EEE340 Protective Relaying

Lecture 7 – Protection for Grounded Faults 2

Today

- Types and Protection Principles for Grounded Faults
  - Zero sequence current directional protection

- Protection for Single Phase Ground Fault in the Neutral Indirectly Grounded Systems
  - Characteristics of single phase ground fault in the neutral ungrounded system
  - Characteristics of single line-to-ground fault in the system grounded via Petersen coil

Zero Sequence Current Directional Protection

- Direct grounding is normally applied for high voltage power transmission networks whose structures may have multiple power sources;

- The neutral points of transformers at power source side may often be grounded (at least one);

- Zero sequence currents flow from the fault location to grounded transformers, so direction would be an important factor to be considered for zero sequence current protection, similar to phase faults in networks with multiple power sources.

Zero Sequence Current Directional Protection

- Reference direction:

Zero sequence current: from bus to the protected line;
Zero sequence voltage: line is higher than ground;

- Zero sequence source only exists at the fault location;

- The real zero sequence current direction is from the fault location to the grounded neutral.

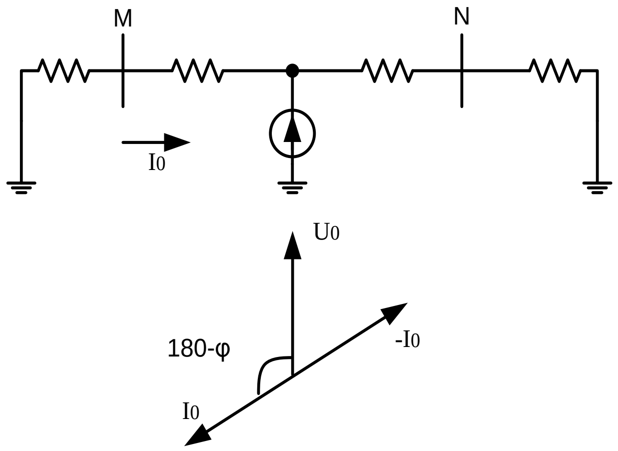
Zero Sequence Current Directional Protection

Analysis for phasors of zero sequence current and zero sequence voltage

Ground fault at positive direction:

The zero-sequence voltage lags the zero-sequence current by $180-\varphi_{k0}$

$$\arg\frac{\dot{U}_0}{\dot{I}_0}=\varphi_{k0}-180$$

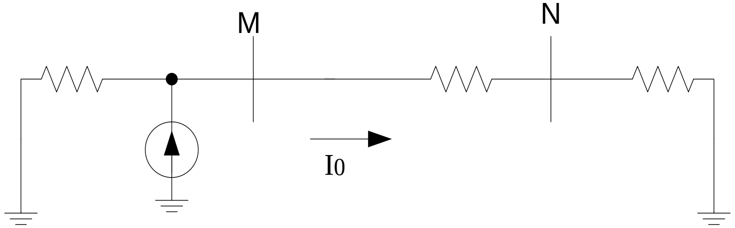


Zero Sequence Current Directional Protection

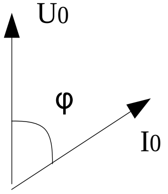
Analysis for phasors of zero sequence current and zero sequence voltage

Ground fault at opposite direction:

The zero-sequence voltage leads the zero-sequence current by φ_{k0}



$$\arg \frac{\dot{U}_0}{\dot{I}_0} = \varphi_{k0}$$



Zero Sequence Current Directional Protection

- As the zero sequence voltage would be higher for locations closer to the fault, zero sequence directional element has no dead zone;

- When the fault location is further from the protection, the zero sequence voltage would be lower, this may cause problem in sensitivity;

- When the zero sequence protection is backup for neighboring element (line), the minimum fault current, voltage and power for faults at the end of next line should be used to check the sensitivity of the directional relay:

$$K_{lm} > 1.5$$

Evaluation for Zero Sequence Current Protection

- Set by only avoiding unbalance current, the activating value is relatively lower and the sensitivity is better (zero sequence current at normal operation is zero);
- Zero sequence networks would be simpler than the normal networks, the levels for coordination may be less and operating speed may be faster;
- Less impacts from system operational modes because it mainly depends on grounding modes of neutral points;
- No dead zone for zero sequence directional element;
- Reliable protection for grounded faults.

