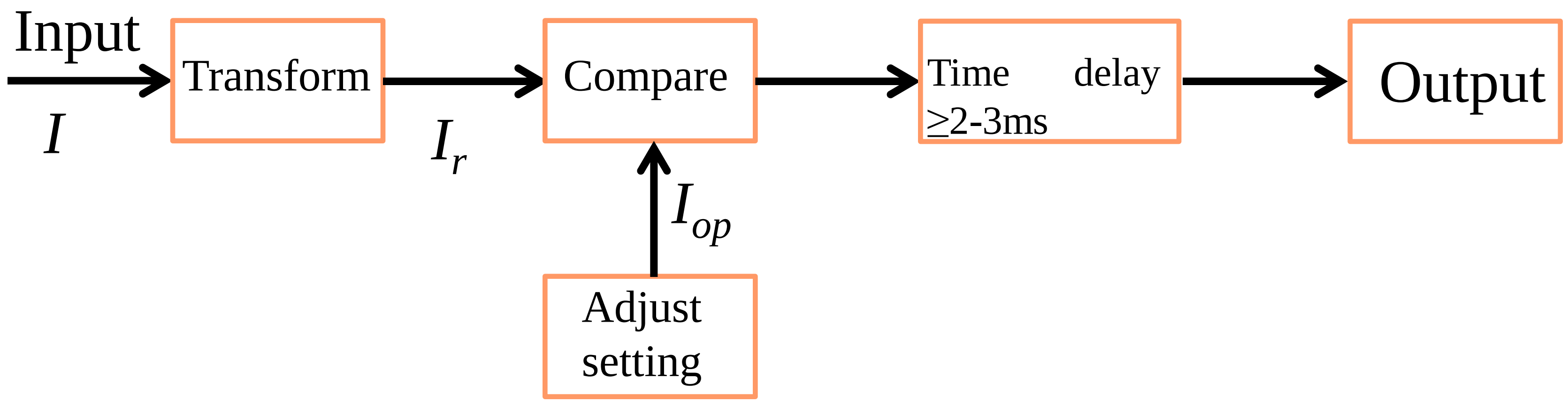
EEE340 Protective Relaying

Lecture 4 – Overcurrent Protection 1

Today

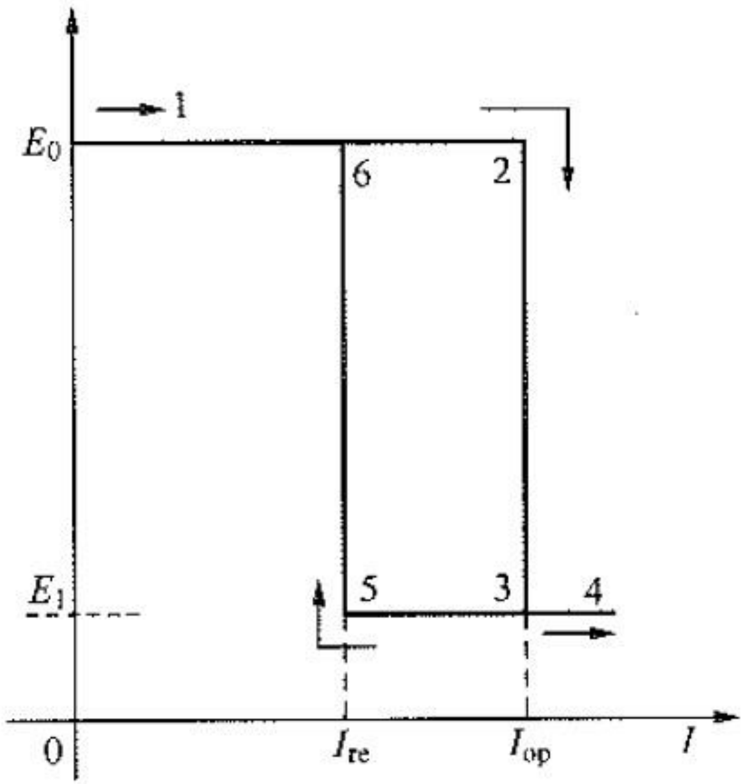
- Overcurrent Protection
  - Instantaneous protection
  - Time delay protection

Overcurrent Protection



- The input current I from CT secondary side is applied to the input of relay.
- After transformation, the input current is compared with the operating value I_{op} which can be adjusted for different applications.
- When the input current is larger than the operating value, there will be output from the comparison.
- There will be inherent operating time delay for electromagnetic relays.

