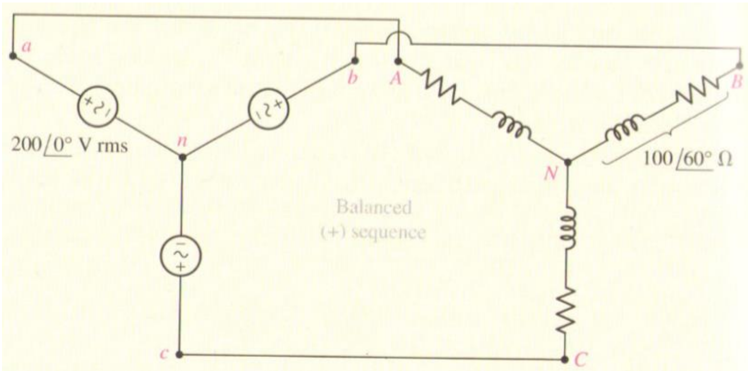
Power System

Quiz I

108. 04.10

1. For the circuit shown below, find both the phase and line currents, and the phase and line voltages throughout the circuit; then calculate the total power dissipated in the load. (20%)



Solution:

Since one of the source phase voltages is given and we are told to use the positive phase sequence, the three phase voltages are:

$$\mathbf{V}_{an} = 200\underline{/0^\circ} \text{ V} \qquad \mathbf{V}_{bn} = 200\underline{/-120^\circ} \text{ V} \qquad \mathbf{V}_{cn} = 200\underline{/-240^\circ} \text{ V}$$

The line voltage is $200\sqrt{3} = 346$ V; the phase angle of each line voltage can be determined by constructing a phasor diagram, as we did in Fig. 12.13 (as a matter of fact, the phasor diagram of Fig. 12.13 is applicable), subtracting the phase voltages using a scientific calculator, or by invoking Eqs. [1] to [3]. We find that $\mathbf{V}_{ab}$ is $346\underline{/30^\circ}$ V, $\mathbf{V}_{bc} = 346\underline{/-90^\circ}$ V, and $\mathbf{V}_{ca} = 346\underline{/-210^\circ}$ V.

The line current for phase A is

$$\mathbf{I}_{aA} = \frac{\mathbf{V}_{an}}{\mathbf{Z}_p} = \frac{200\underline{/0^\circ}}{100\underline{/60^\circ}} = 2\underline{/-60^\circ} \text{ A}$$

Since we know this is a balanced three-phase system, we may write the remaining line currents based on $\mathbf{I}_{aA}$:

$$\mathbf{I}_{bB} = 2\underline{/(-60^\circ - 120^\circ)} = 2\underline{/-180^\circ} \text{ A}$$
$$\mathbf{I}_{cC} = 2\underline{/(-60^\circ - 240^\circ)} = 2\underline{/-300^\circ} \text{ A}$$

Finally, the average power absorbed by phase A is $\text{Re}\{\mathbf{V}_{an}\mathbf{I}^*_{aA}\}$, or

$$P_{AN} = 200(2)\cos(0^\circ + 60^\circ) = 200 \text{ W}$$

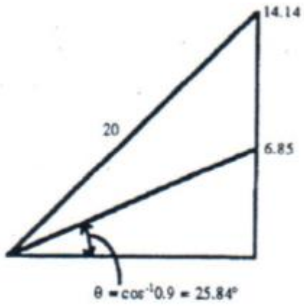
Thus, the total average power drawn by the three-phase load is 600 W.

2. A three-phase motor draws 20 kVA at 0.707 power-factor lagging from a 220-V source. Determine the KVA rating of capacitors to make the combined power factor 0.90 lagging and determine the line current before and after the capacitors are added. (20%)

Solution:

From the figure,

$$
\begin{aligned}
\theta &= \cos^{-1} 0.9 = 25.84^\circ \\
14.14 \tan 25.84^\circ &= 6.85 \\
14.14 - 6.85 &= 7.29 \ \text{ kvar}
\end{aligned}
$$



Without capacitors:

$$|I| = \frac{20,000}{\sqrt{3} \times 220} = 52.5 \ \text{ A}$$

With capacitors:

$$|I| = \frac{|14.14 + j6.85| \times 1000}{\sqrt{3} \times 220} = 41.2 \ \text{ A}$$