Evaluation for Zero Sequence Current Protection

- For great change in system operational modes or grounding modes, requirement for sensitivity may not be met;
- During open-phase operation with system swing, possible large zero sequence current may influence the correct operation of protection;
- In case of autotransformer connecting two networks with different voltage levels, zero sequence fault current can induce zero sequence current in another side, this will make the coordination complicated;
- Widely applied in neutral point direct grounding networks at 110kV and higher voltage as main and backup protections.

Today

- Types and Protection Principles for Grounded Faults
  - Zero sequence current directional protection

- Protection for Single Phase Ground Fault in the Neutral Indirectly Grounded Systems
  - Characteristics of single phase ground fault in the neutral ungrounded system
  - Characteristics of single line-to-ground fault in the system grounded via Petersen coil

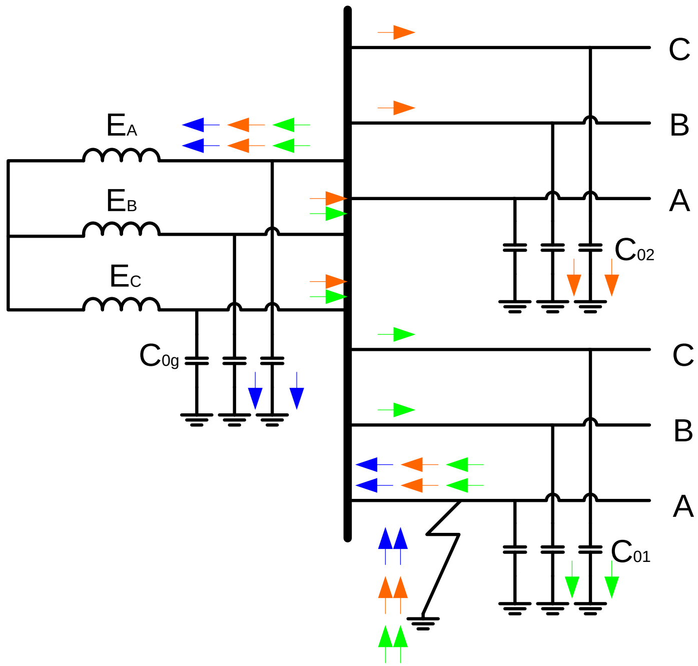
Characteristics of single line-to-ground fault in the neutral indirectly grounded system

- Fault current is relatively small;
- Line voltage between three phases is still symmetrical;
- No influence on power supply to loads;
- Voltage of non-faulted phase will be increased for $\sqrt{3}$ times;

Characteristics of single phase ground fault in the neutral indirectly grounded system

