EEE340 Protective Relaying

Lecture 6 – Overcurrent Protection 2 & Protection for Grounded Faults 1

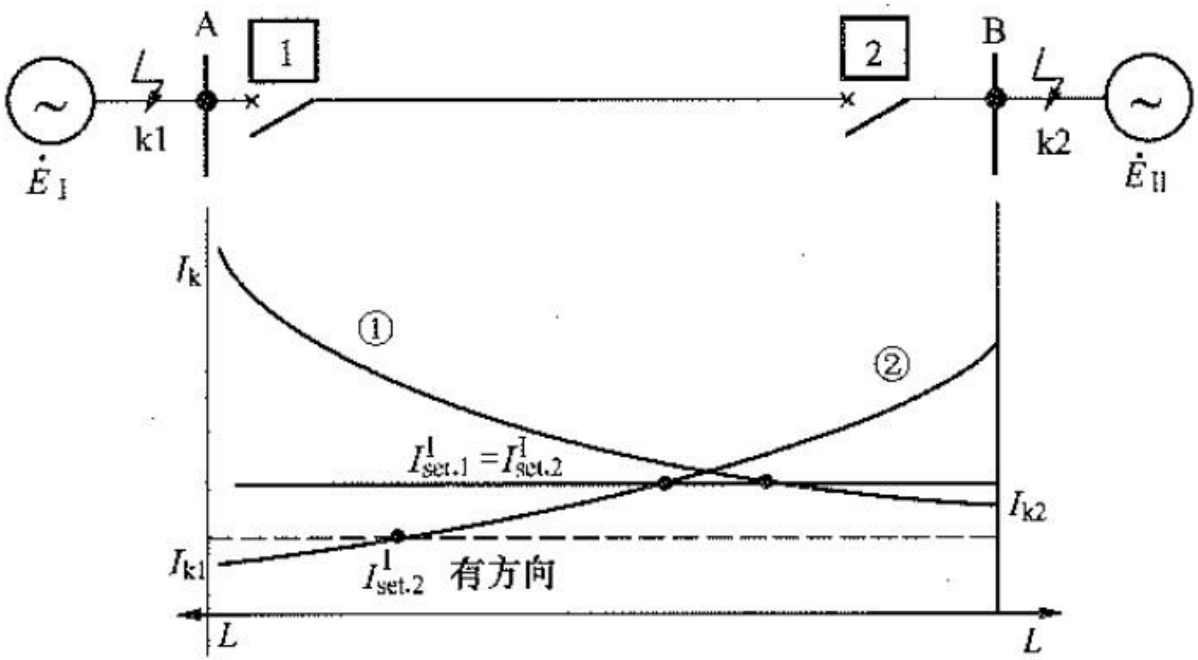
Today

- Directional Overcurrent Protection
  - Application of Directional Overcurrent Protection

- Types and Protection Principles for Grounded Faults
  - Grounding modes for neutral point
  - Protection for earth faults in the neutral directly grounded system

Application of Directional Overcurrent Protection

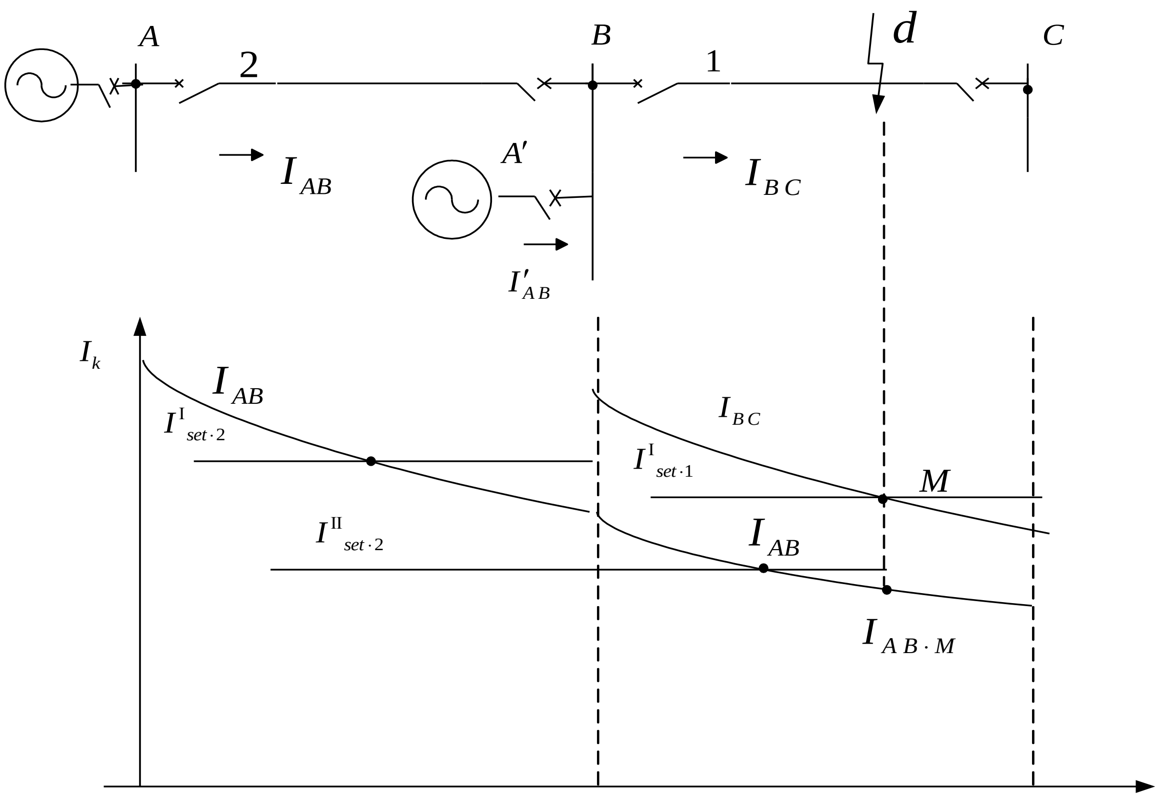
- Distribution of fault currents supplied by both sources for faults at any location is given.
- For faults at k1 or k2, protection 1 and 2 should not act.
- If there is no directional element and $I_{k2.max}$>$I_{k1.max}$, $I^{I}_{set.1} = I^{I}_{set.2} = K^{I}_{rel} I_{k2.\max}$
- If a directional element is added to protection 2: $I^{I}_{set.2} = K^{I}_{rel} I_{k1.\max}$
- Directional element is not needed for protection 1, because its setting value for current can avoid the negative fault current at k1.



