EEE340 Protective Relaying

Lecture 16 – Power Transformer Protection 1

Today

- Power Transformer Protection 1
  - Classification of Transformer Protection
  - Longitudinal Differential Protection for Power Transformer
  - Unbalance Current of Differential Protection
  - Setting calculation of Longitudinal Differential Protection

Power Transformer Protection

Internal Faults of Transformer

• Faults inner oil tank: phase-to-phase faults of windings, inter turn faults, winding-to-ground faults, damage of iron core ;

• Faults outside oil tank: phase-to-phase or grounded faults on bushing and lead wire.

• In fact, the faults outside oil tank are not faults of transformer. However, according to the setting policy of protection, they are inside the protected zone of transformer protection, so they are considered as faults of transformer.

Abnormal Operation of Power Transformer

- Overcurrent caused by external faults;

- Overcurrent or overvoltage of neutral point caused by external grounded faults;

- Over load, over excitation, decrease of oil level, faults of refrigerating system.

Classification of Transformer Protection

Classification:

• Protection of non-electrical quantity (Gas protection);

• Protection of electrical quantity (deployed according to capacity and voltage level of transformer);

Configuration:

• Main protection: Differential protection, Instantaneous overcurrent protection, Gas protection;

• Backup protection: Overcurrent protection, Zero sequence overcurrent protection, Zero sequence overvoltage protection;

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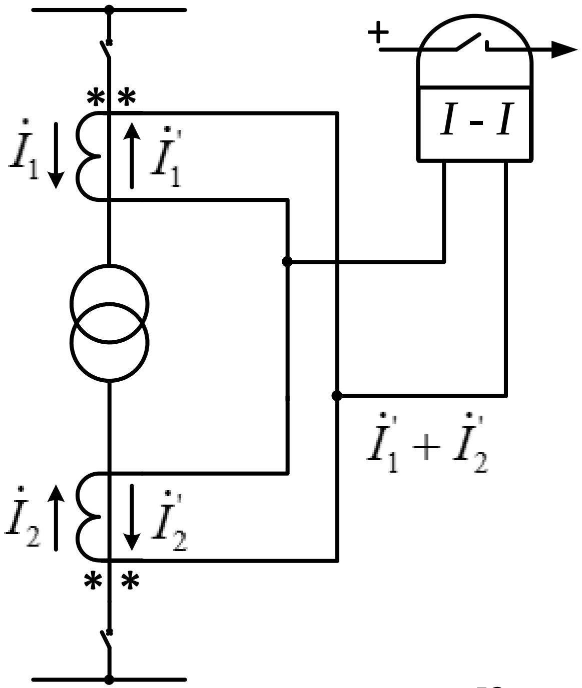
Longitudinal Differential Protection for Power Transformer



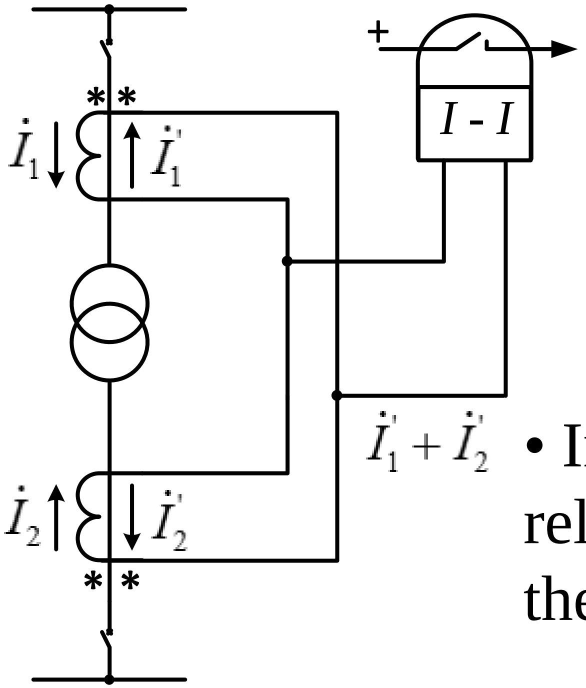
$$\dot{I}_1 = -\frac{1}{n_T}\dot{I}_2 \qquad \dot{I}_r = \dot{I}_1' + \dot{I}_2'$$

