EEE340 Protective Relaying

Lecture 18 – Generator Protection 1

Today

- Generator Protection 1
    - Classification of Generator Protection
    - Longitudinal Differential Protection for Stator Winding

Faults of Generator

A generator is composed of stator and rotor.

Faults of stator

- Phase-to-phase fault of stator winding;
- Grounded faults of stator winding;
- Turn-to-turn faults of stator winding.

Faults of rotor

- Single or second ground fault of field;
- Field underexcitation or loss of excitation.

Abnormal Operation of Generator

- Stator overcurrent caused by external faults;
- Symmetrical overload of three phases;
- Negative sequence overcurrent caused by external unsymmetrical faults or unsymmetrical loads;
- Overvoltage of stator winding caused by load shedding;
- Overload of rotor winding;
- Reverse power operation of generator;
- Loss of synchronism: out of step.

Configuration of Generator Protection

Principle: the protections should be equipped to generators based on fault types, abnormal operation and according to capacity, extent of importance and regulations.

- Current differential protection;
- Protection for turn-to-turn faults;
- Turn-to-turn faults of stator winding;
- Protection for stator ground faults;
- Negative-sequence current protection;
- Overcurrent protection for external faults;
- Overload protection;
- Overvoltage protection for stator winding;
- Protection for single ground of field winding;
- Overload protection for field winding;
- Protection for loss of excitation;
- Protection for reverse-power, overexcitation, out of step, low frequency……

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  - Classification of Generator Protection
  - Longitudinal Differential Protection for Stator Winding
  - Transverse Differential Protection
  - Protection for Generator Stator Single Phase Earth Fault

Longitudinal Differential Protection for Stator Winding

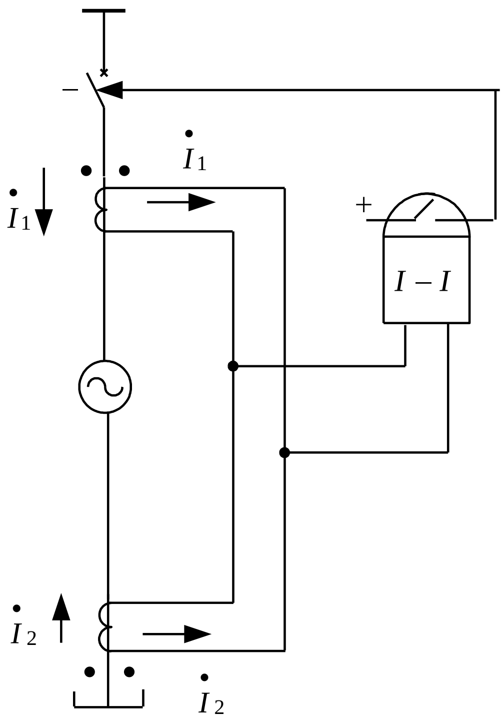
- Longitudinal differential protection is the main protection for phase-to-phase faults of stator winding;

- Its principle is the same as other differential protection;

- Differential protection with restraint characteristic is often applied;

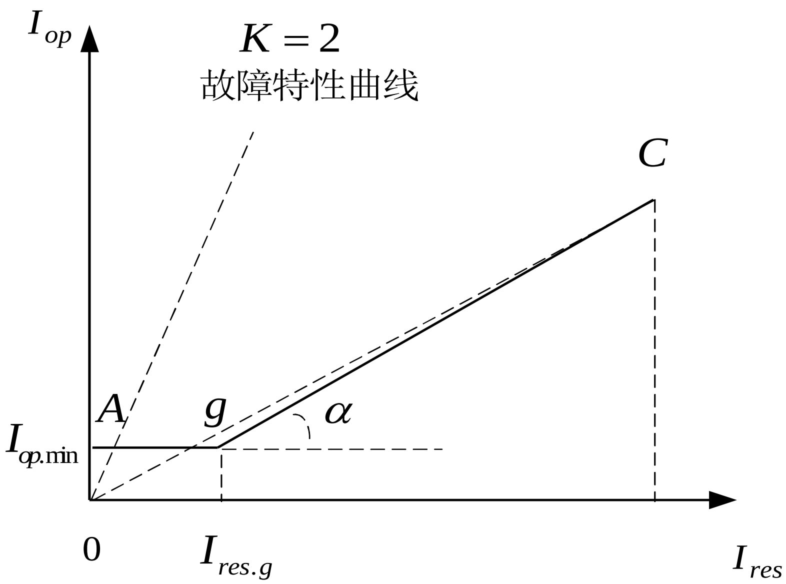
$$I_{res} = \left| \frac{I_1^{'} - I_2^{'}}{2} \right|$$