Infeed current

- In case of fault at *d*, the fault current of line B-C is supplied by two sources: $\dot{I}_{B-C} = \dot{I}_{A-B} + \dot{I}'_{AB}$
- The instantaneous protection of 1 is set as point M.
- The time delay instantaneous protection of 2 is set by avoiding fault at M:

$$I^{II}_{set.2} = K^{II}_{rel} I_{A-B.M} \qquad I_{A-B.M} < I^{I}_{set.1} = I_{B-C.M}$$

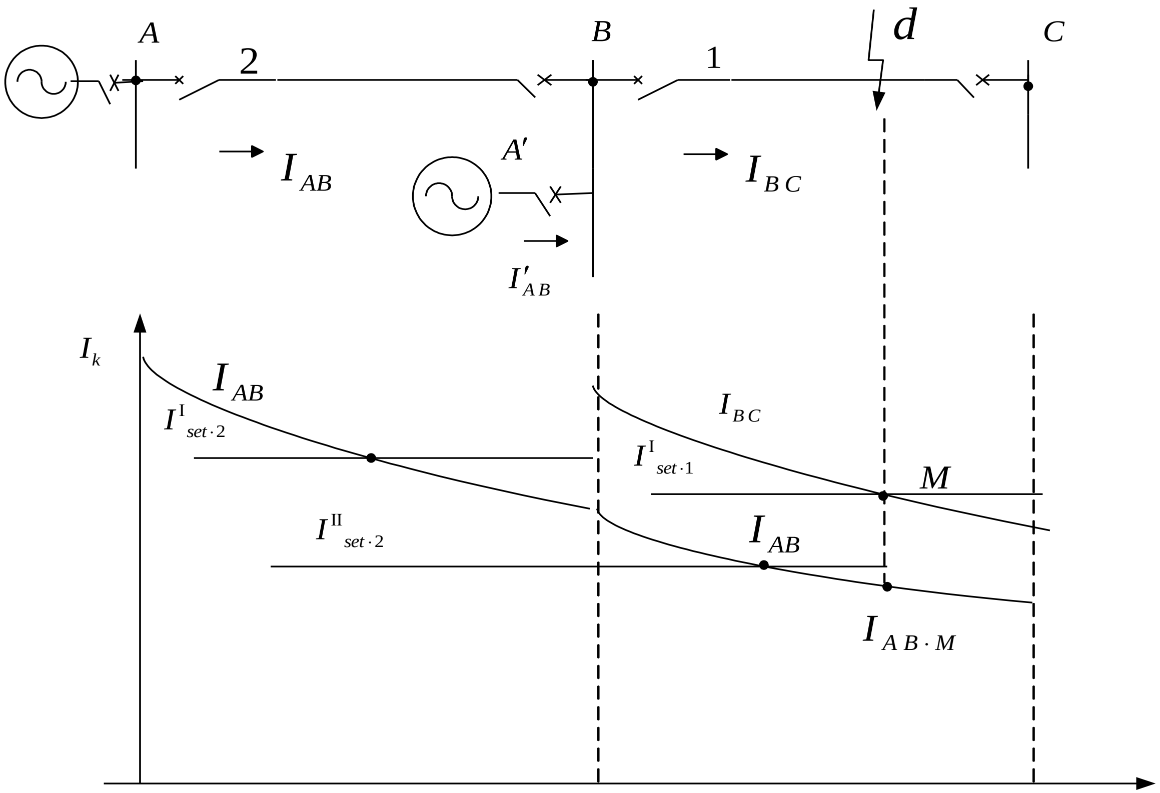


Infeed current

$$K_b = \frac{\textit{Fault current of faulted line}}{\textit{Fault current through previous line protection}}$$

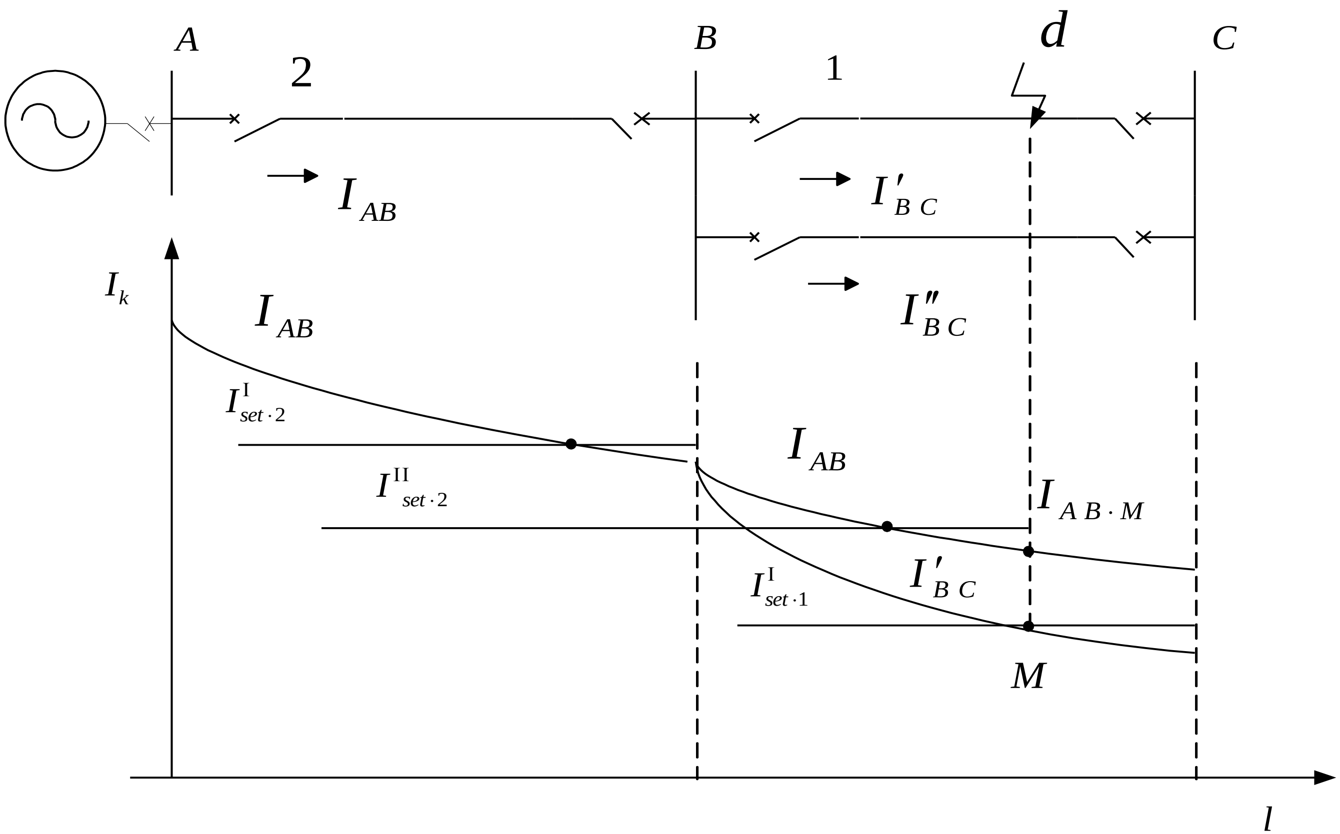
$$K_b = \frac{I_{B-C.M}}{I_{A-B.M}} = \frac{I^{I}_{set.1}}{I_{A-B.M}}$$

