Loughborough University

ELECTRICAL POWER AND MACHINES

23WSB045

Semester 2 23/24 | In-Person Exam Paper

Student ID Number:		Desk Number:	

The standard length of time for this paper is **2 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.

Use of a calculator is permitted - 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).

Answer **ALL FOUR** questions.

Each question carries a total of 25 marks.

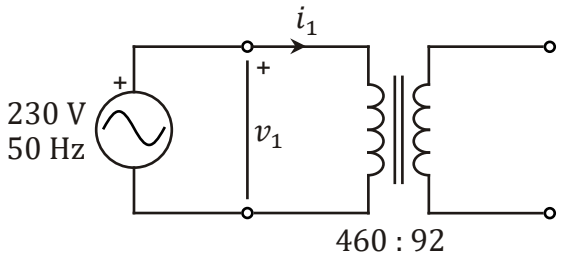
Write your answers in the spaces provided below each question part.

Do all rough work in this book.

Additional space is provided towards the back of this book if you need it.

A formulae sheet is provided at the back of this book.

1. The transformer shown in the diagram below is connected to a 230 V 50 Hz supply and has nothing connected to the secondary (open circuit output).

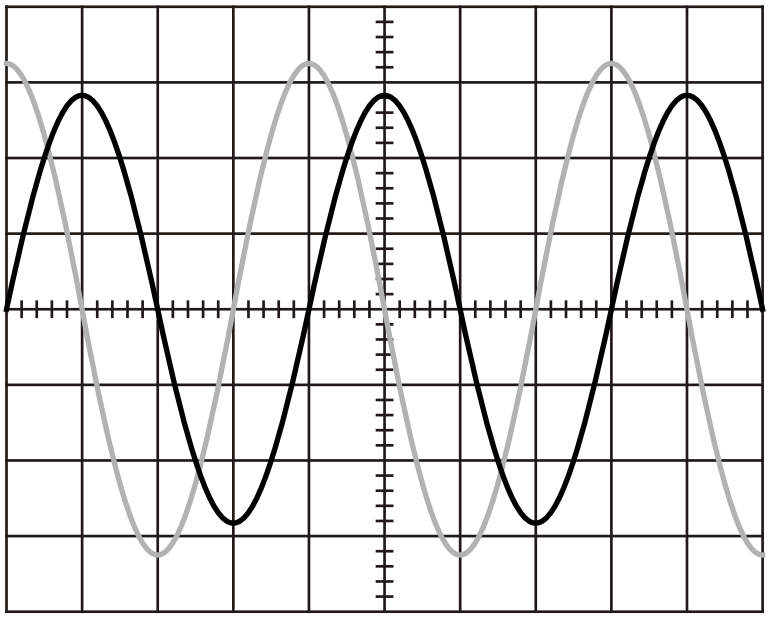


You may assume the transformer is lossless and neglect leakage reactances. But it is ***not*** completely ideal, because it does have a significant inductive magnetising current.

The oscilloscope image below shows the voltage v_1 in grey and current i_1 in black. This current is the magnetising current.

The horizontal scale is 5 ms per div, where a div is about 1 cm.

The vertical scale for voltage is 100 V per div and for current it is 1 A per div.



a) Circle the RMS value of the magnetising current. [1 mark]

0 A	0.71 A	1 A	1.41 A	2 A	2.83 A
4 A	5.66 A	8 A	±0.71 A	±1.41 A	±2.83 A

b) Circle the phase angle of this current with respect to the voltage. [1 mark]

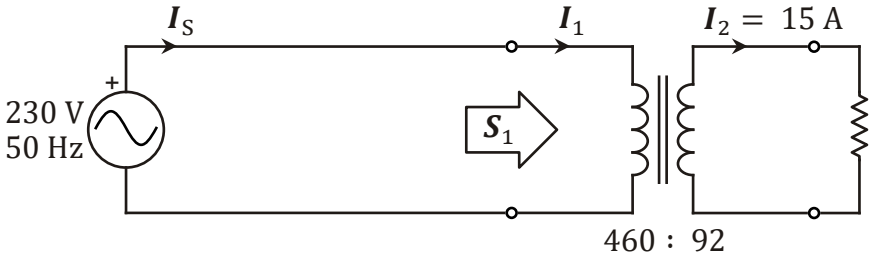
0°	30°	37°	45°	53°	60°
90°	120°	240°	–30°	–60°	–90°

/continued

c) Express this current as a phasor (complex number), taking the voltage as the reference phasor at zero angle. [2 marks]

d) Calculate the complex power going into the transformer, when there is nothing connected to the secondary. [4 marks]

e) A purely resistive load is now connected and allows 15 A to flow in the secondary.

