Solution HW5
172 EE306

Solution Problem 1

$$V_t = \frac{208}{\sqrt{3}} = 120 \ \text{V/phase}$$

Stator current at rated kVA;

$$I_a = \frac{5000}{\sqrt{3} \times 208} = 13.9 \ \text{A}$$

$$\phi = -36.9^\circ \quad \text{for lagging pf of } 0.8$$

$$E_f = V_t\underline{/0^\circ} + I_a jX_s$$

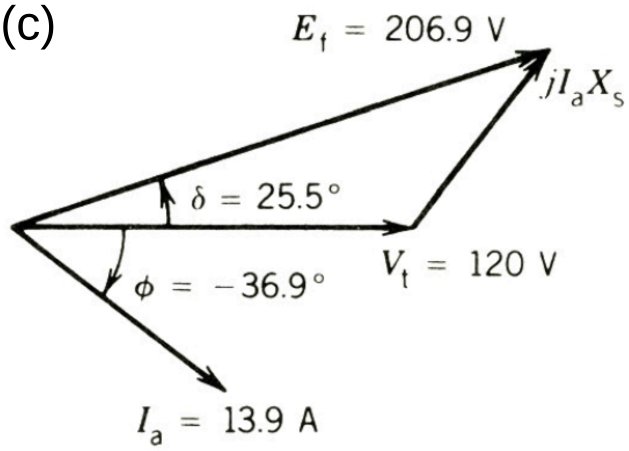
$$= 120\underline{/0^\circ} + 13.9\underline{/-36.9^\circ} \cdot 8\underline{/90^\circ}$$

(a) $$= 206.9\underline{/25.5^\circ}$$

Excitation voltage $E_f = 206.9$ V/phase

(b) Power angle $\delta = +25.5^\circ$

(c)



(d)

The new excitation voltage $E_f' = 1.2 \times 206.9 = 248.28$ V. Because power transfer remains same,

$$\frac{V_t E_f}{X_s} \sin \delta = \frac{V_t E_f'}{X_s} \sin \delta'$$

or

$$E_f \sin \delta = E_f' \sin \delta'$$

or

$$\sin \delta' = \frac{E_f}{E_f'} \sin \delta = \frac{\sin 25.5^\circ}{1.2}$$

$$\delta' = 21^\circ$$

The stator current is

$$I_a = \frac{E_f - V_t}{jX_s}$$

$$= \frac{248.28\angle 21^\circ - 120\angle 0^\circ}{8\angle 90^\circ}$$

$$= \frac{142.87\angle 38.52^\circ}{8\angle 90^\circ}$$

$$= 17.86\angle -51.5^\circ \text{ A}$$

Solution Problem 2

$$I_A = I_L = \frac{S}{\sqrt{3}\,V_T} = \frac{120\text{ MVA}}{\sqrt{3}(13.8\text{ kV})} = 5020\text{ A}$$

The power factor is 0.8 lagging, so $\mathbf{I}_A = 5020\angle -36.87°\text{ A}$. The phase voltage is 13.8 kV / $\sqrt{3}$ = 7967 V. Therefore, the internal generated voltage is

$$\mathbf{E}_A = \mathbf{V}_\phi + R_A\mathbf{I}_A + jX_S\mathbf{I}_A$$

$$\mathbf{E}_A = 7967\angle 0° + (0.1\ \Omega)(5020\angle -36.87°\text{ A}) + j(1.2\ \Omega)(5020\angle -36.87°\text{ A})$$

$$\mathbf{E}_A = 12{,}800\angle 20.7°\text{ V}$$

The resulting voltage regulation is

$$\text{VR} = \frac{12{,}800 - 7967}{7967} \times 100\% = 60.7\%$$

(b) If the generator is to be operated at 50 Hz with the same armature and field losses as at 60 Hz (so that the windings do not overheat), then its armature and field currents must not change. Since the voltage of the generator is directly proportional to the speed of the generator, the voltage rating (and hence the apparent power rating) of the generator will be reduced by a factor of 5/6.

$$V_{T,\text{rated}} = \frac{5}{6}(13.8\text{ kV}) = 11.5\text{ kV}$$

$$S_{\text{rated}} = \frac{5}{6}(120\text{ MVA}) = 100\text{ MVA}$$

Also, the synchronous reactance will be reduced by a factor of 5/6.

$$X_S = \frac{5}{6}(1.2\ \Omega) = 1.00\ \Omega$$

(c) At 50 Hz rated conditions, the armature current would be

$$I_A = I_L = \frac{S}{\sqrt{3}\,V_T} = \frac{100\text{ MVA}}{\sqrt{3}(11.5\text{ kV})} = 5020\text{ A}$$

