Question 1

- $pf = \cos\theta = 0.8$; $\theta = 36.86°$ (Lagging)
- $X_s = 1.1\,\Omega$; $R_A = 0.15\,\Omega$
- $V_{L\,rated} = 2300V$; $V_{ph\,rated} = 1328\,V$ $\because V_L = \sqrt{3}\,V_\phi$

a) At no load , $I_F = ?$

From the open circuit curve,

» $V_t = 2300\,V \rightarrow \underline{I_F = 4.3\,A}$

b) Internal generated Voltage

$V_{ph\,rated} = 1328\,V$; $S = \sqrt{3}\,V_L I_A$

$$I_A = \frac{1000\,k}{\sqrt{3}\,2300} = 251\,A$$

» $E_A = V_\phi + R_A I_A + jX_s I_A$

» $E_A = 1328 + (251\angle -36.86°)(0.15) + j(251\angle -36.86°)(1.1)$

$= \underline{1537\angle 7.4°\,V}$

c) Field current at rated conditions

$E_A = 1537$ corresponds to $V_{T,oc} = \sqrt{3}\,(1537)$

» $V_{T,oc} = 2662\,V \rightarrow \underline{I_F = 5.85\,A}$

d) Power and Torque

» $P_{out} = 3\,V_\phi I_A \cos(\theta) = 800\,kW$

» $P_{in} = P_{out} + P_{cu} + P_{F\&W} + P_{core}$

» $P_{cu} = 3 I_A^2 R_A = 28.35\ kW$

$P_{in} = 800k + 28.35k + 24k + 18k$

$= \underset{\sim\sim\sim}{870.35\ kW}$

» Torque $\tau_{app} = P_{in} / \omega_m$

$n_m = \frac{120 f}{P} = \frac{120(60)}{2} = 3600$ rev/min

$\omega_m = 3600$ rev/min $(1 \text{ min}/60s)(2\pi \text{ rad}/1 \text{rev})$

$= 120\pi$ rad/s

$\tau_{app} = \frac{870.35k}{120\pi} = \underset{\sim\sim\sim}{2308\ N.m}$

Question 2

a) Torque angle δ

At rated conditions, $I_A = 251$ (from Q1) with a pf of 1 (unity pf).

» $E_A = V_\phi + R_A I_A + j X_S I_A$

$= 1328 + (0.15)(251 \angle 0^\circ) + j(1.1)(251 \angle 0^\circ)$

$= 1393 \angle 11.4^\circ$

» Torque angle $\underset{\sim\sim\sim}{\delta = 11.4^\circ}$

b) Stability Limit

- Stability is limited to $\delta = 90°$

  Factor $\varepsilon = \frac{90°}{11.4°} = 7.89$

» Static stability limit is 7.89 times away from the computed torque angle δ.

Example 5.2

Δ connected : $V_t = V_\phi$; $I_L = \sqrt{3}\, I_\phi$

a) Speed n_m

$$n_m = \frac{120 f}{P} = \frac{120\,(60)}{4} = \underline{1800 \text{ rev/min}}$$

b) OC $\rightarrow I_A = 0$

$V_t = V_\phi = E_A = 480V$

From OCC, $\underline{I_F = 4.5A}$

c) $I_L = 1200$ A

Δ connected ; $I_A = \frac{1200}{\sqrt{3}} = \underline{692.8 \text{ A}}$

$$E_A = V_\phi + I_A R_A + j X_S I_A$$

$$= 480 + (692.8 \angle -36.87°)(0.015) + j(692.8 \angle -36.87°)(0.1)$$

$$= 532 \angle 5.3° \text{ V}$$

From OCC, $I_F = 5.7\ A$

d) $P_{out} = \sqrt{3}\ V_T I_L \cos\theta = 798\ kW$

$P_{in} = P_{out} + P_{cu} + P_{f\&w} + P_{core}$

$= 798k + 3I_A^2 R_A + 30k + 40k$

$= 889.6\ kW$

Efficiency $\eta = \dfrac{P_{out}}{P_{in}} \times 100\,\% = 89.75\,\%$

e) After load is disconnected, $I_A \to 0$ and since I_F remains unchanged, V_ϕ rises to match $E_A = 532\ V$.

