EEE340 Protective Relaying

Lecture 17 – Power Transformer Protection 2

Today

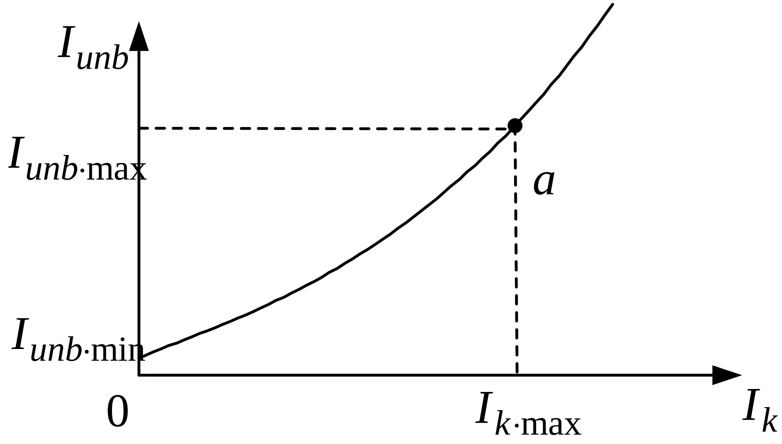
- Power Transformer Protection 1
  - Differential Relay with Restraint Characteristics
  - Analysis of Differential Relay with Restraint Characteristics
  - Magnetizing Inrush Current and Identification Methods
  - Gas Protection

Differential Relay with Restraint Characteristics

- The unbalance current can estimated as (without consideration of inrush current):

$$I_{unb.\max} = (\Delta f_{za} + \Delta U + 0.1 K_{np} K_{st}) I_{k.\max}$$

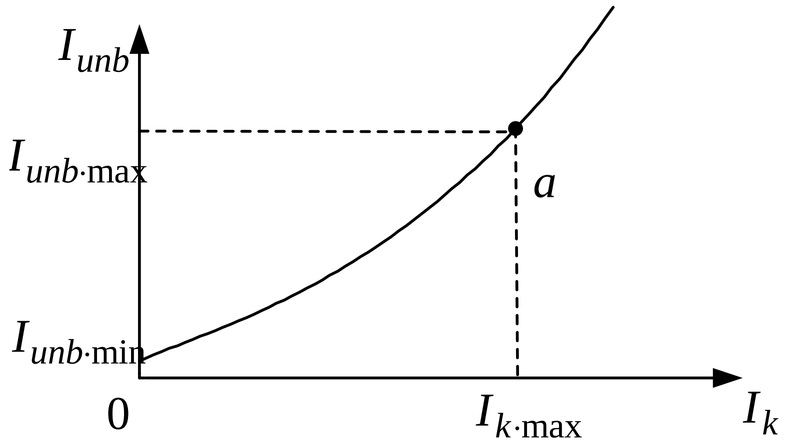
- The unbalance current is tightly related to the through current; more through current may take more unbalance current.



Differential Relay with Restraint Characteristics

• If the setting value is calculated based on the maximum through current $I_{k.\max}$, then the setting value must be higher than point a in the figure, which may reduce the sensitivity of protection.

• If the threshold of setting value can be adjusted according to the fault current, the operating zone just needs to be higher than the unbalance current curve.



Differential Relay with Restraint Characteristics

- As $\dot{I}_1 = -\frac{1}{n_T}\dot{I}_2$, we can select the restraint current as:

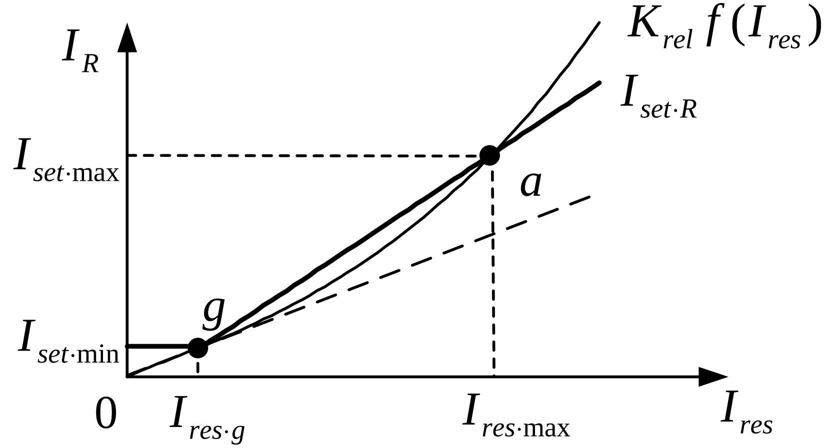
$$I_{res} = I_1$$

- For external faults, we suppose the relation between unbalance current and the fault current is:

$$I_{unb} = f(I_{res})$$

- Then the operating equation should be:

