UNIVERSITY OF RUHUNA

Faculty of Engineering

End-Semester 5 Examination in Engineering: December 2020

Module Number: EE5304 **Module Name: Power Electronics (N/C)**

[Three Hours]

[Answer **all questions**, each question carries 10 marks]

Q1 a)

i) Thyristor is categorized as a semi-controllable semiconductor device. Explain the reason for that.

ii) What is the purpose of the gate terminal of a thyristor? What are requirements of the signal given to the gate terminal?

iii) Explain the forward-breakdown-voltage and the reverse-breakdown-voltage of a thyristor.

iv) Compare the diode and the thyristor in terms of the requirements for 'on' and 'off ' states.

[3.5 Marks]

b) The thyristor converter shown in Figure Q1 is connected to a single-phase 230 V, 50 Hz supply. The dc side of the converter is connected to an armature of a separately excited dc motor. The armature resistance is r_d = 0.5 Ω. Assume that the L_d is large enough to have a constant dc current at the dc side. Also, assume that the L_s=0 and the thyristors in the circuit have ideal characteristics.

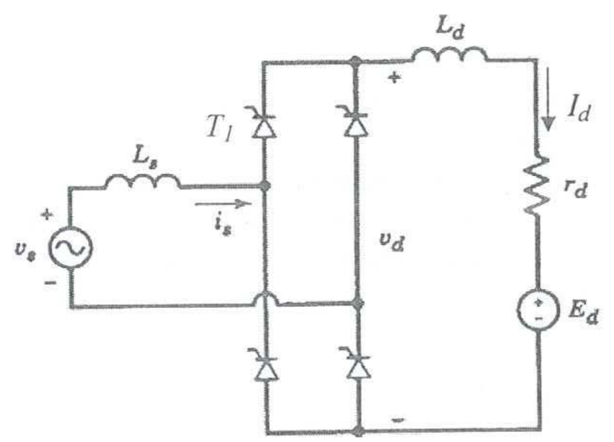

Figure Q1: Single-phase thyristor converter with a dc motor load

At a certain operating point of the dc motor, it was found that the back-emf E_d was -155 V and the armature current I_d = 20 A. At this operating point,

i) determine the firing angle α of the converter.

ii) for one cycle of ac source voltage, draw the waveforms of v_d, the ac side current i_s and the anode to cathode voltage of the thyristor T_1.

iii) giving reasons, explain the direction of the average power flow in the converter.

iv) What is the minimum forward-breakdown-voltage, the minimum reverse-breakdown-voltage and the minimum current rating to be selected for the thyristors in this circuit?

v) If it is assumed $L_s \neq 0$, draw the waveform of v_d for one cycle of ac source voltage, taking the commutation interval as u. Write the required integral equation to obtain the commutation interval u.

[6.5 Marks]

Q2 a)

i) Explain the purpose of a power electronic system.

ii) Draw a block diagram to illustrate the structure of a power electronic system. Explain the function of each component of your block diagram.

iii) Efficiency is important in a power electronic system. Explain what affects the efficiency of a power electronic system.

iv) A three-phase induction motor is connected to a power electronic system as the load. It is required to control the speed of the induction motor by varying both the amplitude and the frequency of the three-phase input voltage of the induction motor. Assume that fixed three-phase ac supply is available as the input to the power electronic system. Clearly stating the power stages draw a block diagram to illustrate the structure of the power processor needed in the power electronic system.

[3.5 Marks]

b) It is required to charge a battery bank from a dc voltage source of 150 V. The battery bank consists of 100 identical batteries connected in series. Each battery has an internal resistance $R_i = 0.1\ \Omega$. At the beginning of the charging process, each battery voltage is $V_{b1} = 1.2$ V. When each battery is charged up to $V_{b2} = 3.2$ V, the charging process is completed. The average charging current should be kept constant at 0.5 A.

i) What type of single-switch dc-dc converter is suitable for this application? Give reason to your answer. Draw the circuit diagram of the converter you have proposed.

ii) Assuming the ideal conditions and the continuous-conduction mode,

(I) calculate the minimum and maximum duty ratio of the converter you proposed in i) for the whole charging process.

