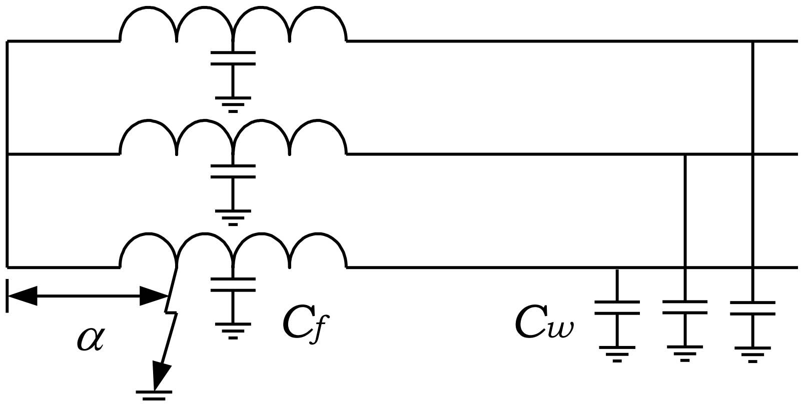
EEE340 Protective Relaying

Lecture 19 – Generator Protection 2
Bus Protection 1

Stator Single Phase Earth Fault



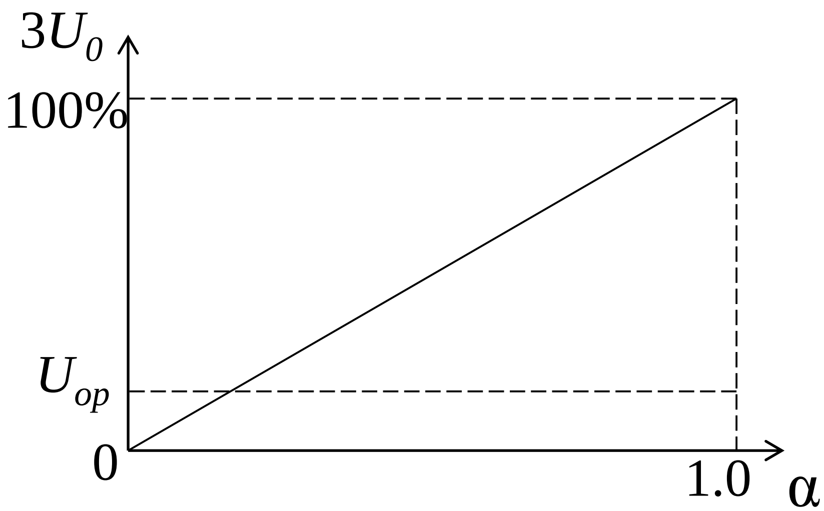
If phase A has grounded fault at α from the neutral point, then the relative voltage to ground for each phase can be estimated as:

$$\begin{cases} \dot{U}_{AG} = (1-\alpha)\dot{E}_A \\ \dot{U}_{BG} = \dot{E}_B - \alpha\dot{E}_A \\ \dot{U}_{CG} = \dot{E}_C - \alpha\dot{E}_A \end{cases}$$

Then the zero-sequence voltage can be calculated as: $\dot{U}_{0\alpha} = -\alpha\dot{E}_A$

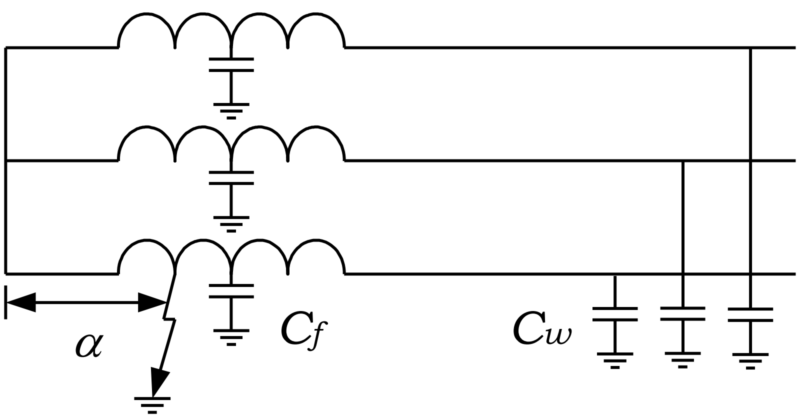
So the zero-sequence voltage varies with the fault position. The zero-sequence voltage will be smaller when the fault position is closer to the neutral point.

