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Problem set 2

Date No.

Student number: A0199806L

$a=9,\ b=8,\ c=0,\ d=6$

1. At no load, $s \approx 0\%$

$\Rightarrow N_s \approx N_{r,\text{no load}} = 988$

$$s_{\text{full load}} = \frac{988-902}{988} \times 100\% = 8.7045\%$$

$$= 8.7\%$$

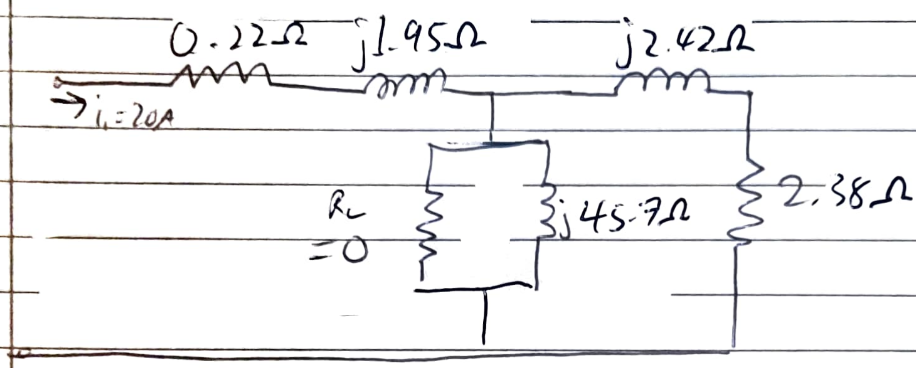
$$f_{r,\text{full load}} = s_{\text{full load}} \cdot f = 0.087045\,(50)$$

$$= 4.35225$$

$$= 4.35\ \text{Hz}$$

Date No.

$$\frac{R_2}{s} = \frac{0.207}{0.087} = 2.3793\,\Omega$$



Date No.

P_{SCL} = stator copper loss

$P_{SCL} = 3I_1^2 r_1 = 3(20)^2(0.22)$
$= 264$

$P_{AG} = P_{in} - P_{core} - P_{SCL}$ | $P_{in} = X = 27kW$
$= 27\times10^3 - 0 - 264$
$= 26\,736W$

$P_{AG} = 3I_2'^2 \frac{R_2'}{s}$
$\Rightarrow s.P_{AG} = 3I_2'^2 R_2' = P_{RCL}$
$P_{RCL} = 0.087 \times 26736$
$= 2326.032W$

2. 345kV, 50Hz, 200km

$r = 0.036\,\Omega/km$, $L = 0.8mH/km$, $c = 0.112\,\mu F/km$

$g = 0$

Load = Y = 260 MVA, 0.8 lag, @ 325kV

$$Z = (r + j\omega L) \times 200$$
$$= [0.036 + j(2\pi \cdot 50 \cdot 0.8 \times 10^{-3})]\,200$$
$$= 7.20 + j50.2655\,\Omega$$

$$Y = (j\omega C) \times 200$$
$$= j(100\pi \cdot 0.112 \times 10^{-6}) \times 200$$
$$= j\,7.0372 \times 10^{-3}\,s$$

$$A = D = 1 + \frac{YZ}{2} = 0.823136 + j0.02533 = 0.823526\angle 1.76258^\circ$$
$$B = Z = 7.20 + j50.2655\,\Omega = 50.77854\angle 81.8484^\circ\,\Omega$$
$$C = \left(1 + \frac{YZ}{4}\right)Y = (0.911568 + j0.012667)(j7.0372 \times 10^{-3})$$
$$= -8.914 \times 10^{-5} + j6.41489 \times 10^{-3})s = 6.4155 \times 10^{-3}\angle 89.2039^\circ\,s$$

a. Load ⇒ 260 MVA @ 0.8 lag @ 325kV

$$V_R = \frac{325 \times 10^3}{\sqrt{3}}\angle 0^\circ V = 187.64\,kV\angle 0^\circ$$

$$|I_R| = \frac{260 \times 10^6}{3 \times \frac{325 \times 10^3}{\sqrt{3}}} = 461.88\,A$$

$$\leftarrow -\cos(0.8) = -36.87^\circ$$

$$I_R = 461.88\angle -36.87^\circ A$$

$$\begin{bmatrix} V_S \\ I_S \end{bmatrix} = \begin{bmatrix} A & B \\ C & D \end{bmatrix} \begin{bmatrix} V_R \\ I_R \end{bmatrix}$$

$$\cancel{V_S = AV_R + BI_R = (0.823526\angle 1.76258^\circ)(187.64 \times 10^3\angle 0^\circ)}$$
$$\cancel{+ (50.77854\angle 81.48}$$

Date No.

