SEMESTER 2 EXAMINATIONS 2018/19

POWER ELECTRONICS AND DRIVES

Duration 120 mins (2 hours)

This paper contains 6 questions

Answer **TWO** questions in **Section A** and **TWO** questions in **Section B.**

Section A carries 50% of the total marks for the exam paper.

Section B carries 50% of the total marks for the exam paper.

All numerical answers should be given to **5 significant figures**.

Only University approved calculators may be used.

A foreign language dictionary is permitted ONLY IF it is a paper version of a direct ‘Word to Word’ translation dictionary AND it contains no notes, additions or annotations.

An outline marking scheme is shown in brackets to the right of each question.

11 pages examination paper (+ data sheets)

SECTION A

Answer *TWO* out of *THREE* questions

Question A1

Figure 1 is a diagram of an ac to ac power transmission system.

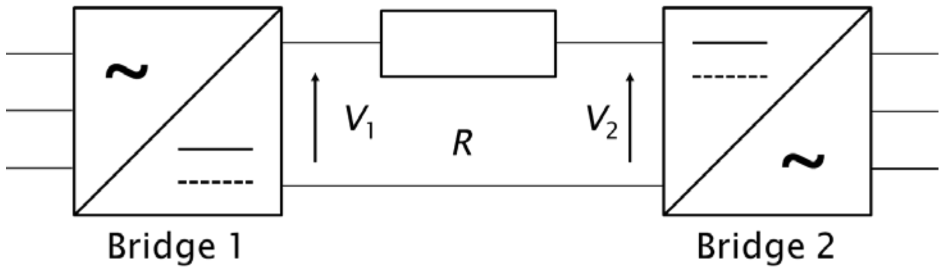

Figure 1

(a) Write a list of bullet points to illustrate the operation and features of the ac to ac power transmission system in Figure 1. [4 marks]

The system specification of the ac to ac power transmission system is given in Table 1.

Table 1

	Bridge Converter 1	Bridge Converter 2
Type	6-pulse fully controlled	6-pulse fully controlled
Supply voltage (RMS)	415 V	208 V
Frequency f ($=\omega/2\pi$)	50 Hz	60 Hz
Source inductance per phase L_s	16.667 μH	22.223μH
Mode	Rectifier	Inverter
Power P		0.8 MW
DC current I_d		5 kA
Resistance R	4.0000 mΩ	

(b) Calculate the voltages V_1 and V_2 for the transmission circuit shown in Figure 1. [4 marks]

Question continues on the following page

The mean output voltage of a p pulse converter, including overlap is given by

$$V_{mean} = p\frac{V_m}{\pi}\sin\frac{\pi}{p}\cos\alpha - \frac{p\omega L_s I_d}{2\pi},$$

where V_m is the peak voltage and α is the phase delay.

(c) Calculate the firing angle of the rectifier, and the firing advanced angle of the inverter. [4 marks]

(d) Calculate the system efficiency, ignoring any power loss in the two converters. [2 marks]

In the circuit shown in Figure 2, the thyristor is turned on at time t = 0, where the supply voltage, v_s, is given by $v_s = kt$, where k is a constant.
At time $t = T$ the supply voltage is instantaneously set to zero.

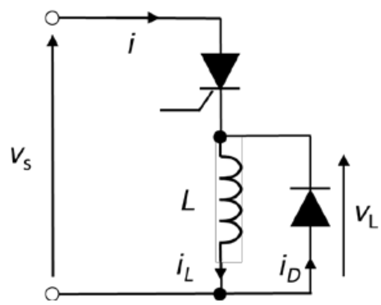

Figure 2

(e) Calculate the peak current from the supply cycle for k = 2,000 V/s if T = 100 ms. The inductance L is 2 mH. [2 marks]

(f) Calculate the time taken for the diode current to decay to zero after the supply voltage is instantaneously set to zero. The voltage across the diode is 0.9 V during forward conduction. [2 marks]

(g) Draw waveforms for the voltage across the inductor, v_L, and the inductor current, i_L when the supply voltage is rising i.e. for the first 100 ms. [2 marks]

TURN OVER

Question A2

The cycloconverter is a device that converts an ac waveform to another ac waveform of a lower frequency.