Stator Single Phase Earth Fault



The zero-sequence voltage will be higher when the fault position is closer to the terminal.
The zero-sequence voltage can be used to construct protection for single phase earth fault:

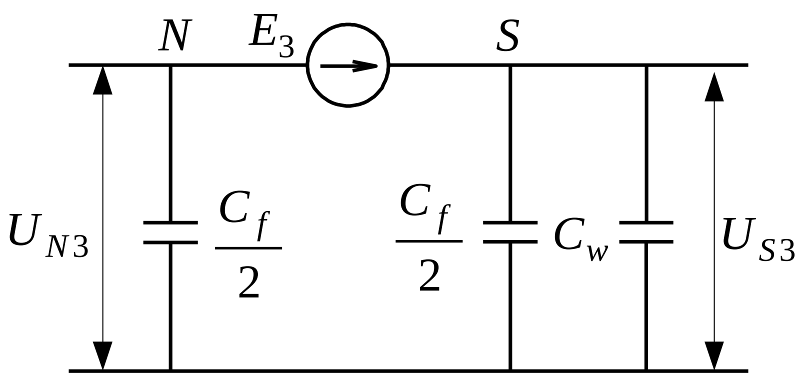
$$3U_0 > U_{op}$$



Needs to avoid unbalance zero-sequence voltage (such as third harmonic), so the zero-sequence voltage protection can only protect about 85% of the whole stator winding (faults which are too closer to neutral point may not be discovered).

How to protect 100% of the stator winding?

Stator Single Phase Earth Fault Protection Using Third Harmonic Voltages



Third harmonic voltage at neutral point:

$$U_{N3} = \frac{C_f + 2C_w}{2(C_f + C_w)} E_3$$

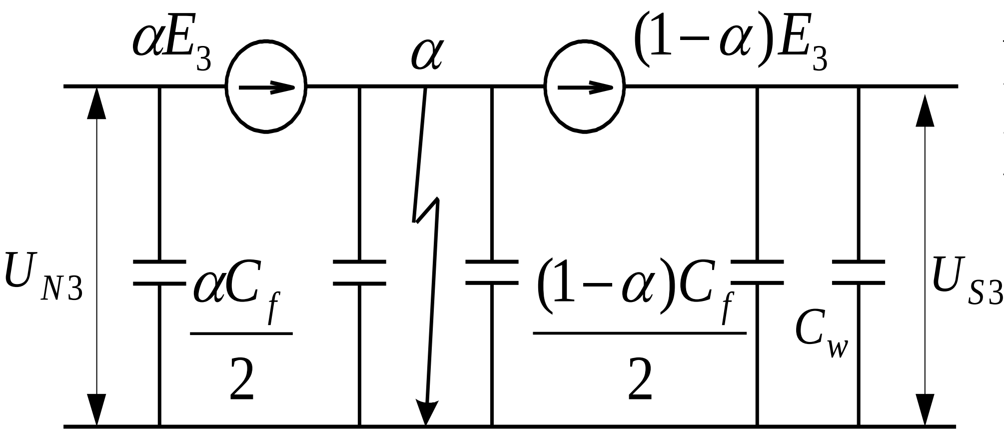
Third harmonic voltage at terminal:

$$U_{S3} = \frac{C_f}{2(C_f + C_w)} E_3$$

$$\frac{U_{S3}}{U_{N3}} = \frac{C_f}{C_f + 2C_w} < 1$$

During normal operation, the third harmonic voltage at the neutral point is always higher than the terminal.

Stator Single Phase Earth Fault Protection Using Third Harmonic Voltages



In case of single earth fault, third harmonic voltage at the neutral point:

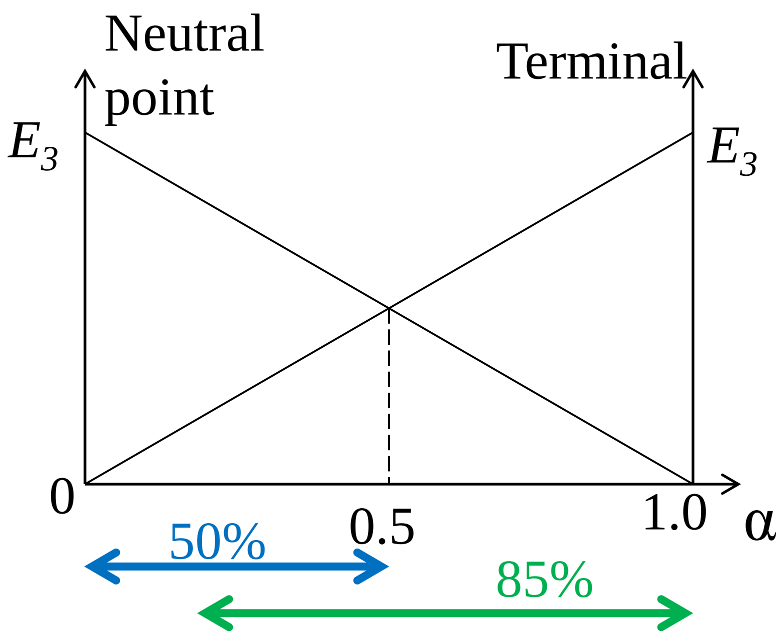
$$U_{N3} = \alpha E_3$$

Third harmonic voltage at terminal:

$$U_{S3} = (1-\alpha)E_3$$

$$\frac{U_{S3}}{U_{N3}} = \frac{1-\alpha}{\alpha}$$

Stator Single Phase Earth Fault Protection Using Third Harmonic Voltages



The third harmonic voltage can be used to construct protection:

$$U_{S3} \geq U_{N3}$$

This protection cannot operate during normal operation.

This protection can protect against single phase earth faults within 50% range of stator winding close to the neutral point.

The zero-sequence voltage protection and the third harmonic voltage protection can jointly protect 100% of the stator winding.

Today

- Generator Protection 2
  - Generator Negative Current Protection
  - Loss of Excitation Protection of Generator
- Bus Protection 1
  - Bus Fault and Principle of Protection
  - Single Bus Complete Differential Protection
  - High Impedance Bus Differential Protection

Effect of negative sequence current protection

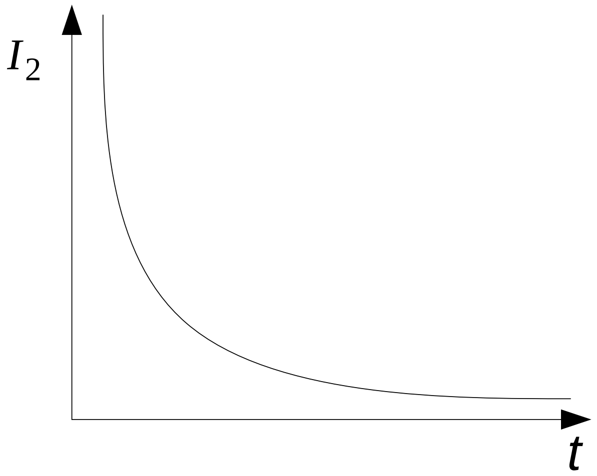
In case of unsymmetrical faults or unsymmetrical loads, negative sequence current could be detected in stator windings;

The corresponding negative rotating field has double synchronous speed with reference to the rotor;

The induced double power frequency current and vibration may threaten the generator;

The heat caused by negative sequence current in the rotor is proportional to the product of its square and duration time.

Generator Negative Current Protection



To avoid overheat by negative sequence current, its value and duration should meet following constraint:

$$\int_0^t i_{2*}^2 dt = I_{2*}^2 \cdot t \le A$$

The value of A is provided by the manufacturer. It is related to the capacity and cooling methods of the generator.

i_2 is the negative sequence current of the generator;
t is the duration time of the negative sequence current;

