EEE340 Protective Relaying

Lecture 5 – Overcurrent Protection 2

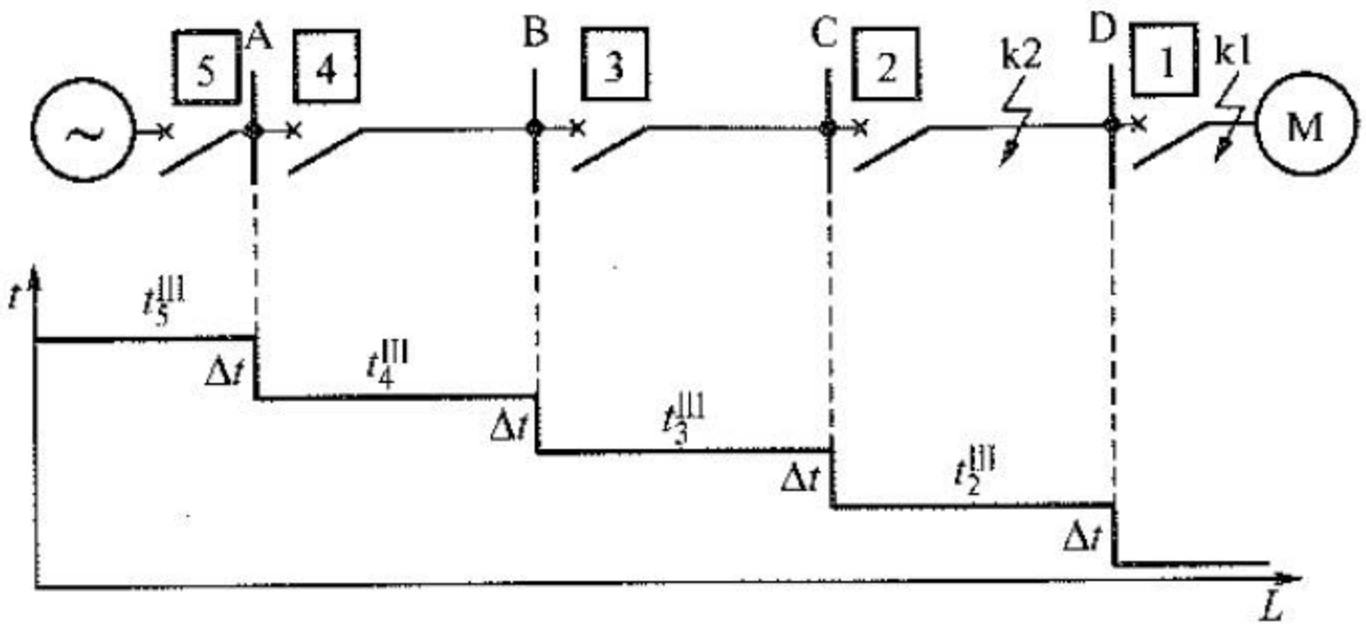
Today

- Overcurrent Protection for Phase Faults in Single Source Network
  - Definite Time Overcurrent Protection
  - Coordination of Overcurrent Protection Zones
  - Inverse Time Relay with Definite Minimum Time Overcurrent Protection
- Directional Overcurrent Protection
  - Phase Fault in Double Ended Source System
  - Directional Element for Power Flow
  - Application of Directional Overcurrent Protection

Definite Time Overcurrent Protection

- The setting value is calculated by avoiding the maximum load current;
- The protection will be activated when the current is larger than the maximum load current;
- Remote backup protection for the main protections of the next line in case of failures to trip;
- Local backup protection for the main protections of the current protected line in case of failures to trip;
- Definite time overcurrent protection: the operating time is constant as set;
- Inverse time relay overcurrent protection: the operating time is related to the magnitude of the current; larger current corresponding to faster operation.

Definite Time Overcurrent Protection



- To ensure no operation at normal conditions, the activating value of current must be larger than the maximum load current $I_{L.max}$;
- The return value of current must be larger than the self-starting current of loads to ensure the relay will return during self-starting of loads after clearing the faults;
- In case of fault at k2, the fault should be cleared by protection 2;
- Protection 3, 4, 5 should return when the current is decreased.

