Name ______________________

ECE 560
Final Examination
Autumn 2018

Problem 1 (30 Points) _______

Problem 2 (30 Points) _______

Problem 3 (30 Points) _______

Problem 4 (30 Points) _______

Sub Total (120 Points) _______

Problem 5 (30 Points Extra Credit) _______

Total _______

THIS IS AN OPEN BOOK, 120 MINUTE EXAMINATION

Good luck!

Trig Identities

$$\cos(2\cdot\theta) = 2\cdot\cos(\theta)^2 - 1$$

$$\sin(2\cdot\theta) = 2\cdot\sin(\theta)\cdot\cos(\theta)$$

$$\cos(\theta)^2 = \frac{1}{2}\cdot(1 + \cos(2\cdot\theta))$$

$$\cos(\theta_1 + \theta_2) = \cos(\theta_1)\cdot\cos(\theta_2) - \sin(\theta_1)\cdot\sin(\theta_2)$$

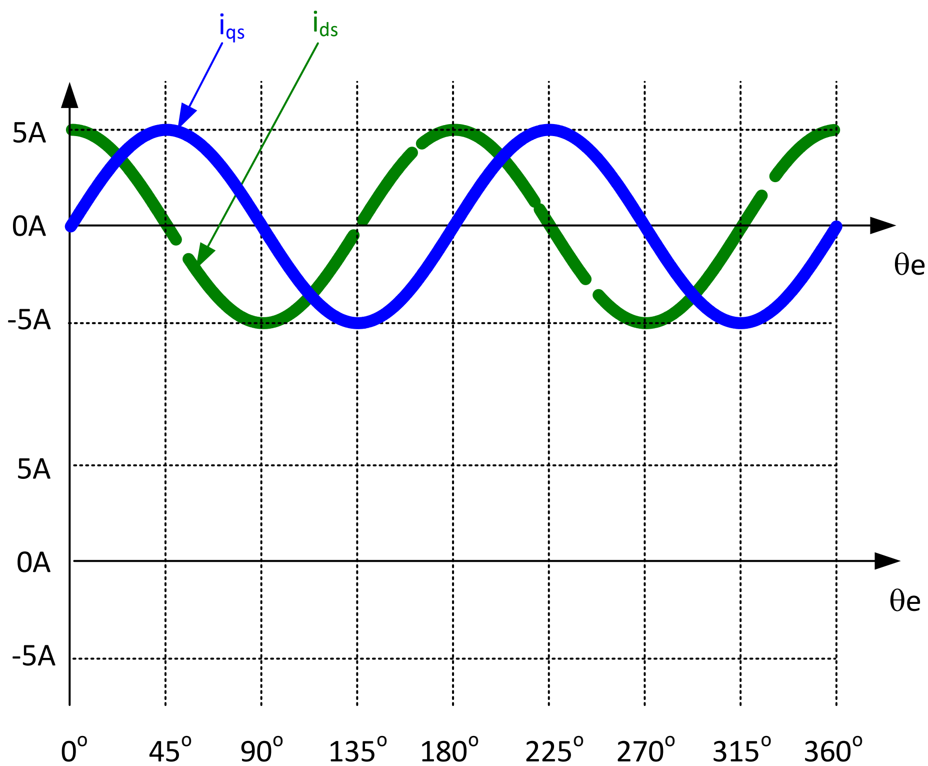
$$\cos(\theta_1 - \theta_2) = \cos(\theta_1)\cdot\cos(\theta_2) + \sin(\theta_1)\cdot\sin(\theta_2)$$

$$\cos(\theta_1)\cdot\cos(\theta_2) = \frac{1}{2}\cdot(\cos(\theta_1 - \theta_2) + \cos(\theta_1 + \theta_2))$$