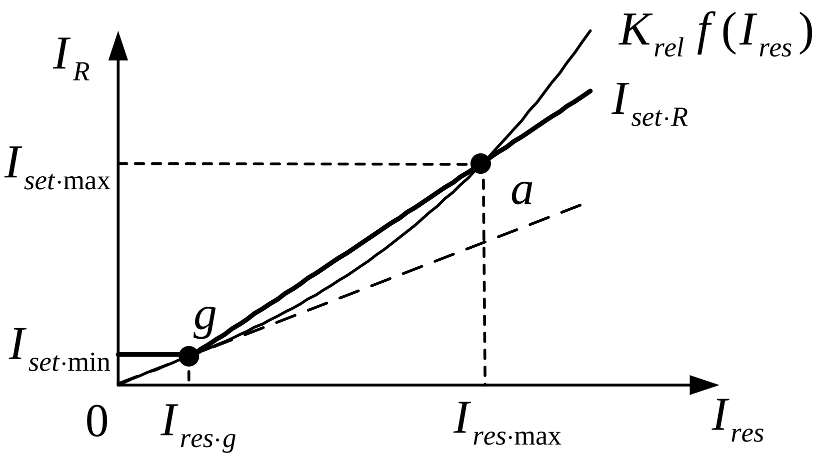
$$I_R > K_{rel} f(I_{res})$$



Differential Relay with Restraint Characteristics

- The actual characteristic is difficult to obtain, it is often simplified in practice:

$$I_{set\cdot R} = \begin{cases} I_{set\cdot\min}, I_{res} < I_{res\cdot g} \\ K(I_{res} - I_{res.g}) + I_{set\cdot\min}, I_{res} \geq I_{res\cdot g} \end{cases}$$



Differential Relay with Restraint Characteristics

$$I_{set\cdot R} = \begin{cases} I_{set\cdot\min}, I_{res} < I_{res\cdot g} \\ K(I_{res} - I_{res.g}) + I_{set\cdot\min}, I_{res} \geq I_{res\cdot g} \end{cases}$$

$$I_{set\cdot\min} = (0.2 \sim 0.5) I_N$$

$$I_{res\cdot g} = (0.6 \sim 1.1) I_N$$

Restraint factor K is normally as 0.4~1.

Today

- Power Transformer Protection 2
  - Differential Relay with Restraint Characteristics
  - Analysis of Differential Relay with Restraint Characteristics
  - Magnetizing Inrush Current and Identification Methods
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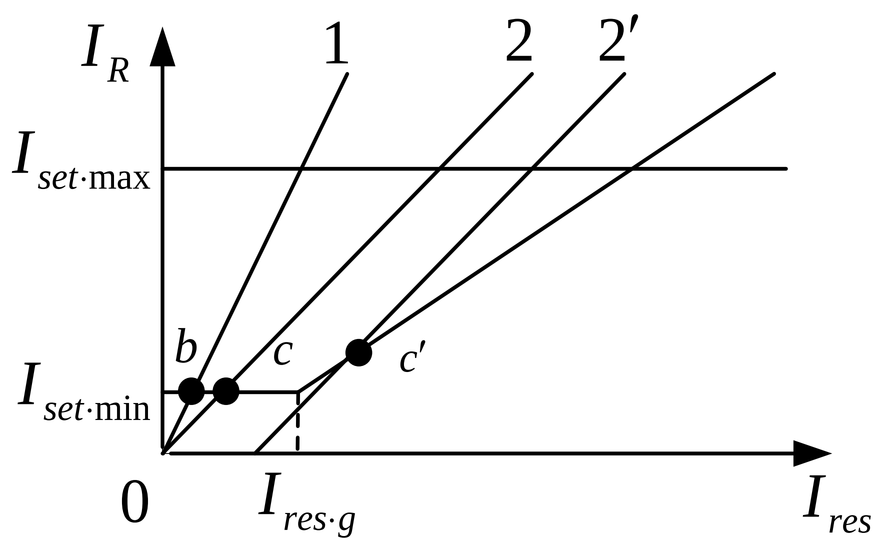
Analysis of Differential Relay with Restraint Characteristics

