

Complete, fold and seal
(see note 2 below)

SURNAME: HARRIES

FORENAME(S): DAVID SAMUEL

Examination Answer Books

12 Pages

Instructions to Candidates

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.**

1	Student Number	150 299 7/1
2	Title of Examination Paper	Power electronics and drives
3	Module Code	SGEE 6001
4	Date and Time of Examination	17/05/2019
5	Examination Venue	Coleg Sir Gwr C27
6	Seat Number	1

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

List the numbers of the questions you have attempted	Office Use
Q2	24
Q1	15
Q3	24
Q4	20
Total	83

83



Prifysgol Cymru
Y Drindod Dewi Sant
University of Wales
Trinity Saint David

Llyfr Atebion Arholiadau

12 Tudalen

Cyfarwyddiadau i Ymgeiswyr

1. Rhwch yr holl wybodaeth y gofynnir amdani yn y blychau isod.
2. Rhwch eich enw yn y lle a ddarparwyd ar y dde, plynwch ef a'i seio i lawr (gan ddefnyddio'r label a ddarparwyd) i guddio'ch enw.

3. Rhaid i'r atebion fod mewn llawysgriften ddarllenadwy. Gall yr Arholiwr naill ai anwybyddu sgrïpt annarllenadwy, neu drefnu iddi gael ei theipio a chael yr ymgeisydd i dalu.
4. Ysgrifennwch eich atebion mewn inc.
5. Dechreuwch bob ateb ar dudalen newydd. Gwnewch unrhyw fras nodiadau yn y llyfr atebion a thynnu llinell drwyddynt.
6. Ni ddylid rhwgo unrhyw ran o'r llyfr hwn; rhaid ei gyflwyno yn gyfan.
7. Os defnyddir mwy nag un llyfr, rhwymwch hwy gyda'i gilydd gan ddefnyddio'r tagiau sydd ar gael oddi wrth y gwyllwr/gwylywyr.
8. Rhaid dychwelyd pob llyfr. Ni chaniateir mynd â llyfrau atebion, wedi eu defnyddio neu heb eu defnyddio, allan o'r lleoliad arholi o dan unrhyw amgylchïadau.

[illegible]

(See the other side for English version)

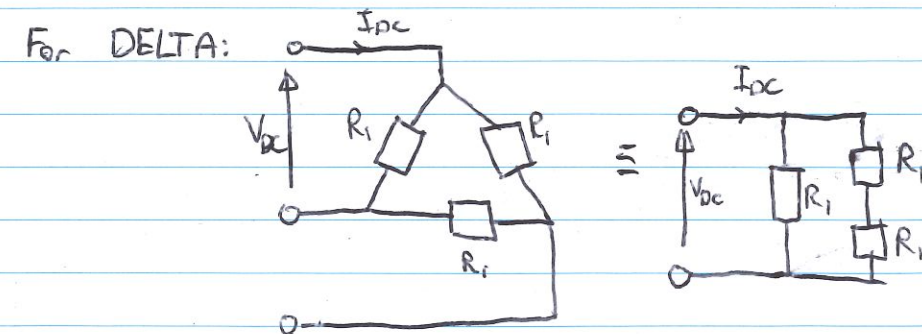
Llenwch, plygwrch a seilwch
(gweler nodyn 2 isod)

CYFENW:

ENW(AU) CYNTAF:

Q2. i) DC test - Stator Resistance R_1

For this test the rotor is locked and a DC is injected to the stator. The Voltage and current measurements can be used to find R_1 .

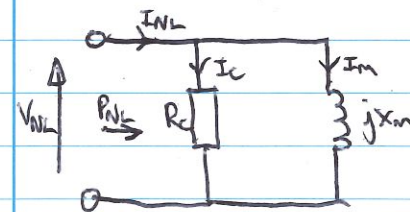


$$R_T = \frac{R_1 \times 2R_1}{R_1 + 2R_1} = \frac{2R_1^2}{3R_1} = \frac{2R_1}{3}$$

$$R_T = \frac{V_{dc}}{I_{dc}} \quad \therefore R_1 = \frac{3 \times V_{dc}}{2 I_{dc}}$$

ii) No-load test

This test is used to find R_c and X_m . It is done by using a VSD to drive the rotor to synchronous speed before applying rated voltage to the stator. ~~At $S=0$~~
 $S=0$, therefore $R_2' = \infty$. This makes the load on open circuit and leaves the equivalent circuit as:



Because of the low current, impedance can be ignored.