Characteristics of Overcurrent Relay



- With normal current, the relay will not trip (or keep higher voltage level);
- When current $I \geq I_{op}$, the relay should trip reliably (or keep lower voltage level);
- When current $I < I_{re}$, the relay should return to open (or output higher voltage level);
- To assure stable output after trip and to avoid frequent acting around I_{op}, I_{re} should be smaller than I_{op}.
- Return ratio:

$$K_{re} = \frac{I_{re}}{I_{op}} < 1 \quad (e.g.\ 0.85 \sim 0.9)$$

Characteristics of Phase Faults in Single Source Network

- The steady-state fault current for phase faults can be approximately calculated:

$$I_k = \frac{E_\varphi}{Z_\Sigma} = K_\varphi \frac{E_\varphi}{Z_s + Z_k}$$

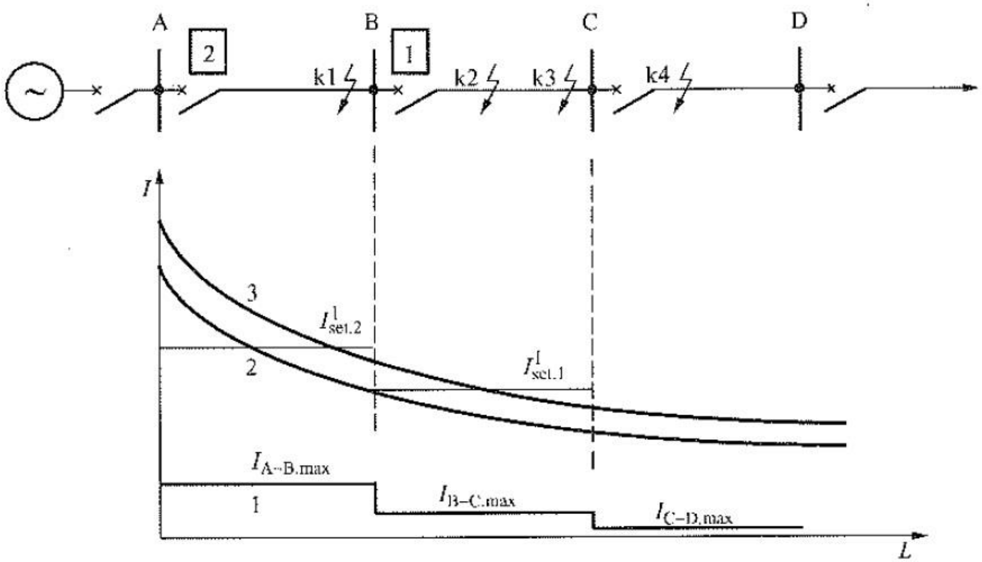
- E_φ is the phase voltage of the equivalent power source.

- Z_k is the equivalent impedance from the fault location to the installed location of relay.

- Z_s is the equivalent impedance from the relay location to the equivalent power source.

- K_φ is the coefficient for fault type, 1 for three-phase short circuit, $\frac{\sqrt{3}}{2}$ for line-to-line fault.

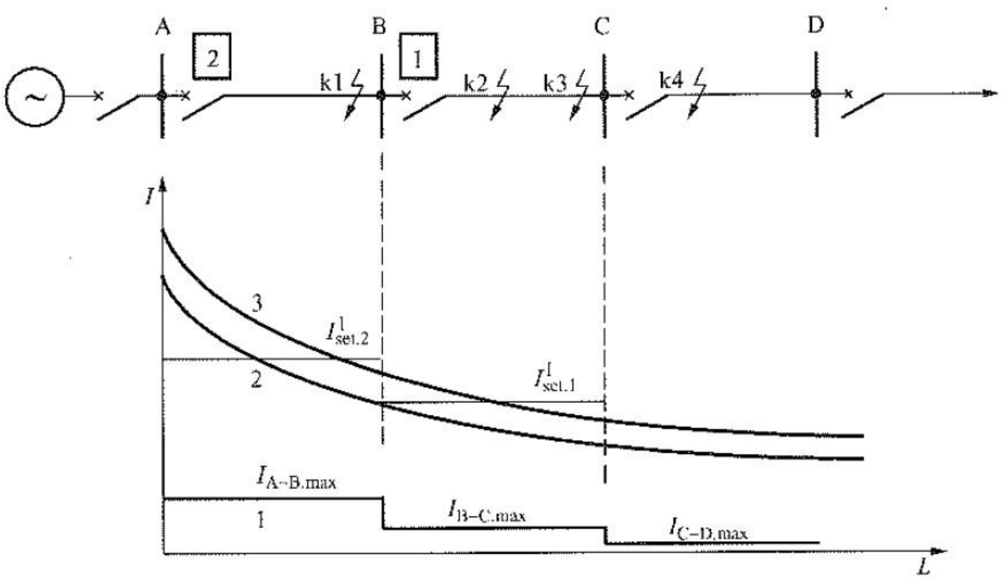
Characteristics of Phase Faults in Single Source Network



