EEE340 Protective Relaying

Lecture 8 – Distance Protection 1

Today

- Distance Protection
  - Principles of Distance Protection
  - Connection of Impedance Relay
  - Elements and Time Coordination

Principles of Distance Protection

- Defects of overcurrent protection:

Low sensitivity;
Impacts from operating modes;
Difficult for coordination;

- Problem:

It is difficult to meet the requirements of speed, selectivity and sensitivity for high voltage networks (higher than 35kV).

Principles of Distance Protection

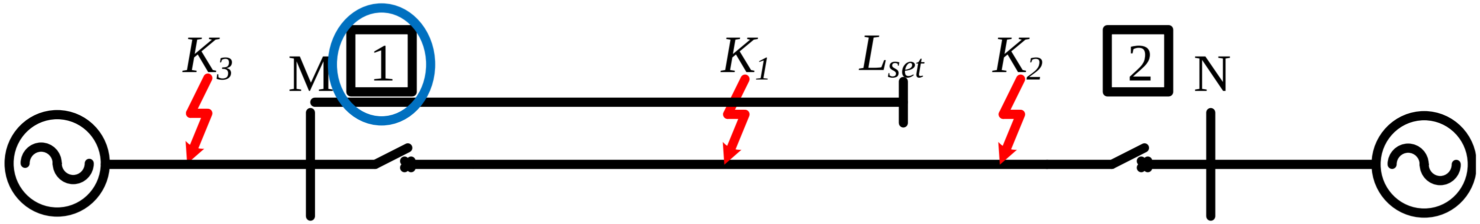
- Characteristics of faults:

Currents increase during faults;
Voltages decrease during faults;

- Idea: $$Z_m = \frac{\dot{U}_m}{\dot{I}_m} = Z_1 l_k$$

If the characteristics of current and voltage can be integrated, the sensitivity can be improved.
So the impedance as the ratio between voltage and current can be considered as new characteristic of fault.

Principles of Distance Protection



$$Z_m = \frac{\dot{U}_m}{\dot{I}_m} = |Z_m| \angle \phi_m$$

- Inside protected zone:

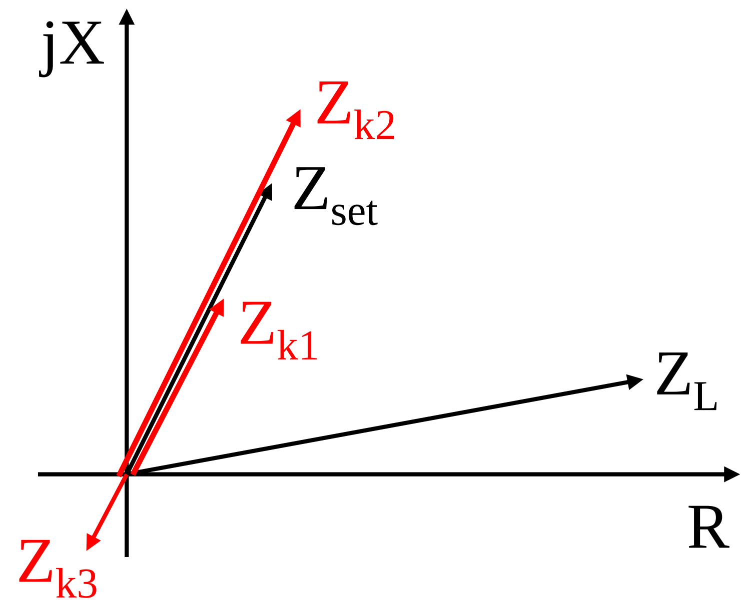
$$|Z_m| < Z_{set}$$

- Outside protected zone:

$$|Z_m| > Z_{set}$$

- Opposite direction:

$$\phi_m \notin (0^o, 90^o)$$



Principles of Distance Protection

$$Z_{set} = z_1 L_{set}$$

z_1 is the impedance for unit length of line.

- The measured impedance in fault circuit is proportional to the length from the fault location to where protection is installed;
- To compare L_k and L_{set} by comparing Z_m and Z_{set} to judge if a fault has happened and is inside the protected zone;
- To compare the phase angle to judge if the fault is at the positive or opposite direction;
- Coordination in terms of zones is necessary because the faults at the end of this line and the beginning of next line are difficult to be distinguished.

