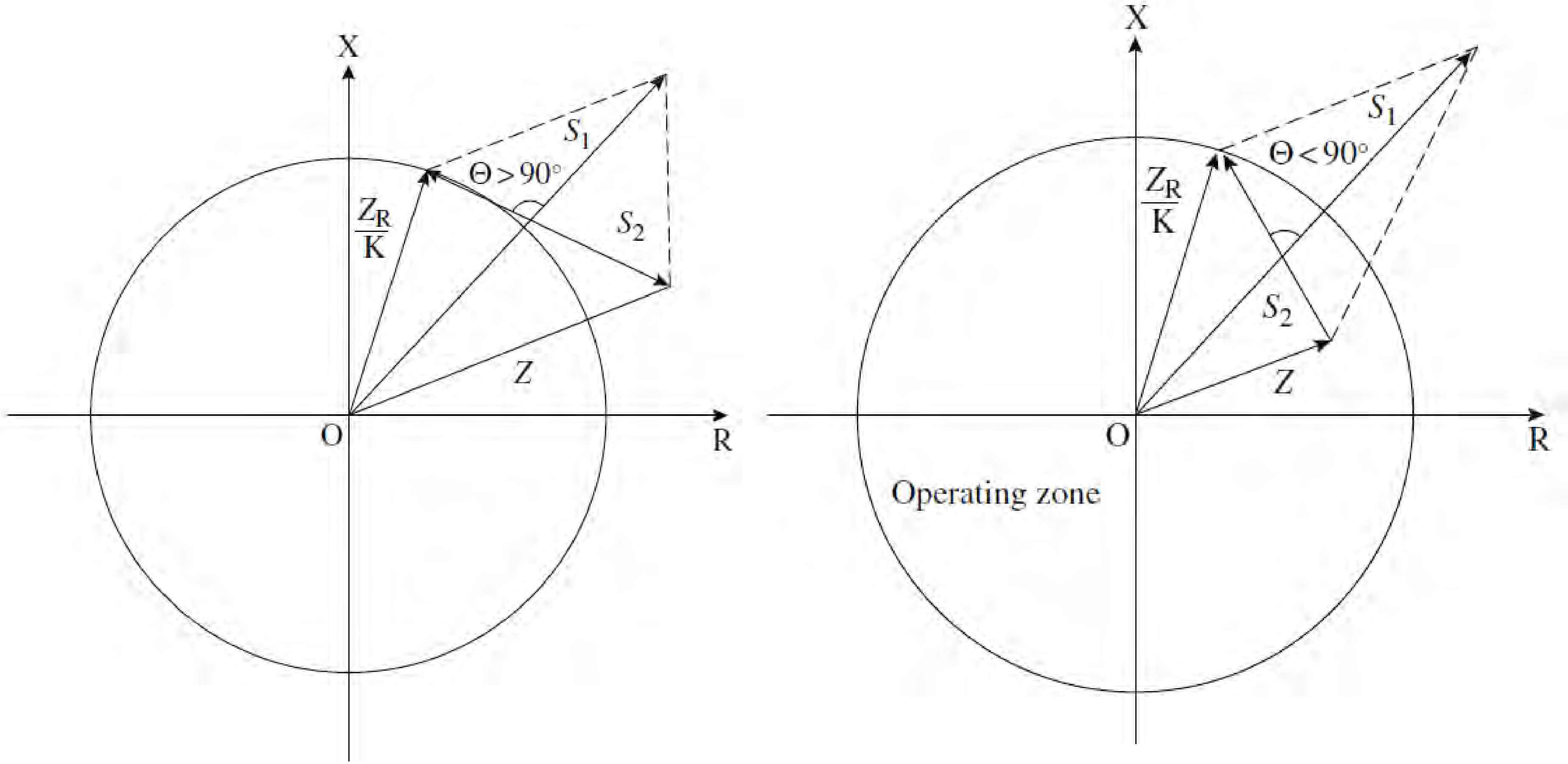


Impedance relay

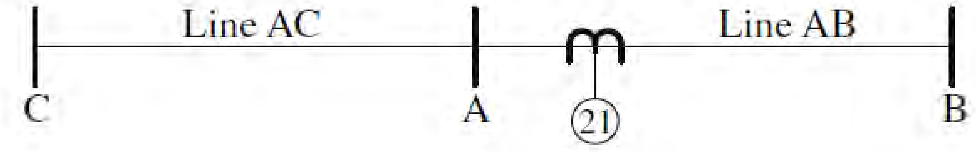
Drawing Z_R/K in the R-X plane, the operating characteristic of the relay is determined by the locus of the points Z such that θ, the phase angle between $S1$ and $S2$, is given by $-90° \leq \theta \leq +90°$.



Impedance relay

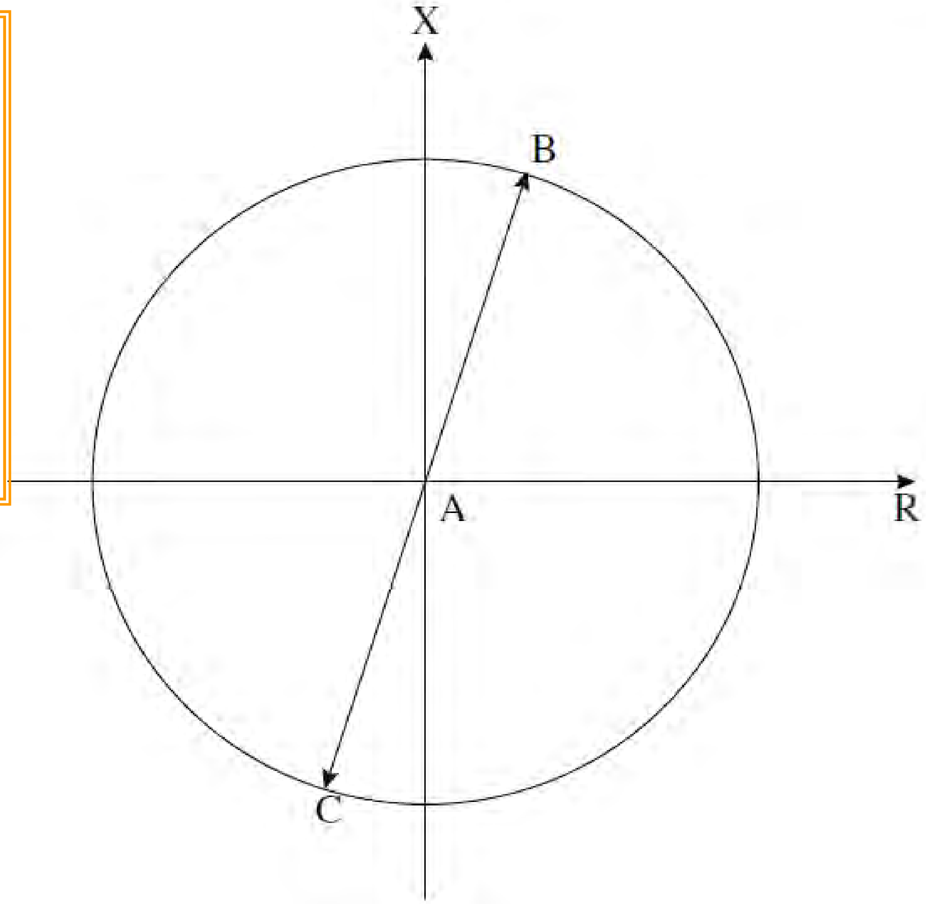


Impedance relay



Three main disadvantages:

1. **It is not directional;**
2. **It is affected by the arc resistance.**
3. **It is highly sensitive to oscillations on the power system**

