University of KwaZulu-Natal

Discipline of Electrical, Electronic and Computer Engineering

Examinations: June 2026

Subject, Course & Code: ELECTRICAL MACHINES 3 – ENEL4MAH1

DURATION: 2 HOURS | TOTAL MARKS: 100

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Instructions: Answer ALL Questions. **Start answering each question on a fresh page of the answer booklet.**

The use of scientific calculators is permitted but their memories must be cleared.

Question 1 Salient Pole Synchronous Machine [42 Marks]

A three-phase, 120 MVA, 13.2 kV, 60 Hz, star-connected, salient pole synchronous motor has the d- and q-axis synchronous reactances are 0.4270 pu and 0.2755 pu respectively. Its armature has a resistance of 0.0344 pu. The efficiency of the machine is 92%.

(a) Determine the actual values of the d- and q-axis synchronous reactances and stator resistance. [6]

(b) Determine the excitation voltage $\overline{E_0}$ and draw the motor phasor diagram using **actual values** when the machine is operating at 90 MVA at a power factor of 0.82 lagging. [18]

(c) Determine the excitation voltage $\overline{E_0}$ and draw the motor phasor diagram using **actual values** when the machine is operating at full load at a power factor of 0.82 leading. [18]

Question 2 DQ Synchronous Machine Model [16 Marks]

Consider a three-phase synchronous generator delivering rated apparent power at rated terminal voltage. The DC component is 0.15 pu. The machine operates at 0.84 lagging power factor.

Transform the set of these phase currents and voltages into dqz reference frame and calculate power in both abc and dqz reference frames. Compare the results of power calculation and comment on them. Remember that Park's transformation applies to both currents and voltages.

Question 3 Transient behaviour of Synchronous Machines [20 Marks]

A three-phase 750 kVA, 4.16 kV, star-connected, 60 Hz synchronous generator has the following parameters:

$$X_d = 1.57\,pu \qquad X_d^{/} = 0.28\,pu \qquad X_d^{//} = 0.15\,pu$$

$$T_d^{/} = 0.48\,s \qquad T_d^{//} = 0.01\,s \qquad T_a = 0.25\,s$$

The generator is delivering full rated output to the infinite bus at 0.8 lagging power factor. A three-phase short-circuit suddenly occurs at the machine terminals.

(a) Determine the prefault values of the voltages 'behind' the reactances in pu. [6]

(b) Determine the initial value of subtransient, transient and steady state short circuit currents in pu. [6]

(c) Determine the initial value of the maximum possible DC offset current in the machine in pu. [2]

(d) Hence write an expression for the machine fault current as a function of time. Consider conditions of maximum possible DC offset current in the machine. [2]

(e) Determine the RMS value of the machine fault current at t = 0.4 s in pu. [2]

Question 4 **DC Machine Dynamics** **[22 Marks]**

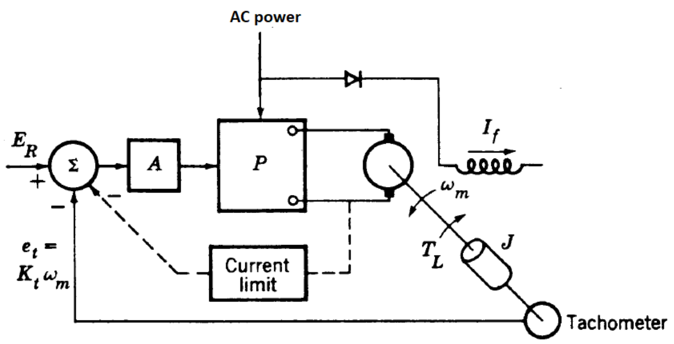


Fig.1

The speed control system in Fig. 1 is used with a 4 kW, 1750 rpm, 240 V separately excited motor.

Motor + source resistance R_a = 1.25 Ω
Motor + source inductance L_a = 0.02 H
Motor + load inertia J = 0.215 Kgm^2
Motor speed-voltage constant K_m = 1.25 $Vsrad^{-1}$
Tachometer constant = 1.43 $Vsrad^{-1}$

The voltage gain of the error-detector amplifier and rectifier is K_A = 10 V/V

The reference voltage E_R is adjusted for 1800 rpm at no load.

(a) Solve for E_R [4]
(b) Find the steady-state speed drop resulting from an applied torque of 30 Nm. [4]
(c) Determine the natural frequency, damping ratio and damping factor. [10]
(d) Explain the transient characteristics of the speed changes of this motor and how can transient response of the system be improved. [4]

Park's matrix:

$$[P] = 2/3 \begin{bmatrix} \cos\theta & \cos(\theta - 120) & \cos(\theta - 240) \\ \sin\theta & \sin(\theta - 120) & \sin(\theta - 240) \\ 1/2 & 1/2 & 1/2 \end{bmatrix}$$

$$P_{abc} = \tfrac{1}{3}(e_a i_a + e_b i_b + e_c i_c) \quad p.u.$$

$$P_{dqz} = \tfrac{1}{2}(e_d i_d + e_q i_q) + e_z i_z \quad p.u.$$

The short circuit current of an initially loaded synchronous generator is:

$$i_{sc} = \sqrt{2}\left[\frac{E_i}{X_d} + \left(\frac{E_i^{'}}{X_d^{'}} - \frac{E_i}{X_d}\right)e^{-t/T_d^{'}} + \left(\frac{E_i^{''}}{X_d^{''}} - \frac{E_i^{'}}{X_d^{'}}\right)e^{-t/T''_d}\right]\sin\omega t + I_{dc0}\, e^{-t/T_a}$$