Today

- Distance Protection
  - Principles of Distance Protection
  - Connection of Impedance Relay
  - Elements and Time Coordination

Connection of Impedance Relay

○ For single phase system:

U_m is just the voltage at installed location;

I_m is just the current of the protected component;

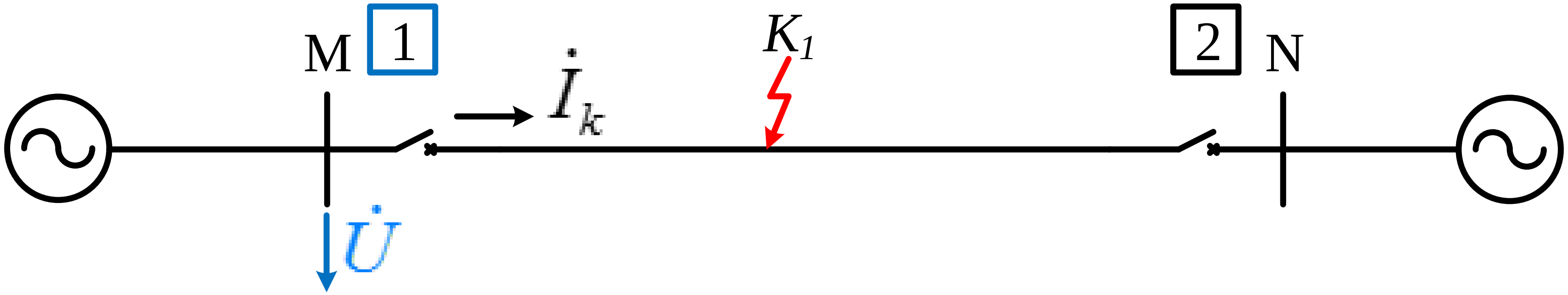
$$\dot{U}_m = \dot{I}_m Z_m = \dot{I}_m Z_k = \dot{I}_m z_1 L_k$$

The measurement of voltage and current should have this form of relation so that the corresponding impedance can be proportional to the fault distance.

○ For three-phase system:

For different types of faults, the voltage and current of each phase may not directly meet the above-mentioned form. Specific measurements of voltage and current need to be identified for this form.

Connection of Impedance Relay



$$\dot{U}_{\varphi} = \dot{U}_{\varphi 1} + \dot{U}_{\varphi 2} + \dot{U}_{\varphi 0}$$

$$= (\dot{U}_{K1} + \dot{I}_1 z_1 l_k) + (\dot{U}_{K2} + \dot{I}_2 z_2 l_k) + (\dot{U}_{K0} + \dot{I}_0 z_0 l_k)$$

$$= \dot{U}_{K\varphi} + \underline{\dot{I}_1 z_1 l_k + \dot{I}_2 z_1 l_k + \dot{I}_0 z_1 l_k} - \dot{I}_0 z_1 l_k + \dot{I}_0 z_0 l_k$$

$$= \dot{U}_{K\varphi} + \left[\dot{I}_{\varphi} + 3\dot{I}_0 \frac{z_0 - z_1}{3z_1} \right] z_1 l_k$$

$$= \dot{U}_{K\varphi} + \left[\dot{I}_{\varphi} + K \times 3\dot{I}_0 \right] z_1 l_k \qquad \varphi : A, B, C$$

Connection of Impedance Relay

Connections for phase faults:

$$\dot{U}_{\phi\phi} = \dot{U}_{K\phi\phi} + \dot{I}_{\phi\phi} z_1 l_k$$

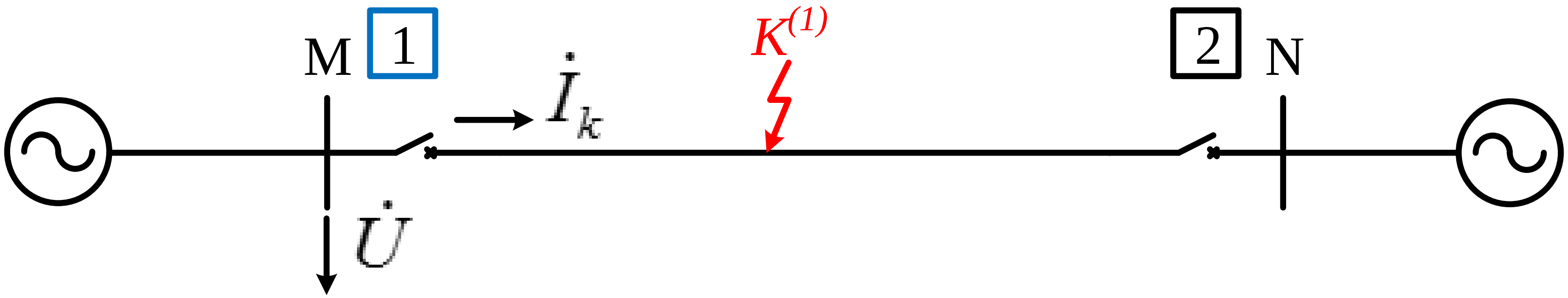
$\dot{U}_m$	$\dot{I}_m$
$\dot{U}_{AB}$	$\dot{I}_{AB}$
$\dot{U}_{BC}$	$\dot{I}_{BC}$
$\dot{U}_{CA}$	$\dot{I}_{CA}$

Connections for grounded faults:

$$\dot{U}_{\varphi} = \dot{U}_{K\varphi} + (\dot{I}_{\varphi} + K \cdot 3\dot{I}_0) z_1 l_k$$

$\dot{U}_m$	$\dot{I}_m$
$\dot{U}_A$	$\dot{I}_A + K \cdot 3I_0$
$\dot{U}_B$	$\dot{I}_B + K \cdot 3I_0$
$\dot{U}_C$	$\dot{I}_C + K \cdot 3I_0$

Connections for grounded faults: Single Line-to-Ground Fault



$$\dot{U}_{\varphi} = \dot{U}_{k\varphi} + (\dot{I}_{\varphi} + K \cdot 3\dot{I}_0) \cdot z_1 l_k$$

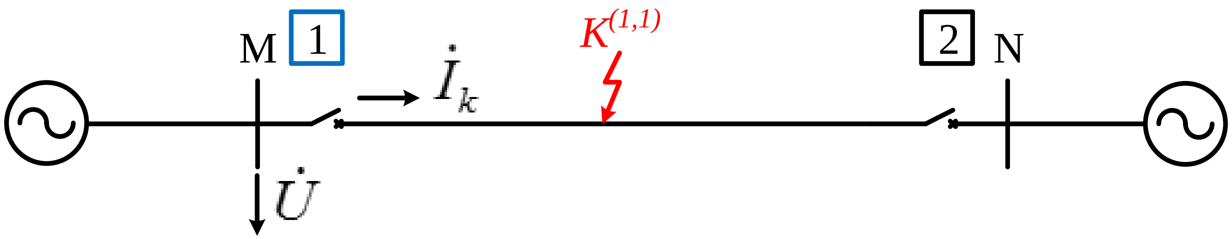
$$\dot{U}_A = \underbrace{\dot{U}_{kA}}_{=0} + (\dot{I}_A + K \cdot 3\dot{I}_0) \cdot z_1 l_k$$

$$Z_m = \frac{\dot{U}_m}{\dot{I}_m} = \frac{\dot{U}_A}{\dot{I}_A + K \cdot 3\dot{I}_0} = z_1 l_k$$

The impedance measured for Phase B and C may be closed to load impedance, because their voltage and current are closed to normal states, so their relay will not trip.

$\therefore\ Z_m \propto l_k$ The impedance relay of the faulted phase can trip.

Connections for grounded faults: Double Line-to-Ground Fault



Fault at phase B-C as example

$$\dot{U}_\varphi = \dot{U}_{k\varphi} + (\dot{I}_\varphi + K \cdot 3\dot{I}_0) \cdot z_1 l_k$$

$$\dot{U}_B = \overset{=0}{\dot{U}_{kB}} + (\dot{I}_B + K \cdot 3\dot{I}_0) \cdot z_1 l_k$$

$$\dot{U}_C = \overset{=0}{\dot{U}_{kC}} + (\dot{I}_C + K \cdot 3\dot{I}_0) \cdot z_1 l_k$$

$$Z_m = \frac{\dot{U}_m}{\dot{I}_m} = \frac{\dot{U}_\varphi}{\dot{I}_\varphi + K \cdot 3\dot{I}_0} = z_1 l_k$$