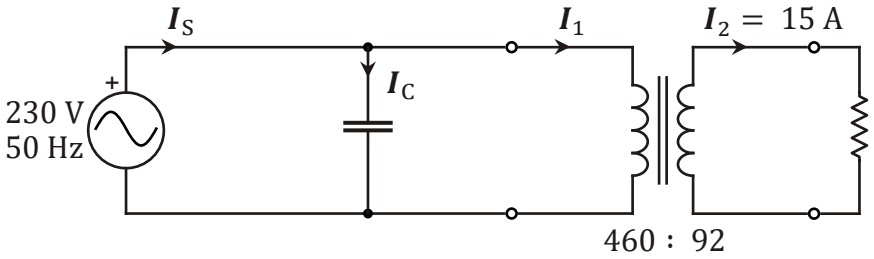


Calculate the complex value of the primary current I_1, including the magnetising current from part c). You may assume the transformer is lossless and neglect leakage reactances. [5 marks]

/continued

f) Calculate the new value of complex power flowing into the transformer. [3 marks]

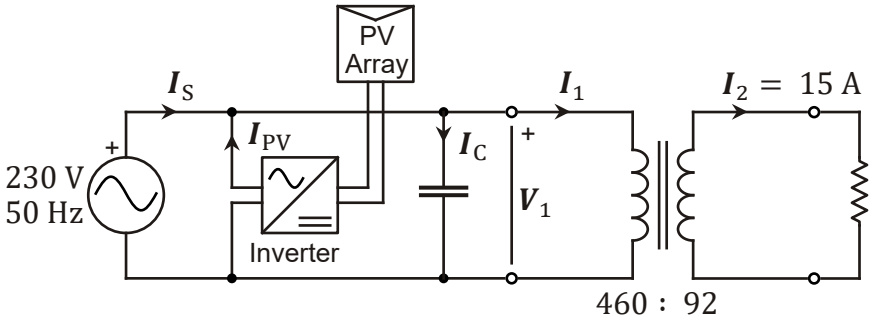
g) A capacitor is added across the primary of the transformer to bring the power factor to unity.



Calculate the required value of capacitance. [5 marks]

/continued

h) A photovoltaic array and inverter are added to the system and provide 920 W at unity power factor.



Calculate the new value of supply current, as a complex number. [4 marks]

/continued

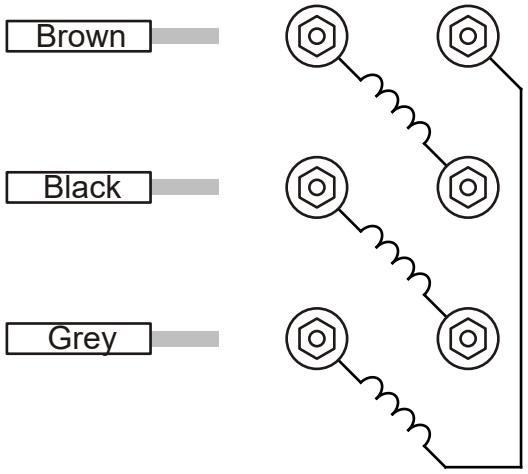
2. A three-phase induction motor nameplate says:

230 V or 400 V 50 Hz 6 pole 980 r.p.m.

a) Describe in one word how it should be wired to work on 400 V. [1 mark]

b) Draw the connections required for 400 V operation on the diagram below. [3 marks]

The inductor symbols represent the winding coils within the motor.
The circles are terminal posts.
Brown, Black and Grey are the conductors of the supply cable.

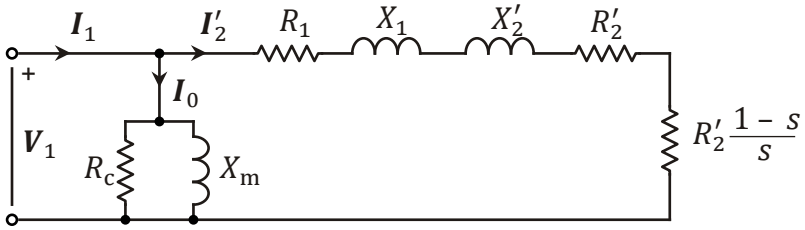


c) What is the voltage across each coil? [1 mark]

/continued

d) Calculate the slip at full load. [4 marks]

An approximate equivalent circuit of the motor is shown below. It represents a single phase of the three-phase machine.