Longitudinal Differential Protection for Stator Winding



Take one phase as example;
Positive direction is to flow into the generator;
For normal operation and external faults, the differential current should be zero;
For internal faults, the differential current would be huge and the differential relay should trip the breakers;
To avoid the maximum unbalance current, the setting value would be relatively large and reduce the sensitivity of the protection, so restraint characteristic would be more appropriate.

Longitudinal Differential Protection for Stator Winding



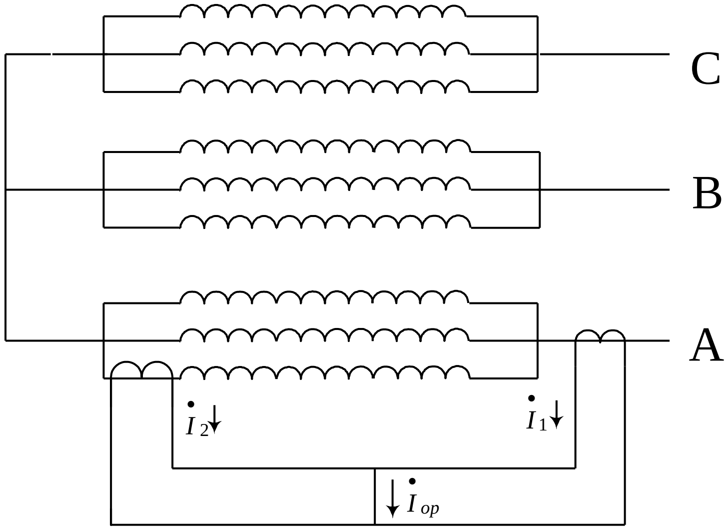
Percentage Restraint:

$$I_d = \left| \dot{I}_1^{'} + \dot{I}_2^{'} \right| \qquad I_{res} = \left| \frac{\dot{I}_1^{'} - \dot{I}_2^{'}}{2} \right|$$

Operating Equation:

$$\begin{cases} I_d > K(I_{res} - I_{res.\min}) + I_{d.\min},\ I_{res} > I_{res.\min} \\ I_d > I_{d.\min},\ I_{res} \le I_{res.\min} \end{cases}$$

Incomplete Longitudinal Differential Protection



For turn-to-turn fault in the same phase, the differential current from the complete phase is still zero, protection cannot operate.

At the side of neutral point, only take the current of a parallel branch and select TA appropriately, the differential current at normal operation can still be zero.

For internal phase-to-phase or turn-to-turn faults, the differential current will be enough to trip the protection.

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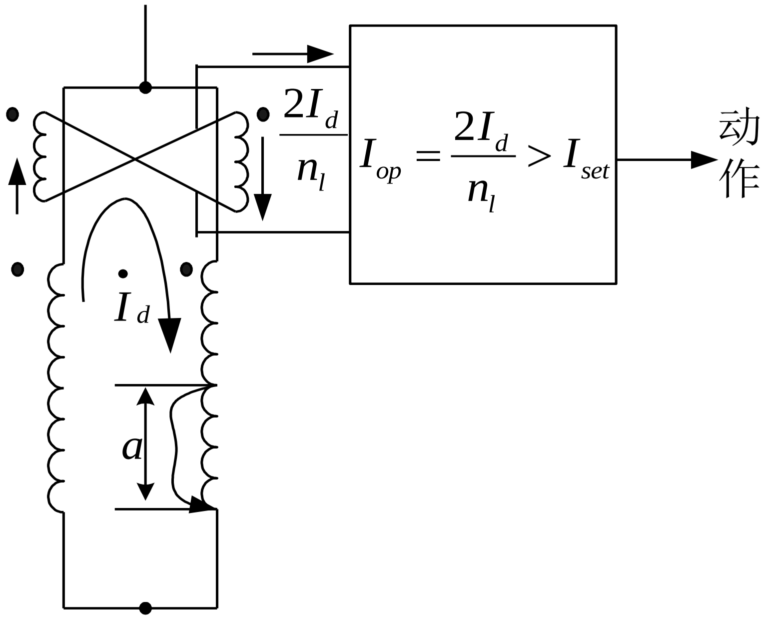
Transverse Differential Protection

