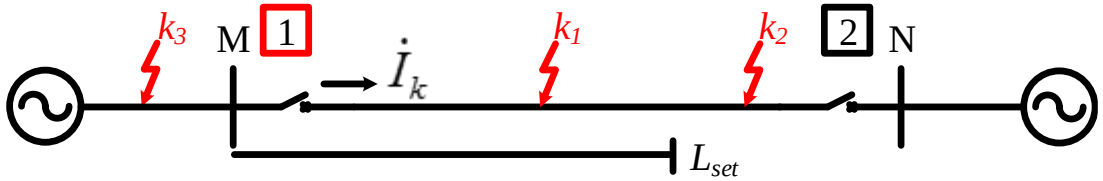
EEE340 Protective Relaying

Lecture 9 – Distance Protection 2

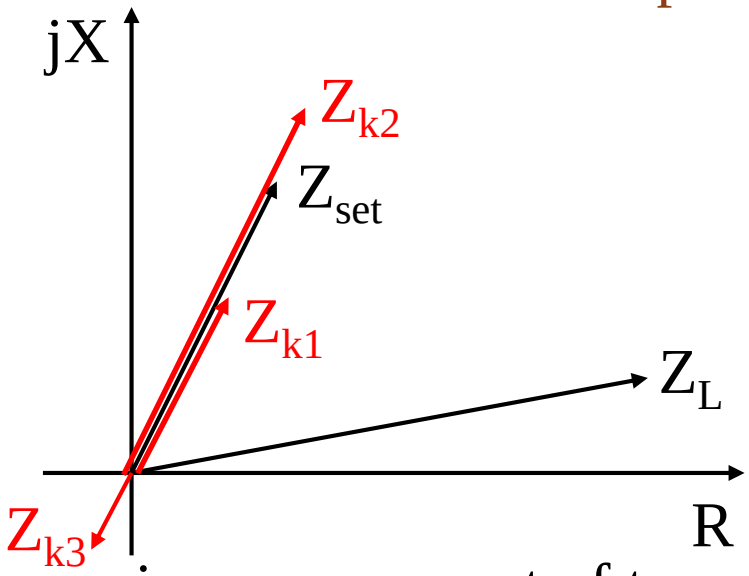
Today

- Impedance Relay and Characteristics
  - Impedance Relay with Circular Characteristic
  - Deflection of Circular Characteristic
  - Characteristics with Shape of Apple or Olive
  - Linear and Other Characteristic
  - Conversion Between Amplitude and Phase Comparison

Impedance Relay



- Impedance relay is to measure the impedance Z_m of the fault loop during a fault and compare with the presetting impedance Z_{set}, to judge if the fault is inside or outside of the protected zone.



- Because of the errors in measurement of transformer, transition resistance and other factors, Z_m may not be completely at the same line with Z_{set}.

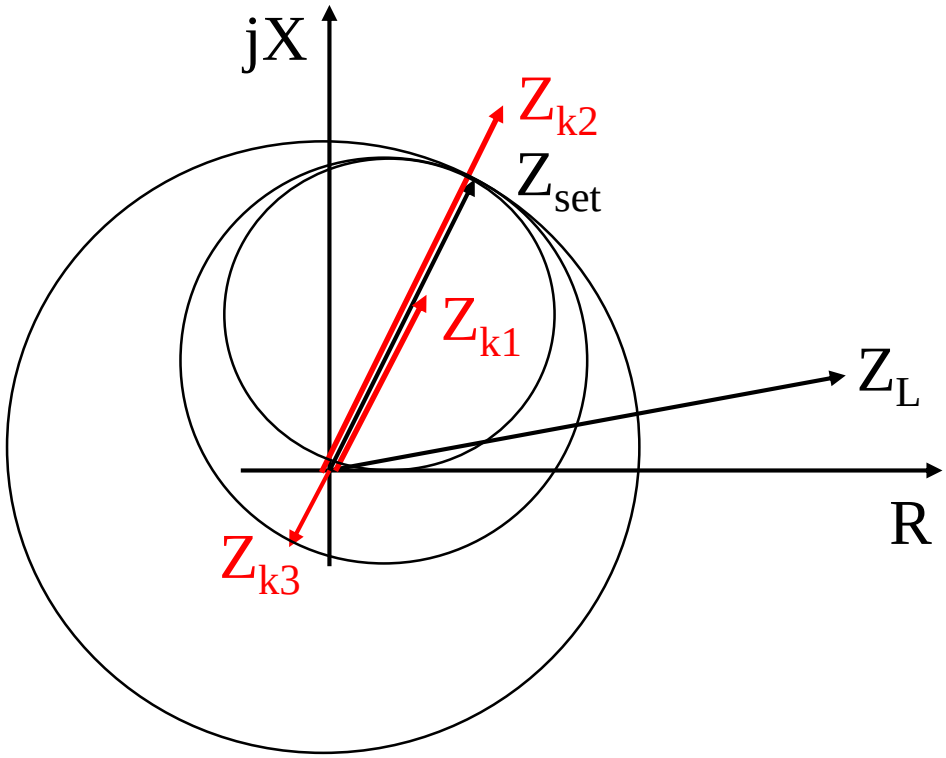
Trip Zone and Operating Characteristic

- Trip zone:

The set of all values for impedance in complex plane that can trip the impedance relay is the trip zone of this relay.

