S. Karaki | EECE 370 - Q1 | November 6, 2008 | 1

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(4)

1. a)

→ Length and area of air gap:

$$l_g = 0.1 \text{ cm} \qquad a_g = 45 \times \frac{\pi}{180} \times 13.1 \times 20 = 205.8 \text{ cm}^2$$

→ Rotor

$$l_r = \frac{13 \times \cos 22.5 \times 2 + 26}{2} = 25 \text{ cm}$$

$$a_r = 13 \times \sin 22.5 \times 2 \times 20 = 199 \text{ cm}^2 = 0.02 \text{ m}^2$$

→ Poles

$$l_p = 15 - 13 - 0.1 = 1.9 \text{ cm}$$

$$a_p \cong a_g = 13.1 \times \sin 22.5^\circ \times 2 \times 20 = 200.5 \text{ cm}^2$$

→ Yoke

$$l_y \cong 15 \times \pi = 47.1 \text{ cm}$$

$$a_y = 0.5 \times 20 = 10 \text{ cm}^2$$

b) If the steel is unsaturated,

$$\mu_s = \frac{0.8}{100} = 8 \times 10^{-3} \text{ H/m} \qquad \mu_0 = 4\pi \times 10^{-7} \text{ H/m}.$$

Calculate reluctances

$$\mathcal{R}_g = \frac{1}{\mu_0} \frac{l_g}{a_g} = \frac{10^7}{4\pi} \times \frac{0.1 \times 10^{-2}}{205.8 \times 10^{-4}} = 38\,667 \text{ A/Wb}$$

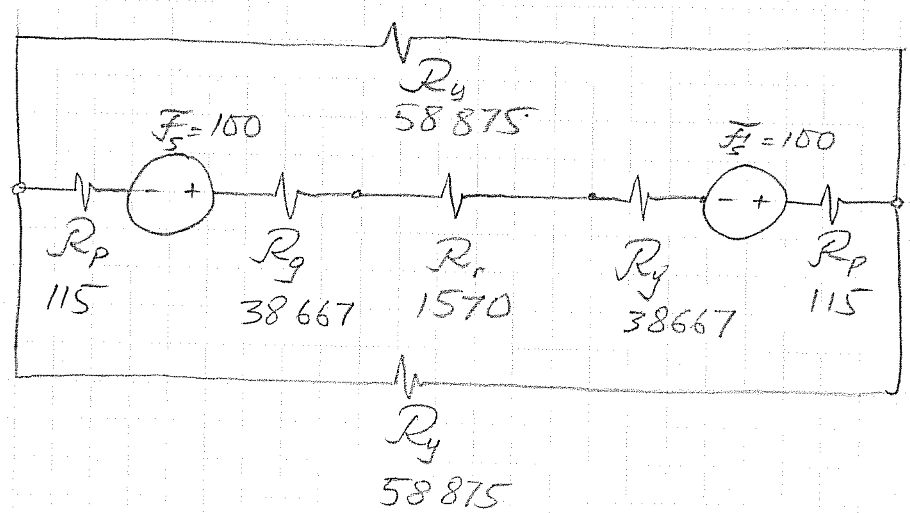
$$\mathcal{R}_r = \frac{1}{\mu_s} \times \frac{l_r}{a_r} = \frac{1}{8 \times 10^{-3}} \times \frac{25 \times 10^{-2}}{199 \times 10^{-4}} = 1570 \text{ A/Wb}$$

$$\mathcal{R}_p = \frac{1}{\mu_s} \times \frac{l_p}{a_p} = \frac{1}{8\times10^{-3}} \times \frac{1.9\times10^{-2}}{200.5\times10^{-4}} = 118 \ A/W_b$$

$$\mathcal{R}_y = \frac{1}{\mu_s} \times \frac{l_y}{a_y} = \frac{1}{8\times10^{-3}} \times \frac{47.1\times10^{-2}}{10\times10^{-4}} = 58\,875 \ A/W_b$$

$$\mathcal{F}_s = 50\times2 = 100 \ A.t$$

The magnetic circuit is:



c) Calculate equivalent reluctance:

$$\mathcal{R}_{eq} = \underbrace{2\mathcal{R}_g + 2\mathcal{R}_p + \mathcal{R}_r}_{\mathcal{R}_c = 79134} + \frac{\mathcal{R}_y}{2} = 108\,578 \ A/W_b$$

Machine flux:

$$\phi = \frac{\mathcal{F}_s \times 2}{\mathcal{R}_{eq}} = \frac{100\times2}{108578} = 18.42\times10^{-4} \ Wb$$

