



Complete, fold and seal
(see note 2 below)

SURNAME: BRITS

FORENAME(S): LOURENS

1. Please give the information requested in the boxes below.
2. Enter your name in the space provided to the right, fold over and seal down (using the label provided) to hide your name.
3. The answers must be legibly written. The Examiners can either ignore illegible script or have it typed and the expense of typing charged to the candidate.
4. Write your answers in ink.
5. Begin each answer on a fresh page. Do all rough work in the answer book and cross it through.
6. No part of this book is to be torn out; it must be handed in complete.
7. If more books than one are used, fasten them together using the tags available from the invigilator(s).
8. **Every book must be handed in. In no circumstances may answer books, used or unused, be taken out of the examination venue.**

List the numbers of the questions you have attempted	Office Use
Q2	25
Q5.	17
Total	42

7	Number of Answer Books handed in	1.
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(Gweler yr ochr arall am y fersiwn Cymraeg)

Mark confirmed as 42

$$* V_m = V_s \cdot \sqrt{2}$$

Q2.	T_e $V_f = \frac{2V_m}{\pi} \cos(0^\circ)$ $I_f = V_f / R_f$ $T_e = k_v \cdot I_f \cdot I_a$ $V_a = -E + (I_a \cdot R_a)$ $V_a = \frac{2V_m}{\pi} \cos(\alpha)$ $\cos(\alpha) = \frac{V_a \cdot \pi}{2V_m}$	ω_m $V_a = \frac{2V_m}{\pi} \cos(\alpha)$ $E = V_a - (I_a \cdot R_a)$ $\omega_m = \frac{E}{k_v \cdot \Phi \cdot f_s}$ $\omega_m = \frac{E}{k_v \cdot I_f}$ $P_{(mech)}$ $= V_a \cdot I_a$	$P_{(in)}$ $P_{in} = (V_f \cdot I_f) + (V_a \cdot I_a)$ $I_{s(eng)} = (I_a^2 + I_f^2)^{\frac{1}{2}}$ $V_A > V_s \cdot I_s$ $P.F. = \frac{P_{in}}{V_s \cdot I_s}$
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Q2 a) $V_s = 440V$, $R_a = 0.25\Omega$, $R_f = 175\Omega$, $I_a = 45$, $k_v = 1.4 \text{ Nm/A}^2$
 $\alpha = 60^\circ$, $f_s = 50\text{Hz}$

i) $V_f = \frac{2V_m}{\pi} \cos(0^\circ)$ $* V_m = V_s \cdot \sqrt{2}$
 $= \frac{2(622.25)}{\pi} \cos(0^\circ)$ $= 440 \times \sqrt{2}$
 $= 622.25V$ $= 622.25V$

$V_f = 396.14V$

$I_f = \frac{V_f}{R_f}$ Therefore: $T_e = k_v \cdot I_f \cdot I_a$
 $= \frac{396.14}{175}$ $= 1.4 \cdot 2.26 \cdot 45$
 $I_f = 2.26A$ $T_e = 142.38 \text{ Nm}$ ✓

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ii) $V_a = \frac{2V_m}{\pi} \cos(\alpha)$ $E = V_a - (I_a \cdot R_a)$
 $= \frac{2(622.25)}{\pi} \cos(60^\circ)$ $= 198.07 - (45 \times 0.25)$
 $= 198.07V$ $= 186.82V$

Therefore: $\omega_m = \frac{E}{k_v \cdot I_f}$ $\omega_m = \frac{E}{k_v \cdot I_f}$
 $= \frac{186.82}{1.4(2.26)}$ $= \frac{186.82}{1.4(2.26)}$
 $\omega_m = 2.67 \text{ rad/s}$ $= 59.05 \text{ rad/s}$ ✓

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iii) $P_{in} = (V_f \cdot I_f) + (V_a \cdot I_a)$
 $= (396.14 \times 2.26) + (198.07 \times 45)$
 $= 9804.47W$ ✓