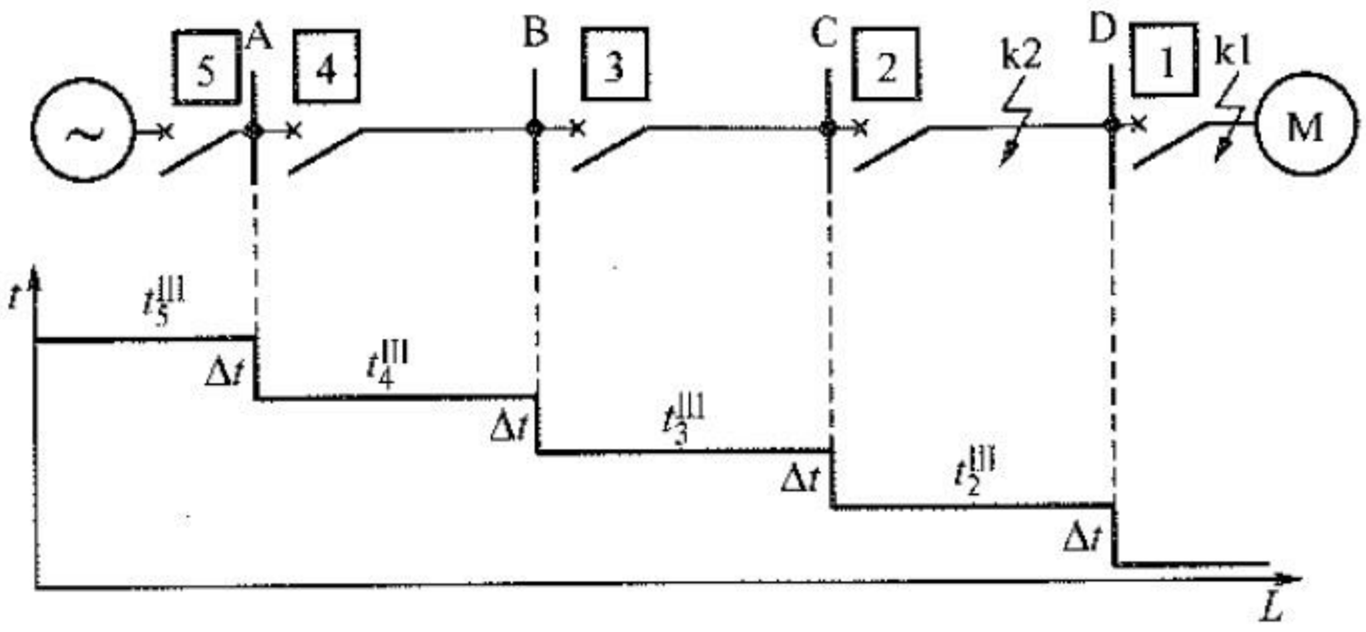
Definite Time Overcurrent Protection

- The currents through 3,4,5 after clearing fault at k2 are their load currents in operation;
- Motors at A,B,C will be self-started, the self-starting current is larger than the normal operating current; $I_{SS.\max} = K_{SS} I_{L.\max}$
- Protection 3,4,5 must return instantaneously under corresponding self-starting currents; $I_{re}^{'} = K_{rel}^{III} I_{SS.\max} = K_{rel}^{III} K_{SS} I_{L.\max}$
- The setting value for protection can be calculated as:

$$I_{set}^{III} = \frac{1}{K_{re}} I_{re}^{'} = \frac{K_{rel}^{III} K_{SS}}{K_{re}} I_{L.\max}$$

- K_{rel}^{III}---reliability factor, 1.15~1.25;
- K_{SS}---self-starting factor, larger than 1, related to concrete loads;
- K_{re}---return factor, 0.85~0.95;

Definite Time Overcurrent Protection



- The activating value of current for each protection is set by avoiding (be larger than) the corresponding maximum load currents;
- In case of fault at k1, protection 1~5 will all be possibly activated;
- Only protection 1 should trip to clear the fault, the others should return;
- This can only be achieved by different operating time (time delay) for different protections.

Definite Time Overcurrent Protection

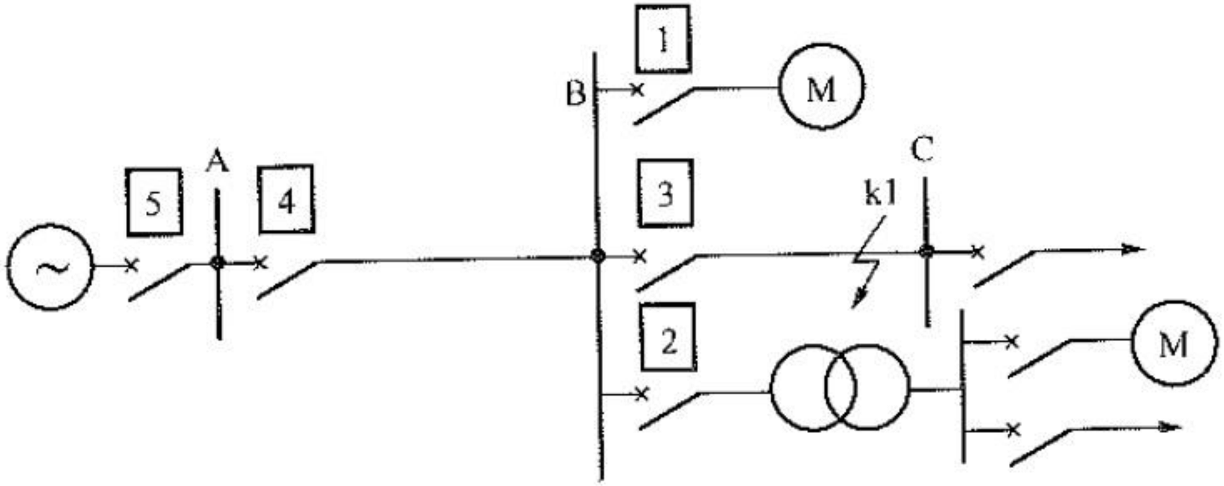
- Since protection 1 is at the end of line, its operating time t^{III}_1 is just inherent value;

- For protection 2, to ensure selectivity of fault at k1, $t^{III}_2 = t^{III}_1 + \Delta t$;

- The operating time for 3,4,5 can be set similarly to ensure selectivity;

- The protection 4 in the following figure should be set as **constant** as:

$$t_4^{III} = \max\{t_1^{III} + \Delta t, t_2^{III} + \Delta t, t_3^{III} + \Delta t\}$$



Sensitivity

- If the definite time protection is a main protection of the current line, the fault current of line-to-line fault at the end of line with minimum operational mode should be applied for checking;

- If the definite time protection is a backup protection of the neighboring line, the fault current of line-to-line fault at the end of the neighboring line with minimum operational mode should be applied for checking;

- For the same fault location, then sensitivity of protection more closed should be higher; $K_{sen.1} > K_{sen.2} > K_{sen.3} > K_{sen.4} > \ldots\ldots$

- In single source network, the load currents nearer to the source are larger, so the setting value is larger;

- But at fault, the fault current flowing through all protections is the same, so the coordination requirement can be met naturally.