$$V_s = AV_R + BI_R = (0.823526\angle 1.76258^\circ)(187.64\times10^3\angle 0^\circ)$$
$$+ (50.77854\angle 81.48^\circ)(461.88\angle -36.87^\circ)$$
$$= 154.5264\times10^3\angle 1.76258^\circ + 23.45359\times10^3\angle 44.61^\circ$$
$$= 172.236865\times10^3\angle 7.078248^\circ$$
$$= 172.236865\angle 7.078248^\circ \text{ kV}$$

$$I_s = CV_R + DI_R = (6.4155\times10^{-3}\angle 89.2039^\circ)(187.64\times10^3\angle 0^\circ)$$
$$+ (0.823526\angle 1.76258^\circ)(461.88\angle -36.87^\circ)$$
$$= 1203.80442\angle 89.2039^\circ + 380.3702\angle -35.10742^\circ$$
$$= 1038.079829\angle 71.5867^\circ \text{ A}$$

$$|V_{RNL}| = \frac{|V_{SFL}|}{|A|} = \frac{172.236865}{0.823526}$$
$$= 209.1456 \text{ kV}$$

$$\%V_R = \frac{209.1456 - 187.64}{187.64} \times 100\%$$

$$= 11.46\%$$

$$S_{3\phi s} = 3V_s I_s^* = 536.3868\angle -64.508452^\circ \text{ MW}$$
$$P_{S3\phi} = 536.3868\cos(-64.508452) = 230.849 \text{ MW}$$
$$P_{R3\phi} = 260\text{ MVA} \times 0.8 = 208 \text{ MW}$$
$$\eta = \frac{208}{230.849} \times 100\% = 90.1\%$$

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Date No.

when p.f ⇒ 0.9 lead

$I_{R,new} = 461.88\angle 25.8419°\ A$

$V_{S,new} = AV_R + BI_{R,new} = 154.5264\times10^3\angle 1.76258°$
$+(50.77854\angle 81.48°)(461.88\angle 25.8419°)$
$= 154.5264\times10^3\angle 1.76258° + 23.45359\times10^3\angle 107.3219°$
$= 149.94739\angle 10.4287°\ kV$

$I_{S,new} = CV_R + DI_{R,new} = 1203.8044\angle 89.2039°$
$+(0.823526\angle .76258°)(461.88\angle 25.8419°)$
$= 1203.8044\angle 89.2039° + 380.3702\angle 27.6045°$
$= 1424.5713\angle 75.61989°\ A$

$$V_{R,NL,new} = \frac{|V_{S,new}|}{|A|} = \frac{149.94739}{0.823526}$$
$$= 182.0797\ kV$$

$$\%V_R = \frac{182.0797 - 187.64}{187.64} \times 100\%$$

$= -2.96\%$

$$S_{3\phi S,new} = 3 V_{S,new} I_{S,new}^{*} = 640.575 \angle -65.19119^{\circ} \text{ MW}$$

$$P_{S3\phi,new} = 640.575 \cos(-65.19119^{\circ}) = 268.78 \text{ MW}$$

$$\eta_{new} = \frac{P_{R3\phi}}{P_{S3\phi,new}} \times 100\% = \frac{208}{268.78} \times 100\%$$

$$= 77.39\%$$

3. $\Rightarrow$ 50Hz, 1000km, $D = 106cm = 1.06m$ conductor spacing, diameter $= 0.01m$

$$r' = 0.78\left(\frac{0.01}{2}\right) = 3.9\times10^{-3}\,m$$

$$\lambda_A = \frac{\mu_0}{2\pi}\left[i_A \ln\frac{1}{r_A'} + i_B \ln\frac{1}{D_{AB}} + i_C \ln\frac{1}{D_{AC}}\right]$$

3 wire system $\Rightarrow$ no neutral wire $\Rightarrow$ no neutral current $\Rightarrow$ Balanced system

$$\Rightarrow i_A + i_B + i_C = 0$$

$$i_B + i_C = -i_A$$

$$D_{AB} = D_{AC} = 1.06 = D$$

$$\lambda_A = \frac{\mu_0}{2\pi}\left[i_A \frac{1}{r'} + \ln\frac{1}{1.06}\left[-i_A\right]\right]$$

$$= \frac{\mu_0}{2\pi} i_A \ln\left|\frac{1.06}{3.9\times10^{-3}}\right|$$

$$L_A = \frac{\lambda_A}{i_A} = \frac{\mu_0}{2\pi}\ln\left|\frac{1.06}{3.9\times10^{-3}}\right| = 1.121\times10^{-6}\,H/m$$

$$X_L = 2\pi f \cdot L_A \cdot (1000\times10^3) = 2\pi(50)(1.121\times10^{-6})(1000\times10^3)$$

