Power System Protection

EE454

Distance Protection (completed)

Lecture ppt. # 6 – a
ODL Week (Dec. 7 – Dec. 11)
for lectures on 8th and 10th Dec.

- **Note:**

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Session No.	Content of the Lecture presentation (Ch#5 of PS Relaying)	
1	Slide 4 - 10	Relay operation with zero voltage, Relays for multi-terminal lines, (Theory of) Protection of parallel lines
2	Slide 11 - 16	Example of Protection of parallel lines, Effect of transmission line compensation devices, Loadability of Relays


بسم الله الرحمن الرحيم

5.6 Relay operation with zero voltage

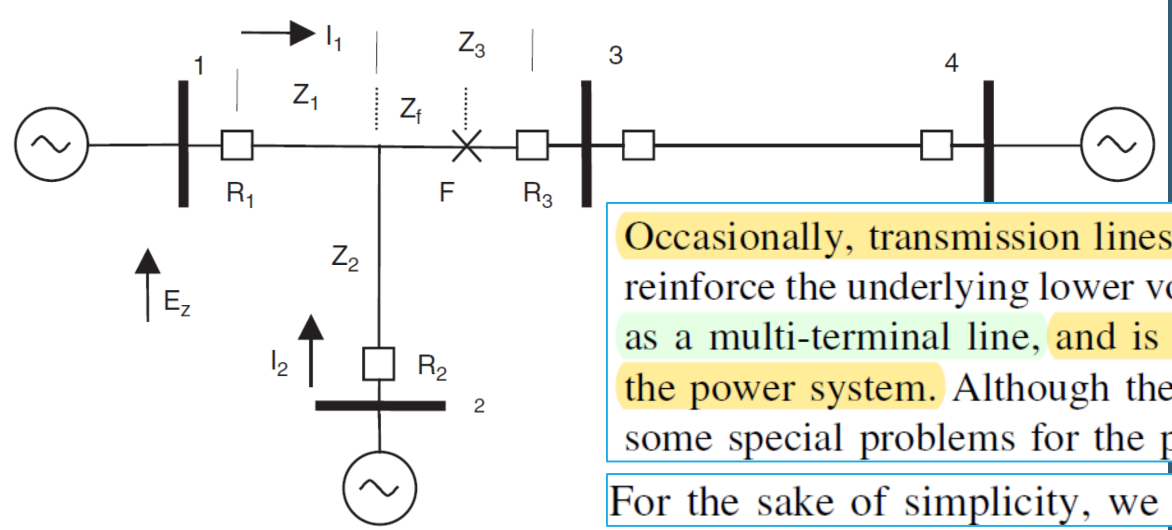
Distance relay needs voltage (magnitude and phase) for its proper operation. However, if a fault reduces the line voltage to zero, then there is a problem.

It is possible to design relays which will overcome the problem of zero-voltage faults. A common technique is to provide a memory-action circuit in the voltage coil, which, due to a subsidence transient, will sustain the prefault voltage in the polarizing circuit for a few cycles after the occurrence of the zero-voltage fault. The phase angle of the voltage impressed by the memory circuit on the voltage coil is very close to that of the voltage before the occurrence of the fault. Since the memory action is provided by a transient that may last only a few cycles, this feature can be used in high-speed relaying functions only.

Memory action requires that the prefault voltage seen by the relay is normal, or close to normal. If there is no prefault voltage in the primary circuit (as would be the case if the transmission line is being energized after having been de-energized for some time, and line-side potential is being used for relaying) no memory action is available.

In the case of computer-based distance relays, it is a simple matter to provide memory action by storing prefault data for as long a duration as one wishes. Thus, it may be possible to provide memory action for reclosing functions as well, when prefault voltage may not exist for several seconds prior to the reclosing action. Of course, one cannot use memory voltage functions over very long periods of time, as the phase angle of the memory voltage may no longer be valid due to small deviations and drifts in the power system frequency.

5.8 Relays for multi-terminal lines



Occasionally, transmission lines may be tapped to provide intermediate connections to loads, or to reinforce the underlying lower voltage network through a transformer. Such a configuration is known as a multi-terminal line, and is often built as a temporary, inexpensive measure for strengthening the power system. Although the resulting power system configuration is inexpensive, it does pose some special problems for the protection engineer.

