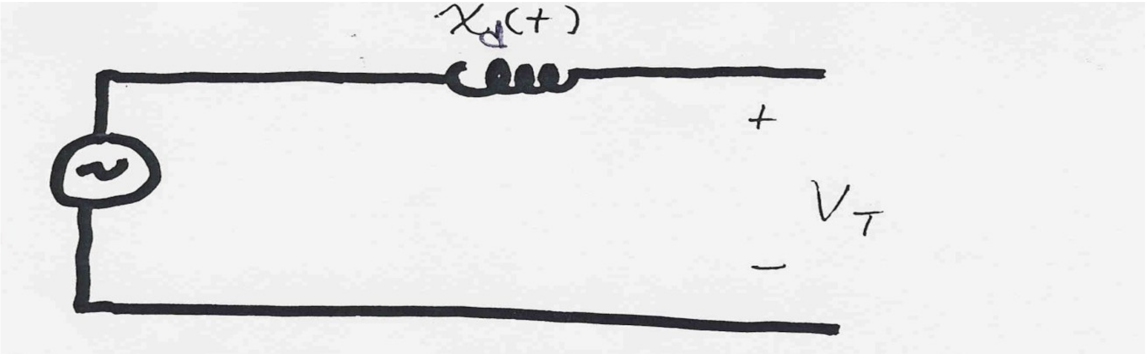
EEE- 601
POWER SYSTEM ANALYSIS
Unit-1

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:

$E_a^{'}$



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

X_d'' = direct-axis subtransient reactance

X_d' = direct-axis transient reactance

X_d = 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.

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For a balanced three-phase fault on the generator terminal the ac fault current is (see page 362)

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

where

$T_d^{''}$ = direct-axis subtransient time constant (≈ 0.035sec)

$T_d^{'}$ = direct-axis transient time constant (≈ 1sec)

Generator Modeling, cont'd

The phasor current is then

$$I_{ac} = E_a' \left[\frac{1}{X_d} + \left(\frac{1}{X_d'} - \frac{1}{X_d} \right) e^{-t/T_d'} + \left(\frac{1}{X_d''} - \frac{1}{X_d'} \right) e^{-t/T_d''} \right]$$

The maximum DC offset is

$$I_{DC}(t) = \frac{\sqrt{2}\, E_a'}{X_d''} e^{-t/T_A}$$

where T_A is the armature time constant (≈ 0.2 seconds)