The parameters are:

$$R_c = 75\ \Omega \qquad X_m = 10\ \Omega$$

$$R_1 = 0.047\ \Omega \qquad X_1 = 0.25\ \Omega$$

$$R_2' = 0.082\ \Omega \qquad X_2' = 0.25\ \Omega$$

e) What does the resistor on the right represent? [2 marks]

/continued

f) Calculate the value the resistor on the right in ohms at full load. [2 marks]

g) Calculate the impedance of the branch through which $\boldsymbol{I}_2'$ flows. [2 marks]

h) Show that the **magnitude** of current $\boldsymbol{I}_2'$ is 55 A.
Hints: Use $|\boldsymbol{V}| = |\boldsymbol{I}| \times |\boldsymbol{Z}|$ and your answer to part c). [2 marks]

i) Calculate the mechanical power output of the motor.
Hint: You already know that the magnitude of current $\boldsymbol{I}_2'$ is 55 A. [2 marks]

j) Calculate the power lost in the copper windings. [2 marks]

k) Calculate the power lost in the iron core.
Hint: Use your answer to part c). [2 marks]

l) Calculate the efficiency of the motor (neglecting friction and windage). [2 marks]

/continued

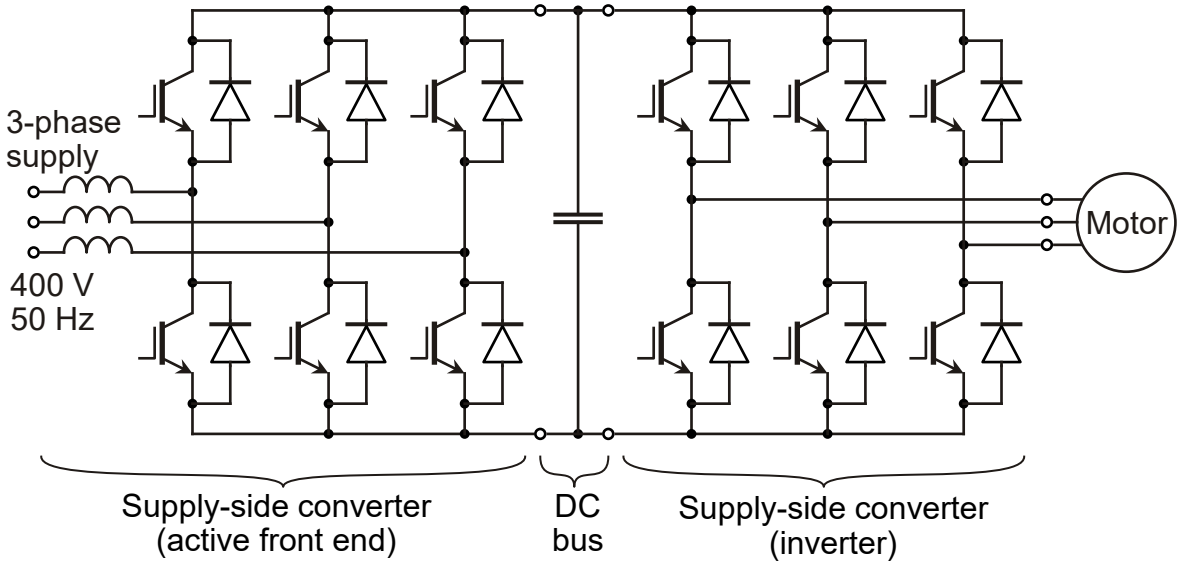
3. A synchronous motor is rated at:

400 W 3000 r.p.m. 200 Hz

a) The motor can deliver its full rated torque at any speed, up to the rated speed in either direction. Calculate the rated torque. [4 marks]

b) How many poles does the motor have? [3 marks]

The motor is equipped with a power-electronic drive as shown below.



c) Explain the purpose of the power-electronic converters. [4 marks]