$$\approx 352.173$$

$$= 352\,\Omega \quad (3s.f.)$$

$G_1 \Rightarrow X_s = j12\,\Omega$, $V_s = 7kV$

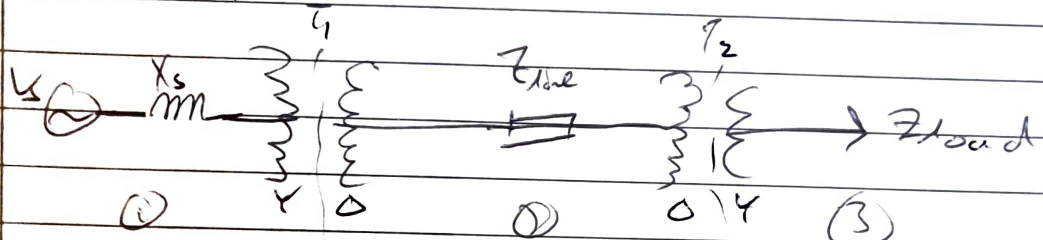
$T_1 \Rightarrow 14MVA, 11kV/220kV$, leakage reactance $= 0.07$ p.u., Y-Δ

$T_2 \Rightarrow 7MVA, 240kV/120kV$, leakage reactance $= 0.14$ p.u., Δ-Y

$Z_{line} = R + jX_L = 23 + j352.173\,\Omega$

$Z_{load} = 800\,\Omega$, Y

$S_B = 10MVA$



$V_{B1} = \frac{11}{220} \times 240$

$= 12kV$

$Z_{B,1} = \frac{(V_{B1}^{line})^2}{S_B^{3\phi}}$

$= \frac{(12\times10^3)^2}{10\times10^6}$

$= 14.4\,\Omega$

$V_{B2} = 240kV$

$Z_{B,2} = \frac{(240\times10^3)^2}{10\times10^6}$

$= 5760\,\Omega$

$V_{B,3} = \frac{120}{240} \times 240$

$= 120kV$

$Z_{B,3} = \frac{(120\times10^3)^2}{10\times10^6}$

$= 1440\,\Omega$

$V_{s,pu} = \frac{V_s}{V_{B,1}}$

$= \frac{7}{12}$

$= 0.5833\angle 0°$ p.u.

Z_{line} p.u. $= \frac{23 + j352.173}{5760}$

$= 0.003993 + j0.06114$ p.u.

$= 0.06127\angle 89.263°$ p.u.

Z_{load} pu $= \frac{800}{1440}$

$= 0.556$ p.u.

$X_{s,pu} = \frac{j12}{14.4}$

$= j0.8333$ p.u.

Date No.

T_1

14MVA, 11kV/220kV, $Z^{p.u.}_{T,old} = j0.07\,p.u.$, Y-Δ

$$Z_{T_1,new} = \frac{Z^{T_1}_{actual}}{Z^1_B}$$

$$= \frac{Z^{T_1}_{pu,old} \times Z^{T_1,prim}_{B,old}}{Z_B^1}$$

$$Z^{T_1,prim}_{B,old} = \frac{V^{prim}_{B,old}}{S_{B,old}} = \frac{(11\times10^3)^2}{14\times10^6}$$

$$Z_{T_1,new} = \frac{j0.07 \times \left(\frac{11\times10^3}{14\times10^6}\right)^2}{14.4}$$

$$= j0.042\,p.u.$$

T_2

7MVA, 240kV/120kV, $Z_{T_2} = j0.14\,p.u.$, Δ-Y

$$Z_{T_2,new} = \frac{Z_{actual}}{Z_B^2}$$

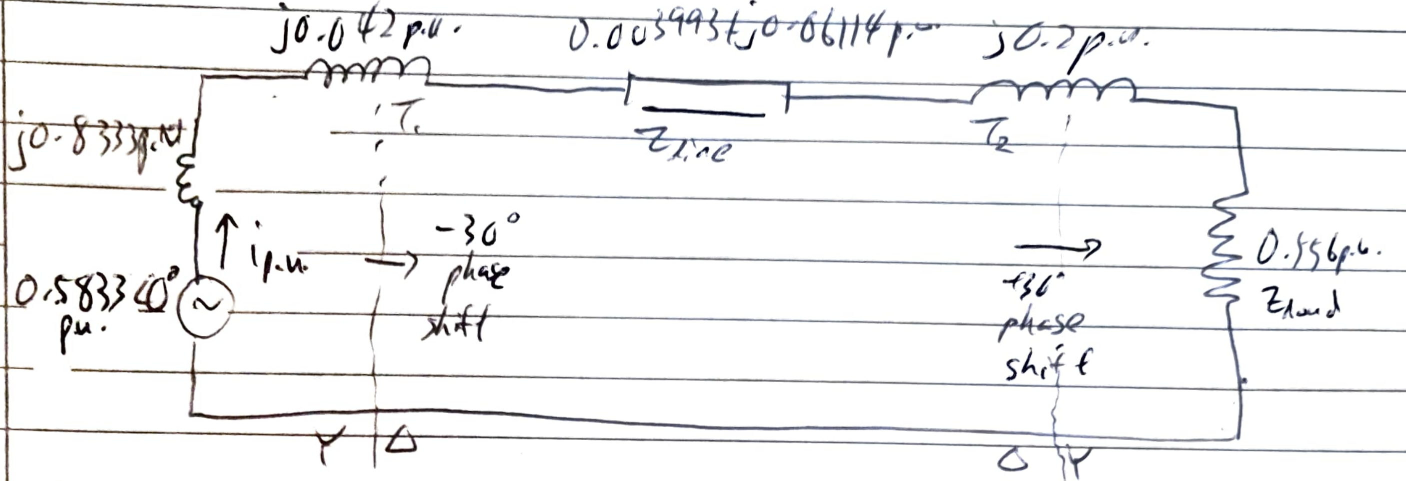
$$= \frac{Z_{pu,old} \times Z^{T_2,primary}_{B,old}}{Z_B^2}$$