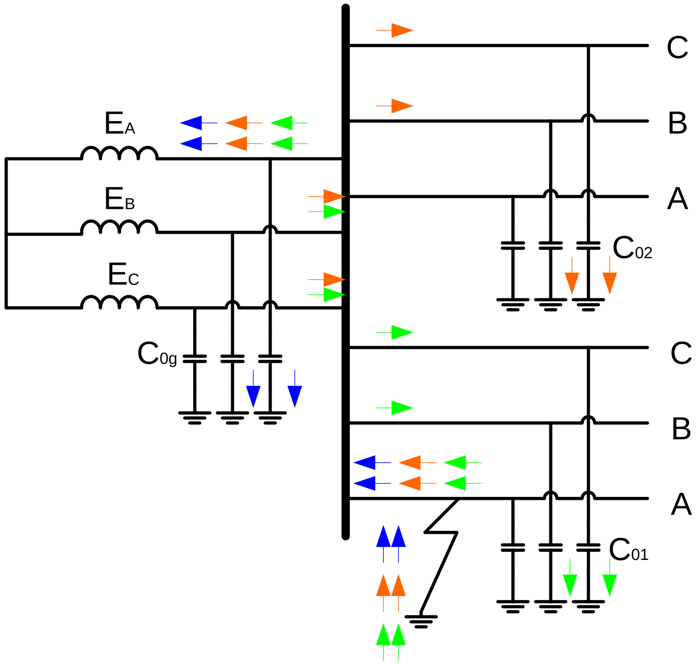
- For the neutral indirectly grounded system, it is permitted to keep operation under single line-to-ground fault for 1~2 hours;
- So high reliability for power supply is a key advantage of neutral indirectly grounded systems;
- For single line-to-ground faults of neutral indirectly grounded systems, it is only required to identify the faulted line and send out warning signal;
- But when it is dangerous for human and equipment, the protection should trip breakers.

Characteristics of single phase ground fault in the neutral ungrounded system



- Neutrals of power sources and loads are ungrounded;
- There are equal capacitance C_0 between each phase and ground;
- Capacitive current flow from each phase to ground, their sum (three phases) is zero;
- We neglect the voltage drop on lines caused by zero sequence or load current.

Characteristics of single phase ground fault in the neutral ungrounded system



- In case of single phase grounded fault at *k* of phase A:

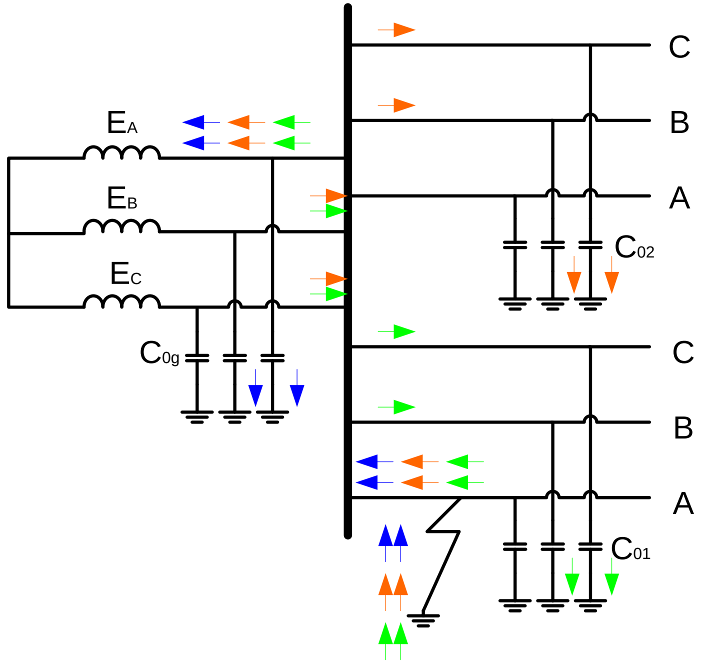
$$\dot{U}_{Ak} = 0$$

$$\dot{U}_{Bk} = \dot{E}_B - \dot{E}_A = \sqrt{3}\dot{E}_A e^{-j150°}$$

$$\dot{U}_{Ck} = \dot{E}_C - \dot{E}_A = \sqrt{3}\dot{E}_A e^{+j150°}$$

- Capacitive current of phase A to ground is zero since voltage of phase A is zero.