- Maximum operational mode: with minimum $Z_{s,min}$, maximum fault current for the same location and fault type;

- Minimum operational mode: with maximum $Z_{s,max}$, minimum fault current for the same location and fault type;
- Line 2: fault current at different locations of line-to-line fault at minimum operational mode;
- Line 3: fault current at different locations of three phase fault at maximum operational mode;
- Any phase faults at any operational mode will be between these two lines.

Instantaneous Overcurrent Protection



- The protection will act instantaneously when the current is larger than the setting value;
- Suppose such protections are installed at each line; protection 2 should act for faults on A-B, protection 1 should act for B-C;
- Protection 2 should not act for fault at k2 (beginning of B-C), but should act for k1 (end of A-B);
- Fault currents at k1 and k2 are almost the same;
- Similar problem to protection 1 for k3 and k4;
- To guarantee selectivity by adjusting the setting values.

Instantaneous Overcurrent Protection

- The acting condition: the fault current is larger than the setting value $I_k \geq I_{set}$;
- I_{set} is the parameter of protection for primary side;
- To guarantee selectivity, the setting value $I^{\mathrm{I}}_{set.2}$ for protection 2 must be larger than the maximum fault current at the beginning of the next line (*k2*);
- So this protect cannot act for faults at the end of this line (*k1*);
- The range that cannot be protected will be variable according to different operational modes and fault types;
- The minimum protected range is the minimum range of fault locations which can be completely protected at any operational mode with any fault type.

Setting Calculation for Overcurrent Protection

- To guarantee selectivity, the setting value for protection 1 must be larger than the maximum fault current at k4 (the fault current $I_{\mathrm{k.C.max}}$ of three-phase short circuit at the maximum operational mode at bus C);

$$I_{set.1}^{I} > I_{k.C.\max} = \frac{E_{\varphi}}{Z_{S.\min} + Z_{B-C}}$$

- So the setting value can be calculated as:

$$I_{set.1}^{I} = K_{rel}^{I} I_{k.C.\max}$$

- K^{I}_{rel} is the reliability coefficient to give some margin.

- The same policy can be applied to protection 2 and maximum fault current at bus B:

$$I_{set.2}^{I} = K_{rel}^{I} I_{k.B.\max}$$

Setting Calculation for Overcurrent Protection

- With the setting value of primary side given, the acting value for the secondary side needs to be calculated:

$$I_{op}^{I} = \frac{I_{set}^{I}}{n_{TA}} K_{con}$$

- n_{TA} is the turns ratio of current transformer (CT).

- K_{con} is the connection coefficient of CT. 1 for three phase Y connection or two phase Y connection, $\sqrt{3}$ for Δ connection on the secondary side.

- The acting time of instantaneous overcurrent protection depends on the inherent acting time of the relay, normally smaller than 10ms.

Setting Calculation for Overcurrent Protection

- With the setting value given, the range of fault locations with fault current larger than the setting value is just the protected range.

- The protected range is variable with the operational modes and fault types.

- The minimum protected range is corresponding to line-to-line fault at the minimum operational mode, which is required to be larger than 15%-20% of the total line length.

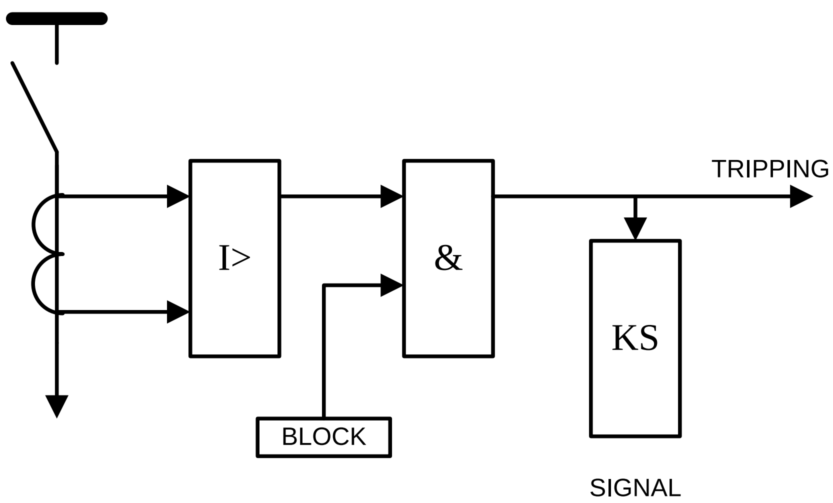
- The minimum protected range can be calculated by:

$$I_{set}^{I} = I_{k.L.\min} = \frac{\sqrt{3}}{2} \frac{E_{\varphi}}{Z_{S.\max} + z_1 L_{\min}}$$

