UNIVERSITY OF RUHUNA

Faculty of Engineering

End-Semester 5 Examination in Engineering: March 2022

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

[Three Hours]

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

Q1 a)

i) Draw the steady-state practical *i-v* characteristics and the idealized *i-v* characteristics of a thyristor. During the analysis of power electronic circuits, explain when practical and idealized characteristics are used.

ii) 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?

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

iv) Explain the reverse-recovery time of a thyristor.

[3.5 Marks]

b) A single-phase thyristor converter is shown in Figure Q1. Since the dc side has a large inductive load it is represented by a constant dc current source I_d as shown in the figure. The ac source voltage $v_s = \sqrt{2}V_s \sin \omega t$. The delay angle of the converter is α. Assume that the L_s=0 and the thyristors in the circuit have ideal characteristics.

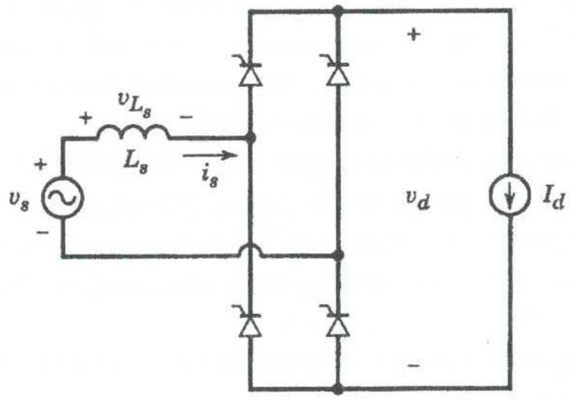

Figure Q1: Single-phase thyristor converter

i) For one cycle of ac source voltage, draw the v_d and i_s waveforms when the converter is in the rectifier mode of operation. Name the thyristors in the circuit and indicate which thyristors are 'on' in the each sector of the i_s waveform.

ii) Obtain the expression for average dc side voltage V_d.

iii) Obtain the rms value of the line current i_s.

iv) For one cycle of ac source voltage, draw the v_d and i_s waveforms when the converter is in the inverter mode of operation. Also, indicate which thyristors are 'on' in the each sector of the i_s waveform.

v) Assume that the $L_s \neq 0$ in the thyristor converter shown in Figure Q1. For one cycle of ac source voltage, draw the v_d and i_s waveforms when the converter is in the rectifier mode of operation. Also, indicate which thyristors are 'on' in the each sector of the i_s waveform.

[6.5 Marks]

Q2 a) The general block diagram of a power electronic system is given in Figure Q2.

i) What is the function of the power processor in a power electronic system?
ii) Draw a block diagram to illustrate the structure of a power processor in a power electronic system. Explain the function of each component of your block diagram.
iii) Briefly explain the types of power converters used in power processor of a power electronic system.
iv) What is the function of the controller in a power electronic system?
v) How do you decide the reference to the controller?

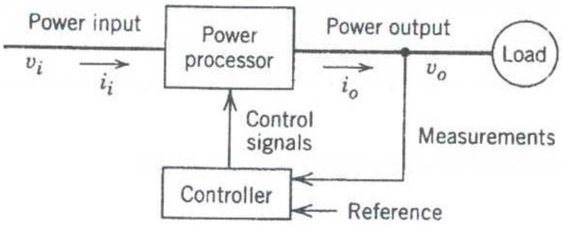

Figure Q2: Block diagram of a power electronic system.

[4 Marks]

b) The armature of a separately excited dc machine is connected to a power electronic system as the load. The field circuit of the machine is connected to a constant dc source. The armature voltage and current are required to change in both positive and negative directions. Also, the armature voltage's ripple should be as less as possible. It is expected to have two power conversion stages in the power processor of the power electronic system. Assume that fixed three-phase ac supply is available as the input to the power electronic system.

i) Showing the power conversion stages draw the detailed circuit diagram for the power converters required in the power processor.
ii) Giving reasons explain what type of PWM strategy is suitable for the power converter in the second stage of the power conversion. Briefly explain how it is implemented for the power converter.
iii) Explain how a negative voltage is obtained for the armature of the machine from the PWM strategy proposed in ii).
iv) If the line to line (rms) voltage of the three-phase ac supply, which is input to the power electronic system, is 400 V, what is the maximum possible dc voltage to the armature of the machine from the proposed power processor?