$$\dot{I}_r = \frac{\dot{I}_2}{n_{TA2}} + \frac{\dot{I}_1}{n_{TA1}}$$

$$\dot{I}_r = \frac{n_T\dot{I}_1 + \dot{I}_2}{n_{TA2}} + \left(1 - \frac{n_{TA1}n_T}{n_{TA2}}\right)\frac{\dot{I}_1}{n_{TA1}}$$

$$\frac{n_{TA2}}{n_{TA1}} = n_T \quad \Rightarrow \quad \dot{I}_r = \frac{n_T\dot{I}_1 + \dot{I}_2}{n_{TA2}}$$

Longitudinal Differential Protection for Power Transformer



- Normal Operational or External faults:

$$\dot{I}_1 = -\frac{1}{n_T}\dot{I}_2 \quad \Rightarrow \quad \dot{I}_r = 0$$

- Internal faults: the current in differential relay is equal to the fault current referred to the secondary side.

$$\dot{I}_r = \left|\dot{I}_1' + \dot{I}_2'\right|$$

$$I_r \geq I_{set}$$

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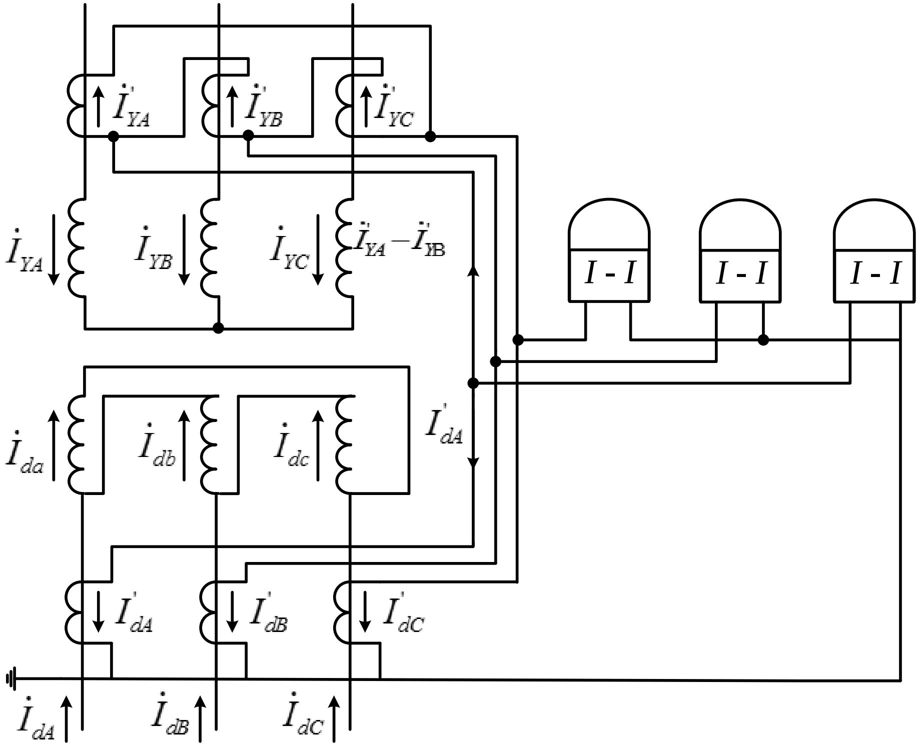
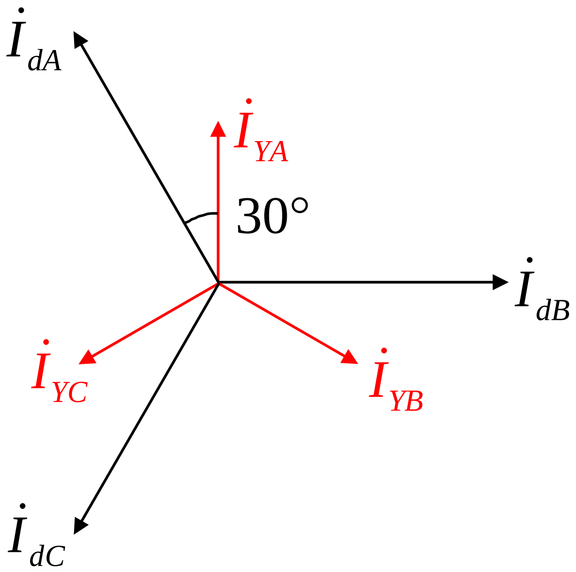
Unbalance Current by Connection