- L_{min} is the length of the minimum protected range.

- z_1 is the positive sequence impedance for one unit length of line.

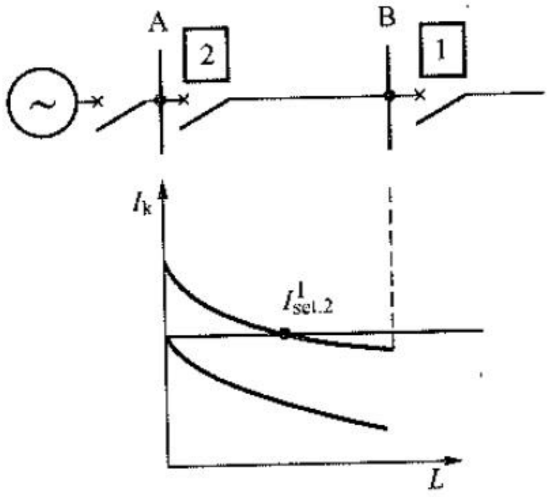
Construction of Overcurrent Protection



- The construction of overcurrent protection is shown in the picture.
- When the current from CT is larger than the acting value I_{op}, there will be output from the comparison segment KA.
- A locking segment is required for some special situations to lock the tripping circuit. Its output is 1 when no locking is needed, and 0 when locking is required.
- When KA has output with no locking, the segment of & will have output to trip beakers and activate the signal circuit through KS.

