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THE NATIONAL UNIVERSITY OF IRELAND, CORK

COLAISTE NA hOLLSCOILE, CORCAIGH
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B.E. DEGREE (ELECTRICAL)

POWER ELECTRONICS AND ENERGY CONVERSION (EE4001)

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Time Allowed – 3 Hours

Attempt **five** questions total.

The use of non-programmable electronic calculators is permitted.

Question 1

A 2000 kg electric van is travelling at 50 km/hr down a slope of 5° with a 5 km/hr tailwind. The van has a blended braking system, which integrates the drum braking applied to the wheels and the regenerative braking of the electric motor. The vehicle has the following attributes: drag co-efficient $C_W = 0.6$, vehicle cross-section $A = 3$ m^2, density of air ρ_{air} = 1.202 kg m^{-3}, co-efficient of rolling resistance C_{Ro}=0.015, tire diameter D_{tire} = 0.7 m, gear ratio from rotor to drive axle n = 10.946, and internal moment of inertia referenced to the drive axle of J = 10 kg m^2. Assume a gear efficiency of 95%.

A. Calculate (i) the aerodynamic drag, (ii) the rolling resistance, (iii) the downgrade force acting on the van, and (iv) the overall load torque, referenced to the axle, applied to the vehicle.
B. The van brakes linearly from 50 km/hr to 0 km/hr over 20 seconds. Instantaneously at 50 km/hr the drum brakes apply 400 Nm of braking torque to the wheels. At this speed of 50 km/hr, calculate (i) the axle torque due to the internal inertia, (ii) the overall axle torque required to decelerate the vehicle, (iii) the regenerative rotor torque, and (iv) the regenerative power to the rotor.

Question 2

A. Derive an expression for the magnetizing-current space vector in a three-phase ac motor which has sinusoidally-distributed windings. Neglect the leakage and winding resistance, and assume an open-rotor condition.

B. A two-pole, three-phase permanent-magnet ac motor has the following characteristics: motor torque constant k_T = 0.5 Nm/A, motor voltage constant k_E = 0.5 V/(rad/s), and synchronous inductance L_m = 5 mH. The motor is supplying a torque of 50 Nm at a speed of 6000 rpm. Calculate the per-phase voltage across the power-processing unit as it supplies current to the motor.

Question 3

In a balanced three-phase inverter supplied by a dc link voltage V_d = 300 V, the phase A average output voltage is $\bar{v}_{An} = 112.5\cos 283t$. The ac motor internal voltage in phase A can be represented as a pure sinusoid by $e_A(t) = 106.14\cos(283t - 6.6^o)$, and the inductance in each phase is 5 mH. The inverter is switching at 20 kHz.

A. Calculate (i) the duty-ratios of the three phases, $d_A(t)$, $d_B(t)$, and $d_C(t)$, and (ii) the phase A current, $i_A(t)$.
B. Calculate (i) the MOSFET conduction and switching power losses, (ii) the diode conduction power losses, and (iii) the total inverter power loss. The MOSFET parameters are: on-resistance $R_{DS(on)}$ = 0.5 Ω, turn-on energy E_{on} = 0.60 mJ and turn-off energy E_{off} = 0.20 mJ at 400V, 10 A. Assume an ideal diode with a forward drop V_f = 2 V, and a conduction loss approximated by $P_{C,Diode} = V_f I_{Pk}\left(\frac{1}{2\pi} - \frac{m}{8}\cos\theta\right)$. Approximate the MOSFET conduction loss by $P_{C,MOS} = R_{DS(on)} I_{Pk}{}^2\left(\frac{1}{8} + \frac{m}{3\pi}\cos\theta\right)$.

Question 4

A symmetrical, four-pole, three-phase, wye-connected induction motor is characterized as follows. The dc phase-to-phase resistance is measured to be 1.1 Ω. A no-load test with an applied voltage of 208 V (line-line), 60 Hz, results in a phase current of 6.5 A, and a three-phase power of 175 W. A locked-rotor test with an applied voltage of 53 V (line-line), 60 Hz, results in a phase current of 18.2 A, and a three-phase power of 900 W.

A. Estimate the per-phase equivalent circuit parameters: R_S, L_{LS}, L_M, L_{LR}', and R_R'.
B. When supplied by a current-controlled inverter operating at 60 Hz, the motor generates a torque of 30 Nm at 1746 rpm. Estimate (i) the sum of the core and mechanical power losses, (ii) the total power transferred across the airgap, and (iii) the per-phase rotor current.

Question 5

The system parameters of a permanent-magnet dc motor supplied by a switch-mode PWM dc-dc converter are as follows: armature resistance $R_a = 2\ \Omega$, armature inductance $L_a =$ 5.2 mH, equivalent load moment of inertia $J = 152 \times 10^{-6}$ kg m^2, damping $B = 0$, motor torque constant $k_T = 0.1$ V/(rad/s), motor voltage constant $k_E = 0.1$ Nm/A, converter dc bus voltage $V_d = 42$ V, amplitude of triangular waveform control voltage $V_{tri} = 3$ V, switching frequency f = 20 kHz. The motor is controlled by a cascaded feedback controller, which has an inner loop controlling current (torque) and a outer loop controlling speed. Both loops utilize proportion-integral controllers and have unity feedback. The feedback effects of the motor-induced back emf and the load torque on the control loops can be neglected.

A. Sketch a block diagram of the inner current-control loop.
B. Derive the open-loop gain function of the current loop.
C. Calculate the proportional and integral controller gains for the current loop, selecting the current loop crossover frequency to be one tenth of the switching frequency, and the phase margin to be 90°.
D. Sketch a block diagram of the outer speed control loop.
E. Derive the open-loop gain function of the speed loop.
F. Calculate the proportional and integral controller gains for the outer speed loop, assuming the speed loop crossover frequency to be one tenth of that of the current loop crossover frequency. Select the phase margin to be 60°.

Question 6

An enhancement-mode n-channel vertically diffused power MOSFET operates in a step-down converter switching at 20 kHz, with a dc link voltage $V_d = 400$ V, and load current I_o = 10 A. The device characteristics are as follows: threshold voltage $V_{GS(th)} = 4$ V, drain current $I_D = 10$ A at gate voltage $V_{GS} = 7$ V, gate-source capacitance $C_{gs} = 1000$ pF, gate-drain capacitance $C_{gd} = 150$ pF, and on-state resistance $R_{DS(on)} = 1\ \Omega$. The MOSFET is driven by an ideal voltage-source square wave v_{GG}, of amplitude 0 V to 15 V, in series with an external gate resistance $R_G = 50\ \Omega$. Assume the diode has a 1V forward drop and no reverse recovery.

A. Sketch $v_{GG}(t)$, $v_{GS}(t)$, $v_{DS}(t)$, $i_D(t)$, $v_{diode}(t)$, and $i_{diode}(t)$ during turn-on of the MOSFET.
B. Calculate the following (i) turn-on delay time t_{don}, (ii) current rise time t_{ir}, (iii) voltage fall time t_{fv}.
C. Calculate the power dissipation in the MOSFET due to turn-on switching losses.
D. Estimate the MOSFET junction temperature due to turn-on switching loss only, if the MOSFET is bonded to a 70 °C heatsink. The thermal impedance from the heatsink to the junction is $\theta_{J\text{-}C} = 2$ °C/W.