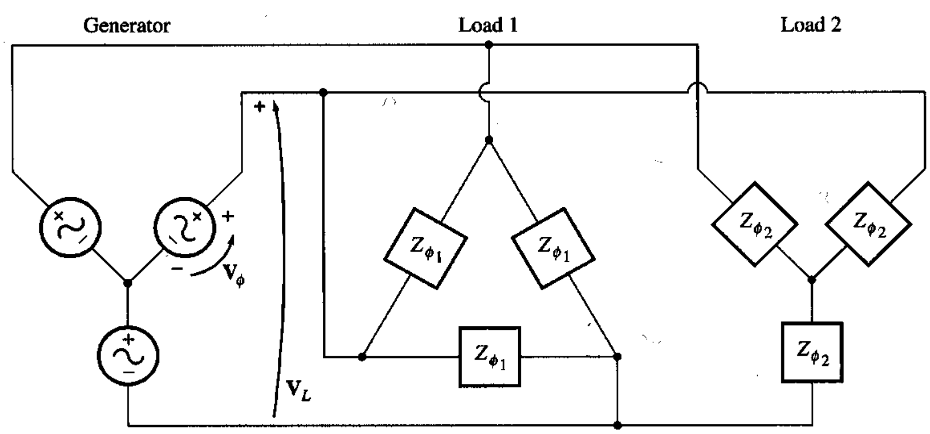
Concordia UNIVERSITY

COURSE : FUNDS OF ELECT POWER ENG.	NUMBER: ELEC 331 SECTION: W
EXAMINATION : FINAL	DATE : 04-16-14 TIME : 09:00 - 12:00 # OF PAGES : 3
INSTRUCTORS: Luiz Lopes	
MATERIALS ALLOWED: [X] NO	[ ] YES (PLEASE SPECIFY
CALCULATORS ALLOWED: [ ] NO	[X] YES
SPECIAL INSTRUCTIONS:	- Answer all questions. In cascaded questions, you can assume suitable values for parameters you have not been able to calculate in previous sub-questions.

1. Consider the 440 V_{LL} / 60 Hz three-phase system shown below. Load 1 is Δ-connected and consists of a series connection of R = 116.3 Ω and L = 0.154 H in each phase. Load 2 is Y-connected and consumes P = 4 kW and Q = -2 kVAr. A) Draw the per-phase equivalent circuit showing the values of the source voltage and load impedances; B) Compute the reactive power supplied by the source; C) Calculate the current circulating in one element of load 2. (15 marks)



2. The impedances of a single-phase transformer are as follows: R_{eq} = 0.02 pu, X_{eq} = 0.05 pu, X_m = 40 pu and R_c = 25 pu. Using the pu system and considering the case of "full load" with PF = 0.8 leading: A) Calculate the percentage voltage regulation; B) Compute the efficiency of the transformer. (10 marks)

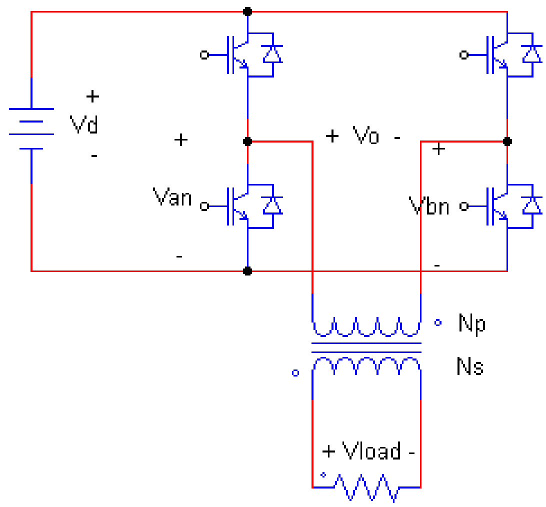
3. A three-phase, 120 kVA, 60 Hz, six-pole, Y-connected synchronous generator is connected to a 440 V_{LL} grid. It has a synchronous impedance of 1.5 Ω per phase. Neglect all losses. Compute: A) The shaft speed in rpm. B) The power factor when it operates injecting 90 kW with an internal induced voltage

(E_A) equal to the grid voltage. C) Draw the phasor diagram, relating voltages (E_A, V_ϕ and V_{XS}) and current (I_S). Indicate the values of all magnitudes and angles; D) What value of internal induced voltage would be required for operation with rated power and unit power factor? (20 marks).

