SEMESTER 2 EXAMINATIONS 2014/15

POWER ELECTRONICS AND DRIVES

Duration 120 mins

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 word to word® translation dictionary (paper version) is permitted provided it contains no notes, additions or annotations.

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

12 page examination paper (Hand out included)

SECTION A

Answer *TWO* out of *THREE* questions

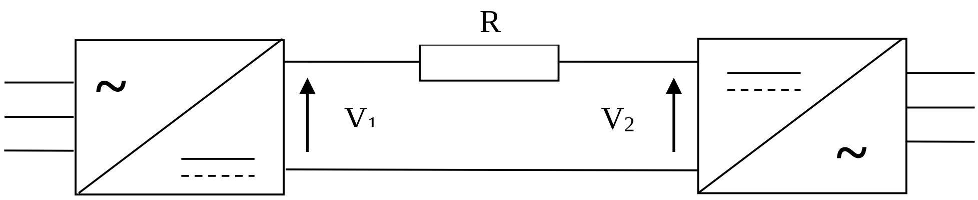
Question A1

(a) Describe and discuss the operation and features of the ac to ac power transmission system shown in Figure 1.

[4 marks]

(b) Calculate the voltages V_1 and V_2 for the transmission circuit shown in the figure with the firing advance angle of the inverter and the firing angle of the rectifier. Calculate the system efficiency, ignoring any power loss in the two converters. The system specification is given below.

	Bridge Converter 1	Bridge Converter 2
Type	6-pulse fully controlled	6-pulse fully controlled
Supply voltage	415V	208V
Frequency	50Hz	60Hz
Source inductance per phase	0.04mH	0.022222mH
Mode	Rectifier	Inverter
Power		400kW
dc current		2,500A
The resistance, R is 0.004 Ω.		



Bridge 1 Figure 1 Bridge 2

[10 marks]

Question continues on following page

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

$$V_{mean} = p\frac{V_m}{\pi}\sin\frac{\pi}{p}\cos\alpha - \frac{pXI_L}{2\pi}$$

(c) In the circuit shown in Figure 2, the thyristor is turned on at time t = 0, where the supply voltage, v, is given by

$$v = k\,t$$

where k is a constant
At time t = T the supply voltage is instantaneously set to zero.
Calculate the peak current from the supply cycle for k = 4,000 Vs^{-1} if T = 50 ms. The inductance is 1 mH.
Also 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 1.1V during forward conduction.
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 50ms.

[6 marks]

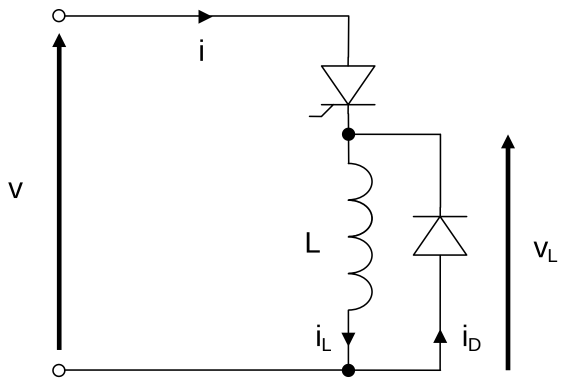


Figure 2

TURN OVER

Question A2

(a) (i) 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 50Hz and 16.667Hz respectively. The delay angles of the converter are all equal at $\pi/6$ rad.

(ii) 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.

(iii) Explain the operation of this cycloconverter with a load consisting of an inductor and resistor in series over an output cycle.

[7 marks]

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

(i) Calculate the average voltage over the positive half cycle of the output voltage.

(ii) Also calculate the average power dissipated in a resistive load of 0.23967Ω.

[7 marks]

Question continues on following page

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

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

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

Sketch the voltage over the interval

$$-4\pi < t < 4\pi$$

Determine the Fourier series expansion for this voltage. Express the series in terms of the n^{th} harmonic.

[6 marks]

Question A3

(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 from first principles, determine an expression for the inductance, L, in terms of the input and output voltages (E and V_o), duty cycle (δ), switching period (T) and mean current ($\bar{I}$).

State any assumptions made in deriving your expressions. [Hint: Draw and complete a table in your answer book which is similar to the one shown below].

	Assumption
1	
2	
3	

Calculate the following values if the maximum input power is 500W at a voltage of 12V. The output voltage is 600V when the switching frequency is 100kHz.

(i) The transistor on time.
(ii) The average inductor current.
(iii) The inductance.
(iiii) The peak inductor current.

[7 marks]

Question continues on following page

(c) An inductor, L, 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(t), flowing through the inductor. 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 linear positioning system incorporates a high performance ballscrew with a lead (as defined in figure 3) of 0.01m, and is required to position the load to a resolution of 10^{-5}m.

a) Determine the minimum pulses per revolution (PPR) of the incremental rotary position transducer that is used in this system, assuming the encoder is directly coupled to the ballscrew. [4 marks]

b) Discuss the operation of the optical rotary encoder suitable for this application, and highlight its advantages and disadvantages when used in this type of application. [6 marks]

c) If the maximum linear speed of the load is 5m sec^{-1}, determine the encoder's maximum speed and maximum output frequency. [4 marks]

d) Comment on the precautions required when connecting the lead-screw to the encoder, and how any problems can be minimised.

