Loughborough University

POWER ELECTRONICS

22WSC322

Semester 2 2023 In-Person Exam paper

This examination is to take place in-person at a central University venue under exam conditions. The standard length of time for this paper is **3 hours**.

You will not be able to leave the exam hall for the first 30 or final 15 minutes of your exam. Your invigilator will collect your exam paper when you have finished.

Help during the exam

Invigilators are not able to answer queries about the content of your exam paper. Instead, please make a note of your query in your answer script to be considered during the marking process.

If you feel unwell, please raise your hand so that an invigilator can assist you.

You may use a calculator for this exam. It must comply with the University's Calculator Policy for In-Person exams, in particular that it must not be able to transmit or receive information (e.g. mobile devices and smart watches are **not** allowed).

Loughborough University

POWER ELECTRONICS

(22WSC322)

Semester 2 2023 3 Hours

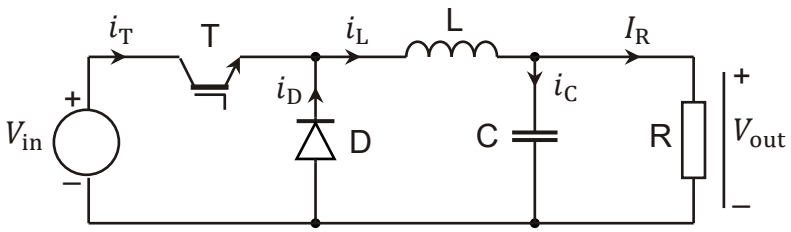
Answer **ALL FIVE** questions.

Each question carries a total of 20 marks.

Any University-approved calculator is permitted.

1.

a) A DC/DC converter is shown below.



The input voltage $V_{in} = 15$ V.

The power switching device T is an IGBT controlled by PWM.

The duty cycle $D = 0.4$ and the switching frequency $f_s = 50$ kHz.

The inductor is 180 μH and the load resistor is 10 Ω.

Assume ideal operation and no power loss.

i. Name the converter. [1 mark]

ii. Determine the output voltage V_{out} and current I_R [2 marks]

iii. Determine the peak-to-peak inductor current ripple using:

$$|\Delta i_L| = \frac{(1-D)V_{out}}{f_s L}$$ [2 marks]

iv. Sketch two cycles of the IGBT current i_T waveform, clearly showing the amplitude and timings. [5 marks]

b) A DC/DC converter is required to meet the following specification.

- DC input voltage ranges from $10\ \text{V}$ to $20\ \text{V}$
- Load ranges from $10\ \Omega$ to $30\ \Omega$
- DC output voltage must be kept constant at $40\ \text{V}$

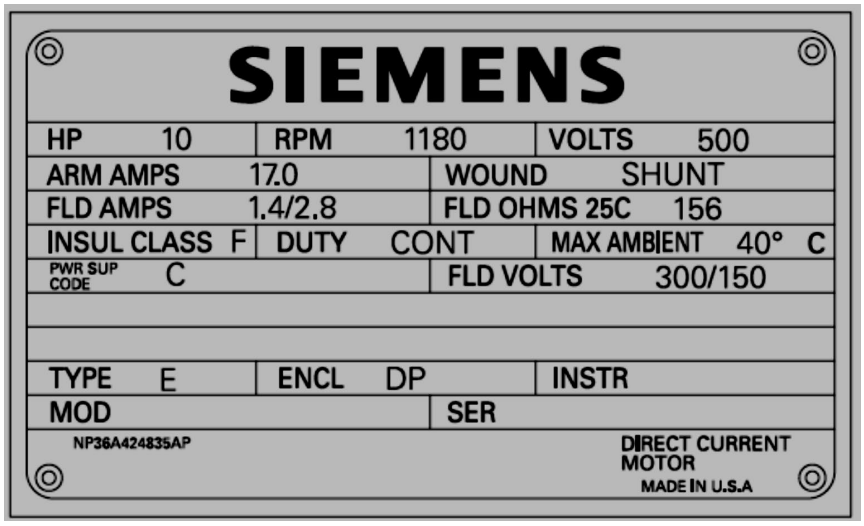
Assume ideal operation and no power loss.

i. Sketch a suitable DC/DC converter circuit. [3 marks]

ii. Determine the range of the duty cycle D [4 marks]

iii. Explain why closed-loop feedback control is needed for this converter to meet the design specification. [3 marks]

2. A single-quadrant DC chopper is used to control the speed of a separately excited DC motor which has the following name plate.