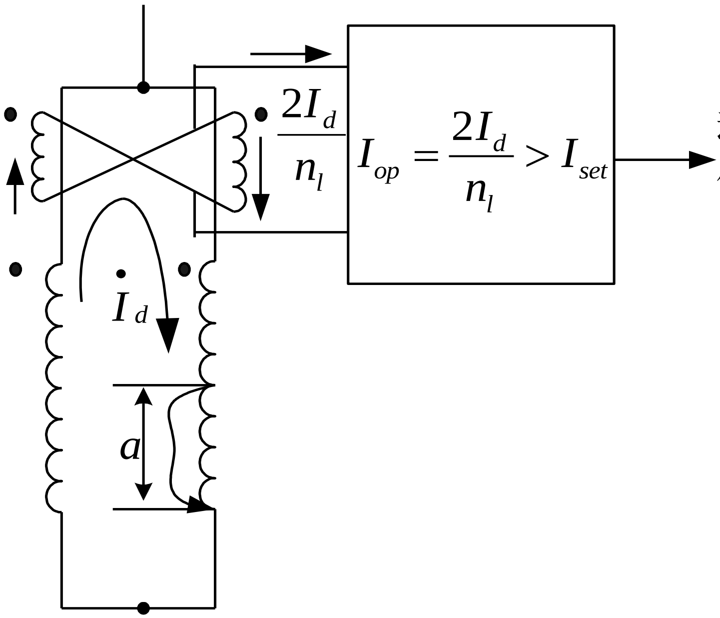


For generators of large capacity, the winding of each phase may be composed of several branches in parallel.

During normal operation, each branch has same EMF and equal load currents.

In case of turn-to-turn short circuit in the same phase, the EMF of each winding may not be equal and circulating current may be caused by this EMF difference.

Transverse Differential Protection



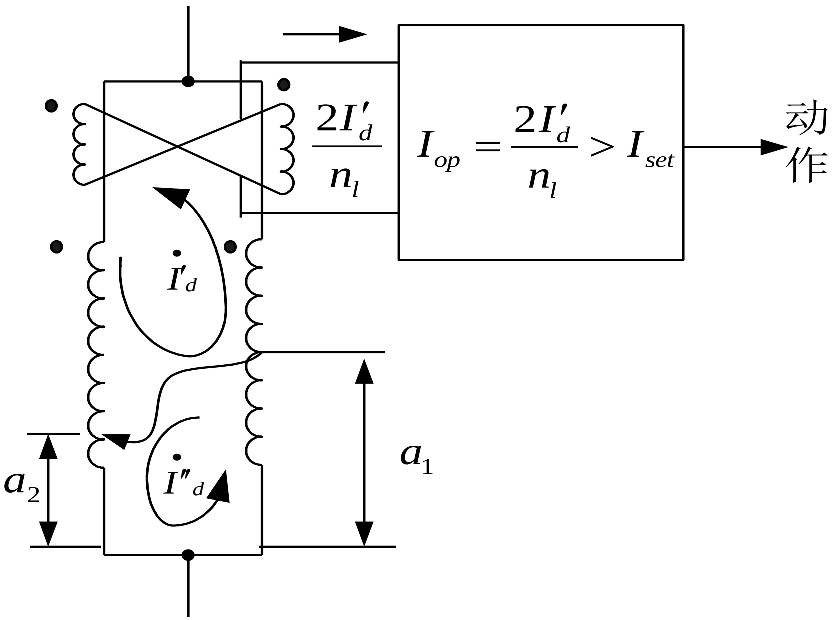
If the circulating current is I_d, then the differential current in differential relay is:

$$I_{op} = \frac{2I_d}{n_l}$$

When this differential current is larger then the setting value, the protection will trip.