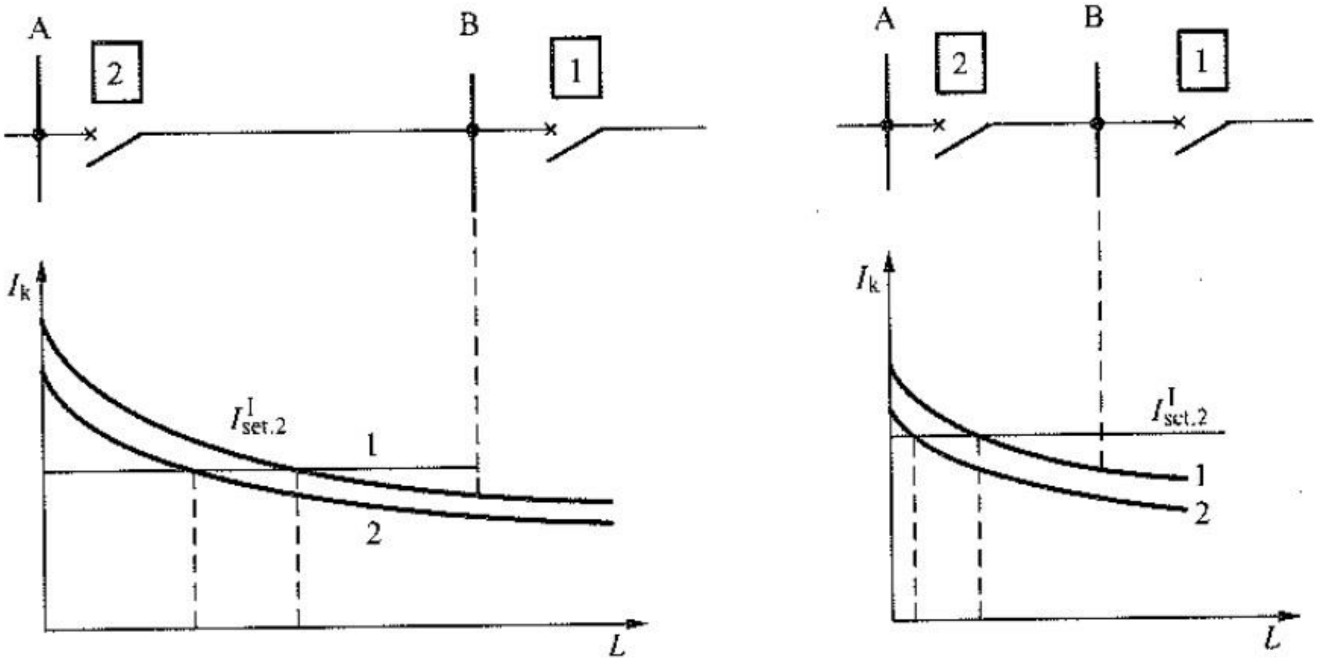
Discussion on Overcurrent Protection

- Advantage: simple and reliable, speedy.
- Disadvantage: **cannot protect the whole line**, protected range depends on operational modes.
- If the variation of operational modes is too large, or the protected line is too small, there may be no protected range.
- In following picture, if protection 2 is set by selectivity at the maximum operational mode, there will be no protected range at the minimum operational mode.



Discussion on Overcurrent Protection

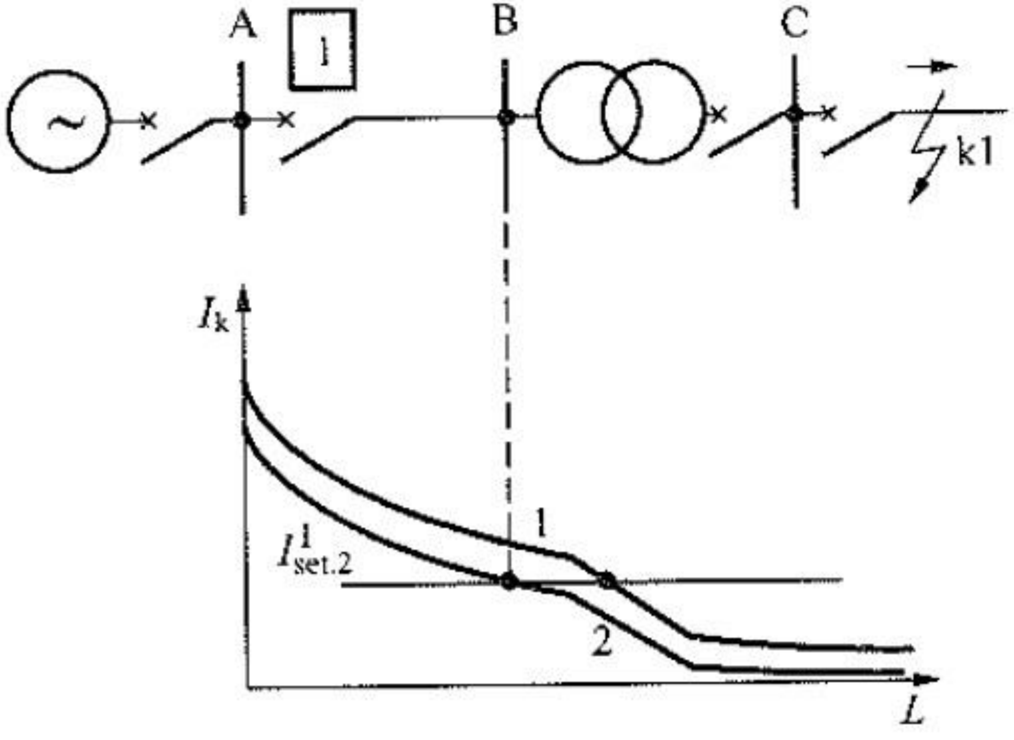
- In the following picture, if line A-B is longer, the protected range will be large. If line A-B is shorter, the protected range will be very small, or even zero.



(a) (b)

Discussion on Overcurrent Protection

- In the following picture, if protection 1 is set by selectivity at the low voltage side of the transformer, because of the impedance of the transformer, the protected range can cover the whole line.



Today

- Overcurrent Protection
  - Instantaneous protection
  - Time delay protection

Time Delay Instantaneous Overcurrent Protection

- Disadvantage of instantaneous overcurrent protection: **cannot protect the whole line**, so the fault location (inside or outside the zone) cannot be judged only by fault current.

- Requirement: Another set of protection (II) which can respond to any fault inside the protected zone is required.