f) With 0.8 pf leading;

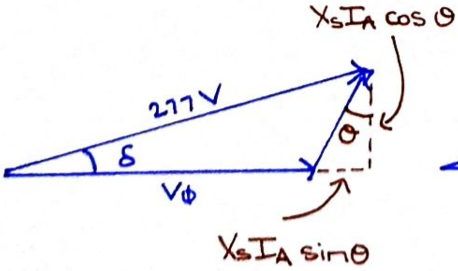
$E_A = 480 + (692.8\angle 36.87)(0.015) + j(692.8\angle 36.87)(0.1)$

$= 451\angle 7.1°\ V$

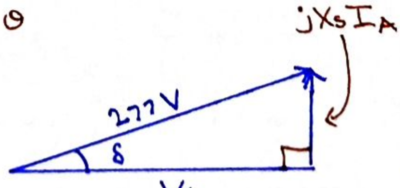
Example 5.3

a) $n_m = \dfrac{120 f_e}{P} = \dfrac{120\,(60)}{6} = 1000\ rev/min$

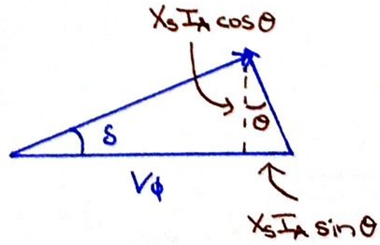
b) Y-connected $\rightarrow E_A = 480/\sqrt{3} = 277\ V$



1.



2.



3.

1. $E_A = \sqrt{(V_\phi + X_s I_A \sin\theta)^2 + (X_s I_A \cos\theta)^2}$

$277 = \sqrt{(V_\phi + 36)^2 + 2304}$

$V_\phi = 236.8\text{ V} \longrightarrow V_t = \sqrt{3}\ 236.8 = \underline{410\text{ V}}$

2. $E_A = \sqrt{V_\phi^2 + (X_s I_A)^2}$

$277 = \sqrt{V_\phi^2 + 3600}$

$V_\phi = 270.4\text{V} \longrightarrow V_t = \sqrt{3}\ 270.4 = \underline{468.4\text{V}}$

3. $E_A = \sqrt{(V_\phi - X_s I_A \sin\theta)^2 + (X_s I_A \cos\theta)^2}$

$277 = \sqrt{(V_\phi - 36)^2 + 2304}$

$V_\phi = 308.8\text{ V} \longrightarrow V_t = \sqrt{3}\ 308.8 = \underline{535\text{ V}}$

c) $P_{out} = 3\, V_\phi\, I_A \cos\theta = 34.1\text{ kW}$

$P_{in} = P_{out} + P_{core} + P_{mech}$

$= 34.1\text{k} + 1\text{k} + 1.5\text{k}$

$= 36.6\text{ kW}$

Efficiency $\eta = \dfrac{P_{out}}{P_{in}} \times 100\,\% = 93.2\,\%$

d) Input Torque $\tau_{app} = \dfrac{P_{in}}{\omega_m} = \dfrac{36.6\text{k}}{125.7} = \underline{291.2\text{ N.m}}$

Counter Torque $\tau_{ind} = \dfrac{P_{out}}{\omega_m} = \dfrac{34.1\text{k}}{125.7} = \underline{271.3\text{ N.m}}$

e) $VR = (V_{nl} - V_{fl}) / V_{fl} \times 100\,\%$

1. Lagging $VR = (480 - 410)/410 \times 100\,\% = 17.1\,\%$

2. Unity $VR = (480 - 468)/468 \times 100\% = 2.6\,\%$

3. Leading $VR = (480 - 535)/535 \times 100\% = -10.3\,\%$

Problem 5.3

a) $I_F = 4.5A \longrightarrow$ From OCC, $V_t = 2385\ V$

$E_A = V_\phi = 1377\ V$

Δ - Load $= 20 \angle 30^\circ\ \Omega$

» Equivalent to $Y = \frac{R^2}{3R} = \frac{1}{3}(20 \angle 30^\circ) = 6.67 \angle 30^\circ$

