**OLLSCOIL NA hEIREANN, CORCAIGH**
**THE NATIONAL UNIVERSITY OF IRELAND, CORK**

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

# APPLIED POWER ELECTRONICS AND MOTION CONTROL (EE4001)


Prof. G. Irwin
Prof. R. Yacamini
Dr. J.G. Hayes


Time Allowed – 3 Hours

Attempt **all five** questions. Each question carries equal marks.

The use of non-programmable electronic calculators is permitted.

## Question 1 - DC Motor and Power Electronics

The system parameters of a permanent-magnet dc motor supplied by a switch-mode PWM dc-dc converter are as follows: armature resistance $R_a = 0.35\,\Omega$, armature inductance $L_a$ = 1.5 mH, motor moment of inertia 0.02 kg m$^2$, motor voltage constant $k_E$ = 0.5 V/(rad/s), converter dc bus voltage $V_d$ = 200 V, switching frequency $f_S$ = 25 kHz, and amplitude of triangular waveform control voltage $V_{tri}$ = 3 V. The motor is spinning in a forward direction at a speed of 1500 RPM and supplies a load torque of 10 Nm.

A. Calculate the following: (i) the applied armature voltage $V_{AB}$; (ii) duty ratios for (a) overall converter, (b) pole A, and (c) pole B; and (iii) the peak-to-peak ripple on the armature current.
B. Sketch the waveforms for the triangular voltage $v_{tri}(t)$, control voltage $v_c(t)$, pole A voltage $v_A(t)$, the pole B voltage $v_B(t)$, armature voltage $v_{AB}(t)$, armature current $i_a(t)$ and the dc bus current $i_d(t)$.

## Question 2 – Mechanical Systems and PMAC Motor

A. An electric vehicle has the following attributes: mass $M$ = 1400 kg, drag co-efficient $C_W$ = 0.19, vehicle cross section $A$ = 2.4 $m^2$, co-efficient of rolling resistance $C_{RR}$ = 0.0044, wheel diameter $d_W$ = 0.6 m, gear ratio from rotor to drive axle $n$ = 10.946, and a nominal gear efficiency of 95%. Neglect internal moment of inertia and use density of air $\rho_{air}$ = 1.202 kg $m^{-3}$.
The vehicle is required to accelerate from 0 to 100 km/hr in 8 s on a flat road surface under calm wind conditions. Instantaneously at 60 km/hr, calculate (i) the aerodynamic drag, (ii) the rolling resistance, (iii) the acceleration force, and (iv) the electromagnetic torque required from the rotor.

B. A four-pole three-phase permanent-magnet ac motor is used for traction in a hybrid-electric vehicle. The vector-controlled motor is rated at 100 Nm at 6000 rpm, and is powered by a three-phase sinusoidal PWM inverter supplied by a 300 V NiMH battery pack. The motor efficiency and power factor at rated power are 90% and 0.9, respectively. Determine the following drive parameters at rated power and speed:
   (i) per-phase voltage, $V_{ph}$,
   (ii) per-phase back emf, $E_{ph}$,
   (iii) per-phase current, $I_{ph}$,
   (iv) per-phase synchronous inductance, $L_S$,
   (v) motor voltage and torque constants, $k_E$ and $k_T$,
   (vi) motor copper loss, given a per-phase series resistance of $R_S$ = 15 mΩ,
   (vii) core, friction and windage losses for the machine.

## Question 3 – Power Semiconductors

The IRFP460 power MOSFET from International Rectifier operates in a boost converter switching at 20 kHz with a dc link voltage $V_d$ = 400 V, and load current $I_o$ = 20 A. The MOSFET is driven by a voltage-source square wave $v_{GG}$, of amplitude 0 V to 15 V, in series with an external gate resistance $R_G$ = 25 Ω. Assume the boost diode has a 1V forward drop and no reverse recovery.

A. Sketch $v_{GG}(t)$, $v_{GS}(t)$, $v_{DS}(t)$, and $i_D(t)$ during turn-on of the MOSFET.
B. Determine the following parameters from the data sheet at a junction temperature of 80°C: threshold voltage, forward transconductance, gate-source capacitance, gate-drain capacitance, and on-state resistance.
C. Calculate the following (i) turn-on delay time $t_{don}$, (ii) current rise time $t_{ir}$, (iii) voltage fall time $t_{fv}$ and (iv) turn-on energy loss.

**Question 4 – Induction Motor**

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 50 Nm at 1764 rpm. Estimate (i) the sum of the core and mechanical power losses, and (ii) the per-phase rotor current.
C. Determine approximate values for the applied per-phase voltage, per-phase current and power factor.

**Question 5 – Controller Design**

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 Ω, electrical time constant $\tau_e$=0.5 ms, motor voltage constant $k_E$ = 0.2 V/(rad/s), controller IC UC3637, armature current transducer LA 03-PB, input control +/-2 V to output an torque of +/- 0.4 Nm. Torque is controlled by regulating the armature current with a proportional-integral controller. The feedback effects of the motor-induced back emf and the load torque on the control loop can be neglected.

A. Referring to the schematic in Fig. 1 determine (i) the amplitude of triangular waveform control voltage, $V_{TH}$, (ii) switching frequency, $f_S$, (iii) the gain of the PWM power amplifier, and (iv) the gain of the feedback stage.
B. Sketch a block diagram of the current-control loop.
C. Derive the open-loop gain function of the current loop.
D. Calculate the values of the error amplifier compensation components $R_I$, $R_F$, and $C_F$ selecting the current loop crossover frequency to be one tenth of the switching frequency, and the phase margin to be 45°.

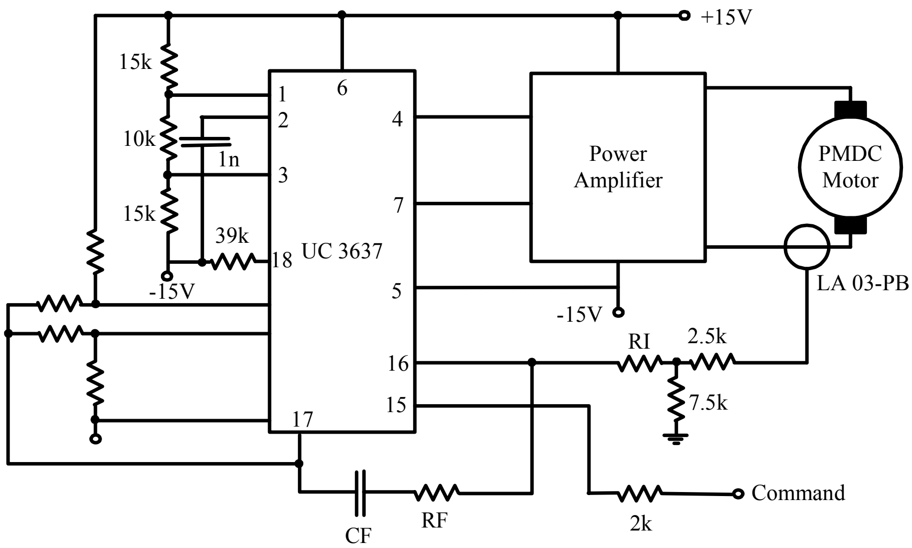


Figure 1