UNIVERSITY OF RUHUNA

Faculty of Engineering

End-Semester 5 Examination in Engineering: May 2023

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

[Three Hours]

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

Q1 a)

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

ii) By giving two reasons, explain why the power electronic systems have an expanded market demand recently.

iii) 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 single-phase ac supply is available as the input to the power electronic system. Clearly showing the power converter stages, draw the detailed circuit diagram to illustrate the structure of the power processor needed in the power electronic system. Assume that only diodes, Insulated Gate Bipolar Transistors (IGBTs) and passive components are available to make the circuits for power converters.

[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 Ra = 0.1 Ω and the motor's back emf constant is 0.06 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 70 V and the switching frequency of the converter is 500 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 800 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 -800 rpm speed in the motor.

[6 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) What are requirements of the signal given to the gate terminal 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 Q2 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 $r_d = 0.5\ \Omega$. 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.

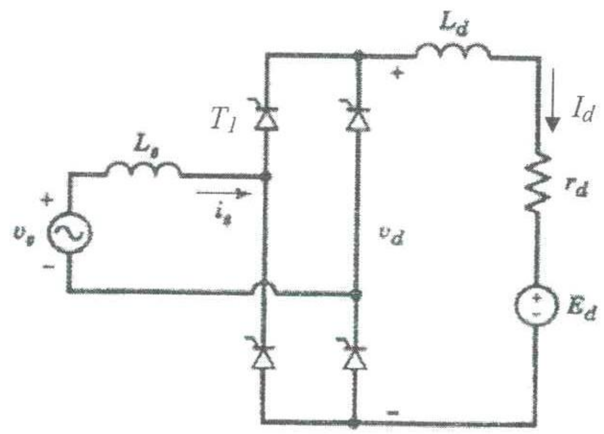

Figure Q2: Single-phase thyristor converter with a dc motor load

i) Name the thyristors in the circuit and giving reasons explain which thyristors should be given gate trigger signals in the positive half cycle and in the negative half cycle of the v_s.

ii) Assuming a firing angle α, 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) Obtain the expression for average dc side voltage V_d.

iv) 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 = 10 A. At this operating point,

I) determine the firing angle α of the converter.

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

III) what is the ac ripple frequency of the armature voltage?

IV) what are the harmonic frequencies exist in the ac side line current?

[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.

[2.5 Marks]

b) A step-down dc-dc converter supplies a load of 128 W. The input voltage to the converter is 40 V and the output voltage of the converter is to be regulated at 16 V. The converter operates at 1 kHz switching frequency. The inductance of the converter's inductor is L=1.0 mH. Assume ideal conditions for the converter.

i) Determine whether the converter operates in continuous or discontinuous conduction mode.

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

iii) Draw the waveform of the converter's input current for a one switching period and calculate the peak-to-peak ripple in the input current.

iv) Assuming that there are no ripples in the output current, draw the waveform for the current through the capacitor for a one switching period.

[7.5 Marks]

Q4 a) Two single-phase inverter circuits are shown in Figure Q4(1) and Figure Q4(2). Assume that both inverters use PWM with bipolar voltage switching to obtain ac output voltage.

i) Explain separately, how the switches in the two circuits are switched to generate an ac output voltage.

ii) Define the following terms associated with these inverter circuits.

(I) Amplitude modulation ratio (m_a)

(II) Frequency modulation ratio (m_f)

iii) Both inverter circuits should be able to operate in all four-quadrants of the v_o - i_o plane. Explain the reason for that.

[3 Marks]

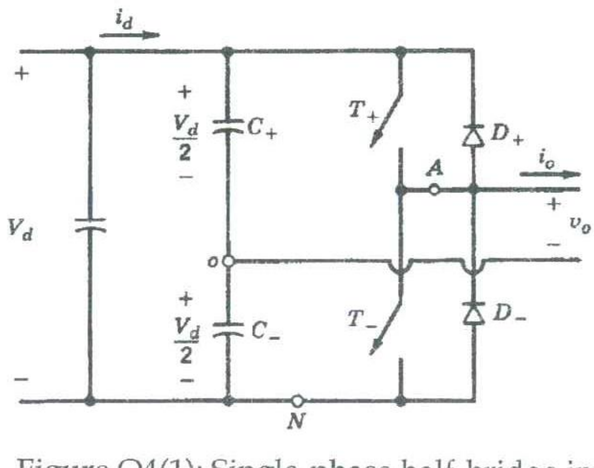

Figure Q4(1): Single-phase half-bridge inverter.