- Operating characteristic:

The shape of the trip zone is the operating characteristic of the relay;
The equation for the characteristic is the operating equation (amplitude comparison, phase comparison).



Impedance Relay with Circular Characteristic

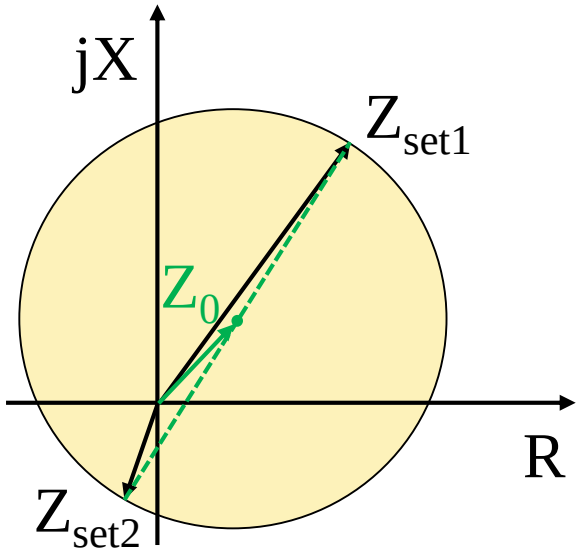
- Positive direction:

The voltage higher than ground is positive, the current flowing from bus to line is positive.

The impedance with shape of trip zone as a circle.
Normal operating equation:

$$\left|Z_m - Z_o\right| \le r$$

$$\left|Z_m - \frac{1}{2}(Z_{set1} + Z_{set2})\right| \le \left|\frac{1}{2}(Z_{set1} - Z_{set2})\right|$$



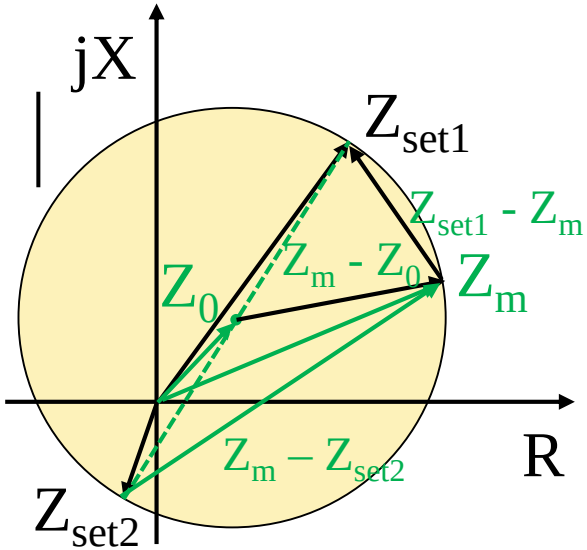
Z_{set1} and Z_{set2} are two terminals of any diameter.

Impedance Relay with Circular Characteristic

(1) Amplitude comparison:

$$\left|Z_m - Z_0\right| \le R$$

$$\left| Z_m - \frac{1}{2}\left(Z_{set1} + Z_{set2}\right) \right| \le \frac{1}{2}\left| Z_{set1} - Z_{set2} \right|$$



(2) Phase comparison:

a. When Z_m is at the border of right side (90^o)

b. When Z_m is at the border of left side (-90^o)

$$-90^o \le \arg\frac{Z_{set1} - Z_m}{Z_m - Z_{set2}} \le 90^o$$

Impedance Relay with Circular Characteristic

- Operating impedance Z_{op}:

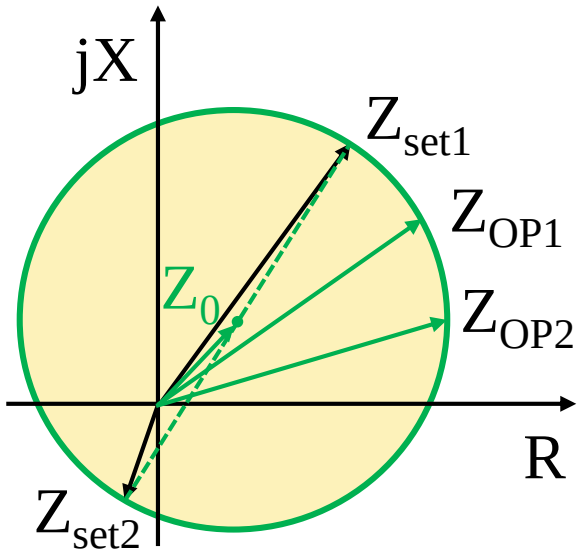
The critical impedance to make the relay trip.
With different phasor angle, the amplitude of Z_{op} is different.

- Most sensitive phasor angle Φ_{set1} :

The phasor angle with the largest operating impedance, with the longest protected zone.
Normally set as the impedance angle of line.

- Directional characteristic:

It can avoid dead zone in positive direction, but still have a little trip zone in opposite direction, so false trip in opposite direction is still possible.



- Application:

Backup distance protection (zone III).