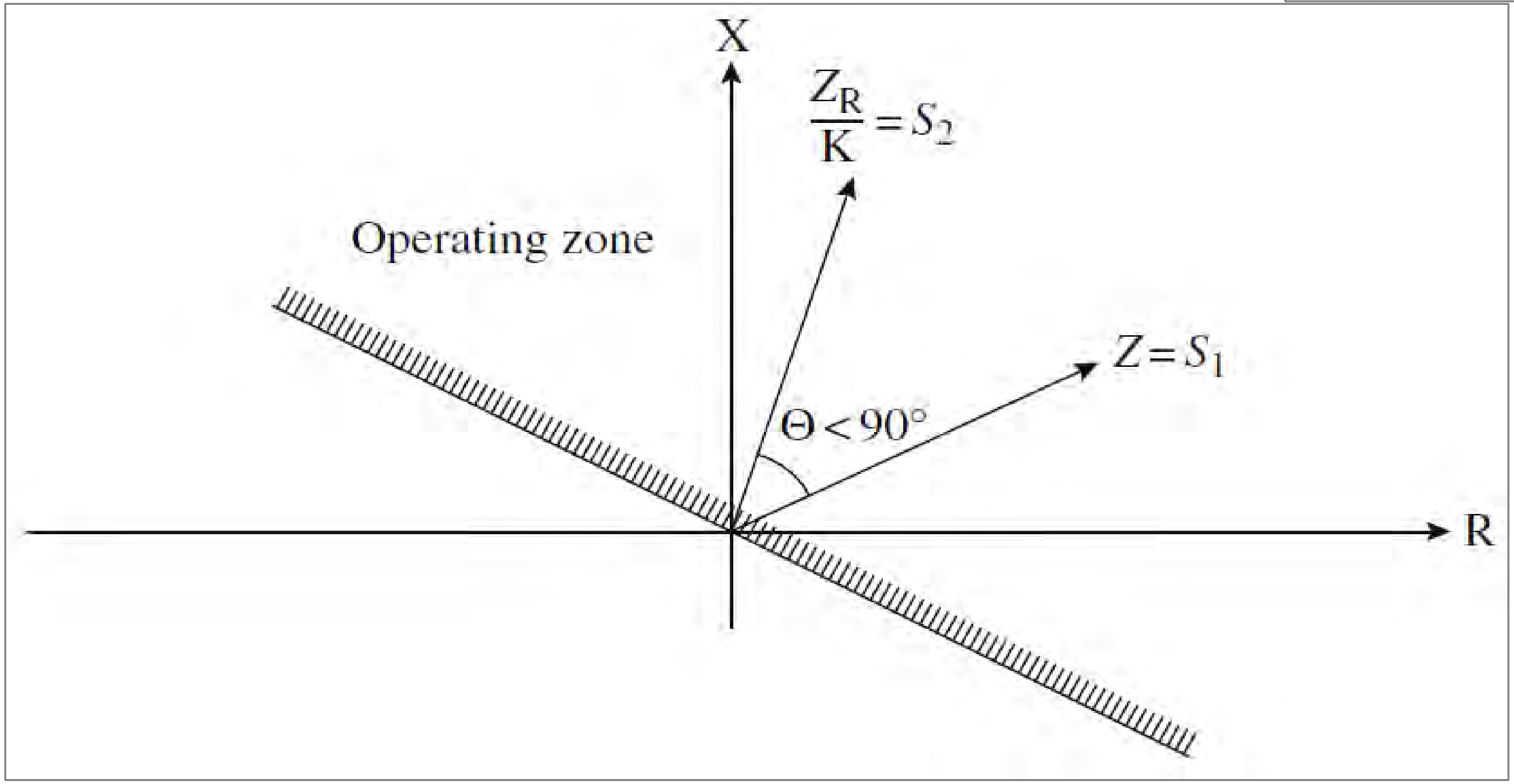


Directional relay

$$S_1 = KV$$
$$S_2 = Z_R I$$

Dividing by K*I* , and defining *Z*=*V/I*, gives

$$S_1 = Z$$
$$S_2 = Z_R / K$$



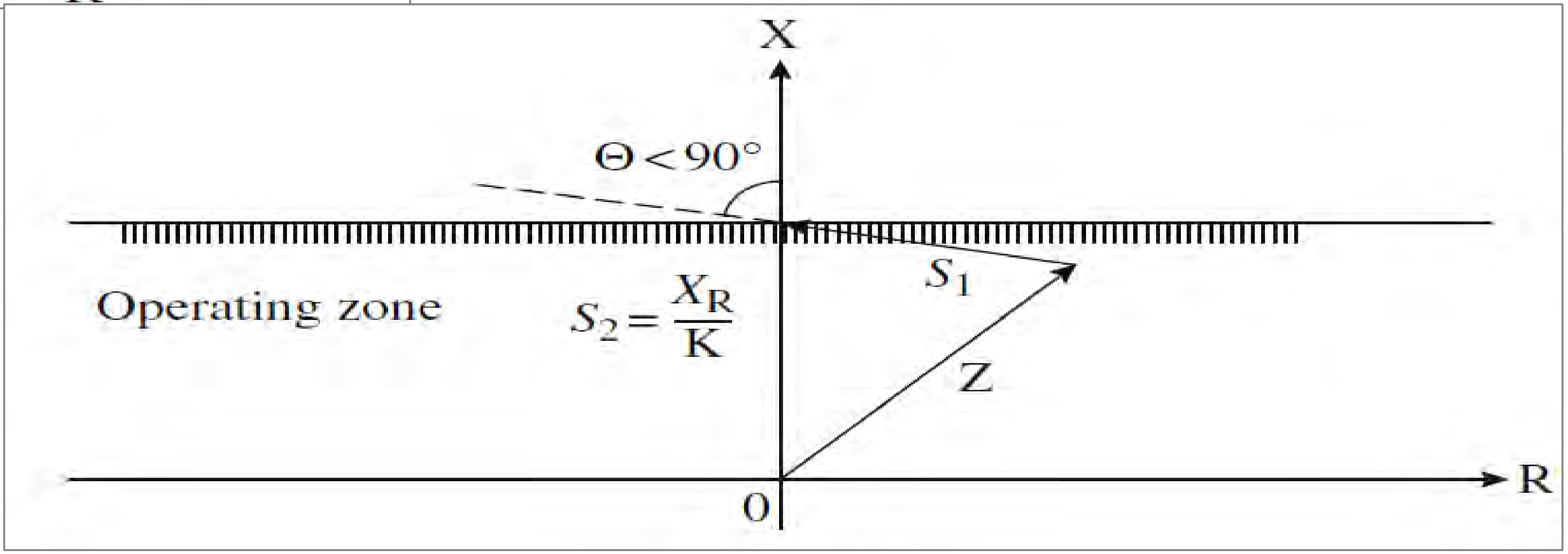
Reactance relay

To Measure Only the Reactive Component of the Line Impedance

$$S_1 = -KV + X_R I$$
$$S_2 = X_R I$$

dividing by KI

$$S_1 = -Z + X_R/K$$
$$S_2 = X_R/K$$



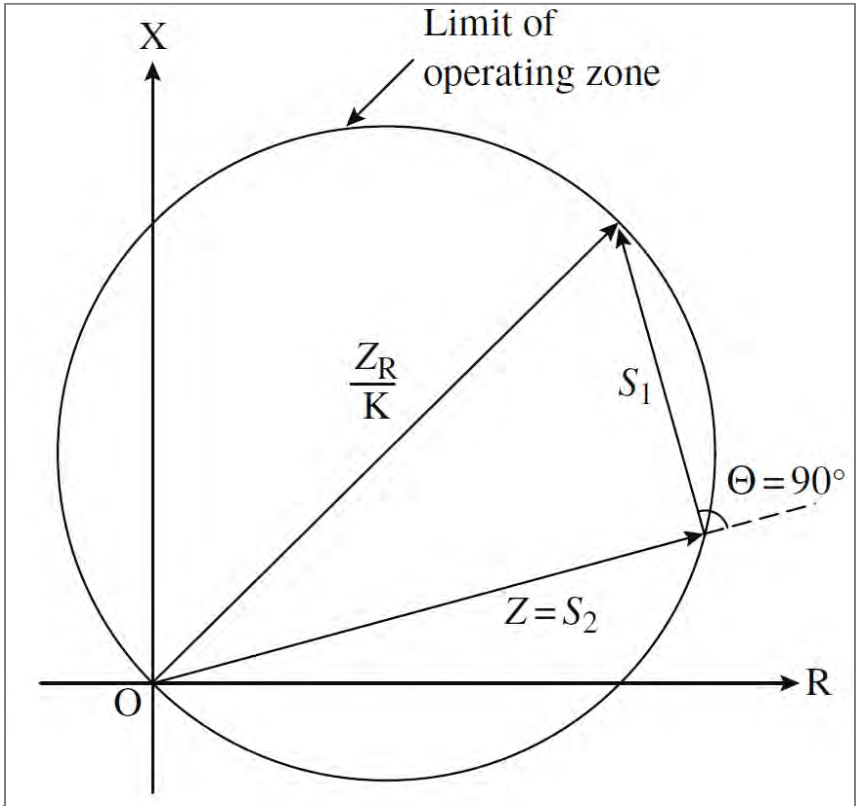
As the impedance of the fault is almost always resistive, it might be assumed that the fault resistance has no effect on the reactance relays. In a radial system this is generally true, but not necessarily if the fault is fed from two or more points