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  - Coordination of Overcurrent Protection Zones
  - Inverse Time Relay with Definite Minimum Time Overcurrent Protection

Coordination of Overcurrent Protection Zones

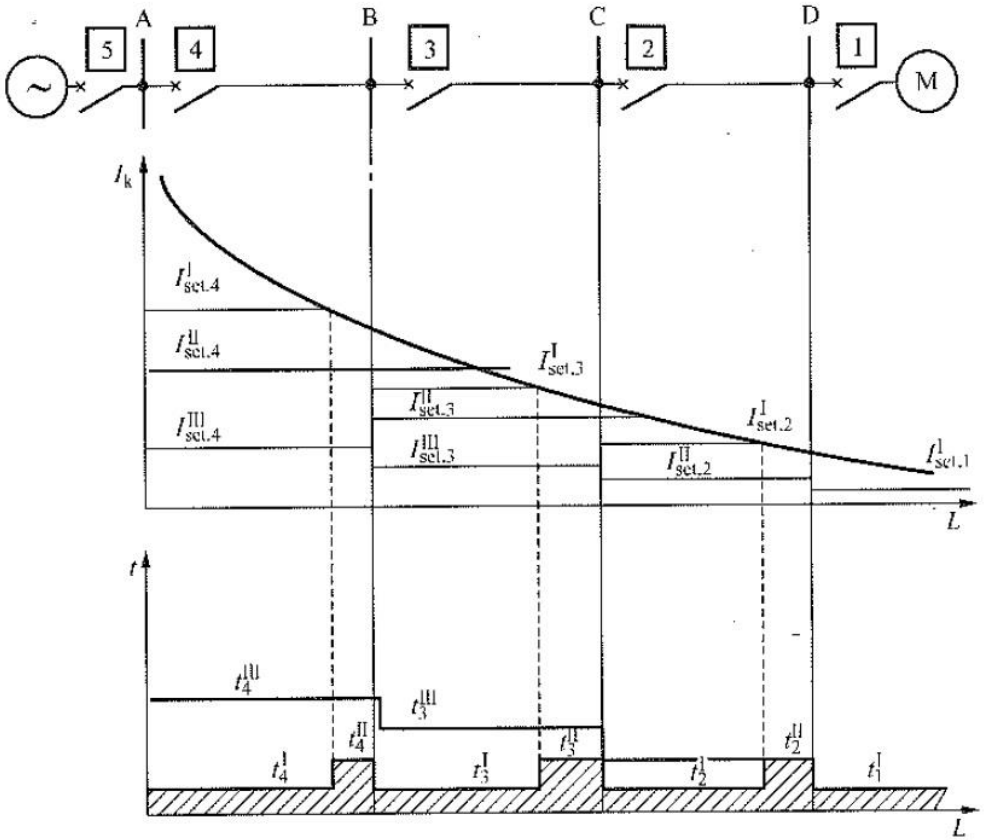
- Instantaneous overcurrent protection, time delay instantaneous overcurrent protection and definite time overcurrent protection are all be activated when current is over the setting value;

- The difference is just how to select the setting value of current (to avoid the maximum fault current at the end of current line, to avoid the maximum zone of the instantaneous protection of the neighboring line, to avoid the maximum load current);

- The first one cannot protect the whole line, the second one cannot be backup protection for neighboring components;

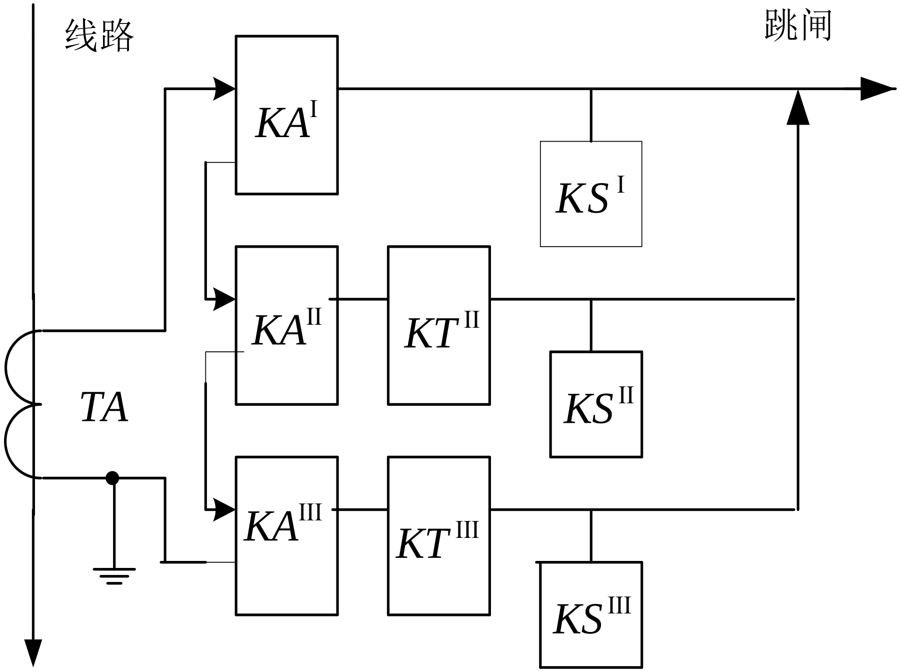
- These three sets of protection can be grouped together as overcurrent protection zones (Zone I, Zone II, Zone III).

Coordination of Overcurrent Protection Zones



- Instantaneous protection for 1 by avoiding the maximum starting current of the motor;
- Instantaneous protection + definite time protection of 0.5s for 2;
- The definite time protection at 3 will need 1~1.2s for coordination with 2;
- Instantaneous protection + time delay instantaneous protection + definite time protection for 3;
- Any fault at any location can be cleared within 0.5s.