$$I_A = \frac{E_A}{|R_A + jX_s + Z|} = \frac{1377}{|0.15 + j1.1 + 6.667 \angle 30^\circ|}$$

$$= 186\ A$$

$V_\phi = I_A Z = 1240\ V$

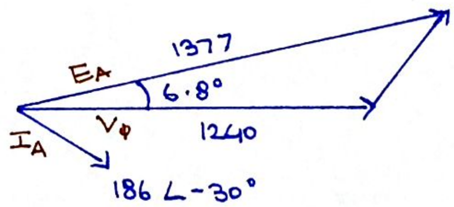
$V_t = \sqrt{3}\, V_\phi = 2148\ V$

b) $I_A = 186 \angle -30^\circ$

$E_A = V_\phi + R_A I_A + jX_s I_A$

$= 1240 + (0.15)(186 \angle -30^\circ) + j(1.1)(186 \angle -30^\circ)$

$= 1377 \angle 6.8^\circ\ V$



c) $P_{out} = 3 V_\phi I_A \cos\theta = 599\ kW$

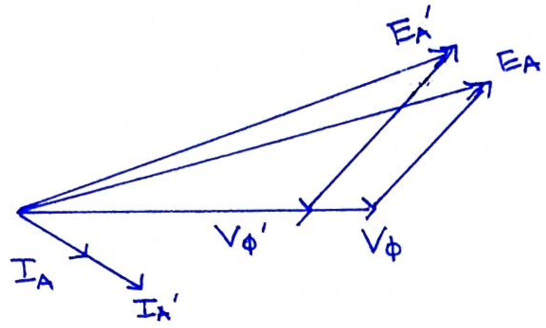
$P_{in} = P_{out} + P_{cu} + P_{f\&w} + P_{core}$

$= 599k + 3I_A^2 R_A + 24k + 18k$

$= 657\ kW$

Efficiency $\eta = \dfrac{P_{out}}{P_{in}} \times 100\% = 91.1\%$

d) Due to new load ; $V_\phi' < V_\phi$



Inference

$\therefore |E_A'| = |E_A|$

$\therefore I_A' > I_A$

$\therefore V_\phi' < V_\phi$

e) New impedance will be halved (in parallel)

$Z = 3.33 \angle 30°\ \Omega$

$I_A = \dfrac{E_A}{|R_A + jX_S + Z|} = 335\ A$

$V_\phi = I_A Z = 1117\ V$

$V_t = \sqrt{3}\, V_\phi = 1934\ V$

f) To restore V_t to its original value, E_A must be increased (which can be done by increasing field current I_F)

Problem 5.4

a) As computed in "Question 1";

$P_{out} = 800\ kW$; $P_{in} = 870.4\ kW$

Efficiency $\eta = \dfrac{P_{out}}{P_{in}} \times 100\% = 91.9\%$

b) As computed in "Question 1";

$E_A = 1537 \angle 7.4^\circ$

$V_\phi = \frac{V_t}{\sqrt{3}} = 1328 \text{ V}$

$VR = \frac{1537 - 1328}{1328} \times 100\% = 15.7\%$

c) Leading load $\rightarrow I_A = 251 \angle 36.87^\circ$ A

$E_A = V_\phi + R_A I_A + jX_s I_A$

$= 1328 + (0.15)(251 \angle 36.87^\circ) + j(1.1)(251 \angle 36.87^\circ)$

$= 1217 \angle 11.5^\circ \text{ V}$

$VR = \frac{1217 - 1328}{1328} \times 100\% = -8.4\%$

d) Unity pf $\rightarrow I_A = 251 \angle 0^\circ$ A

$E_A = V_\phi + R_A I_A + jX_s I_A$

$= 1328 + (0.15)(251 \angle 0^\circ) + j(1.1)(251 \angle 0^\circ)$

$= 1393 \angle 11.4^\circ \text{ V}$

$VR = \frac{1393 - 1328}{1328} \times 100\% = 4.9\%$