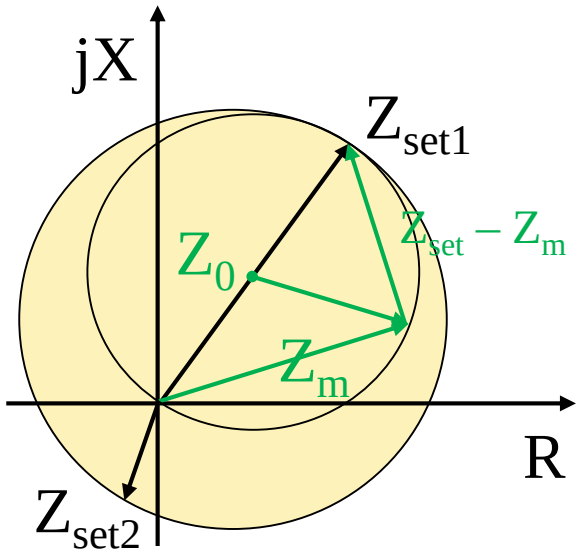
Directional Circular Characteristic (MHO Unit)

Operating equation:

$$Z_{set1} = Z_{set}, \quad Z_{set2} = 0$$

$$\left| Z_m - \frac{1}{2} Z_{set} \right| \leq \left| \frac{1}{2} Z_{set} \right|$$

$$-90^{o} \leq \arg \frac{Z_{set} - Z_m}{Z_m} \leq 90^{o}$$



Centre: $Z_0 = \frac{1}{2} Z_{set}$ Radius: $R = \left| \frac{1}{2} Z_{set} \right|$

Directional Circular Characteristic (MHO Unit)

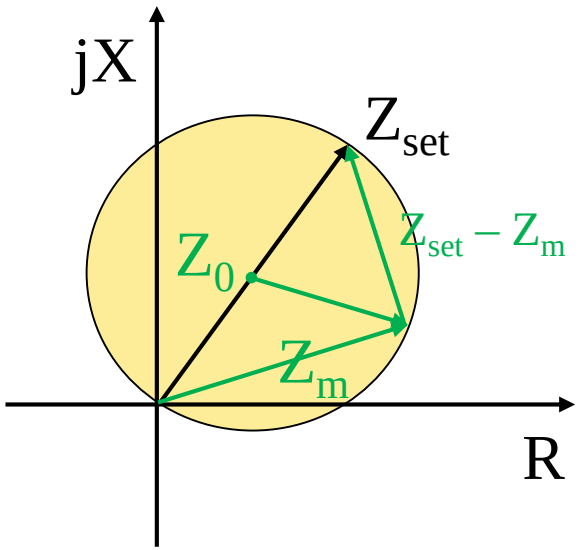
- Operating impedance Z_{op}:

With different phasor angle of Z_m, the amplitude of Z_{op} is different.

- Most sensitive phasor angle Φ_{set1} :

The phasor angle with the largest operating impedance, with the longest protected zone.

Normally set as the impedance angle of line.



- Directional characteristic:

It will not trip for faults at opposite direction, so it has directional characteristic by itself.

- Application:

As main distance protection (zone I and zone II).

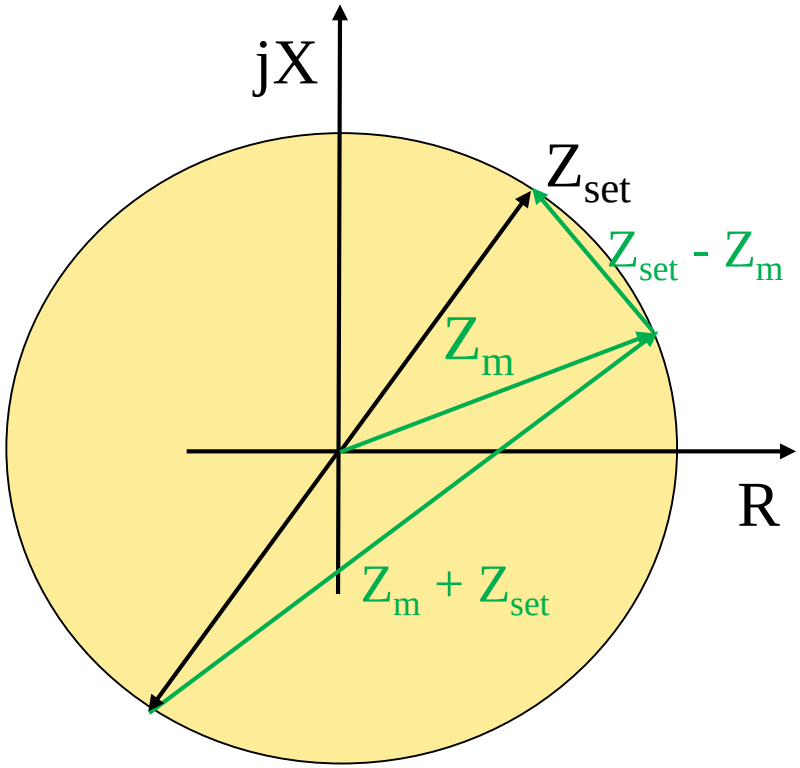
Impedance Relay with Complete Circular Characteristic