Coordination of Overcurrent Protection Zones



- Three sets of protection at one bus share the same CT for input current;
- The three overcurrent components KA are connected in series;
- The two time delay components are different, there is no time delay component for zone I (instantaneous);
- The three signal components KS send out acting signal of zone I, II, III respectively;

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Inverse Time Relay Overcurrent Protection

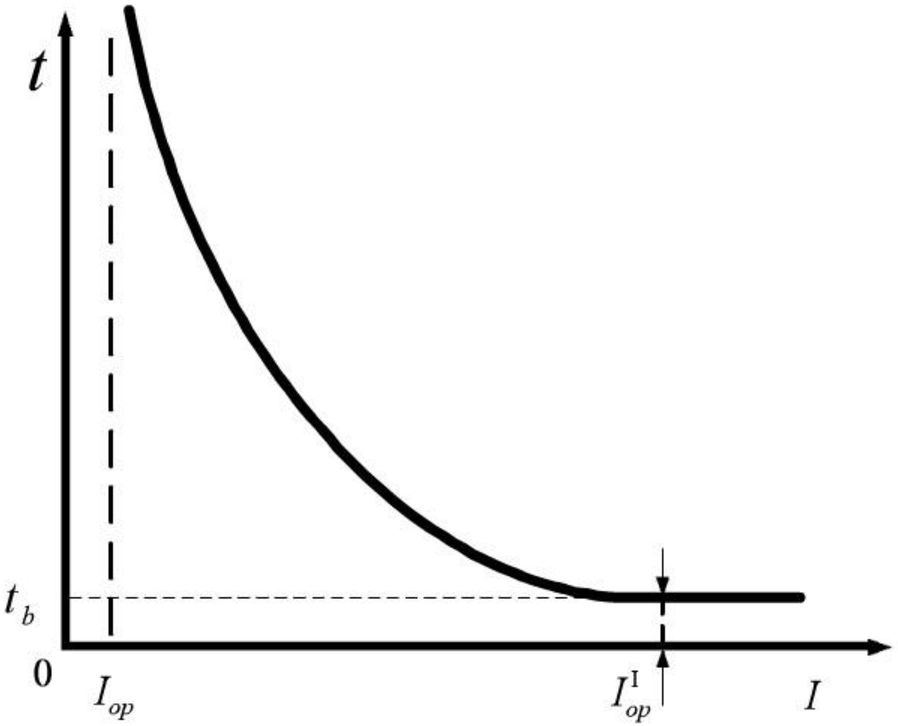
- Protection zones have to use more relays to ensure selectivity and sensitivity;

- The definite time overcurrent protection can only ensure selectivity by time coordination gradually along different lines, so locations nearer to power source will have longer operating time;

- Inverse time relay: the operating time is related to the magnitude of current;

- Inverse: larger current is corresponding to shorter operating time, smaller current is corresponding to longer operating time..

Inverse Time Relay Overcurrent Protection

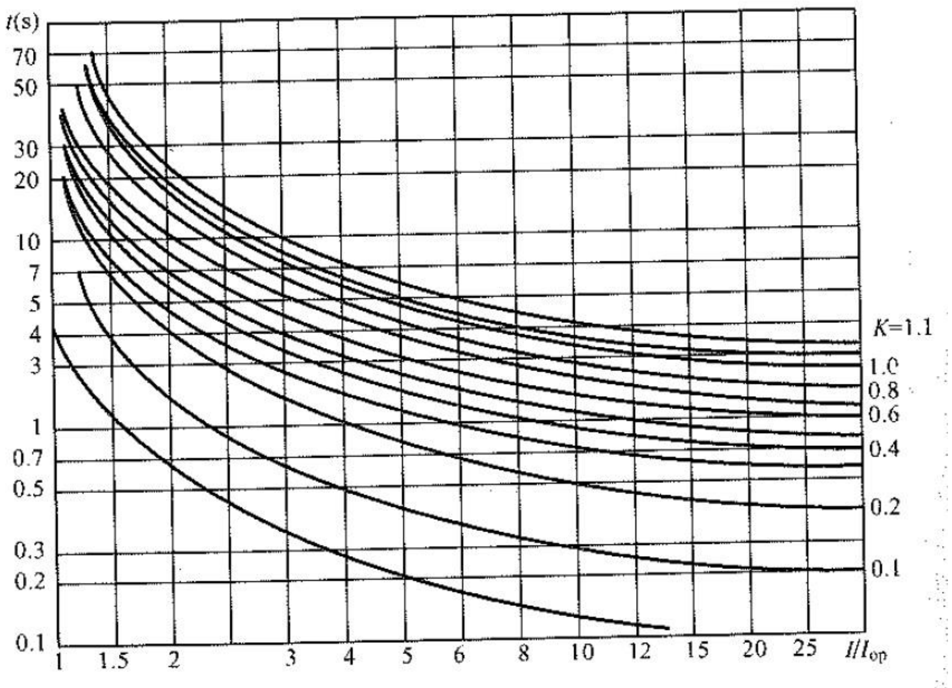


- Principle: to adjust operating time according to extent of severity of faults;
- Complicated for coordination;
- General operating feature:

$$t = \frac{0.14K}{\left(\frac{I}{I_{op}}\right)^{0.02} - 1}$$

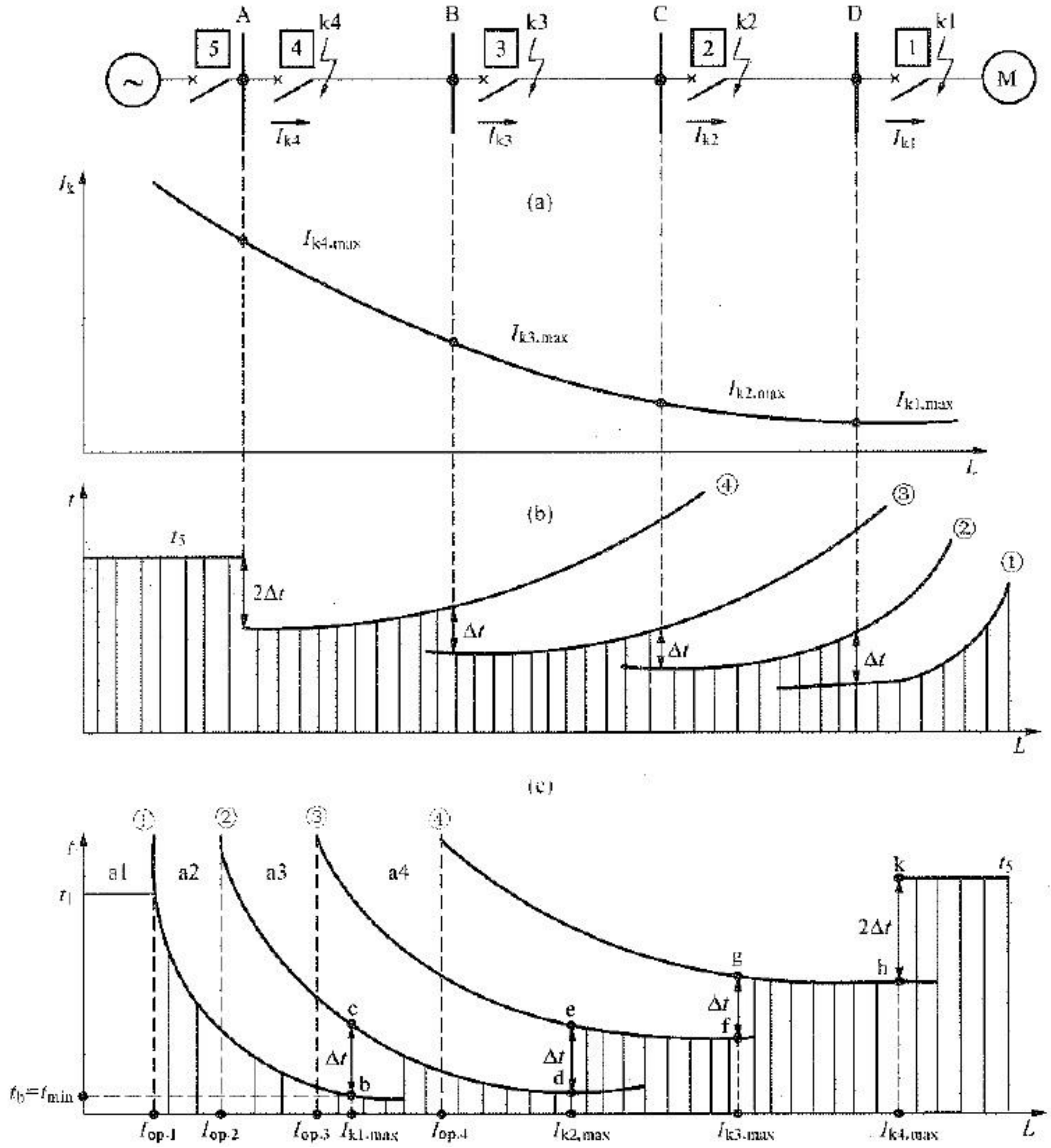
- I_{op} is the operating value; I_{op}^{I} is the instantaneous operating value.

Inverse Time Relay Overcurrent Protection



- When the current is smaller than I_{op}, the relay will not act;
- When the current is larger than I_{op}^{I}, the relay will act with minimum operating time (instantaneously);
- For currents between former two cases, the relay will act according to the time feature $t=f(I/I_{op})$;
- K is a factor to adjust the time feature;

Coordination for Inverse Time Relay Protection



- The operating values $I_{op.}$ (1,2,3,4) are still set by avoiding maximum load currents respectively;
- Under maximum fault current $I_{k1.max}$,$I_{k2.max}$,$I_{k3.max}$, $I_{k4.max}$, each protection should have the minimum operating time respectively;
- For protection 1, with the operating value $I_{op.1}$, the operating time is t_1, so point a1 can be identified. Under $I_{k1.max}$, the operating time is t_b, so b can be identified.
- So a1 and b can determine K and the time feature.

Coordination for Inverse Time Relay Protection

- Then for protection 2, point a2 can be identified by $I_{op.2}$ and required operating time; Under $I_{k1.max}$, $t_c = t_b + \Delta t$, point c is identified; time feature can be determined by a2 and c. Under $I_{k2.max}$, the operating time is $t_d < t_c$.

- Then for protection 3, point a3 can be identified by $I_{op.3}$ and required operating time; Under $I_{k2.max}$, $t_e = t_d + \Delta t$, point e is identified; time feature can be determined by a3 and e. Under $I_{k3.max}$, the operating time is $t_f < t_e$.

- Similarly for protection 4;

- Normally, a definite time overcurrent protection is applied for generator bus 5 as backup protection;

- As remote backup, for fault at k3, its operating time should have Δt more than protection 4, or $2\Delta t$ more than protection 4 at k4.

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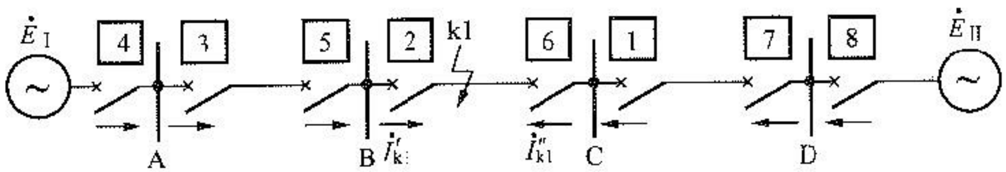
  - Phase Fault in Double Ended Source System
  - Directional Element for Power Flow
  - Application of Directional Overcurrent Protection

Phase Fault in Double Ended Source System

- In single source network, faults are only detected by magnitude of current, selectivity is only ensured by coordination of current and operating time.
- In double ended source system, to cut one end of faulted line is not enough, breakers and protections are needed at both ends;
- In single source network, fault current can only have one identical direction;
- In double ended source system, for the same relay, fault current through it can have two possible directions;

