



Fault Analysis

EE 340

Spring 2012

Introduction

- A **fault** in a circuit is any failure that interferes with the normal system operation.
- Lighting strokes cause most faults on high-voltage transmission lines producing a very high transient that greatly exceeds the rated voltage of the line.
- This voltage usually causes flashover between the phases and/or the ground creating an arc.
- Since the impedance of this new path is usually low, an excessive current may flow.
- Faults involving ionized current paths are also called transient faults. They usually clear if power is removed from the line for a short time and then restored.



Introduction

- If one, or two, or all three phases break or if insulators break due to fatigue or inclement weather, this fault is called a permanent fault since it will remain after a quick power removing.
- Approximately 75% of all faults in power systems are transient in nature.
- Knowing the magnitude of the fault current is important when selecting protection equipment (type, size, etc..)



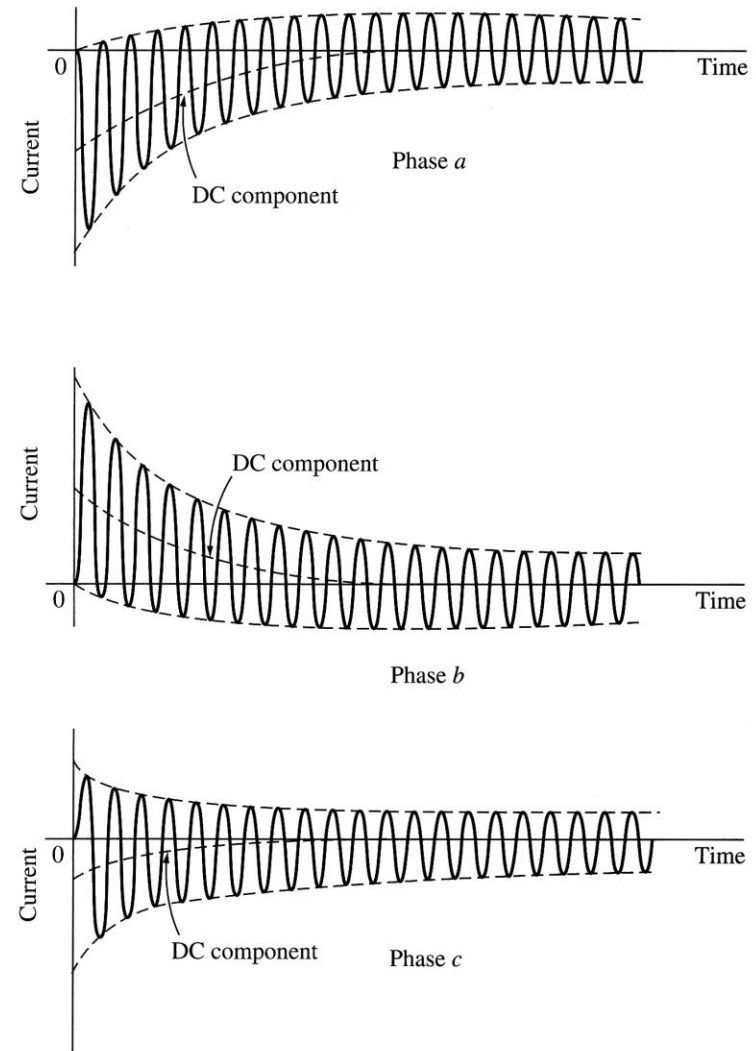
Type of fault	Abbreviation	Type
Single line-to-ground	SLG	Unsymmetrical
Line-to-line	LL	Unsymmetrical
Double line-to-ground	LLG	Unsymmetrical
Symmetrical three-phase	3P	Symmetrical

3-Phase fault current transients in synchronous generators

When a symmetrical 3-phase fault occurs at the terminals of a synchronous generator, the resulting current flow in the phases of the generator can appear as shown.

The current can be represented as a transient DC component added on top of a symmetrical AC component.