$$I^{II}_{set.2} = \frac{K^{II}_{rel}}{K_b} I^{I}_{set.1}$$



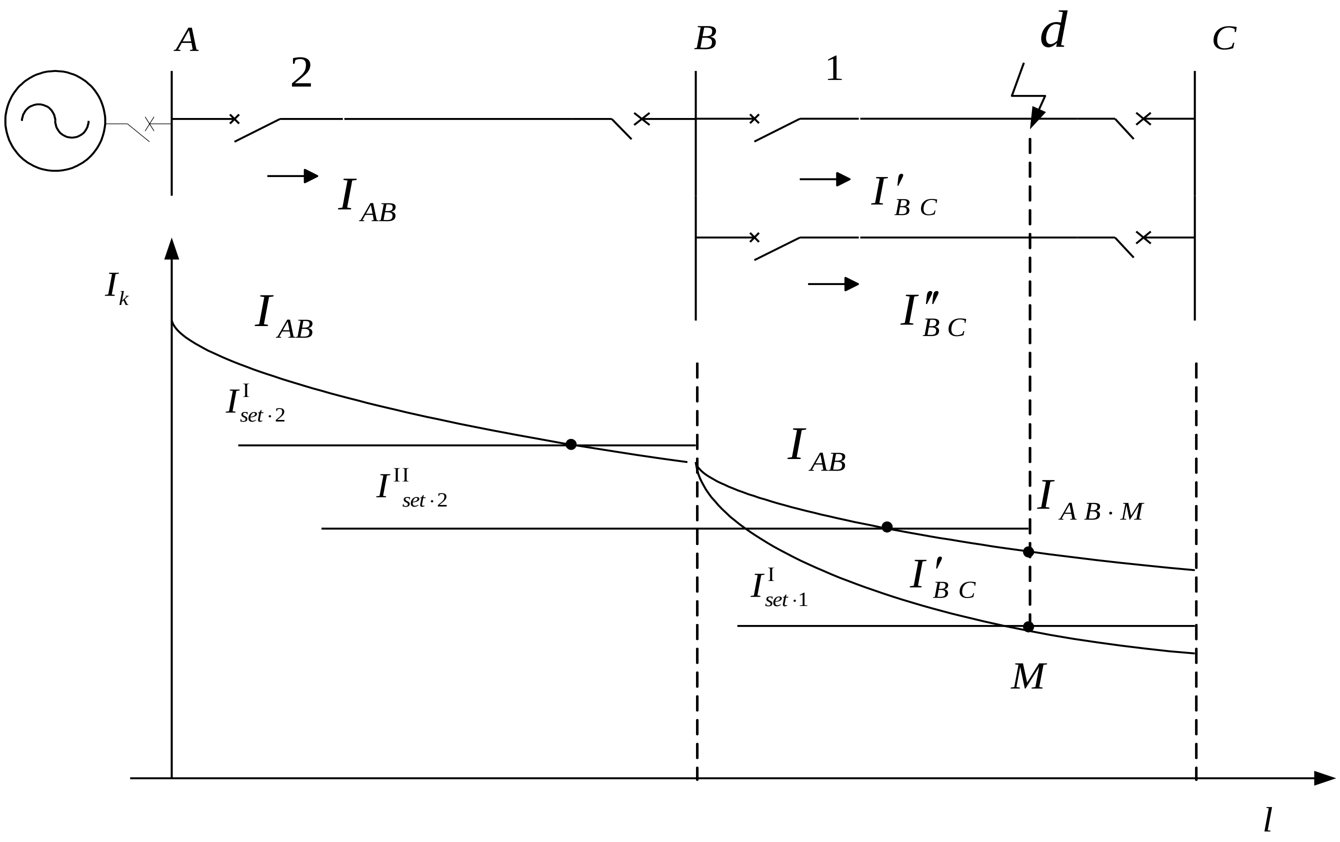
Out flowing current

- In case of fault at d, the fault current of faulted line is smaller than the current of line A-B: $\dot{I}_{A-B} = \dot{I}'_{\text{B-C}} + \dot{I}''_{\text{B-C}}$
- The branch factor K_b is smaller than 1.
- The setting with out-flowing current is similar to setting with in-feed current, but K_b is different.



Out flowing current

- When bus B has both power source and parallel line connected, K_b may be possibly larger or smaller than 1.
- Single line with single power source is a specific case, K_b =1.



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Grounded Faults and Grounding Modes

- Grounded faults are abnormal connection between conductors and ground, including single line-to-ground fault and double line-to-ground fault.

- The percentage of single line-to-ground faults is over 70% for high voltage system faults and over 80% for distribution system faults.

- Grounded faults are tightly related to grounding modes of neutral points.

- With the same fault conditions but different grounding modes, the characteristics, results and impacts of faults could be totally different.