Power is measured with a wattmeter and equals: $\cos(\phi) = \frac{P_{NL}}{V_{NL} \times I_{NL}}$

$$I_{NL} = I_c + I_m$$

$$R_c = \frac{V_{NL}}{I_{NL} \cos(\phi)}$$

$$X_m = \frac{V_{NL}}{I_{NL} \sin(\phi)}$$

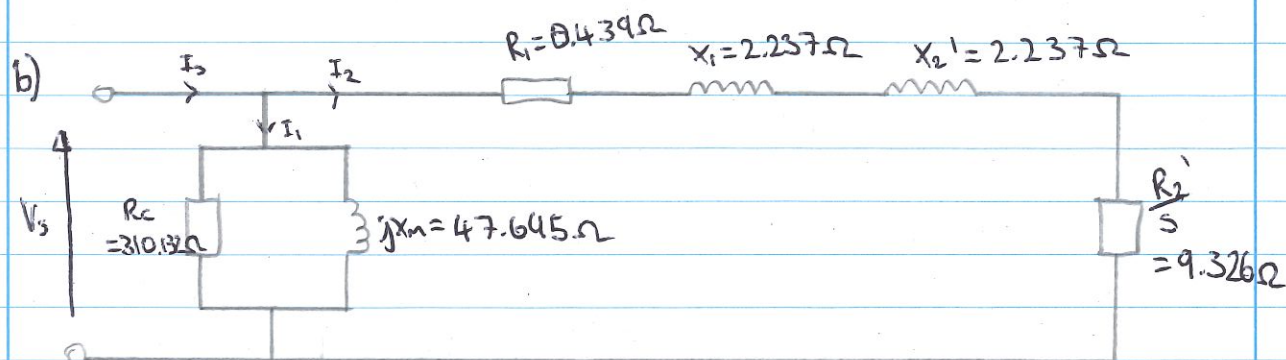
iii) Blocked Rotor Test

For this test the rotor is locked and a small DC voltage is applied to the motor. Because the voltage is low, the core can be ignored allowing X_1 , X_2' and $\frac{R_2'}{s}$ to be calculated.

where $S=1$ because the rotor is locked. $\therefore \frac{R_2'}{S} = R_2'$

$$Z_{BR} = \frac{V_{BR}}{I_{BR}} \quad R_1 + R_2' = Z_{BR} \cos(\phi) \quad \therefore R_2' = Z_{BR} \cos(\phi) - R_1$$

$$\cos(\phi) = \frac{P_{BR}}{V_{BR} \times I_{BR}} \quad X_1 + X_2' = Z_{BR} \sin(\phi) \quad \text{where } X_1 \text{ and } X_2' \text{ can be considered equal.}$$



DC Test

$$R_1 = \frac{3}{2} \times \frac{V_{DC}}{I_{DC}} = \frac{3}{2} \times \frac{12}{41} = 0.439 \Omega$$

NL Test

$$\Delta = \frac{I}{\sqrt{3}} \quad \text{and} \quad \frac{P}{3} \quad \therefore V_{NL} = 230V \quad I_{NL} = 4.879A$$

$$P_{NL} = 170W$$

$$\cos(\phi) = \frac{P_{NL}}{V_{NL} \times I_{NL}} = 0.152 \quad \therefore \phi = 81.257^\circ$$

$$R_c = \frac{V_{NL}}{I_{NL} \cos(\phi)} = \frac{230}{4.879 \times \cos(81.257)} = 310.132 \Omega$$

$$X_m = \frac{V_{NL}}{I_{NL} \sin(\phi)} = \frac{230}{4.879 \times \sin(81.257)} = 47.645 \Omega$$