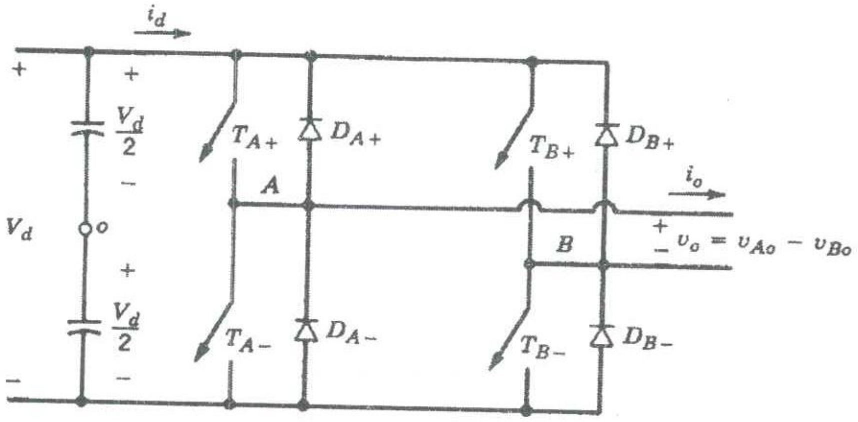

Figure Q4(2): Single-phase full-bridge inverter.

b) In a certain application, the available dc input voltage to an inverter is 500 V. The required ac fundamental frequency of the output voltage is 50 Hz. It is also required to maintain the switching frequency f_s to 750 Hz and the amplitude modulation ratio m_a to 0.6.

i) Calculate the rms value of the fundamental ac output voltages that can be obtained from the inverter circuits given in Figure Q4(1) and Figure Q4(2).

ii) If the PWM with bipolar voltage switching is used by both inverter circuits, what are the most dominant harmonic frequencies that can be expected in each inverter output voltage?

iii) Is it possible to obtain a better harmonic frequency spectrum in the output voltage than in the calculations in ii)? Giving reasons explain your answer.

iv) What is the advantage and the disadvantage of operating the inverters in the overmodulation region? Explain how these inverter circuits can be operated in overmodulation region.

v) If square-wave switching is used for the inverters, how the switches in the circuits are switched to obtain an ac output voltage. Draw the waveforms of the inverters' output voltage when square-wave switching is used for the inverters.

[7 Marks]

Q5 a) A three-phase, star-connected induction motor is supplied by a three-phase inverter. The stator frequency f of the induction motor is required to vary from 5 Hz to 50 Hz. The stator's line-to-line rms voltage V_{LL} is proportional to the stator frequency f and it is given by

$$\frac{V_{LL}}{f} = 8$$

The inverter uses sinusoidal PWM switching and the switching frequency is set at 750 Hz. It is required to operate the inverter without overmodulation. Assume that constant dc voltage supply is available to the inverter and all the components in the circuit of the inverter are ideal.

i) Draw the detailed circuit diagram of the inverter including the connection of the stator of the induction motor.

ii) Calculate the minimum dc voltage required to operate the inverter for the required frequency range without overmodulation.

iii) Calculate the required amplitude modulation ratio (m_a) for the inverter when the induction motor runs at the lowest stator frequency with the minimum dc voltage calculated in ii).

iv) What is the range of frequency modulation ratio (m_f) for the inverter for this application?

v) The maximum output voltage distortion of the inverter occurs at which stator frequency of the induction motor? Give reasons to your answer.

[6 Marks]

b) In an industrial heating application, it is required to use ac voltage controllers that are made of triacs to control the heat. The heating load is a star-connected, balanced, three-phase, resistive load with the resistance of R for each phase.

i) Draw the detailed circuit diagram for the three-phase heat control system with ac voltage controllers including the connection of the three-phase load.

ii) It is required to use integral half-cycle control technique for the ac voltage controllers for this application. Using necessary diagrams and waveforms explain how the integral half-cycle control technique is implemented for the ac voltage controllers for this application.

iii) Derive an integral equation to express the power deliver to the three-phase load through the ac voltage control technique mentioned in ii). Assume that the rms value of the phase voltage in the power system is V_s.

[4 Marks]