For the sake of simplicity, we will assume this to be a single-phase system

$$E_1 = Z_1 I_1 + Z_f(I_1 + I_2)$$

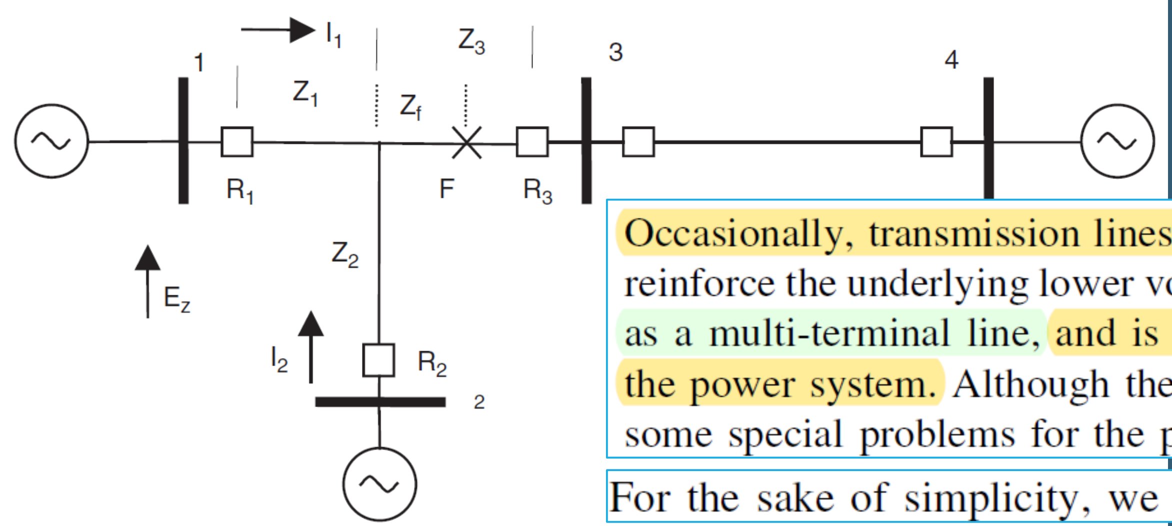
$$Z_{app} = \frac{E_1}{I_1} = Z_1 + Z_f\left(1 + \frac{I_2}{I_1}\right) \qquad (5.19)$$

Equation (5.19) shows that the apparent impedance seen by relay R_1 is different from the true impedance to the fault: $(Z_1 + Z_f)$. When the tap current is an infeed, the apparent impedance is greater than the correct value. Thus, if we set the zone 1 setting of relay R_1 at about 85 % of the line length 1–2, many of the faults inside the zone of protection will appear to be outside the zone, and the relay will not operate. We must accept this condition, since, when the tap is out of service, the correct performance of the relay is restored.

On the other hand, zones 2 and 3 of relay R_1 must reach beyond buses 2 and 3, respectively, under all possible configurations of the tap.

underreaching zones are set with infeeds removed from consideration, and overreaching zones are set with the infeeds restored. These ideas are illustrated in the following example.

5.8 Relays for multi-terminal lines



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Zone 1: set with infeed ignored –
so, with infeed present (actually), a point inside 85% zone may appear outside and thus zone 1 operation does not occur.
When the tap is out of service, correct zone 1 operation is restored.
This condition is accepted.
If zone 1 was set while considering the infeed, then if the tap is out of service, the relay becomes insecure and may operate beyond the next bus.

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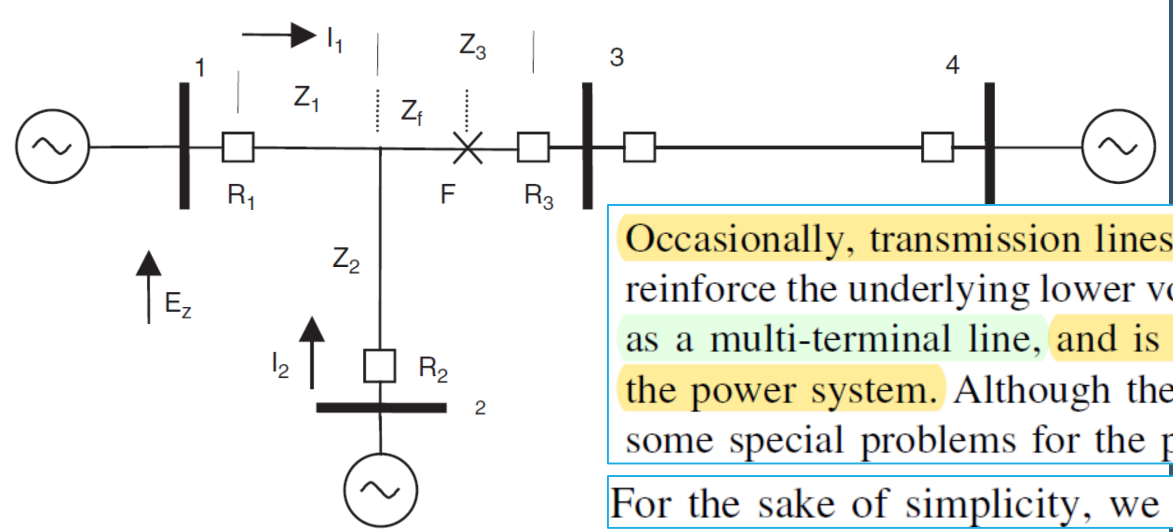

Occasionally, transmission lines may be tapped to provide intermediate connections to loads, or to reinforce the underlying lower voltage network through a transformer. Such a configuration is known as a multi-terminal line, and is often built as a temporary, inexpensive measure for strengthening the power system. Although the resulting power system configuration is inexpensive, it does pose some special problems for the protection engineer.