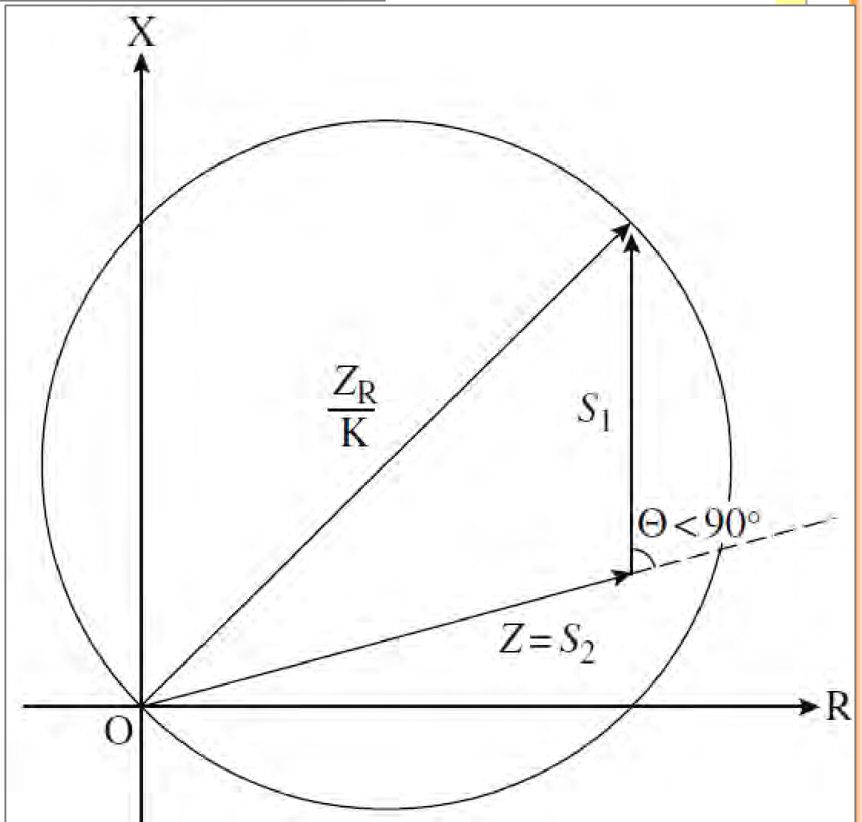
Mho relay

The mho relay combines the properties of impedance and directional relays

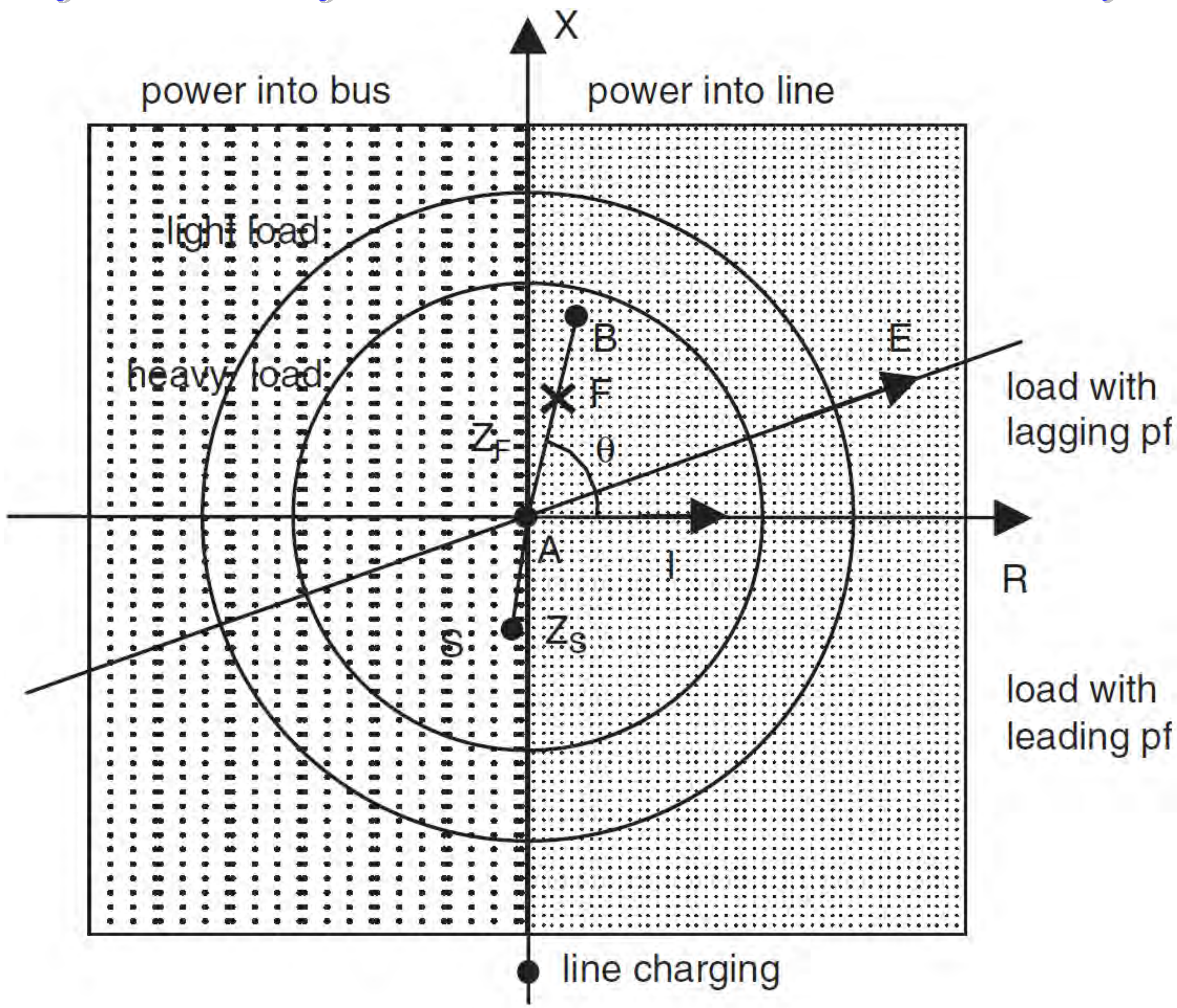
$$S_1 = -KV + Z_R I$$
$$S_2 = KV$$

$$S_1 = -Z + Z_R / K$$
$$S_2 = Z$$

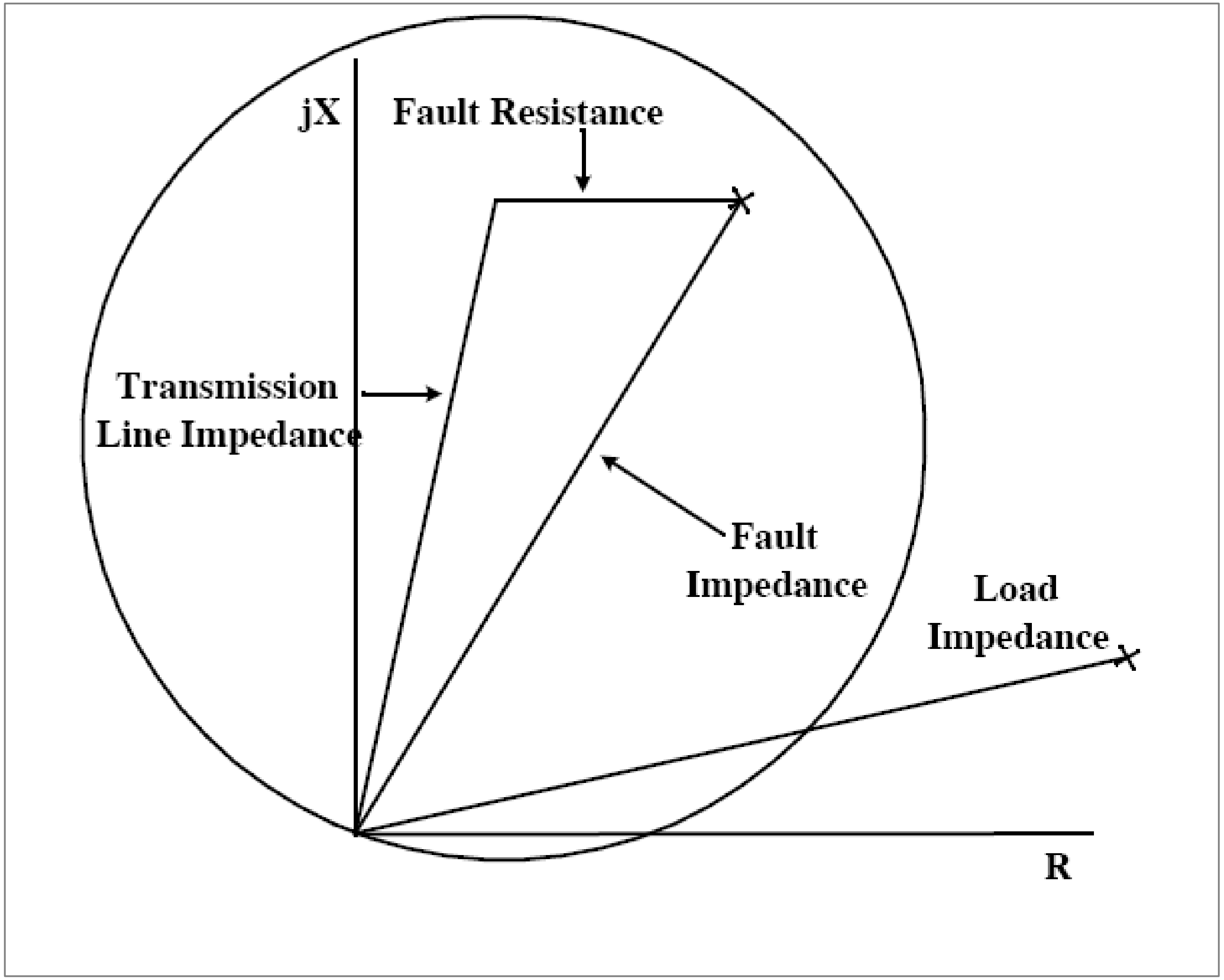




Influence of load and fault resistance on distance relays



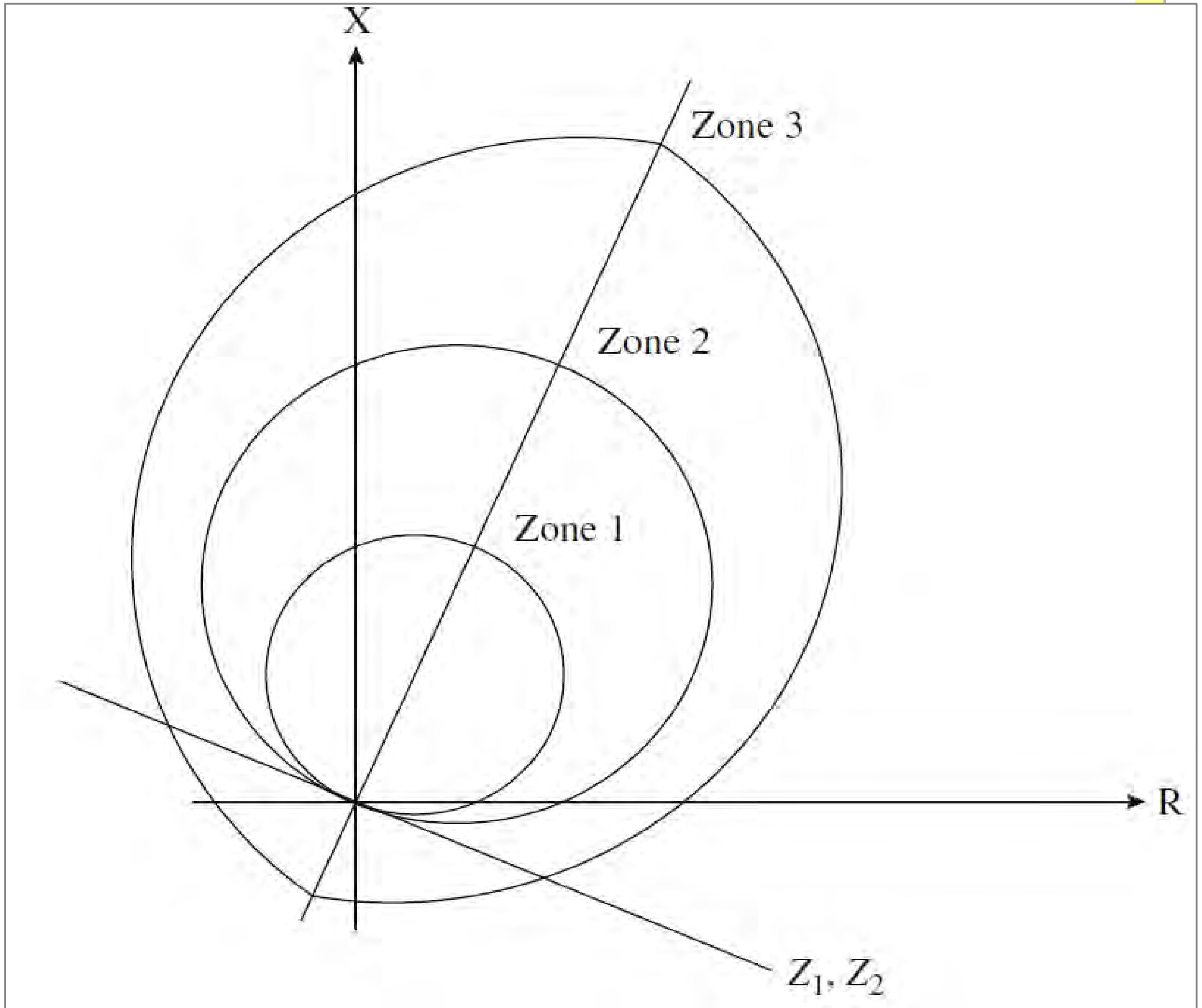
Influence of load and fault resistance on distance relays



Relays with lens characteristics

Distance relays with lens characteristics are very useful for protecting high impedance lines that have high power transfers.