Q2. a) iii) $I_{S(rms)} = (I_a^2 + I_r^2)^{\frac{1}{2}}$

$$= (45^2 + 2.26^2)^{\frac{1}{2}}$$

$$= 45.06 \text{ A}$$

$$VA = V_s \cdot I_s$$

$$= 440 \times 45.06$$

$$= 19826.4$$

$$\text{Power factor} = \frac{P_{in}}{V_s I_s}$$

$$= \frac{9804.47}{19826.4}$$

$$= 0.495 \text{ Lagging. } \checkmark$$

b) At time of polarity reversal $E = 186.82 \text{ V}$. $I_a = 45 \text{ A}$
 After polarity reversal $E = -186.82 \text{ V}$

i) $V_a = -E + (I_a \cdot R_a)$

$$= -186.82 + (45 \times 0.25)$$

$$= -175.57 \text{ V}$$

Also:

$$V_a = \frac{2V_m}{\pi} \cos(\alpha)$$

$$\cos(\alpha) = \frac{V_a \cdot \pi}{2V_m} \Rightarrow \alpha = \cos^{-1} \left(\frac{V_a \cdot \pi}{2V_m} \right)$$

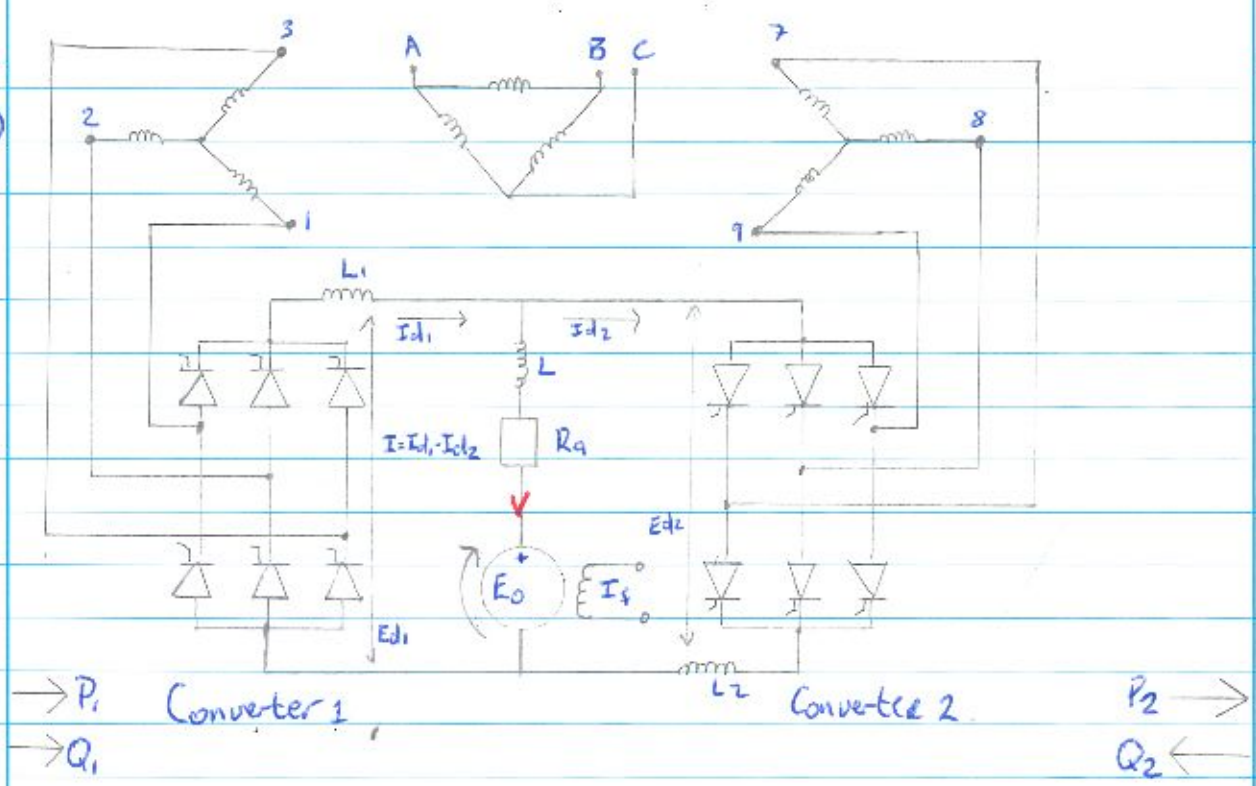
$$\alpha = \cos^{-1} \left(\frac{-175.57 \cdot \pi}{2(622.25)} \right)$$