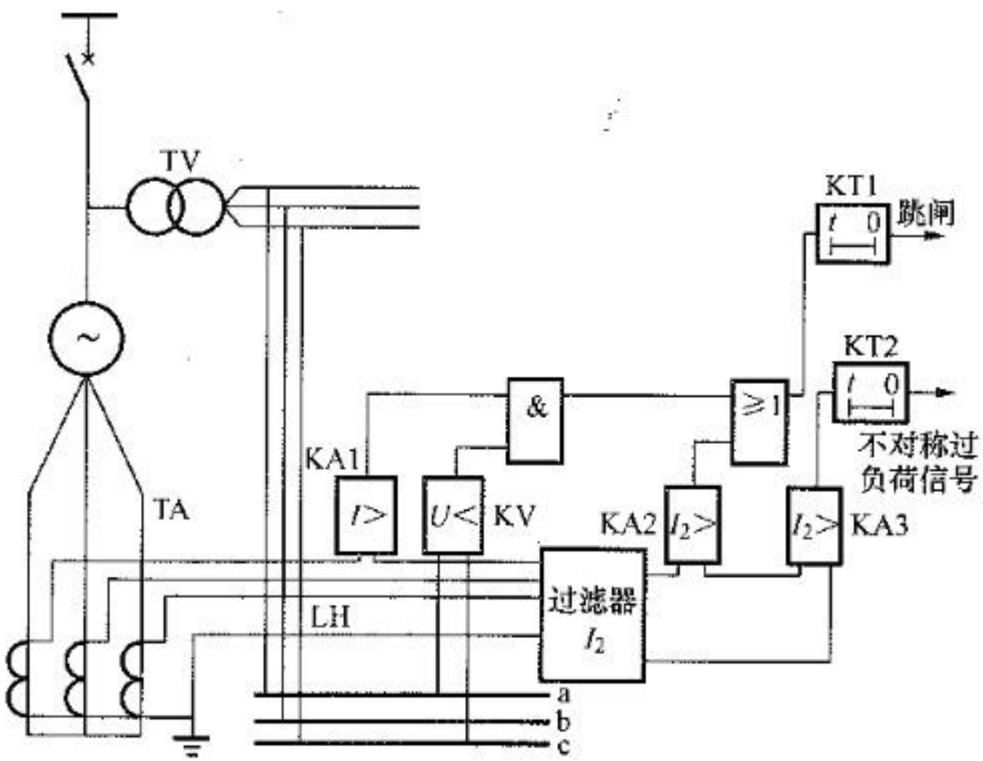
Definite Time Negative Current Protection

Normally, two zones of negative current protection are applied.

Zone I: that will trip the breakers to avoid overheat of rotor and as backup protection for external faults.

Zone II: that will send out warning signal as asymmetric overload signal.

Definite Time Negative Current Protection

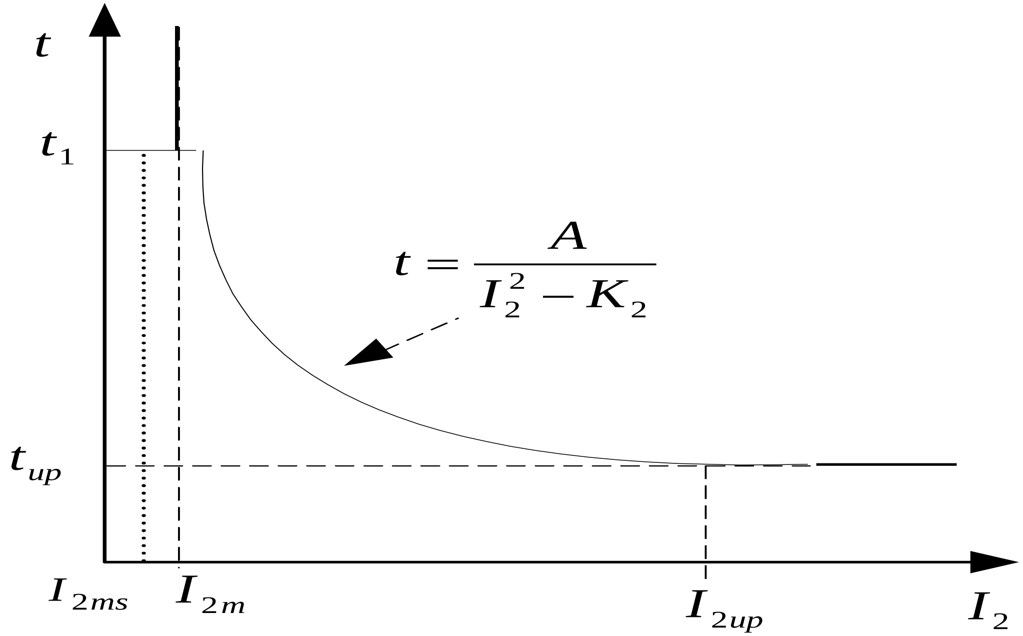


As Zone I, KA2 has larger setting value and trip breaker after time delay of KT1.

As Zone II: KA3 has lower setting value to send out unsymmetrical overload warning signal after time delay KT2.

The overcurrent relay KA1 and under voltage relay KV jointly protect against three phase short circuit, which also trips breaker after time delay KT1.

Inverse Time Negative Current Protection



The operating time is definite as t_{up} if the negative sequence current is larger than the upper limit.

The operating time is definite as t_1 if the negative sequence current is smaller than the lower limit.