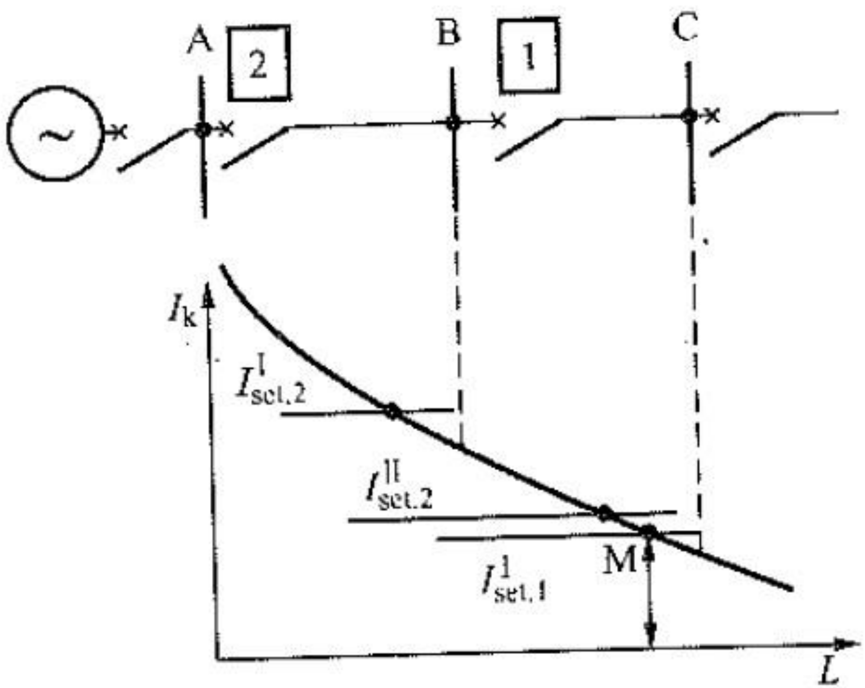
- Solution : Time Delay Instantaneous Overcurrent Protection.

- Principle: to appropriately (how?) reduce the setting value of overcurrent relay.

- The overcurrent relay will respond to smaller fault current which is caused by further fault location.

- New challenge : The protected zone will be extended to the next line, selectivity is difficult to be handled.

Time Delay Instantaneous Overcurrent Protection



- If the protected zone of 2 needs to cover whole line A-B, then it must be extended to the next line (B-C), so it will respond to the faults at both sides of B.
- To guarantee the selectivity, time delay Δt is added to coordinate with the protection of the next line (protection 1). To guarantee selectivity by decrease of speed.
- To minimize this time delay, the protected zone should not be beyond the zone of instantaneous protection of the next line (protection 1).
- Any fault in the protected zone will be cleared within $t_1^I + \Delta t$. t_1^I is the acting time of instantaneous protection.

Setting of Time Delay Protection

- Task: to make decision on the value of fault current for tripping, as well as the corresponding extension of protected zone.

- Policy: Priority to guarantee the sensitivity within the protected line, and then to guarantee the selectivity of faults of the next line.

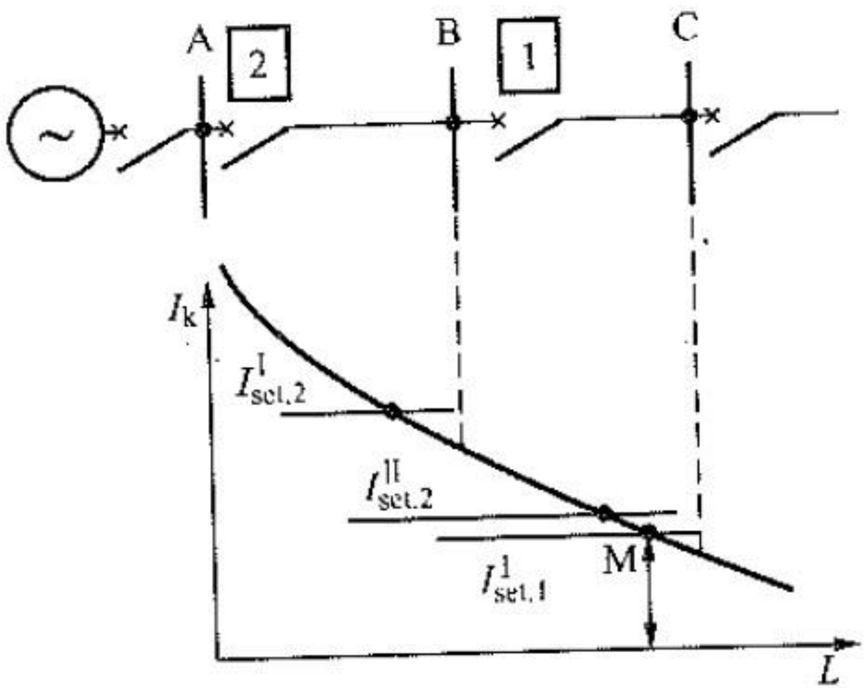
- Solution : Time Delay Instantaneous Overcurrent Protection.