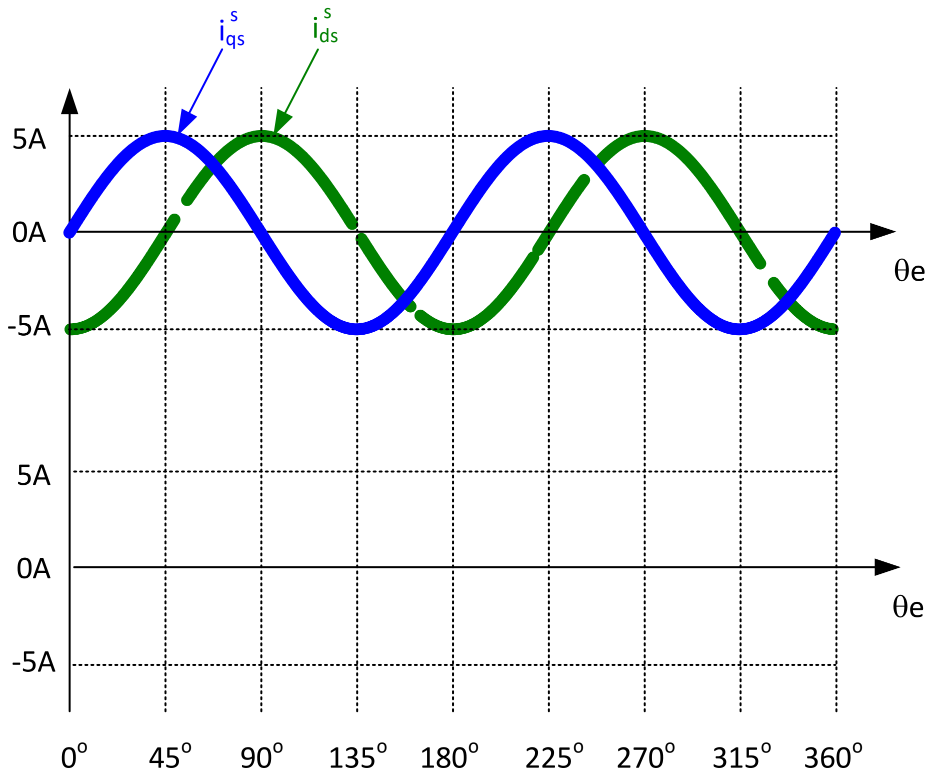
$$\cos(\theta_1)\cdot\cos(\theta_2) = \frac{1}{2}\cdot(\cos(\theta_1 - \theta_2) - \cos(\theta_1 + \theta_2))$$

Problem 1 (30 Points)

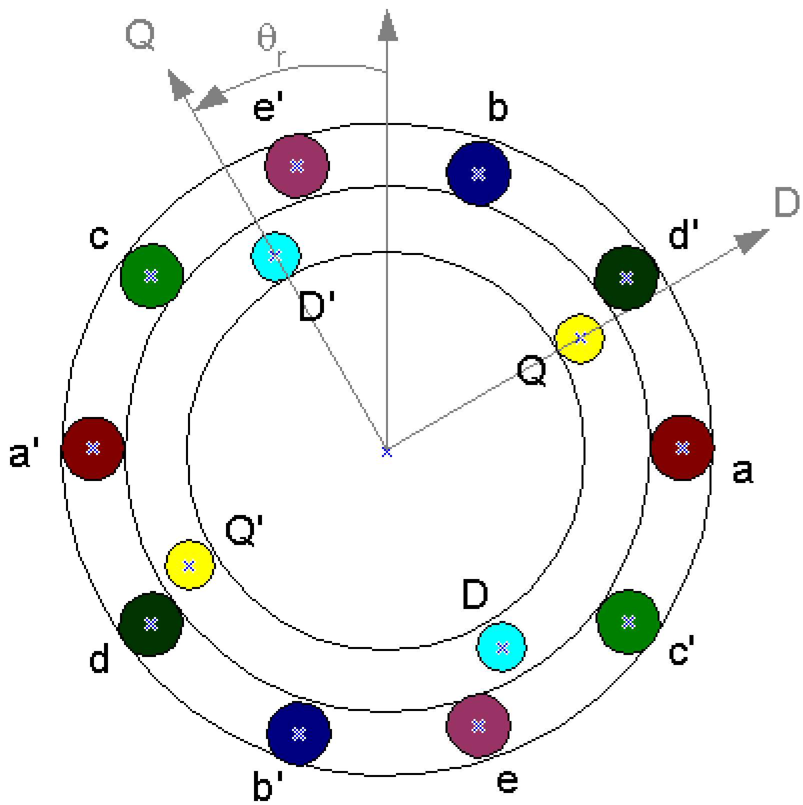
a) Given the q- and d-axis stator currents in the stationary frame shown below, draw the corresponding q- and d-axis stator currents in the synchronous frame. Label the synchronous frame currents i_{qs}^{e} and i_{ds}^{e}.