Flux densities:

$$B_g = \frac{\phi}{a_g} = \frac{18.42\times10^{-4}}{205.8\times10^{-4}} = 0.0895 \ T$$

$$B_p = \frac{18.42\times10^{-4}}{199\times10^{-4}} = 0.0926\ T$$

$$B_p = \frac{18.42\times10^{-4}}{205.8\times10^{-4}} = 0.0895\ T$$

$$B_y = \frac{18.42\times10^{-4}}{2\times10\times10^{-4}} = 0.921\ T$$

Flux density in the yoke is higher than the knee of the curve and hence, the yoke is saturated.

d) To obtain the maximum current we set the flux density in the yoke to 0.8T at the knee of curve.

$$\phi_y = 0.8\times10\times10^{-4} = 8\times10^{-4}\ Wb$$

$$\phi_g = 2\phi_y = 16\times10^{-4}\ Wb$$

The required mmf accross yoke is:

$$\mathcal{F}_y = \phi_y\times\mathcal{R}_y = 8\times10^{-4}\times 58875 = 47.1\ At$$

$$2\mathcal{F}_s = \mathcal{R}_c\,\phi_\phi + \mathcal{F}_y = 2NI_{max}$$

$$\mathcal{F}_s = (\mathcal{F}_y + \mathcal{R}_c\,\phi_g)/2 = NI_{max} \Longrightarrow$$

$$I_{max} = \frac{47.1 + 79134\times16\times10^{-4}}{2\times50} = 1.74\ A.$$

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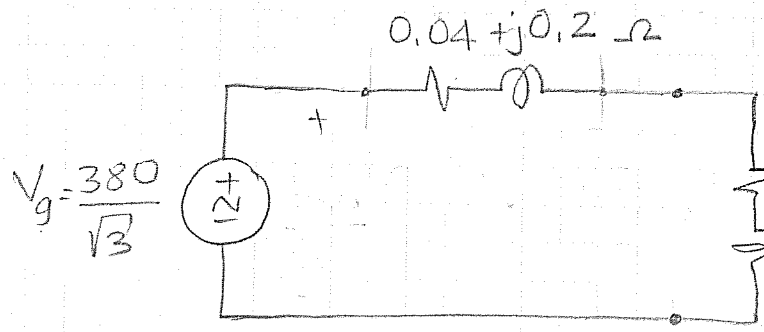
2. a) The per-phase equivalent circuit:



$Z_L = Z_\phi / 3$
$= 2 \angle 36^\circ \,\Omega$
$= 1.62 + j1.18 \,\Omega$

b) Current in transmission line:

First calculate load current or generator current:

$I_L = V_G / (Z_L + Z_T) =$

$= \frac{380}{\sqrt{3}} \times \frac{1}{(1.62 + j1.18) + (0.04 + j0.2)}$ ↓ wrong $V_g = 380V$

$= 78.38 - j65.03 = 101.8 \angle -39.68^\circ$ I_L 176.3

$V_L = I_L Z_L = 101.8 \angle -39.68 \times 2 \angle 36^\circ$
$= 203.6 \angle -3.68^\circ$ V V_L 352.6

$|V_{\phi L}| = 203.6 \times \sqrt{3} = 352.6$ V

$|\Delta V_T| = |219.4 - 203.6 \angle -3.68| = 20.8$V ΔV 47.5V
$= 9.48\%$

c) Active and reactive power supplied to the load :

$$P_L + jQ_L = 3V_L I_L^* = 3 \times 203.6 \angle -3.69^\circ \times (101.8 \angle 39.68)$$

$$= 62179 \angle 36^\circ$$

$$= 50304 + j\,36548 \quad VA$$

Active and reactive power delivered by generator :

$$P_G + jQ_G = 3V_G I_L^* = 3 \times \frac{380}{\sqrt{3}} \times 101.8 \angle 39.68$$

$$= 67005 \angle 39.68^\circ$$

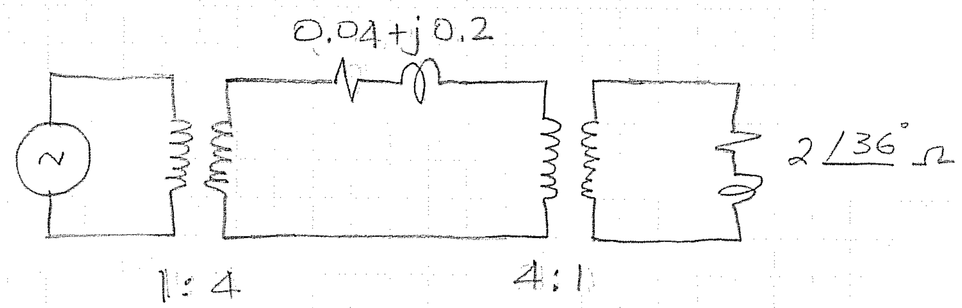
$$= 51569 + j\,42783 \quad VA$$

Active losses in the transmission lines:

$$P_{losses} = 51569 - 50304 = 1265\ W$$

$$PF_G = \frac{51569}{67005} = 0.77$$

d) One way is to raise the voltage at the generator side and lower it back on the load side using two transformers. The per phase equivalent circuit would be:



For example if we raise the voltage by 4 the current would drop by . The new current magnitude in the transmission lines is nearly equal to 101.8/4. The losses are given by:

$$P'_{losses} = 3\left(\frac{101.8}{4}\right)^2 \times 0.04 = 77.7\,W$$

instead of 1265 W!

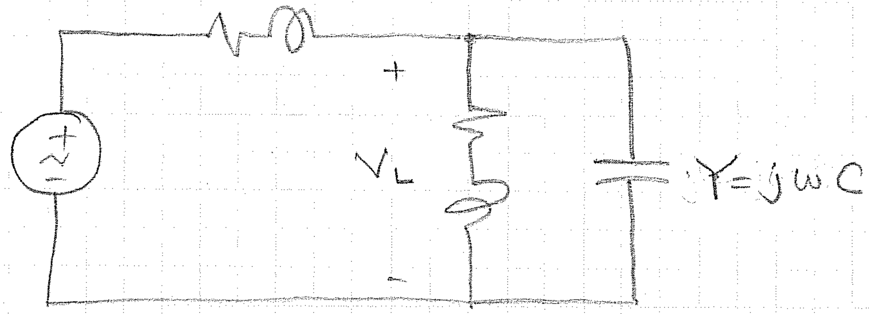
Another way is to add a second transmission line so that the equivalent impedance of the line becomes:

$$Z'_L = 0.02 + j0.1\ \Omega$$

The new losses are

$$P'_{losses} = 3 \times \left(\frac{101.8}{2}\right)^2 \times 0.02 \times 2 = 310.9\,W$$

The power factor of the load may be increased by adding a capacitor in parallel with the load. The size of the capacitor should be such that to provide reactive power equal to that needed by the load:



The reactive power supplied by capacitor:

$$Q_c = 3\frac{V_L^2}{X_c} = 3V_L^2 Y_c$$

Let $Q_c = Q_L = 36548$ VAr

$$\therefore \quad Y_c = \frac{Q_c}{3V_L^2} = \frac{36548}{3\times(203.6)^2} = 0.294 \text{ S}$$

$$C = \frac{|Y_c|}{\omega} = 9.35\times10^{-4}\text{ F} \simeq 1.\text{mF} \; !$$

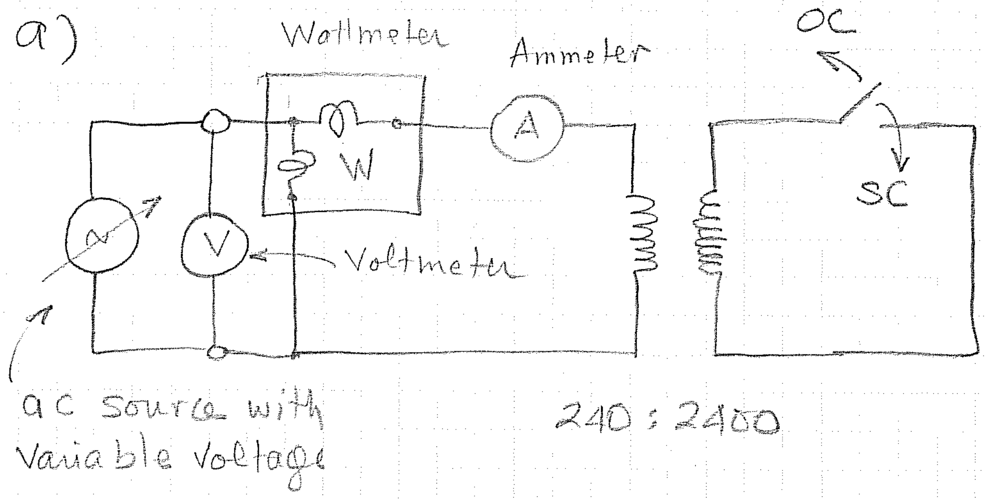
The new current is approximately given by:

$$I_{L(n)} = I_L \times \cos\theta_L = 101.8\times\cos 36^\circ = 82.4\text{A}$$

The new losses: $P_{Losses(n)} = 3I_{L(n)}^2 R = 814$ W

3.