BR Test

$$V_{BR} = 58.5V \quad I_{BR} = 12.759A \quad P_{BR} = 163.3W$$

$$Z_{BR} = \frac{V_{BR}}{I_{BR}} = \frac{58.5}{12.759} = 4.585 \Omega \quad \cos(\phi) = \frac{P_{BR}}{V_{BR} \times I_{BR}} = \frac{163.3}{58.5 \times 12.759} = 0.2109$$

$$\phi = 77.349^\circ$$

$$R_1 + R_2' = Z_{BR} \cos(\phi) = 4.585 \times \cos(77.349) = 9.765 \Omega$$

$$R_2' = 9.765 - R_1 = 9.326 \Omega$$

$$X_1 + X_2' = Z_{BR} \sin(\phi) = 4.585 \times \sin(77.349) = 4.474 \Omega$$

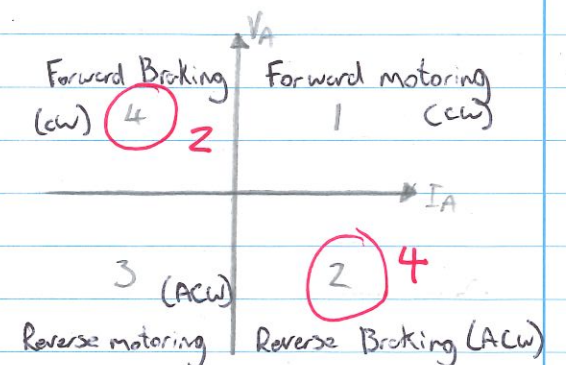
$$X_1 = 2.237 \Omega$$

$$X_2' = 2.237 \Omega$$

Q1. a) Quadrant 1

Positive power, positive direction.

Q2 remains constantly closed,
Q1 is the chopping device.

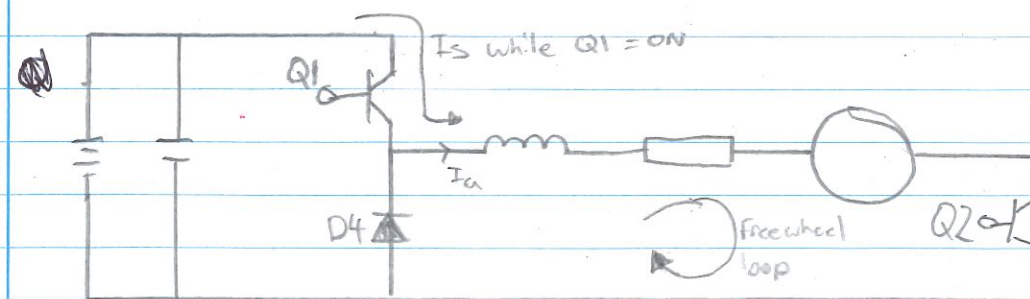


While Q1 is closed I_s supplied I_a

and the inductor field L_a stores energy.

When Q1 opens, L_a reverses polarity and releases its energy causing current to flow through Q2 and D4 which acts as a freewheel diode allowing current to continue flowing in a loop until the next closed period.

The speed of the motor is determined by the duty cycle of Q1 in the clockwise direction.



Quadrant 2

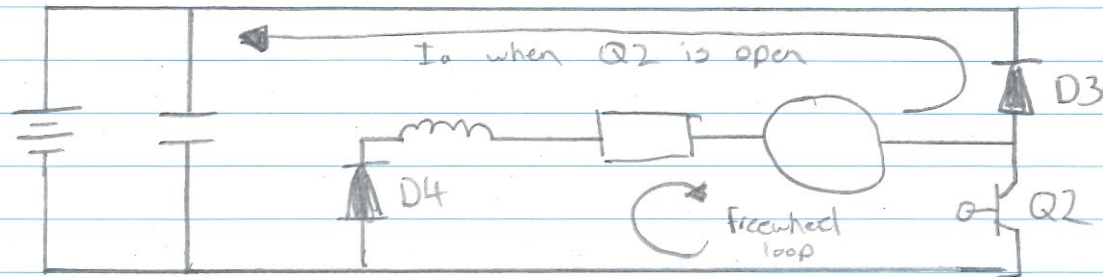
Negative power, Negative direction

Q2 is the chopping device.

As the motor rotates Anti-clockwise, it generates back emf (E) while Q2 is closed. It uses D4 to create a freewheel loop.

When Q2 opens L_a reverses polarity and the current flows through D3 and charges the supply and C above V_s .

The duty cycle determines the average voltage generated. This continues until E is reduced, hence braking Torque.