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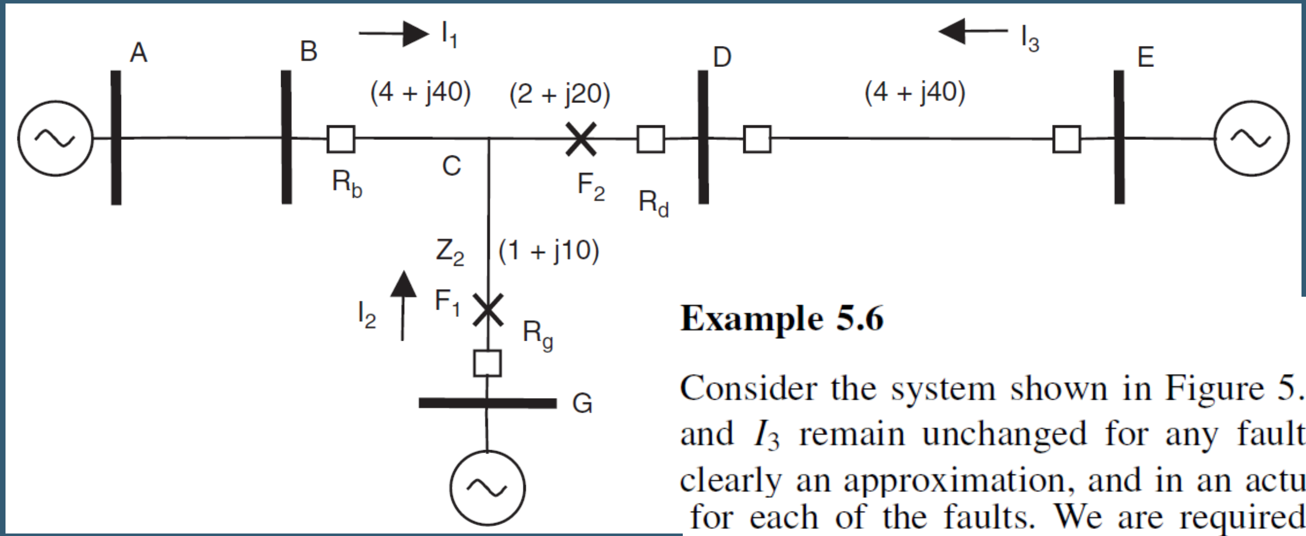
On the other hand, zones 2 and 3 of relay R_1 must reach beyond buses 2 and 3, respectively, under all possible configurations of the tap.

underreaching zones are set with infeeds removed from consideration, and overreaching zones are set with the infeeds restored. These ideas are illustrated in the following example.

Zone 2 : set with infeed considered – so, with infeed removed (actually), the zone boundary moves forward – but that should not be a problem.
Same is case of zone 3.



Example 5.6

Consider the system shown in Figure 5.18. We may assume that the relative magnitudes of I_1, I_2 and I_3 remain unchanged for any fault on the system between the buses A through G. This is clearly an approximation, and in an actual study we must use appropriate short-circuit calculations for each of the faults. We are required to set the three zones of the relay R_b. It is assumed (as determined by the short-circuit study) that $I_2/I_1 = 0.5$.

Zone 1

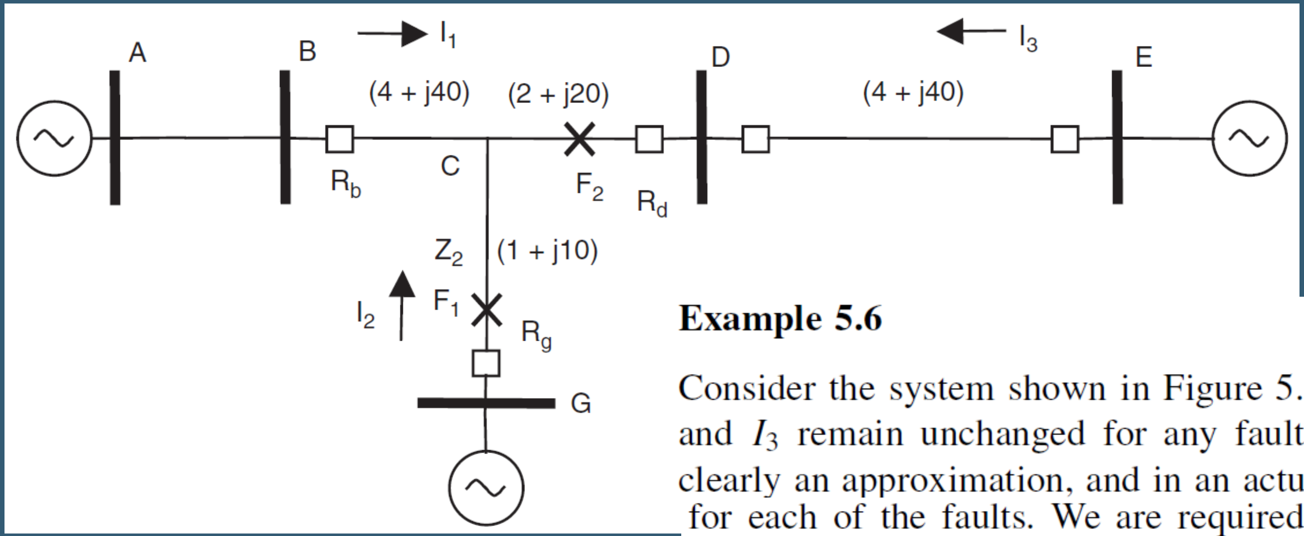
This must be set equal to 85 % of the smaller of the two impedances between buses B and D, and B and G. Also, we will consider the infeed to be absent for setting zone 1. Thus, the zone 1 setting is $0.85 \times (4 + j40 + 1 + j10) = 4.25 + j42.5\ \Omega$.