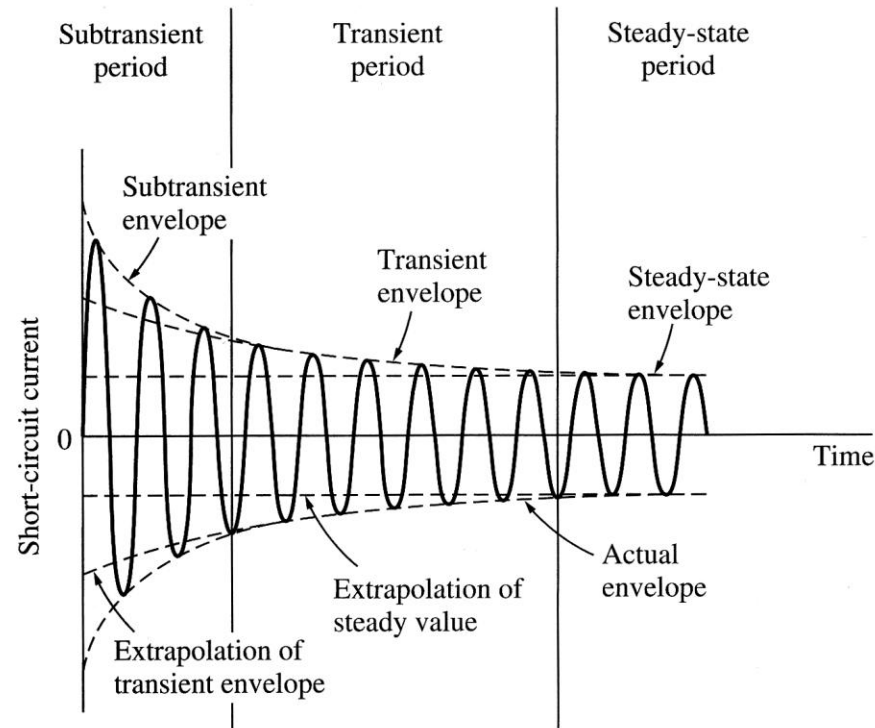
Before the fault, only AC voltages and currents are present, but immediately after the fault, both AC and DC currents are present.



Fault current transients in machines

- When the fault occurs, the AC component of current jumps to a very large value, but the total current cannot change instantly since the series inductance of the machine will prevent this from happening.
- The transient DC component of current is just large enough such that the sum of the AC and DC components just **after** the fault equals the AC current just **before** the fault.
- Since the instantaneous values of current at the moment of the fault are different in each phase, the magnitude of DC components will be different in different phases.
- These DC components decay fairly quickly, but they initially average about 50 - 60% of the AC current flow the instant after the fault occurs. The total initial current is therefore typically 1.5 or 1.6 times the AC component alone.

Symmetrical AC component of the fault current:



- There are three periods of time:
 - Sub-transient period: first cycle or so after the fault – AC current is very large and falls rapidly;
 - Transient period: current falls at a slower rate;
 - Steady-state period: current reaches its steady value.
- It is possible to determine the time constants for the sub-transient and transient periods .

Fault current transients in machines

- The AC current flowing in the generator during the sub-transient period is called the sub-transient current and is denoted by I'' . The time constant of the sub-transient current is denoted by T'' and it can be determined from the slope. This current can be as much as 10 times the steady-state fault current.
- The AC current flowing in the generator during the transient period is called the transient current and is denoted by I' . The time constant of the transient current is denoted by T' . This current is often as much as 5 times the steady-state fault current.
- After the transient period, the fault current reaches a steady-state condition I_{ss} . This current is obtained by dividing the induced voltage by the synchronous reactance:

$$I_{ss} = \frac{E_A}{X_s}$$

Fault current transients in machines

- The rms value of the AC fault current in a synchronous generator varies over time as

$$I(t) = (I'' - I')e^{-t/T''} + (I' - I_{ss})e^{-t/T'} + I_{ss}$$

- The sub-transient and transient reactances are defined as the ratio of the internal generated voltage to the sub-transient and transient current components:

$$X'' = \frac{E_A}{I''}$$

$$X' = \frac{E_A}{I'}$$

Fault current calculations

Example 1: A 100 MVA, 13.8 kV, Y-connected, 3 phase 60 Hz synchronous generator is operating at the rated voltage and no load when a 3 phase fault occurs at its terminals. Its reactances per unit to the machine's own base are

$$X_s = 1.00 \quad X' = 0.25 \quad X'' = 0.12$$

and the time constants are

$$T' = 1.10 \text{ s} \quad T'' = 0.04 \text{ s}$$

The initial DC component in this machine averages 50% of the initial AC component.