Generator Short Circuit Currents

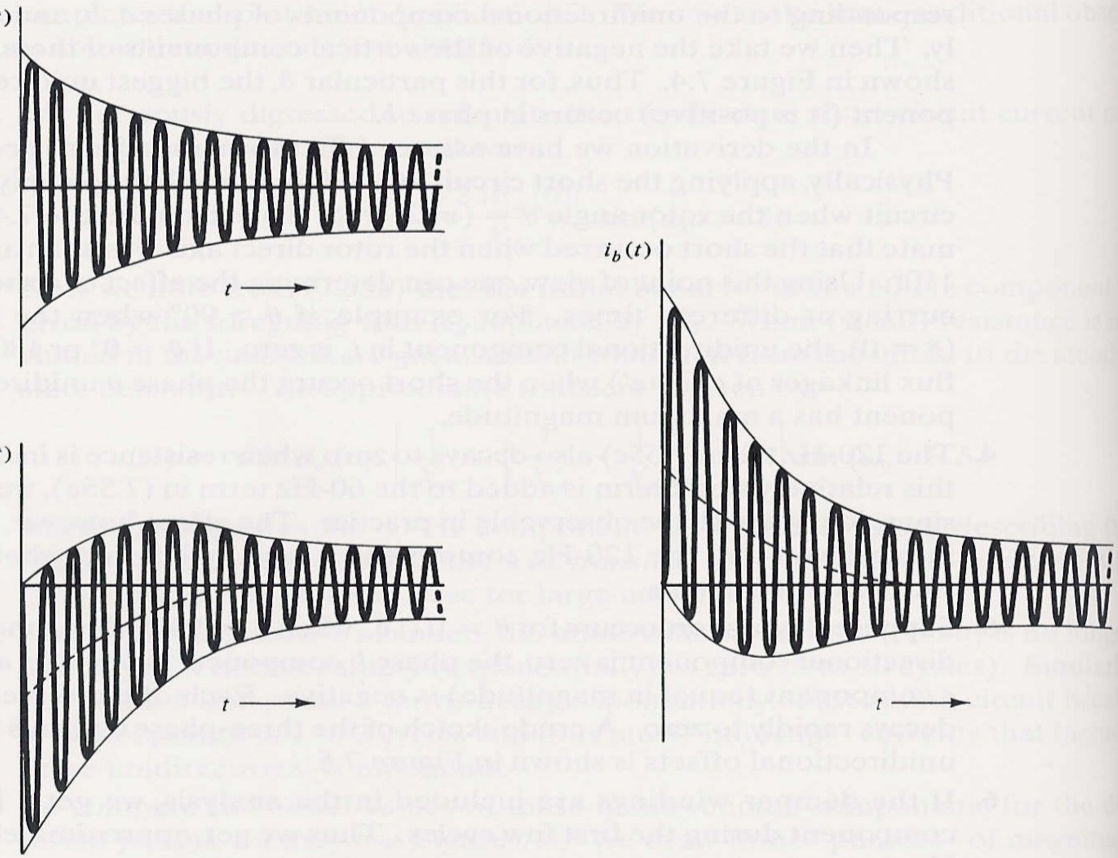
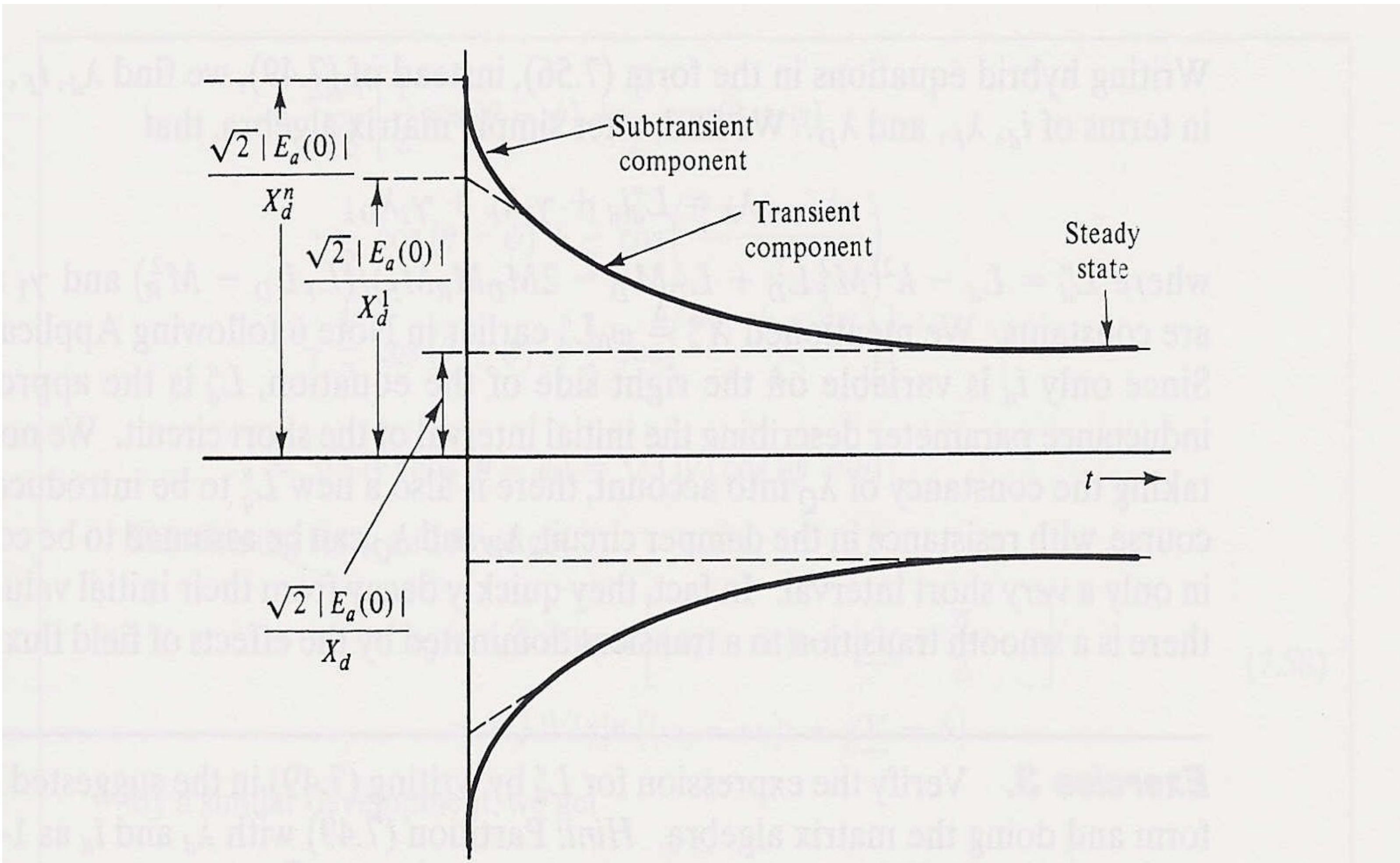


