NEW SECTION:

SECTION ID: ELEC2208

This section contains questions pertaining to the material taught in

ELEC2208 – POWER ELECTRONICS AND DRIVES

This section contains 2 questions with the following QUESTION IDs:

- **ELEC2208_1**
- **ELEC2208_2**

Answer ALL questions

This section also contains an Appendix with useful formulae.

In your record of the answers, remember to record the **CFA ID**, the **SECTION ID**, the **QUESTION ID** and **YOUR ID** at the top of **EVERY** page and include a **page number** for your answers to assist in ordering.

Once you have completed the answers, produce and save an **individual PDF file** for the answers to **THIS SECTION ONLY**.

To upload your file, follow the instructions at the start of this document.

Question ELEC2208_1

Figure Q1 is a diagram of a DC power transmission system between two three-phase AC systems.

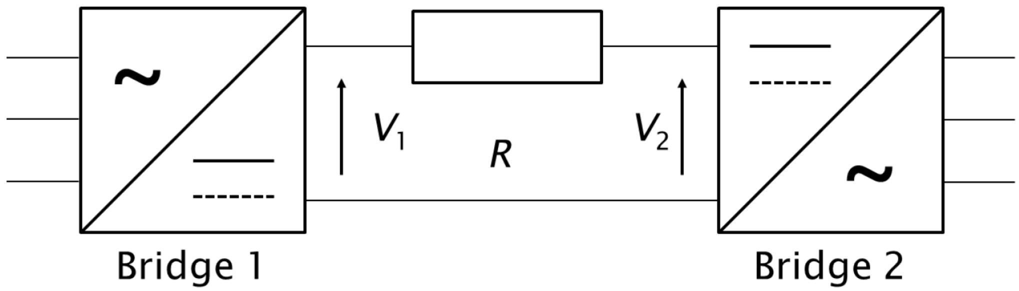

Figure Q1

The system specification is given in Table Q1.

Table Q1

	Bridge Converter 1	Bridge Converter 2
Type	6-pulse fully controlled	6-pulse fully controlled
AC line-to-line voltage	230 kV rms	230 kV rms
AC frequency *f*	60 Hz	50 Hz
Source inductance per phase L_s	27.778 mH	66.667 mH
Mode	Rectifier	Inverter
Power *P*		100 MW
DC current I_d		500 A
Resistance *R*	20.000 Ω	

(a) Calculate the voltages V_1 and V_2 for the transmission circuit shown in Figure Q1.

[5 marks]

Question continues

The mean DC 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 AC peak voltage and α is the phase delay.

(b) Calculate the firing angle of the rectifier, and the firing advanced angle of the inverter.

[5 marks]

(c) Calculate the system efficiency, ignoring any power loss in the two converters.

[2 marks]

(d) List 4 general advantages of using DC transmission systems over common AC transmission systems without AC/DC conversions.

[5 marks]

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

(e) 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.

[4 marks]

(f) When the supply and output frequencies are 50 Hz and 16.667 Hz respectively, and the delay angles of the converter are all equal at $\pi/4$ rad, 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 in (e).

[4 marks]

Question continues

The supply to a single phase to single phase cycloconverter is 100 V rms and 50 Hz. During an output half cycle, the delay angles are 143, 98, 50, 42.447, 42.447, 50, 98, and 143 degrees.

(g) Calculate the average voltage over the positive half cycle of the output voltage for a frequency of 6.25 Hz.

[6 marks]

(h) Calculate the average power dissipated in a resistive load of 257.02 mΩ.

[4 marks]

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

(i) Draw and label a circuit diagram for a dc-dc switch-mode and step-down (buck) converter using a power MOSFET as the main semiconductor switching device.

[2 marks]

(j) Describe the operation of this circuit, when continuous current flows in the inductor. Include in you answer, voltage and current waveforms for the inductor, and equivalent circuit diagrams in each state.

[7 marks]

(k) Calculate the average load current and the load resistance if the supply voltage is 400 V, the output power is 1.2 kW, and the duty cycle is 0.3.

[2 marks]

(l) Calculate the average load current and the peak current at the boundary of continuous and discontinuous current for a switching frequency of 50 kHz. The inductor has a value of 0.2 mH.

[4 marks]

Question ELEC2208_2

(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 (showing the power electronic switches) that can enable the control of armature voltage, and briefly illustrate its operation.

[12 marks]

(b) 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 the ideal maximum torque behaviour in the base speed, rated speed, and field-weakening regions. State clearly the assumptions and/or mathematical equations used.