Characteristics of single phase ground fault in the neutral ungrounded system



- Zero sequence voltage at k :

$$\dot{U}_{k0} = \frac{1}{3}(\dot{U}_{Ak} + \dot{U}_{Bk} + \dot{U}_{Ck}) = -\dot{E}_A$$

- Capacitive current of non-faulted phases to ground:

$$\dot{I}_B = \dot{U}_{Bk} j\omega C_0$$

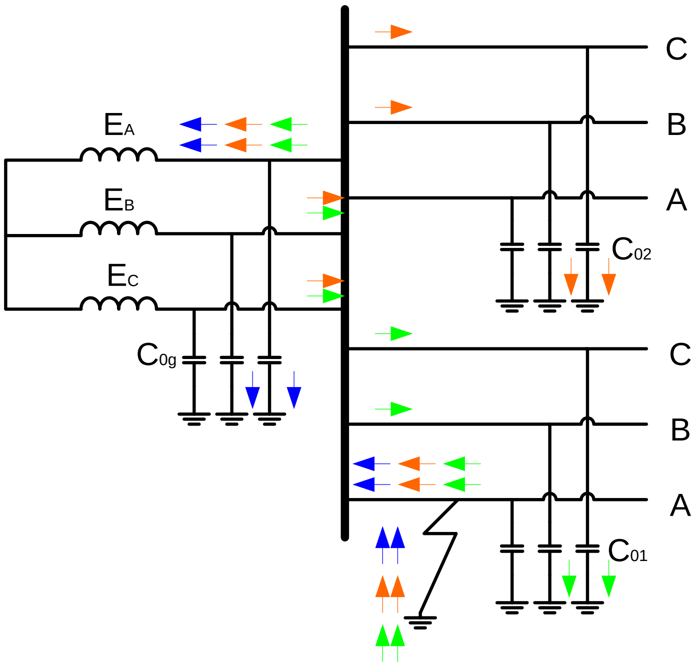
$$\dot{I}_C = \dot{U}_{Ck} j\omega C_0$$

- Corresponding RMS value:

$$I_B = I_C = \sqrt{3}U_{\varphi}\omega C_0$$

Characteristics of single phase ground fault in the neutral ungrounded system

- By neglecting voltage drop on line, the voltage of phase A for all system is zero.



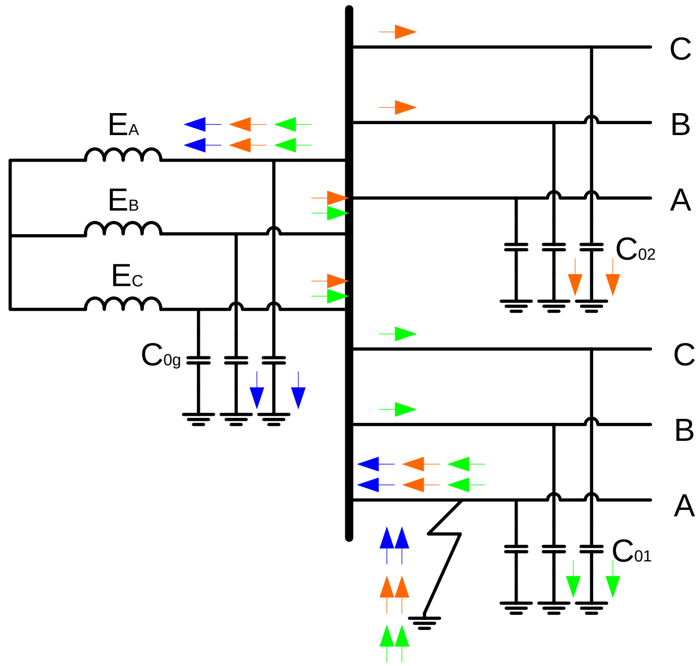
- For non-faulted line, the zero sequence current detected by protection is:

$$3I_0 = \dot{I}_B + \dot{I}_C = -3\dot{E}_A \cdot j\omega C_0$$

- The zero sequence current of non-faulted line is the sum of its own capacitive currents; the direction of capacitive reactive power is from bus to line.

Characteristics of single phase ground fault in the neutral ungrounded system

- For generator, it has its own capacitive current I_{BG} and I_{CG}.



- As power source, all capacitive currents from the fault location will flow back to phase A and out from B and C.