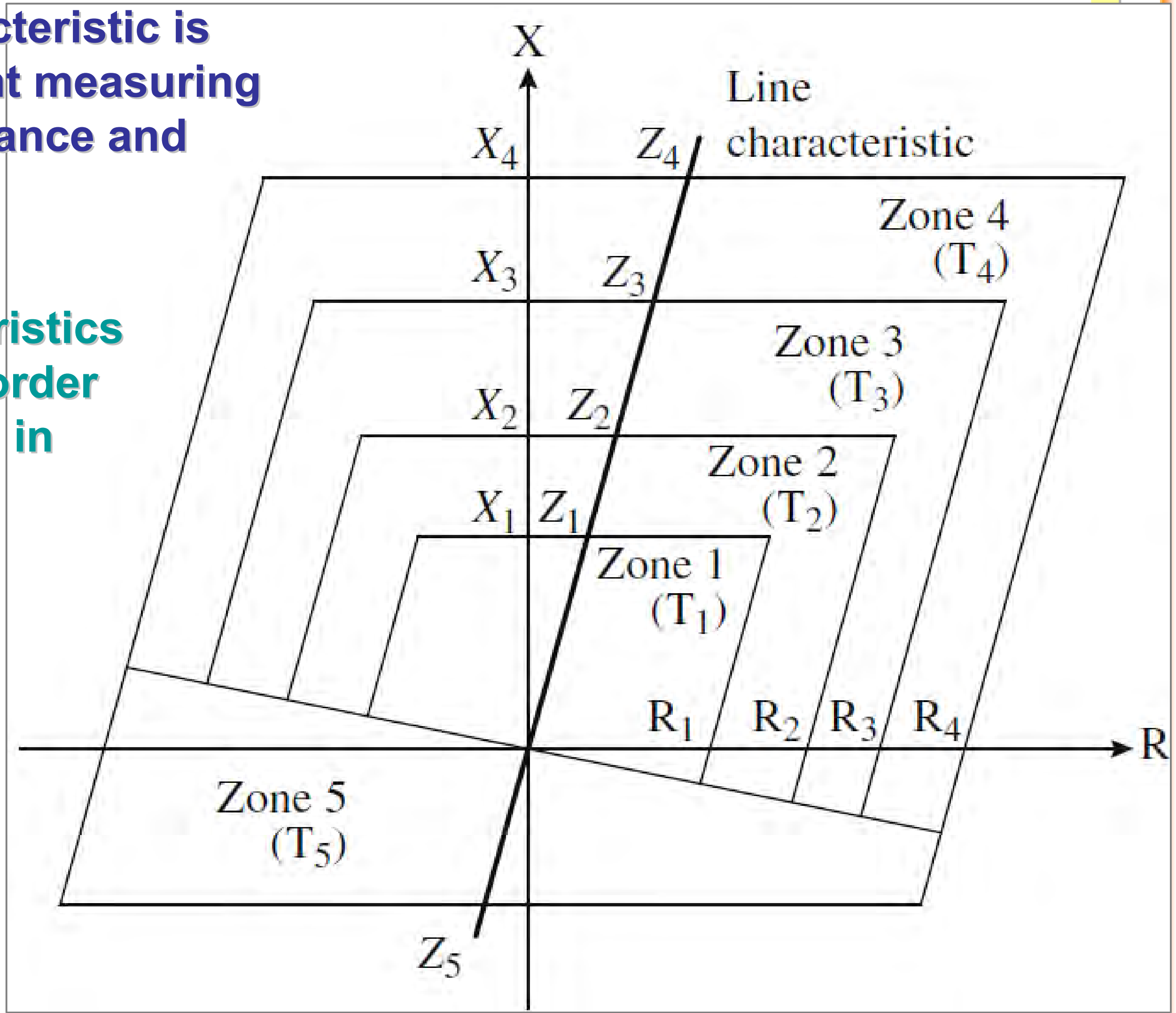
Zone 3 offset lens characteristic



Relays with polygonal characteristics

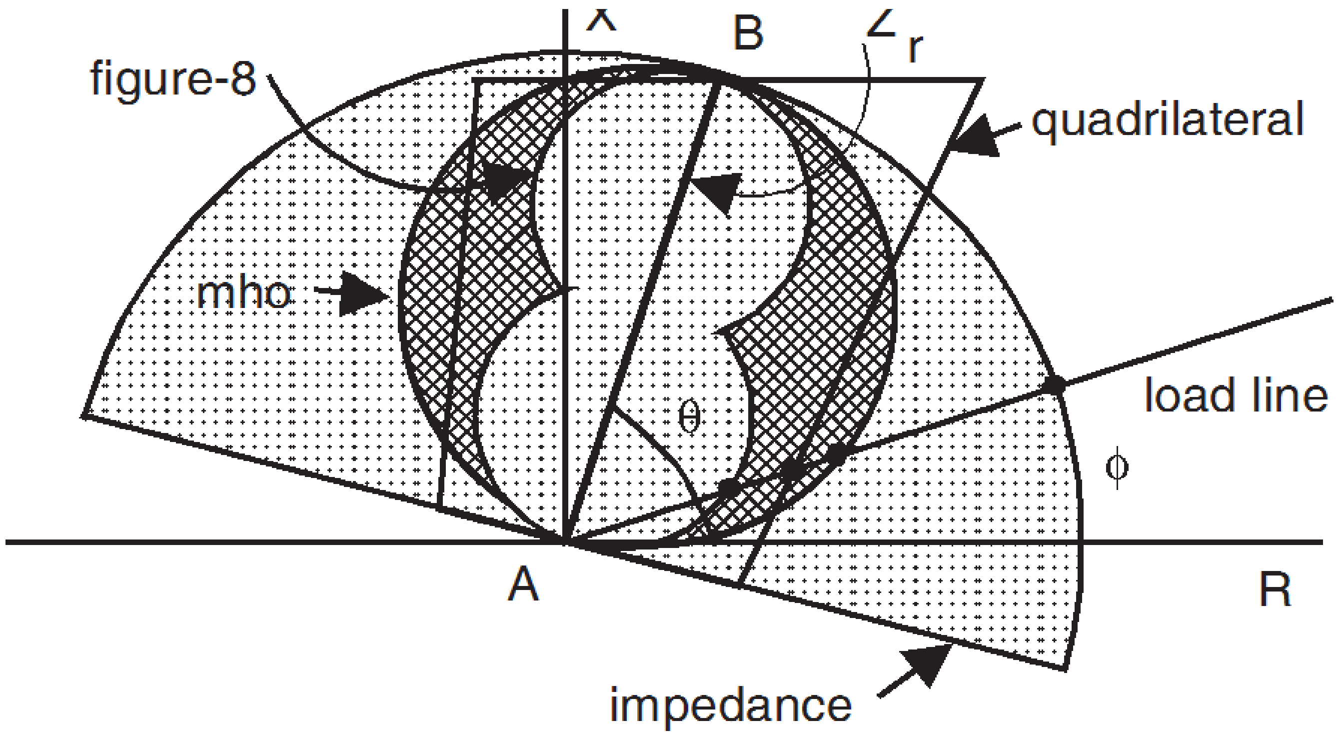
The polygonal tripping characteristic is obtained from three independent measuring elements – reactance, resistance and directional

Relays with polygonal characteristics provide an extended reach in order to cover the fault resistance, in particular for short lines



بار پذیری خط با وجود رله دیستانس:

$$S_{1,\text{imp}} = 3\frac{E^2}{Z_\text{p}} = 3\frac{E^2 n_\text{i}}{Z_\text{r} n_\text{v}} \qquad S_{1,\text{moh}} = 3\frac{E^2 n_\text{i}}{Z_\text{r}\cos(\theta + E\varphi) n_\text{v}}$$



Setting the reach and operating time of distance relays

$$\frac{V_{\text{prim}}}{I_{\text{prim}}} = Z_{\text{prim}} = \frac{V_{\text{sec}} \times \text{VTR}}{I_{\text{sec}} \times \text{CTR}}$$

Thus

$$Z_{\text{sec}} = Z_{\text{prim}} \times (\text{CTR}/\text{VTR})$$

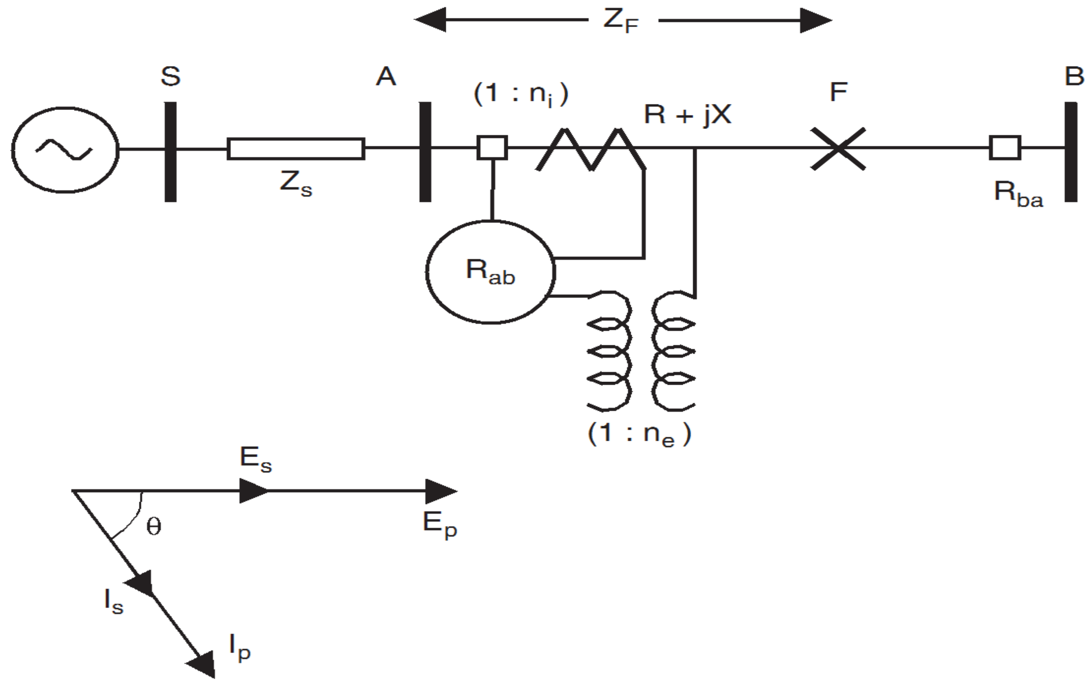
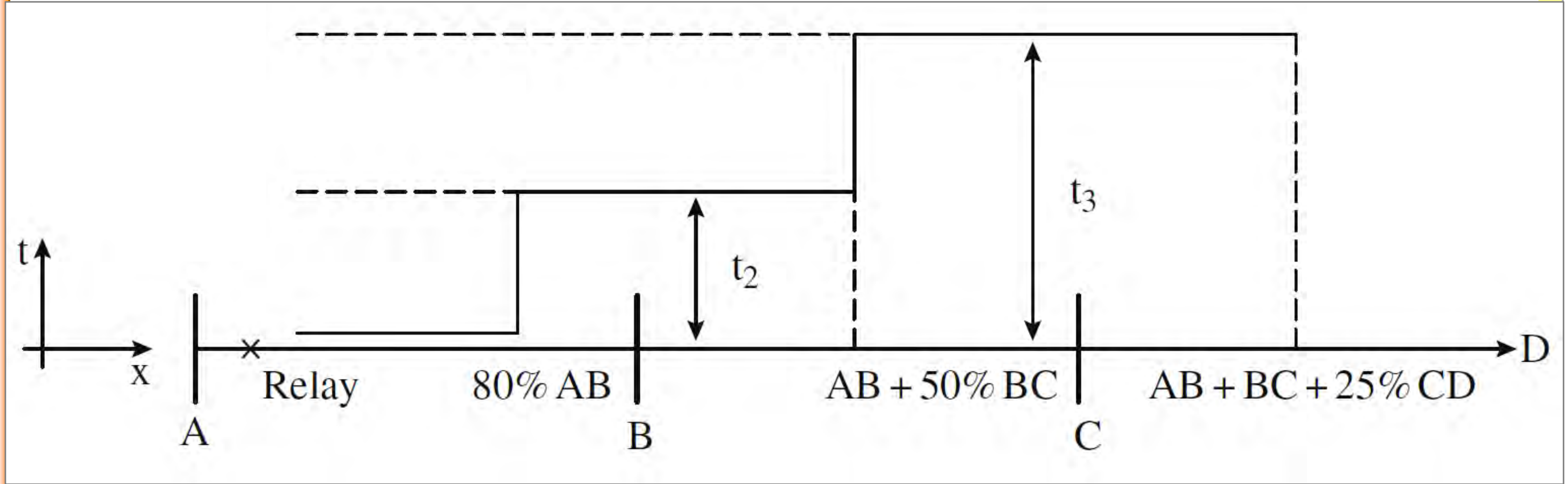


Figure 5.4 Voltage, current and impedance as seen by the relay

Distance relay protection zones for a radial



***t*1 is normally set instantaneously.**
t2 is usually of the order of 0.25 to 0.4 s.
t3 is in the range of 0.6 to 1.0 s.