(II) If the switching frequency of the converter is 250 Hz, for one switching period, draw the steady-state voltage waveform across the controllable switch, inductor and the diode of the converter you proposed in i) for $V_{b1} = 1.2$ V.

[6.5 Marks]

Q3 a)

i) Draw the power circuit for the single-switch step-down dc-dc converter.

ii) Using necessary steady-state waveforms and stating the assumptions you make, show that at the edge of the continuous conduction mode of the converter, the average inductor current I_{LB} can be expressed as

$$I_{LB} = \frac{DT_S}{2L}(V_d - V_o),$$

where all the symbols have their usual meaning.

iii) The step-down dc-dc converter supplies a load of 60 W. The input voltage to the converter is 25 V and the output voltage of the converter is to be regulated at 10 V. The converter operates at 12.5 kHz switching frequency. The inductance of the converter's inductor is L=0.05 mH. Assuming ideal conditions, determine whether the converter operates in continuous or discontinuous conduction mode.

[4 Marks]

b) A full-bridge dc – dc converter controls the speed of a separately excited dc motor. The armature of the motor is connected to the converter. The armature resistance R_a = 0.1 Ω and the motor's back emf constant is 0.08 V/rpm. The motor is connected to a constant load and the armature current is constant at 200 A. The dc input voltage of the converter is 125 V and the switching frequency of the converter is 250 Hz. The converter employs PWM with bipolar voltage switching. Assume that all the components in the converter are ideal and, the armature current is continuous and has negligible ripple.

i) Draw the power circuit of the converter including the connection of the armature of the motor.

ii) When the motor runs at 1000 rpm,

(I) for one switching period, draw the triangular waveform and necessary control voltage waveforms required to decide the switching of the switches of the converter. Assume that the peak amplitude of the triangular waveform $\hat{V}_{tri}$ = 10 V.

(II) for one switching period, draw the instantaneous converter output voltage waveform v_o. On the waveform, show the switches that are in 'on' state.

iii) Drawing the triangular waveform and necessary control voltage waveforms, explain how to achieve -1000 rpm speed in the motor.

[6 Marks]

Q4 a) The single-phase half-bridge inverter shown in Figure Q4 uses sinusoidal PWM switching to generate an ac output voltage v_o.

i) Explain why this inverter belongs to Voltage Source Inverter (VSI) category.

ii) Explain the reason for having the diodes D_+ and D_- in the circuit.

iii) Explain how the switches in the circuit are switched to generate an ac output voltage.

iv) Define the following terms associated with this inverter.

(I) Amplitude modulation ratio (m_a)

(II) Frequency modulation ratio (m_f)

[3 Marks]

b) From this inverter, it is required to obtain a 50 Hz ac output voltage with the rms value of 120 V. The dc input voltage to the inverter is 600 V and the switching frequency is 850 Hz.

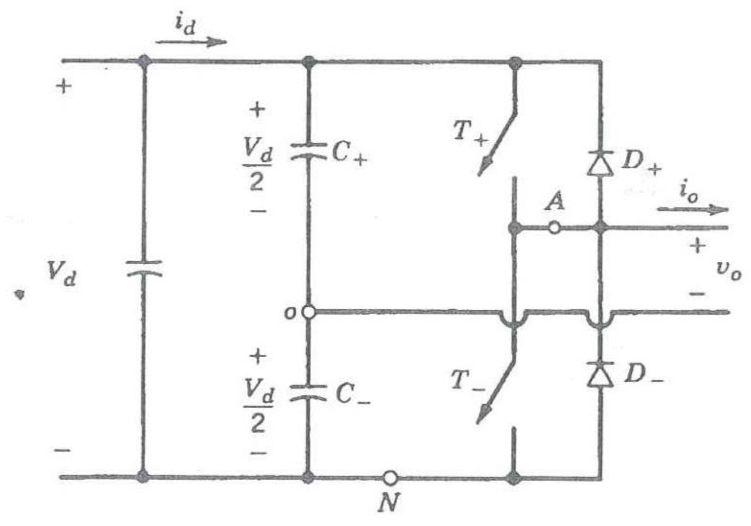

Figure Q4: Single-phase half-bridge inverter.