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Loss of Excitation Protection of Generator

Reasons for Loss of Excitation

- Faults in rotor windings;
- Faults in exciter;
- False trip of automatic magnetic blow-out switch;
- Faults of components in excitation system;
- False operation of human;

Consequence

- Acceleration of rotor;
- To absorb large quantity of inductive reactive power;
- Collapse of system;
- Overheat of rotor;
- Oscillation;

Loss of Excitation Protection of Generator

Judging criteria

- The voltage u_f of excitation windings on rotor will decrease in case of loss of excitation; the characteristic of this can be used as judging criteria for loss of excitation.
- Characteristic of impedance measurement at terminal of generator;
- Low voltage at high voltage side of transformer;
- Overcurrent of stator;

Other Protections of Generator

- Out of step protection for generator.
- Grounded field winding protection of generator;

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Bus Fault and Principle of Protection

Normally the faults of bus are initially single line to ground faults, then develop to phase-to-phase faults;

Normally, the faults are permanent;

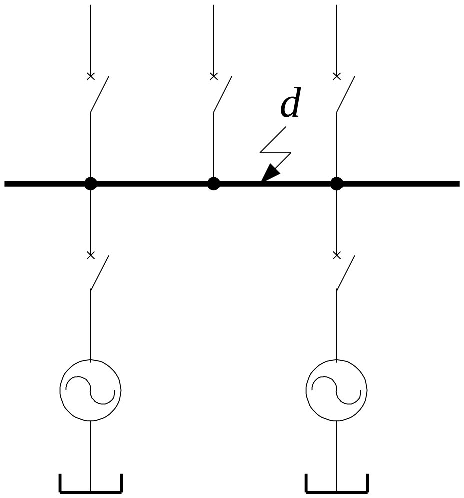
Bus is important device for energy collection and redistribution, the faults of bus may have serious impacts;

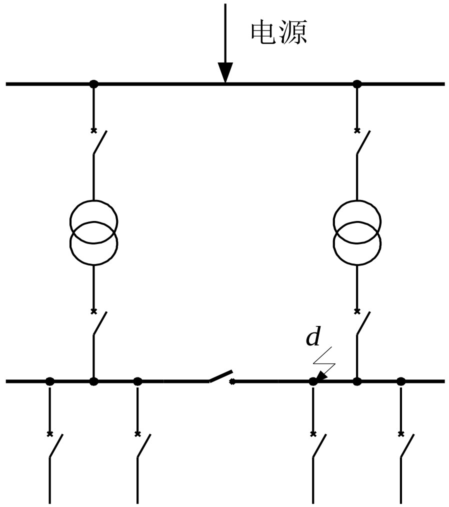
Faults of high voltage bus may have impacts on system stability;

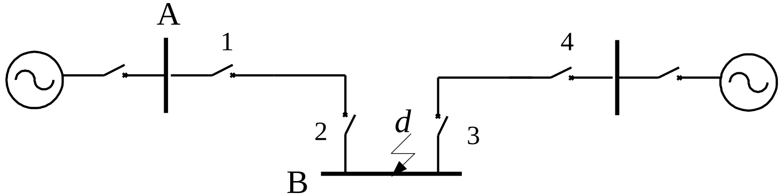
Bus Fault and Principle of Protection

Normally no dedicated bus protection is installed for low voltage power grids (lower than 110kV); the over current protections for neighbouring components of power source side can be used to protect buses.

Clearing time may be long.







Bus Fault and Principle of Protection

For following situations, dedicated bus protection must be installed:

By consideration of power supply reliability, for power grids higher than 110kV with double bus and sectionalized single bus, if it is necessary to guarantee selectivity in clearing bus faults.

By consideration of system stability, if it is necessary to clear the fault in high speed.

Bus Fault and Principle of Protection

According to the requirements of speed and selectivity, bus protections are all based on differential protection;

Compared with other differential protection, bus protections have more connections with components, but the basic principle is similar:

- For normal operation and external faults, the sum of currents for all connections is zero; $\sum \dot{I}_{pi} = 0$
- In case of faults on bus, $\sum \dot{I}_{pi} = \dot{I}_k$
- For normal operation or external faults, the phase angles of input current and output current are relatively inverse; for internal faults, currents of all connections are almost all input currents with similar phase angles.