- The current detected at terminal is still the capacitive current of the generator:

$$3\dot{I}_{0G} = \dot{I}_{BG} + \dot{I}_{CG}$$

- The direction of capacitive reactive power is from bus to generator.

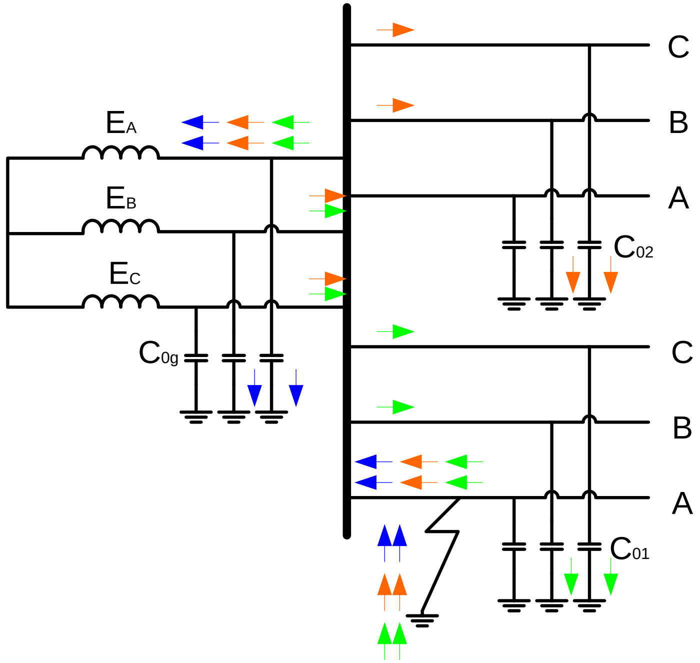
Characteristics of single phase ground fault in the neutral ungrounded system

- For faulted line, the current through the fault location of phase A is:

$$\dot{I}_k = \dot{I}_B + \dot{I}_C$$

- For faulted line, the zero sequence current detected by protection is:

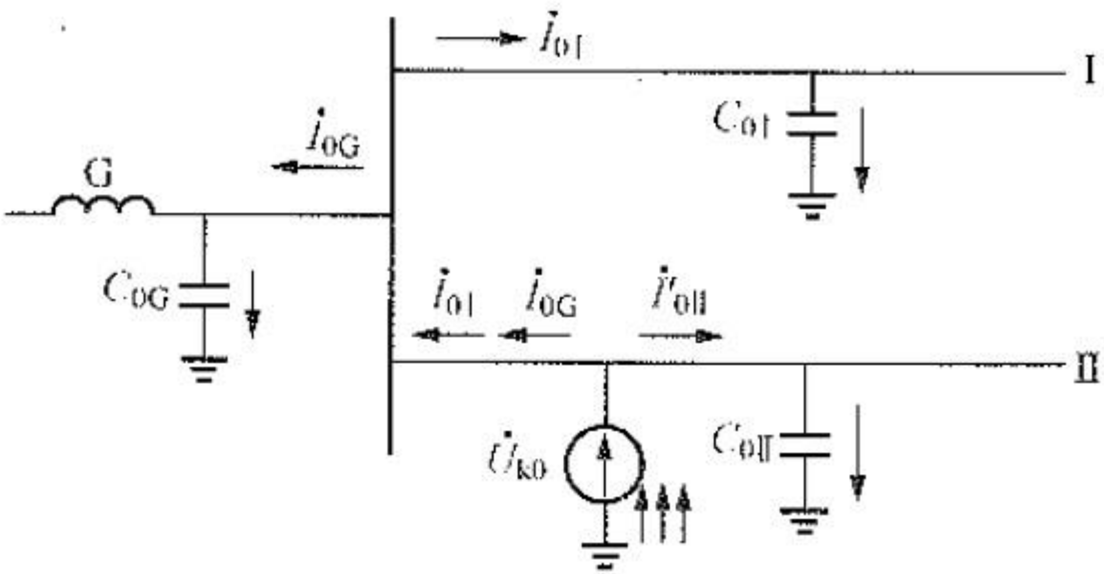
$$3I_0 = \dot{I}_B + \dot{I}_C = 3\dot{E}_A \cdot j\omega(C_{0\Sigma} - C_{01})$$



- The detected zero sequence current of faulted line is the sum of capacitive currents of all system minus the sum of its own capacitive currents; the direction of capacitive reactive power is from line to bus.

