UNIVERSITY OF RUHUNA

Faculty of Engineering

End-Semester 5 Examination in Engineering: March 2026

Module Number: EE5303 **Module Name: Power Electronics (C-18)**

[Three Hours]

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

Q1 a) In a wind power harvesting application, a three-phase synchronous generator is directly coupled to a turbine to generate electricity. Since wind speed varies, the generator produces electricity with the variation of the amplitude and the frequency. Therefore, the generator cannot be directly connected to the power grid.

i) Showing the detailed circuit diagrams of the power converters, draw the power electronic system that is needed between the synchronous generator and the power grid. Name key parts of the power electronic system you have drawn.

ii) In terms of power grid's requirements, explain a limitation in the power electronic system you have drawn.

[3 Marks]

b) A full-bridge dc – dc converter connected to a dc motor load is shown in the Figure 1.1.

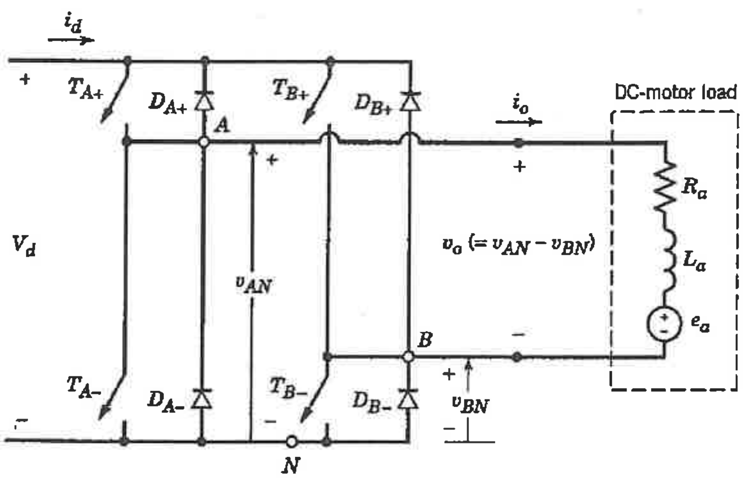

Figure 1.1: Full-bridge dc – dc converter connected to a dc motor load.

i) Giving reasons, explain which quadrants of the v_o-i_o plane this converter can be operated.

ii) Assume that the armature resistance R_a is negligible, and the dc input voltage of the converter is 125 V. The armature inductance L_a is 1 mH. The switching frequency of the converter is 250 Hz. The converter employs PWM with bipolar voltage switching and the peak amplitude of the triangular waveform $\hat{V}_{tri}$ = 10 V. At a certain operating point, the motor's back-emf is 80 V. For this operating point, the PWM is achieved by maintaining the $v_{control}$ to 2 V. Assume that all the components in the converter are ideal.

Note: When drawing the waveforms, assume that the positive half-cycle of the triangular waveform starts at t = 0.

For one switching period,

I) draw the waveforms of the necessary signals for PWM generation and the control signals for the switches T_{A+}, T_{A-} T_{B+}, and T_{B-}.

II) draw the waveform of the output voltage v_o.

III) stating the time ranges, write the necessary equations to decide the output current i_o. Assume that at t = 0, the $i_o = 0$. Hence, **roughly sketch** the current waveform i_o.

[7.0 Marks]

Q2 a) i) Classify the power semiconductor devices according to their degree of controllability.

ii) Giving the reason explain the thyristor falls into the which category according to the classification given in i).

iii) For a thyristor, what are the conditions to be fulfilled to change it from off-state to on-state? How can a conducting thyristor be turned off?

[3 Marks]

b) To control the speed and torque of a separately excited dc motor, the armature and the field circuit are connected to two separate three-phase fully controlled thyristor converters. The ac input to both converters is three-phase, 400 V (line-line rms voltage), 50 Hz. The converter connected to the field circuit is set to operate in maximum field current. The back-emf (E_a) of the armature is given by $E_a = KI_f n$, where K is the voltage constant, I_f is the field current and n is the rotor speed in rads^{-1}. The parameters of the separately excited dc-motor are given below.