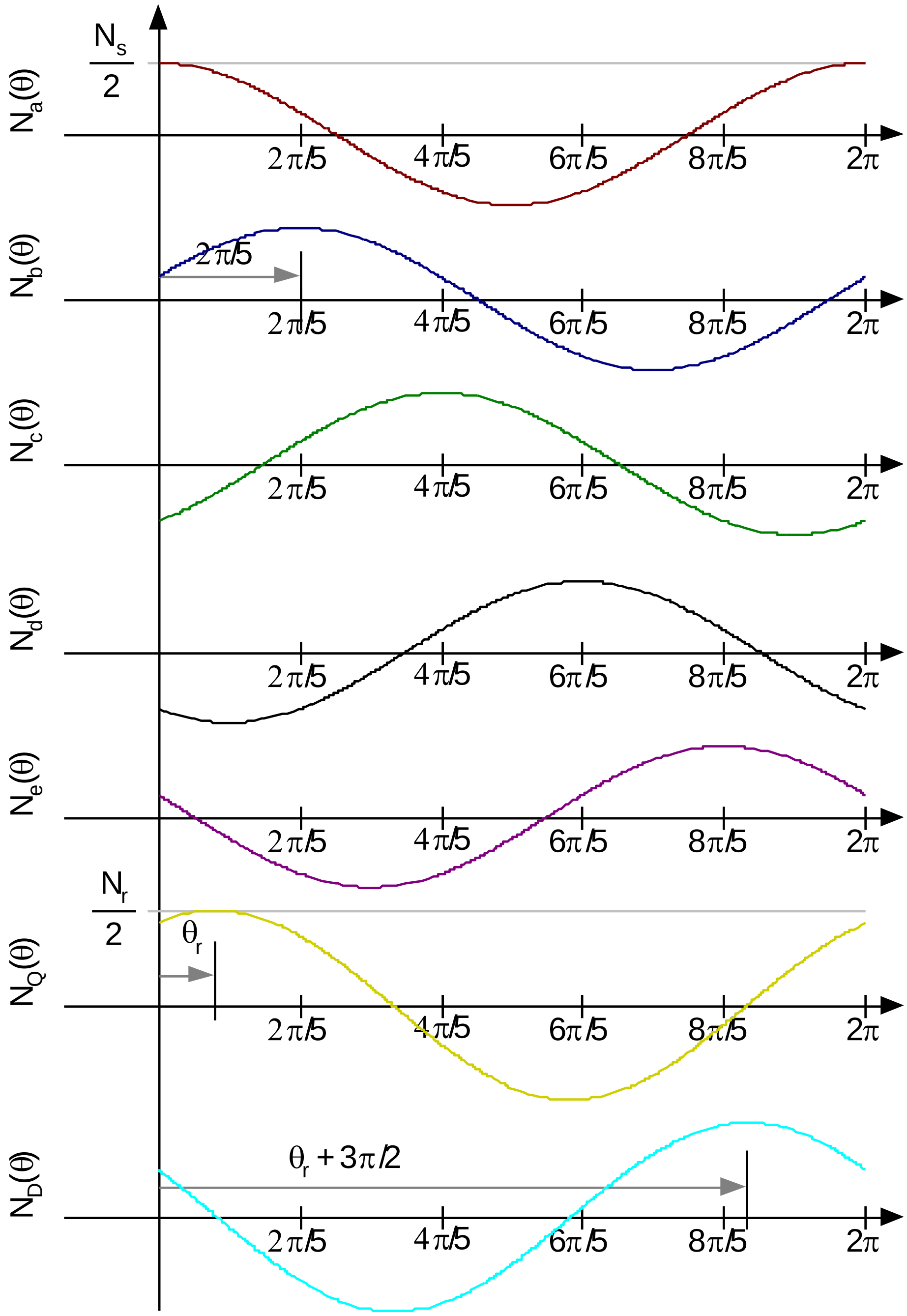


b) Given the q- and d-axis stator currents in the stationary frame shown below, draw the corresponding q- and d-axis stator currents in the synchronous frame. Label the synchronous frame currents i_{qs}^{e} and i_{ds}^{e}.



Problem 2 (30 Points)
Given the following winding configuration for a five phase induction motor and the winding distribution functions shown on the next page (assume sinusoidal distribution with peak values of winding as shown):





$\frac{N_s}{2}$
$N_a(\theta)$