The power factor is 0.8 lagging, so $\mathbf{I}_A = 5020\angle -36.87°\text{ A}$. The phase voltage is 11.5 kV / $\sqrt{3}$ = 6640 V. Therefore, the internal generated voltage is

$$\mathbf{E}_A = \mathbf{V}_\phi + R_A\mathbf{I}_A + jX_S\mathbf{I}_A$$

$$\mathbf{E}_A = 6640\angle 0° + (0.1\ \Omega)(5020\angle -36.87°\text{ A}) + j(1.0\ \Omega)(5020\angle -36.87°\text{ A})$$

$$\mathbf{E}_A = 10{,}300\angle 18.8°\text{ V}$$

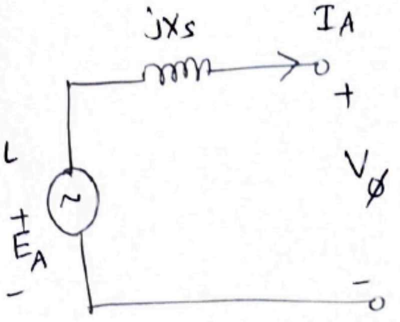
The resulting voltage regulation is

$$\text{VR} = \frac{10{,}300 - 6640}{6640} \times 100\% = 55.1\%$$

Solution Problem 3

$V_{rated\,L} = V_{rated\,ph} = 13.8\,kV$

$S_{rated} = 40\,MVA$



From,

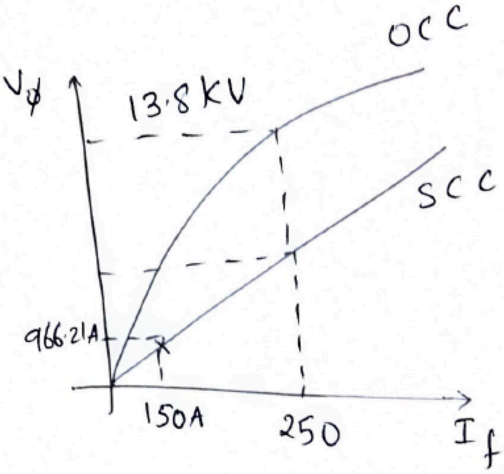
$S_{rated} = \sqrt{3}\, V_{rated\,L}\, I_{A\,rated\,L}$

$\Rightarrow I_{A\,rated} = 1673.53\,A$

$I_{A\,rated\,ph} = 966.21\,A$

$I_A\Big|_{250A} = 966.21 \times \dfrac{250}{150}$

$= 1610.35\,A.$



Now,

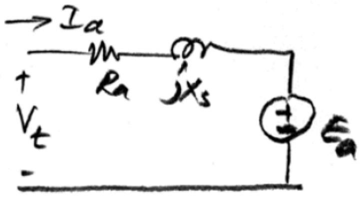
$$X_S = \frac{V_\phi}{I_{Aph}}\Bigg|_{\text{same } I_f}$$

[* one observation
$X_{S\Delta} = 3X_{SY}$]

$$= \frac{13.8 \times 10^3}{1610.35}$$

$$X_S = 8.569\ \Omega/\text{phase}$$

Solution Problem 4



$$V_t = \frac{380}{\sqrt{3}} \angle 0^\circ$$
$$= 219.393 \angle 0^\circ$$

$$P_{in} = 10 \times 746 + 1500$$
$$= 8960\,W$$

$$I_a = \frac{8960}{\sqrt{3} \times 380 \times 0.8} \angle \cos^{-1} 0.8$$

$$= 17.0166 \angle 36.87^\circ\ A$$

$$E_a = \frac{380}{\sqrt{3}} \angle 0^\circ - j\,2.5 \times 17.0166 \angle 36.87^\circ$$

$$= 247.2713 \angle -7.9^\circ\ V$$

Torque angle 7.9°

Solution Problem 5

(a) If this motor is assumed lossless, then the input power is equal to the output power. The input power to this motor is

$$P_{IN} = \sqrt{3} V_T I_L \cos\theta = \sqrt{3}(230 \text{ V})(40 \text{ A})(1.0) = 15.93 \text{ kW}$$

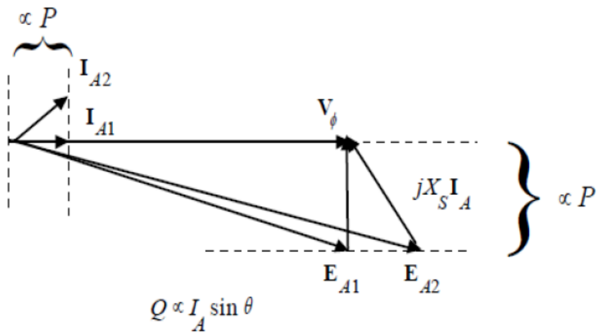
The rotational speed of the motor is

$$n_m = \frac{120 f_{se}}{P} = \frac{120(50 \text{ Hz})}{4} = 1500 \text{ r/min}$$

The output torque would be

$$\tau_{LOAD} = \frac{P_{OUT}}{\omega_m} = \frac{15.93 \text{ kW}}{(1500 \text{ r/min})\left(\frac{1 \text{ min}}{60 \text{ s}}\right)\left(\frac{2\pi \text{ rad}}{1 \text{ r}}\right)} = 101.4 \text{ N}\cdot\text{m}$$

(b) To change the motor's power factor to 0.8 leading, its field current must be increased. Since the power supplied to the load is independent of the field current level, an increase in field current increases $|\mathbf{E}_A|$ while keeping the distance $E_A \sin\delta$ constant. This increase in E_A changes the angle of the current $\mathbf{I}_A$, eventually causing it to reach a power factor of 0.8 leading.



(c) The magnitude of the line current will be

$$I_L = \frac{P}{\sqrt{3}\, V_T \text{ PF}} = \frac{15.93 \text{ kW}}{\sqrt{3}(230 \text{ V})(0.8)} = 50.0 \text{ A}$$