In the case of zone 3, when the settings of relays at different locations overlap, then the timer for the zone 3 of the furthest relay should be increased by at least 0.2 s to avoid incorrect co-ordination

حفاظت دیستانس برای خط از دو طرف تغذیه:

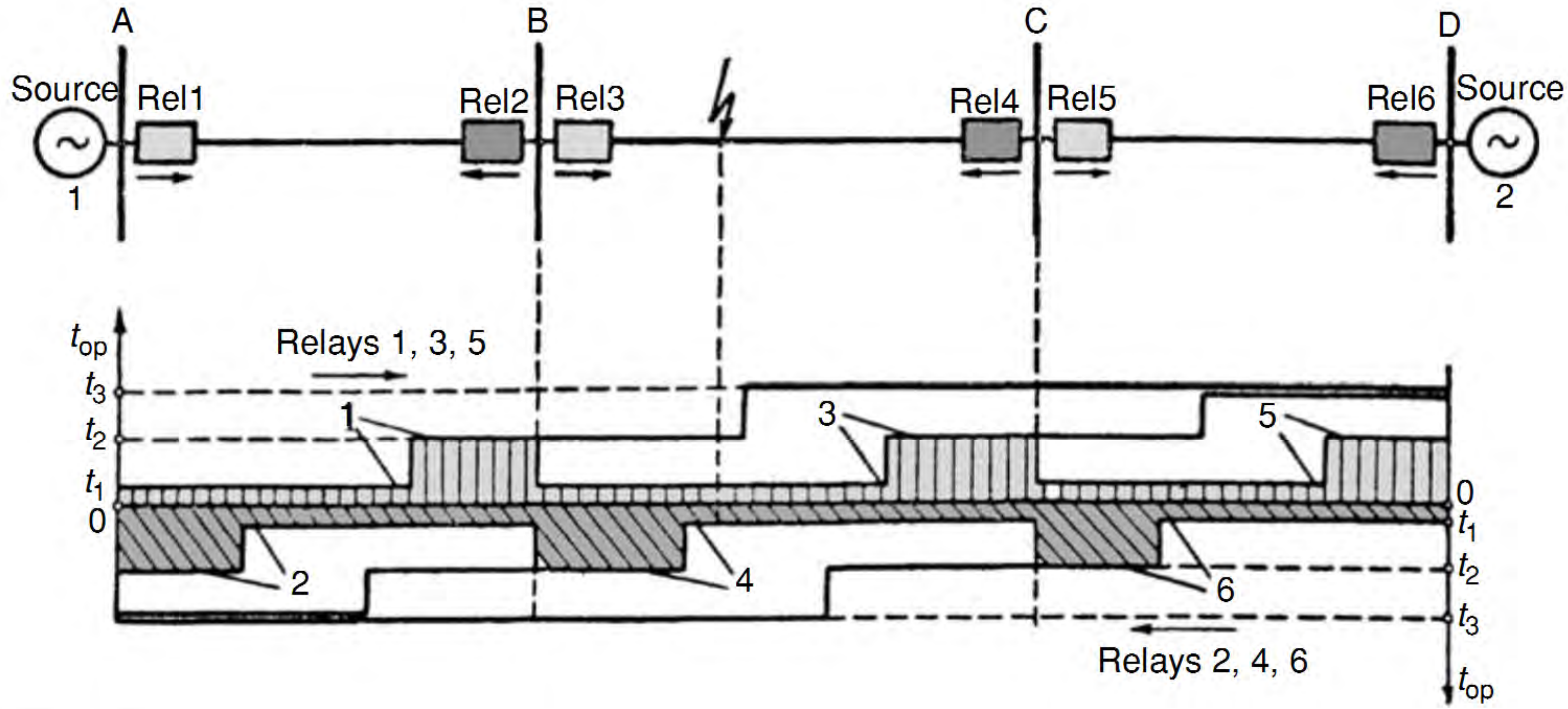


FIGURE 13.3
Principle of construction of directional distance protection with a time grading in power system with two-way supply.

اثر جبران کننده های خط بر رله دیستانس:

خازن سری

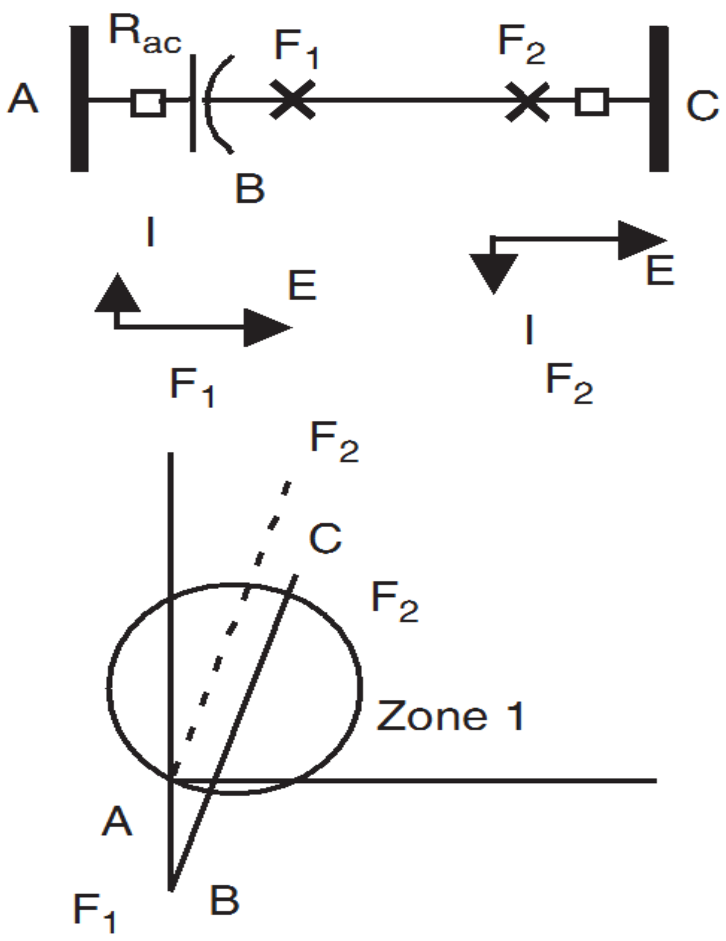


Figure 5.22 $R-X$ diagram with a series capacitor

اثر جبران کننده های خط بر رله دیستانس:

راکتور سری

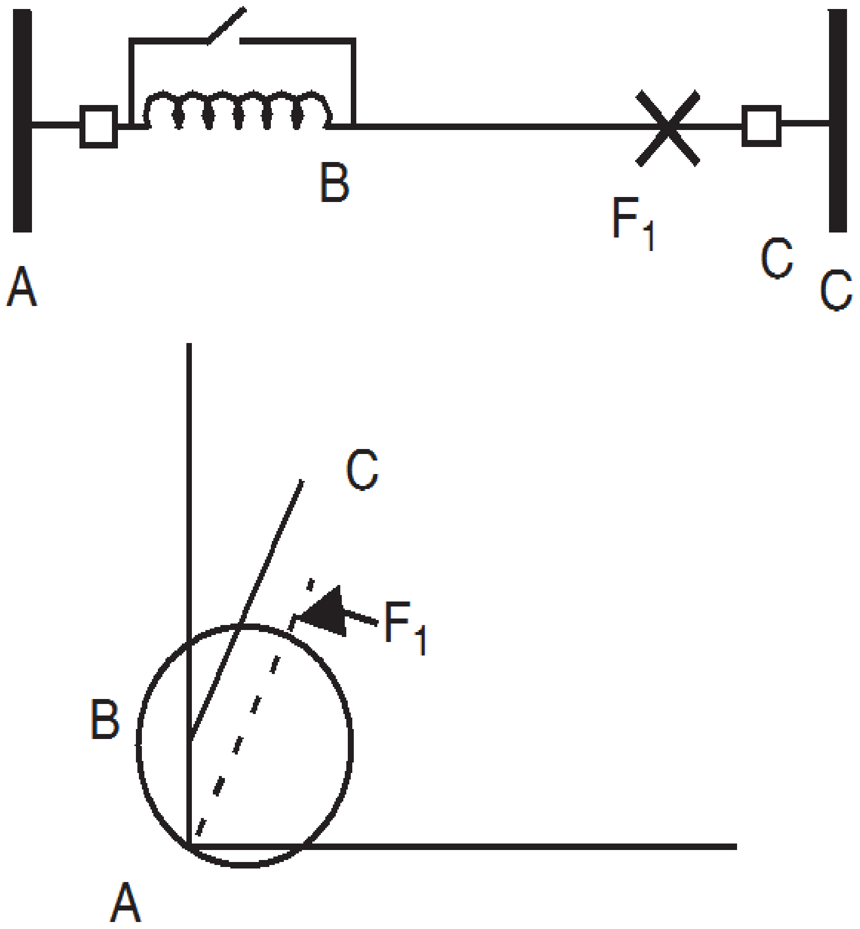


Figure 5.23 $R-X$ diagram with a series reactor

اثر جبران کننده های خط بر رله دیستانس:

راکتور موازی

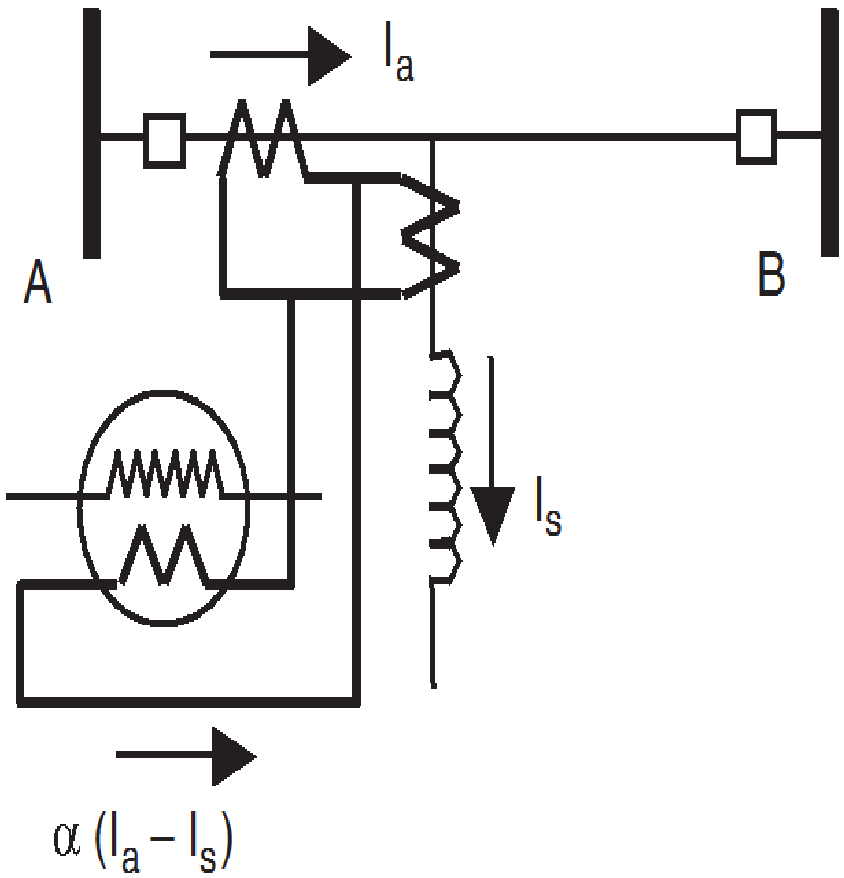


Figure 5.24 Compensation of shunt current in a relay

Three-phase distance relays

On a three-phase power system, there are ten distinct types of possible faults: a three-phase fault, three phase-to-phase faults, three phase-to-ground faults and three double-phase-to-ground faults.

The equations that govern the relationship between voltages and currents at the relay location are different for each of these faults. We should therefore expect that it will take several distance relays, each of them energized by a different pair of voltage and current inputs, to measure the distance to the fault correctly. It is a fundamental principle of distance relaying that, regardless of the type of fault involved, the voltage and current used to energize the appropriate relay are such that the relay will measure the positive sequence impedance to the fault

Three-phase distance relays

Phase-to-phase faults: (b-c fault)

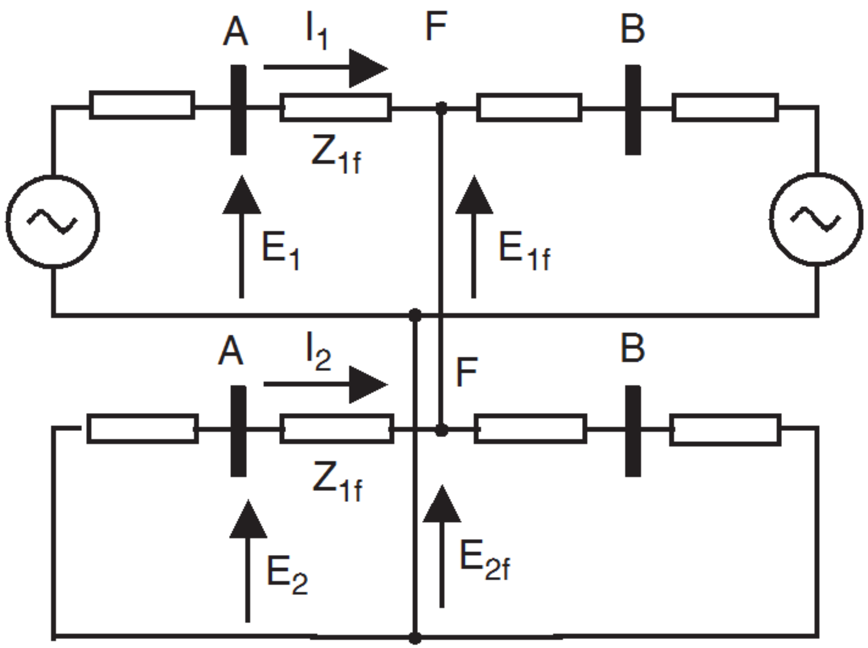


Figure 5.7 Symmetrical component circuit for b–c fault

$$E_{1f} = E_{2f} = E_1 - Z_{1f} I_1 = E_2 - Z_{1f} I_2$$

$$\frac{E_1 - E_2}{I_1 - I_2} = Z_{1f}$$

$$E_b = E_0 + \alpha^2 E_1 + \alpha E_2$$

$$E_c = E_0 + \alpha E_1 + \alpha^2 E_2$$

$$(E_b - E_c) = (\alpha^2 - \alpha)(E_1 - E_2)$$

$$(I_b - I_c) = (\alpha^2 - \alpha)(I_1 - I_2)$$

$$\frac{E_b - E_c}{I_b - I_c} = \frac{E_1 - E_2}{I_1 - I_2} = Z_{1f} A$$

Phase-to-phase to ground faults: (b-c –g fault)

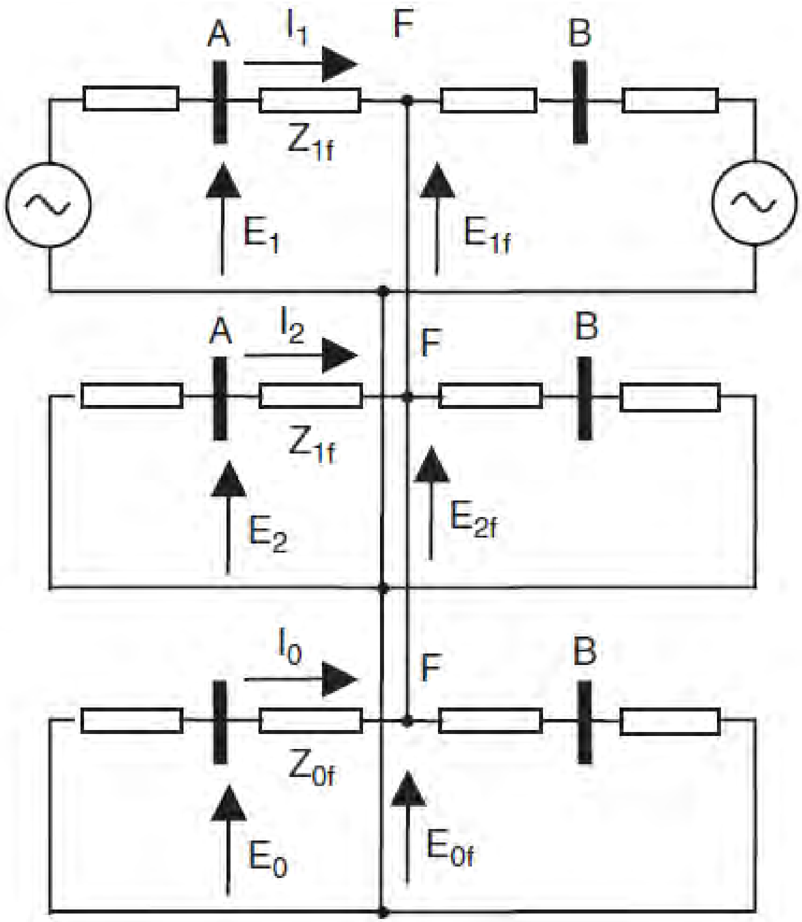


Figure 5.8 Symmetrical component circuit for b–c–g fault

$$\frac{E_b - E_c}{I_b - I_c} = \frac{E_1 - E_2}{I_1 - I_2} = Z_{1f}A$$

Thus, a distance relay, to which the line-to-line voltage between phases b and c is connected, and which is supplied by the difference between the currents in the two phases, will measure the positive sequence impedance to the fault, when a fault between phases b and c or b-c-g occurs.

Three-phase fault:

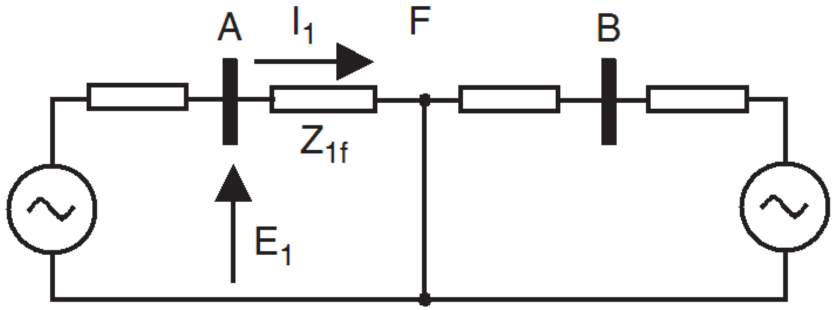


Figure 5.9 Symmetrical component circuit for a three-phase fault

$$E_1 = E_a = Z_{1f} I_1 = Z_{1f} I_a$$

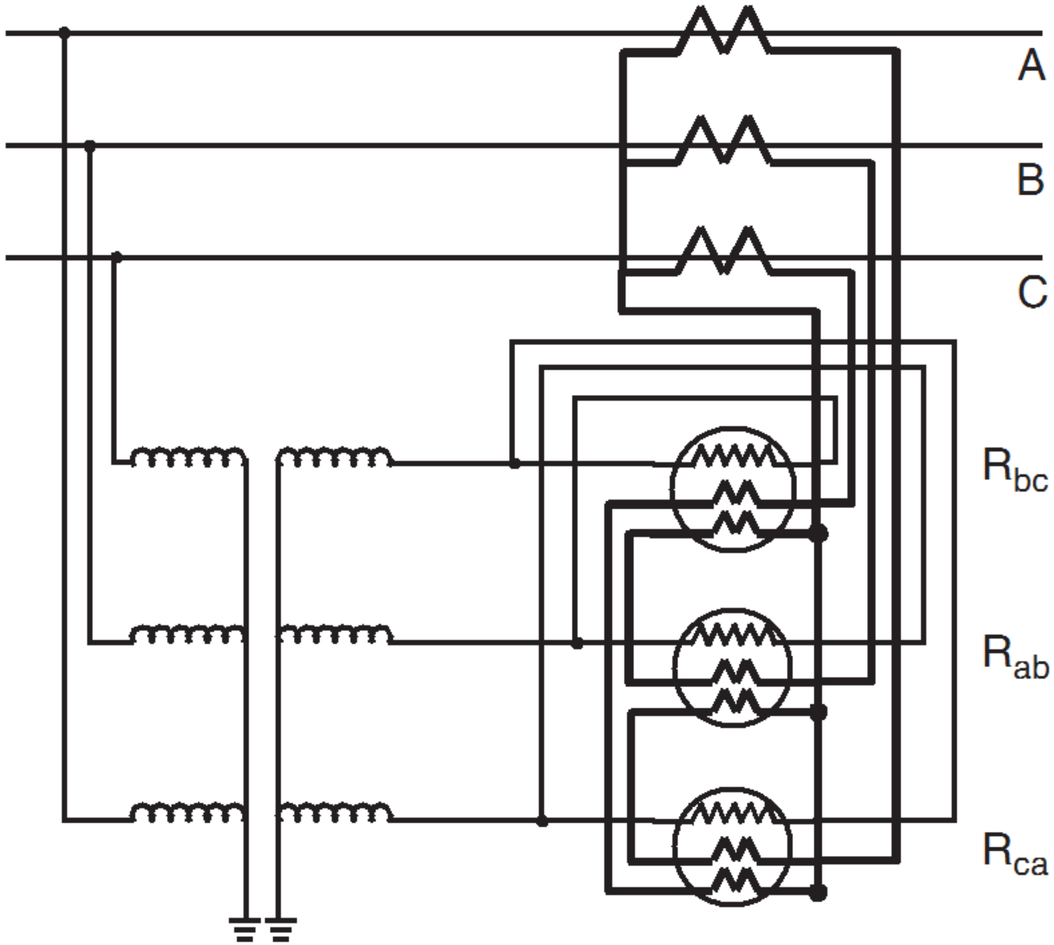
$$E_a = E_1,\ E_b = \alpha^2 E_1 \text{ and } E_c = \alpha E_1,$$

$$E_2 = E_0 = 0$$

$$I_2 = I_0 = 0$$

$$\frac{E_a - E_b}{I_a - I_b} = \frac{E_b - E_c}{I_b - I_c} = \frac{E_c - E_a}{I_c - I_a} = Z_{1f}$$