$$\alpha = 116.31^\circ \quad \checkmark$$

ii) $V_a \cdot I_a = -175.57 \times 45 = -7900.65 \text{ W}$

Q2

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- Converter 1 allows the DC machine to operate in Quadrant 1 (forward motoring) and in Quadrant 2 (Generating in reverse).
- Converter 2 allows the DC machine to operate in Quadrant 3 (Reverse motoring) and in Quadrant 4 (Generating forward).
- The system is designed in a manner which allows both converters to operate simultaneously, with one converter providing power whilst the other absorbs power. One converter will operate as a rectifier, whilst the other operates as an inverter.
- Both converters will absorb reactive power.

Due to the addition of inductors L_1 & L_2 & the transformer secondary

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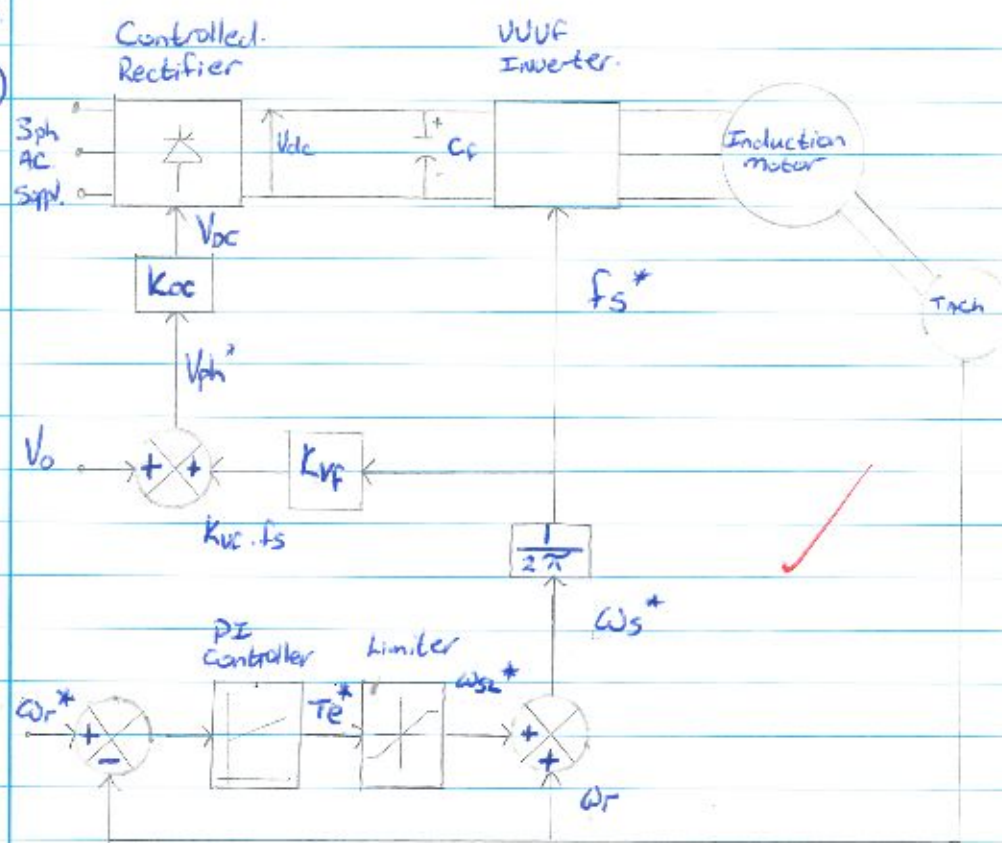
In the non-circulating current drive one converter is on, whilst the other is off, this is due to not ~~not~~ utilising additional inductors. At very low torques the motor speed will be erratic, this is caused by discontinuous current, due to the operation below rated current. Switching Quadrants will take a long time, as one converter will need to switch off, ~~before~~ before the other can switch on.

With the circulating current drive, the simultaneous operation is enabled through the use of inductors L_1 & L_2 , as well as the ~~the~~ transformer secondaries.

Continuous current will ~~not~~ always be present, ensuring the

Q2 c). switching between Quadrants will be instantaneous.