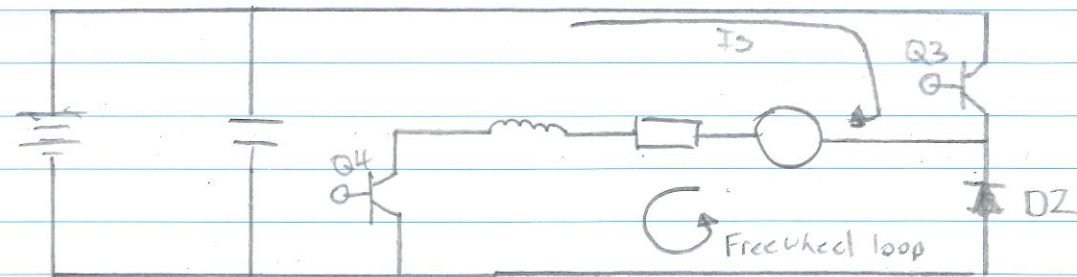
Quadrant 3

Positive power, Negative direction.

Q4 constantly closed, Q3 chopping device.

Same as Quadrant 1, except current flows through armature and freewheel loop in opposite direction. When Q3 is closed I_s supplies I_a . When open, current flows through Q4 and D2 which is a freewheel diode.

Duty cycle determines speed in ACW Direction.



Quadrant 4²

Negative power, Positive direction

Q4 chopping device

Same operation as Quadrant 2, however in opposite direction

$$b) L_a = 80 \text{ mH}$$

$$\omega = 150 \text{ rad/s}$$

$$f = 2 \text{ kHz}$$

$$T_L = 6 \text{ Nm}$$

$$K_b = 0.4 \text{ V/rad/s (Nm/A)}$$

$$V_s = 84 \text{ V}$$

$$i) V_a = V_s - 2 \times V_{TR} = 84 - (2 \times 2 \text{ V}) = 80 \text{ V}$$

$$E = K_b \times \omega = 0.4 \times 150 = 60 \text{ V}$$

$$D = \frac{E}{V_a} = \frac{60}{80} = 0.75$$

$$P = \frac{1}{f} = \frac{1}{2 \text{ kHz}} = 0.5 \text{ ms}$$

$$t_{on} = P \times D = 0.5 \text{ ms} \times 0.75 = 0.375 \text{ ms}$$

$$\therefore t_{off} = P - t_{on} = 0.5 \text{ ms} - 0.375 \text{ ms} = 0.125 \text{ ms}$$

$$ii) I_a = \frac{T}{K_b} = \frac{6}{0.4} = 15 \text{ A}$$

$$iii) V_a - E = L \frac{di}{dt} \quad 20 = L \frac{di}{dt} \quad \frac{di}{dt} = \frac{20}{L} = \frac{20}{80 \text{ mH}} = 250 \text{ A/s}$$

$$\text{Gradient} = \frac{I_{max} - I_{min}}{t_{on}} \quad \therefore 250 \times 0.375 \text{ ms} = I_{max} - I_{min} = 0.0938 \text{ A}$$

$$\frac{I_{max} + I_{min}}{2} = 15 \quad \therefore I_{max} + I_{min} = 30$$

$$\therefore I_{max} + I_{min} = 30$$

$$+ I_{max} - I_{min} = 0.0938$$

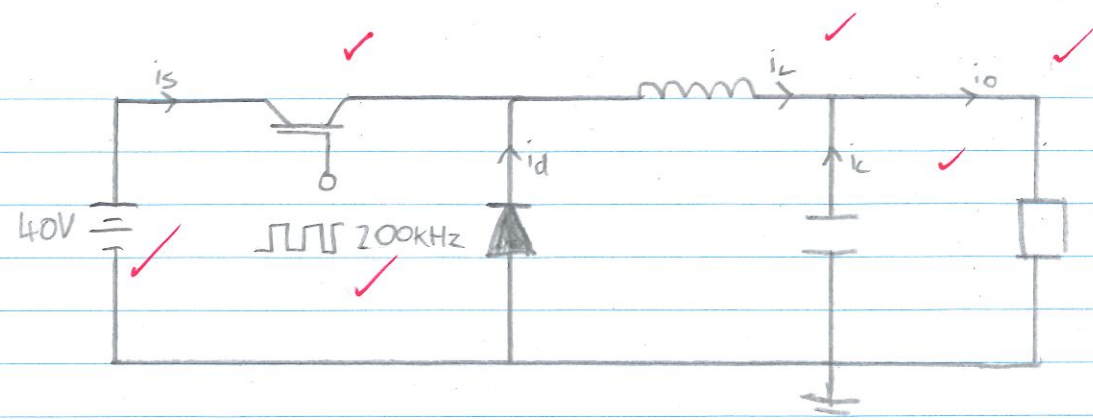
$$2 I_{max} = 30.0938$$

$$I_{max} = 15.0469 \text{ A}$$

$$\therefore I_{min} = 30 - I_{max} = 14.953 \text{ A}$$

4

Q3 a)



(step down)

A buck converter is used to reduce the voltage provided by a voltage source so it may be used for a specific application which has a lower voltage rating.