Figure 7.5 Short-circuit currents.

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

$$I_{ac}(0.05) = 1.05\left[\frac{1}{1.1} + \left(\frac{1}{0.24} - \frac{1}{1.1}\right)e^{-0.05/2.0} + \left(\frac{1}{0.15} - \frac{1}{0.24}\right)e^{-0.05/0.035}\right]$$

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

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

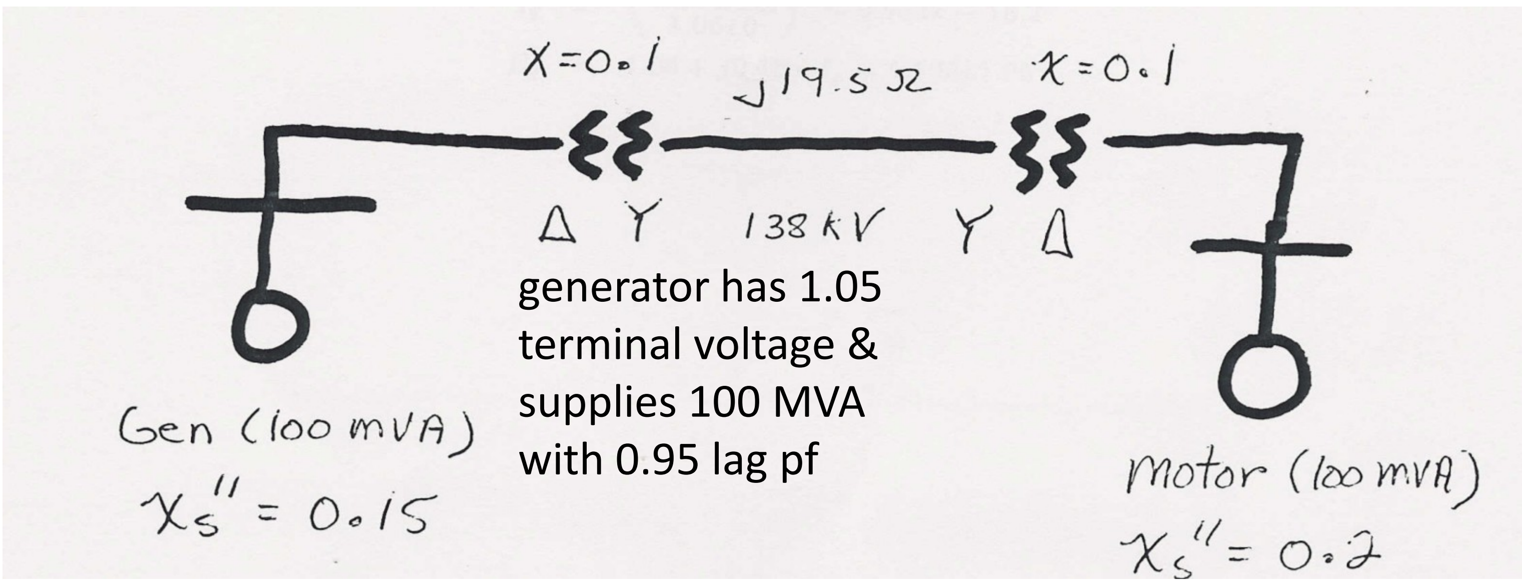
$$I_{RMS}(0.05) = \sqrt{70.8^2 + 111^2} = 132 \text{ kA}$$