- **Requirements**:

For any fault type and operational mode, the protected zone should always cover the whole protected line; Enough sensitivity for any fault at the end of the protected line.

For any fault type and operational mode, the protected zone should not exceed the zone of the instantaneous protection of the next line, or selectivity cannot be ensured.

Setting of Time Delay Protection



- To ensure selectivity, $I^{II}_{set.2} \geq I^{I}_{set.1}$.
- By considering possible errors,

$$I^{II}_{set.2} > I^{I}_{set.1}$$

- By using reliability coefficient,

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

- $K_{rel}{}^{II}$ is generally 1.1~1.2
- For any fault at the beginning of the next line, instantaneous protection of 1 should act earlier than time delay protection of 2.

$$t_2^{II} = t_1^{I} + \Delta t$$

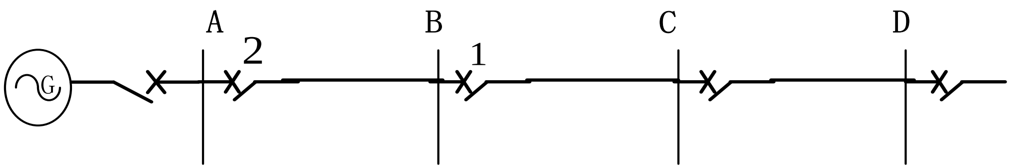
Setting of Time Delay Protection

Factors to be considered for Δt :

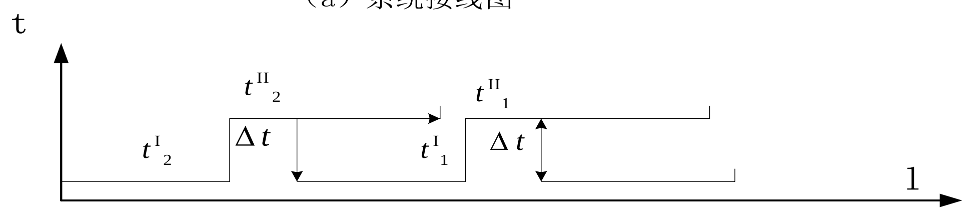
- Tripping time of breaker and time for arc extinction.
- Errors of time relay of protection 1 for the next line.
- Errors of time relay of protection 2 for this line.
- The time for relay of protection 2 to return after the fault is cleared.
- Some further margin.
- Normally between 0.3~0.5s

Coordination of Time Delay Protection

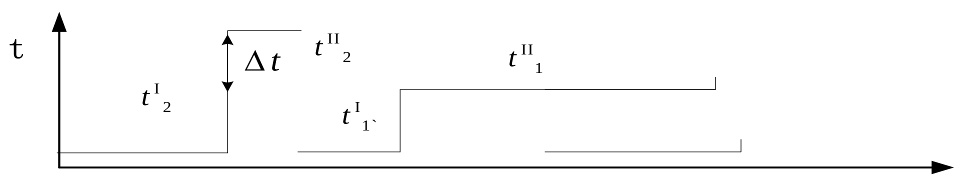
- Any fault within the protected zone of instantaneous protection 1 will be cleared within t_1^I. Time delay protection of 2 will return after that because t_2^{II} is larger than t_1^I.
- If sensitivity is not enough, the setting value of time delay protection of 2 can be further reduced and coordinate with the time delay protection of 1.



（a）系统接线图



（b）与电流速断配合



（c）与限时电流速断配合

$$t_2^{II} = t_1^{I} + \Delta t$$

$$t_2^{II} = t_1^{II} + \Delta t$$

Check Sensitivity

- Policy: to ensure with any fault and any operational mode, the protected zone can cover the whole protected line.

- Requirement: with minimum fault current at line-to-line short-circuit, the fault current should be still larger than the setting value with some margin.

- To calculate and check the minimum sensitivity coefficient for the most adverse case.

- Definition of sensitivity coefficient for overcurrent relay:

K_{sen} =
(Calculated value for metallic fault inside the protected zone)/Setting value

Check Sensitivity

- In all possible faults inside the protected zone, to select the most insensitive case for checking.

- The sensitivity coefficient is minimum and the fault characteristic is most obscure, which is most adverse for acting of the protection.

$$K_{sen} = \frac{I_{K.B.\min}}{I_{set.2}^{II}}$$

- $I_{K.B.min}$ is the line-to-line fault current for fault at the end of the protected line (B of A-B) at the minimum operational mode.