4. A four-pole, 208 V, 60 Hz, Y-connected, three-phase squirrel cage induction motor has the following parameters, in Ω/phase referred to the stator: $R_1 = 0.220$, $X_1 = 0.430$, $X_m = 15.0$, $R_2 = 0.127$ and $X_2 = 0.430$. Its rated slip is equal to 0.04. Mechanical and core losses can be neglected. Compute: A) The torque at rated speed; B) The power factor at rated speed; C) The shaft speed when the load torque is reduced to half rated torque; D) Now consider that the motor is supplied with a frequency converter. What should be the frequency supplied by the frequency converter to the motor so that it operates with *half rated speed* and rated slip ($s = 0.04$)? (20 marks)

5. A separately excited dc machine has the following characteristics: Armature resistance is 0.2 Ω, induced voltage at 1500 rpm and rated field current is 220 V. Mechanical losses: 750 W at 1800 rpm and proportional to the square od the speed. Core losses at 1500 rpm: 500 W proportional to the speed. The machine is not saturated. For a 120 V armature voltage, the recorded armature current is - 50 A, that is, the machine is operating as a generator. Find**:** A) The shaft speed, B) the electromagnetic (converted) power, C) the shaft (input) power and torque, D) The shaft speed and power at which there is no power flow from the machine to the dc bus voltage. (20 marks).

6. Consider the emergency power supply shown below. The inverter is controlled with "linear sinusoidal pulse-width modulation (SPWM)" to allow the regulation of the voltage across the load, as the battery discharges and its voltage (Vd) decreases. When the battery voltage is equal to the *rated value*, the modulation index (m_a) is equal to 0.75, what, for a transformer with a turns ratio (Np:Ns) of 1 : 6.285, results in a load voltage of 240 V_{RMS}. A) What is the *rated voltage value* of the battery bank? B) What is the minimum battery voltage for which the linear SPWM method can still provide a load voltage of 240 V? C) For this battery voltage level, what would be the magnitude of the fundamental component and harmonics of order (h) 3 and 5 of the load voltage if the modulation scheme of the inverter is changed to "square-wave?" (15 marks).


+
Vd
-
+
Van
-
+ Vo -
+
Vbn
-
Np
Ns
+ Vload -

Formula sheet

Ac circuits:

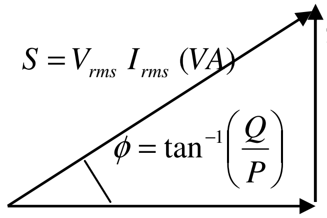
$\bar{S} = \bar{V}\,\bar{I}^* = P + j\,Q = |\bar{V}||\bar{I}|(\cos\phi + j\sin\phi)$

$S = \sqrt{P^2 + Q^2} \qquad PF = P/S = \cos\phi$

$P_{3\phi} = \sqrt{3}\,V_L I_L \cos\theta = 3\,I_L^2\,Z\cos\theta$

$Q_{3\phi} = \sqrt{3}\,V_L I_L \sin\theta = 3\,I_L^2\,Z\sin\theta$

$S_{3\phi} = \sqrt{3}\,V_L I_L = 3\,I_L^2\,Z$



$S = V_{rms}\ I_{rms}\ (VA)$

$Q = V_{rms}\ I_{rms}\sin\phi\ \ (VAr)$

$\phi = \tan^{-1}\left(\frac{Q}{P}\right)$

$P = V_{rms}\ I_{rms}\cos\phi\ \ (W)$

$Z_Y = Z_\Delta / 3$

System with multiple elements

$\bar{S}_T = \bar{S}_1 + \bar{S}_2$ (complex power!), $Q_T = Q_{L1} + Q_{L2}$, $P_T = P_{L1} + P_{L2}$