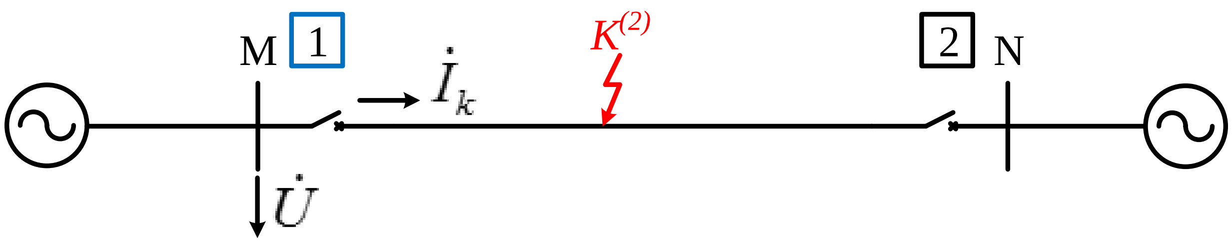
$\varphi : B, C$

$\therefore \; Z_m \propto \; l_k$

The impedance measured for phase A would be higher than the setting value, because its voltage and current are closed to normal states, so its relay will not trip.

The impedance relay of the faulted phases B and C can trip.

Connections for grounded faults: Line-To-Line Fault



Fault at phase B-C as example

$$\dot{U}_{\varphi} = \dot{U}_{k\varphi} + (\dot{I}_{\varphi} + K \cdot 3\dot{I}_0) \cdot z_1 l_k$$

$$\neq 0$$

$$\dot{U}_{B} = \dot{U}_{kB} + (\dot{I}_{B} + K \cdot 3\dot{I}_0) \cdot z_1 l_k$$

$$\neq 0$$

$$\dot{U}_{C} = \dot{U}_{kC} + (\dot{I}_{C} + K \cdot 3\dot{I}_0) \cdot z_1 l_k$$

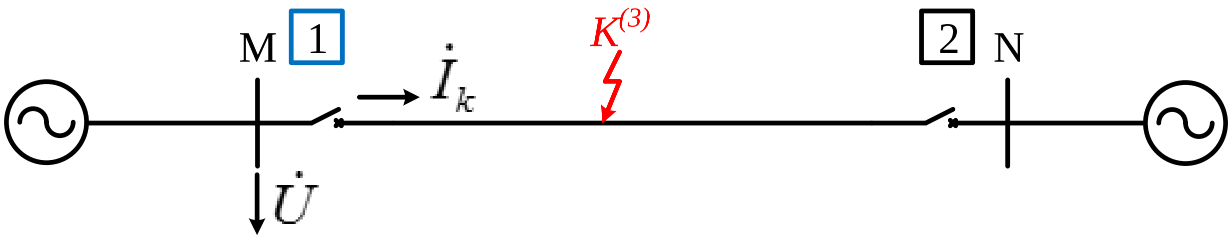
$$\neq 0$$

$$Z_m = \frac{\dot{U}_m}{\dot{I}_m} = \frac{\dot{U}_{\varphi}}{\dot{I}_{\varphi} + K \cdot 3\dot{I}_0} = z_1 l_k + \frac{\dot{U}_{K\varphi}}{\dot{I}_{\varphi} + K \cdot 3\dot{I}_0}$$

$\varphi : B, C$

$\therefore\ Z_m \not\propto l_k$ The measurement cannot indicate the distance of fault.