a)



b) From the OC test we can calculate the components of excitation admittance:

$Y_E = \frac{1}{R_c} - j\frac{1}{X_M}$ $\qquad Y_E = \frac{I_{oc}}{V_{oc}} \angle -\cos^{-1} PF_{oc}$

$PF_{oc} = \frac{127}{240 \times 1.07} = 0.495$

$Y_E = \frac{1.07}{240} \angle -\cos^{-1} 0.495 = 4.458 \angle -60.36^\circ$

$= (2.205 - j\,3.875)\,10^{-3}$ S

$\therefore$ $R_c = 453.5\ \Omega$

$X_M = 258.1\ \Omega$

The series impedance is essentially given by the short circuit test:

$$Z_{eq} = R_{eq} + jX_{eq} = \frac{V_{sc}}{I_{sc}} \angle -\cos^{-1} PF_{sc}$$

$$PF_{sc} = \frac{P_{sc}}{V_{sc} I_{sc}} = 0.592$$

$$\therefore \quad Z_{eq} = \frac{5.75}{83.4} \angle +\cos^{-1} 0.592$$

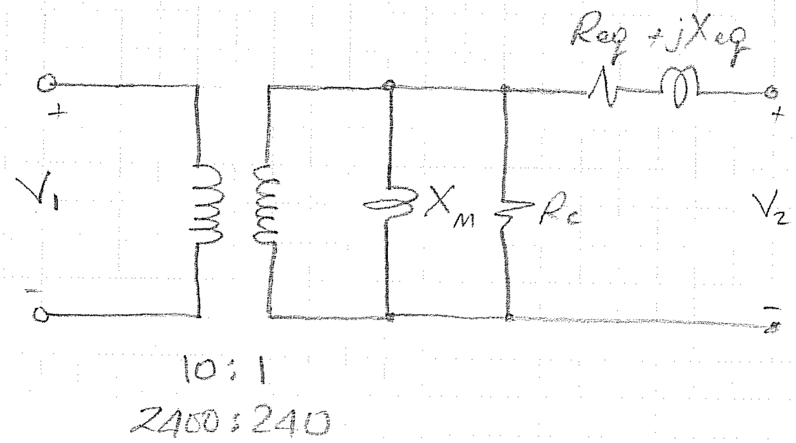
$$= 0.06894 \angle +53.68^\circ$$

$$= 0.0408 + j\,0.0555 \quad \Omega$$

$$R_{eq} = 0.0408\,\Omega \qquad X_{eq} = 0.0555\,\Omega$$

referred to low voltage.

c)



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d)

Transformer efficiency at full load:

The full load current on low voltage is:

$$I_{2fl} = \frac{20\,000}{240} \angle -31.79 \quad A$$

$$V_{2,fl} = 240 \text{ V}$$

The transformer losses are:

$$P_{losses} = (I_{2,fl})^2 R_{eq} + \frac{V_{2fl}^2}{R_c} = 283 + 127$$

$$= 410 W$$

$$\eta_T = \frac{240 \times 83.3 \times 0.85}{240 \times 83.3 \times 0.85 + 410} = \frac{16993}{16993 + 410}$$

$$= 97.6\%$$

Voltage regulation is given by:

$$V_{2,nl} = \frac{V_1}{a}$$

$$\frac{V_1}{a} = V_{2,fl} + I_{2fl} \times (R_{eq} + jX_{eq})$$

$$= 240 + (83.3 \angle -31.79)(0.06894 \angle 53.68)$$

$$= 240 + 5.7 \angle 21.9 =$$

$$= 245.3 + j\,2.13 = 245.3 \angle 0.5^\circ$$

2.2%

$$V_R = \frac{245.3 - 240}{240} = 0.022 = 2.2\%.$$

(1)

4.

a) Eddy currents flow in magnetic cores subjected to a time-varying flux. The flow of these current cause losses that are propotional to the path followed by these currents. These losses can be reduced by laminating the core along the path of the flux.

b) The excitation current has two components, the core loss current and magnetization current. The core loss current is in phase with the applied voltage and is modeled by a resistance in parrallel with the source. The magnetization current lags the voltage by 90° and is thus modeled by an inductance, the magnetizing inductance, in parrallel with the source.