Operating equation:

$$Z_{set1} = Z_{set}, \quad Z_{set2} = -Z_{set}$$

$$\left| Z_m \right| \leq \left| Z_{set} \right|$$

$$-90^{o} \leq \arg \frac{Z_{set} - Z_m}{Z_m + Z_{set}} \leq 90^{o}$$



Centre: $Z_0 = 0$ Radius: $R = \left| Z_{set} \right|$

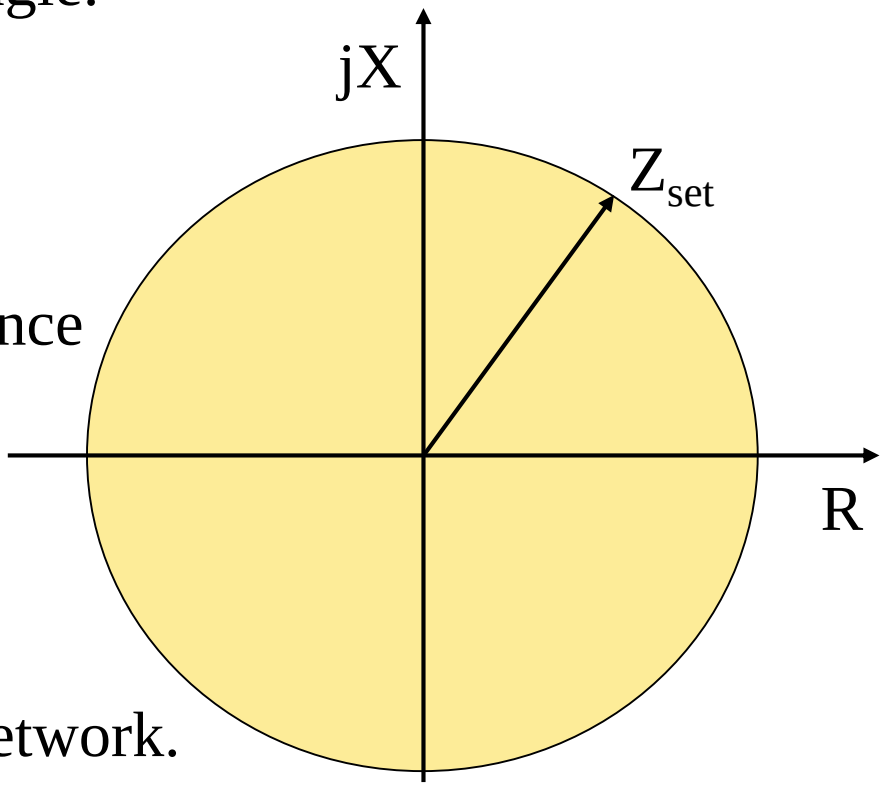
Impedance Relay with Complete Circular Characteristic

- Operating impedance Z_{op}:

With different phasor angle of Z_m, the amplitude of Z_{op} is equal.

- Most sensitive phasor angle Φ_{set1} :

There is no most sensitive phasor angle.



- Directional characteristic:

It has no directional characteristic since any direction is the same.

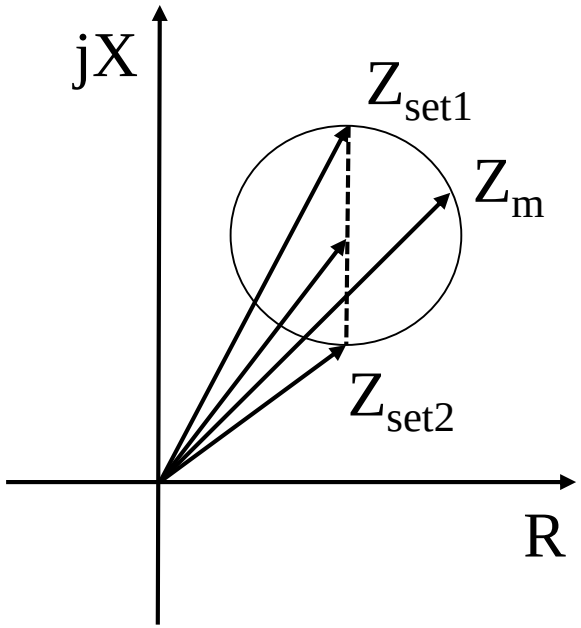
- Application:

Normally applied in single source network.

Impedance Relay with Upthrow Circular Characteristic

Operating equation:

$$-90^{o} \le \arg \frac{Z_{set1} - Z_m}{Z_m - Z_{set2}} \le 90^{o}$$



Z_{set1} and Z_{set2} are all in the first quadrant.

Centre: $Z_0 = \frac{1}{2}(Z_{set1} + Z_{set2})$ Radius: $Z_0 = \frac{1}{2}\left|Z_{set1} - Z_{set2}\right|$

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Deflection of Circular Characteristic

For the circular characteristics abovementioned, in phasor comparison, the critical operating conditions are all at 90 or -90 degree.

The tripping range is 90-(-90)=180 degree.