Grounded Faults and Grounding Modes

- High current earth

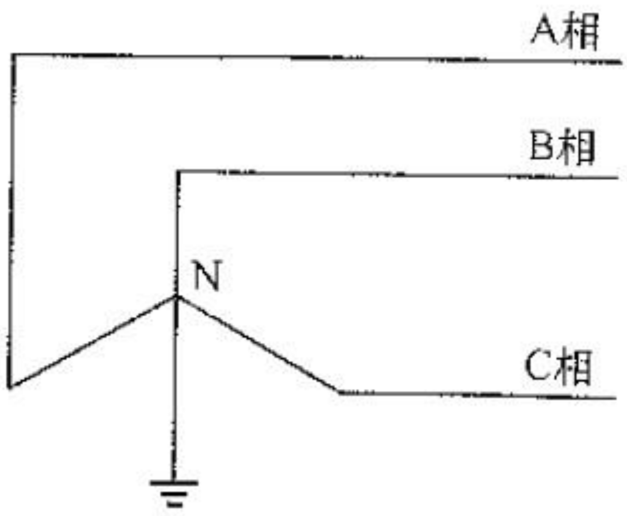
Direct grounding at neutral point;
Grounded via small resistance;

- Small current earth

Ungrounded neutral point;
Grounded via arc - suppression coil (Petersen coil);

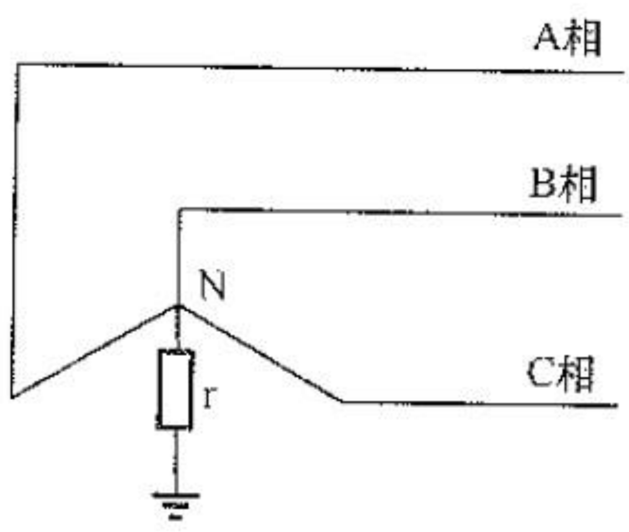
- In China, direct grounding for 110kV and higher voltage systems; Ungrounded or grounded via arc - suppression coil for 35kV and lower voltage systems.

Direct Grounding at Neutral Point



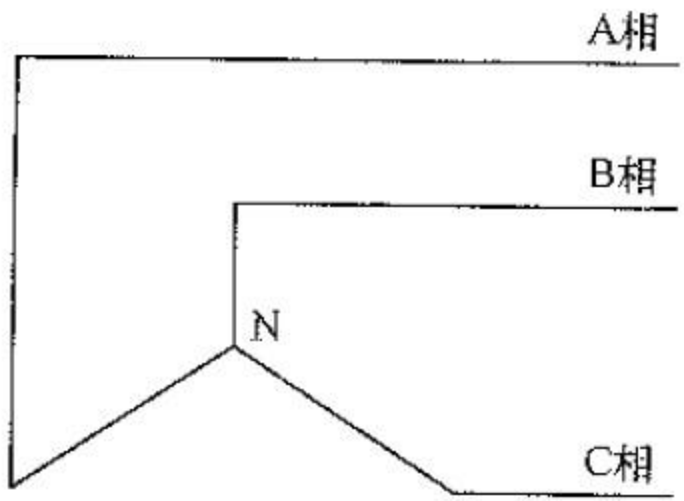
- In case of grounded fault, the fault location, ground, neutral point N and phase line conductor will construct circuit for current;
- High fault current will flow through this circuit;
- Breakers must be tripped to clear the faulted line;
- With high probability of faults, the reliability is low.

Grounded via Small Resistance



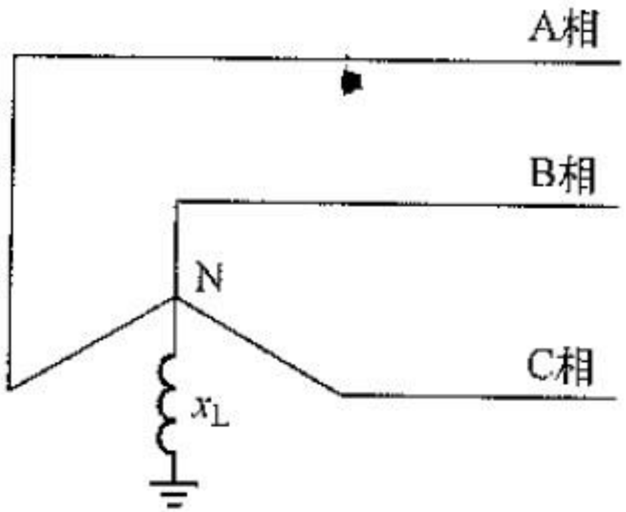
- Resistance *r* is to limit the fault current and overvoltage level after faults;
- High fault current will still flow through the ground circuit;
- Breakers must be tripped to clear the faulted line;
- Power supply to customers will be interrupted.

Ungrounded Neutral Point



- In case of single line-to-ground fault, there is no circuit for current;
- With only normal load current, the fault can be kept for short time, reliability is higher;
- Voltage is decreased for the faulted phase and increased for the non-faulted phases, so insulation is threatened;
- Small capacitive current (arc) will exist due to distributed capacitance between line and ground.

Grounded via Arc - suppression Coil



- In case of grounded fault, inductive current will counteract with the capacitive current;
- To eliminate or mitigate impacts of arc or current;
- No or only small capacitive current will exist;
- Long time operation is forbidden.

Fault Conditions

- Metallic grounding

- Non-metallic grounding

Grounded via arc;
Grounded via tree;
Grounded via tower;
Grounded via combination of former cases;

- Grounded via high impedance will decrease the fault current and is difficult to be detected.