Rated speed = 180 rads^{-1},
The armature resistance = 0.25 Ω,
Voltage constant (K) = 1.2 V/(A rads^{-1}),
Field circuit resistance = 245 Ω.

Assume that the inductances are large enough to have a constant dc current at the dc side of the converters. Also, assume that the source inductance L_s=0 and the thyristors in the circuits have ideal characteristics.

i) Draw the detailed circuit diagram of the converter system showing the connection of the dc motor's armature and the field circuit.

ii) In an operating point, it is observed that the dc motor is running at the rated speed while delivering armature current of 20 A. Determine the delay angle of the converter connected to the armature at that operating point.

iii) Draw the phasor diagrams to illustrate the phasor relationship between the fundamental-frequency phase voltage and the fundamental-frequency phase current at the ac side of the two converters connected to the armature and the field circuit. *Note: The rms value of the fundamental phase current of a three-phase full-controlled thyristor converter is given by $0.78I_d$, where all notations have usual meaning.*

iv) If three-phase full-controlled thyristor converters are replaced by single-phase full-controlled thyristor converters, explain two disadvantages.

[7 Marks]

Q3 a) The single-switch buck-boost type dc-dc converter is used in many power electronic applications.

i) Draw the power circuit for the single-switch buck-boost type dc-dc converter.

ii) For the continuous-conduction mode of operation of the converter, using suitable waveforms, obtain the input/output voltage and input/output current relationships, in terms of the switch duty ratio D. State clearly the assumptions you made.

iii) Assuming a constant input voltage, draw the variation of output voltage with duty ratio D for the continuous-conduction mode of operation of the converter. Show important points on the curve you have drawn.

iv) Using the curve you have drawn in iii), explain the reason why this converter is defined as buck-boost type.

v) Show that at the edge of the continuous-conduction of the converter, when the output voltage is kept constant, the average output current I_{oB} can be expressed as

$$I_{oB} = (1 - D)^2 I_{oB,max}.$$

vi) Show that in the discontinuous-conduction mode, the duty ratio D can be expressed as

$$D = \frac{V_o}{V_d}\sqrt{\frac{I_o}{I_{oB,\max}}}.$$

Note that all the symbols have their usual meaning.

[10 Marks]

Q4 a) An inverter circuit is shown in Figure 4.1.

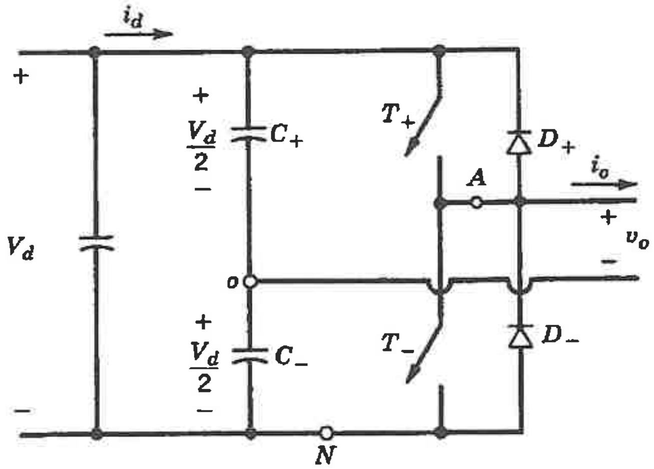

Figure 4.1: Inverter circuit.

i) If sinusoidal PWM switching is used to generate the ac output voltage v_o, explain how the switches in the circuit are switched.

ii) This inverter circuit should be able to operate in all four-quadrants of the v_o - i_o plane. Explain the reason for that.

iii) Explain the reason for having a capacitor at the dc side of the inverter circuit.

iv) What is the dead-time and why should it be associated with this circuit?