- $I^{II}_{set.2}$ is the setting value of the time delay protection for protection 2.

- $K_{sen} \geq 1.3 \sim 1.5$

Check Sensitivity

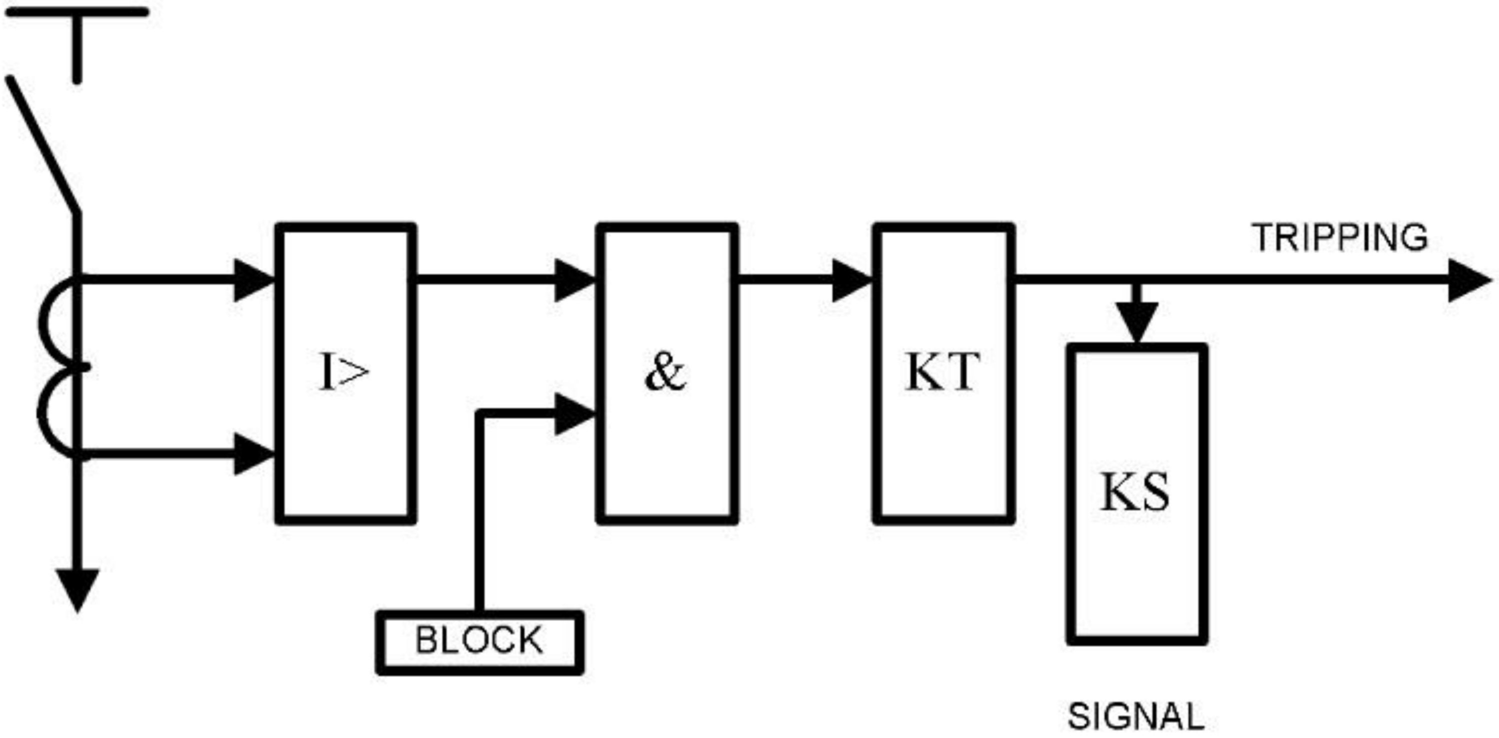
Factors to be considered for sensitivity :

- Real faults may not be metallic and the fault current may be smaller.
- Errors in calculation.
- Errors of current transformers.
- Errors of setting values.
- Some further margin.

If the sensitivity cannot meet the requirements:

- To further reduce the setting value and extend the protected zone. To coordinate with time delay protection of the next line.
- To keep this protection and add another set of protection.
- To use other protection principles with higher sensitivity.

Diagram for Single Phase Connection



Compared with the instantaneous protection, a time relay KT is added.

Next Lecture

Overcurrent Protection 2

Thanks for your attendance