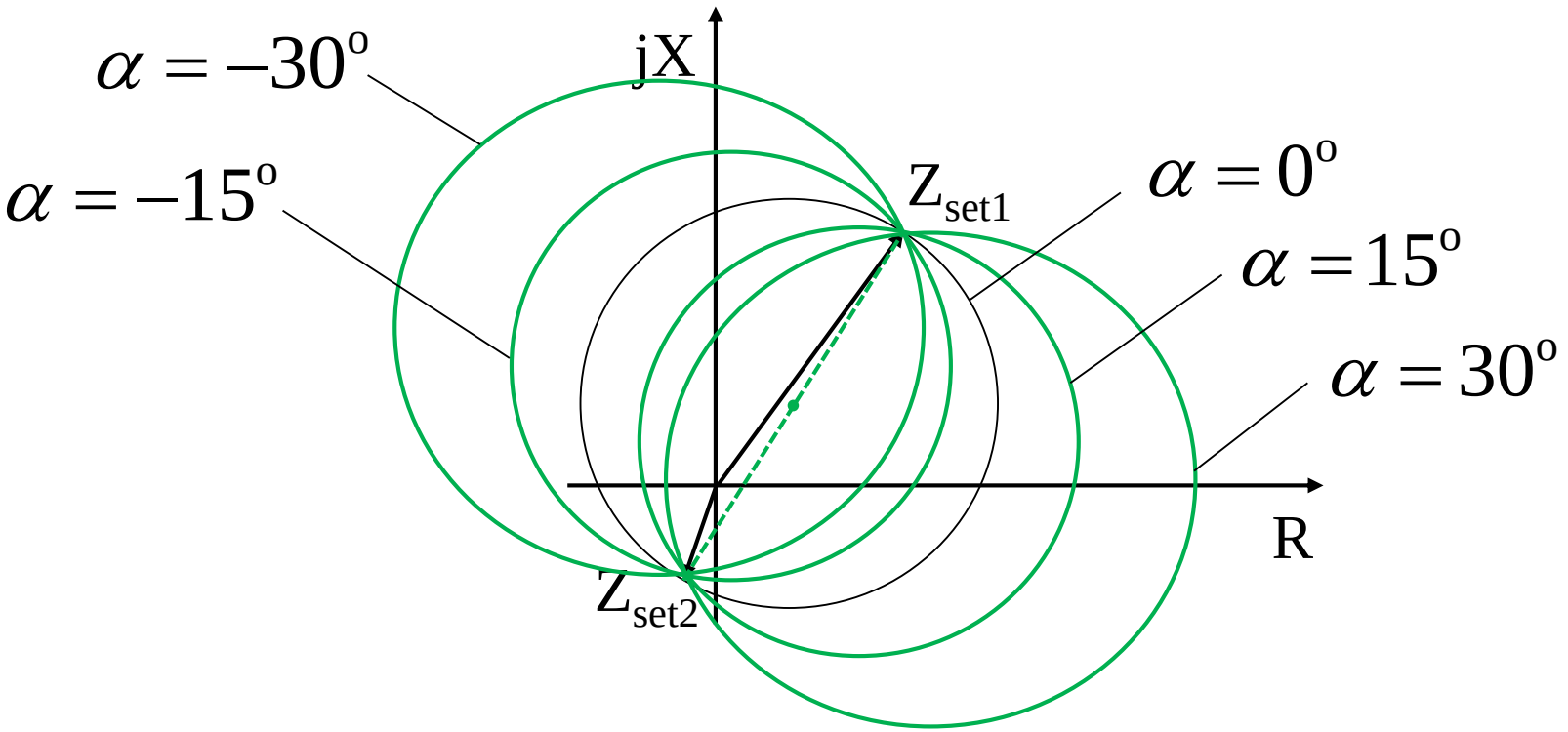
If the tripping conditions are 90+α and -90+α degree, the tripping range is still 90+α-(-90+α)=180 degree.

However, if α≠0, Z_{set1} -Z_{set2} is not a diameter, but a chord.

Deflection of Circular Characteristic

Operating equation:

$$-90^{o} + \alpha \le \arg \frac{Z_{set1} - Z_m}{Z_m - Z_{set2}} \le 90^{o} + \alpha$$



Deflection of Circular Characteristic

When α is positive, the deflection is to the right side.

When α is negative, the deflection is to the left side.

In deflection, if Z_{set} keeps unchanged, the diameter may be increased.

The length of protected zone at direction of Z_{set} may be unchanged, but the length of protected zone in other directions may be increased.

It is important to avoid false tripping for faults outside the protected zone.

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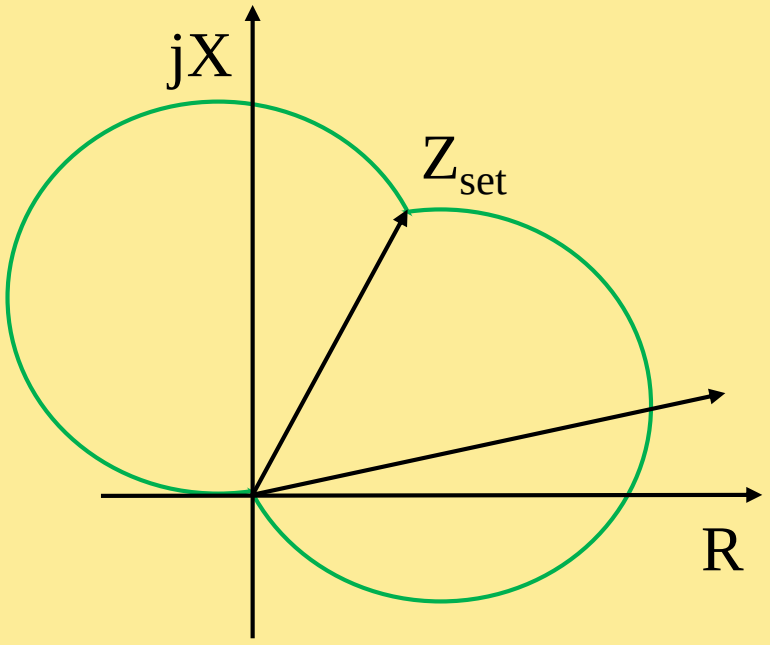
Characteristics with Shape of Apple or Olive