Connections for grounded faults: Three phase short-circuit



$$\dot{U}_A = \underbrace{\dot{U}_{kA}}^{=0} + (\dot{I}_A + K \cdot 3\dot{I}_0) \cdot z_1 l_k$$

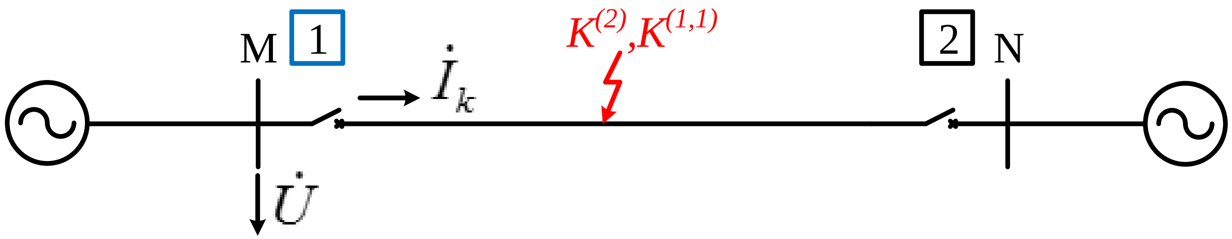
$$\dot{U}_B = \overbrace{\dot{U}_{kB}}^{=0} + (\dot{I}_B + K \cdot 3\dot{I}_0) \cdot z_1 l_k$$

$$\dot{U}_C = \overbrace{\dot{U}_{kC}}^{=0} + (\dot{I}_C + K \cdot 3\dot{I}_0) \cdot z_1 l_k$$

$$Z_m = \frac{\dot{U}_m}{\dot{I}_m} = \frac{\dot{U}_\varphi}{\dot{I}_\varphi + K \cdot 3\dot{I}_0} = z_1 l_k \qquad \varphi : A, B, C$$

$\therefore \; Z_m = z_1 l_k \; \propto \; l_k$ Impedance relay of all phases can trip.

Connections for phase faults: Double Line-to-Ground Fault, Line-to-Line Fault



Fault at phase B-C as example

$$\dot{U}_{\varphi} = \dot{U}_{k\varphi} + (\dot{I}_{\varphi} + K \cdot 3\dot{I}_0) \cdot z_1 l_k$$

$$\dot{U}_B = \overset{=0}{\dot{U}_{kB}} + (\dot{I}_B + K \cdot 3\dot{I}_0) \cdot z_1 l_k$$

$$\dot{U}_C = \overset{=0}{\dot{U}_{kC}} + (\dot{I}_C + K \cdot 3\dot{I}_0) \cdot z_1 l_k$$

$$\dot{U}_B - \dot{U}_C = (\dot{I}_B - \dot{I}_C) \times z_1 l_k$$

$$\dot{U}_{mBC} = \dot{U}_B - \dot{U}_C$$

$$\dot{I}_{mBC} = \dot{I}_B - \dot{I}_C$$

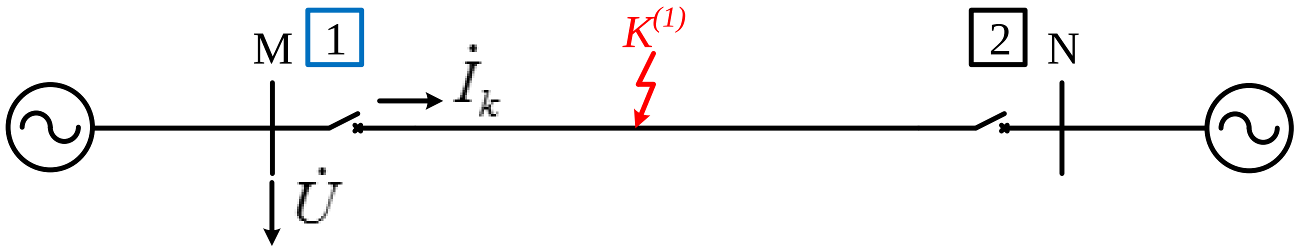
$$Z_m = \frac{\dot{U}_m}{\dot{I}_m} = \frac{\dot{U}_{BC}}{\dot{I}_{BC}} = z_1 l_k$$

The impedance relays of phase A-B and C-A may not trip because non-faulted phase A.

$$\therefore \; Z_m \propto l_k$$

The impedance relay of phase B-C can trip.