(a) Draw and label a circuit diagram of a single phase to single phase cycloconverter. Identify each power electronic device in your circuit by numbering them in order. The supply and output frequencies are 50 Hz and 16.667 Hz respectively. The delay angles of the converter are all equal at $\pi/6$ rad. [2 marks]

(b) Draw voltage waveforms for the supply and output for one complete cycle of the output voltage. Also show which devices are conducting using the device numbers shown in your circuit diagram. [3 marks]

(c) Explain the operation of this cycloconverter with a load consisting of an inductor and resistor in series over an output cycle. [2 marks]

The supply to a single phase to single phase cycloconverter is 230 V and 50 Hz. During an output half cycle the delay angles are 152, 121, 61, 14.135, 14.135, 61, 121, and 152 degrees.

(d) Calculate the average voltage over the positive half cycle of the output voltage. [5 marks]

(e) Calculate the average power dissipated in a resistive load of 0.29013 Ω. [2 marks]

Question continues on the following page

In a different converter, the voltage, $v(t)$ across a load, over the time $0 < t < 2\pi$ is given by

$$v(t) = t \quad \text{for } 0 < t < 2\pi$$

$$v(t) = v(t + 2\pi)$$

(f) Sketch the voltage over the interval,

$$-4\pi < t < 4\pi.$$ [2 marks]

(g) Determine the Fourier series expansion for this voltage. Express the series in terms of the n^{th} harmonic. Write in your answer book the first three terms of the series.

[4 marks]

TURN OVER

Question A3

The DC-to-DC converter is a device that converts a source of DC from one voltage level to another.

(a) Draw and label a circuit diagram for a dc-dc switch-mode and step-up (boost) converter using a power MOSFET as the main semiconductor switching device. Describe the operation of this circuit, when continuous current flows in the inductor. Include voltage and current waveforms for the inductor and circuit diagrams in your answer. [7 marks]

(b) Determine an expression from first principles relating the input voltage, E to the output voltage, V_o, as a function of the duty cycle, δ. Also determine an expression from first principles for the inductance, L, in terms of the E, V_o, δ, switching period, T_p, and mean output current I_{o_mean}. State any assumptions made in deriving your expressions, by drawing and completing a table in your answer book which is similar to the one shown below. [3 marks]

	Assumption
1	
2	
3	

(c) Calculate the following values if the maximum input power is 400 W at a voltage of 12 V. The output voltage is 400 V when the switching frequency is 50 kHz.

i. The transistor on time.
ii. The average inductor current.
iii. The inductance.
iv. The peak inductor current.

[4 marks]

Question continues on the following page

An inductor is connected in parallel with the drain and source of an n-channel power MOSFET that is turned off. The drain to source voltage, v_{ds}, is negative. There is a current, i, flowing through the inductor.

(d) Derive a second order differential equation for the time, t, behaviour of the current, i. Define all the symbols used in your equations. By making a linear approximation for the relationship between current and voltage, show that the voltage decays exponentially with time. [6 marks]

TURN OVER

SECTION B

Answer *TWO* out of *THREE* questions

Question B1

(a) Speed control of a separately excited DC motor can be realised through DC motor drives by controlling the field current or the armature voltage. Please draw a DC motor drive topology that can enable the control of these parameters, and briefly illustrate its operation. [4 marks]

(b) A heavy-duty linear positioning system uses a ballscrew mechanism to move a 500kg load mass on a horizontal surface. The ballscrew is driven by a three-phase 200V (line-line) 50Hz 4 poles AC squirrel cage induction motor. The system has the following parameters: The ballscrew has a length of 2m, a lead of 10mm/rev, and a radius of 20mm; the ballscrew is made of steel with density 7850kg/m^3; the efficiency of the ballscrew is 0.95; the coefficient of surface friction between the mass and its slipway is 0.5. Assume that the gravitational constant is 9.81m/s^2.