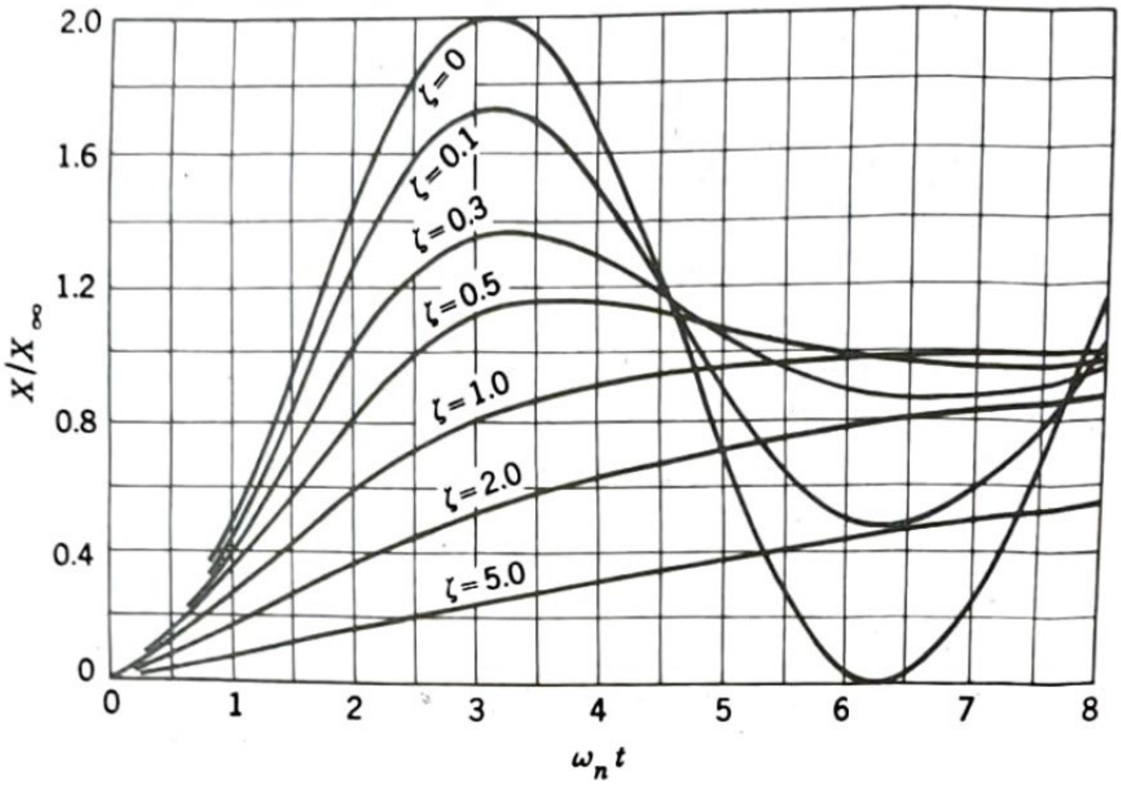
where: $T_d^{'} \approx \dfrac{X_d^{'}}{X_d} T_{d0}^{'}$; $\quad T_d^{''} \approx \dfrac{X_d^{''}}{X_d^{'}} T_{d0}^{''}$ and $\quad (I_{dc0})_{\max} = \sqrt{2}\,\dfrac{E_i^{''}}{X_d^{''}}$

Closed loop control of DC motor:

$$\omega_n = \sqrt{\frac{1 + K_0}{\tau_a \tau_m}} \qquad \delta = \frac{1}{2}\sqrt{\frac{\tau_m}{\tau_a}\frac{1}{1 + K_0}}$$

$$\tau_m = \frac{J R_a}{K_m^2} \qquad K_0 = \frac{K_t K_A}{K_m}$$

$$\frac{\Delta\omega_m(\infty)}{\Delta T_L} = -\frac{R_a}{K_m^2}\frac{1}{1 + K_0} \qquad \frac{\Delta\omega_m(\infty)}{\Delta E_R} = \frac{1}{K_t}\frac{K_0}{1 + K_0}$$



Normalised solutions of second-order linear differential equation for initial rest conditions.

Time function	**Laplace transform**
Unit impulse $\delta(t)$	1
Unit step $u(t)$	$\frac{1}{s}$
t	$\frac{1}{s^2}$
$\frac{t^2}{2}$	$\frac{1}{s^3}$
$\frac{t^2}{n!}$	$\frac{1}{s^{n+1}}$
e^{-at}	$\frac{1}{s+a}$
$t\,e^{-at}$	$\frac{1}{(s+a)^2}$
$1-e^{-at}$	$\frac{a}{s(s+a)}$
$\sin\omega t$	$\frac{\omega}{s^2+\omega^2}$
$e^{-at}\sin\omega t$	$\frac{\omega}{(s+a)^2+\omega^2}$
$\cos\omega t$	$\frac{s}{s^2+\omega^2}$
$e^{-at}\cos\omega t$	$\frac{s+a}{(s+a)^2+\omega^2}$