EEE- 601
POWER SYSTEM ANALYSIS
Unit-1
Calculation of 3-phase short circuit current and reactance of synchronous machine

Generator Modeling During Faults

- During a fault the only devices that can contribute fault current are those with energy storage.
- Thus the models of generators (and other rotating machines) are very important since they contribute the bulk of the fault current.
- Generators can be approximated as a constant voltage behind a time-varying reactance:

\[ E'_a \]

\[ X_a(+) \]

\[ V_T \]
The time varying reactance is typically approximated using three different values, each valid for a different time period:

\[ X_d'' = \text{direct-axis subtransient reactance} \]
\[ X_d' = \text{direct-axis transient reactance} \]
\[ X_d = \text{direct-axis synchronous reactance} \]

Can then estimate currents using circuit theory:
For example, could calculate steady-state current that would occur after a three-phase short-circuit if no circuit breakers interrupt current.
For a balanced three-phase fault on the generator terminal the ac fault current is (see page 362)

\[ i_{ac}(t) = \sqrt{2}E_a \left[ \frac{1}{X_d} + \left( \frac{1}{X_d'} - \frac{1}{X_d''} \right) e^{-t/T_d'} + \left( \frac{1}{X_d''} - \frac{1}{X_d'} \right) e^{-t/T_d''} \right] \sin(\omega t + \alpha) \]

where

\[ T_d'' = \text{direct-axis subtransient time constant} \ (\approx 0.035 \text{sec}) \]
\[ T_d' = \text{direct-axis transient time constant} \ (\approx 1 \text{sec}) \]
Generator Modeling, cont'd

The phasor current is then

\[ I_{ac} = E'_a \left[ \frac{1}{X_d} + \left( \frac{1}{X'_d} - \frac{1}{X_d} \right) e^{-t/T'_d} \right. \]

\[ \left. + \left( \frac{1}{X''_d} - \frac{1}{X'_d} \right) e^{-t/T''_d} \right] \]

The maximum DC offset is

\[ I_{DC}(t) = \frac{\sqrt{2}}{X_d} \frac{E'_a}{X''_d} e^{-t/T_A} \]

where \( T_A \) is the armature time constant (\( \approx 0.2 \) seconds)
Generator Short Circuit Currents

Figure 7.5  Short-circuit currents.
Generator Short Circuit Currents
Generator Short Circuit Example

- A 500 MVA, 20 kV, 3φ is operated with an internal voltage of 1.05 pu. Assume a solid 3φ fault occurs on the generator's terminal and that the circuit breaker operates after three cycles. Determine the fault current. Assume

\[
X''_d = 0.15, \quad X'_d = 0.24, \quad X_d = 1.1 \text{ (all per unit)}
\]

\[
T''_d = 0.035 \text{ seconds, } T'_d = 2.0 \text{ seconds}
\]

\[
T_A = 0.2 \text{ seconds}
\]
Generator S.C. Example, cont'd

Evaluating at $t = 0.05$ seconds for breaker opening

$$I_{ac}(0.05) = 1.05 \left[ \frac{1}{1.1} + \left( \frac{1}{0.24} - \frac{1}{1.1} \right) e^{-0.05/2.0} \right]$$

$I_{ac}(0.05) = 70.8$ kA

$I_{DC}(0.05) = 143 \times e^{-0.05/0.2}$ kA $= 111$ kA

$I_{RMS}(0.05) = \sqrt{70.8^2 + 111^2} = 132$ kA
Network Fault Analysis Simplifications

To simplify analysis of fault currents in networks we'll make several simplifications:

1. Transmission lines are represented by their series reactance
2. Transformers are represented by their leakage reactances
3. Synchronous machines are modeled as a constant voltage behind direct-axis subtransient reactance
4. Induction motors are ignored or treated as synchronous machines
5. Other (nonspinning) loads are ignored
Network Fault Example

For the following network assume a fault on the terminal of the generator; all data is per unit except for the transmission line reactance.

Convert to per unit: \( X_{\text{line}} = \frac{19.5}{138^2 / 100} = 0.1 \) per unit

generator has 1.05 terminal voltage & supplies 100 MVA with 0.95 lag pf
To determine the fault current we need to first estimate the internal voltages for the generator and motor.

For the generator $V_T = 1.05$, $S_G = 1.0 \angle 18.2^\circ$

$$I_{Gen} = \left(\frac{1.0 \angle 18.2^\circ}{1.05}\right)^* = 0.952 \angle -18.2^\circ \quad E_a' = 1.103 \angle 7.1^\circ$$
Network Fault Example, cont'd

The motor's terminal voltage is then

\[ 1.05 \angle 0 - (0.9044 - j0.2973) \times j0.3 = 1.00 \angle -15.8^\circ \]

The motor's internal voltage is

\[ 1.00 \angle -15.8^\circ - (0.9044 - j0.2973) \times j0.2 \]

\[ = 1.008 \angle -26.6^\circ \]

We can then solve as a linear circuit:

\[ I_f = \frac{1.103 \angle 7.1^\circ}{j0.15} + \frac{1.008 \angle -26.6^\circ}{j0.5} \]

\[ = 7.353 \angle -82.9^\circ + 2.016 \angle -116.6^\circ = j9.09 \]
Fault Analysis Solution Techniques

- Circuit models used during the fault allow the network to be represented as a linear circuit
- There are two main methods for solving for fault currents:
  1. Direct method: Use prefault conditions to solve for the internal machine voltages; then apply fault and solve directly.
  2. Superposition: Fault is represented by two opposing voltage sources; solve system by superposition:
     - first voltage just represents the prefault operating point
     - second system only has a single voltage source.
Determination of Fault Current

Define the bus impedance matrix $Z_{bus}$ as

$$ Z_{bus} \begin{bmatrix} \cdots \end{bmatrix} V = Z_{bus} I $$

Then

$$ \begin{bmatrix} Z_{11} & \cdots & \cdots & 0 \end{bmatrix} \begin{bmatrix} \vdots \end{bmatrix} = \begin{bmatrix} V^{(2)}_{2} \end{bmatrix} $$

For a fault a bus $i$ we get $-I_f Z_{ii} = -V_f = -V_i^{(1)}$
Determination of Fault Current

Hence

\[ I_f = \frac{V_i^{(1)}}{Z_{ii}} \]

Where

\[ Z_{ii} \quad \text{driving point impedance} \]

\[ Z_{ij}(i \neq j) \quad \text{transfer point impedance} \]

Voltages during the fault are also found by superposition

\[ V_i = V_i^{(1)} + V_i^{(2)} \quad V_i^{(1)} \text{ are prefault values} \]
Thank you