3. A three-phase generator feeds three large synchronous motors over a 16 km, 115 kV transmission line, through a 115 kV:13.8 kV transformer bank, as shown below.

(a) Draw a per unit, per phase equivalent circuit with all reactances indicated in per unit on a 100 MVA base. Start the voltage bases from 13.8 kV base on the generator source.

(b) The generator is controlled to maintain the voltage at the motor bus at 1.0 pu at an angle of 0 degrees. The three motors are operating at full rating and 90% PF lagging. Determine the voltage required at the generator terminals assuming that there is no voltage regulating taps or similar equipment in this system.

(c) Calculate the voltage required behind the subtransient reactance for the generator and each of the motors.

(d) Calculate the line current in Amperes.
4. Draw the per unit, Thevenin equivalent circuit for the system below looking out from the load bus if:

(a) The generator internal voltages are equal in magnitude and angle (label both as $E_1$ and present your results as a function of $E_1$)

(b) The generator internal voltages are not equal (label one as $E_1$ and the other $E_2$ in your solution, and present your results as a function of $E_1$ and $E_2$)

Impedance values (all on consistent bases, no change of base needed):

- G1: $X = 0.1$ pu
- G2: $X = 0.1$ pu
- Line 1: $X = 0.1$ pu
- Line 2: $X = 0.1$ pu
- Load: $Z = j0.1$ pu
5. The following table of values has been prepared for the various line sections. Find the total pu impedance and shunt susceptance of each line on a 10 MVA base, using the line nominal voltage as a voltage base. Sketch a nominal pi model for each line.

<table>
<thead>
<tr>
<th>Nominal Voltage (kV)</th>
<th>Line Length (mi)</th>
<th>Wire Size and Material</th>
<th>R (Ω/mi)</th>
<th>X (Ω/mi)</th>
<th>Xc (MΩ-mi)</th>
</tr>
</thead>
<tbody>
<tr>
<td>13.8</td>
<td>5.0</td>
<td>4/0 Cu</td>
<td>0.278</td>
<td>0.690</td>
<td>0.160</td>
</tr>
<tr>
<td>13.8</td>
<td>2.0</td>
<td>4 Cu</td>
<td>1.374</td>
<td>0.816</td>
<td>0.193</td>
</tr>
<tr>
<td>13.8</td>
<td>3.9</td>
<td>4/0 Al</td>
<td>0.445</td>
<td>0.711</td>
<td>0.157</td>
</tr>
<tr>
<td>13.8</td>
<td>6.2</td>
<td>336.4 Al</td>
<td>0.278</td>
<td>0.730</td>
<td>0.172</td>
</tr>
<tr>
<td>13.8</td>
<td>7.3</td>
<td>556.5 Al</td>
<td>0.088</td>
<td>0.330</td>
<td>0.142</td>
</tr>
<tr>
<td>69.0</td>
<td>10.0</td>
<td>4/0 Al</td>
<td>0.445</td>
<td>0.711</td>
<td>0.157</td>
</tr>
<tr>
<td>69.0</td>
<td>25.0</td>
<td>336.5 Al</td>
<td>0.278</td>
<td>0.730</td>
<td>0.172</td>
</tr>
</tbody>
</table>
- Motors or generators
  with power electronic interfaces

Motor drives $\rightarrow$ Variable Frequency Drive (VFD)
Adjustable Speed Drives (ASD)

controls frequency & amplitude & phase of motor current
Wind Turbines

1. Standard Squirrel Cage Induction Machine
2. Wound Rotor Induction Machine
3. Doubly Fed Induction Machine

Type 1

Type 2

Type 3 - Doubly Fed Induction Machine is regulated by Current Source

\[ V_{sc} = \frac{V}{V_{dc}} \]
- Representing connection to neighboring system (or subsystem)

→ Thévenin's Equivalent for system states

- How do you store this information?

\[ MUA_s c \xrightarrow{} \text{positive & zero sequence} \]

\[ I_{sc} \]
3. \( \text{mVAsc} \)

\[
\begin{align*}
\text{MVA}_{\text{asc}} & = \left| V_{\text{TH}} \right| \cdot \left| I_{\text{sc}} \right| \\
& = \left| V_{\text{TH}} \right| \cdot \frac{\left| V_{\text{TH}} \right|}{\left| Z_{\text{TH}} \right|} \\
\end{align*}
\]

\[
\text{MVA}_{\text{asc}} (\text{pu}) = \frac{\left| V_{\text{TH}} \right|^2}{\left| Z_{\text{TH}} \right|} \rightarrow 1.0
\]

\[
= \sqrt{\left| Z_{\text{TH}} \right|}
\]

\( X/R \rightarrow \text{angle of} Z_{\text{TH}} \)
\[ \text{MVA}_{\text{sc}} = 20,000 \text{ MVA} \]

\[ \rightarrow \text{pu+ on 100 MVA} \]

\[ \text{MVA}_{\text{sc}} = 20 \text{ pu} \]

\[ Z_{\text{TH}} = \frac{1}{20} \text{ pu} \]

\[ X/R = 20 \quad \Theta_Z = \text{atan} \left( \frac{X}{R} \right) \]
$$\text{MVA}_{\text{SLG}} \Rightarrow$$

$$I_0 = I_1 = I_2 = \frac{V_F}{Z_1 + Z_2 + Z_0}$$

$$I_{AC} = I_0 + I_1 + I_c$$

$$= 3I_0$$

$$\text{MVA}_{\text{SC SLG \ mu}} = \frac{3V_{TH}^2}{Z_1 + Z_2 + Z_0}$$
Symmetrical Components

Paper by Fortesque in early 1900s

Arbitrary number of phases, n-phases

→ Any unbalanced set of phasors can be transformed linearly to decompose to

1) N-1 balanced N-phase sets

2) A single common mode (zero mode) sequence set