But if the faulted part α of winding is too small, the circulating current may also be too small compared with the setting value, the protection may have dead zone.

Transverse Differential Protection

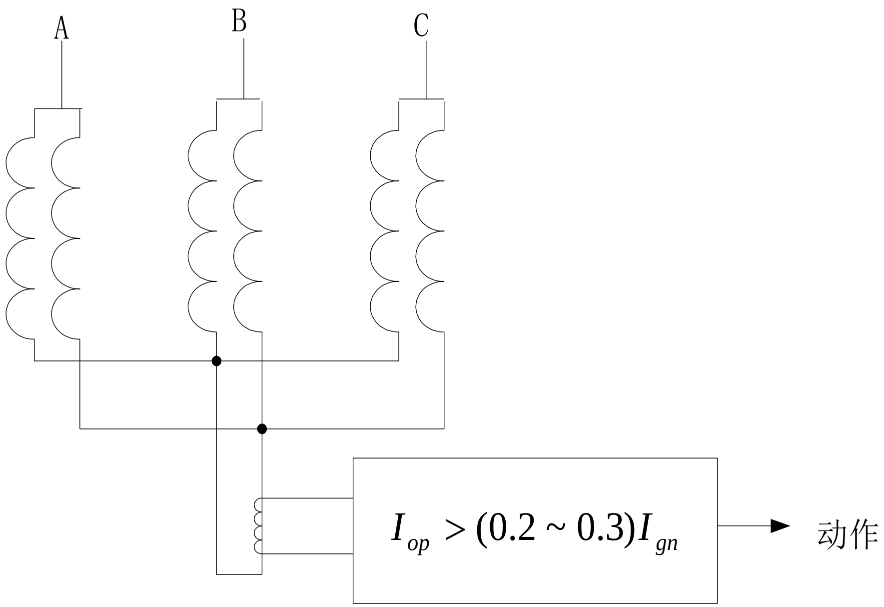


In case of turn-to-turn short circuit between two branches, if there is EMF difference ($\alpha_1 \neq \alpha_2$), two circulating currents $I_d{}'$ *and* $I_d{}''$ can be identified.

The differential current through the differential relay will be:

$$I_{op} = \frac{2I_d{}'}{n_l}$$

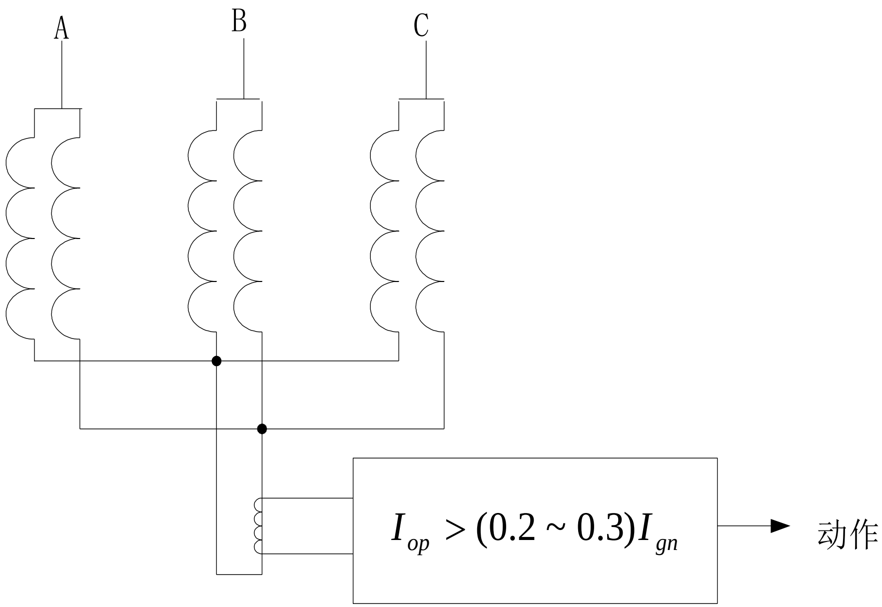
Transverse Differential Protection



If stator windings have multiple branches and more than two outgoing lines from the neutral points, differential protection can be equipped as the picture.

Ideally, during normal operation, there should be no current flowing through the line between neutral points.