[3 Marks]

b) In a certain application, the available dc input voltage to this inverter is 600 V. The required fundamental frequency of the output voltage is 50 Hz. It is also required to maintain the switching frequency f_s to 1450 Hz and the amplitude modulation ratio m_a to 0.8. Answer the following questions with the help of Figure 4.2, whenever necessary. Note that all the notations have their usual meaning in Figure 4.2.

i) Find the frequency modulation ratio m_f.
ii) Discuss the advantages and disadvantages of selecting low frequencies and high frequencies for the switching frequency.
iii) Calculate the rms value of the fundamental component of the output voltage.
iv) What is the advantage and disadvantage when this inverter operates in linear range?
v) What is the advantage and the disadvantage when this inverter operates in overmodulation?
vi) What is the maximum possible rms value of the fundamental component of the output voltage that can be obtained from this inverter with any type of modulation?
vii) It was observed that the current to the load at the output of this inverter exceeds the rated value on some occasions. Using a new circuit diagram, explain how you modify this circuit so that the output current to be reduced while maintaining the m_a, m_f, and V_d unchanged. Explain the reason for your answer.

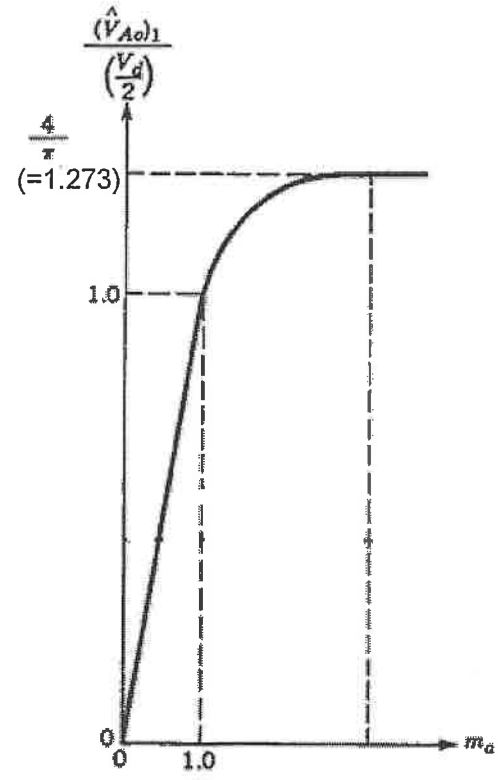

Figure 4.2

[7 Marks]

Q5 a) A three-phase load is supplied by a three-phase inverter. The dc input voltage to the inverter is 600 V. Answer the following questions with the help of Figure 4.2, whenever necessary. Note that all the notations have their usual meaning in Figure 4.2.

i) Draw the power circuit of the three-phase inverter clearly showing the three-phase ac output terminals.

ii) The three-phase inverter uses sinusoidal PWM with the switching frequency of 1050 Hz. It is required to obtain a 50 Hz three-phase ac output voltage with the line-to-line rms value of 300 V. Calculate the amplitude modulation ratio (m_a) required for the inverter.

iii) What is the main disadvantage, if it is required to increase the output line to line rms value to 420 V?

iv) Briefly explain how you implement square-wave PWM switching for this inverter.

v) State two disadvantages if the inverter is operated in square-wave mode.

[5 Marks]

b) A single-phase, integral half-cycle controlled, ac voltage controller is shown in Figure 5.1. 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 half-cycles and disconnected for m half- cycles. Assume that the thyristors T_1 and T_2 are ideal.

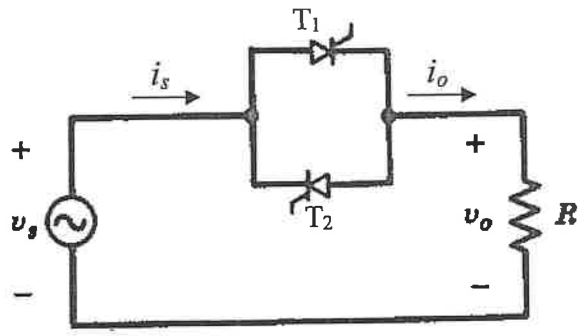

Figure 5.1: ac voltage controller.

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 anode to cathode 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 5.1 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 half-cycles and is disconnected for 2 half-cycles. Determine the input power factor of the ac voltage controller.

[5 Marks]