Q5. a)



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The closed loop rotor speed feedback is compared to the rotor speed demand (ω_r^*), where the error is fed into a PI controller. The PI controller produces a torque demand (T_e^*), which is amplified and limited, by the limiter block, to ensure the maximum rated slip speed is not exceeded. The slip speed demand is added to the actual rotor speed, to produce the stator speed demand (ω_s^*). The stator speed demand is divided by 2π to give the stator frequency demand to the VVVF inverter.

The stator frequency demand (f_s^*) is scaled by the voltage-frequency constant, which is added to the offset Voltage (V_o), to produce the phase Voltage demand V_{ph}^* . The V_{ph}^* is used to produce the DC link voltage.

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This control strategy will not be suitable for large motors and will typically be used in fans & HVACs.

The offset voltage (V_o) - continued on next page

$$V_{ph} = V_o + K_{VF} f_s, \quad V_o = I_s R_s$$

$$V_{DC} = 2.22 (V_o + K_{VF} f_s)$$

Q5 b) 6HP $V_{line} = 220V$ $0.87 pf$ $\eta = 0.83$ $f = 50Hz$
 $R_s = 0.281 \Omega$, $R_r = 0.185 \Omega$, $X_m = 21.1 \Omega$, $X_s = 0.56 \Omega$, $X_r = 0.853 \Omega$

i) $\omega_{sl} = \frac{R_r}{L_s + L_r}$ where $L_s = \frac{X_s}{2\pi f}$ & $L_r = \frac{X_r}{2\pi f}$

$= \frac{0.56}{2\pi \times 50} + \frac{0.853}{2\pi \times 50}$
 $= 0.000589 H + 0.00272 H$

So, $\omega_{sl} = \frac{0.185}{(0.000589 + 0.00272)}$

$= 55.91 \text{ rad/s}$

Correct method
 looks like you have used
 60 Hz
 or something
 else

ii) $P_e = 3 V_{ph} I_s \cos \phi$

$I_s = \frac{P_e}{3 V_{ph} \cos \phi}$

$V_{ph} = \frac{V_{line}}{\sqrt{3}}$

$= \frac{220}{\sqrt{3}}$

$= 127.02 V$

also: $P_e = \frac{P_{mech}}{\eta}$

$= \frac{6 \times 745.6}{\eta}$

$= \frac{6 \times 745.6}{0.83} = 5389.88 W$

So: $I_s = \frac{5389.88}{3(127.02)(0.87)}$

$I_s = 16.26 A$

iii) $V_0 = V_s I_s$

$= 220(16.26)$

$V_0 = I_s R_s$

$= 16.26 \times 0.281$

$= 4.57 V$

iv) $k_{vf} = \frac{V_{ph} - V_0}{f_s}$

$= \frac{127.02 - 4.57}{50}$

$= 2.45 \text{ V/c}$

v) $V_{acrated} = 2.22(2.45 f_s + 4.57)$

$= 282.1 V$

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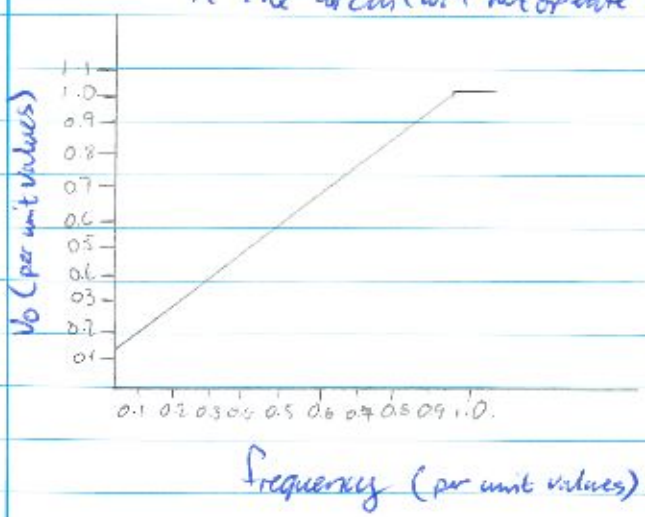
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Q5 a) 'Continued' - The graph below shows the importance of the offset voltage, without it the circuit will not operate during low speeds.



not required

Q5c) Using PWM enables the width of the pulses to be varied, in doing so, the "on" time of the thyristors can be set. This is an efficient and accurate way to control the drive output.

read the question again