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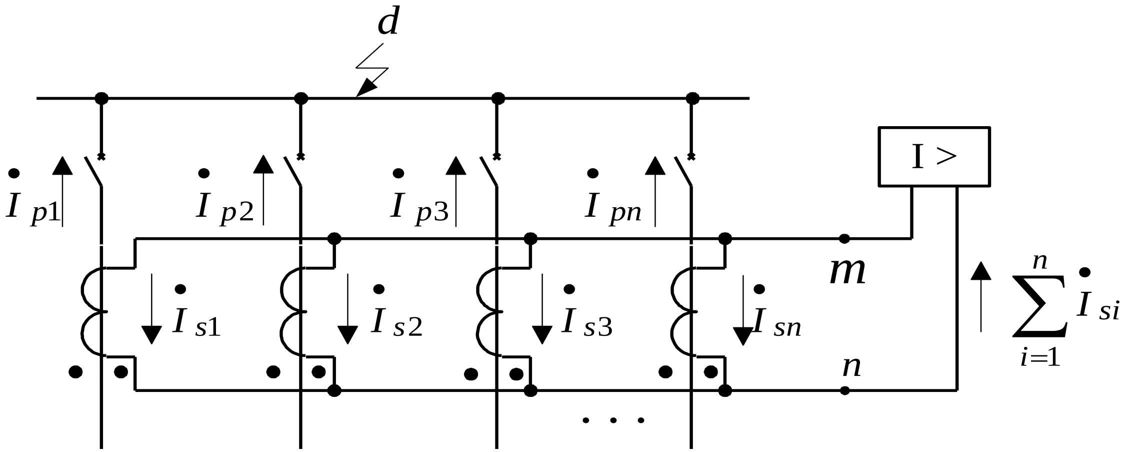
Single Bus Complete Differential Protection

TA of all connected branches have the same transfer ratio and characteristics;
For normal operation and external faults, the sum of currents on primary side are zero, and then with the same transfer ration of TA, the sum of currents on secondary side is zero;
The sum of currents on secondary side flows through the differential relay.



Single Bus Complete Differential Protection

Actually, there are unbalance currents due to errors of TA in case of normal operation or external faults;

In case of internal faults, the current through the differential relay is:

$$\dot{I}_{k\mathrm{A}} = \sum_{i=1}^{n} \dot{I}_{si} = \frac{1}{n_{TA}} \sum_{i=1}^{n} \dot{I}_{pi} = \frac{1}{n_{TA}} \dot{I}_{k}$$

The setting value for the differential relay should avoid the maximum unbalance current:

$$I_{r.set} = K_{rel} I_{unb\cdot\max} = K_{rel} \times 0.1 I_{k\cdot\max} / n_{TA}$$

Also avoid the maximum load current in case of broken TA :

$$I_{r\cdot set} = K_{rel} I_{l\cdot\max} / n_{TA}$$

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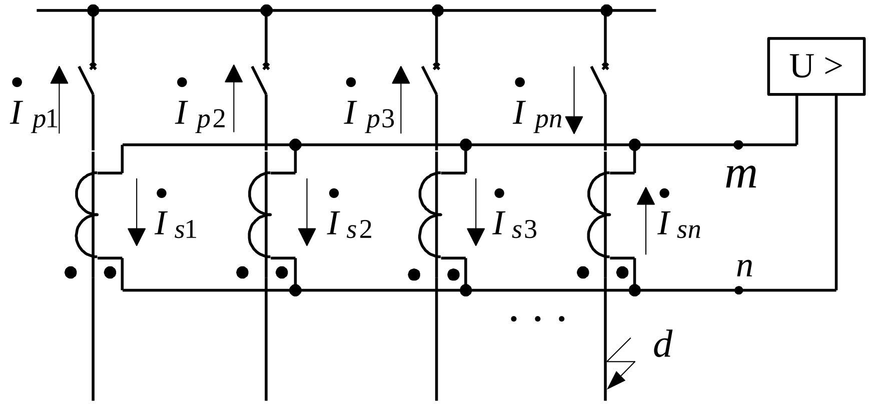
High Impedance Bus Differential Protection