Connections for phase faults: Single Line-to-Ground Fault



$$\dot{U}_{\varphi} = \dot{U}_{k\varphi} + (\dot{I}_{\varphi} + K \cdot 3\dot{I}_0) \cdot z_1 l_k$$

$$\dot{U}_A = \dot{U}_{kA} + (\dot{I}_A + K \cdot 3\dot{I}_0) \cdot z_1 l_k$$

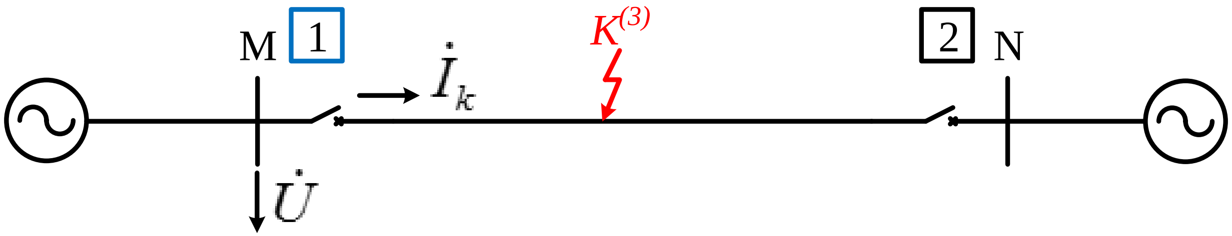
$$\dot{U}_B = \dot{U}_{kB} + (\dot{I}_B + K \cdot 3\dot{I}_0) \cdot z_1 l_k$$

No impedance relay can indicate the fault distance and may not trip.

$$\dot{U}_A - \dot{U}_B = (\underbrace{\dot{U}_{kA}}_{=0} - \underbrace{\dot{U}_{KB}}_{\neq 0}) + (\dot{I}_A - \dot{I}_B) \times z_1 l_k$$

$$Z_m = \frac{\dot{U}_m}{\dot{I}_m} = \frac{\dot{U}_{AB}}{\dot{I}_{AB}} = z_1 l_k + \frac{\dot{U}_{KAB}}{\dot{I}_{AB}} \qquad |Z_m| > |z_1 l_k|$$

Connections for phase faults: Three phase short-circuit



$$\dot{U}_{AB} = \underbrace{\dot{U}_{kAB}}_{=0} + \dot{I}_{AB} z_1 l_k$$

The same relation for phases B-C and phases C-A.

$$Z_m = \frac{\dot{U}_m}{\dot{I}_m} = \frac{\dot{U}_{AB}}{\dot{I}_{AB}} = z_1 l_k$$

$$\therefore \ Z_m \propto \ l_k$$

All impedance relay of all phases can trip.