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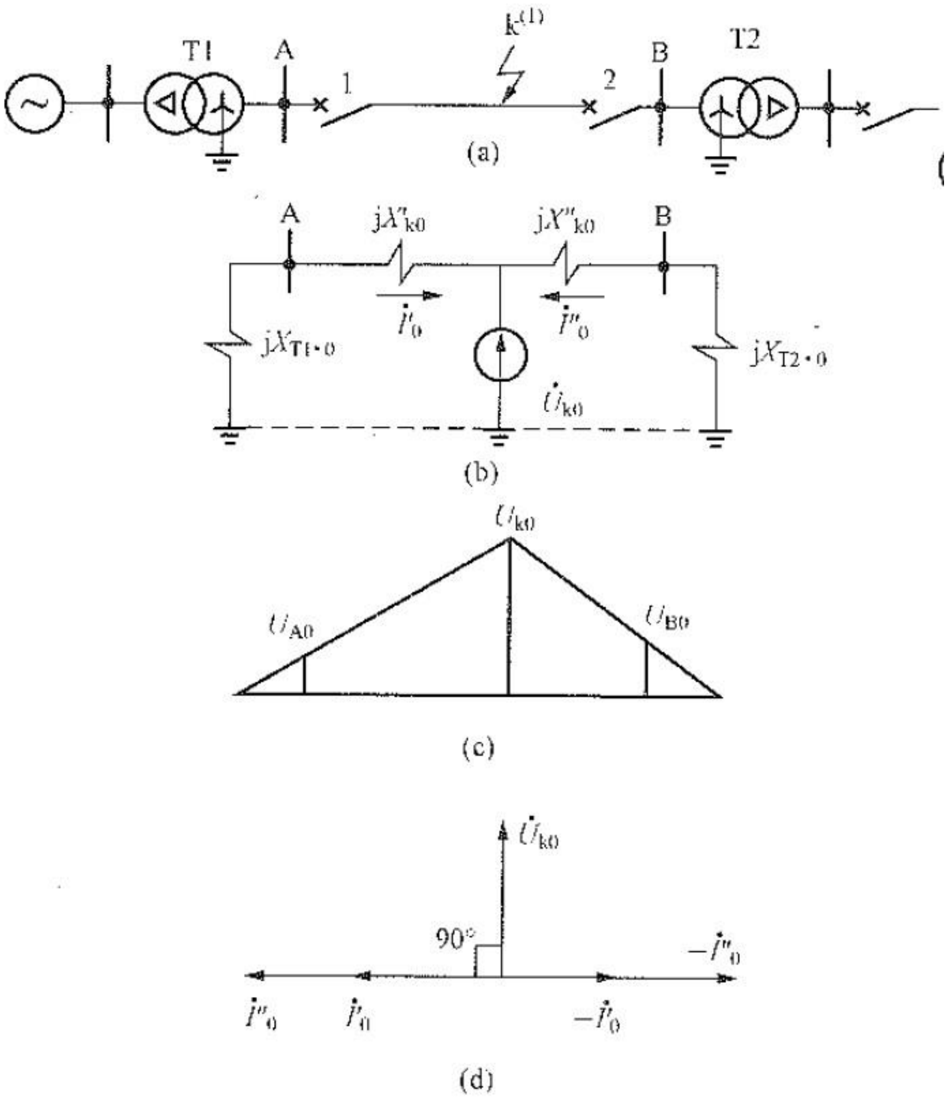
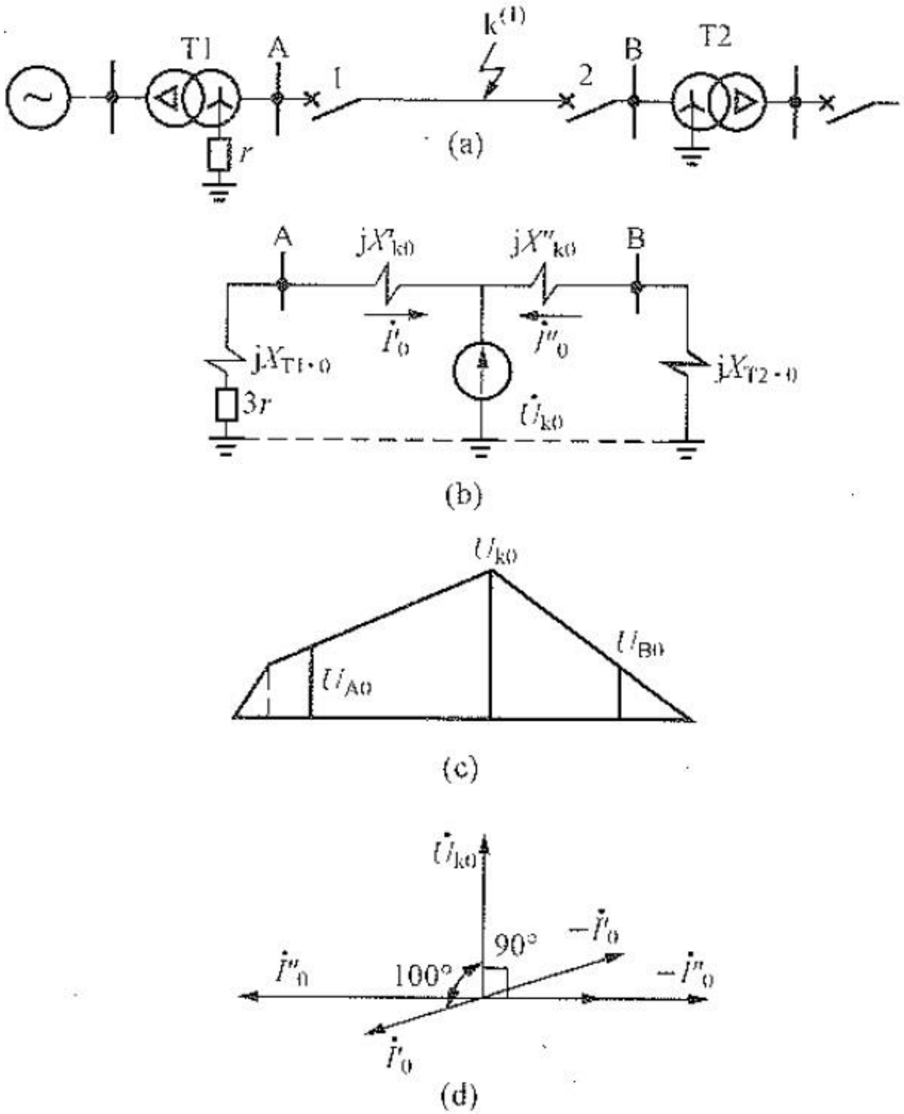
Zero Sequence Network for Directly Grounded System



- Zero sequence current is caused by a zero sequence source at fault location;
- Circuit is constructed by the grounded neutral point of transformer;
- Reference direction for zero sequence current is still from bus to line (Actually?);
- Reference direction for zero sequence voltage: the level of line is higher than ground.