(i) If the load mass must reach linear velocity of 10m/min from rest in 1s through constant acceleration, and it is known that there is an external linear, non-frictional force of 1000N to overcome, what is the minimum rotational torque required to achieve the required acceleration? The reflected inertia of the load mass and the ballscrew inertia should be taken into account but the inertia of the motor can be omitted. [8 marks]

(ii) Electrical parameters of the induction motor are (standard symbols apply): R_s = 2.0Ω, R_r = 1.5Ω, X_{ls} = 4.0Ω, X_{lr} = 4.0Ω, and X_m = 110Ω. Assume that the induction motor is now supplied from a variable speed drive with constant *V/f* control (i.e. scalar control). Determine the stator supply rms voltage and the motor mechanical speed, in rpm, when the motor is supplied at 35Hz while being subjected to a load torque of 3Nm. [8 marks]

Question B2

To test the component shown in Figure 3, it is spun at 5000 rev.min^{-1} around the Z-Z axis using a directly coupled permanent magnet brushed d.c. motor. Assuming that the component has a uniform density of 7700 kg.m^{-3}, determine:

(a) The inertia of the component, around the axis of rotation, and hence the torque required to accelerate the component to 5000 rev min^{-1} in 20 seconds. [6 marks]

(b) The stored energy in the rotating system at 5000 rev min^{-1} [2 marks]

(c) Based on the results from part (a), estimate the constant braking torque required to stop the motor from 5000 rev.min^{-1} to 0 rev.min^{-1} in 20 s. Then, determine the associated regenerative current and the energy returned to the supply, assuming a constant regenerative current throughout. [12 marks]

The motor's constants are K_e = 0.6 volt sec rad^{-1} and K_t = 0.6 N.m .amp^{-1}. The motor's rotor resistance is 0.4 ohm and its inertia is 0.20 kg.m^2.

Question continues on the following page

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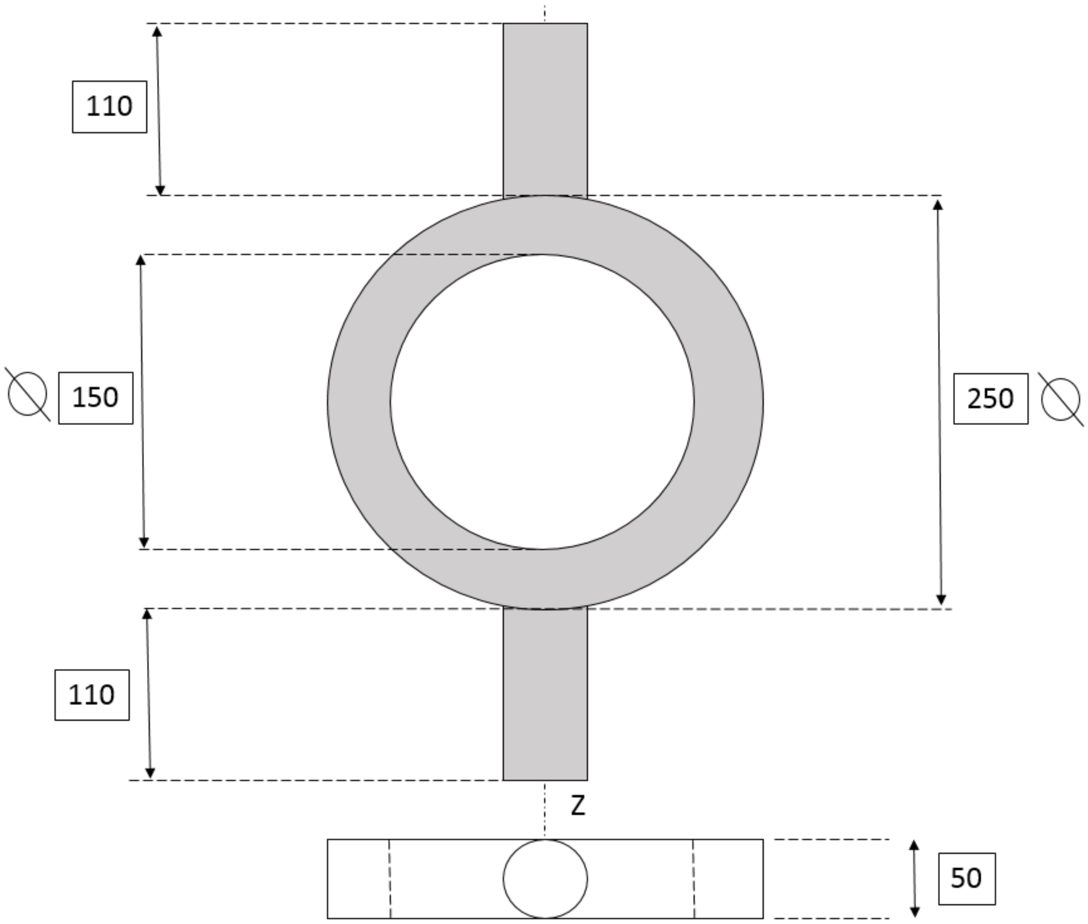