Zone 2

This is set equal to 120 % of the longer of the two impedances between buses B and D, and B and G. The infeed will be considered to be present, and will apply to the impedance of the segment C–D. Thus, the zone 2 setting is $1.2[4 + j40 + 1.5 \times (2 + j20)] = 8.4 + j84\ \Omega$.

Zone 3

Assuming that line D–E is the only one needing backup by the relay R_b, the zone 3 setting is obtained by considering the infeed to be in service. The apparent impedance of the line B–D with the infeed is $(4 + j40) + \boxed{1.5} \times (2 + j20) = 7 + j70\ \Omega$. To this must be added 150 % of the impedance of line D–E, duly corrected for the infeed. Thus, the zone 3 setting of R_b is $7 + j70 + 1.5 \times 1.5 \times (4 + j40) = 16 + j160\ \Omega$.



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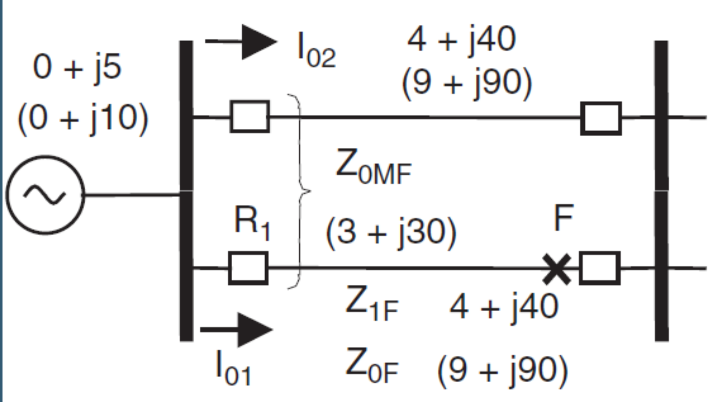
5.9 Protection of parallel lines

Transmission lines that are on the same tower, or paralleled along the same right of way, present unique problems to the associated line relays. The difficulty stems from the fact that the lines are mutually coupled in their zero-sequence circuits. The small amount of negative- and positive-sequence mutual coupling can usually be neglected. The zero-sequence coupling causes an error in the apparent impedance as calculated by equation (5.14).

$$\frac{E_a}{I'_a} = Z_{1f} \qquad (5.14)$$

$$I'_a = I_a + \frac{Z_{0f} - Z_{1f}}{Z_{1f}} I_0 = I_a + \frac{Z_0 - Z_1}{Z_1} I_0 = I_a + m I_0 \qquad (5.13)$$



$$\begin{aligned} E_{1f} &= E_1 - Z_{1f} I_1 \\ E_{2f} &= E_2 - Z_{1f} I_2 \\ E_{0f} &= E_0 - Z_{0f} I_{01} - Z_{0mf} I_{02} \end{aligned} \qquad (5.20)$$

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$$E_{af} = E_{0f} + E_{1f} + E_{2f} = (E_0 + E_1 + E_2) - Z_{1f}(I_1 + I_2) - Z_{0f} I_{01} - Z_{0mf} I_{02} = 0 \qquad (5.21)$$

$$= E_a Z_{1f} I_a - (Z_{0f} - Z_{1f}) I_{01} - Z_{0mf} I_{02} = 0 \qquad (5.22)$$

$$\begin{aligned} I'_a &= I_a + \frac{Z_{0f} - Z_{1f}}{Z_{1f}} I_{01} + \frac{Z_{0mf}}{Z_{1f}} I_{02} \\ &= I_a + \frac{Z_0 - Z_1}{Z_1} I_{01} + \frac{Z_{0m}}{Z_1} I_{02} = I_a + m I_{01} + m' I_{02} \end{aligned} \qquad (5.23)$$

$$\frac{E_a}{I'_a} = Z_{1f} \qquad (5.24)$$

Example 5.7

Let the system shown in Figure 5.19 represent two mutually coupled transmission lines, with impedance data as shown in the figure. The zero-sequence impedances are given in parentheses, and the mutual impedance in the zero-sequence circuits of the two transmission lines is $(3 + j30)\ \Omega$. The rest of the system data are similar to those of Example 5.4. For a phase-a-to-ground fault at F, the transmission line impedance is divided by two because of the parallel circuit of equal impedance. Thus, the positive and negative sequence impedance due to the transmission lines in the fault circuit is $(2 + j20)\ \Omega$, while the zero-sequence impedance is $0.5 \times (9 + j90 + 3 + j30) = (6 + j60)\ \Omega$. The symmetric components of the fault current are given by