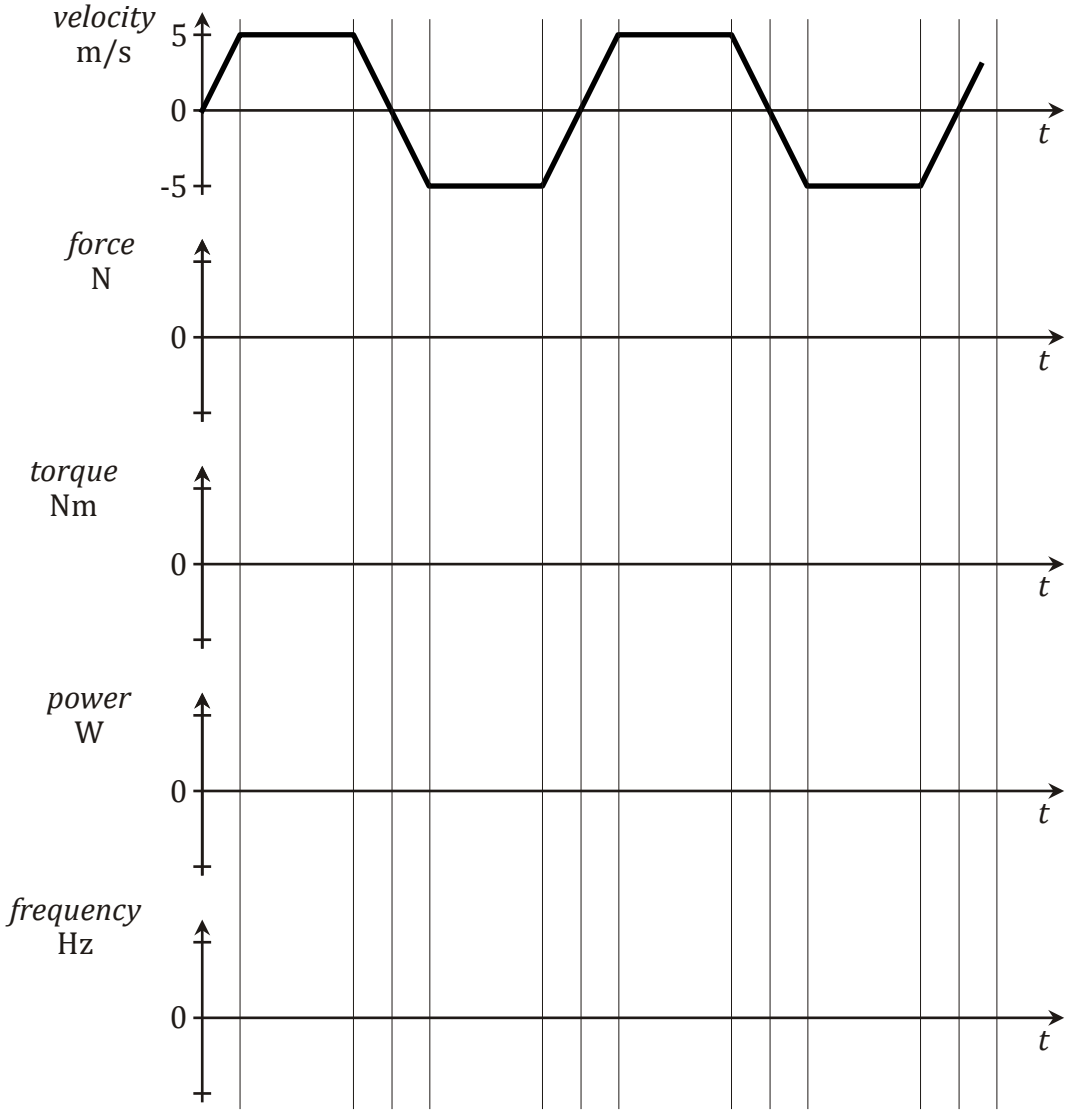
/continued

The motor is fitted with a pulley and toothed belt (timing belt) to provide a linear motion. It is to move a mass horizontally back and forth, as shown the velocity graph below.

Assume friction is negligible, and that the inertia of the motor is small compared to that of the mass.

The aim is to minimise the acceleration and deceleration times.

d) Sketch the **shapes** of the graphs of required force, torque, power and frequency on the axes below. [8 marks]



/continued

e) The mass is 8 kg.
The pulley and toothed belt (timing belt) provide
0.1 metres of horizontal travel per revolution.
Using the rated torque from part a),
calculate the time required to go from stand-still to 5 m/s, [6 marks]

/continued

4. A portable generator comprises an internal combustion engine running on diesel and a single-phase synchronous machine. It supplies electricity to a single house and is operated stand-alone, meaning that it is not connected to any other electricity network or grid. The electricity demand varies as the people in the house switch things on and off.

a) In which part of the synchronous machine is the electricity generated? [2 marks]

b) The generator is equipped with two control systems.
State what two parameters they control and
suggest suitable set points (target values) for each. [6 marks]

/continued

c) Referring to the following equation, describe the action of ONE of those control systems. [10 marks]

$$P_{\text{in}} - P_{\text{out}} = J\omega \frac{\mathrm{d}\omega}{\mathrm{d}t}$$

/continued

d) There is a heavy flywheel on the rotating shaft between the engine and the synchronous machine. Explain what this is for. [7 marks]

End of questions

Murray Thomson

/continued

If you write any answers on this page, please indicate the question numbers clearly.