The transistor is used to cut the voltage at a high frequency to reduce the average voltage on the output.

The inductor is used as a filter that provides the output with a constant output voltage and current. During the ON period it stores energy, so when the off period begins, it can provide the output with current while the supply does not.

The capacitor is used to balance the current so that a constant 8A is output. When the inductor is at peak current, the capacitor is at peak negative current to compensate so that not too much current is on the output. Likewise, when the inductor has no current left, the capacitor is at its peak positive current and provides current to the output until the next OFF cycle. As the inductor gains energy in its magnetic field.

The diode is used as a freewheel diode. This allows the current to continue flowing during the transistor's OFF period.

The supply provides current and voltage which is partially stored in the inductor.

$$b) i) D = \frac{V_o}{V_s} = \frac{16}{40} = 0.4$$

$$P = \frac{1}{f} = \frac{1}{200\text{kHz}} = 5\mu\text{s}$$

$$t_{on} = P \times D = 2\mu\text{s} \quad \therefore t_{off} = 5 - 2 = 3\mu\text{s}$$

$$ii) \text{Mean } i_L = 0\text{V}$$

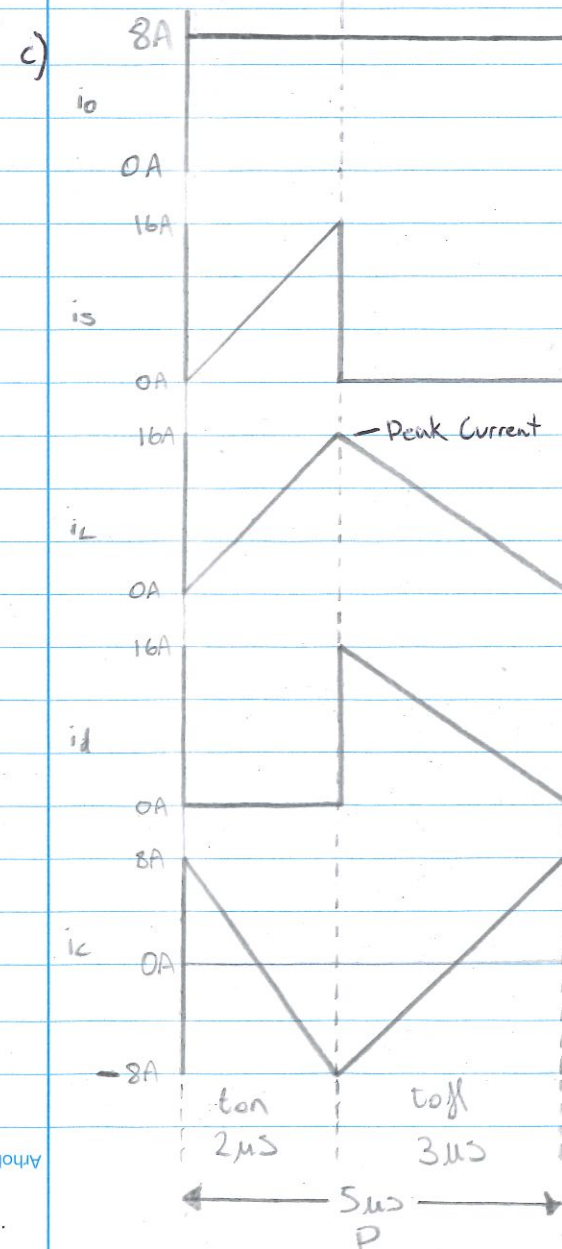
$$\text{Mean } i_L = 8\text{A}$$

Due to current change being linear, i_L must have a range of 8A to -8A.
 $\therefore$ peak inductor current = 16A

