Problem 1. 35 pts. Consider an electromechanical device with the flux linkage equations given below. Compute an expression for torque $T_e$ in terms of $i_1$, $i_2$, and $\theta_{rm}$.

$$\lambda_1 = 10i_1 + 2(5 + 2\sin(2\theta_{rm}))\frac{2i_1 + i_2}{\sqrt{1 + (2i_1 + i_2)^2}}$$

$$\lambda_2 = 5i_2 + (5 + 2\sin(2\theta_{rm}))\frac{2i_1 + i_2}{\sqrt{1 + (2i_1 + i_2)^2}}$$

Problem 2. 35 pts. The rotor flux linkage equations of a 2-phase induction machine may be expressed

$$\lambda_{ar} = L_{ar}i_{ar} + L_{qs} \cos \theta_{r}i_{qs} + L_{qs} \sin \theta_{r}i_{bs}$$

$$\lambda_{br} = L_{br}i_{br} - L_{qs} \sin \theta_{r}i_{qs} + L_{qs} \cos \theta_{r}i_{bs}$$

Derive the rotor flux linkage equations in terms of unreferred qd variables using the transformations

$$K_s = \begin{bmatrix} \cos \theta & \sin \theta \\ -\sin \theta & \cos \theta \end{bmatrix}$$

$$K_r = \begin{bmatrix} \cos(\theta - \theta_r) & \sin(\theta - \theta_r) \\ -\sin(\theta - \theta_r) & \cos(\theta - \theta_r) \end{bmatrix}$$

Recall

$$\cos A \cos B = 0.5(\cos(A + B) + \cos(A - B))$$

$$\sin A \sin B = 0.5(\cos(A - B) - \cos(A + B))$$

$$\sin A \cos B = 0.5(\sin(A + B) + \sin(A - B))$$

$$\cos(A \pm B) = \cos A \cos B \mp \sin A \sin B$$

$$\sin(A \pm B) = \sin A \cos B \pm \cos A \sin B$$

You must show all work for credit. Stating the result is not acceptable.

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3. 5 pts. Is the co-energy approach to finding torque valid for magnetically saturated conditions?

4. 5 pts. Is the co-energy approach to finding torque valid in the presence of magnetic hysteresis?

5. 5 pts. In what reference frames would it be valid to set the time derivative equal to zero when performing steady-state analysis?

6. 5 pts. Name the key attribute of the flux linkage equation of an electromechanical device that enables it to transfer power between electrical and mechanical systems.

7. 5 pts. In what reference frame (if any) can a 3-phase unbalanced set of voltages be represented as constants.

8. 5 pts. What are three commonly used reference frames (aside from the arbitrary reference frame)?