$Q_{Cap} = -\frac{V^2}{X_C} = -V^2\omega C$

Magnetic Circuits:

$\oint H \bullet dl = I_{net},\ H\,l_c = N\,i,\ H = \frac{N\,i}{l_c}$ (Ampere - turn/m) $\quad B = \mu\,H,\ \ \mu = \mu_r\,\mu_0,\ \ \mu_0 = 4\pi \text{ x}10^{-7}$ H/m

$\phi = \int_A B \bullet dA,\ \ \phi = BA, \phi = \frac{\mu\,N\,i\,A}{l_c}$ (Weber – Wb) $\quad \Im = N\,i,\ \ \Im = \phi\,\Re,\ \ \Re = \frac{\Im}{\phi} = \frac{l_c}{\mu\,A} \qquad e_{ind} = N\frac{d\phi}{dt}$

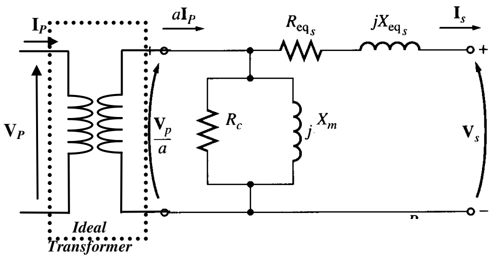
Transformers:

(ideal) $\quad \frac{v_P(t)}{v_S(t)} = \frac{N_P}{N_S} = a,\ \ \frac{i_P(t)}{i_S(t)} = \frac{N_S}{N_P} = \frac{1}{a},\ \ \phi(\text{t}) = -\frac{V_M}{\omega N_P}\cos(\omega t)$

$P_{in} = P_{out}, Q_{in} = Q_{out}, S_{in} = S_{out},\ Z_{in} = a^2 Z_L$

$Y_E = \frac{1}{R_C} - j\frac{1}{X_M} = |Y_E|\angle -\theta_{OC},\ \ |Y_E| = \frac{I_{OC}}{V_{OC}},\ \cos\theta_{OC} = \frac{P_{OC}}{I_{OC}\,V_{OC}}$

$Z_{SE} = R_{eq} + jX_{eq} = |Z_{SE}|\angle\theta_{SC},\ \ |Z_{SE}| = \frac{V_{SC}}{I_{SC}},\ \cos\theta_{SC} = \frac{P_{SC}}{I_{SC}\,V_{SC}}$



Approximate equivalent Transformer Model

$VR = \frac{V_{S,nl} - V_{S,fl}}{V_{S,fl}}\,x100\% \qquad \eta = \frac{P_{out}}{P_{in}}\,x100\% = \frac{P_{out}}{P_{out} + P_{core} + P_{Cu}}\,x100\%, \qquad P_{Cu} = I_S{}^2 R_{eq}, \qquad P_{core} = \frac{(V_p/a)^2}{R_C}$

$autotransformers\text{:}\ \frac{V_C}{V_{SE}} = \frac{N_C}{N_{SE}} \qquad N_C I_C = N_{SE} I_{SE} \qquad \frac{V_L}{V_H} = \frac{N_C}{N_{SE} + N_C} \qquad \frac{I_L}{I_H} = \frac{N_{SE} + N_C}{N_C} \qquad \frac{S_{IO}}{S_{Wind}} = \frac{N_{SE} + N_C}{N_{SE}}$

AC Machinery:

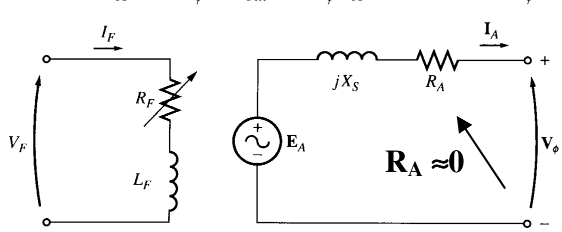
$e_{ind} = (v \times B) \bullet l, e_{ind} = \phi_{Max}\omega\sin\omega t, F = i(l \times B), \tau = F(r\sin\theta), \tau_{ind} = 2rilB\sin\theta, f_e = \frac{P}{2}f_m, \omega_e = \frac{P}{2}\omega_m$ P poles

Synchronous machines (generator oriented formulas):

$f_e(Hz) = \frac{n_m(r/\min)P(\#)}{120}, \quad E_A = K\phi\omega, \quad V_\phi = V_T/\sqrt{3}$ (Y Connection), $\quad \vec{V}_\phi = \vec{E}_A - jX_S\vec{I}_A \quad (R_A \approx 0)$

$P_{in} = \tau_{shaft}\ \omega_m = P_{Rot\_loss} + P_{conv},\ \ P_{conv} = \tau_{ind}\ \omega_m = 3E_A I_A\cos\gamma,\ \ \gamma = \angle E_A - \angle I_A,\ \ \omega_m = n_m\frac{2\pi}{60}$

$P_{out} = P_{conv} = \frac{3V_\phi E_A\sin\delta}{X_S},\ \ \delta = \angle E_A - \angle V_\phi,\ Q_{out} = 3V_\phi I_A\sin\theta,\ \ \theta = \angle V_\phi - \angle I_A,\ \ VR = \frac{V_{nl} - V_{fl}}{V_{fl}}\,x100\%$



Induction machines (Y-connected motor oriented formulas):

$$n_{sync} = \frac{120 f_e}{P} \text{ (rev/min)}, \; n_{slip} = n_{sync} - n_m, \; s = \frac{n_{sync} - n_m}{n_{sync}} (\text{x}100\%), \; n_m = (1-s) n_{sync}$$

$$P_{in} = \sqrt{3} V_T I_L \cos\theta, P_{SCL} = 3 I_1^2 R_1, P_{core} = 3 E_1^2 G_C, P_{AG} = 3 I_2^2 R_2 / s, P_{RCL} = 3 I_R^2 R_R = 3 I_2^2 R_2$$

$$P_{conv} = P_{AG} - P_{RCL} = 3 I_2^2 R_2 \left(\frac{1-s}{s} \right), P_{out} = P_{conv} - P_{F\&W} - P_{misc}, \tau_{ind} = \frac{P_{conv}}{\omega_m} = \frac{P_{AG}}{\omega_{sync}}, \; \tau_{shaft} = \frac{P_{out}}{\omega_m}$$

$$\tau_{ind} = \frac{3 V_{TH}^2 R_2 / s}{\omega_{sync} \left[(R_{TH} + R_2/s)^2 + (X_{TH} + X_2)^2 \right]}, V_{TH} \approx \frac{X_M}{X_1 + X_M} V_\phi, R_{TH} \approx R_1 \left(\frac{X_M}{X_1 + X_M} \right)^2, \; X_{TH} \approx X_1$$

$$\tau_{\max} = \frac{3 V_{TH}^2}{2 \omega_{sync} \left[R_{TH} + \sqrt{R_{TH}^2 + (X_{TH} + X_2)^2} \right]}, s_{\max} = \frac{R_2}{\sqrt{R_{TH}^2 + (X_{TH} + X_2)^2}}$$

Relation for the linear region of the τ versus ω (or s) curve: $\dfrac{\tau_{Load\_1}}{s_1} = \dfrac{\tau_{Load\_2}}{s_2}$

No-load Test: $P_{in} = P_{losses} \approx P_{SCL} + P_{core} + P_{F\&W}, \; |Z_{eq}| = \dfrac{V_\phi}{I_{nl}} \approx X_1 + X_M$