Equivalent Zero Sequence Network

- A zero sequence power source is applied at the grounding location.
- The circuit for zero sequence current is through distributed capacitance of each component.



Characteristics of single phase ground fault in the neutral ungrounded system

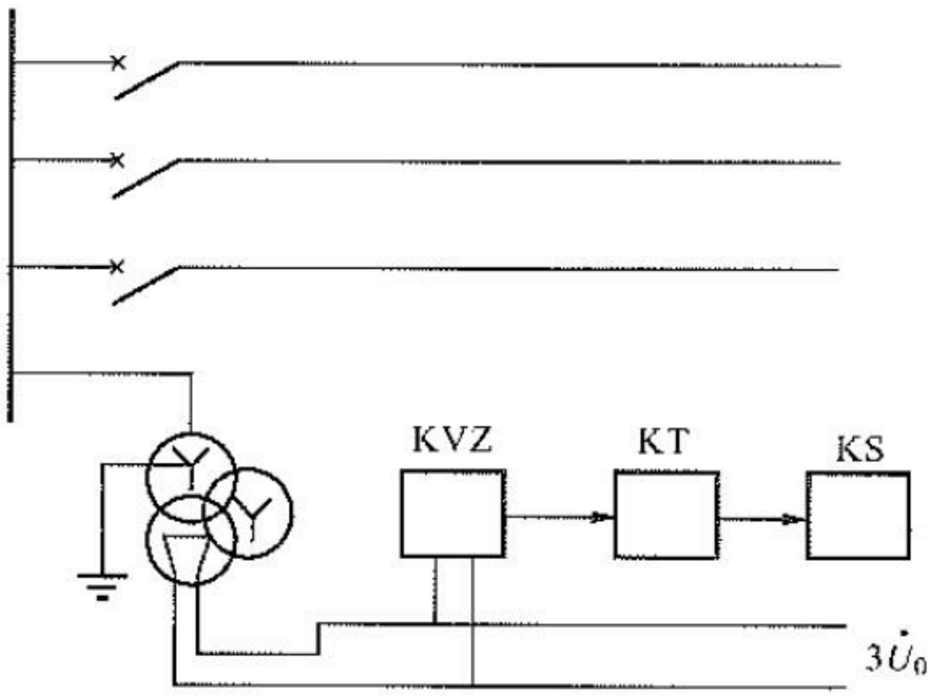
- Circuits of zero sequence are through capacitances of components to ground, the zero sequence impedance is much larger than the neutral directly grounded systems;

- For single line-to-ground fault, it is equivalent as a zero sequence voltage with the same magnitude but opposite direction of phase voltage before fault of the faulted phase;

- Zero sequence current through non-faulted components is equal to its own capacitive current to ground; the direction of capacitive reactive power is from bus to line.

- Zero sequence current through the faulted component is the sum of capacitive currents of the non-faulted components in the whole system; the direction of capacitive reactive power is from line to bus.