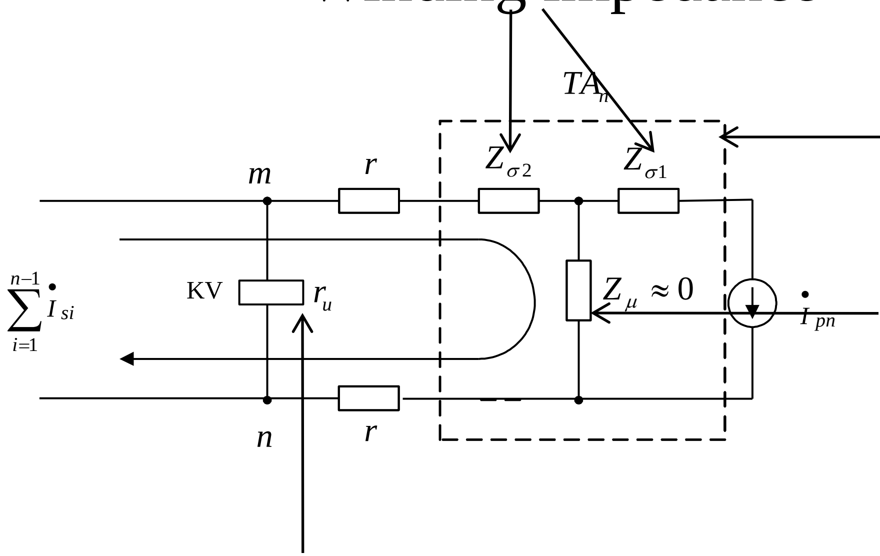
In case of external faults, for complete differential protection, if the current of the faulted branch is very large and the currents of non-faulted branches may not be large;

The TA of the faulted branch then may be saturated with very small secondary current and TAs of non-faulted branches may not be saturated, so the differential current may be large to trip the protection;



High Impedance Bus Differential Protection

Winding impedance



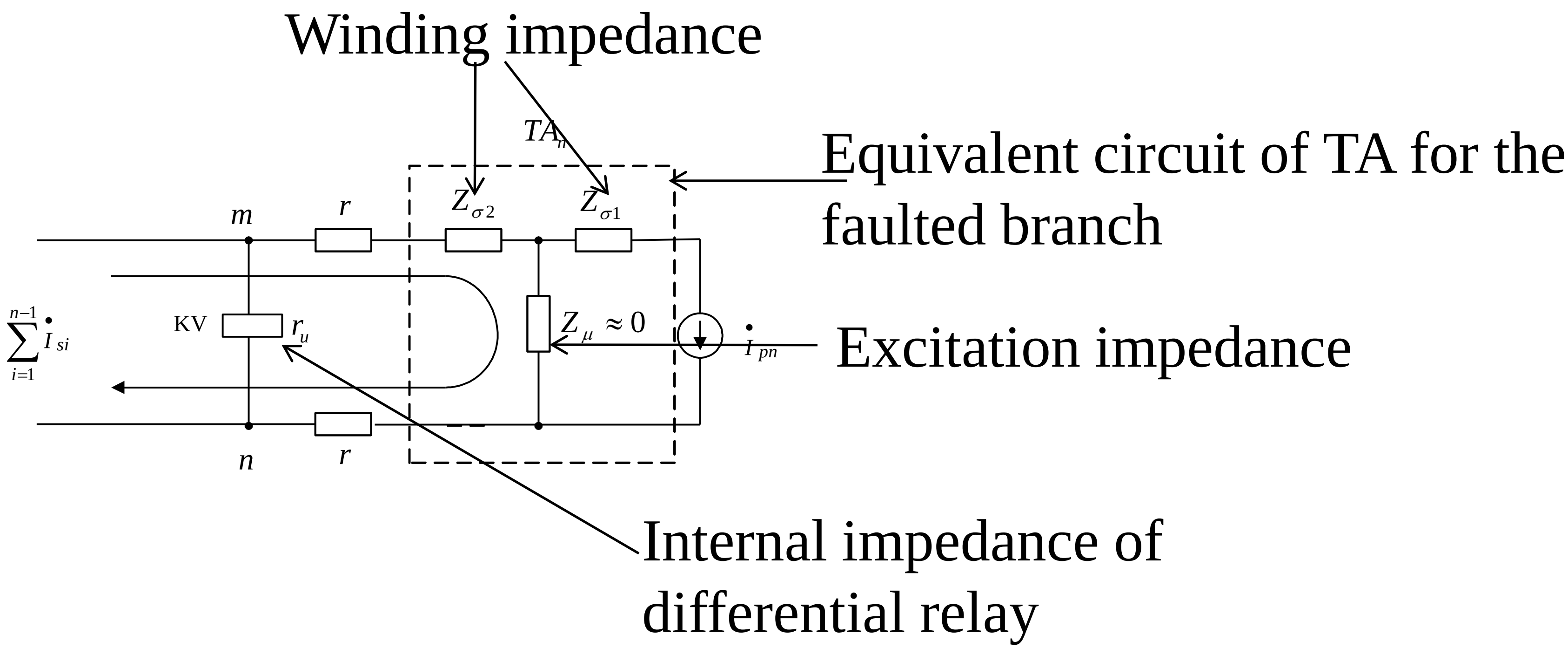
Equivalent circuit of TA for the faulted branch