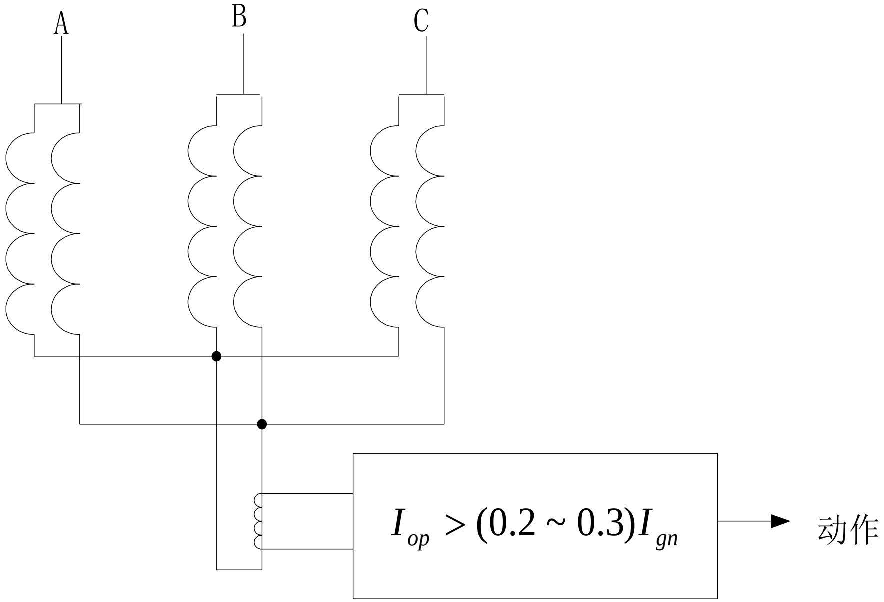
Transverse Differential Protection



Actually, there will be unbalance current through the neutral lines, due to following reasons:

- Parameters of different branches in the same phase are not completely same;
- Induced EMF of stators windings are not completely same due to uneven air gap and magnetic field;
- EMF difference caused by off-center rotor;
- Third harmonic;

Transverse Differential Protection



Therefore, the setting of such differential protection would avoid these unbalance currents:

$$I_{set} = (0.25 \sim 0.31)I_{gn}$$

I_{gn} is the rated current of the generator.

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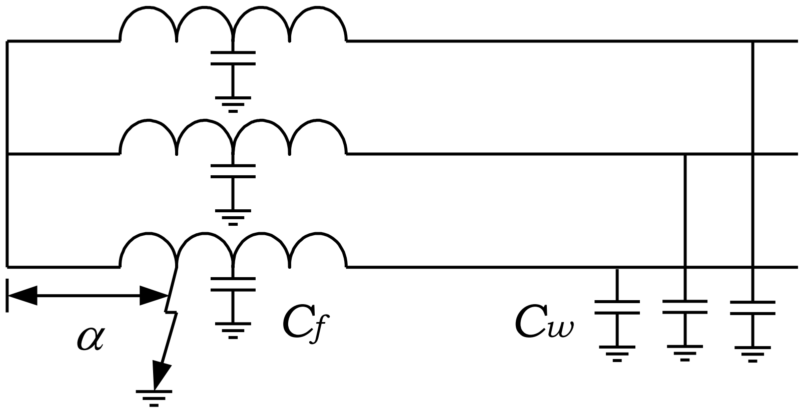
Stator Single Phase Earth Fault



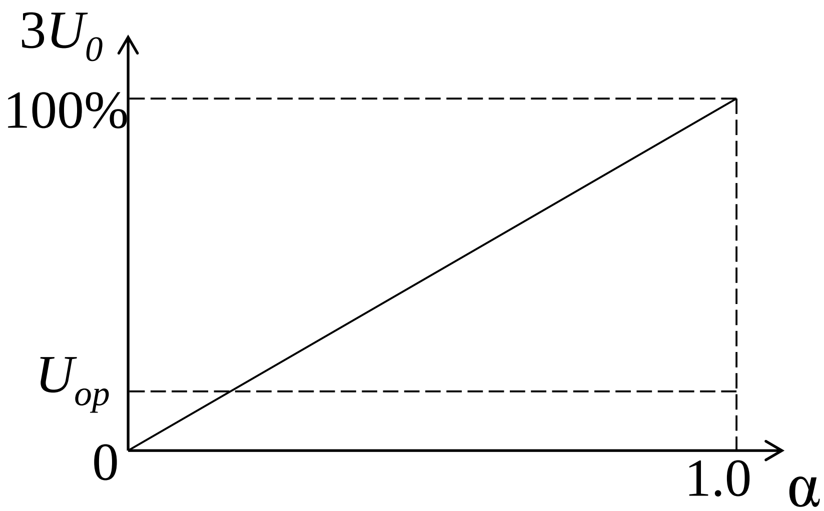
If phase A has grounded fault at α from the neutral point, then the relative voltage to ground for each phase can be estimated as:

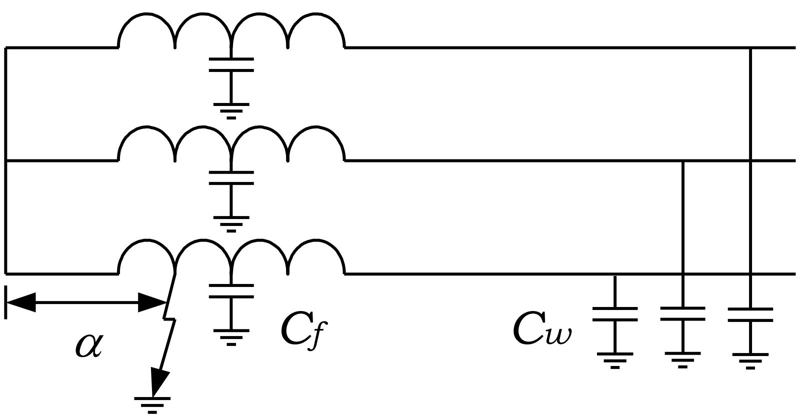
$$\begin{cases} \dot{U}_{AG} = (1-\alpha)\dot{E}_A \\ \dot{U}_{BG} = \dot{E}_B - \alpha\dot{E}_A \\ \dot{U}_{CG} = \dot{E}_C - \alpha\dot{E}_A \end{cases}$$

Then the zero-sequence voltage can be calculated as: $\dot{U}_{0\alpha} = -\alpha\dot{E}_A$

So the zero-sequence voltage varies with the fault position. The zero-sequence voltage will be smaller when the fault position is closer to the neutral point.

Stator Single Phase Earth Fault





The zero-sequence voltage will be higher when the fault position is closer to the terminal.

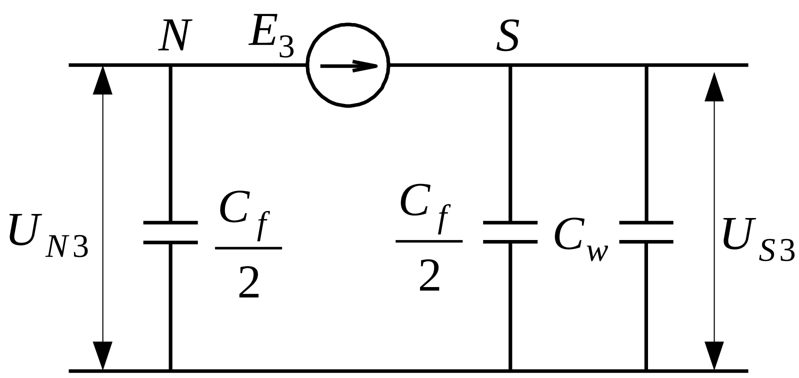
The zero-sequence voltage can be used to construct protection for single phase earth fault:

$$3U_0 > U_{op}$$

Needs to avoid unbalance zero-sequence voltage (such as third harmonic), so the zero-sequence voltage protection can only protect about 85% of the whole stator winding (faults which are too closer to neutral point may not be discovered).

How to protect 100% of the stator winding?

