EE595S
Fall 2001
Exam 2

Problem 1 (20 pts)

Consider a salient permanent magnet synchronous machine. Starting with the expression for torque in qd variables, as well as the expression for peak current in terms of q- and d-axis variables, derive the expression which must be solved (you do not have to solve it) in order to calculate the optimal q- and d-axis current command (in terms of optimizing torque per amp) for the salient machine. One expression should be for the q-axis current in terms of torque and parameters; the other expression should be for the d-axis current in terms of torque, q-axis current, and parameters. If you do not remember the starting point expressions for torque and current, you may ask the instructor but it will cost 5 pts (Ask for Hint 1a).

Problem 2 (20 pts)

Starting with the q- and d- axis voltage and flux linkage equations for an induction machine, derive the phasor equivalent circuit (singly excited case). You do not need to derive the torque expression. If you do not remember the required voltage and flux linkage equations, they will be provided to you at a cost of 5 pts (Hint 2a). If you do not remember the needed phasor relationships to qd variables, they will be provided at a cost of 5 pts (Hint 2b). If you do not remember the definition of slip, it will be provided at a cost of 5 pts (Hint 2c).

Problem 3 (20 pts)

Consider an induction machine. Recall that

$$T_e = \frac{1.5P\omega_e s L_M^2 r_r' V_s^2}{\left(r_s r_r' + s\omega_e^2\left(L_M^2 - L_{ss}L_{rr}'\right)\right)^2 + \omega_e^2\left(r_r' L_{ss} - s r_s L_{rr}'\right)^2}$$

Derive an expression for the relationship for V_s in terms of ω_e, V_b, and ω_b for compensated volts-per-hertz control. Note you do not have to derive the entire compensation scheme – just the relationship requested in the last sentence. If you do not remember the basis for this relationship, it will be provided to you at a cost of 10 pts (Hint 3a).

Problem 4 (20 pts)

Consider an induction machine. Show that if

$$\omega_e = \omega_r + \frac{r_r'}{L_{rr}'}\frac{i_{qs}^{e*}}{i_{ds}^{e*}}$$

and that if the d-axis current command is held constant that the rotor flux and current vectors will be perpendicular, even in transients. If you do not remember the needed voltage and flux linkage equations they will be provided to you at a cost of 5 pts (don't do this if you asked for Hint 2a) (Hint 4a). If you don't remember the condition or strategy for field oriented control, this will be provided at a cost of 5 pts (Hint 4b).

<u>Problem 5</u>

A machine has a radius r, length L, and air-gap g. A winding on the stator has a turns density function given by

$$N_{as} = N_s (\cos\phi_s - \alpha_s \cos(3\phi_s))$$

and a winding on the rotor has the turns density of the form

$$N_{ar} = N_r \cos\phi_r$$

where

$$\phi_s = \theta_r + \phi_r$$

If the permeability of air is denoted μ_0, derive an expression for the self inductance of the stator winding, the self inductance of the rotor winding, and the mutual inductance between the two windings. If you forget how to calculate the winding function, it will cost 5 pts (Hint 5a). If you forget how to calculate inductance given the winding function, it will cost 5 pts (Hint 5b).

Free hint 1: when you integrate around the machine, you must do so in terms stator angle ϕ_s with everything in terms of stator angle or in rotor position; don't leave your expression in terms of ϕ_r because it is a function of ϕ_s.

Free hint 2: $\cos(A \pm B) = \cos(A)\cos(B) \mp \sin(A)\sin(B)$

Hint 1a

$$T_e = \frac{3}{2}\frac{P}{2}(\lambda_m^{'} i_{qs}^r + (L_d - L_q) i_{qs}^r i_{ds}^r) \qquad I_s = \frac{1}{\sqrt{2}}\sqrt{i_{qs}^{r2} + i_{ds}^{r2}}$$

Hint 2a/4a

$$v_{qs} = r_s i_{qs} + \omega\lambda_{ds} + p\lambda_{qs} \qquad \lambda_{qs} = L_{ls} i_{qs} + L_M (i_{qs} + i_{qr}^{'})$$

$$v_{ds} = r_s i_{ds} - \omega\lambda_{qs} + p\lambda_{ds} \qquad \lambda_{ds} = L_{ls} i_{ds} + L_M (i_{ds} + i_{dr}^{'})$$

$$v_{qr}^{r'} = r_{rr}^{'} i_{qr}^{r'} + (\omega - \omega_r)\lambda_{dr}^{r'} + p\lambda_{qr}^{r'} \qquad \lambda_{qr}^{r'} = L_{lr}^{'} i_{qr}^{r'} + L_M (i_{qs} + i_{qr}^{'})$$

$$v_{dr}^{r'} = r_{rr}^{'} i_{dr}^{r'} - (\omega - \omega_r)\lambda_{qr}^{r'} + p\lambda_{dr}^{r'} \qquad \lambda_{dr}^{r'} = L_{lr}^{'} i_{dr}^{r'} + L_M (i_{qs} + i_{qr}^{'})$$

Hint 2b

With Appropriate Selection of Time Zero Position and Balanced Steady-State: $\tilde{F}_{as} = \tilde{F}_{qs}$

For Balanced Steady-State Conditions: $\tilde{F}_{ds} = j\tilde{F}_{qs}$ $\tilde{F}_{dr} = j\tilde{F}_{qr}$

Hint 2c

$$s = \frac{\omega_e - \omega_r}{\omega_e}$$

Hint 3

The voltage is varied with frequency such that the slope of the torque-speed curve at synchronous speed is kept constant (and equal to the value obtained using base voltage at base frequency)

Hint 4a-See Hint 2a

Hint 4b

Our Strategy: $\lambda_{qr}^{'e} = 0$, $i_{dr}^{'e} = 0$

Hint 5a

$\frac{dW_x}{d\phi_s} = -N_x$ (constant of integration such that average value is zero)

Hint 5b

$$L_{x,y} = \mu_0 r L \int_0^{2\pi} \frac{W_x(\phi_s, \theta_r) W_y(\phi_s, \theta_r)}{g(\phi_s, \theta_r)} d\phi_s$$