[6 Marks]

Q3 A single-switch step-up 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) of the motor is 2.0 Ω. The back-emf (E_a) of the motor is given by $E_a = Kn$, where n is the motor speed in rpm and K = 0.2 V/rpm. The motor is connected to a constant load and the armature current is constant at 10 A. The dc input voltage of the converter is 48 V and the switching frequency of the converter is 250 Hz. The inductance of the inductor and the capacitance of the capacitor of the converter are L = 24 mH and C = 9.6 mF, respectively. 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) Derive the relationship between the motor speed and the duty ratio of the converter.

iii) Show the quadrant of operation of the converter in the v - i plane.

iv) When the motor runs at 500 rpm,

   I) calculating the coordinates of relevant points draw the waveform of the converter's inductor current for a one switching period.

   II) Hence, draw the waveform of the current through the diode and the waveform of the current through the capacitor in the converter circuit for a one switching period.

   III) Calculate the peak to peak ripple in the output voltage of the converter.

   IV) Calculate the peak to peak ripple in the input current of the converter.

[10 Marks]

Q4 a)

i) Explain two main requirements that are expected from an inverter circuit in power electronics.

ii) Explain the inverter type called Voltage Source Inverter (VSI).

iii) Why is it necessary to connect diodes in anti-parallel with the controllable switches in inverter circuits?

[2 Marks]

b) The single-phase full-bridge inverter shown in Figure Q4 uses PWM with bipolar voltage switching to obtain ac output voltage. The circuit's input voltage V_d is a 120 V dc supply. Its fundamental frequency of the output voltage is 50 Hz and the switching frequency f_s is 400 Hz. At a certain operating point, the inverter's amplitude modulation ratio m_a is 0.6.

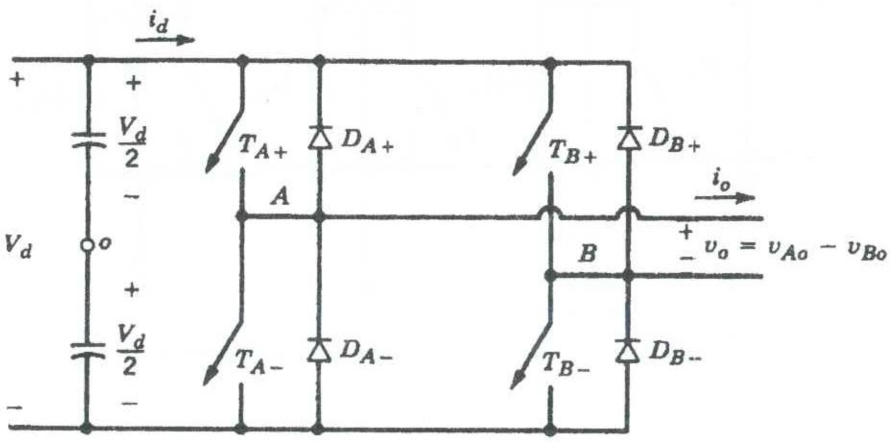

Figure Q4: Single-phase full-bridge inverter.

i) Explain how the switches in the circuit are switched to obtain an ac output voltage.

ii) Draw the waveform of the inverter's output voltage for the above given parameters.

iii) What is the rms value of the fundamental ac output voltage that can be obtained from this inverter?

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

v) Why is it required to operate an inverter in the overmodulation region? Explain how this inverter can be operated in overmodulation region.

vi) Instead of PWM with bipolar voltage switching, if square-wave switching is used for the inverter, how the switches in the circuit are switched to obtain an ac output voltage. Draw the waveform of the inverter's output voltage when square-wave switching is used for the inverter.