The motor armature has negligible resistance and 20 mH inductance. The chopper is supplied from a constant DC bus voltage of 500 V and switched at 20 kHz. It is required to operate the motor at its rated torque and 2/3 of its rated speed.

a) What is the required duty cycle? [2 marks]

b) Sketch the voltage across the motor terminals within two switching cycles indicating the value of each voltage level and time intervals [4 marks]

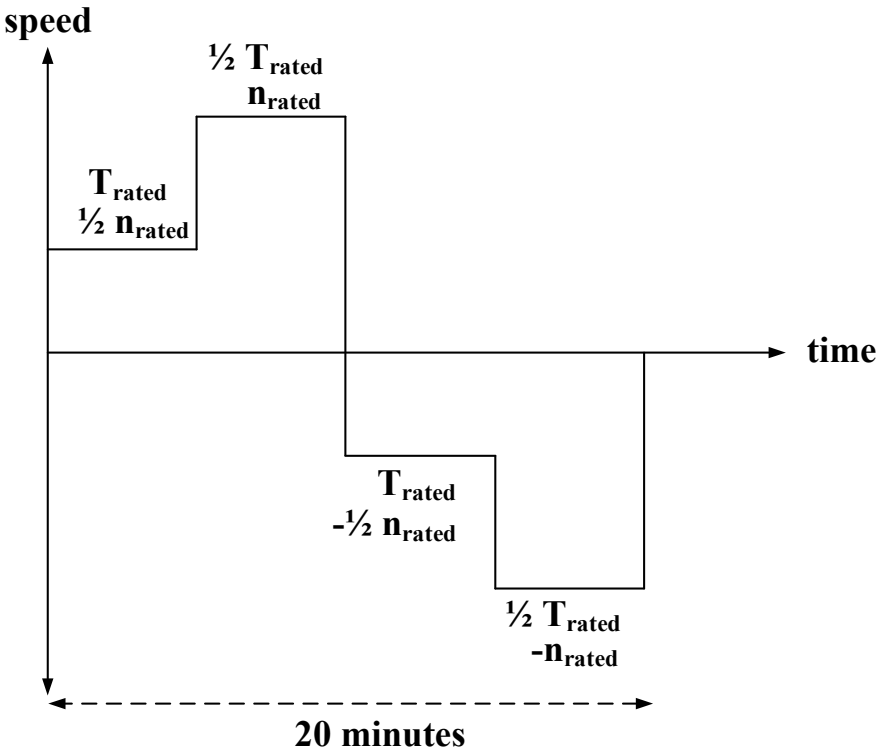
c) Calculate the motor ripple current. [4 marks]

d) Calculate the chopper average input current, assuming ideal semiconductor devices. [4 marks]

e) Calculate the chopper effective input resistance [2 marks]

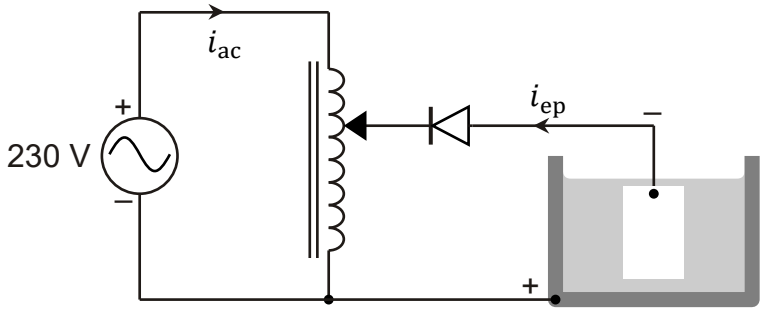
/continued

f) In a new application, the motor is required to operate at different speeds and load torques as shown below.