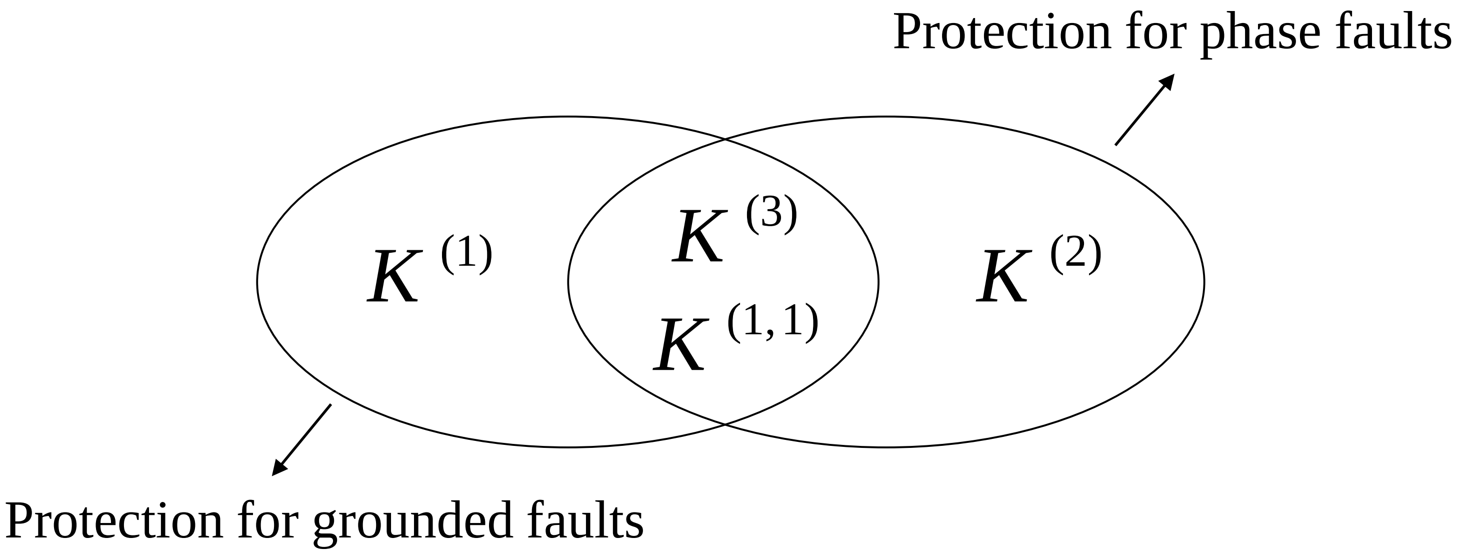
Fault Loop

- A fault loop is a circuit loop that the fault current flows through;
- For single line-to-ground faults, there is a fault loop between the faulted phase and ground (phase-to-ground fault loop);
- For double line-to-ground faults, there are fault loops between the two faulted phases and ground (phase-to-ground fault loop), also a fault loop between the two faulted phases (phase-to-phase fault loop);
- For line-to-line faults, there is a fault loop between the two faulted phases (phase-to-phase fault loop);
- For three-phase short circuit, there are three fault loops between each faulted phase and ground (phase-to-ground fault loop), and three fault loops between any two faulted phases(phase-to-phase fault loop).

Summary

- Only the current and voltage related to fault circuit or fault loop can be used to measure the distance of fault. Different connections of impedance relay may take different voltage and current as input;
- If phase-to-phase fault loop exists, the difference of voltage and current between these two phases can be used to indicate the distance of fault, which is called as distance protection for phase faults;
- If phase-to-ground fault loop exists, the phase voltage and the phase current compensated by zero sequence can indicate the distance of fault, called as distance protection for grounded faults;
- Distance protections for phase faults and grounded faults need to be installed; any impedance relay connected in any fault loop can be used for measurement of fault distance.

Summary



Impedance relay in phase-to-ground fault loop:

$$\dot{U}_{\varphi} = \dot{U}_{K\varphi} + (\dot{I}_{\varphi} + K \cdot 3\dot{I}_{0}) z_1 l_k$$

Impedance relay in phase-to-phase fault loop:

$$\dot{U}_{\varphi\varphi} = \dot{U}_{K\varphi\varphi} + \dot{I}_{\varphi\varphi} z_1 l_k$$

Summary

Connection / Fault type		Connection for Grounded faults			Connection for phase faults		
		A	B	C	AB	BC	CA
Single line-to-ground	A	+	-	-	-	-	-
	B	-	+	-	-	-	-
	C	-	-	+	-	-	-
Double line-to-ground	AB	+	+	-	+	-	-
	BC	-	+	+	-	+	-
	CA	+	-	+	-	-	+
Line-to-line	AB	-	-	-	+	-	-
	BC	-	-	-	-	+	-
	CA	-	-	-	-	-	+
Three - phase	ABC	+	+	+	+	+	+

Today

- Distance Protection
  - Principles of Distance Protection
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  - Elements and Time Coordination

Elements of Distance Protection

- Starting unit: to detect if a fault has happened and activate the whole protection device, but doesn't judge if the fault is inside the protected zone; enough sensitivity in case of fault at the end of protected zone as remote backup protection.
- Measuring unit: impedance relay to measure impedance and compare with presetting range to judge if the fault is inside (software in digital protection);
- Power swing blocking: to block the protection device during power swing to avoid false tripping;
- Detection for PT disconnection: block the protection device during PT disconnection to avoid false tripping;
- Coordination: to make coordination among different units of device and among three protection zones;
- Output: to trip the breaker or send out corresponding signal.

Time Coordination of Distance Protection

- As the value of impedance is continuous, distance protection cannot distinguish a fault at the end of this line and at the beginning of the next line, three protection zones are still necessary to ensure selectivity.
- Zone I has no time delay and protects about 85% of the whole line;
- Zone II has definite time delay which is normally 0.3~0.6s and the protected zone should not exceed the protected zone of zone I for the next line;
- Zone I + Zone II construct the main protection for lines.
- The time delay of zone III needs to coordinate with zone II or zone III of the neighboring line by adding time delay Δt.

Next Lecture

Thanks for your attendance