UNIVERSITY OF RUHUNA

Faculty of Engineering

End-Semester 5 Examination in Engineering: August 2018

Module Number: EE5304 **Module Name: Power Electronics**

[Three Hours]

[Answer **all questions**, each question carries 12.5 marks]

Q1 a) A simplified three-phase diode rectifier (3φ DR) is shown in Figure Q1(a)1.

Note : Use the Table Q1 and Figure Q1 (a)2 to answer the part (ii) and (iii) and attach them to your answer script.

i) What are the assumptions you made to obtain the 3φ DR circuit shown in Figure Q1(a)1 from a practical 3φ DR circuit?

ii) For the five cases of the three phase supply voltage shown in Figure Q1(a)2, state which devices are conducting in each case and the corresponding DC ripple voltage by filling the Table Q1.

iii) Sketch the waveforms of the output voltage (v_d) and the input phase A and phase B currents (i_a and i_b) of the converter for the given supply voltage in Figure Q1(a)2.

iv) Derive an expression for the average output voltage (V_d) of the converter. In the $v_d - i_d$ plane, indicate in which quadrant(s), the converter can operate and justify your answer.

[6.5 Marks]

b) The armature of a 100 hP separately excited DC machine is connected to a three-phase thyristor converter to control the speed of the DC machine. The thyristor converter is supplied by a 480 V (line to line), 50 Hz three phase supply. The armature resistance, inductance and the voltage constant of the machine are 0.1 Ω, 5 mH and 0.3 V/rpm, respectively.

i) Draw a circuit diagram to illustrate the power electronic system.

ii) The DC machine operates as a motor, running a rated load at the rated speed of 1500 rpm.

I) Clearly stating your assumptions, calculate the firing angle (α) of the converter.

II) Determine the ripple frequency of the armature voltage.

III) Calculate the rms values of the first four dominant harmonics of the supply current.

IV) Find the power factor of the converter supply.

iii) Calculate the firing angle and the power fed back to the supply when the DC machine is operating in the generating mode at 1500 rpm.

[6.0 Marks]

Q2 Consider a boost type DC-DC converter.

a) i) Define the following terms associated with a boost type DC-DC converter.

I) Switching frequency (f_s)

II) Duty ratio (D)

ii) Briefly explain the continuous-conduction mode (CCM), discontinuous-conduction mode (DCM) and the critical conditions of a DC-DC boost converter.

[2.0 Marks]

b) i) Draw the steady-state waveforms for the inductor current (i_L) and the inductor voltage (v_L) of a DC-DC boost converter for CCM.

Note : Answers without supporting relevant derivations will carry no marks.

ii) Obtain the input/output voltage (V_{in}, V_o) and current (I_{in}, I_o) relationships in terms of D of the DC-DC boost converter for the CCM.

iii) Derive expressions for the following terms associated with a DC-DC boost converter.

I) The peak-peak inductor current ripple (Δi_L) in terms of L, V_{in}, D and f_s.

II) The minimum and the maximum value of the inductor current ($i_{L,min}$ and $i_{L,max}$) in terms of L, V_{in}, I_{in}, D and f_s

[5.0 Marks]

c) It is required to charge a battery bank from a DC voltage source with the voltage of 120 V. The Battery bank consists of 100 identical batteries connected in series, each with internal resistance of 0.1 Ω. The average charging current of a battery should be kept at 0.5 A. At the beginning of the charging process, each battery voltage ($V_{b,S}$) is 2.5 V and the each battery is charged up to ($V_{b,E}$) 5.0 V at the end. For whole charging process, the D of the DC-DC converter is adjusted using PWM switching with the switching frequency of 25 kHz.

i) What type of single-switch DC-DC converter is suitable for this application? Justify your answer.

ii) Calculate the variation of D of the converter for the whole charging process.

iii) For the whole charging process, find the peak current that should be handled by the switch of the converter proposed in part i), if the inductance of the converter is 2 mH.

iv) Calculate the critical inductance (L_{crit}) of the converter such that this converter remains in the CCM at and above the input power of 150 W.

[5.5 Marks]

Q3 a) Consider the full-bridge DC-DC converter given in Figure Q3.

i) Distinguish the main difference between full-bridge DC-DC converters over single switch DC-DC converters in terms of the direction of the output voltage and current.

ii) If the converter shown in Figure Q3 uses the PWM with bi-polar voltage switching, sketch the waveforms of v_{AN}, v_{BN}, v_O and i_O for three half cycles of the triangular signal, used in the PWM generator, indicating which devices are conducting.

iii) Indicate in the v_O - i_O plane, in which quadrant(s), the converter can operate and justify your answer

iv) Using the waveforms drawn in part ii), show that the duty ratios (D_1) of the switch pair (T_{A+}, T_{B-}) can be expressed as,

$$D_1 = (1/2)(1 + v_{control}/\hat{V}_{tri})$$

Where $v_{control}$ and $\hat{V}_{tri}$ denotes the control voltage and the peak value of the triangular signal used in the PWM generator respectively.