Draw a power electronic circuit schematic that can be used to drive the motor. [4 marks]

3. A simple system for electroplating comprises a Variac (controllable autotransformer) and a single diode. The Variac can be adjusted manually to control the speed of electroplating.



a) Sketch the waveform of the supply current i_{ac} assuming that the Variac is ideal. [3 marks]

b) Sketch a circuit with more diodes that would improve the supply current quality and speed up the electroplating. [4 marks]

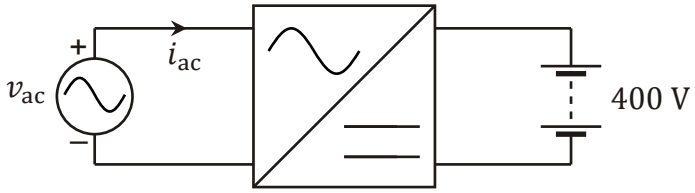
c) Propose a thyristor circuit to replace the Variac and diode(s). [5 marks]

/continued

d) Sketch the waveforms of the electroplating current i_{ep} and the supply current i_{ac} of the thyristor circuit, assuming that the electroplating process is purely resistive. [4 marks]

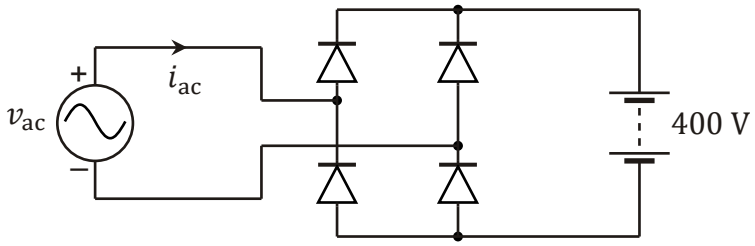
e) Describe how the thyristors would be controlled. [4 marks]

4. An electric vehicle charger is required to charge a 400 V battery from a 230 V AC grid at a power of 2 kW.



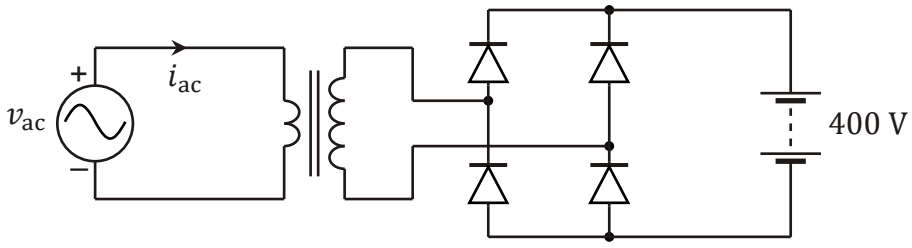
a) Sketch the ideal waveforms of v_{ac} and i_{ac} indicating their amplitudes and relative phase. [5 marks]

b) One proposal is to use a simple diode bridge rectifier.



Explain why this will not work. [2 marks]