Current transformer and voltage transformer connections for distance relays for phase faults



Ground faults

$$E_{1f} = E_1 - Z_{1f} I_1$$

$$E_{2f} = E_2 - Z_{1f} I_2$$

$$E_{0f} = E_0 - Z_{0f} I_0$$

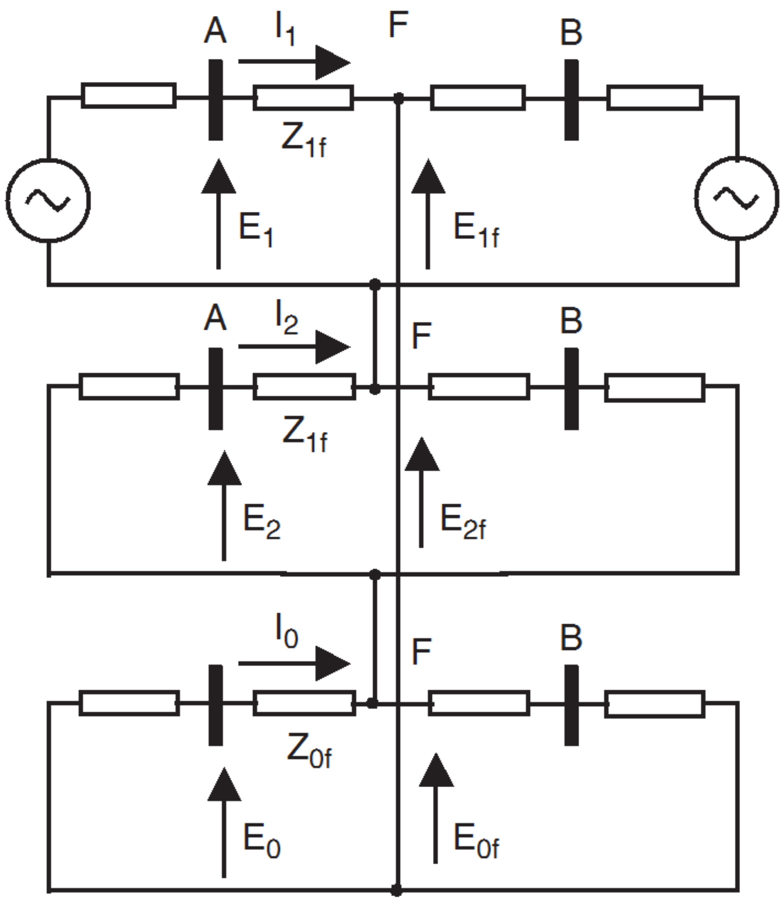


Figure 5.11 Symmetrical component circuit for an a–g fault

$$\begin{aligned} E_{af} &= E_{0f} + E_{1f} + E_{2f} \\ &= (E_0 + E_1 + E_2) - Z_{1f}(I_1 + I_2) - Z_{0f} I_0 = 0 \\ &= E_a - Z_{1f} I_a - (Z_{0f} - Z_{1f}) I_0 = 0 \end{aligned}$$

where I_a has been substituted for the sum $(I_0 + I_1 + I_2)$

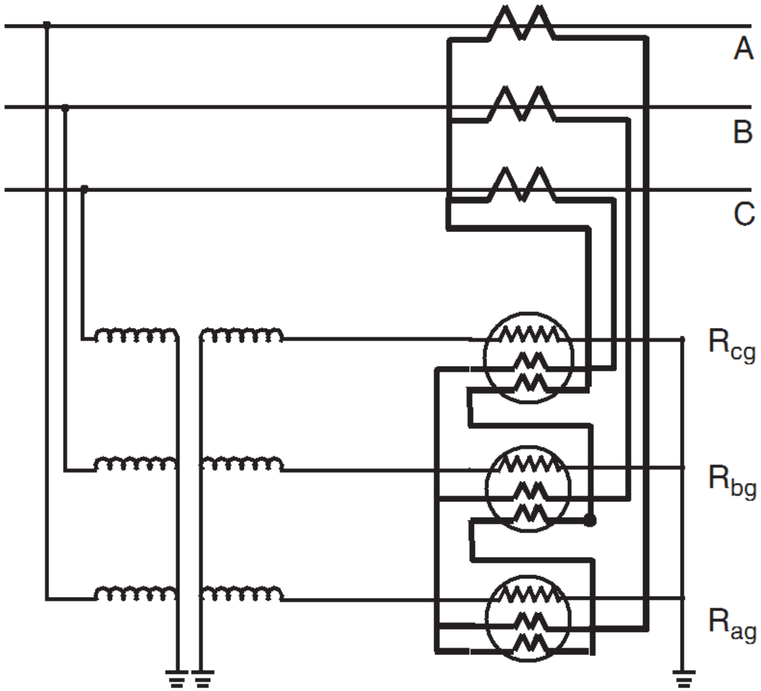
a new current is defined as follows:

$$I'_a = I_a + \frac{Z_{0f} - Z_{1f}}{Z_{1f}} I_0 = I_a + \frac{Z_0 - Z_1}{Z_1} I_0 = I_a + m I_0$$

$$\frac{E_a}{I'_a} = Z_{1f}$$

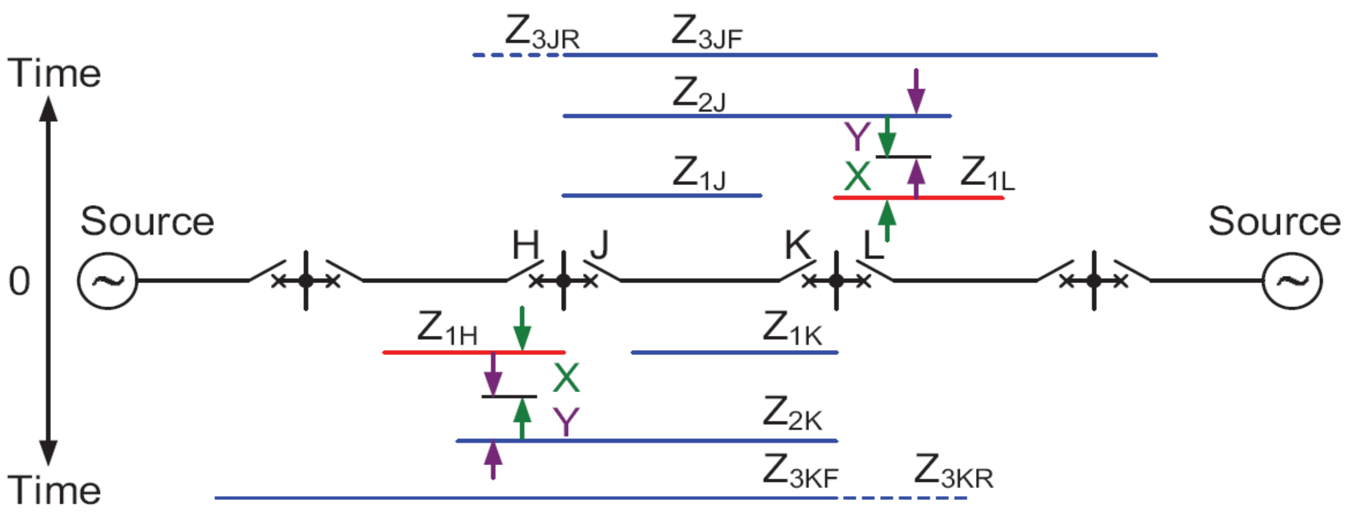
The factor m for most overhead transmission lines is a real number, and varies between 1.5 and 2.5. A good average value for m is 2.0, which corresponds to Z0 of a transmission line being equal to 3Z1

Current transformer and voltage transformer connections for distance relays for ground faults



$$I_a' = I_a + \frac{Z_{0f} - Z_{1f}}{Z_{1f}} I_0 = I_a + \frac{Z_0 - Z_1}{Z_1} I_0 = I_a + m I_0$$

حفاظت دیستانس



Zone 1 = 80-85% of protected line impedance

Zone 2 (minimum) = 120% of protected line

Zone 2 (maximum) < Protected line + 50% of shortest second line

Zone 3F = 1.2 (protected line + longest second line)