Phase Fault in Double Ended Source System



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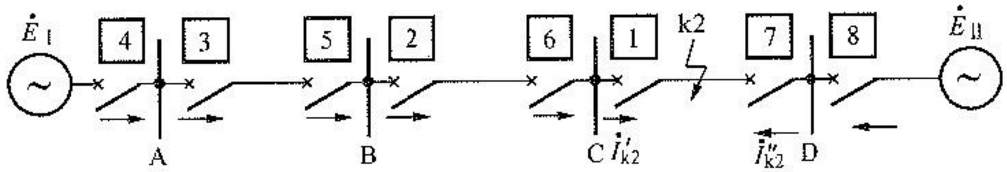

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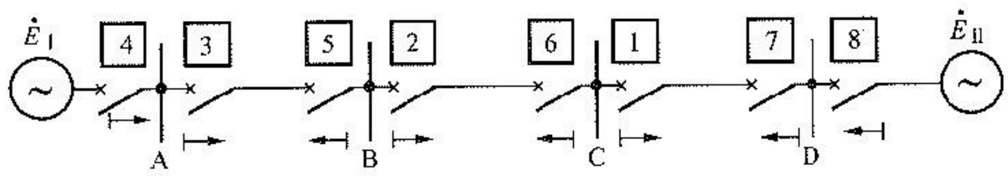

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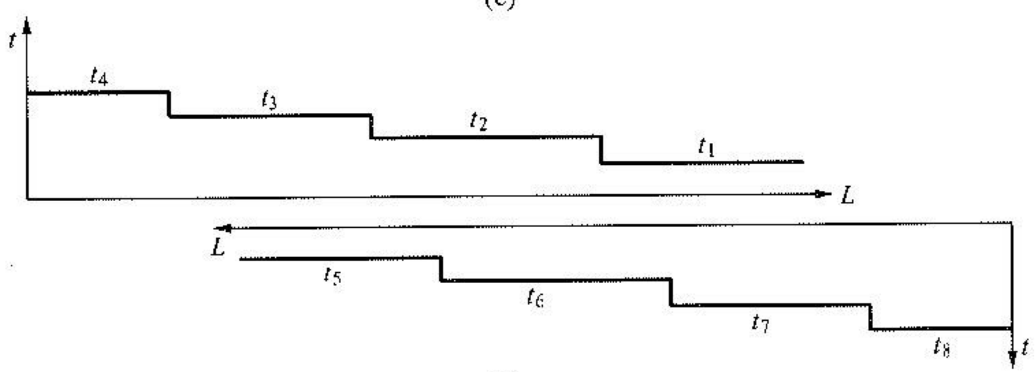

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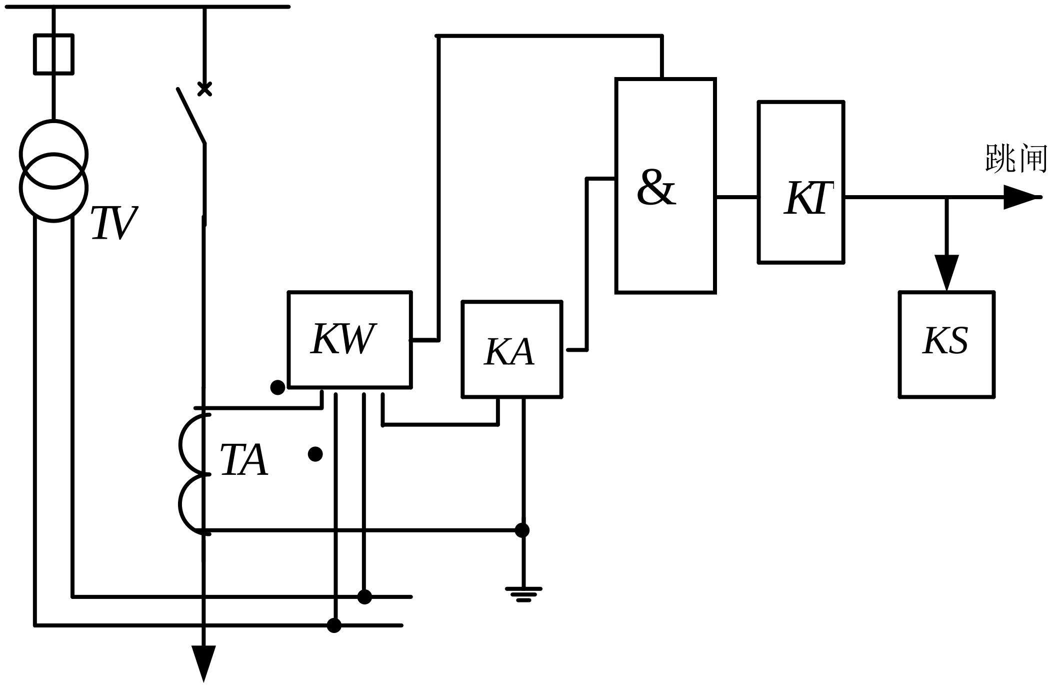
Phase Fault in Double Ended Source System

- In case of fault at k1, protection 2 and 6 should trip to clear the fault and power supply is maintained for each bus, which is the advantage of double ended source network;
- Protection 5 and 1 are so closed to 2 and 6 that the currents through them are exactly the same (5 and 2, 1 and 6);
- For 5, a fault between A-B may have smaller fault current than a fault between B-C;
- If 5 is set by fault current at A-B, then it may trip for a fault at B-C (k1), which is not expected.
- Similar problem for protection 1.

Directional Overcurrent Protection

- The direction from bus to the protected line can be defined as a reference direction or positive direction;
- The false tripping of 5 and 1 all happen to the negative direction;
- For a fault at k1, the fault power flow direction is consistent with the reference direction of 2,3,4 and 6,7,8;
- Each protection will only act for fault power flow of the reference direction;
- All protections with the same reference direction can coordinate just like single source network.
- If power source E_{II} doesn't exist, protection 1,2,3,4 can work properly as only supplied by E_I; if E_I doesn't exist, protection 5,6,7,8 can work properly as only supplied by E_{II}.