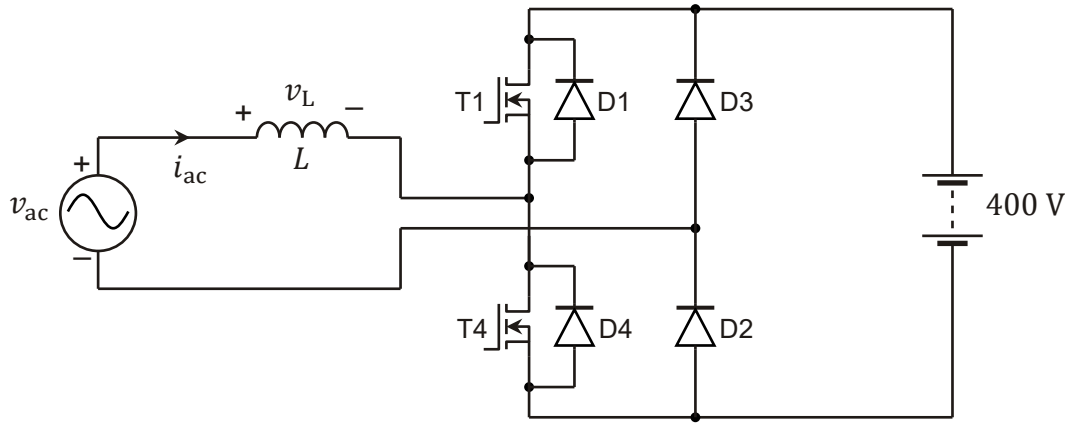
c) A second proposal is a transformer with a diode bridge rectifier.



Discuss how this would work. [4 marks]

/continued

d) The circuit below shows a better idea.



The transistors, T1 and T4, are switched alternately at high frequency

When v_{ac} and i_{ac} are positive and T4 is on, current flows from the $+$ of the grid (v_{ac}), through the inductor, down through T4, up through D2 and back to the $-$ of the grid.

Explain any energy flowing in this state, referring to the inductor equation $v = L\,\mathrm{d}i/\mathrm{d}t$ [2 marks]

e) For the next state, T4 turns off and T1 turns on.

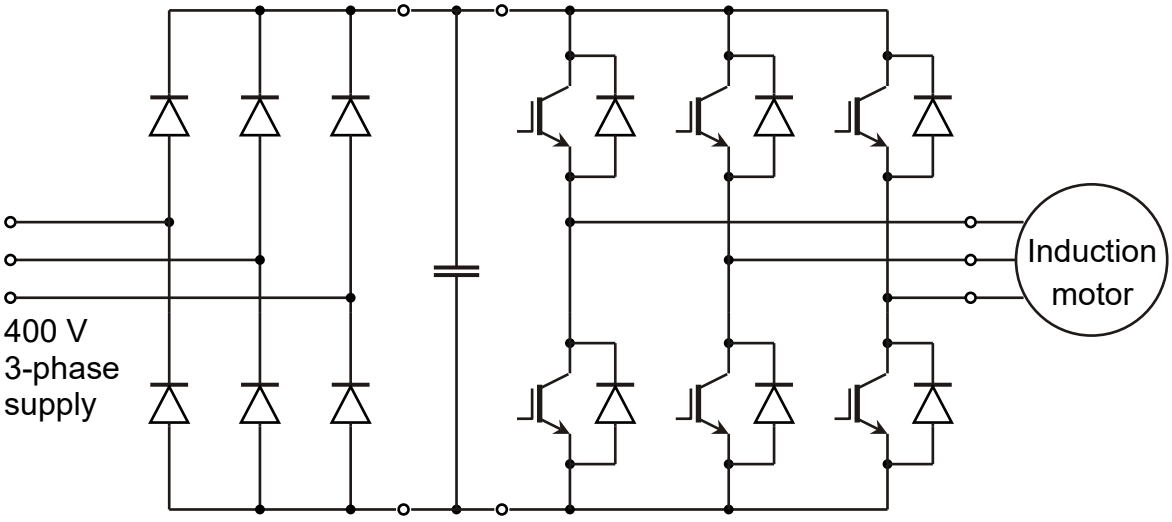
i. Describe the path of the current. [2 marks]

ii. Describe the flow of energy. [2 marks]

f) Explain briefly how the switching of the transistors can be controlled to achieve better performance than the diode bridge circuit of part c). [3 marks]

/continued

5. A water pump has the following drive circuit.



Explain how this circuit can be used to vary the speed of the pump, and describe a simple way to create the switching pattern necessary for the transistors. [20 marks]

Murray Thomson
Mohamed Diab
Zhengyu Lin