Figure 3: Components to be tested, all dimensions are in millimetres

Question B3

(a) A variable speed drive with constant *V/f* control enables a squirrel-cage induction motor to be operated in a frequency other than its rated frequency. Explain, with diagram, the principle of constant *V/f* control and its maximum torque behaviour in the based speed and field-weakening regions. State clearly the assumptions and mathematical equations used to facilitate the explanation.

[9 marks]

(b) The speed of a 20hp 300 V 1500 rpm separately excited DC motor is controlled by a three-phase full converter drive supplied by star-connected 415V (line-line) 50Hz voltage source. The field current is controlled by single-phase full converter supplied by a single-phase 240V 50Hz voltage source. The armature and field resistances are 0.3Ω and 150Ω respectively, and the motor voltage constant is 1.2V/(A-rad/s). The field converter's delay angle has been set to be 15^o. The armature and field currents can be assumed continuous and ripple-free. The viscous/windage friction is negligible.

(i) Determine the field current. [2 marks]

(ii) Determine the delay angle of the armature converter α_a if the three-phase converter supplies a rated current to the motor operating at rated speed. [4 marks]

(iii) Determine the no-load speed if the armature converter's delay angle is the same as in part (b.ii) and the armature current is 30% of the rated value. [3 mark]

(iv) The speed regulation at the no-load condition as in part (b.iii).

[2 marks]

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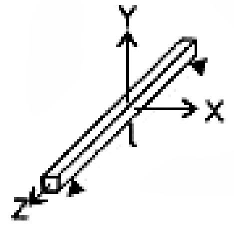
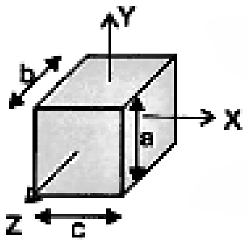
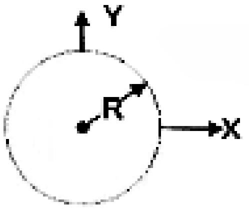
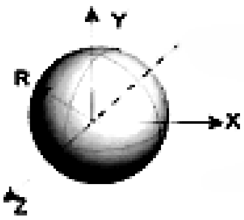
Body		I_{xx}	I_{yy}	I_{zz}
Slender bar		$\frac{ml^2}{12}$	$\frac{ml^2}{12}$	–
Cuboid		$\frac{m}{12}(a^2 + b^2)$	$\frac{m}{12}(b^2 + c^2)$	$\frac{m}{12}(a^2 + c^2)$
Thin disc*		$\frac{mR^2}{4}$	$\frac{mR^2}{4}$	$\frac{mR^2}{2}$
Cylinder		$\frac{m}{12}(3R^2 + h^2)$	$\frac{m}{12}(3R^2 + h^2)$	$\frac{mR^2}{2}$
Sphere		$\frac{2}{5}mR^2$	$\frac{2}{5}mR^2$	$\frac{2}{5}mR^2$

*A thin disc is considered a special case of a cylinder where h=0

END OF PAPER