Directional Overcurrent Protection



- A directional element of power flow KW is added; the time element KT can only be activated to trip the breaker after time delay when both KW and KA have tripped.
- When only KA trips, but KW doesn’t trip, KT and breaker will not be activated.
- The protections can be divided into two groups for two directions, no coordination is required between these two groups.

- The principles and setting calculation for three zones of overcurrent protection are still valid.

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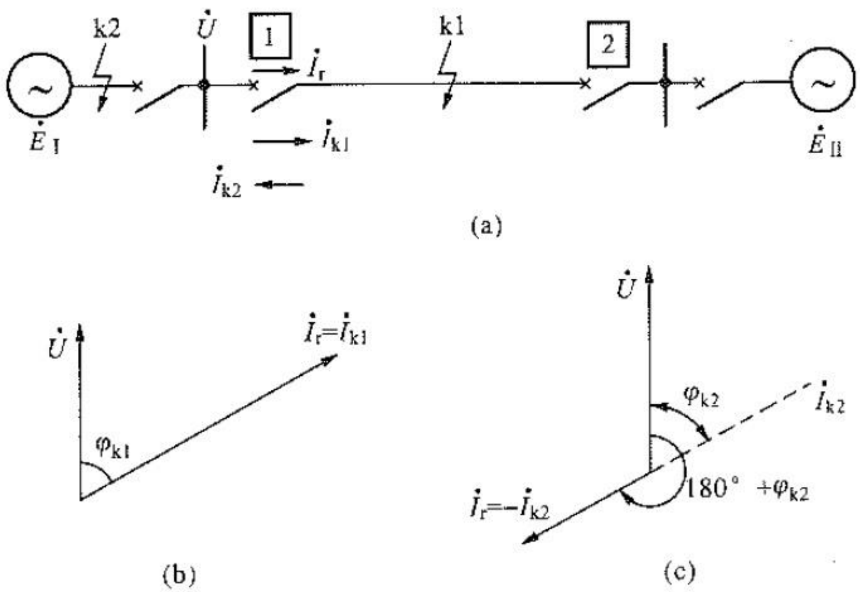
Directional Element for Power Flow



- For a three-phase fault at k1, the fault current I_r through 1 lagged its voltage U for φ_{k1} (phase angle of line impedance between 1 and k1, $0^o < \varphi_{k1} < 90^o$).
- For a fault at k2, the fault current $-I_{k2}$ through 1 lagged its voltage U for $180^o+\varphi_{k2}$ (φ_{k2} is phase angle of line impedance between 1 and k1, $180^o < 180^o+\varphi_{k2} < 270^o$).

- If we suppose $\varphi_{k1} = \varphi_{k2} = \varphi_k$, phase angles of fault currents for these two cases have 180^o difference.
- A directional element for power flow is to detect and judge the phase angle between the input current and voltage.

Directional Element for Power Flow

- Requirements: to reliably act for all faults at the reference or positive direction, does not act for any faults at the opposite direction; Enough sensitivity for action at the positive direction.

- For directional element of phase A, if the input voltage is U_r (U_A) and current is I_r (I_A), then the phase angle between them for positive and opposite direction faults:

$$\varphi_{rA} = \arg\frac{\dot{U}_A}{\dot{I}_{K1A}} = \varphi_{k1} \qquad \varphi_{rA} = \arg\frac{\dot{U}_A}{-\dot{I}_{K2A}} = 180^o + \varphi_{k2}$$

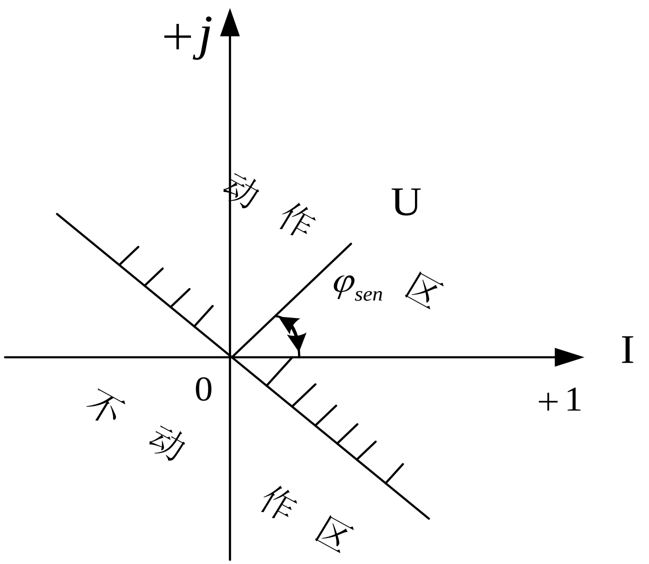
- The magnitude of output (voltage or torque) depends on the magnitude of phase angle. To make the protection most sensitive for normal faults, the most sensitive angle can be adjusted as $\varphi_{sen} = \varphi_k = 60^o$ (suppose the normal phase angle of line impedance is 60^o).

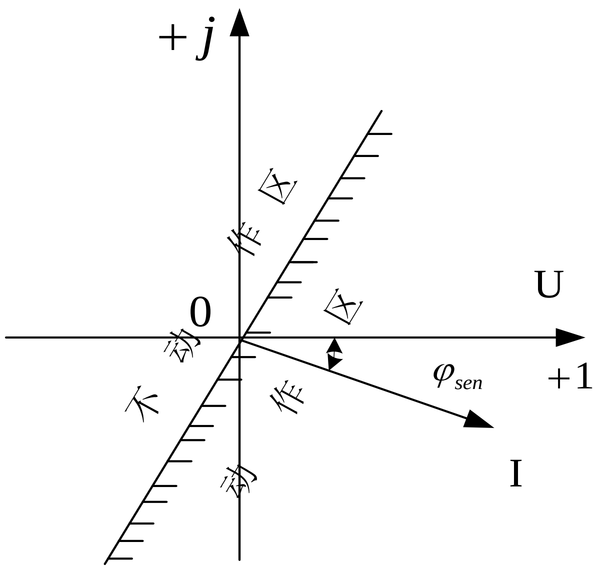
Directional Element for Power Flow

- When φ_k is in the range of $0^o \sim 90^o$ (in case of fault resistance), the protection should act reliably, the acting range of the directional element should be $\varphi_{sen} \pm 90^o$, which is a line in the complex plane:

$$90^o > \arg \frac{\dot{U}_r e^{-j\varphi_{sen}}}{\dot{I}_r} > -90^o \qquad \varphi_{sen} + 90^o > \arg \frac{\dot{U}_r}{\dot{I}_r} > \varphi_{sen} - 90^o$$