[8 Marks]

Q5 a) The three-phase inverter shown in Figure Q5(a) uses sinusoidal PWM switching. The input voltage to the inverter is supplied by a renewable energy source and the dc value of it 400 V. The required fundamental frequency of the output voltage is 50 Hz. The switching frequency of the inverter is set at 750 Hz. Assume that all the components in the circuit of the inverter are ideal.

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

ii) Using necessary waveforms, briefly explain how the sinusoidal PWM switching is implemented for the inverter.

iii) What is the maximum fundamental line-to-line rms output voltage this inverter can supply without overmodulation?

iv) What is the most significant lower order harmonic frequency that appears in the output voltage of the inverter during the linear modulation?

v) If the switches in the circuit of the inverter are not ideal, when implementing the PWM switching, how can the problem of short circuiting of the dc input of the inverter be overcome?

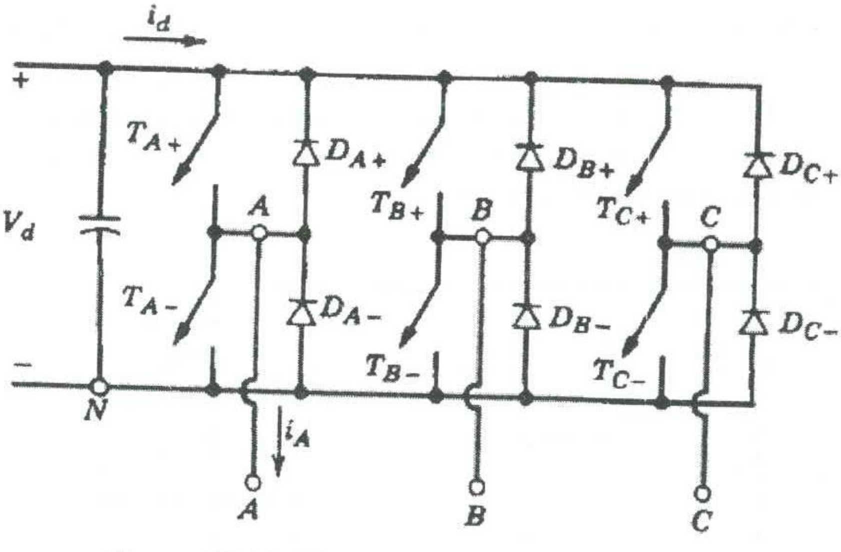

Figure Q5(a): Circuit for the three-phase inverter.

[6 Marks]

b) A single-phase, phase-angle controlled, ac voltage controller is shown in Figure Q5(b). The input voltage $v_S = \sqrt{2}V_S \sin \omega t$, and the delay angles of thyristors T_1 and T_2 are α ($0 < \alpha < \pi$) and $\pi+\alpha$, respectively. It has a resistive load R. Assume that the thyristors in the circuit have ideal characteristics.

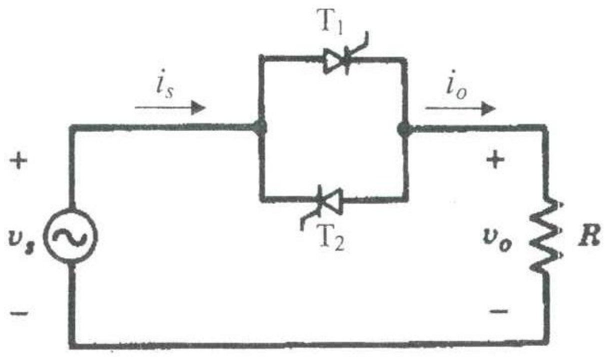

Figure Q5(b): ac voltage controller.

i) For one cycle of ac source voltage, draw the waveforms of output voltage v_o, output current i_o, input current i_s 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.

ii) Write the integral equation, in terms of α, V_s, ω, t and R, to obtain the rms value of the input current i_s.

[4 Marks]