v) Hence, show that the average output voltage (V_o) can be deduced as,

$$V_O = V_d(v_{control}/\hat{V}_{tri})$$

[6.5 Marks]

b) The armature of a 4.0 hP, 1800 rpm separately excited DC motor is supplied by a full bridge DC-DC converter as illustrated in Figure Q3. The armature inductance and the voltage constant of the DC motor are 1.5 mH and 0.15 V/rpm, respectively. The armature resistance is negligible. The DC motor runs its rated load. The input DC voltage to the converter is 320 V. The converter uses the PWM with bi-polar voltage switching with the switching frequency (f_s) of 50 kHz.

i) Calculate D_1 of the switch pair (T_{A+}, T_{B-}) of the converter.

ii) Sketch the armature voltage v_a as a function of time for one switching cycle.

iii) Find the average, maximum and the minimum value of the armature current (i_a). Sketch i_a as a function of time for one switching cycle.

iv) Sketch the input current to the converter (i_d) for one switching cycle.

[6.0 Marks]

Q4 a) i) What is the function of an inverter?

ii) List three applications where inverters are used.

iii) What is the difference between voltage source inverters (VSI) and current source inverters (CSI)?

[3.0 Marks]

b) i) Draw the power circuit of the single phase full-bridge VSI.

ii) Why is it necessary to connect diodes in anti-parallel with the controllable switches in the single phase full-bridge VSI?

iii) By using the expression derived in Q3 a) v), deduce an expression for the rms value of the single phase full-bridge VSI output, if the converter switches are switched by PWM with bi-polar voltage switching.

[4.5 Marks]

c) A 480 V, 50 Hz, split phase single phase induction motor is supplied at the rated condition by a single phase full-bridge VSI through a low pass filter. The motor draws a stator current of 12 A at 0.8 power factor lagging. The DC link of the VSI is kept at 850 V and the switches of the VSI are switched using bi-polar voltage switching with the switching frequency of 1.35 kHz.

i) Calculate m_a and m_f of the VSI. Why is m_f chosen as an odd integer?

ii) Find the DC component of the input current of the inverter.

iii) Using Table Q4(c), compute the rms value of the first five dominant harmonics of the output voltage and the corresponding frequencies at which these harmonics appear.

iv) Suggest a suitable value for the cut-off frequency of the low pass filter in the motor drive. Justify your answer.

[5.0 Marks]

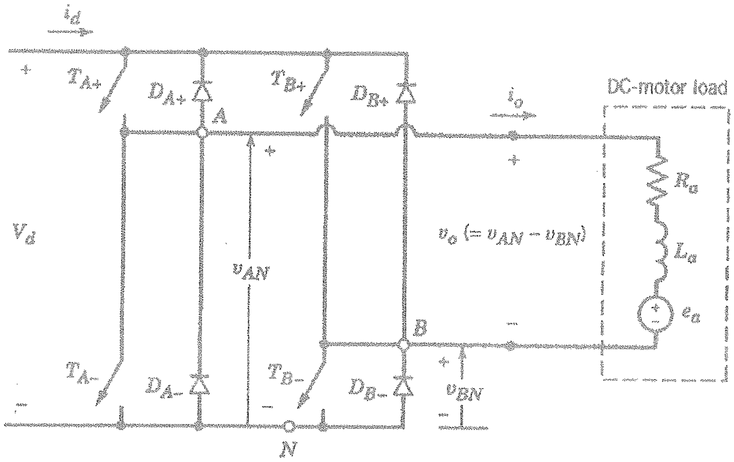

Figure Q3 DC-DC full-bridge converter connected with a DC motor

Table Q4(c) Generalized harmonics ($\hat{V}_{Ao}/(V_d/2)$) for large m_f

h \ m_a	0.2	0.4	0.6	0.8	1.0
1 Fundamental	0.2	0.4	0.6	0.8	1.0
m_f	1.242	1.15	1.006	0.818	0.601
$m_f \pm 2$	0.016	0.061	0.131	0.220	0.318
$m_f \pm 4$					0.018
$2m_f \pm 1$	0.190	0.326	0.370	0.314	0.181
$2m_f \pm 3$		0.024	0.071	0.139	0.212
$2m_f \pm 5$				0.013	0.033
$3m_f$	0.335	0.123	0.083	0.171	0.113
$3m_f \pm 2$	0.044	0.139	0.203	0.176	0.062
$3m_f \pm 4$		0.012	0.047	0.104	0.157
$3m_f \pm 6$				0.016	0.044
$4m_f \pm 1$	0.163	0.157	0.008	0.105	0.068
$4m_f \pm 3$	0.012	0.070	0.132	0.115	0.009
$4m_f \pm 5$			0.034	0.084	0.119
$4m_f \pm 7$				0.017	0.050

where $\hat{V}_{Ao}$ is the peak value of the output of the one-leg inverter.