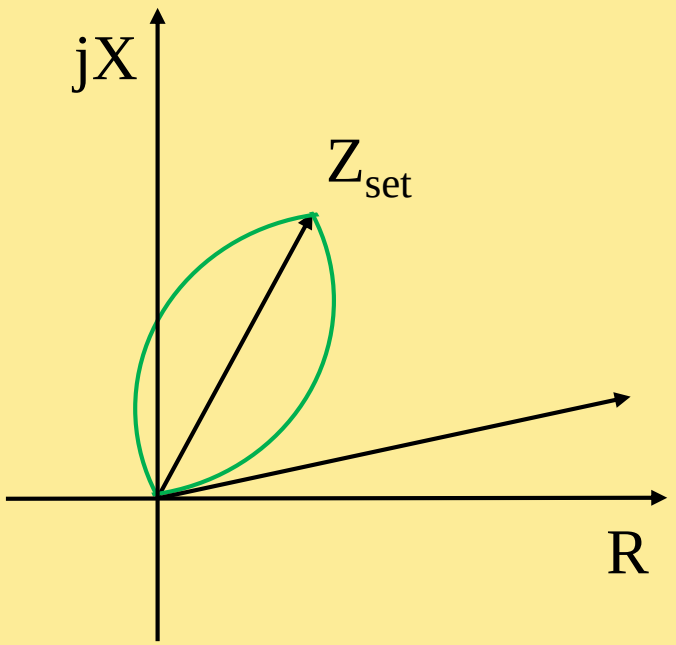
If the tripping range abovementioned is not 180 degree, the corresponding trip zone is not a circle. Suppose the directional circular characteristic is changed as:

$$-\beta \le \arg \frac{Z_{set} - Z_m}{Z_m} \le \beta$$

$\beta > 90°$



$\beta < 90°$



Characteristics with Shape of Apple or Olive

Shape of apple

When $\beta > 90^{o}$, the shape is as an apple, which has larger trip zone in R direction.

Even Z_m has large resistance, it can be within the trip zone. So even with big transition resistance during fault, it can tolerate that and reliably operate.

But normal loads with small resistance may also be possibly within the trip zone, it is poor to tolerate overload.

Shape of olive

Opposite to the characteristic of shape of apple for transition resistance and overload.

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Linear Characteristic

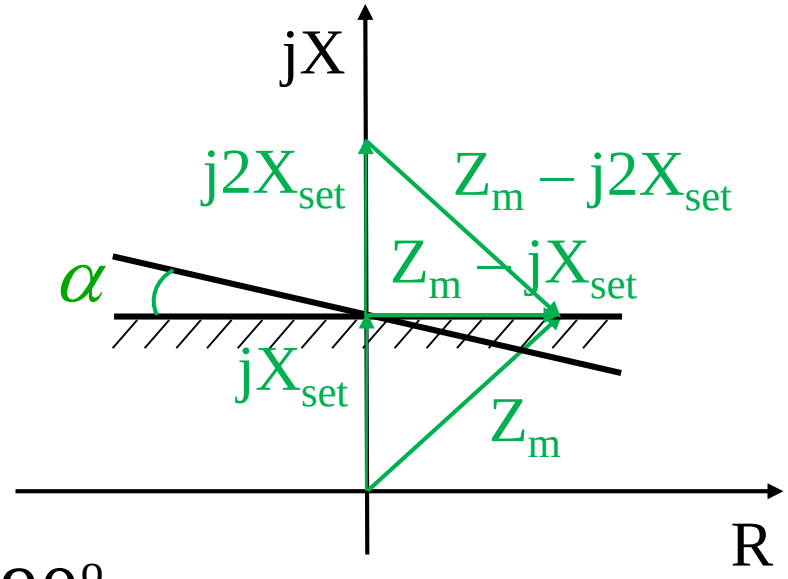
For circular characteristic, if the center is infinitely far and diameter is infinity:

Reactive characteristic

$$\left| Z_m \right| \le \left| Z_m - j2X_{set} \right|$$

$$-90^o \le \arg \frac{Z_m - jX_{set}}{-jX_{set}} \le 90^o$$

$$-90^o - \alpha \le \arg \frac{Z_m - jX_{set}}{-jX_{set}} \le 90^o - \alpha$$



It has nothing to do with resistance, so it can tolerate transition resistance significantly. But it is also possible to trip under normal load. It has no directional characteristic and seldom be used independently.