$$Z^{T_2,primary}_{B,old} = \frac{(240\times10^3)^2}{7\times10^6}$$

$$Z_{T_2,new} = \frac{j0.14\times\left(\frac{240\times10^3}{7\times10^6}\right)^2}{5760}$$

$$= j0.2\,p.u.$$

Per unit impedance diagram



$$i_{p.u.} = \frac{V_{p.u.}}{Z_{total\ p.u.}} = \frac{0.583\angle 0^\circ}{j0.042 + j0.2 + 0.003993 + j0.06114 + 0.556 + j0.8333}$$

$$= \frac{0.583\angle 0^\circ}{1.26692\angle 63.7677^\circ}$$

$$= 0.46041\angle -63.7677^\circ \ p.u.$$

$$i_{p.u., gen} = 0.46041\angle -63.7677^\circ \ p.u.$$

$$i_{p.u., line} = 0.46041\angle -63.7677^\circ - 30^\circ$$

$$= 0.46041\angle -93.7677^\circ \ p.u.$$

$$i_{p.u., load} = 0.46041\angle -63.7677 \ p.u.$$

$$V_{p.u., line} = i_{pu\ line} \times Z_{line\ pu}$$

$$= 0.46041\angle -93.7677^\circ \times 0.06127\angle 89.263^\circ$$

$$= 0.02821\angle -4.4747^\circ \ p.u.$$

Date No.

$$S^{pu}_{line} = (V_{pu,line})(I_{pu,line})^*$$
$$= (0.02821\angle -4.4747^\circ)(0.46041\angle 93.7677^\circ)$$
$$= 0.012988\angle 89.293^\circ \longrightarrow \text{power angle}$$
$$= 0.000160 + j0.01299 \text{ p.u.}$$

$P_{pu,line}$ $Q_{pu,line}$

$$P^{3\phi}_{line} = 0.000160 \times 10 \times 10^6 = 1600 \text{ W}$$

Power angle $= 89.293^\circ$

Date No.

4. 66kVA, 960/120V

	Voltage (V)	Current (A)	Power (W)
SC	85	Rated current	240
OC	rated voltage	12	240

SC Test → I_{rated} → Primary → S.C. secondary side

$$I_{1,rated} = \frac{\text{Rated apparent power}}{V_{1\,rated}} = \frac{66\times10^3}{960} = 68.75\,A$$

$$Z_{eq} = \frac{V_{measured}}{I_{1,rated}} = \frac{85}{68.75} = 1.2364\,\Omega$$

$$P = I_{1,rated}^2 \cdot R_{eq}$$

$$\Rightarrow R_{eq} = \frac{240}{68.75^2} = 0.0507769\,\Omega$$

$$X_{eq} = \sqrt{Z^2 - R_{eq}^2} = \sqrt{1.2364^2 - 0.0507769^2}$$
$$= 1.23536\,\Omega$$

$$Z_{eq} = 0.0507769 + j1.23536\,\Omega$$

OC. Test

$V_{2\,rated} = 120V$, $V_{1\,rated} = 960V$, $I_2 = 12$

$$I_1 = 12\left(\frac{120}{960}\right) = 1.5\,A$$

$$|Y| = \frac{I_1}{V_{1\,rated}} = \frac{1.5}{960} = 0.0015625\,\mho$$

$P_2 = 240\,W = P_1$

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$P_i = V_{i\,rated}^2 \cdot G$

$G = \frac{240}{960^2} = 0.0002604\ \mho = \frac{1}{R_m}$

$R_m = \frac{1}{G} = 3840.246\ \Omega$

$B = \sqrt{Y^2 - G^2} = \sqrt{0.0015625^2 - 0.0002604^2}$

$= 0.0015406\ \mho = \frac{1}{X_m}$

$X_m = \frac{1}{B} = 649.10\ \Omega$