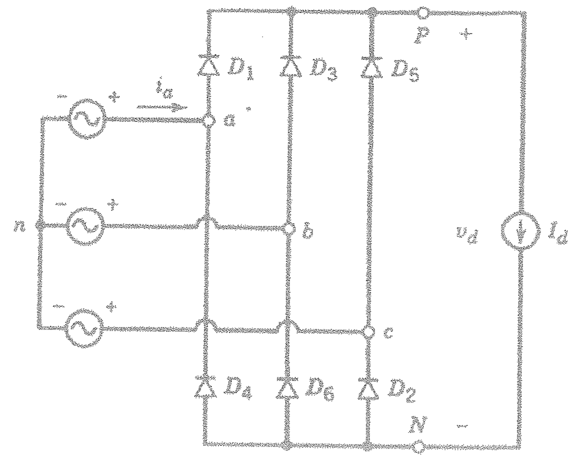

Figure Q1(a)1

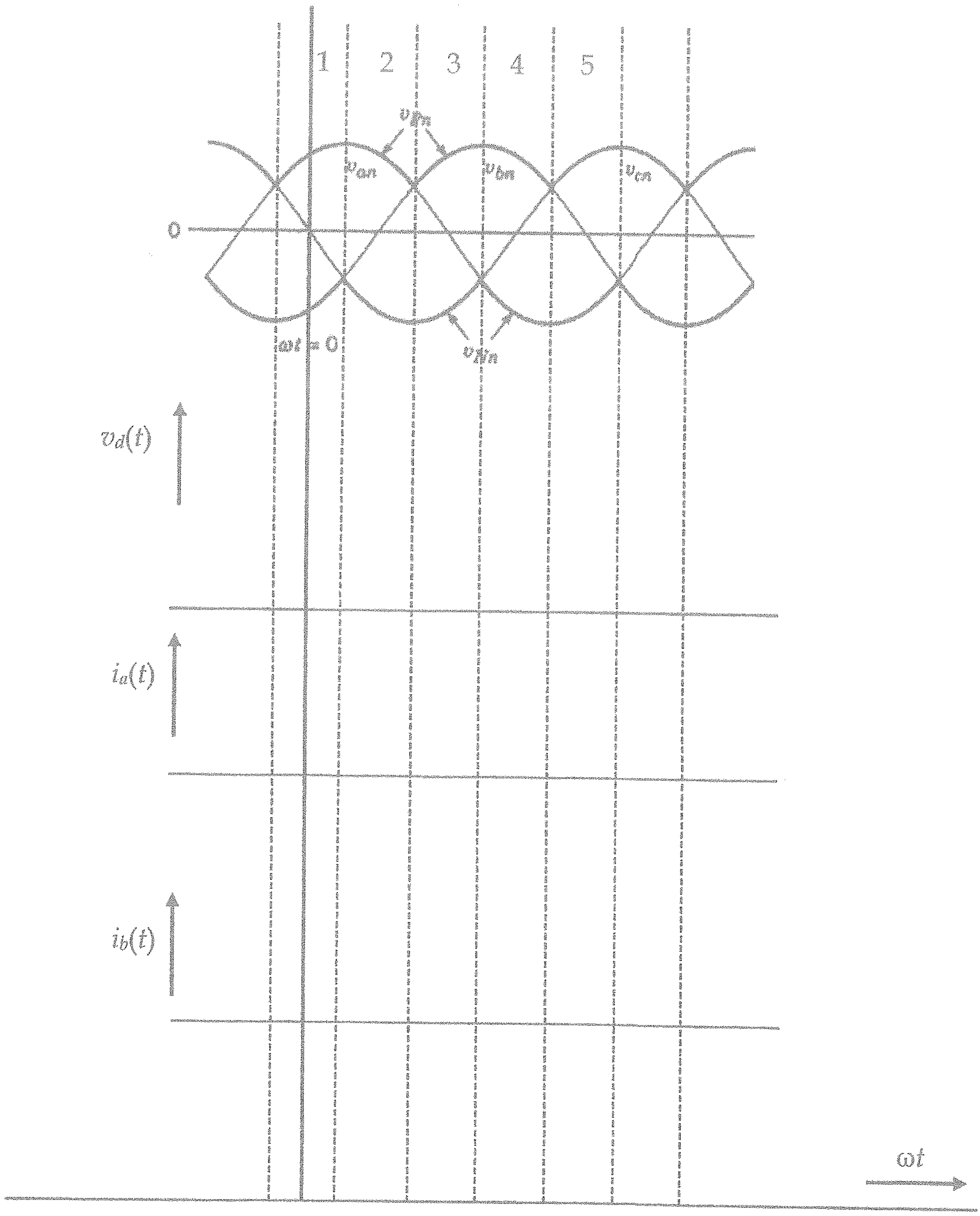

Figure Q1(a)2

Index No : ....

Table Q1

Case	Conducting Diodes		DC Ripple Voltage
	From Top Group of Diodes in DR	From Bottom Group of Diodes in DR	
1			
2			
3			
4			
5			