Stator Single Phase Earth Fault Protection Using Third Harmonic Voltages



Third harmonic voltage at neutral point:

$$U_{N3} = \frac{C_f + 2C_w}{2(C_f + C_w)} E_3$$

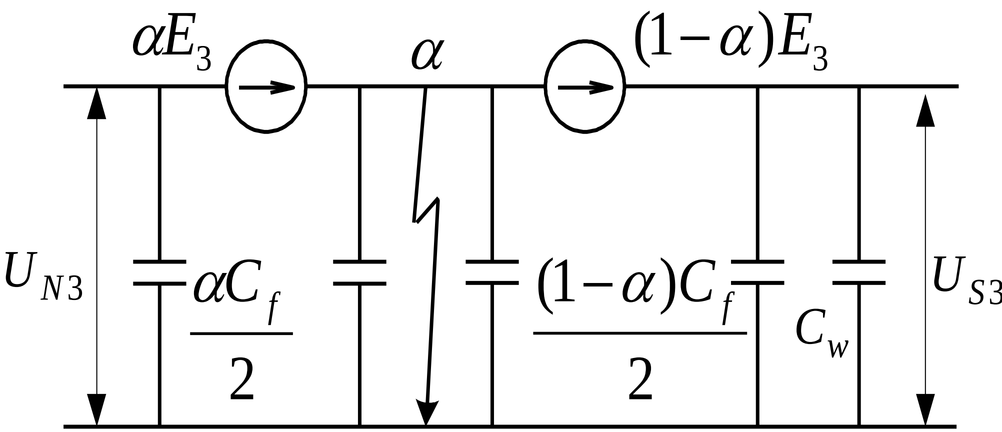
Third harmonic voltage at terminal:

$$U_{S3} = \frac{C_f}{2(C_f + C_w)} E_3$$

$$\frac{U_{S3}}{U_{N3}} = \frac{C_f}{C_f + 2C_w} < 1$$

During normal operation, the third harmonic voltage at the neutral point is always higher than the terminal.

Stator Single Phase Earth Fault Protection Using Third Harmonic Voltages



In case of single earth fault, third harmonic voltage at the neutral point:

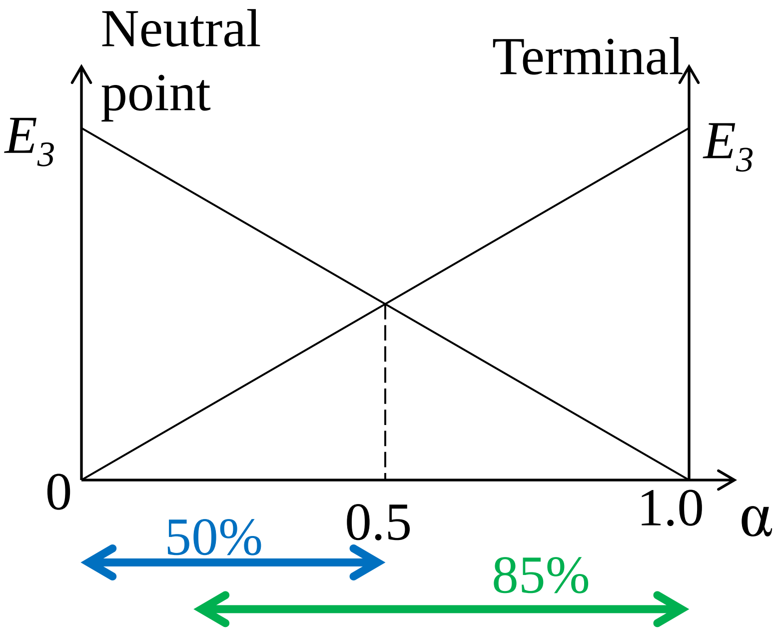
$$U_{N3} = \alpha E_3$$

Third harmonic voltage at terminal:

$$U_{S3} = (1-\alpha)E_3$$

$$\frac{U_{S3}}{U_{N3}} = \frac{1-\alpha}{\alpha}$$

Stator Single Phase Earth Fault Protection Using Third Harmonic Voltages



The third harmonic voltage can be used to construct protection:

$$U_{S3} \geq U_{N3}$$

This protection cannot operate during normal operation.

This protection can protect against single phase earth faults within 50% range of stator winding close to the neutral point.

The zero-sequence voltage protection and the third harmonic voltage protection can jointly protect 100% of the stator winding.

Next Lecture

Generator Protection 2

Bus Protection 1

Thanks for your attendance