1) The stator voltage expressions of a 3-phase wound-rotor synchronous machine with $L_q = L_d$ can be expressed in the rotor frame of reference as:

$$v_{qs}^r = r_s i_{qs}^r + \omega_r \lambda_{ds}^r + p\lambda_{qs}^r$$
$$v_{ds}^r = r_s i_{ds}^r - \omega_r \lambda_{qs}^r + p\lambda_{ds}^r$$
$$v_{fd}' = r_{fd}' i_{fd}' + p\lambda_{fd}'$$
$$v_{kq}' = r_{kq}' i_{kq}' + p\lambda_{kq}'$$
$$v_{kd}' = r_{kd}' i_{kd}' + p\lambda_{kd}'$$

a) Using these, along with the necessary relationships between flux linkages and currents, derive the steady-state expression

$$\tilde{V}_{as} = (r_s + j\omega_e L_q)\tilde{I}_{as} + \tilde{E}_{as}$$

Show all steps in the derivation. Make sure to show the relationship between $\tilde{E}_{as}$, the field winding current, the angle δ, and the frequency of stator excitation. (21 $\frac{1}{3}$ pts)

b) Answer the following True/False Explain your reasoning for full credit. (12 pts)

a) If $i_{kq}' = 0$, then $\lambda_{kq}' = 0$.

b) If $\delta = 0$, $I_{qs}^r = I_{ds}^r = 0$.

c) If $i_{kq}' = 0$, $i_{kd}' = 0$.

2) The flux-linkage-versus-current relationship of a 3-phase, 4-pole permanent-magnet sychronous machine in the rotor frame of reference has the form:

$$\lambda_{qs}^r = L_q i_{qs}^r$$
$$\lambda_{ds}^r = L_d i_{ds}^r - \lambda_m$$

Draw a cross sectional view of a machine that could be modeled using these relationships. Show the phase-a winding, the rotor, the magnets, the q- and d-axis, and a rotor position angle that indicates the relative position between the stator and rotor. Express T_e in terms of I_{qs}^r and I_{ds}^r for this machine. (33 $\frac{1}{3}$ pts)

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3) A 6-pole induction machine is operated as a motor with balanced excitation and $\lambda'^{s}_{dr} = 0.1\cos(377t)$, $\lambda'^{r}_{dr} = 0.1\cos(10t)$.

a) Fill in the following table. (20 pts)

Table 1:

	actual (abc) variables	arbitrary reference frame	'2' reference frame - $\omega = 2$ rad/s	synchronous reference frame $\omega = \omega_e$
frequency of stator currents				
frequency of rotor currents				

b) Determine the speed and direction of the stator and rotor MMF relative to a person a) on the stator and b) on the rotor. (13 $\frac{1}{3}$ pts)

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