Zero Sequence Network for Grounding via Resistance



- The zero sequence voltage is highest at the fault location; lower for further locations.
- The zero sequence voltage at A is:

$$\dot{U}_{A0} = (-\dot{I}_0)Z_0$$

- Z_0 is zero sequence impedance of transformer T1 (with or without resistance):

$$Z_0 = jX_{T1}$$

$$Z_0 = 3r + jX_{T1}$$

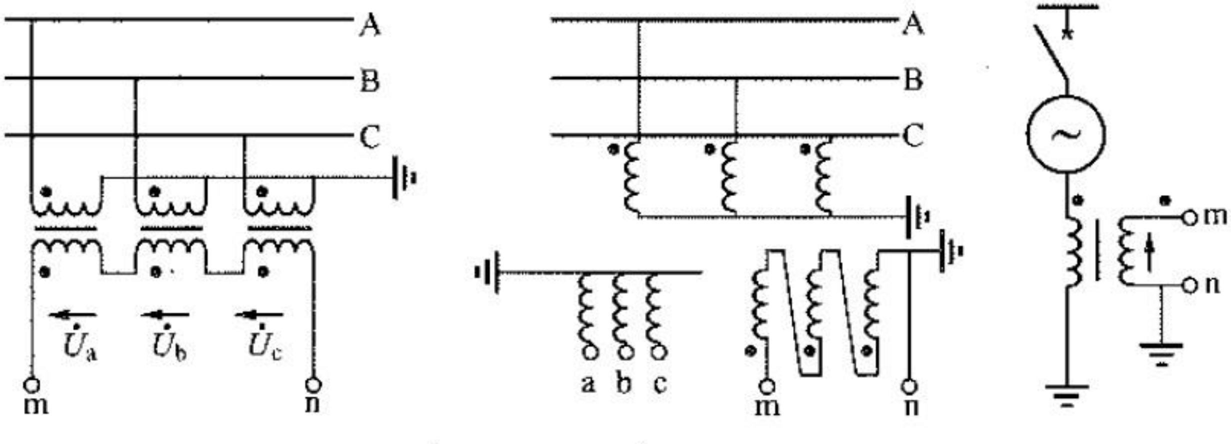
- The resistance generally doesn't influence the distribution feature of zero sequence voltage.

Filter for Zero Sequence Voltage

- Y connection of three phase PT on primary side and is connected as open Δ connection on secondary side, then the output voltage is:

$$\dot{U}_{mn} = \dot{U}_a + \dot{U}_b + \dot{U}_c = 3\dot{U}_0$$

- Digital protection can get three times of zero sequence voltage by add three phase voltages;
- If the neutral point of generator is grounded via reactance, zero sequence voltage can be got from its secondary side.
- To consider and avoid influence of third harmonic, PT errors and unsymmetrical operation on output of open Δ connection.



(a) (b) (c)

Filter for Zero Sequence Current

- To get zero sequence current, three phase CT should be connected as Y, the current through the neutral line is:

$$\dot{I}_r = \dot{I}_a + \dot{I}_b + \dot{I}_c = 3\dot{I}_0$$

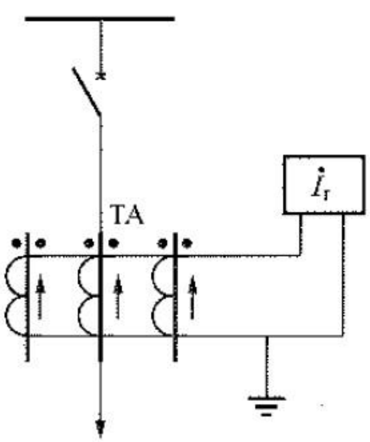
- By considering excitation current, relation between secondary and primary current:

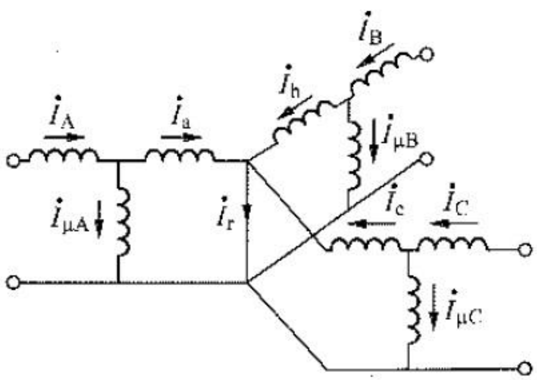
$$\dot{I}_2 = \frac{1}{n_{TA}}(\dot{I}_1 - \dot{I}_\mu)$$

$$\dot{I}_r = \dot{I}_a + \dot{I}_b + \dot{I}_c = \frac{1}{n_{TA}}(\dot{I}_A + \dot{I}_B + \dot{I}_C) - \frac{1}{n_{TA}}(\dot{I}_{\mu A} + \dot{I}_{\mu B} + \dot{I}_{\mu C})$$

- Normally

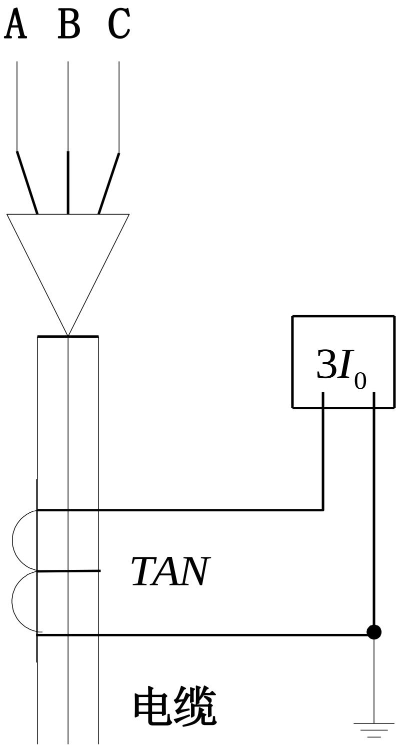
$$\dot{I}_r = \frac{1}{n_{TA}}(\dot{I}_{\mu A} + \dot{I}_{\mu B} + \dot{I}_{\mu C}) = \dot{I}_{unb}$$