$$iii) V_s - V_o = L \frac{di}{dt}$$

$$\therefore 40 - 16 = L \left(\frac{16}{2\mu\text{s}} \right)$$

$$\therefore L = 24 \div \left(\frac{16}{2\mu\text{s}} \right) = 3\mu\text{H}$$



See sheet for waveforms

Q4) a) Line Voltages switch between V_d and $-V_d$ as shown:

$$V_{ab} = V_a - V_b \quad - (1)$$

$$V_{bc} = V_b - V_c \quad - (2)$$

$$V_{ca} = V_c - V_a \quad - (3)$$

$$(1) - (3) \rightarrow V_{ab} - V_{ca} = 2V_a - (V_b + V_c)$$

Because each stator phase is perfectly balanced: $V_a + V_b + V_c = 0$
 $\therefore -V_a = V_b + V_c$

$$\therefore V_{ab} - V_{ca} = 3V_a$$

$$V_a = \frac{1}{3}(V_{ab} - V_{ca})$$

V_{ab}	V_d	V_d	0	$+V_d$	$-V_d$	0
V_{ca}	0	$-V_d$	$-V_d$	0	V_d	V_d
V_a	$\frac{V_d}{3}$	$\frac{2V_d}{3}$	$\frac{V_d}{3}$	$-\frac{V_d}{3}$	$-\frac{2V_d}{3}$	$-\frac{V_d}{3}$

where $V_d = 300V$

$$\frac{V_d}{3} = 100V, \quad \frac{2V_d}{3} = 200V$$

(5)

$$b) i) V_n = \frac{2V_d}{n\pi} \left(\cos\left(\frac{n\pi}{3}\right) + 1 \right)$$

Because it is odd, every odd harmonic is calculated

$$V_1 = \frac{\sqrt{2 \times 300}}{\pi} \left(\cos\left(\frac{\pi}{3}\right) + 1 \right) @ 50Hz = 15.59V$$

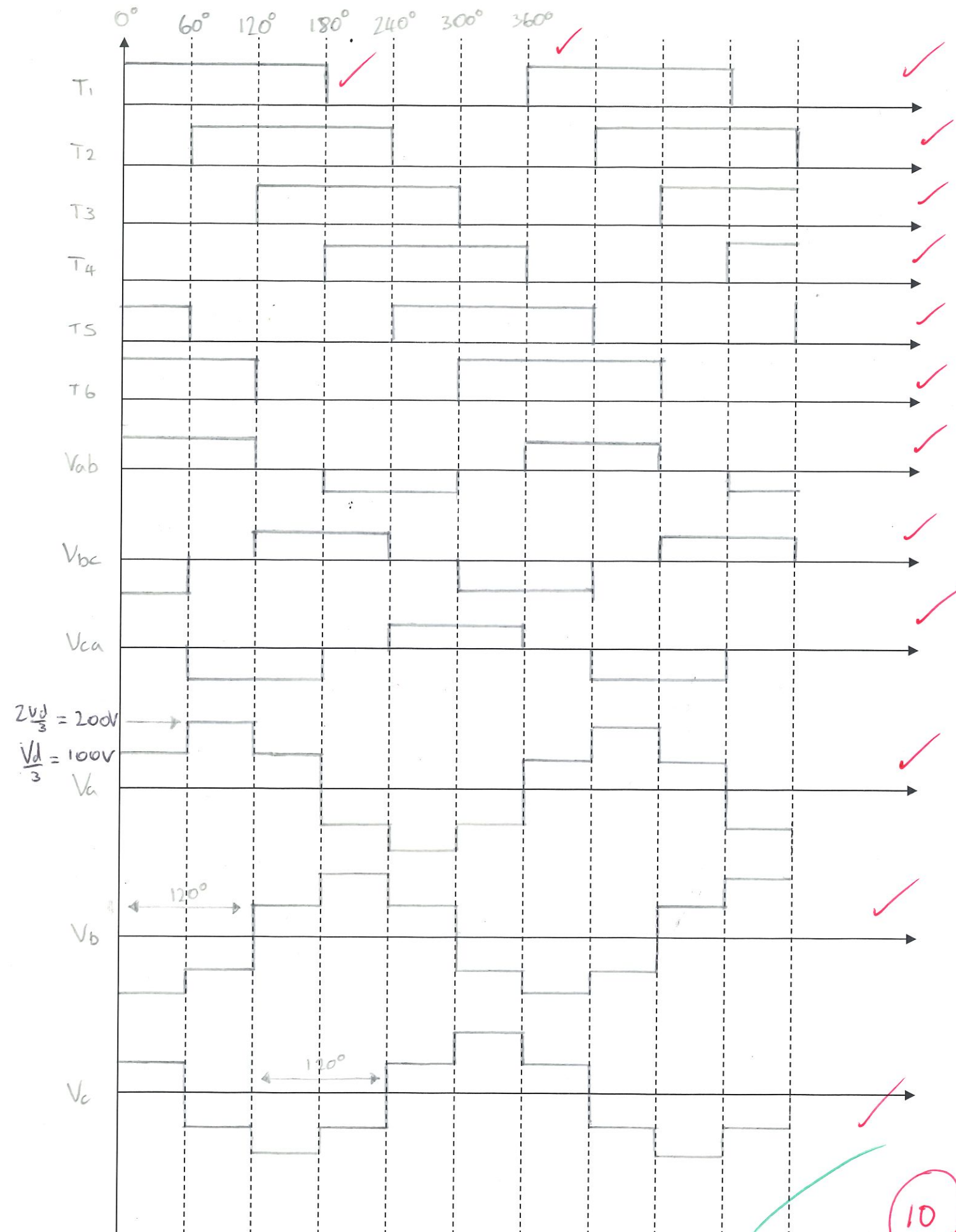
$$V_3 = \frac{\sqrt{2 \times 300}}{3\pi} \left(\cos\left(\frac{3\pi}{3}\right) + 1 \right) @ 150Hz = 5.194V$$