[6 marks]

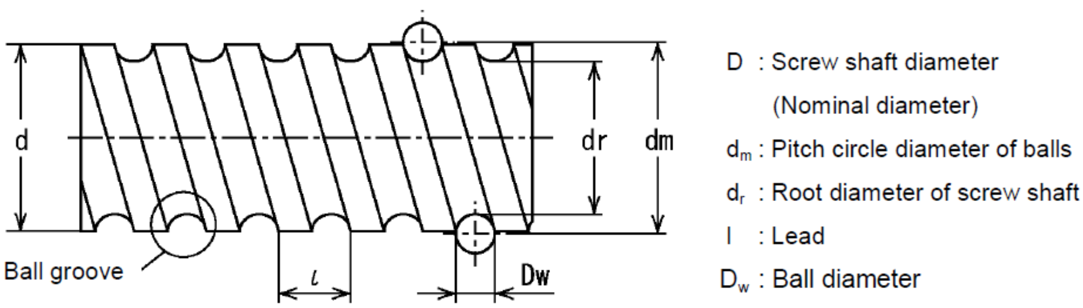


Figure 3: Ball screw schematic

Question B2

To test the components shown in Figure 4, it (referring to the whole structure) is spun at 1000 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 3000 $kg.m^{-3}$, determine:

a) The components of inertia, around the axis of rotation, and hence the torque required to accelerate the components to 1000 rev min^{-1} in 10 seconds.
[6 marks]

b) The stored energy in the rotating system at 1000 rev min^{-1}
[2 marks]

c) The regenerative current required to reduce the rotational speed from 1000 rev min^{-1} to zero in 5 seconds, and the energy returned to the supply.
[12 marks]

The motor's constants are K_e=0.6 Volt sec Rad^{-1} and K_t=0.6 Nm Amp^{-1}. The motor's rotor resistance is 0.2 Ohm and its inertia is 0.15 kg m

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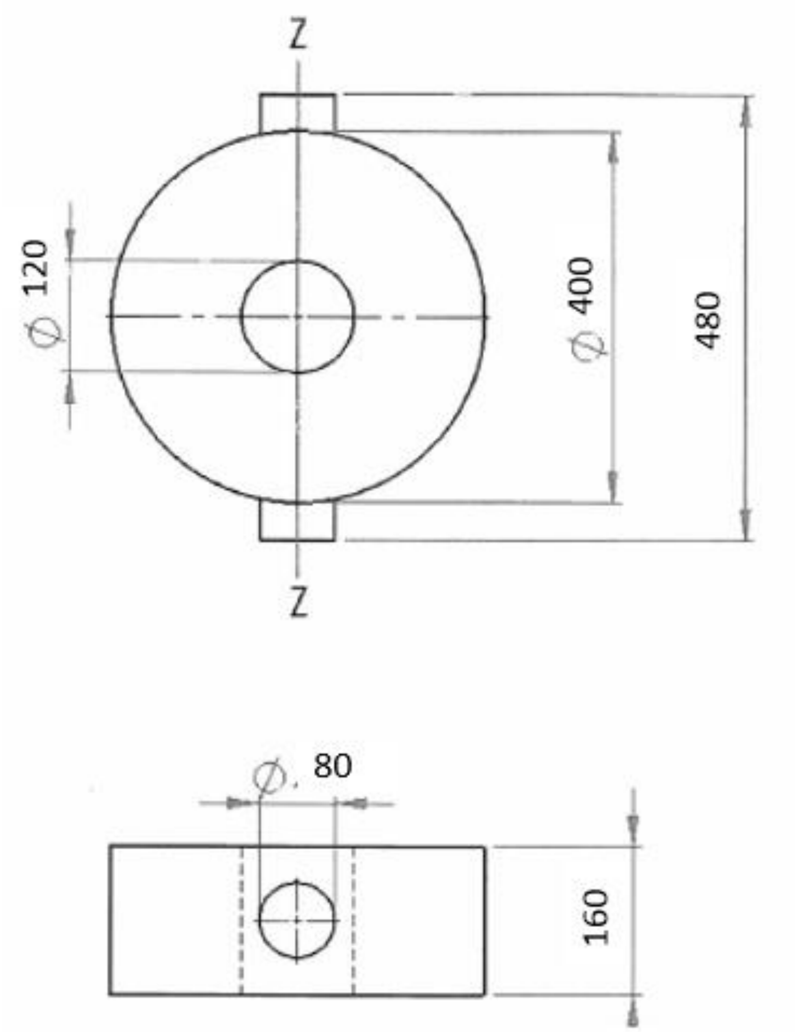

Figure 4: Components to be tested, all dimensions are in millimetres

Question B3

Discuss the following aspects of the motor-drive selection process:

a) The environmental cost savings from the use of variable speed drive.

[6 marks]

b) The cause of electromagnetic and radio frequency interference and how their impact be minimised.

[6 marks]

c) The benefits of using networked systems, including drives across a process line.

[8 marks]

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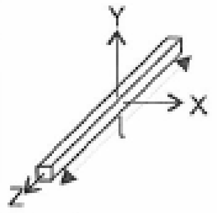
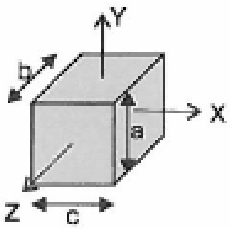
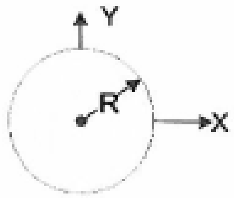
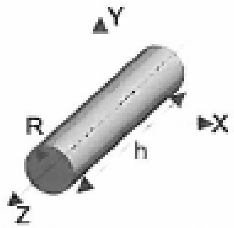
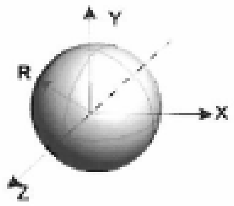
Hand-out for power electronics and drives

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.

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