Zero Sequence Voltage Protection

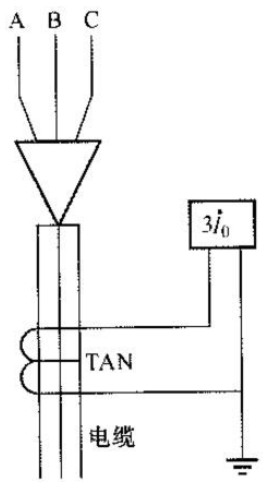


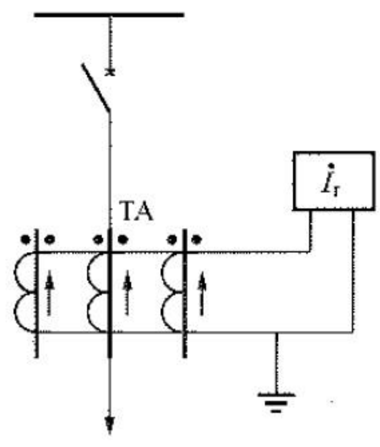
- In case of single line-to-ground fault, high zero sequence voltage will appear in the whole system of the same voltage level;
- An overvoltage relay is connected with the open Δ side of PT;
- To send out signal after time delay;
- No selectivity, to identify the faulted line, operators have to break and reclose each line one by one.

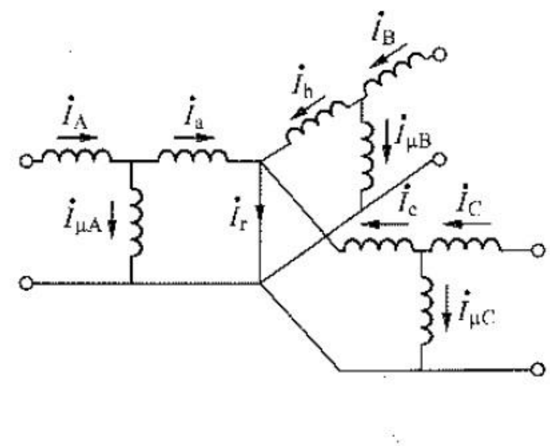
Zero Sequence Current Protection

- The zero sequence current of faulted line is larger than the non-faulted lines;

- This is normally applied where zero sequence current transformer can be installed (cable); or when the fault current is large enough to overcome the unbalanced current in zero sequence current filters, it can be connected in zero sequence circuits by three CT;







Zero Sequence Current Protection

- In case of single line-to-ground fault, zero sequence current of non-faulted line is equal to its own capacitive current to ground, to ensure selectivity:

$$I_{set} = K_{rel} 3U_{\varphi} \omega C_0$$

- To check sensitivity:

$$K_{sen} = \frac{3U_{\varphi}\omega(C_{\Sigma} - C_0)}{K_{rel} 3U_{\varphi} \omega C_0} = \frac{C_{\Sigma} - C_0}{K_{rel} C_0}$$

Minimum C_{Σ} should be used.

Zero Sequence Directional Power Protection

- Directions of zero sequence power is different for faulted and non-faulted lines;

- It is difficult to be applied to the system grounded via Petersen coil with over compensation;

- It is normally applied to systems where zero sequence current protection cannot meet the requirement of sensitivity or where network connection is complicated.