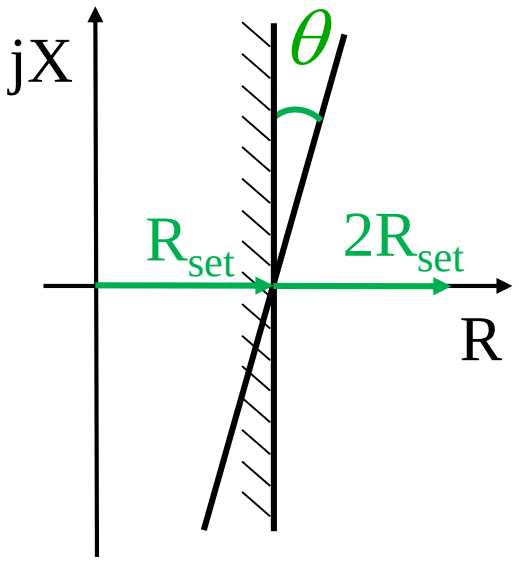
Linear Characteristic

Resistance characteristic

$$\left| Z_m \right| \leq \left| Z_m - 2R_{set} \right|$$

$$-90^o \leq \arg \frac{Z_m - R_{set}}{-R_{set}} \leq 90^o$$

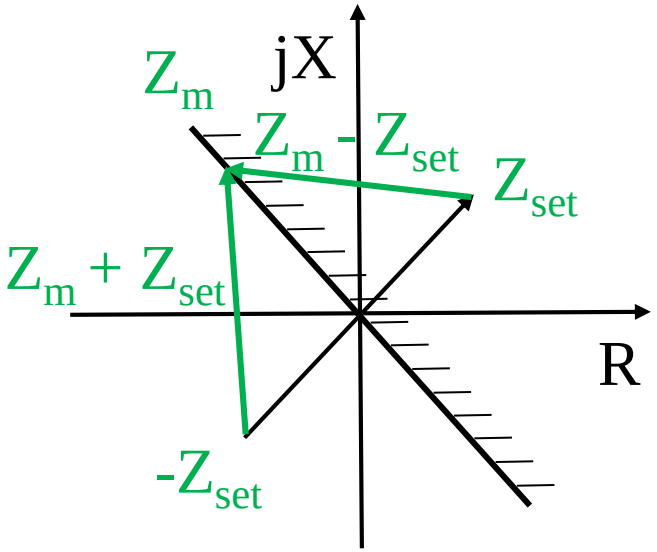
$$-90^o - \theta \leq \arg \frac{Z_m - R_{set}}{-R_{set}} \leq 90^o - \theta$$



Directional characteristic

$$\left| Z_m - Z_{set} \right| \leq \left| Z_m + Z_{set} \right|$$

$$-90^o \leq \arg \frac{Z_m}{Z_{set}} \leq 90^o$$



Other Characteristic

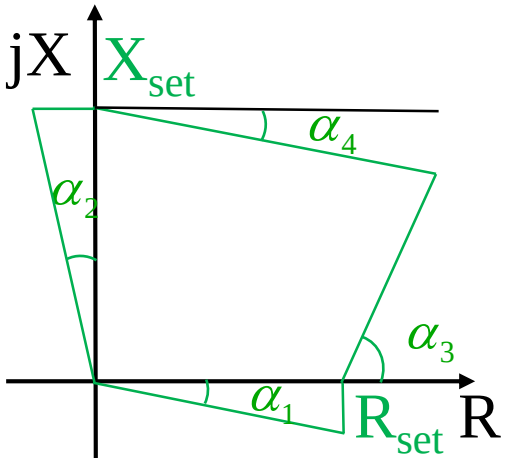
Polygon characteristic

To overcome the conflict of transition resistor and overload in circular characteristic.