Zero Sequence Current Transformer

- For cable, three times of zero sequence current can be got from a CT out of the cable:



- The current of primary side is just:

$$\dot{I}_A + \dot{I}_B + \dot{I}_C$$

- No unbalance current and simple connection

Instantaneous Protection for Zero Sequence Current (Zone I)

- To instantaneously act according to the magnitude of measured zero sequence current (overcurrent); to ensure selectivity, the protected zone is shorter than the whole line;

- The plot (relation) between zero sequence currents of grounded faults and length of line *l* can be firstly identified, then the setting can be calculated;

- (1). Avoiding the maximum zero sequence current of grounded faults at the beginning of next line: $I_{act}^{'} = K_{rel}^{'} \times 3I_{0.\max}$

- (2). Avoiding the maximum zero sequence currents caused by asynchronous closing of three phase of breakers: $I_{act}^{'} = K_{rel}^{'} \times 3I_{0.unb}$

- Some time, the setting value by (2) could be too large and reduce the protected zone.

- Additional time (0.1s) can be applied for zone I during manual or automatic three-phase reclosing of breakers, (2) can be neglected.

Instantaneous Protection for Zero Sequence Current (Zone I)

- (3). During single phase reclosing, Zone I should avoid the maximum zero sequence current caused by open-phase operation and system swing; this will further reduce the protected zone.

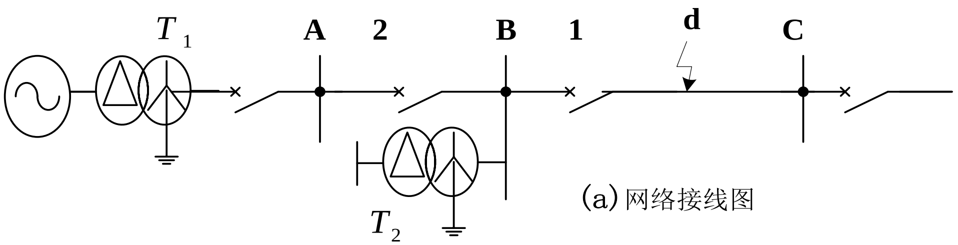
- To solve this problem, two sets of zone I protection can be applied;

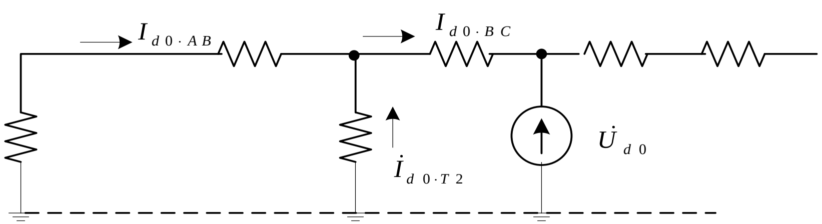
- One is set by principle (1) and (2), which is responsible for grounded faults during three-phase operation; the corresponding protected range is larger.

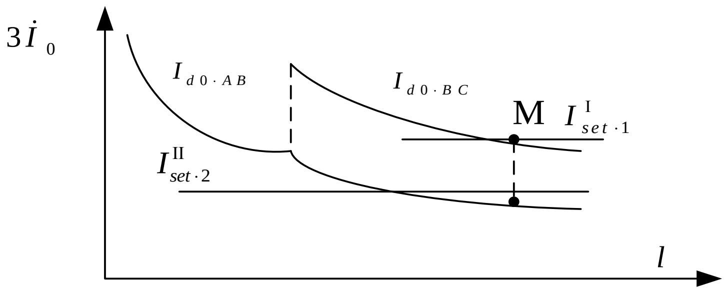
- The first set of zone I will be locked during single phase reclosing and be resumed after that.

- Another one is set by principle (3), which is responsible for grounded faults during single phase reclosing; its protected range is smaller than the first one.

Time Delay Protection for Zero Sequence Current (Zone II)







- Zone II still acts according to magnitude of zero sequence current;
- The activating value is set by coordination with the end of zone I of the next line, with a time delay to ensure selectivity;
- When a transformer between two protections is grounded at neutral point, the distribution of zero sequence current will be changed as shown in (b).

Time Delay Protection for Zero Sequence Current (Zone II)

- In case of grounded fault at B-C, the difference between zero sequence currents in protection 1 and 2 is the current through neutral point of T2, which is similar to infeed effect in phase faults;

- So zone II should be set with a branch factor $K_{0.b}$:

$$I_{set \cdot 2}^{\mathrm{II}} = \frac{K_{rel}^{\mathrm{II}}}{K_{0.b}} I_{set \cdot 1}^{\mathrm{I}}$$

- When the neutral point of T2 is not grounded, $K_{0.b}$ =1.

- Sensitivity should be checked by the minimum zero sequence current for ground faults at the end of this line:

$$K_{sen} \geq 1.5$$

Zone III Protection of Zero Sequence Current

- Similar to Zone III protection for phase faults, normally as backup protection;

- At terminal of neutral point directly grounded system (zero sequence network is open after that), it can perform as main protection;

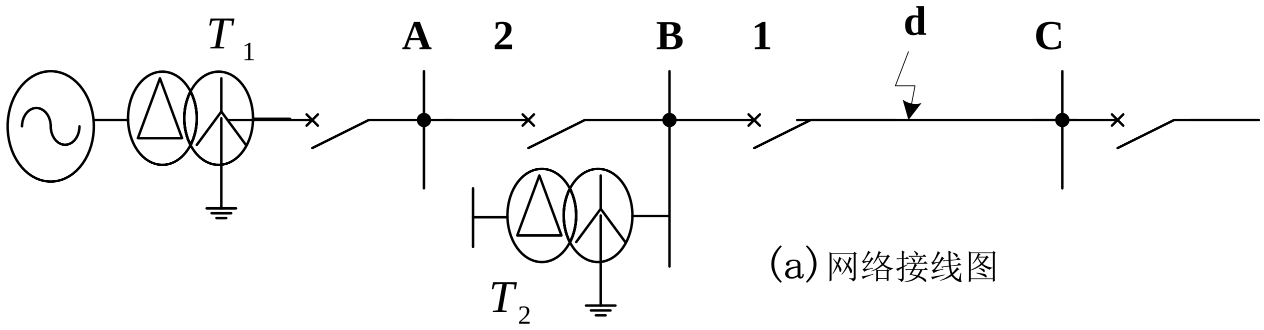
- Setting principle (1): to avoid the maximum unbalanced zero sequence current caused by phase faults at the beginning of next line:

$$I_{set}^{III} = K_{rel}^{III} \cdot 3I_{0.unb.\max}$$

Zone III Protection of Zero Sequence Current

- Setting principle (2): Sensitivities must be coordinated step by step, so the protected range of zone III for this line cannot exceed the protected range of zone III for the next line.