- What is the AC component of current in this generator the instant after the fault?
- What is the total current (AC + DC) in the generator right after the fault occurs?
- What will the AC component of the current be after 2 cycles? After 5 s?

Fault current calculations

The base current of the generator can be computed as

$$I_{L,base} = \frac{S_{base}}{\sqrt{3}V_{L,base}} = \frac{100,000,000}{\sqrt{3} \cdot 13,800} = 4,184 \text{ A}$$

The subtransient, transient, and steady-state currents are (per-unit and Amps)

$$I'' = \frac{E_A}{X''} = \frac{1.0}{0.12} = 8.333 \text{ pu} = 34,900 \text{ A}$$

$$I' = \frac{E_A}{X'} = \frac{1.0}{0.25} = 4 \text{ pu} = 16,700 \text{ A}$$

$$I_{ss} = \frac{E_A}{X_s} = \frac{1.0}{1.0} = 1 \text{ pu} = 4,184 \text{ A}$$

Fault current calculations

- a) The initial AC component of current is $I'' = 34,900 \text{ A}$.
- b) The total current (AC and DC) at the beginning of the fault is

$$I_{tot} = 1.5I'' = 52,350 \text{ A}$$

- c) The AC component of current as a function of time is

$$I(t) = (I'' - I')e^{-\frac{t}{T''}} + (I' - I_{ss})e^{-\frac{t}{T'}} + I_{ss} = 18,200 \cdot e^{-\frac{t}{0.04}} + 12,516 \cdot e^{-\frac{t}{1.1}} + 4,184 \text{ A}$$

After 2 cycles $t = 1/30 \text{ s}$ and the total AC current is

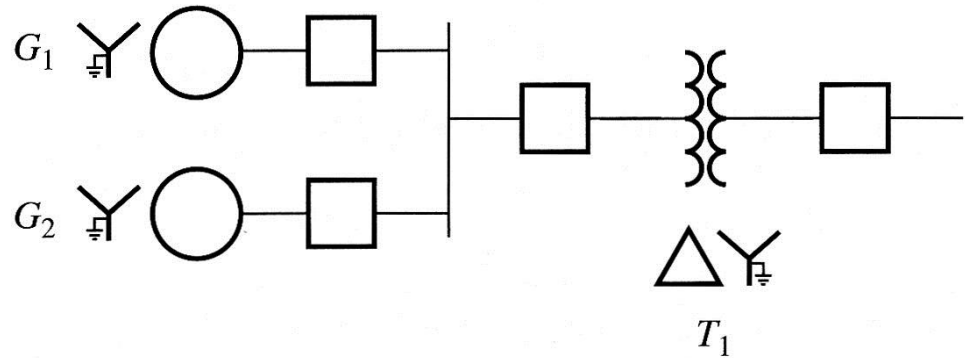
$$I\left(\frac{1}{30}\right) = 7,910 + 12,142 + 4,184 = 24,236 \text{ A}$$

At 5 s, the current reduces to

$$I(5) = 0 + 133 + 4,184 = 4,317 \text{ A}$$

Fault current transients

Example 2: Two generators are connected in parallel to the low-voltage side of a transformer. Generators G_1 and G_2 are each rated at 50 MVA, 13.8 kV, with a subtransient resistance of 0.2 pu. Transformer T_1 is rated at 100 MVA, 13.8/115 kV with a series reactance of 0.08 pu and negligible resistance.



G_1 ratings:
50 MVA
13.8 kV
 $X'' = 0.20$ pu

G_2 ratings:
50 MVA
13.8 kV
 $X'' = 0.20$ pu

T_1 ratings:
100 MVA
13.8/115 kV
 $X = 0.08$ pu

Assume that initially the voltage on the high side of the transformer is 120 kV, that the transformer is unloaded, and that there are no circulating currents between the generators.