$$\alpha_1 = \alpha_2 = 15^o$$

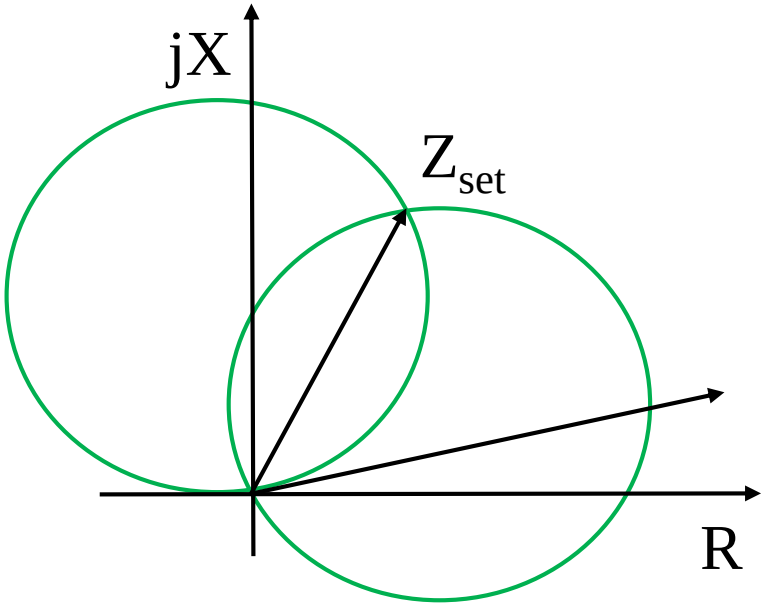
$$\alpha_3 = 45^o$$

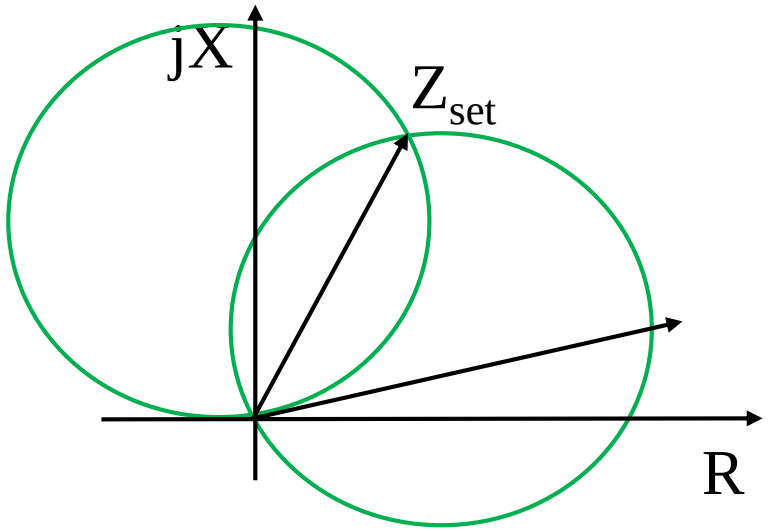
$$\alpha_4 = 7^o$$



Compound characteristic

To make integration by “and” or “or”.





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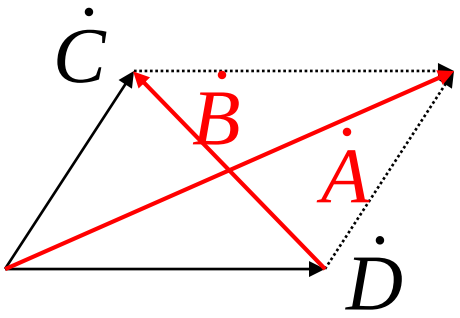
Conversion Between Amplitude and Phase Comparison

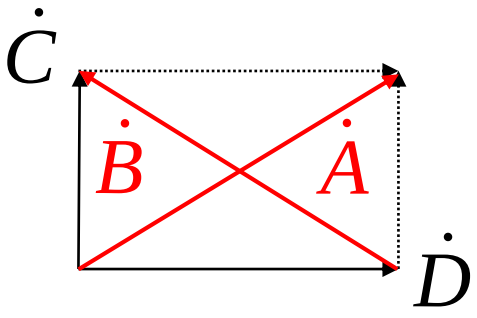
$$|Z_A| \geq |Z_B| \quad \Longleftrightarrow \quad 90^o \geq \arg\frac{Z_C}{Z_D} \geq -90^o$$

$$\begin{cases} Z_A = Z_C + Z_D \\ Z_B = Z_C - Z_D \end{cases} ; \quad \begin{cases} Z_C = \dfrac{Z_A + Z_B}{2} \\ Z_D = \dfrac{Z_A - Z_B}{2} \end{cases}$$



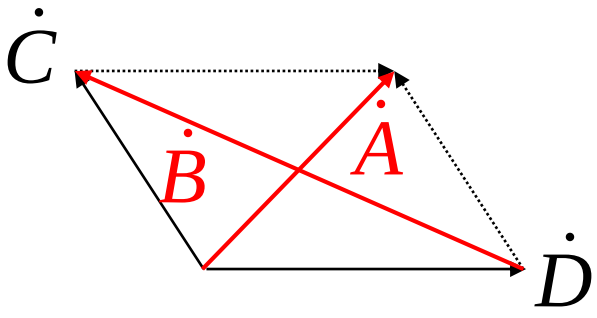
$|Z_A| \geq |Z_B|$

$90^o \geq \arg\frac{Z_C}{Z_D} \geq -90^o$



$|Z_A| = |Z_B|$

$\arg\frac{Z_C}{Z_D} = \pm 90^o$



$|Z_A| \leq |Z_B|$

$270^o \geq \arg\frac{Z_C}{Z_D} \geq 90^o$

Conversion Between Amplitude and Phase Comparison

$$\begin{cases} \left| Z_m - \frac{1}{2}\left(Z_{set1} + Z_{set2}\right) \right| \le \frac{1}{2}\left| Z_{set1} - Z_{set2} \right| \\ -90^o \le \arg\frac{Z_{set1} - Z_m}{Z_m - Z_{set2}} \le 90^o \end{cases}$$

$$\begin{cases} \left| Z_m - \frac{1}{2} Z_{set} \right| \le \left| \frac{1}{2} Z_{set} \right| \\ -90^o \le \arg\frac{Z_{set} - Z_m}{Z_m} \le 90^o \end{cases}$$

Directional circular characteristic

$$\begin{cases} \left| Z_m \right| \le \left| Z_{set} \right| \\ -90^o \le \arg\frac{Z_{set} - Z_m}{Z_m + Z_{set}} \le 90^o \end{cases}$$

Complete circular characteristic

Next Lecture

Distance Protection 3

Thanks for your attendance