- With double power sources, suppose equal emf and equivalent impedance:

$$I_R = I_1 + I_2 = 2I_{res}$$

- Shown as curve 1, the starting value is $I_{set.\min}$

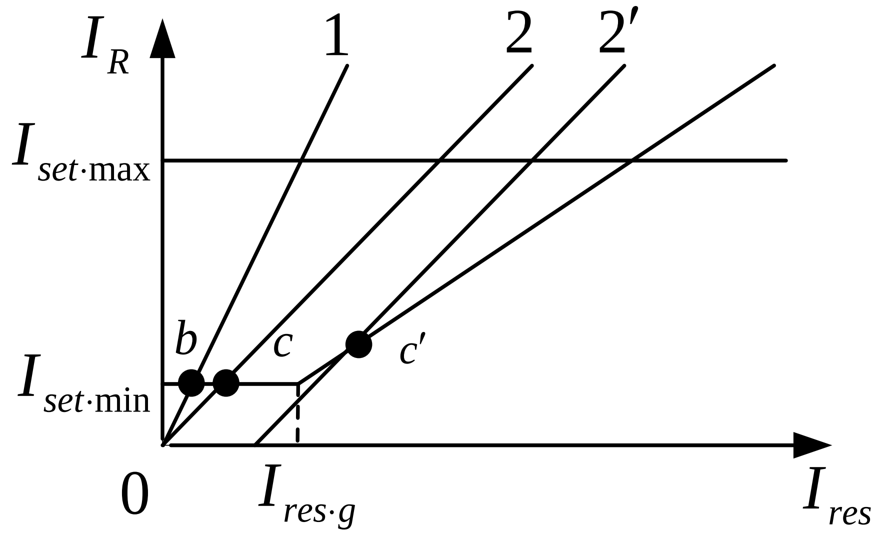


Analysis of Differential Relay with Restraint Characteristics

- With single power sources, select load current as restraint current:

$$I_{res} = 0$$

- There is no restraint, the actual starting value is $I_{set.\min}$.

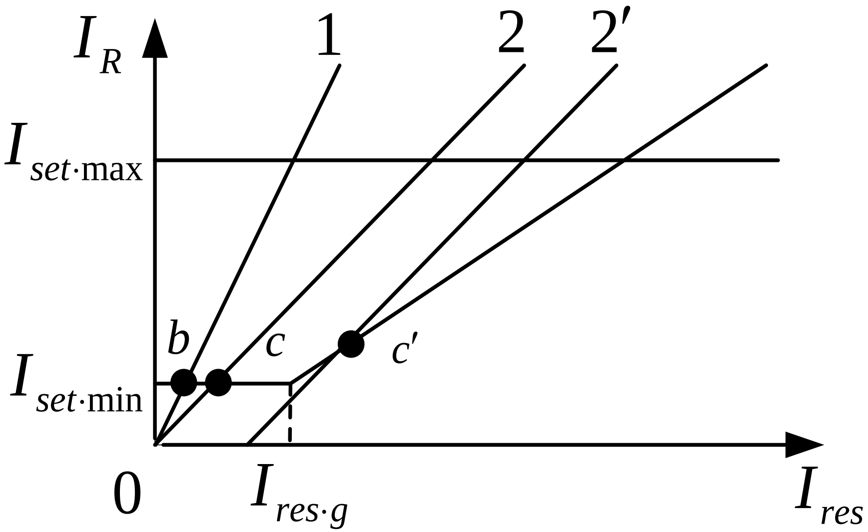


Analysis of Differential Relay with Restraint Characteristics

- With single power sources, select the current of power source side as restraint current:

$$I_R = I_{res} = I_1$$

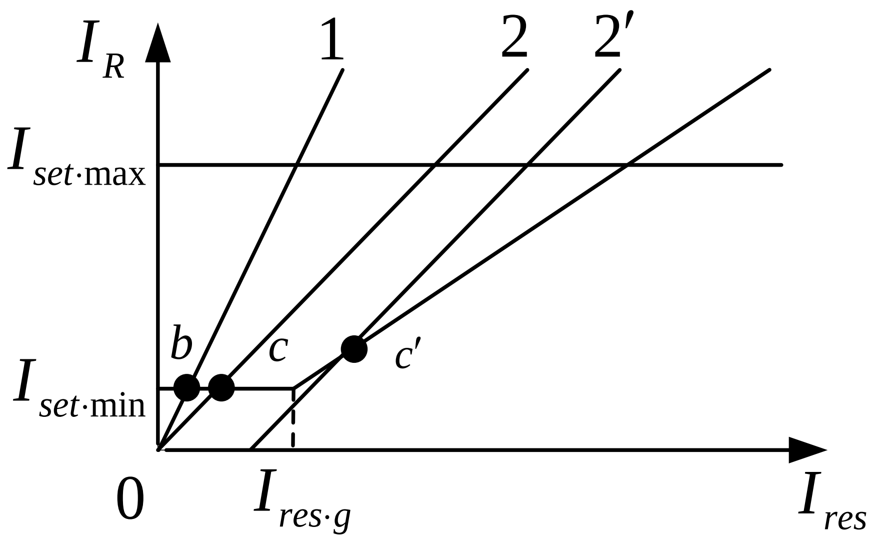
- Shown as curve 2, the starting value is $I_{set.\min}$.



Analysis of Differential Relay with Restraint Characteristics

- With heavy load current and weak fault current, suppose to select current of source side as restraint current:

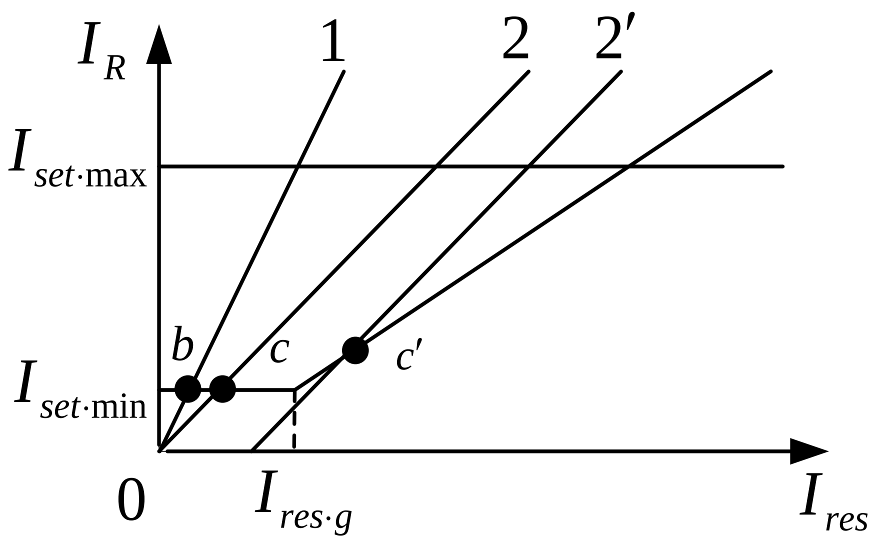
- Because of the load current, the restraint current is increased, as shown by 2'; the actual starting value is higher than $I_{set.\min}$.



Analysis of Differential Relay with Restraint Characteristics

- The characteristic for no restraint is the line parallel to the horizontal axis; and the starting value is fixed as $I_{set.\max}$.

- With restraint characteristic, the starting value is reduced from $I_{set.\max}$ to $I_{set.\min}$, so the sensitivity is increased significantly.



Selection of Restraint Current

Principle:

• The restraint current should be approximately equal to the through fault current for external faults;

• For internal faults, the restraint current should be as small as possible, this is good for sensitivity to internal faults.

