1.) 34 pts. Consider balanced steady-state operation of the induction machine. Recall that for these conditions \( \vec{F}_{ds} = j\vec{F}_{qs} \), \( \vec{F}_{qs} = \vec{F}_{qs} \), \( \vec{F}_{dr} = j\vec{F}_{qr} \), and that, taking the initial rotor position to be zero \( \vec{F}_{qr} = \vec{F}_{ar} \). Starting with the rotor voltage and flux linkage equations expressed in the stationary reference frame, derive the phasor equivalent circuit rotor voltage equation, i.e.,

\[
\frac{\mathcal{V}_{ar}'}{S} = \frac{r_r}{S} \mathcal{I}_{ar} + j\omega_L \mathcal{L}_d (\mathcal{I}_{ar} + \mathcal{I}_{ar}') + j\omega_L \mathcal{L}_r \mathcal{I}_{ar}'.
\]

2.) 33 pts. Consider the operation of a non-salient permanent magnet synchronous machine. Suppose it is desired to achieve a torque \( T_r' \). Derive an expression for the q- and d- axis currents that will achieve this torque with the minimum possible line-to-neutral, rms stator voltage. You may assume stator resistance is negligible. Your expressions should be in terms of \( T_r' \) and the machine parameters.

3.) 33 pts. Consider a wound rotor synchronous machine with a single damper winding in the q-axis. Prove that if the q-axis stator current is constant then the q-axis damper current will go to zero.