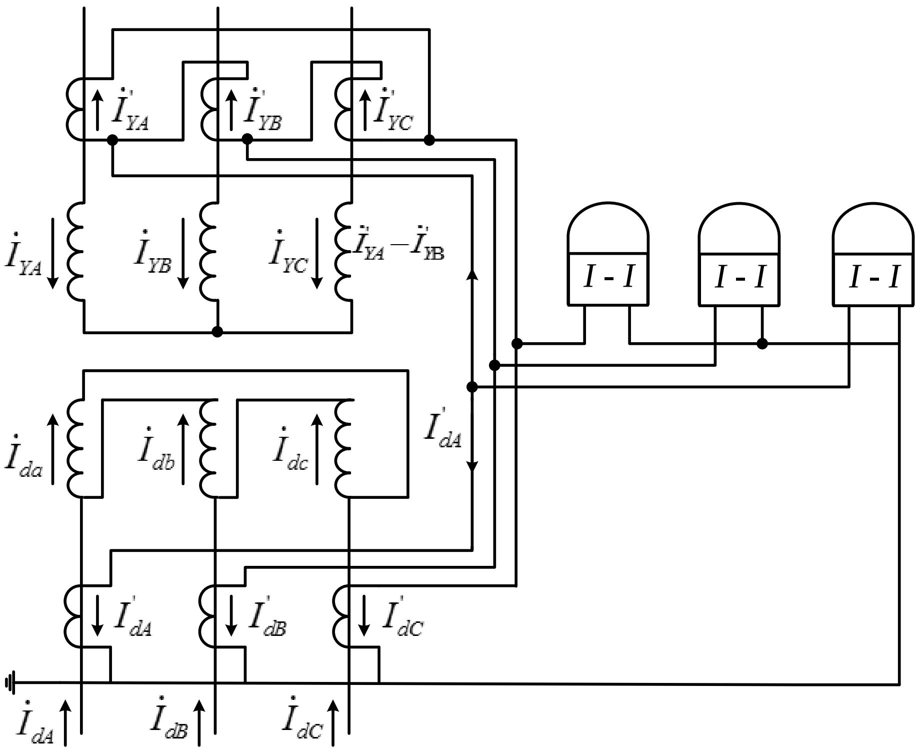
- If two sides of transformer are connected Y/Δ-11 , phase shift will make difference current between two sides;

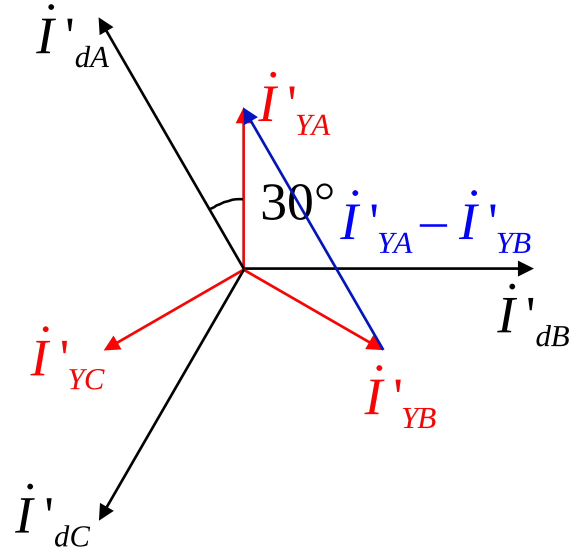




Unbalance Current by Connection

- To solve this problem, the CT of Y side of transformer are connected as Δ, and the CT of Δ side of transformer are connected as Y;