Selection of Restraint Current

Other selection of restraint current:

$$I_{res} = \frac{I_1 + I_2}{2}$$

$$I_{res} = \frac{\left|\dot{I}_1 - \dot{I}_2\right|}{2}$$

$$I_{res} = \begin{cases} \sqrt{\left|\dot{I}_m\right|\left|\dot{I}_n\right|\cos(180^\circ - \theta_{mn})} & \cos(180^\circ - \theta_{mn}) > 0 \\ 0 & \cos(180^\circ - \theta_{mn}) \leq 0 \end{cases}$$

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Magnetizing Inrush Current

- The relation between voltage of coils and magnetic flux can be summarized as:

$$u = \frac{d\Phi}{dt}$$

- If the transformer is putting into operation with no load at time t=0, the voltage on the transformer is:

$$u = U_m \sin(\omega t + \alpha)$$

- Then the magnetic flux can be calculated as:

$$\Phi = -\Phi_m \cos(\omega t + \alpha) + \Phi_{(0)}$$

Magnetizing Inrush Current

- Because the magnetic flux in the iron core must be continuous,

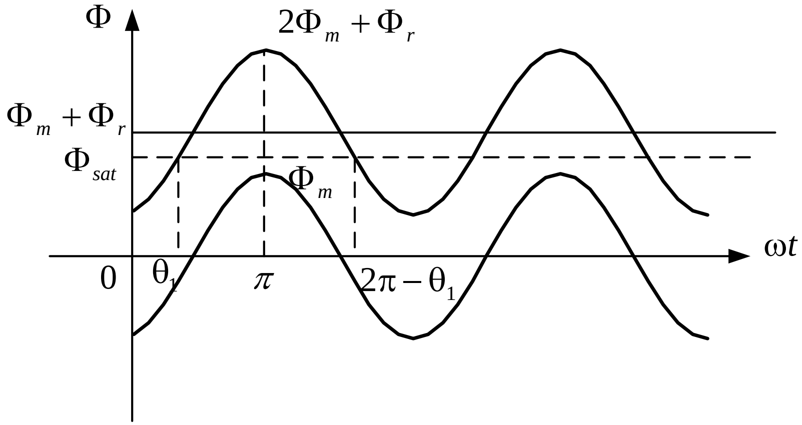
$$\Phi(0) = -\Phi_m \cos\alpha + \Phi_{(0)} = \Phi_r$$

Φ_r is the residual flux at the moment of switching on.

$$\Downarrow$$

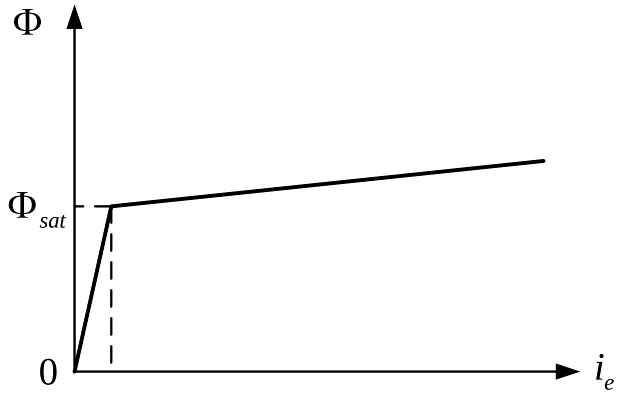
$$\Phi_{(0)} = \Phi_r + \Phi_m \cos\alpha$$

Magnetizing Inrush Current



- If Φ_r >0 and cosα>0, after half period, the flux may have the maximum value 2 Φ_m cosα+ Φ_r ;
- For the most serious situation, when α=0, the maximum flux can be 2 Φ_m + Φ_r , which is much larger than the saturation value Φ_{sat}. The transformer will be seriously saturated.