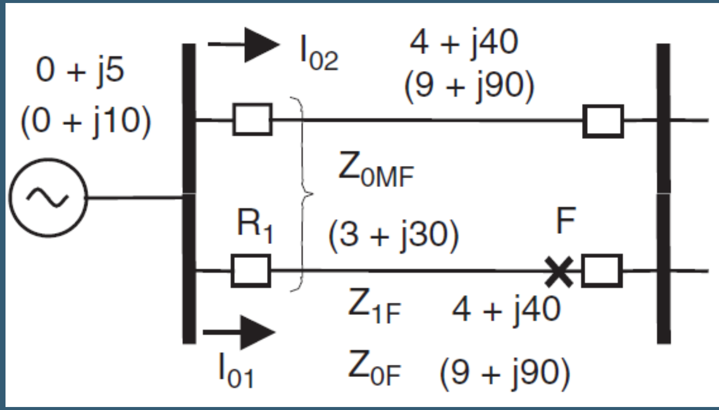
$$I_1 = I_2 = I_0 = \frac{7967.4}{2 \times (0 + j5) + 0 + j10 + 2 \times (2 + j20) + 6 + j60}$$
$$= 66.169\angle - 85.23^\circ$$

The currents seen by the relay are half these values because of the even split between the two lines, and $I_a = 3 \times \frac{1}{2} \times I_1 = 99.25\angle - 85.23^\circ$. The zero-sequence currents in the two lines are

$$I_{01} = I_{02} = 33.085\angle - 85.23^\circ$$

The zero-sequence compensation factors m and m' are given by (see equation (5.23))

$$m = \frac{9 + j90 - 4 - j40}{4 + j40} = 1.25 \quad \text{and } m' = \frac{3 + j30}{4 + j40} = 0.75$$



The compensated phase a current, as given by equation (5.23), is

$$I'_a = I_a + mI_{01} + m'I_{02} = 165.42\angle - 85.23^\circ$$

The symmetrical components of the voltages at the relay location are given by

$$E_1 = 7967.4 - j5 \times 66.169\angle - 85.23^\circ = 7637.7 - j27.51$$
$$E_2 = -j5 \times 66.169\angle - 85.23^\circ = -329.7 - j27.51$$
$$E_0 = -j10 \times 66.169\angle - 85.23^\circ = -659.4 - j55.02$$

and the phase a voltage at the relay location is

$$E_a = E_1 + E_2 + E_0 = 6649.51\angle - 0.95^\circ$$

Finally, the impedance seen by the relay R_a is

$$\frac{E_a}{I'_a} = \frac{6649.5\angle - 0.95^\circ}{165.42\angle - 85.23^\circ} = 4 + j40\ \Omega$$

5.10 Effect of transmission line compensation devices

5.10.1 Series capacitors

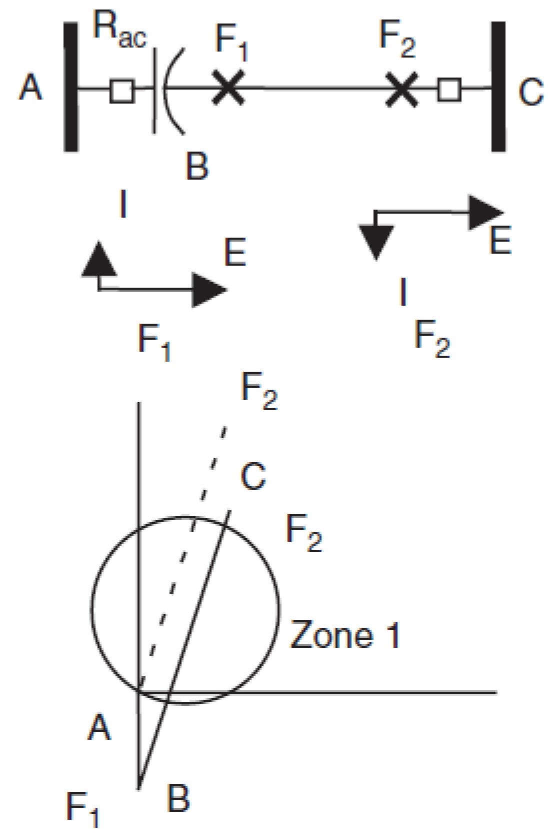


Figure 5.22 *R–X* diagram with a series capacitor

5.10.2 Series reactors

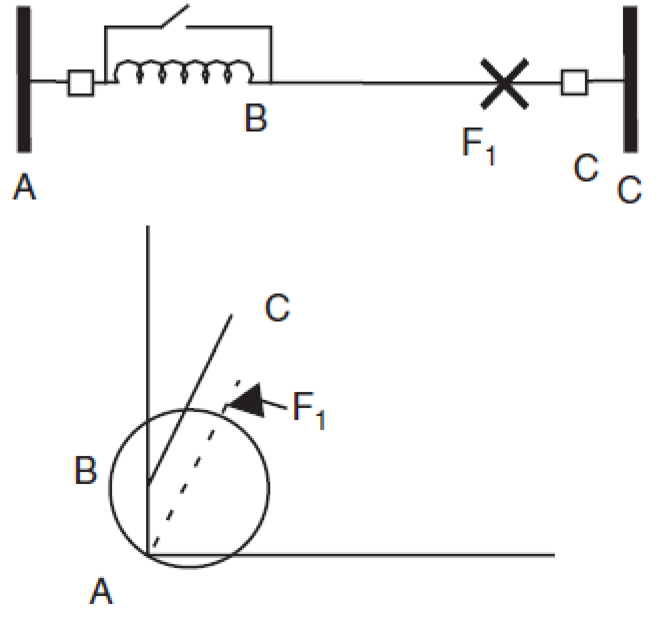


Figure 5.23 *R–X* diagram with a series reactor

For instance, if the reactor shown in Figure 5.23 has an impedance of $Z_{ab} = 10\ \Omega$ and the line section BC has an impedance of j40 (ignoring the resistance), zone 1 at both ends would be set at $0.85 \times (40 + 10) = 42.5\ \Omega$. If the reactor is removed from service the line impedance would be 40 Ω. With the relays set for 42.5 Ω they would see faults beyond the original zone of protection. This may be acceptable if the zone 1 overreach does not extend into the next line section.