$$V_5 = \frac{\sqrt{2 \times 300}}{5\pi} \left(\cos\left(\frac{5\pi}{3}\right) + 1 \right) @ 250Hz = 3.112V$$

$$V_7 = \frac{\sqrt{2 \times 300}}{7\pi} \left(\cos\left(\frac{7\pi}{3}\right) + 1 \right) @ 350Hz = 2.2186V$$

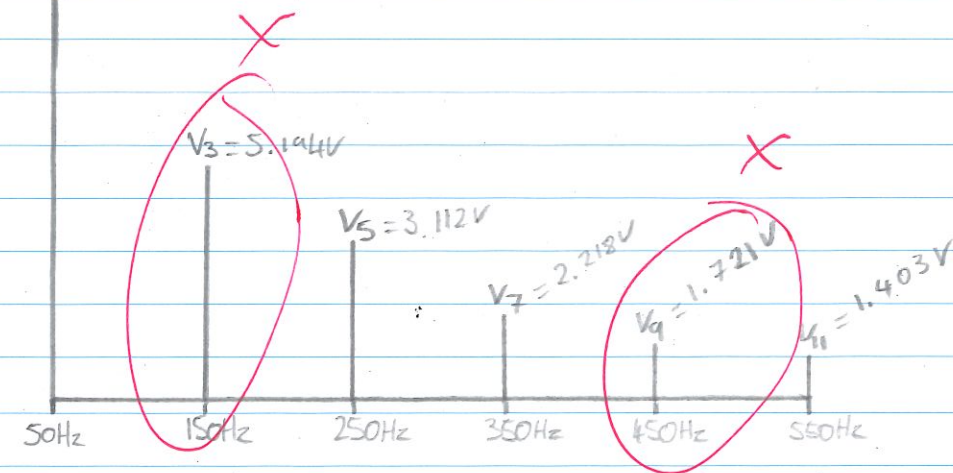
$$V_9 = \frac{\sqrt{2 \times 300}}{9\pi} \left(\cos\left(\frac{9\pi}{3}\right) + 1 \right) @ 450Hz = 1.7209V$$

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$$V_{11} = \frac{2 \times 300}{11\pi} \left(\cos\left(\frac{11\pi}{3}\right) + 1 \right) @ 550 \text{ Hz} = 1.4033 \text{ V} \quad \times$$

$$V_1 = 15.59 \text{ V}$$



$$\text{ii) THD} = \frac{\sqrt{V_3^2 + V_5^2 + V_7^2 + V_9^2 + V_{11}^2}}{V_1} = 0.4375$$

$$0.4375 \times 100\% = 43.75\%$$

correct method, wrong answer