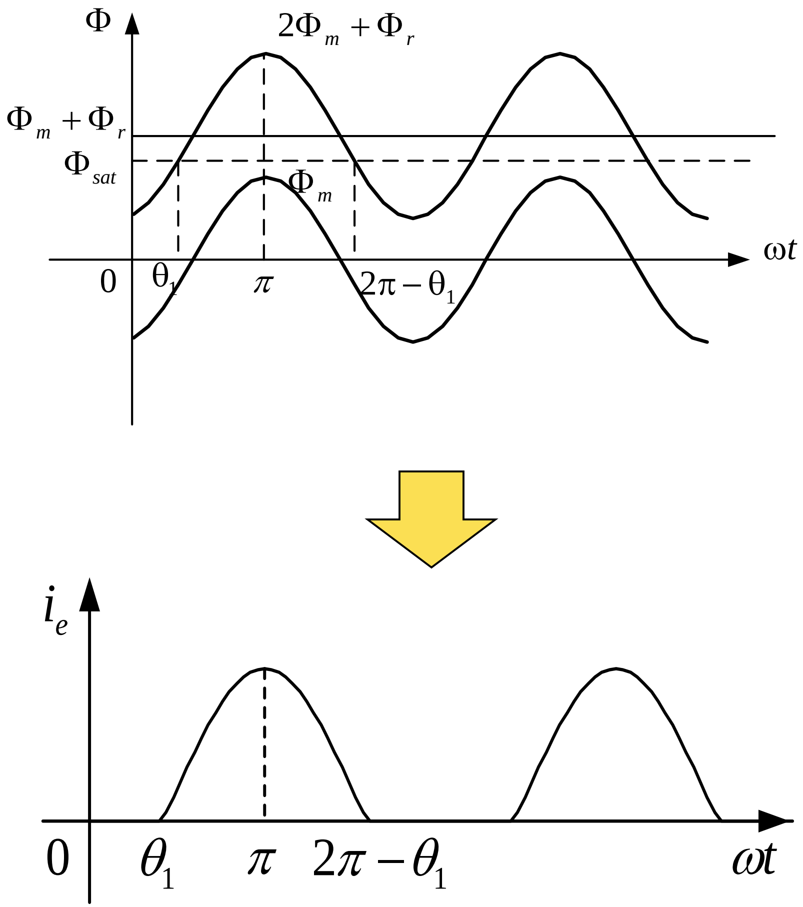
Magnetizing Inrush Current



• The normal operating zone of transformer is near to the saturation point; during normal operation, the transformer works at the linear zone, the excitation current is very small.

• When the iron flux is much larger than the saturation flux, the excitation current would be very huge.

Magnetizing Inrush Current



- There should be intermittent angle in the waveform of inrush current.

Magnetizing Inrush Current

- The inrush current is related to the phase angle corresponding to the moment of switching on, maximum value can be got by angle of 0 or π.
- The waveform is completely on one side of the time axis with intermittent angle; larger inrush current may have smaller intermittent angle.
- The inrush current also contains large non-periodic component.
- The inrush current contains many harmonics, the second harmonic is dominant.

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Gas Protection

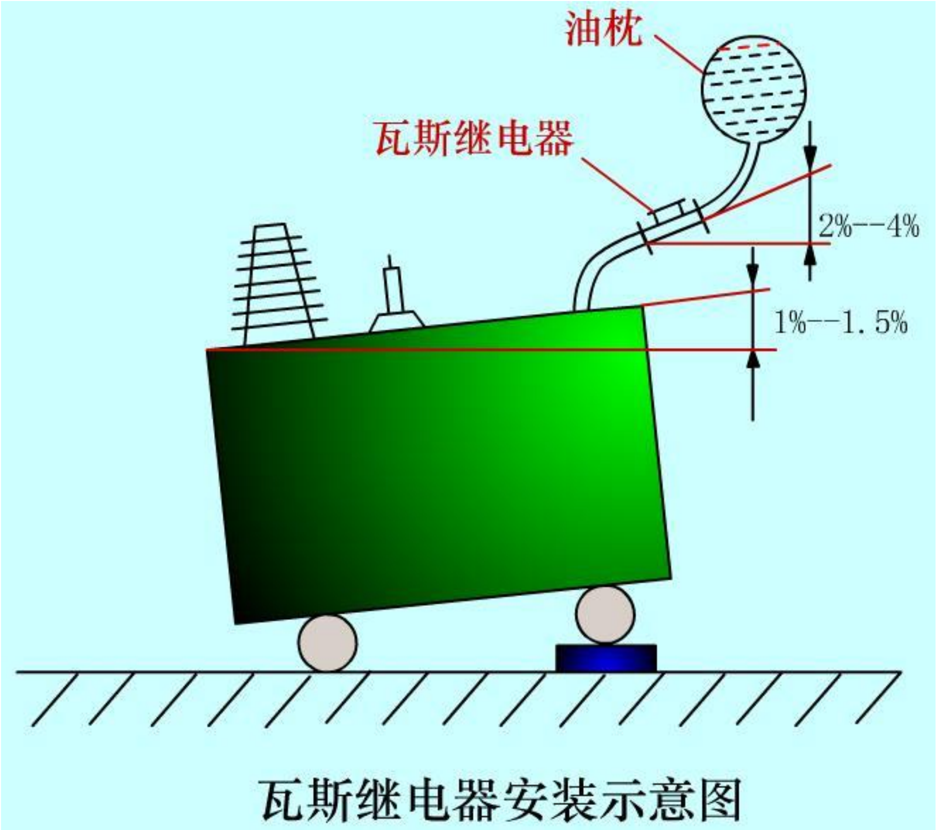
- Oil is often used as cooling medium of transformer.