5.11 Loadability of relays

The value of load MVA at which the relay is on the verge of operation is known as the loadability limit of the relay.

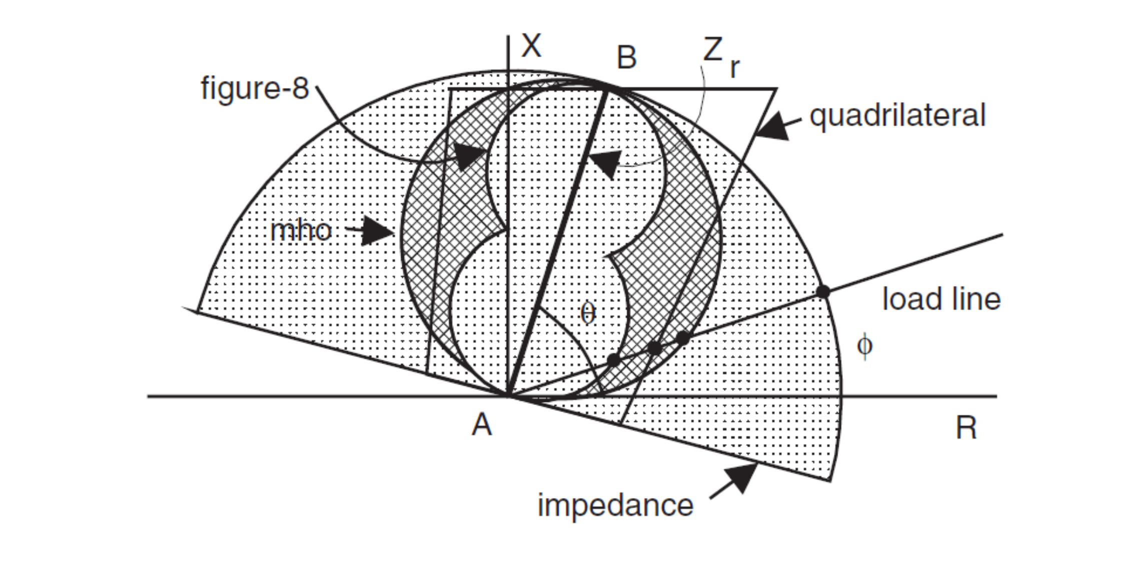
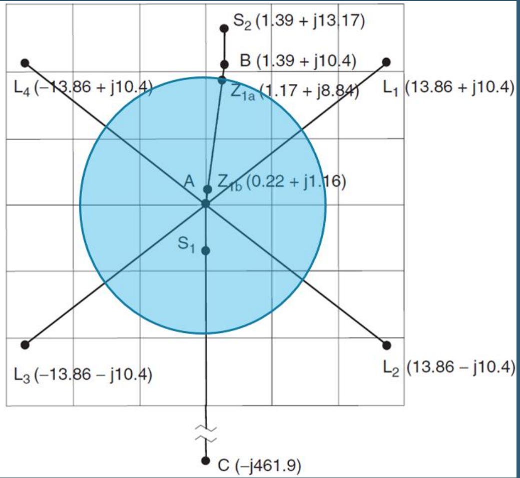
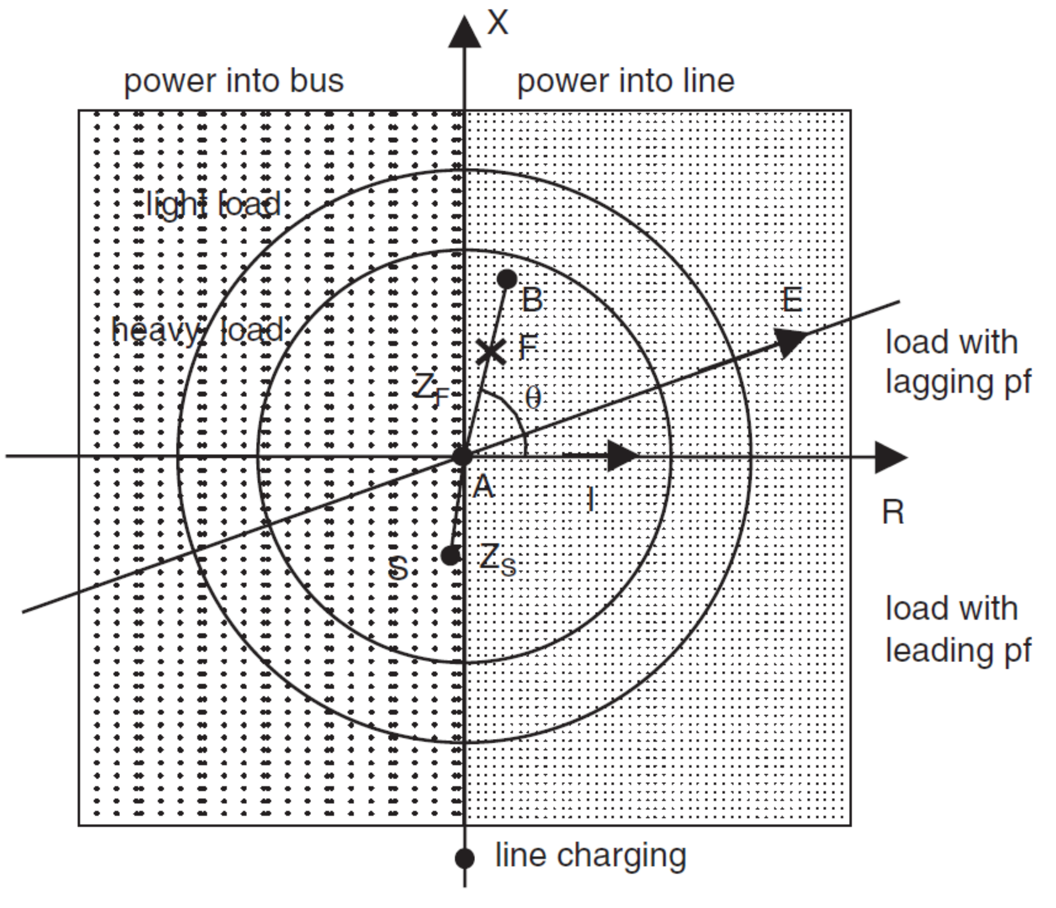