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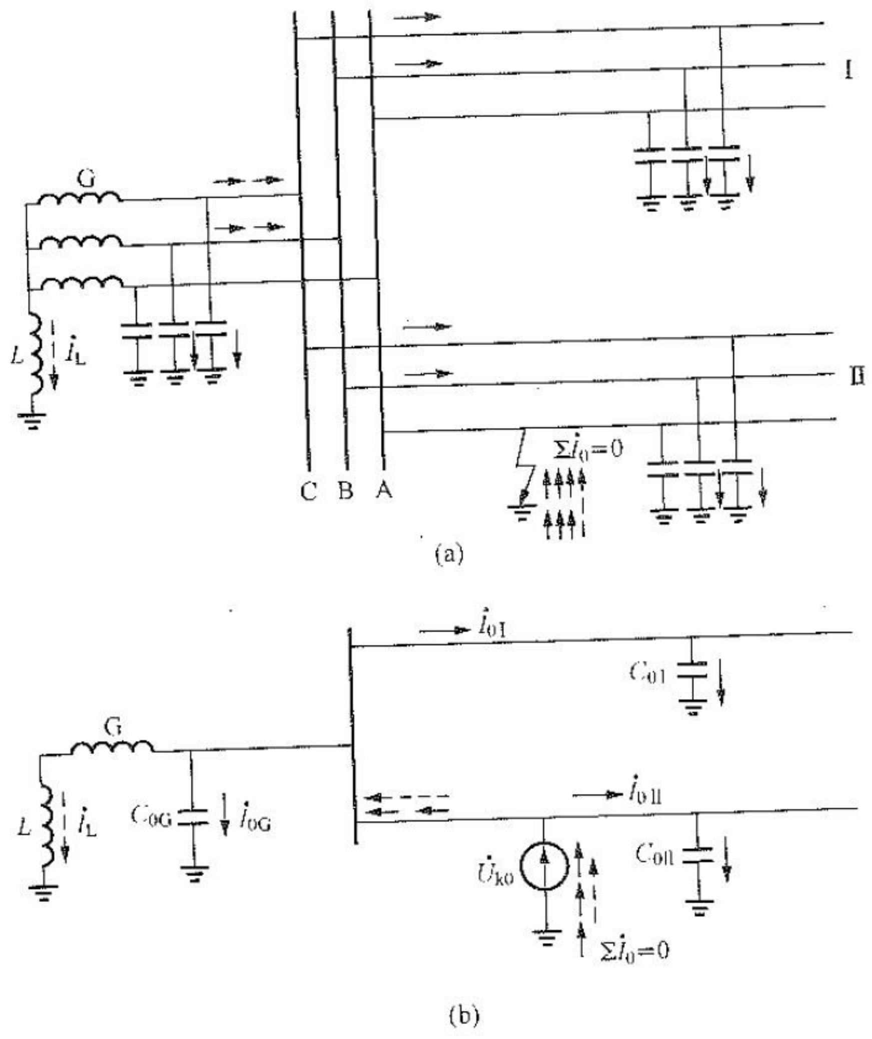
Characteristics of single line-to-ground fault in the system grounded via Petersen coil

- In case of single line-to-ground fault, all capacitive currents of the whole system will flow through the grounded location;
- If this current is much large, electric arc will be caused at the grounded location, which is dangerous for human and devices;
- To solve this problem, a coil (Petersen coil) can be connected to the neutral, which will make inductive current to counteract the system capacitive current.
- Current through the fault location can be significantly reduced and the arc can be suppressed, so it can also be called as arc-suppression coil.

Characteristics of single line-to-ground fault in the system grounded via Petersen coil



- Distribution of capacitive currents is same as in ungrounded system;
- Additional inductive current appears due to the Petersen coil;
- The total current through faulted location is:

$$\dot{I}_k = \dot{I}_L + \dot{I}_{C\Sigma}$$

Compensation of Petersen coil

- Complete compensation: $I_L = I_{C\Sigma}$, the current at fault location is almost zero; series resonance may happen and increase the neutral voltage to ground.

- Under compensation: $I_L < I_{C\Sigma}$, the current at fault location is still capacitive; if some component is cut due to faults or operational mode, capacitive current will be reduced and series resonance may also happen.

- Over compensation: $I_L > I_{C\Sigma}$, the current at fault location is inductive; no series resonance may happen. This is widely applied.

$$P = \frac{I_L - I_{C\Sigma}}{I_{C\Sigma}}$$

Protection for Single line-to-ground Fault in Systems Grounded via Petersen Coil

- Compensation makes the fault characteristics not obvious for detection (magnitude and direction of zero sequence current).

Possible solutions:

- To detect the zero sequence voltage after fault, just like ungrounded systems.
- To utilize the characteristics of transient process at the beginning of single line-to-ground fault.
- To utilize the active power losses of Petersen coil:

$$P_{act} = 0.5P_L$$

For faulted line: $P_0 > P_{act}$

For non-faulted line: $P_0 \le (0.2 \sim 0.3)P_{act}$

Next Lecture

Distance Protection 1

Thanks for your attendance