$2\pi/5$
$4\pi/5$
$6\pi/5$
$8\pi/5$
2π
$N_b(\theta)$
$2\pi/5$
$N_c(\theta)$
$N_d(\theta)$
$N_e(\theta)$
$\frac{N_r}{2}$
θ_r
$N_Q(\theta)$
$\theta_r + 3\pi/2$
$N_D(\theta)$

Calculate the following inductances.

a) The ‘a’ phase self inductance

L_{aa} = __________

b) The mutual inductance between phase ‘a’ and phase ‘b’

L_{ab} = __________

c) The mutual inductance between phase ‘a’ and phase ‘c’

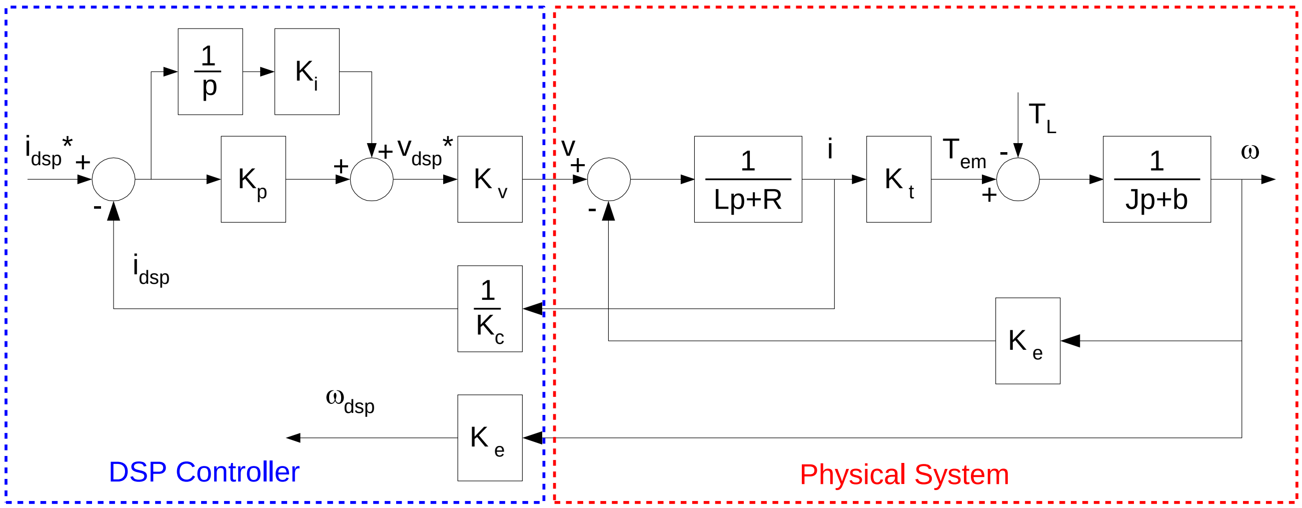
L_{ac} = ___________

d) The mutual inductance between phase ‘a’ and phase ‘q’