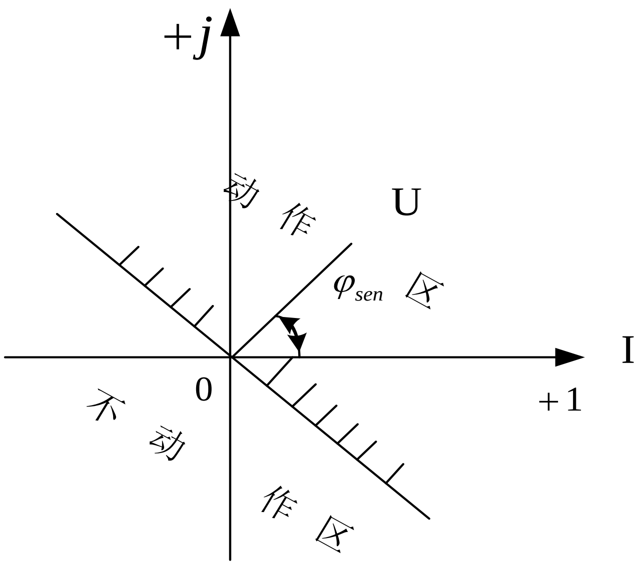
- This can also be written in terms of power: $U_r I_r \cos(\varphi_r - \varphi_{sen}) > 0$

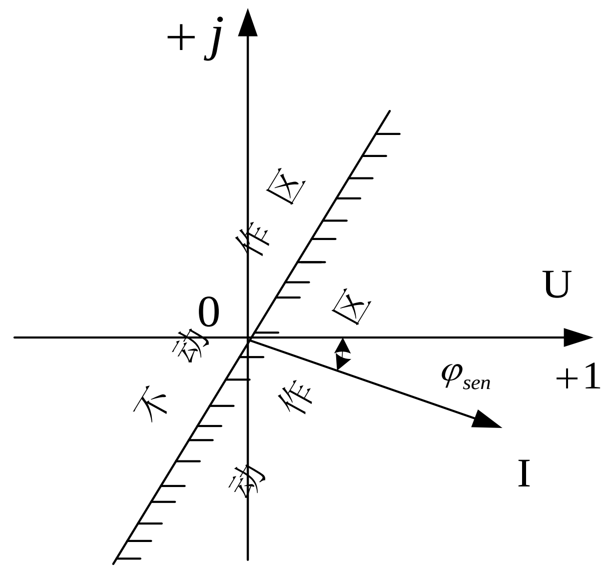




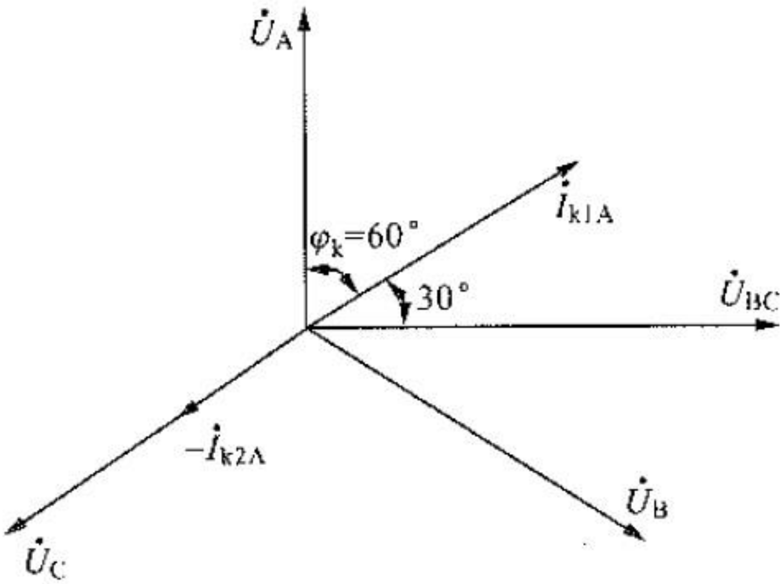
Directional Element for Power Flow

- If a fault much closed to the protection at positive direction, the voltage will be too low ($U_r \approx 0$) for the directional element to act. This is called as "dead zone".
- To solve this problem, the non-fault phase-to-phase voltage can be input as the reference voltage. Such as U_{BC} and I_A for phase A.





Directional Element for Power Flow



- With U_{BC} and I_A as input for phase A,
  $\varphi_{rA} = \arg(\dot{U}_{BC} / \dot{I}_A) = \varphi_k - 90^o$
  $\varphi_{sen} = \varphi_k$ -90º=-30º.
- The acting range can be written as:
  $$90^o > \arg \frac{\dot{U}_r e^{j(90^o - \varphi_k)}}{\dot{I}_r} > -90^o$$
- This can be written in terms of power:
  $$U_r I_r \cos(\varphi_r + \alpha) > 0$$
  $$U_{BC} I_A \cos(\varphi_r + \alpha) > 0$$
  $$\alpha = 90^o - \varphi_k$$
- For any unsymmetrical phase faults of A, U_{BC} will be high enough. This can significantly reduce dead zone and improve sensitivity. (Still dead zone for which case?)

Next Lecture

Overcurrent Protection 2

& Protection for Grounded Faults 1

Thanks for your attendance