$$I_{set.2}^{III} = \frac{K_{rel}^{III}}{K_{0.b.\min}} \cdot I_{set.1}^{III}$$



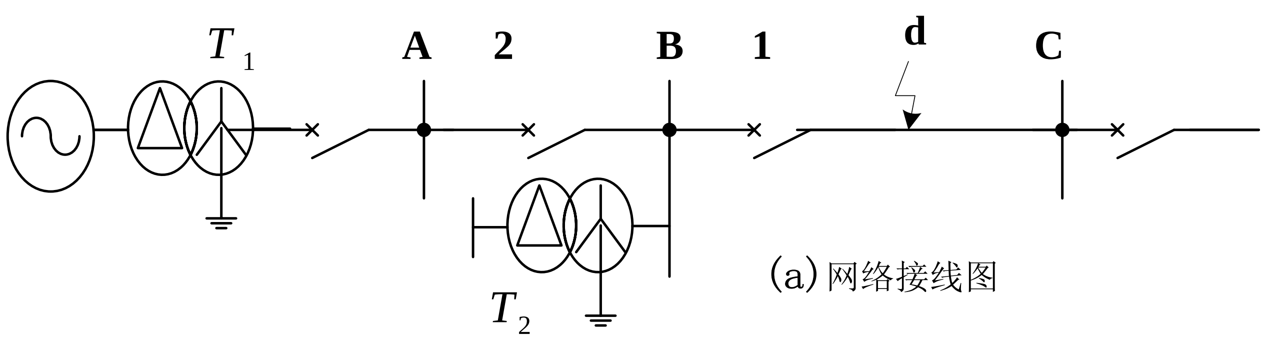
(a) 网络接线图

Zone III Protection of Zero Sequence Current

- When zone III performs as backup protection, the sensitivity should be checked by the minimum zero sequence current for grounded faults at the end of neighboring line (taking into account branch factors).

- Local backup $K_{sen} > 1.5$

- Remote backup $K_{sen} > 1.2$



(a) 网络接线图

Time Coordination for Zone III Protection

- Time delay should be coordinated step by step, the beginning point should be the terminal zero sequence network.
- 4 can act instantaneously because any fault at the Δ side of T1 cannot cause zero sequence current at the other side.
- Coordination of protection for phase faults should begin from protection 1, so for the same line, the protection for grounded faults may have smaller time delay, which is its advantage.

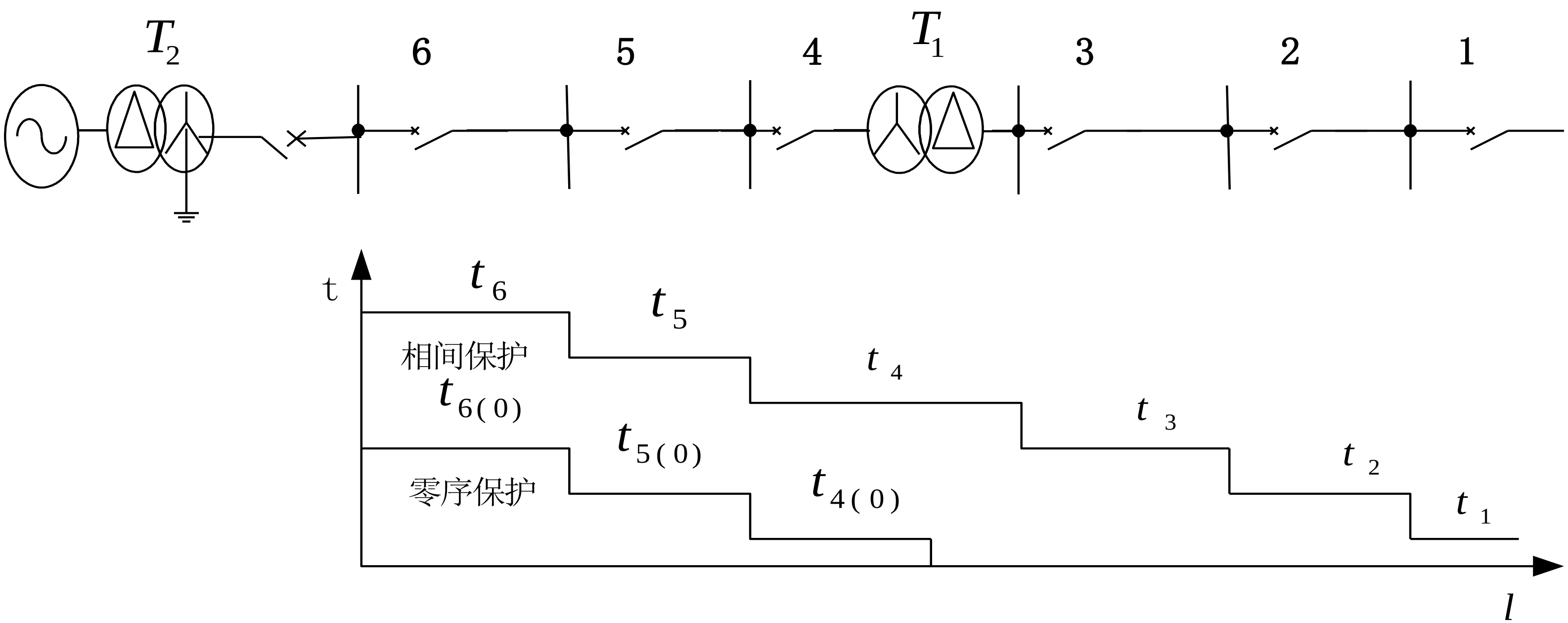


图2—44　零序过电流保护的时限特性

Next Lecture

Protection for Grounded Faults 2

Thanks for your attendance