Zone 3R = 20% of protected line

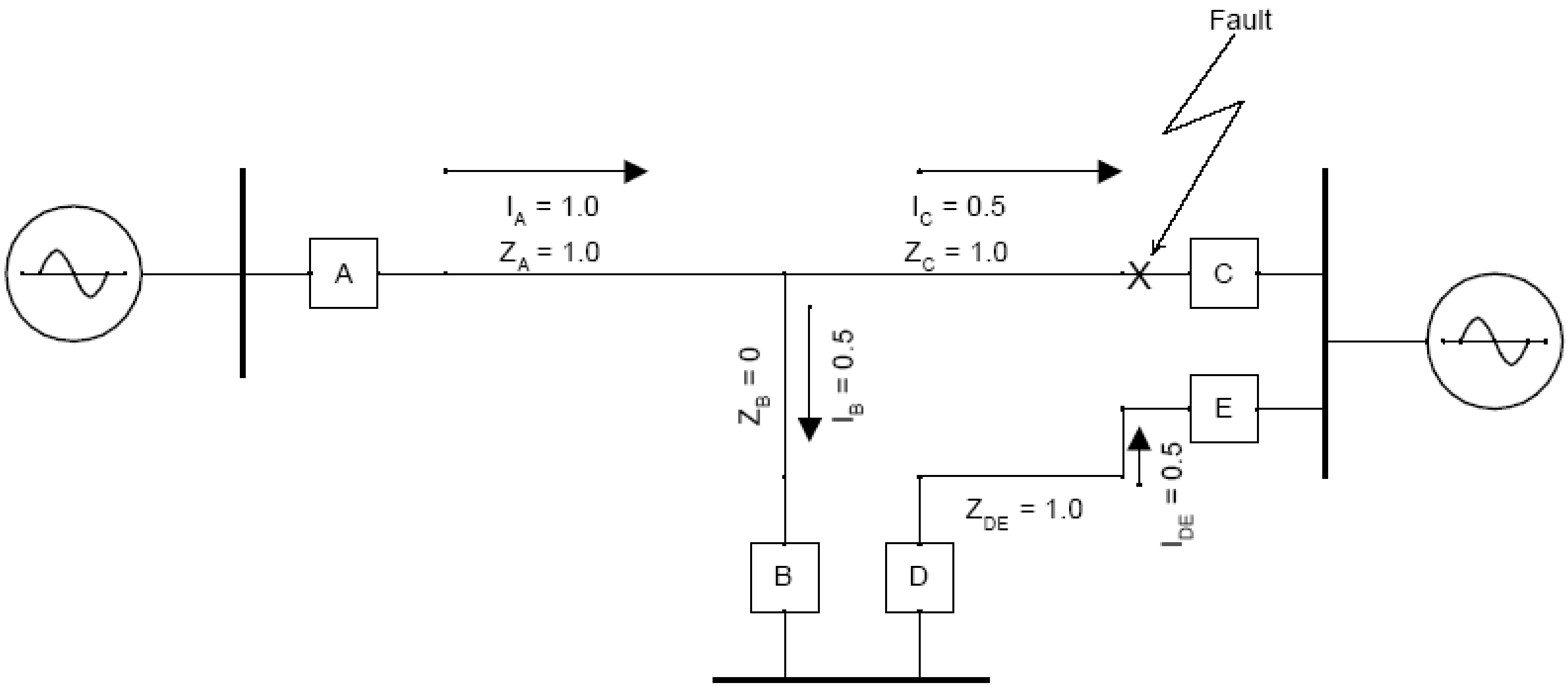
X = Circuit breaker tripping time

Y = Discriminating time

Figure 11.6: Typical time/distance characteristics for three zone distance protection

Multiterminal lines

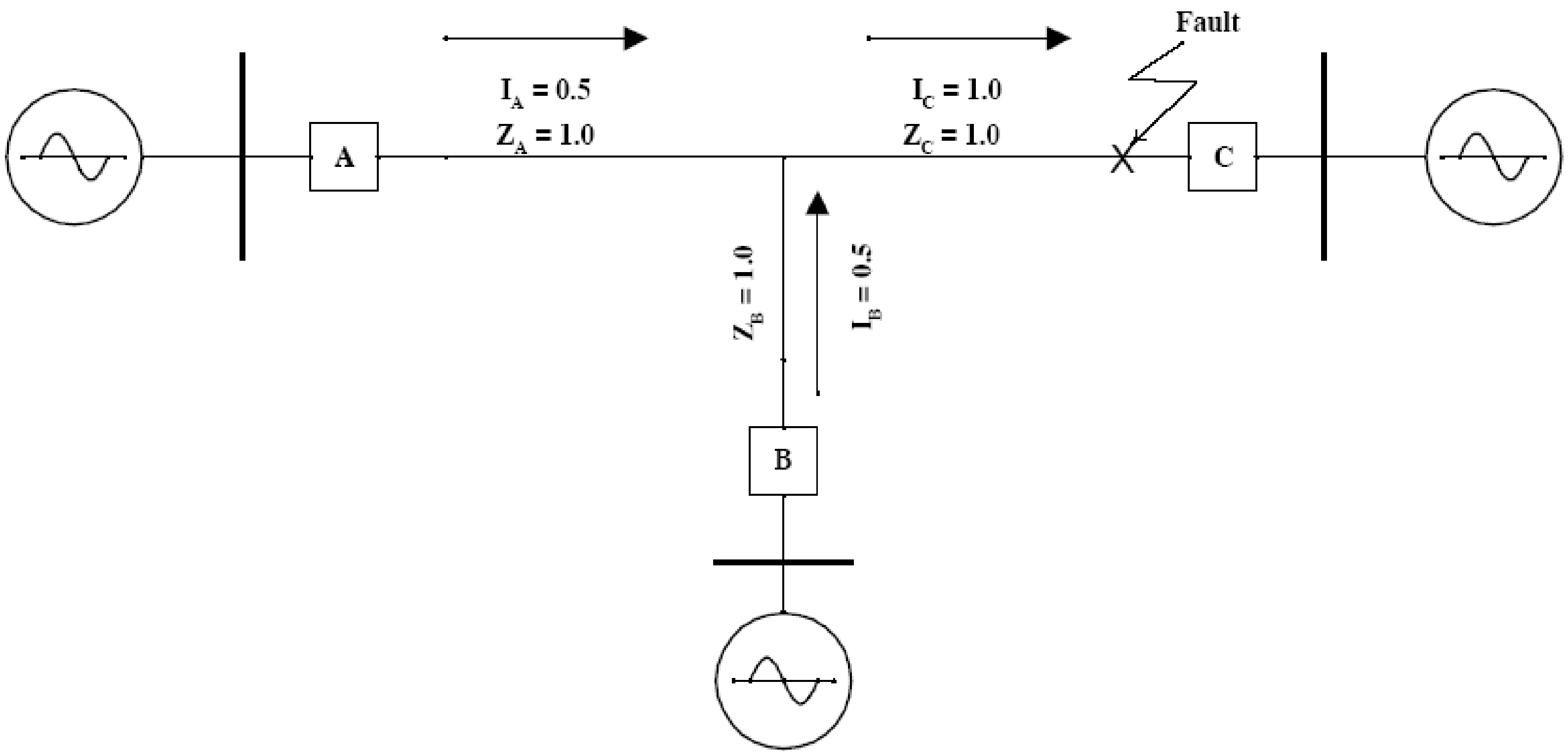
A. Current outfeed



Actual Impedance from "A" to the Fault = 2.0 Ω

$$\text{APPARENT IMPEDANCE} = \frac{E_A}{I_A} = \frac{(I_A \times Z_A) + (I_C \times Z_C)}{I_A} = 1.5\ \Omega$$

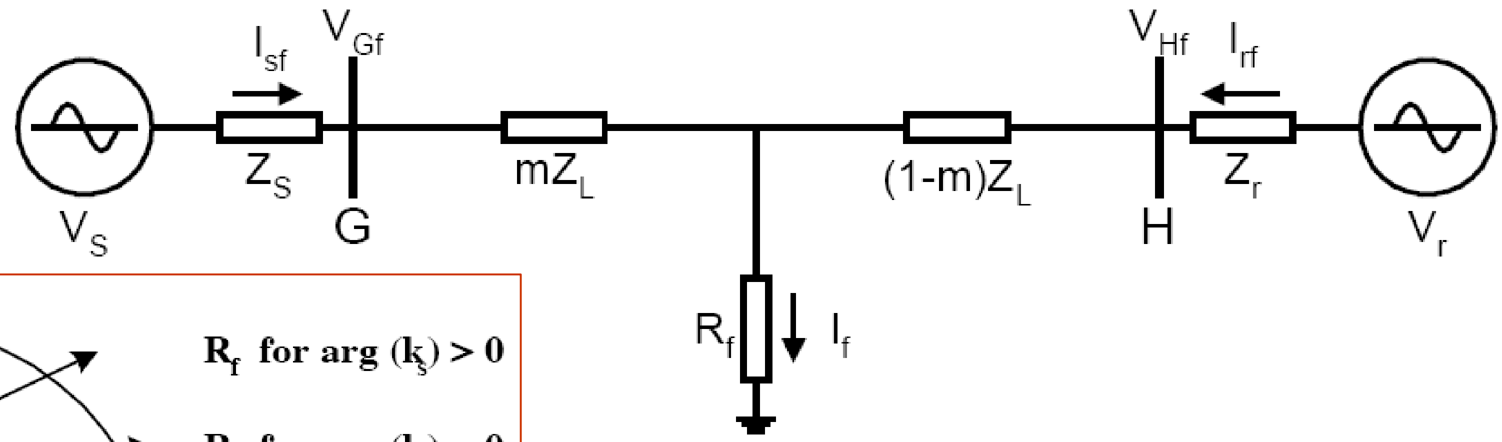
B. Current infeed

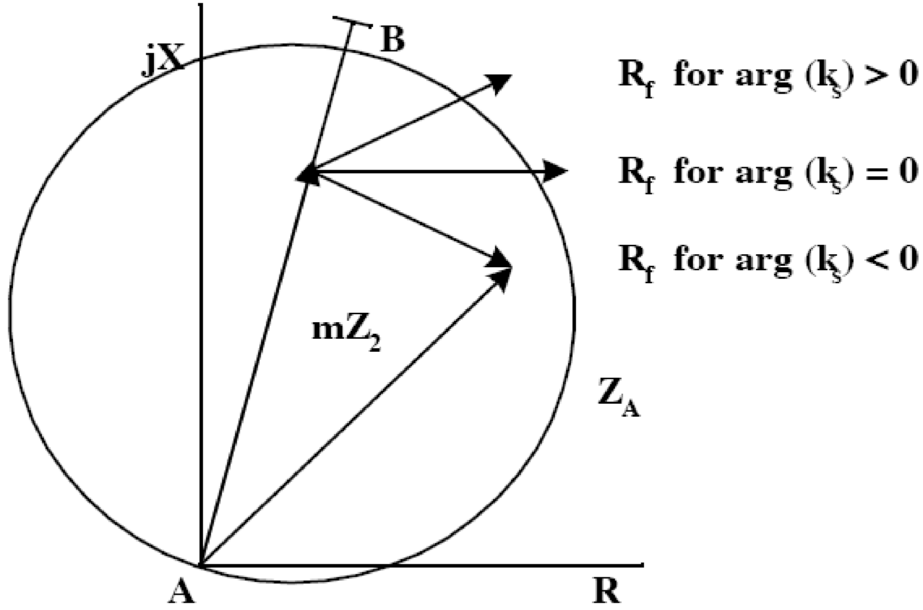


Actual Impedance from "A" to the Fault = 2.0 Ω

$$\text{APPARENT IMPEDANCE} = \frac{E_A}{I_A} = \frac{(I_A \times Z_A) + (I_C \times Z_C)}{I_A} = 3.0\ \Omega$$

Influence of a combined effect of load and Fault resistance on an impedance measurement





$$Z_G = \frac{V_{Gf}}{I_{sf}} = \frac{mZ_L \times I_{sf} + R_f \times I_f}{I_{sf}} = mZ_L + R_f \times \left(\frac{I_f}{I_{sf}}\right) = mZ_L + R_f \times k_s$$