[12 marks]

(c) The speed of a 30 hp 300 V 1500 rpm separately excited DC motor is controlled by a three-phase full converter drive supplied by star-connected 415 V (line-line) 50Hz voltage source. The field current is controlled by single-phase full converter with single-phase 240 V supply. The armature and field resistances are 0.5 Ω and 160 Ω respectively, and the motor voltage constant is 1.2 V/(A-rad/s). The field converter's delay angle has been set to be 20°. The armature and field currents can be assumed continuous and ripple-free. The viscous/windage friction is negligible.

(i) Determine the field current.

[3 marks]

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

[4 marks]

Question continues

(iii) Determine the no-load speed if the armature converter's delay angle is the same as in part (c.ii) and the motor at no load draws an armature current of 10% of the rated value.

[2 marks]

(iv) The no-load speed regulation as per the condition in (c.iii).

[2 marks]

(d) Given that the electrical specifications and parameters of an AC squirrel-cage induction motor are (standard symbols apply):

208 V (line-line), 60 Hz, 4 poles, $R_s = 1.5\ \Omega$, $R_r = 1.0\ \Omega$, $X_{ls} = 5.0\ \Omega$, $X_{lr} = 5.0\ \Omega$, and $X_m = 100\ \Omega$.

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 phase rms voltage and the motor mechanical speed, in rpm, when the motor is supplied at 45 Hz while being subjected to a load torque of 2.5 Nm.

[10 marks]

(e) A three-phase 415 V 50 Hz induction motor is supplied from a sinusoidal PWM voltage source inverter. To account for the resistive drop at low speed, the motor is controlled by V/f control law with a constant voltage boost (V_{boost}) of 15%, i.e.

$$V = k\left(\frac{V_{rated}}{f_{rated}}\right)f + V_{boost}$$

(i) Calculate k that allows fully utilization of the available voltage at rated frequency.

[2 marks]

(ii) Calculate the phase voltage at 20 Hz operation.

[3 marks]

APPENDIX – useful information

Selected equations for *Motor Drives* part:
AC motor drives

Stator copper loss: $P_{scloss} = 3I_s^2 R_s$

Rotor copper loss: $P_{rcloss} = 3I_r^2 R_r$

Core loss: $P_{core-loss} = \dfrac{3E_m^2}{R_m} \approx \dfrac{3V_s^2}{R_m}$

Input active power: $P_{in} = P_{core-loss} + P_{scloss} + P_{ag} = 3V_s I_s \cos\theta_m$

Mechanical power: $P_{mech} = P_{ag}(1-s)$

Motor efficiency: $\eta \approx \dfrac{P_{mech}}{P_{ag}} = \dfrac{P_{ag}(1-s)}{P_{ag}} = (1-s)$

Thevenin equivalent circuit at the rated frequency:

$$V_{TH} = \frac{X_M}{\sqrt{R_s^2 + (X_M + X_{ls})^2}} V_s \qquad R_{TH} = R_s \left(\frac{X_M}{X_M + X_{ls}} \right)^2 \qquad Z_{TH} = X_{ls}$$

Full rotor current, electromagnetic torque, and mechanical power expressions at the rated supply:

$$I_r = \frac{V_{TH}}{\sqrt{(R_{TH} + R_r/s)^2 + (X_{TH} + X_{lr})^2}}$$

$$T_e = \frac{3I_r^2 R_r}{s\omega_s} = \frac{3V_{TH}^2 (R_r/s)}{\omega_s[(R_{TH} + R_r/s)^2 + (X_{TH} + X_{lr})^2]}$$

$$P_{mech} = \frac{3V_{TH}^2 R_r (1-s)}{s[(R_{TH} + R_r/s)^2 + (X_{TH} + X_{lr})^2]}$$

Electromagnetic torque, maximum slip, and maximum torque at variable (β factor of the rated value) frequency operation:

$$V_{TH} = \frac{\beta X_M}{\sqrt{R_s^2 + (\beta X_M + \beta X_{ls})^2}} V_{s@\beta\omega_s}$$

$$T_{e@\beta\omega_s} = \frac{3V_{TH}^2 (R_r/s)}{\beta\omega_s[(R_{TH} + R_r/s)^2 + (\beta X_{TH} + \beta X_{lr})^2]}$$

$$s_{m@\beta\omega_s} = \pm \frac{R_r}{\sqrt{R_{TH}^2 + (\beta X_{TH} + \beta X_{lr})^2}}$$

$$T_{\max@\beta\omega_s} = \frac{3V_{TH}^2}{2\beta\omega_s[R_{TH} + \sqrt{R_{TH}^2 + (\beta X_{TH} + \beta X_{lr})^2}]}$$