$$\sqrt{3}\,\frac{\dot{I}_Y}{n_{TA1}}=\frac{\dot{I}_\Delta}{n_{TA2}}$$

$$\boxed{\frac{\dot{I}_\Delta}{\dot{I}_Y}=n_T=\frac{n_{TA2}}{n_{TA1}/\sqrt{3}}}$$

Unbalance Current by Connection

• For digital protection, CT of both sides can be all connected as Y;

• The current of secondary sides flowing into differential relay will have phase shift;

• Software can be applied to correct current phasor to eliminate this error;

• So the connection of CT can be simplified compared with analog protection.

Unbalance Current of Ratio Error

$$\dot{I}_r = \frac{n_T \dot{I}_1 + \dot{I}_2}{n_{TA2}} + \left(1 - \frac{n_{TA1} n_T}{n_{TA2}}\right) \frac{\dot{I}_1}{n_{TA1}} \quad \Rightarrow \quad \frac{n_{TA2}}{n_{TA1}} = n_T$$

- The transformer and CT are all manufactured based on standard transformation ratio, so it is difficult to completely make $\frac{n_{TA2}}{n_{TA1}} = n_T$ and $1 - \frac{n_{TA1} n_T}{n_{TA2}} = 0$;

$$\Delta f_{za} = \left| 1 - \frac{n_{TA1} n_T}{n_{TA2}} \right| \qquad \dot{I}_{unb} = \frac{n_T \dot{I}_1 + \dot{I}_2}{n_{TA2}} + \Delta f_{za} \frac{\dot{I}_1}{n_{TA1}}$$

$$I_{unb.\max} = \Delta f_{za} I_{k.\max}$$

$I_{k.\max}$ is the maximum through current by external faults referred to the secondary side.

Unbalance Current of Ratio Error

- Solution for digital protection:

$$\Delta n = -(1 - \frac{n_{TA1} n_T}{n_{TA2}})$$

Δn should be a constant once the ratio of CT have been selected.

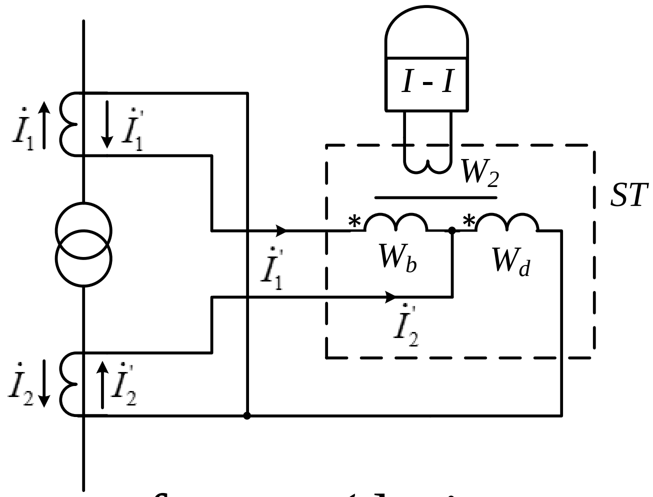
During normal operation or external faults, we should have

$$\dot{I}_r = \dot{I}_1' + \dot{I}_2' + \Delta n \dot{I}_1' = 0$$

Δn is the compensating coefficient.

Unbalance Current of Ratio Error

- Solution for analog protection:



To use intermediate transformer (during normal operation and external faults):

$$W_d\left(\dot{I}_1' + \dot{I}_2'\right) + W_d \dot{I}_1' = 0 \quad \Rightarrow \quad W_b / W_d = \Delta n$$

However, W_b cannot be adjusted continuously, so the actual turns ratio may not be completely equal to the calculated value, so small unbalance current may still exist in the differential relay.