Figure 5.25 Loadability of distance relays with different characteristic shapes





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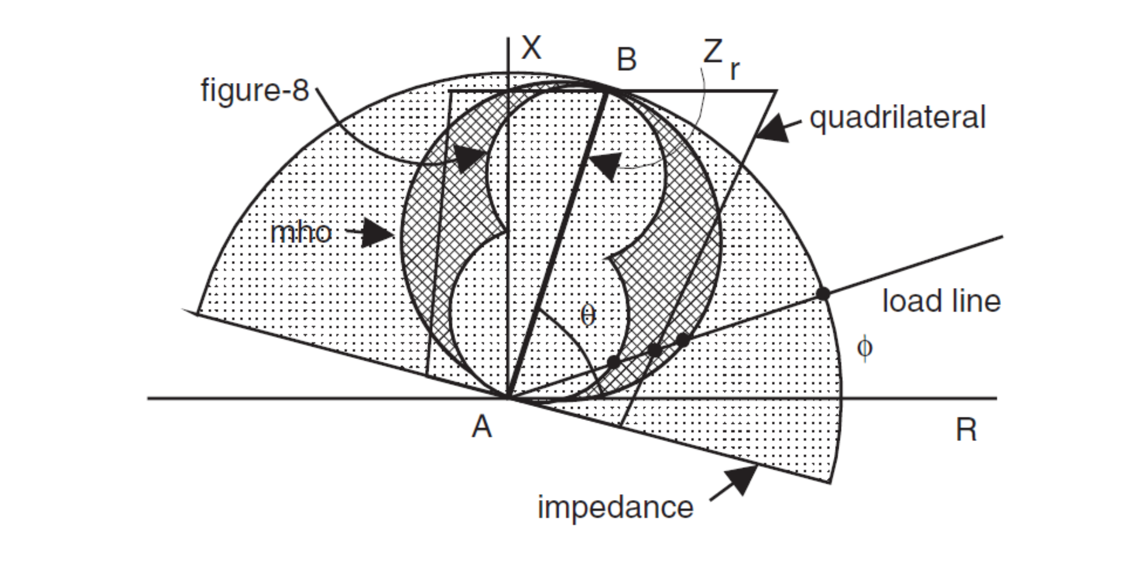
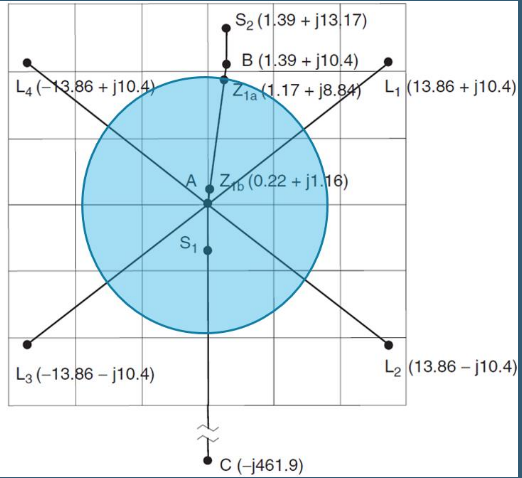
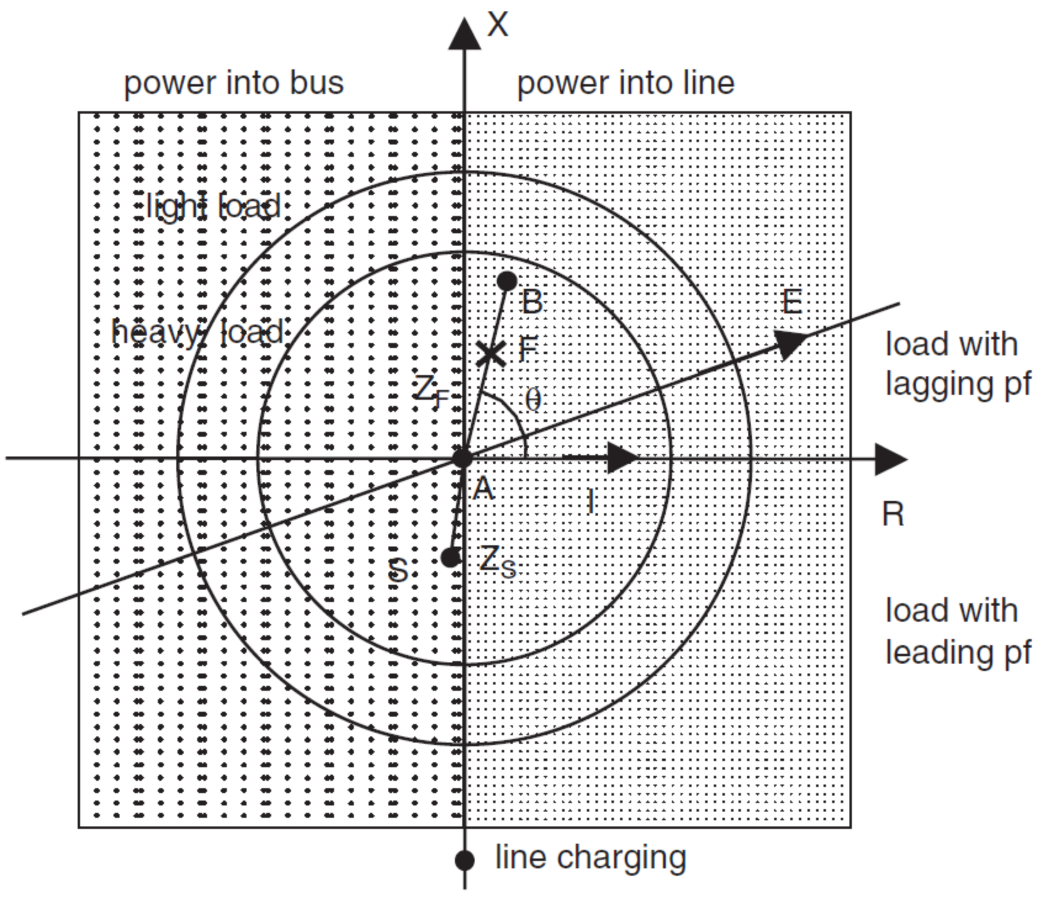