- If a fault happens in the oil tank, the fault current and electric arc may decompose the oil and generate gas.

- The quantity and exhausting speed of gas is related the extent of fault.

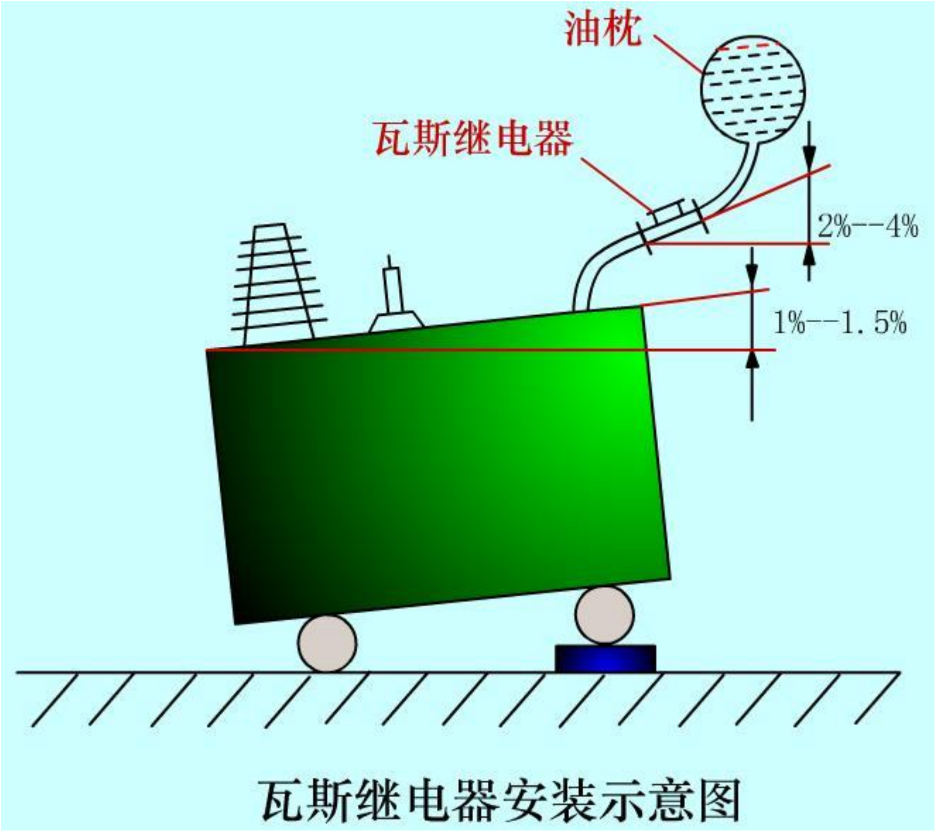
- The main component is the gas relay with two output terminals:
To output warning signal for abnormal operation or weak faults;
To trip breakers of the transformer for serious faults.

Gas Protection



In case of weak fault, the quantity of gas is small and the exhausting speed is slow. The gas will go up along the pipe, the oil level in the gas relay will drop down. When the oil level drops down to the threshold value, warning signal will be activated.

Gas Protection



In case of serious fault, the quantity of gas is huge and the internal pressure is high. The gas will rush through the pipe, when the oil speed through the gas relay exceeds the threshold value, the protection will trip the breakers of the transformer.

Equipping Policy of Transformer Protection

Main Protection

- Gas Protection
- Longitudinal Differential Protection or Instantaneous overcurrent protection

Backup Protection

- Backup protection for grounded faults and phase-to-phase faults.
- Overload protection
- Over excitation protection
- Other non-electric quantity protection (protections based on oil temperature, oil pressure and faults of refrigerating system)

Next Lecture

Generator Protection 1

Thanks for your attendance