3. (1) 有一個三相 Y-Δ變壓器，其高壓側之正序相電壓與低壓側正序相電壓之間的相角關係為 (5%)

(A)高壓側落後低壓側

(B)高壓側與低壓側相同

V (C)高壓側領先低壓側

(D)高壓側落後低壓側

V (E)高壓側領先低壓側

(2) 電力系統中的並聯電抗器(shunt reactor)常安裝於一次或超高壓變電所，主要目的為 (5%)

(A)調節系統的故障電流

V (B)吸收系統中過多的無效功率

(C)改進系統的暫態穩定度

(D)使變電所的功因超前

(E)增進系統傳輸的無效功率

4. A three-phase round-rotor synchronous generator has negligible armature resistance and a synchronous reactance X_d of 1.65 per unit. The machine is connected directly to an infinite bus of voltage $1.0\angle 0^\circ$ per unit. Find the internal voltage E_i of the machine when it delivers a current of

(a) $1.0\angle 30^\circ$ per unit, and

(b) $1.0\angle -30^\circ$ per unit

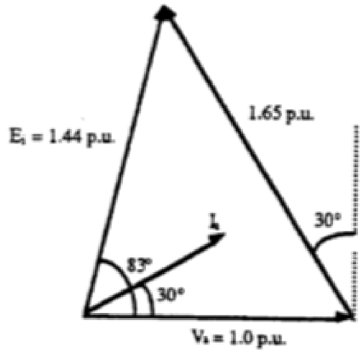
to the infinite bus. Draw phasor diagrams depicting the operation of the machine in each case. (6%, %6, 8%)

Solution:

$$
\begin{aligned}
E_i\angle 0^\circ &= V_a\angle 0^\circ + I_a\angle\theta\, X_d\angle 90^\circ \\
&= 1.0\angle 0^\circ + 1.0\angle\theta \times 1.65\angle 90^\circ \\
&= 1.0\angle 0^\circ + 1.65\angle 90^\circ + \theta
\end{aligned}
$$

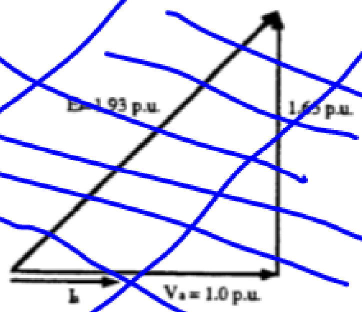
(a)

$$
\begin{aligned}
\theta &= 30^\circ \\
E_i\angle\delta &= 1.0\angle 0^\circ + 1.65\angle 120^\circ \\
&= 1.44\angle 83^\circ \text{ per unit}
\end{aligned}
$$



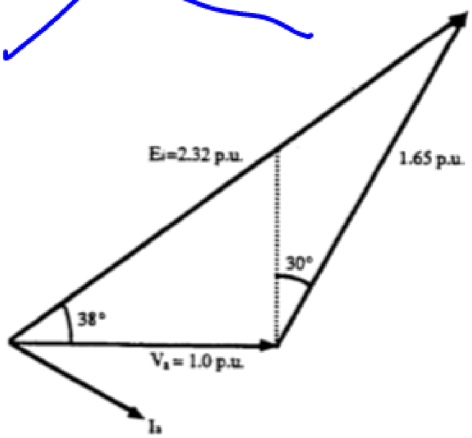
(b)

$$
\begin{aligned}
\theta &= 0^\circ \\
E_i\angle\delta &= 1.0\angle 0^\circ + 1.65\angle 90^\circ \\
&= 1.93\angle 58.8^\circ \text{ per unit}
\end{aligned}
$$



(c)

$$
\begin{aligned}
\theta &= -30^\circ \\
E_i\angle\delta &= 1.0\angle 0^\circ + 1.65\angle 60^\circ \\
&= 2.32\angle 38^\circ \text{ per unit}
\end{aligned}
$$



5. The single-line diagram of an unloaded power system is shown below. Reactances of the two sections of the transmission line are shown on the diagram. The generators and transformers are rated as follows:

   Generator 1: 20 MVA, 13.8 kV, Xd = 0.20 per unit

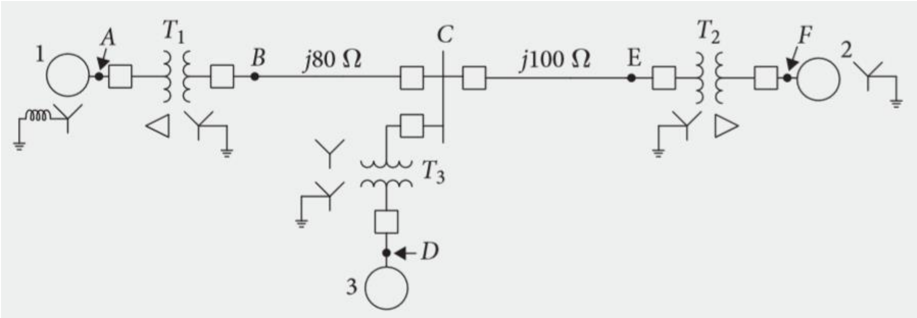
   Generator 2: 30 MVA, 18 kV, Xd = 0.20 per unit

   Generator 3: 30 MVA, 20 kV, Xd = 0.20 per unit

Transformer T1: 25 MVA, 220Y/13.8Δ kV, X = 10%

Transformer T2: single-phase units, each rated 10 MVA, 127/18 kV,   X = 10%

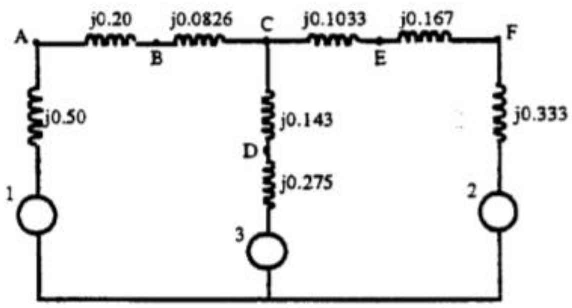
Transformer T3: 35 MVA, 220Y/22Y kV,   X = 10%



Draw the impedance diagram with all reactances marked in per unit and with letters to indicate points corresponding to the single-line diagram. Choose a base of 50 MVA, 13.8 kV in the circuit of generator 1. (20%)

Solution:

(*a*)



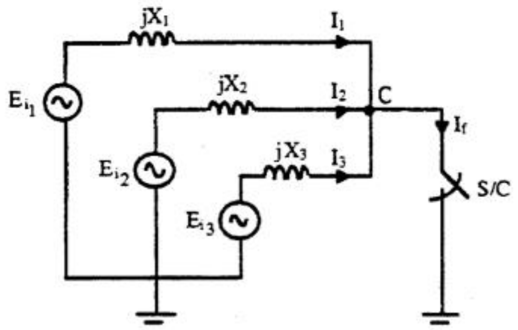
$$
\begin{aligned}
\text{Gen 1: } X'' &= 0.2 \times \frac{50}{20} = 0.50 \text{ per unit} \\
3\phi \text{ rating } T_2 &= 220/18 \text{ kV, } 30 \text{ MVA} \\
\text{Base in trans. line: } & \ 220 \text{ kV, } 50 \text{ MVA} \\
\text{Base for Gen 2} &= 18 \text{ kV} \\
\text{Gen 2: } X'' &= 0.2 \times \frac{50}{30} = 0.333 \text{ per unit} \\
\text{Base for Gen 3} &= 22 \text{ kV} \\
\text{Gen 3: } X'' &= 0.2 \left(\frac{20}{22}\right)^2 \times \frac{50}{30} = 0.275 \text{ per unit} \\
\text{Transformer } T_1\text{: } X &= .01 \times \frac{50}{25} = 0.20 \text{ per unit} \\
\text{Transformer } T_2\text{: } X &= .01 \times \frac{50}{30} = 0.167 \text{ per unit} \\
\text{Transformer } T_3\text{: } X &= .01 \times \frac{50}{35} = 0.143 \text{ per unit}
\end{aligned}
$$

Transmission lines:

$$\text{Base } Z = \frac{220^2}{50} = 968\ \Omega$$

$$\frac{80}{968} = 0.0826 \text{ per unit} \qquad \frac{100}{968} = 0.1033 \text{ per unit}$$