Figure 5.25 Loadability of distance relays with different characteristic shapes

$$S_{1,\text{imp}} = 3\frac{E^2}{Z_p} = 3\frac{E^2 n_i}{Z_r n_v} \qquad (5.25)$$

$$S_{1,\text{moh}} = 3\frac{E^2 n_i}{Z_r \cos(\theta + E\varphi) n_v} \qquad (5.26)$$





Example 5.8

We will consider the loadability of the zone 1 setting of the relay from Example 5.2. (This will illustrate the principle of checking the loadability, although one must realize that the critical loadability, which provides the smaller limit, is that associated with the third zone.) The current and voltage transformer ratios for the relay were determined to be $n_{\mathrm{i}} = 100$ and $n_{\mathrm{v}} = 288.6$. The zone 1 setting is $1.17 + \mathrm{j}8.84 = 8.917\angle 82.46^{\circ}$. From equation (5.25), the loadability of an impedance relay is given by (the phase-to-neutral voltage is 20 kV)

$$S_{1,\mathrm{imp}} = 3 \times \frac{20^2 \times 100}{8.917 \times 288.6} = 46.63\ \mathrm{MVA}$$

In the case of a mho relay, we must calculate the loadability at a specific power factor. Let us assume a power factor of 0.8 lagging. This corresponds to $\varphi = -36.870$. The angle of the line impedance is 82.46°. Thus, $(\theta + \varphi) = (82.46^{\circ} - 36.87^{\circ}) = 45.59^{\circ}$. Using equation (5.26), the loadability of a mho relay for a 0.8 pf lagging load is

$$S_{1,\mathrm{mho}} = 3 \times \frac{20^2 \times 100}{8.917 \times 288.6 \times \cos 45.59^{\circ}} = 66.63\ \mathrm{MVA}$$

Of course, one must check the loadability of all the zones, but the zone 3 loadability, being the smallest, will usually be the deciding criterion.

$$S_{1,\mathrm{imp}} = 3\frac{E^2}{Z_{\mathrm{p}}} = 3\frac{E^2 n_{\mathrm{i}}}{Z_{\mathrm{r}} n_{\mathrm{v}}} \qquad (5.25)$$

$$S_{1,\mathrm{moh}} = 3\frac{E^2 n_{\mathrm{i}}}{Z_{\mathrm{r}} \cos(\theta + E\varphi) n_{\mathrm{v}}} \qquad (5.26)$$