Q1. (30 points):

A balanced, 3-phase, 60 HZ, 3-wire, impedance load is served by a balanced, 3-phase, 3-wire, ABC sequence source. A voltmeter between two lines reads 275 Volts. An ammeter in one line reads 13 Amps. A wattmeter connected to read the power "into" the A-B lines reads 1650 Watts.

a. Find the power factor of the load.
b. Find the total 3-phase real power absorbed by the load.
c. A capacitor bank is used to correct the load power factor to unity. Compute the power readings in the two wattmeter method.
d. Draw a schematic showing how a wattmeter can be used to 'measure' the reactive power consumed by the balanced 3-phase load, with appropriate polarity markings on the voltage and current measurements.

12 a. $V_{LL} = 275V$

$I_L = 13A$

$P_1 = V_{LL} I_L \cos(\theta + 30^\circ) = 1650$

$\cos(\theta+30^\circ) = \frac{1650}{275 \times 13} = 0.4615 \Rightarrow \theta + 30^\circ = 62.51^\circ$

$\theta = 32.51^\circ$

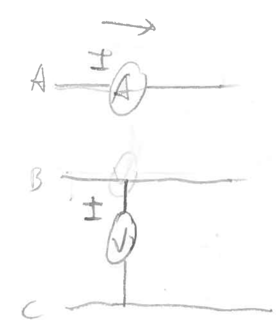
$PF = \cos(\theta) = \boxed{0.8433}$

6 b. $P_{3\phi} = \sqrt{3} V_{LL} I_L \cos(\theta) = \sqrt{3} \times 275 \times 13 \times 0.8433$

$= \boxed{5222\ W}$

6 c. $\theta = 0$. $P_1 = P_2 = V_{LL} I_L \cos(30^\circ) = \frac{P_{3\phi}}{2} = \boxed{2611\ W}$

6 d.



$Q_{3\phi} = \sqrt{3}\, P_{1wm}$

3/6

Q2. (35 points):

The following test results were found for a single-phase, 60 HZ, 30 KVA transformer with voltage ratings 4160/480 Volts:

Open-circuit test: $V_L = 480$ V, $I_L = 4$ A, $P_2 = 380$ W

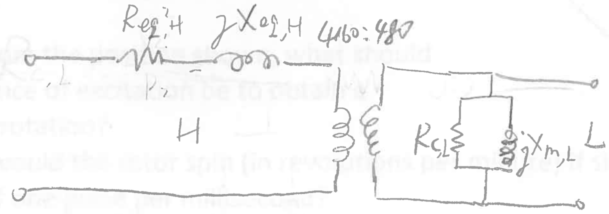
Short-circuit test: $V_H = 142$ V, $I_H = 7.2$ A, $P_1 = 440$W

(a) Compute all the parameters of the approximate equivalent circuit with the shunt elements moved directly across the source.

(b) Draw the approximate equivalent circuit and label all impedances with per unit values.

(c) Find the high side voltage when the transformer is delivering rated kVA at 0.87 lagging power factor to a load on the low voltage side with a 480V across the load.

12 (a)



$R_{c,L} = \frac{V_L^2}{P_2} = \boxed{606.3\,\Omega}$ $Q_2 = \sqrt{(V_L I_L)^2 - P_2^2} = \sqrt{(480\times4)^2 - 380^2} = 1882$ Var $X_{m,L} = \frac{V_L^2}{Q_2} = 122.4$

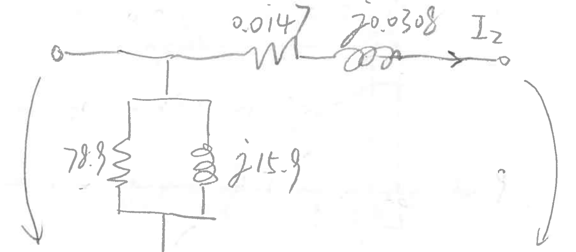
$R_{c,H} = \left(\frac{4160}{480}\right)^2 R_{c,L} = 8.6667^2 R_{c,L} = \boxed{45540\,\Omega}$ $X_{m,H} = \left(\frac{4160}{480}\right)^2 X_{m,L} = \boxed{9193.6\,\Omega}$

$R_{eq,H} = \frac{P_1}{I_H^2} = \boxed{8.488\,\Omega}$ $Q_1 = \sqrt{(V_H I_H)^2 - P_1^2} = 922.9$ Var, $X_{eq,H} = \frac{Q_1}{I_H^2} = \boxed{17.80\,\Omega}$

12 (b) $Z_{H,base} = \frac{V^2_{rated,H}}{S_{rated}} = \frac{4160^2}{30\times10^3} = 576.85\,\Omega$

$R_{c,pu} = \frac{R_{c,H}}{Z_{H,base}} = \boxed{78.9}$ $X_{m,pu} = \frac{X_{m,H}}{Z_{H,base}} = \boxed{15.9}$

$R_{eq,pu} = \frac{R_{eq,H}}{Z_{H,base}} = \boxed{0.0147}$ $X_{eq,pu} = \frac{X_{eq,H}}{Z_{H,base}} = \boxed{0.0308}$