Excitation impedance

Internal impedance of differential relay

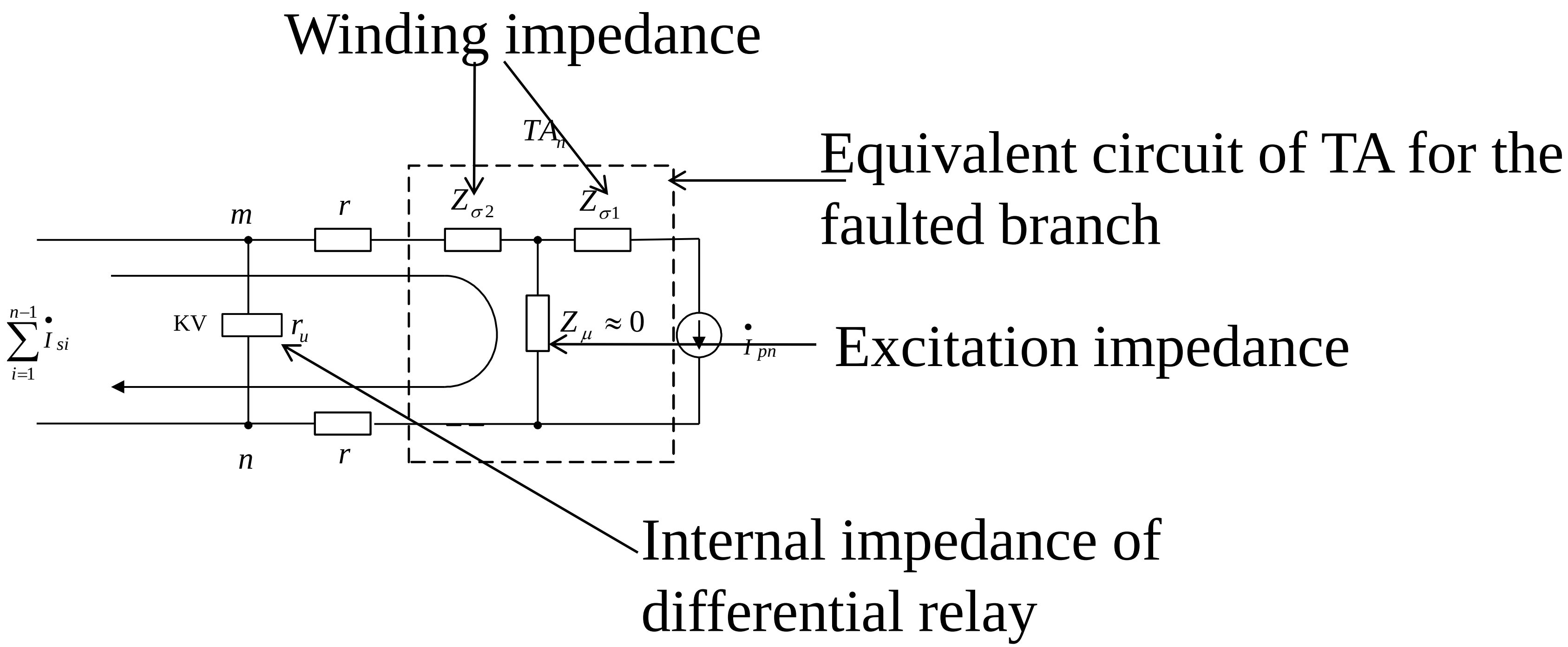
In case of external faults and if all TAs have no errors, the sum of secondary currents for non-faulted branches is equal to the secondary current of the faulted branch with opposite direction; no current flow through the differential relay.

High Impedance Bus Differential Protection



If the TA of the faulted branch is highly saturated, most primary current may flow through the excitation branch as the excitation impedance would be very small; as the internal impedance of differential relay is very high, the secondary currents of non-faulted branches will flow through the secondary winding of the TA of the faulted branch. The differential relay will not operate.

High Impedance Bus Differential Protection



In case of internal faults, the currents of all branches flow into the bus, so all secondary currents will flow into the voltage relay; because its internal impedance is high, so the terminal voltage will be high enough to trip the protection.

Next Lecture

Bus Protection 2

Thanks for your attendance