L_{aq} = ___________

Problem 3 (30 Points)
You are to implement closed loop current control of a brush dc motor using a DSP (digital signal processor). The control structure will be proportional plus integral control (PI). Assume that the DSP calculations are fast enough so that the controller can be tuned in the continuous time domain (i.e. don't need to convert to discrete time domain model for the system). The DSP controller has a voltage amplifier gain K_v and current transducer gain of K_c listed below:

$$K_v = \frac{300V}{FS\_DSP} \qquad K_c = \frac{100A}{FS\_DSP}$$ (FS_DSP is full scale in the DSP)



Given the system described above, find:

a) the transfer function of the measured DSP current to the commanded DSP current **at locked rotor (ω = 0)**.

$$\frac{i_{DSP}}{i^*_{DSP}} = \underline{\hspace{6cm}}$$

b) the formulas for K_p and K_I in terms of machine parameters, voltage amplifier gain K_v, current transducer gain K_c, and desired bandwidth f_b **at locked rotor ($\omega = 0$)**. Use the tuning procedure derived in class for PI controllers (rewriting block diagrams in terms of poles and zeros and canceling the electrical pole with the controller zero).

K_P = ___________

K_I = ___________

c) describe how ω_{DSP} could be used to enhance current loop performance when rotor is not locked (free to move):

Problem 4 (25 Points)
Fill out the following short answer questions:

a) In a DC machine, what parameters are used to select controller gains for the current loop (how do we tune the current loop)?

b) Describe armature reaction in a DC machine. Does an AC induction motor experience the same phenomenon?

c) Describe how a field oriented controlled induction motor is like a separately excited DC motor.

d) What is the difference in torque equations between a salient pole and non-salient pole synchronous machine.

e) Briefly describe how you calculate the rotor flux position with Indirect Field Oriented Control?

Problem 5 – Extra Credit (30 Points)
We have covered several expressions for electromagnetic torque in terms of dq variables. One expression for torque is:

$$T_{em} = \frac{3}{2}\frac{P}{2}\Im m\left(\bar{i}_{qds}^{g}\,\bar{\lambda}_{qds}^{g\,*}\right) = \frac{3}{2}\frac{P}{2}\left(i_{qs}^{g}\lambda_{ds}^{g} - i_{ds}^{g}\lambda_{qs}^{g}\right)$$

For each part express torque in terms of inductances L_m, L_s, L_r, and $\sigma = 1 - \frac{L_m^2}{L_s L_r}$.

a) Determine the torque in terms of scalar quantities i_{qs}^{g}, i_{ds}^{g}, λ_{qr}^{g}, λ_{dr}^{g}. Note: this is what you used in FOC.

b) Determine the torque in terms of scalar quantities i_{qs}^{g}, i_{ds}^{g}, i_{qr}^{g}, i_{dr}^{g}.

c) Determine the torque in terms of scalar quantities λ_{qs}^{g} , λ_{ds}^{g} , λ_{qr}^{g} , λ_{dr}^{g} .

d) Determine the torque in terms of scalar quantities i_{qr}^{g} , i_{dr}^{g} , λ_{qs}^{g} , λ_{ds}^{g} .

e) Considering the various forms of control of an induction motor, which complex variables, $\bar{i}_{qds}^{g}$, $\bar{i}_{qdr}^{g}$, $\bar{\lambda}_{qds}^{g}$, and $\bar{\lambda}_{qdr}^{g}$, are used to express torque when deriving the control strategy (choose two for each part). Given the example:

Stator Flux Field Orientation uses __________________ for torque expression

Find the variables used for expressing torque with the following types of control:

Indirect Field Orientation uses __________________ for torque expression

Direct Torque Control uses __________________ for torque expression