11 (c) $\bar{V}_{2,pu} = 1.0\angle0^\circ$ $\theta = \arccos(0.87) = 29.54^\circ$ $|\bar{I}_{2,pu}| = \frac{|\bar{S}_{2,pu}|}{|\bar{V}_{2,pu}|} = \frac{1.0}{1.0} = 1.0$

$\bar{I}_{2,pu} = 1.0\angle-\theta = 1.0\angle-29.54^\circ = 0.87 - j0.493$

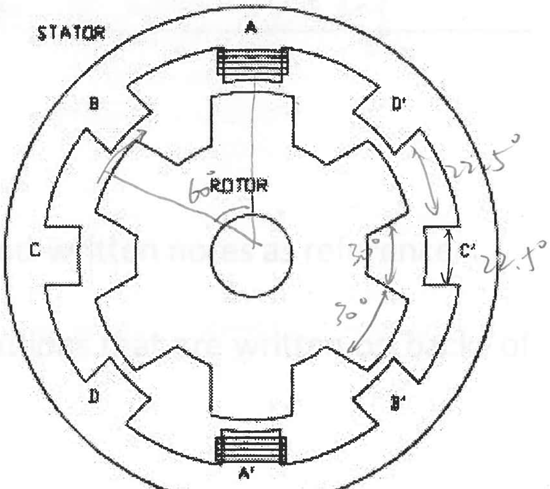
$\bar{V}_{1,pu} = \bar{V}_{2,pu} + (R_{eq,pu} + jX_{eq,pu})\cdot\bar{I}_{2,pu} = 1 + (0.0147 + j0.0308)(0.87 - j0.493)$

$= 1.02797 + j0.01955 = 1.0282\angle1.089^\circ$ $|\bar{V}_1| = 1.0282\times4160 = \boxed{4277\text{ V}}$

Q4. (35 points) 8/16

A reluctance machine with a 6/4 configuration has the following parameters.

Rotor outer radius = 6 cm
Air gap, g = 1mm
Rotor pole angle = $\pi/6$ radians
stator pole angle = $\pi/8$ radians
Axial length = 10 cm
Number of total turns per phase = 40



Assume rotor and stator cores have extremely high permeability. Assume infinite reluctance when there is no stator/rotor pole overlap. Ignore saturation and fringing flux.

a) Starting from the position shown, what should the sequence of excitation be to obtain a clockwise rotation?
b) How fast would the rotor spin (in revolutions per minute) if single phase excitation is applied at the rate of one pulse per millisecond?
c) Plot the phase-A inductance as a function of rotor position θ, as the rotor is rotated clockwise from θ=0 to θ=60 degrees.
d) Plot the torque as the rotor is rotated clockwise from θ=0 to θ=60 degrees with Phase A current =1A and all other currents set to zero.

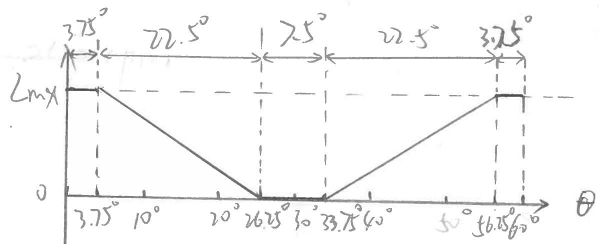
6 (a) $A \to B \to C \to D$

6 (b) 1 pulse/ms = 1 step/ms $\Rightarrow f_s = 1000$ steps/sec

$S = mN_r = 6 \times 4 = 24$ steps/rev

$n = \frac{60 f_s}{S} = \boxed{2500 \text{ rpm}}$

13 (c)

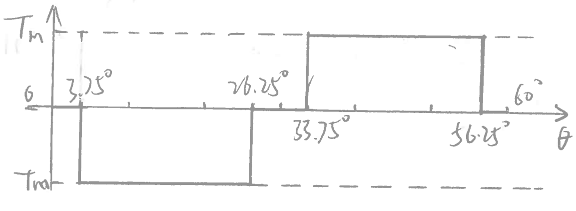


$\frac{30°-22.5°}{2} = 3.75°$

$R = 0.06$ m, $\alpha = \frac{\pi}{8}$, $D = 0.10$ m, $N_{ph} = 40$.

reluctance: $R_g = \frac{2g}{\mu_0 (\alpha R D)}$ $\quad L_{mx} = \frac{N_{ph}^2}{R_g} = \frac{\mu_0 \alpha R D N_{ph}^2}{2g} = \frac{1.2566\times10^{-6}\times\frac{\pi}{8}\times0.06\times0.10\times40^2}{2\times1\times10^{-3}} = \boxed{2.369 \text{ mH}}$

10 (d)



$T_m = \frac{\partial W_m'}{\partial \theta} = \frac{1}{2} I^2 \cdot \frac{L_{mx}}{\alpha} = \frac{1}{2}\times 1^2 \times \frac{2.369\times10^{-3}}{\frac{\pi}{8}}$

$= \boxed{3.016\times10^{-3} \text{ Nm}}$