(b)



$$
\begin{aligned}
E_{i_1} &= E_{i_2} = E_{i_3} = 1.0\underline{/0^\circ} \text{ per unit}\\
X_1 &= 0.50 + 0.20 + 0.0826 \text{ per unit} = 0.7826 \text{ per unit}\\
X_2 &= 0.333 + 0.167 + 0.1033 \text{ per unit} = 0.6033 \text{ per unit}\\
X_3 &= 0.143 + 0.275 \text{ per unit} = 0.418 \text{ per unit}\\
I_1 &= \frac{E_{i_1}}{jX_1} = \frac{1}{0.7826}\underline{/-90^\circ} \text{ per unit} = 1.278\underline{/-90^\circ} \text{ per unit}\\
I_2 &= \frac{E_{i_2}}{jX_2} = \frac{1}{0.6033}\underline{/-90^\circ} \text{ per unit} = 1.658\underline{/-90^\circ} \text{ per unit}\\
I_3 &= \frac{E_{i_3}}{jX_3} = \frac{1}{0.418}\underline{/-90^\circ} \text{ per unit} = 2.392\underline{/-90^\circ} \text{ per unit}\\
I_f &= I_1 + I_2 + I_3 = (1.278 + 1.658 + 2.392)\underline{/-90^\circ} \text{ per unit} = 5.328\underline{/-90^\circ} \text{ per unit}\\
I_{\text{base}} \text{ at C} &= \frac{50 \times 10^6}{\sqrt{3} \times 220 \times 10^3} \text{ A} = 131.22 \text{ A}\\
|I_f| &= 5.328 \times 131.22 \text{ A} = 699 \text{ A}
\end{aligned}
$$

(c)

$$
\begin{aligned}
|S_1| &= E_{i_1} I_1 = 1.0 \times 1.278 \times 50 \text{ MVA} = 63.9 \text{ MVA}\\
|S_2| &= E_{i_2} I_2 = 1.0 \times 1.658 \times 50 \text{ MVA} = 82.9 \text{ MVA}\\
|S_3| &= E_{i_3} I_3 = 1.0 \times 2.392 \times 50 \text{ MVA} = 119.6 \text{ MVA}
\end{aligned}
$$

6. A three-phase transmission line is 483 km long and serves a load of 400 MVA, with 0.8 lagging power factor at 345 kV. The ABCD constants of the line are

   A = D = 0.8180 $\angle 1.3^\circ$

   B = 172.2 $\angle 84.2^\circ$ Ω

   C = 0.001933 $\angle 90.4^\circ$ S

   a. Determine the sending-end line-to-neutral voltage, the sending-end current, and the percent voltage drop at full load. (10%)

   b. Determine the receiving-end line-to-neutral voltage at no load, the sending-end current at no load, and the voltage regulation. (10%)

Solution:

$$V_R = \frac{345,000}{\sqrt{3}} = 199,186\angle 0^\circ \text{ V} \qquad I_R = \frac{400,000}{\sqrt{3}\times 345} = 669.4\angle -36.87^\circ \text{ A}$$

(*a*)

$$\begin{aligned}
V_S &= 0.8180\angle 1.3^\circ \times 199,186\angle 0^\circ + 172.2\angle 84.2^\circ \times 669.4\angle -36.87^\circ \\
&= 256,738\angle 20.15^\circ \text{ V} \\
I_S &= 0.001933\angle 90.4^\circ \times 199,186\angle 0^\circ + 0.8180\angle 1.3^\circ \times 669.4\angle -36.87^\circ \\
&= 447.7\angle 8.54^\circ \text{ A} \\
\text{Voltage drop} &= \frac{256,738 - 199,186}{256,738} \times 100 = 22.4\,\%
\end{aligned}$$

(*b*)

$$\begin{aligned}
V_{R,NL} &= \frac{256,738\angle 20.15^\circ}{0.8180\angle 1.3^\circ} = 313,861\angle 18.85^\circ \text{ V} \\
I_{S,NL} &= 0.001933\angle 90.4^\circ \times 313,861\angle 18.85^\circ = 606.7\angle 109.25^\circ
\end{aligned}$$

(*c*)

$$\%\text{ Reg.} = \frac{313,861 - 199,186}{199,186} = 57.6\,\%$$