Calculate the subtransient fault current that will flow if a 3 phase fault occurs at the high-voltage side of transformer.

Fault current calculations

Let choose the per-unit base values for this power system to be 100 MVA and 115 kV at the high-voltage side and 13.8 kV at the low-voltage side of the transformer.

The subtransient reactance of the two generators to the system base is

$$Z_{new} = Z_{given} \left(\frac{V_{given}}{V_{new}} \right)^2 \left(\frac{S_{new}}{S_{given}} \right)$$

Therefore:

$$X_1'' = X_2'' = 0.2 \cdot \left(\frac{13,800}{13,800} \right)^2 \left(\frac{100,000}{50,000} \right) = 0.4 \text{ pu}$$

The reactance of the transformer is already given on the system base, it will not change

$$X_T = 0.08 \text{ pu}$$

Symmetrical fault current calculations

The per-unit voltage on the high-voltage side of the transformer is

$$V_{pu} = \frac{\text{actual value}}{\text{base value}} = \frac{120,000}{115,000} = 1.044 \text{ pu}$$

Thevenin equivalent circuit:

$$V_{th} = 1.044 \text{ pu}$$

$$Z_{th} = j0.28 \text{ pu}$$

Short circuit current (pu)

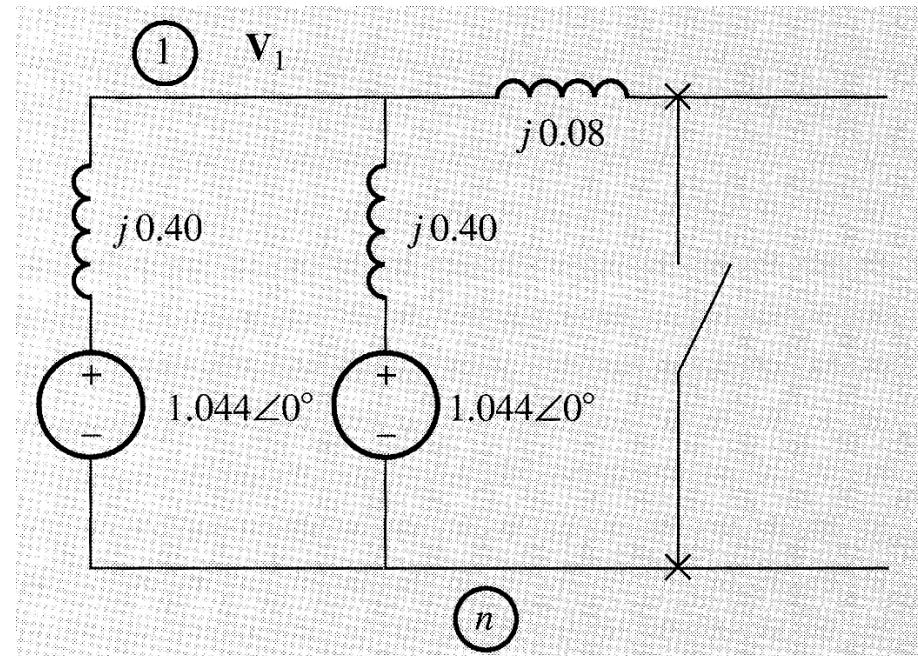
$$I_{sc} = V_{th}/Z_{th} = 3.73 \text{ pu}$$

Base current on the high voltage side:

$$I_{base} = 502 \text{ A}$$

Short circuit current (A):

$$I_{sc} = 1,872 \text{ A}$$



Symmetrical fault current calculations

- To determine the fault current in more complicated system:
 - Create a per-phase per-unit equivalent circuit of the power system using either sub-transient reactances (if subtransient currents are needed) or transient reactances (if transient currents are needed).
 - Find the Thevenin equivalent circuit looking from the fault point, then divide the Thevenin voltage by the Thevenin impedance.
- This approach always works but can get complex while dealing with complex systems.
- Therefore, software tools such as EasyPower come very handy.

Problems

- 12.1
- 12.3
- 12.5
- 12.8
- Refer to experiment 9 (for large systems)