Unbalance Current by Transformer Tap

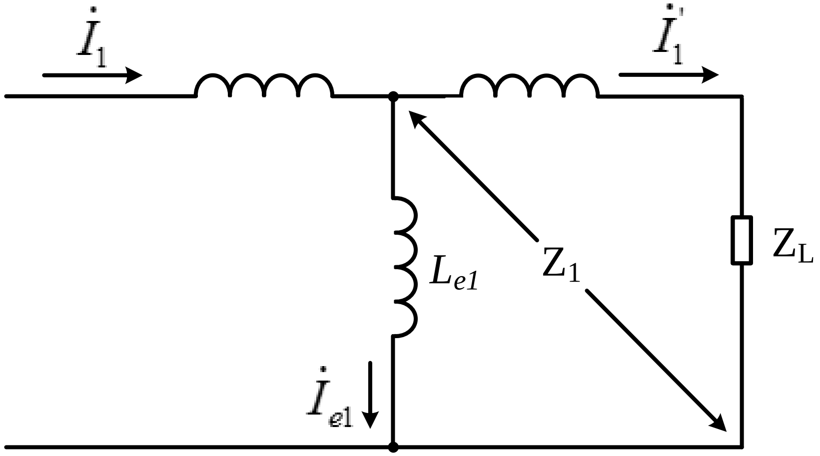
- Some transformer tap can be used to adjust the transformation ratio n_T to maintain the system voltage level;
- But the ratio of CT cannot be adjusted following transformer tap as they are fixed once selected;

$$I_{unb.\max} = \Delta U I_{k.\max}$$

$I_{k.\max}$ is the maximum through current by external faults referred to the secondary side.
ΔU is the relative error caused by transformer tap.

Unbalance Current by CT Transformation Error

Equivalent circuit of CT:



$$\dot{I}_{\mu 1} = \frac{Z_1}{j\omega L_{\mu 1} + Z_1}\dot{I}_1 = \frac{1}{j\dfrac{\omega L_{\mu 1}}{Z_1} + 1}\dot{I}_1$$

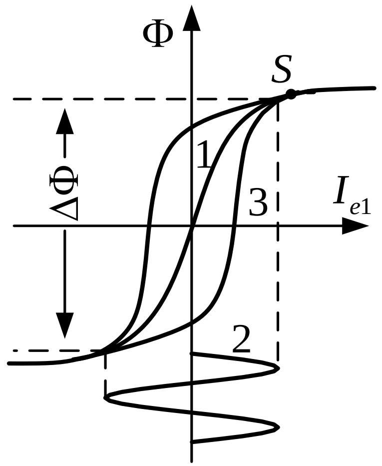
$$\dot{I}_1' = \dot{I}_1 - \dot{I}_{\mu 1} \quad \Rightarrow \quad \dot{I}_{unb} = \left|\dot{I}_1' - \dot{I}_2'\right| = \left|\dot{I}_{\mu 2} - \dot{I}_{\mu 1}\right|$$

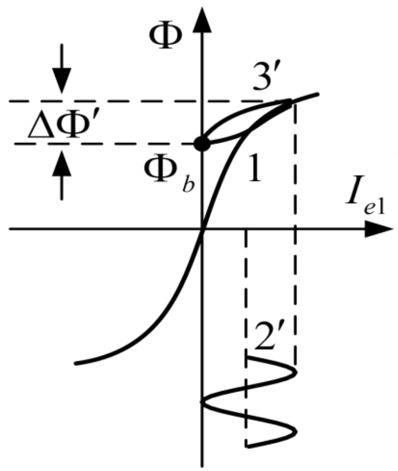
If both CTs have the same type, the unbalance current will be small; if they belong to different types, the unbalance current may be large.

$$I_{unb} = K_{st} I_{\mu 1}$$

For same type $K_{st} = 0.5$, or $K_{st} = 1$.