i) Calculate the m_a and m_f required for the inverter.

ii) What are the most dominant harmonic frequencies that can be expected in the inverter output voltage?

iii) What is the maximum possible rms value of the ac output voltage that can be obtained from this inverter without overmodulation?

iv) With overmodulation, what is the maximum possible rms value of the ac output voltage that can be obtained from this inverter?

v) Explain the main disadvantage when the inverter is operated in overmodulation.

vi) Instead of a half-bridge inverter, a full-bridge inverter with the same dc input voltage is used, what is the maximum possible rms value of the ac output voltage that can be obtained without overmodulation?

vii) Instead of sinusoidal PWM switching, if square-wave switching is used for the inverter, how do you obtain 50 Hz ac output voltage with the rms value of 120 V?

[7 Marks]

Q5 a) A three-phase load is supplied by a three-phase inverter. The load requires 50 Hz, constant three-phase ac voltage with the line to line rms value of 400 V. The dc input voltage to the inverter is supplied by a renewable energy source and it is limited to a constant value of 300 V. The inverter uses sinusoidal PWM switching. It is required to operate the inverter without overmodulation.

i) What is the minimum dc input voltage inverter should be provided for this application?

ii) For this application, draw a detailed circuit diagram showing the inverter and the additional circuit needed at the dc side of the inverter. Briefly explain how you operate the additional circuit you have proposed for the dc side to achieve 0.8 amplitude modulation ratio in the inverter.

iii) Which parameter in sinusoidal PWM switching affects the quality of the output ac voltage of the inverter? Briefly explain how to select that parameter in order to improve the quality of the output ac voltage of the inverter.

[5 Marks]

b). A single-phase, integral half-cycle controlled, ac voltage controller is shown in Figure Q5. The input voltage $v_s = \sqrt{2}V_s \sin \omega t$ and it has a resistive load R (>1 Ω). The input voltage is connected to the load for n cycles and disconnected for m cycles. Assume that the thyristors T_1 and T_2 are ideal.

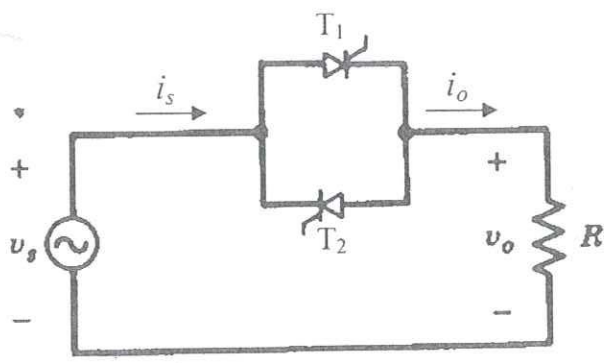

Figure Q5: ac voltage controller.

i) Show that the rms value V_o of the output voltage is given by

$$V_o = V_S\sqrt{\frac{n}{n+m}}$$

ii) When n = 4 and m = 2, draw the waveforms of output voltage v_o, output current i_o and the current through the thyristor T_1 and the thyristor T_2. Show the gate triggering pulses of the thyristor T_1 and the thyristor T_2 in your drawing.

iii) The ac voltage controller shown in Figure Q5 has a resistive load R = 10 Ω and the rms input voltage V_s = 120 V. The input voltage is connected to the load for 4 cycles and is disconnected for 2 cycles. Determine the input power factor of the ac voltage controller.

[5 Marks]