DC test: $R_1 = \dfrac{V_{DC}}{2 I_{DC}}, I_{DC} = \text{rated value}$

Blocked-rotor test:

$$P_F = \cos\theta = \frac{P_{in}}{\sqrt{3} V_T I_L}$$

$$|Z_{LR}| = \frac{V_\phi}{I_1} = \frac{V_T}{\sqrt{3} I_L}$$

$$R_{LR} = |Z_{LR}| \cos\theta = R_1 + R_2$$

$$X'_{LR} = |Z_{LR}| \sin\theta = X'_1 + X'_2$$

$$X_{LR} = \frac{f_{rated}}{f_{test}} X'_{LR} = X_1 + X_2$$

	X_1 and X_2 as functions of X_{LR}	
Rotor Design	X_1	X_2
Wound rotor	$0.5 X_{LR}$	$0.5 X_{LR}$
Design A	$0.5 X_{LR}$	$0.5 X_{LR}$
Design B	$0.4 X_{LR}$	$0.6 X_{LR}$
Design C	$0.3 X_{LR}$	$0.7 X_{LR}$
Design D	$0.5 X_{LR}$	$0.5 X_{LR}$

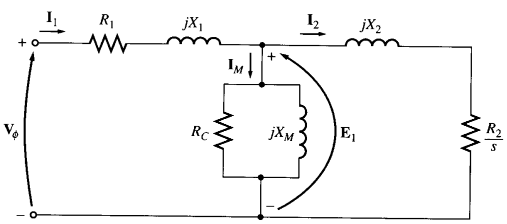


FIGURE 7–12
The per-phase equivalent circuit of an induction motor.

DC Machines (motor oriented formulas):

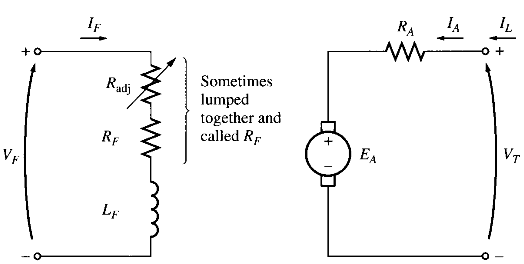
$$E_a = K\phi\omega, \quad E_{a\_2} = E_{a\_1} \left(\frac{n_2}{n_1} \right), \quad \tau_{ind} = K\phi I_a, \quad \omega = \frac{V_T}{K\phi} - \frac{R_A}{(K\phi)^2} \tau_{ind}$$

$$P_{in\_A} = V_A I_A, \; P_{in\_F} = V_F I_F, \; P_{in\_Tot} = V_A I_A + V_F I_F, \; P_{loss\_A} = I_A^2 R_A,$$

$$P_{loss\_F} = I_F^2 R_F = P_{in\_F}, \; P_{conv} = E_A I_A$$

$$P_{Shaft} = P_{conv} - (P_{F\&W} + P_{core}) = P_{conv} - (P_{Loss}), \; P_{Loss\_2} = P_{Loss\_1} \left(\frac{n_2}{n_1} \right)^{1 \text{ or } 2}$$

$$\eta = \frac{P_{out}}{P_{in}} \text{x}100\%, \; \tau_{ind} = \frac{P_{conv}}{\omega_m}, \; \tau_{Shaft} = \frac{P_{Shaft}}{\omega_m}$$



Power Electronics:

DC-AC converters (Inverters):

Square wave modulation scheme:

$(\hat{V}_o)_1 = \frac{4}{\pi} V_d$ (fundamental) $\quad\quad$ $(\hat{V}_o)_h = \frac{(\hat{V}_o)_1}{h}$, h odd integer (harmonics)

SPWM

$(\hat{V}_o)_1 = m_a V_d$, $\quad m_a = \frac{\hat{V}_{control}}{\hat{V}_{tri}} \leq 1$