Unbalance Current by CT Transformation Error





$$\dot{I}_{\mu1} = \frac{Z_1}{j\omega L_{\mu1} + Z_1}\dot{I}_1 = \frac{1}{j\dfrac{\omega L_{\mu1}}{Z_1} + 1}\dot{I}_1$$

Saturation is related to the magnetization curve, I_1 and load on the secondary side.

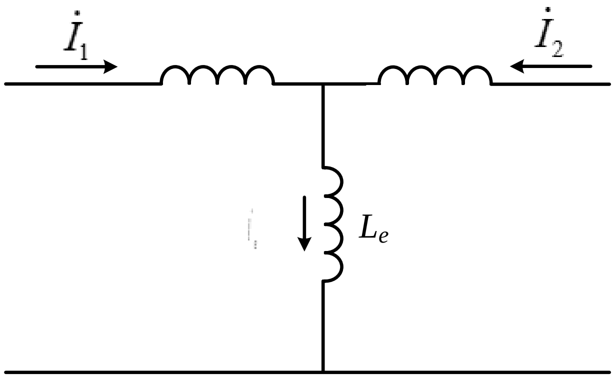
The manufacturer may provide 10% error curve. According to $I_{k.\max}$, we can find corresponding load impedance; if actual load is small than this value, then the maximum error will be less than 10%

$$I_{\mu1.\max} = 0.1 I_{k.\max} \Rightarrow I_{unb.\max} = 0.1 K_{st} I_{k.\max}$$

$$I_{unb.\max} = 0.1 K_{np} K_{st} I_{k.\max}$$

K_{np} is to consider influence from non-periodic component.

Unbalance Current by Excitation Current of Transformer



The excitation current will all flow into the differential relay.

$$I_{unb} = I_{\mu}$$

During normal operation or external faults, the transformer may not be at saturation and the excitation current is normally small and its impact can be ignored.

In case of putting into operation with no load or after cutting external faults, the voltage of transformer may increase from zero or small value to the operating level suddenly, the transformer may have serious saturation with large transient excitation current, which is called as magnetizing inrush.

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Relay Setting for Differential Protection

- Principle 1: to avoid the maximum unbalance current caused by external faults;

$$I_{set} = K_{rel} I_{unb.\max}$$

K_{rel}, reliability coefficient, normally as 1.3.

$I_{unb.max}$, maximum unbalance current caused by external faults.

$I_{unb.max}$ may include errors of CT transformation ratio, errors caused by transformer tap and errors by excitation current of CT:

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

Relay Setting for Differential Protection

- Principle 2: to avoid the maximum magnetizing inrush current of transformer;

$$I_{set} = K_{rel} K_{\mu} I_N$$

K_{rel}, reliability coefficient, normally as 1.3-1.5.

I_N, rated current of transformer.

K_{μ}, the maximum times of magnetizing inrush current (inrush current/rated current), normally 4~8.

If the protection can distinguish inrush current and fault current, and then block the protection for inrush current, this principle can be ignored.

Relay Setting for Differential Protection

- Principle 3: to avoid the differential current caused by broken of circuit on the secondary side;

If circuit of one CT on secondary side is broken, then the current of the other CT will all flow into the differential relay; this may make false trip of the protection. If the protection cannot identify line broken of secondary side, then the setting value must be larger than the maximum load current of transformer:

$$I_{set} = K_{rel} I_{L.\max}$$

K_{rel}, reliability coefficient, normally as 1.3.

$I_{L.max}$, the maximum load current; if the maximum load current is unknown, it can be the rated current.

Relay Setting for Differential Protection

- The setting value of the differential protection should be the maximum value calculated according to the above mentioned three principles.

Check of Sensitivity

$$K_{sen} = \frac{I_{k \cdot \min \cdot R}}{I_{set}}$$

$I_{k.min.R}$, the minimum differential current flowing through the differential relay for all possible internal faults with all possible operating modes.

Normally, $K_{sen} \geq 2$.

Next Lecture

Power Transformer
Protection 2

Thanks for your attendance