MANIPAL INSTITUTE OF TECHNOLOGY
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I SEMESTER M.TECH (POWER ELECTRONICS & DRIVES)
END SEMESTER EXAMINATIONS, JANUARY 2023

MODELLING & ANALYSIS OF ELECTRICAL MACHINES [ELE 5172]

REVISED CREDIT SYSTEM

Time: 3 Hours **Date: 14 January 2023** **Max. Marks: 50**

Instructions to Candidates:
- Answer **ALL** the questions.
- Missing data may be suitably assumed.

1A.	Consider a singly excited coil with linear motion. Show that the force exerted on the coil is $F=0.5\ i^2(dL(x)/dx)$ where L= inductance, i=current & x=displacement.	***(03)***
1B.	Consider a nonlinear relationship between exciting current & flux-linkages given by $i=\{2.5-0.5\cos(2\theta)\}\psi^{1.5}$, where θ is the rotor position. Derive an expression for Torque using i)Energy method & ii)Co-energy method	***(04)***
1C.	Find an expression for torque of a symmetrical 2-winding system whose inductances vary with rotor angle as $L_{11}=L_{22}=0.8+0.3\cos(4\theta)$ & $M_{12}=0.65\cos(2\theta)$ for the condition that $i_1=-i_2=0.4$ A.	***(03)***
2A.	The large signal model of a separately excited DC motor is given below $$\begin{bmatrix} v_f \\ v_a \end{bmatrix} = \begin{bmatrix} r_f + l_f \frac{d}{dt} & 0 \\ M_{fa}\omega_r & r_a + l_a \frac{d}{dt} \end{bmatrix} \begin{bmatrix} i_f \\ i_a \end{bmatrix} \ \& \ T_e = M_{fa} i_f i_a$$ Develop a small signal model of the motor and hence obtain the transfer function $\Delta\omega_r(s)/\Delta V_f(s)$.	***(05)***
2B.	Compute the transfer function $\Delta\omega_r(s)/\Delta V_f(s)$ of a separately excited dc motor with specifications given as below. V_a=200 V, 1480 rpm, R_a=2 Ω, L_a=0.07H, J=0.06kg-m^2, B=0.09 N-m/rad/s, M_{fa}= 0.96 H, V_f=300 V, R_f=275Ω, L_f=150 H.	***(03)***
2C.	Develop a large signal model of a dc series motor.	***(02)***
3A.	Transform the following induction motor currents in abc to stationary frame of reference keeping power invariant. $i_a=10.5\sin 314t$, $i_b=10.5\sin(314t-120°)$ & $i_c=10.5\sin(314t-240°)$.	***(03)***

3B. Derive the dynamic model of a 3-phase induction motor in natural frame of reference where self & mutual inductance of stator phase 'a' is $L_{as}=L_{ls}+L_{ms}$, $M_{ab}=-L_{ms}/2$ & mutual inductance with rotor is $M_{ar}=M_{sr}\cos\theta_r$, θ_r is the rotor position. Discuss the drawbacks of modelling in natural frame of reference. ***(04)***

3C. Compute the stator currents i_d & i_q of a 3-phase induction motor in i)stator reference frame, ii) rotor reference frame & iii) synchronous reference frame if $i_\alpha=I_m \cos\omega_s t$ & $i_\beta=I_m \sin\omega_s t$ ***(03)***

4A. Develop the steady state equivalent circuit diagram of a 3-phase Induction motor from the large signal model given below $V_{dq\text{-}dq}=Z_{dq\text{-}dq}\, I_{dq\text{-}dq}$ where

$\boldsymbol{p}$=d/dt, $V_{dq\text{-}dq}=\begin{bmatrix} v_{ds} \\ v_{qs} \\ v^{dr'} \\ v^{qr'} \end{bmatrix}$, $I_{dq\text{-}dq}=\begin{bmatrix} i_{ds} \\ i_{qs} \\ i^{dr'} \\ i^{qr'} \end{bmatrix}$ & $Z_{dq\text{-}dq}=$

$$\begin{bmatrix} \boldsymbol{r_s + l_s p} & \boldsymbol{-L_s\omega_s} & \boldsymbol{L_{md}p} & \boldsymbol{-L_m\omega_s} \\ \boldsymbol{L_s\omega_s} & \boldsymbol{r_s + l_s p} & \boldsymbol{L_m\omega_s} & \boldsymbol{L_{md}p} \\ \boldsymbol{L_{md}p} & \boldsymbol{-L_m(\omega_s-\omega_r)} & \boldsymbol{r_r' + l_r'p} & \boldsymbol{-L_r'(\omega_s-\omega_r)} \\ \boldsymbol{L_m(\omega_s-\omega_r)} & \boldsymbol{L_{md}p} & \boldsymbol{L_r'(\omega_s-\omega_r)} & \boldsymbol{r_r' + l_r'p} \end{bmatrix}$$ ***(04)***

4B. Consider a 4-pole, 3-phase synchronous machine with uniform airgap. The armature self & mutual inductance is $L_{aa}=L_{bb}=L_{cc}$ & $M_{ab}=M_{bc}=M_{ca}$. The self-inductance of field winding L_f=constant but mutual inductance between field & stator winding is $M_{af}=M_{sfm}\cos(2\theta_m)$, $M_{bf}= M_{sfm}\cos(2\theta_m-120°)$, $M_{cf}= M_{sfm}\cos(2\theta_m-240°)$. Using co-energy concept, show that the torque remains constant when the stator currents are $i_a=I_m\cos(\omega_s t+\delta)$, $i_b=I_m\cos(\omega_s t+\delta-120°)$, $i_c=I_m\cos(\omega_s t+\delta+120°)$. ***(04)***

4C. Draw the phasor diagrams of a salient pole synchronous machine in motor mode when i) under-excited & ii) over-excited. The expression for stator voltage/phase is given by $V_a=r_sI_a+jI_qX_{qs}+jI_dX_{ds}+jE$ ***(02)***

5A. Starting from the dynamic equations of a salient pole synchronous machine with one damper winding on d & q axes, develop the d-axis & q-axis equivalent circuit diagrams in synchronous reference frame. ***(03)***

5B. Derive the expressions for various time constants of d-axis equivalent circuit diagram with $S\psi_{ds}(s)$ as output & $I_{ds}(s)$ & $V_f'(s)$ as the inputs. ***(05)***

5C. Consider an unloaded 3-phase, 50 Hz alternator operating at rated voltage. Suddenly a 3-phase short circuit occurs at its terminals. Compute the symmetrical ac short circuit current at t=0.5 s taking x_d=1.2 pu, x_d'=0.4 pu, x_d''=0.15 pu, E=1 pu, T_d'=1 s, T_d''=0.035 s & delta=0°. ***(02)***