Problem 1. 33 pts. Consider the steady-state operation of a 3-phase non-salient permanent-magnet ac machine. Recall

\[ v_r^r = \sqrt{2}v_r \cos \phi_r \]
\[ v_r^s = -\sqrt{2}v_r \sin \phi_r \]

For a constant \( v_r \), and at a constant electrical rotor speed, derive the expression for the value of \( \phi_r \) which maximizes torque in terms of the appropriate resistance, inductance, and the electrical rotor speed. You must start your derivation with the \( qd \) voltage, flux linkage, and torque equation. An answer without derivation will not be accepted.

Problem 2. 33 pts. Consider a wound rotor synchronous machine. Derive a series of explicit equations which will enable the instantaneous \( d \)-axis currents to be calculated from the \( d \)-axis flux linkages. Your derivation should start from the \( d \)-axis flux linkage equations. Indicate the appropriate execution sequence of the equations.

Problem 3. 34 pts. Consider the steady-state analysis of a balanced 3-phase induction machine. Assuming that

\[ \sqrt{2} F_{qs} = F_{qs} - jF_{ds} \]
\[ \sqrt{2} F_{qs}' = F_{qs}' - jF_{ds}' \]

and starting from the \( qd \) model in the synchronous reference frame, derive the steady-state phasor \( qd \) equivalent circuit.