/continued

If you write any answers on this page, please indicate the question numbers clearly.

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Formula Sheet

$$v = iR \qquad V = IR \qquad R = \frac{l}{\sigma A} \qquad \boldsymbol{Z}_{\mathrm{R}} = R$$

$$p = vi \qquad P = VI \qquad P = I^2 R \qquad P = \frac{V^2}{R}$$

$$V_{\mathrm{rms}} = \sqrt{\frac{1}{T}\int_0^T v^2 \,\mathrm{d}t} \qquad I_{\mathrm{rms}} = \sqrt{\frac{1}{T}\int_0^T i^2 \,\mathrm{d}t} \qquad V_{\mathrm{rms}} = \frac{V_{\mathrm{peak}}}{\sqrt{2}} \qquad P = \frac{1}{T}\int_0^T p \,\mathrm{d}t$$

$$\mathcal{F} = \phi\mathcal{R} \qquad \mathcal{F} = NI \qquad \mathcal{R} = \frac{l}{\mu A} \qquad H = \frac{\mathcal{F}}{l}$$

$$\phi = BA \qquad F = BIl \qquad B = \mu H$$

$$e = N\frac{\mathrm{d}\phi}{\mathrm{d}t} \qquad L = \frac{N^2}{\mathcal{R}} \qquad \mu = \mu_{\mathrm{r}}\mu_0 \qquad \mu_0 = 4\pi \times 10^{-7}\,\frac{\mathrm{H}}{\mathrm{m}}$$

$$v = L\frac{\mathrm{d}i}{\mathrm{d}t} \qquad E_{\mathrm{L}} = \frac{1}{2}Li^2 \qquad X_{\mathrm{L}} = \omega L \qquad \boldsymbol{Z}_{\mathrm{L}} = \mathrm{j}X_{\mathrm{L}}$$

$$i = C\frac{\mathrm{d}v}{\mathrm{d}t} \qquad E_{\mathrm{C}} = \frac{1}{2}Cv^2 \qquad X_{\mathrm{C}} = \frac{1}{\omega C} \qquad \boldsymbol{Z}_{\mathrm{C}} = -\mathrm{j}X_{\mathrm{C}}$$

$$v = V_{\mathrm{peak}}\cos\omega t \qquad \omega = 2\pi f$$

$$\boldsymbol{A} = A\left(\cos(\omega t + \alpha) + \mathrm{j}\sin(\omega t + \alpha)\right) \qquad a = \sqrt{2} \times \mathrm{Re}(\boldsymbol{A}) \qquad \mathrm{e}^{\mathrm{j}x} = \cos x + \mathrm{j}\sin x$$

$$\boldsymbol{V} = \boldsymbol{I}\boldsymbol{Z} \qquad \boldsymbol{Z} = R + \mathrm{j}X \qquad \boldsymbol{Z} = \boldsymbol{Z}_1 + \boldsymbol{Z}_2 + \cdots \qquad \frac{1}{\boldsymbol{Z}} = \frac{1}{\boldsymbol{Z}_1} + \frac{1}{\boldsymbol{Z}_2} + \cdots$$

$$\boldsymbol{S} = \boldsymbol{V}\boldsymbol{I}^* \qquad \boldsymbol{S} = P + \mathrm{j}Q \qquad S = VI \qquad P = S\cos\phi$$

$$a = \frac{N_1}{N_2} = \frac{\boldsymbol{V}_1}{\boldsymbol{V}_2} = \frac{\boldsymbol{I}_2}{\boldsymbol{I}_1} \qquad \boldsymbol{Z}_1 = a^2\boldsymbol{Z}_2 \qquad Q = I^2 X \qquad Q = \frac{V^2}{X}$$

$$V = \sqrt{3}V_{\mathrm{ph}} \qquad n_{\mathrm{s}} = \frac{120f}{p} \qquad s = \frac{n_{\mathrm{s}} - n}{n_{\mathrm{s}}} \qquad T = K_{\mathrm{T}}I_{\mathrm{a}}$$