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

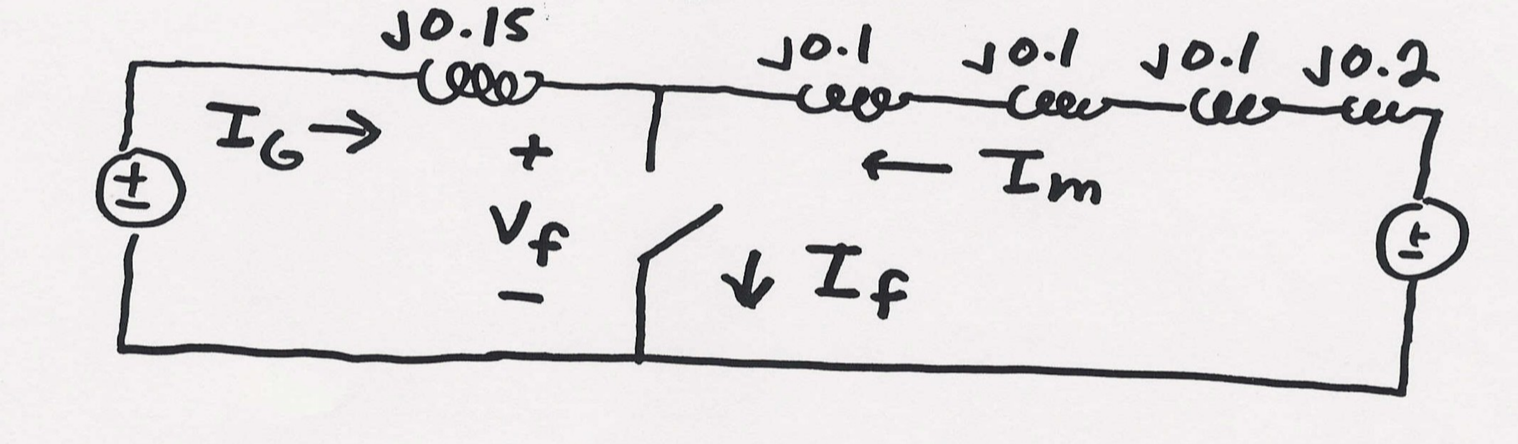
For the following network assume a fault on the terminal of the generator; all data is per unit except for the transmission line reactance



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

Network Fault Example, cont'd

Faulted network per unit diagram



To determine the fault current we need to first estimate the internal voltages for the generator and motor

For the generator $V_T = 1.05, \;\; S_G = 1.0\angle 18.2°$

$$I_{Gen} = \left(\frac{1.0\angle 18.2}{1.05}\right)^* = 0.952\angle -18.2° \quad E_a^{'} = 1.103\angle 7.1°$$

Network Fault Example, cont'd

The motor's terminal voltage is then

$$1.05\angle 0 - (0.9044 - j0.2973) \times j0.3 = 1.00\angle -15.8°$$

The motor's internal voltage is

$$1.00\angle -15.8° - (0.9044 - j0.2973) \times j0.2$$

$$= 1.008\angle -26.6°$$

We can then solve as a linear circuit:

$$I_f = \frac{1.103\angle 7.1°}{j0.15} + \frac{1.008\angle -26.6°}{j0.5}$$

$$= 7.353\angle -82.9° + 2.016\angle -116.6° = j9.09$$

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 $\mathbf{Z}_{\text{bus}}$ as

$$\mathbf{Z}_{\text{bus}} \qquad \mathbf{V} = \mathbf{Z}_{\text{bus}}\mathbf{I}$$

Then

$$\begin{bmatrix} Z_{11} & \cdots & \\ \vdots & \ddots & \vdots \\ Z_{n1} & \cdots & \end{bmatrix} \begin{bmatrix} \vdots \\ 0 \\ \\ 0 \\ \vdots \end{bmatrix} = \begin{bmatrix} \\ V_2^{(2)} \\ \vdots \\ V_{n-1}^{(2)} \\ \end{bmatrix}$$

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} □ ; point impedance

$Z_{ij} (i \neq j)$ □ r point imepdance

Voltages during the fault are also found by superposition

$V_i = V_i^{(1)} + V_i^{(2)}$ $V_i^{(1)}$ are prefault values

Thank you