UNIVERSITY OF RUHUNA

Faculty of Engineering

End-Semester 5 Examination in Engineering: October 2019

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

[Three Hours]

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

Q1 a)

i) Classify the power semiconductor devices according to their degree of controllability. Give an example for each category.

ii) Draw the steady-state practical *i-v* characteristics and the idealized *i-v* characteristics of a thyristor. Explain the forward-breakdown-voltage and the reverse-breakdown-voltage of a thyristor.

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

iv) Describe the turn-off time interval of a thyristor.

[4 Marks]

b) The speed of a dc series machine is controlled by a three-phase full-controlled thyristor converter. The ac input to the converter is three-phase, 400 V (line-line rms voltage), 50 Hz. The combined resistance of the armature and the series field winding of the dc series machine is 1.0 Ω. The back-emf of the machine is given by $E_a=KI_an$, where n is the motor speed, I_a is the armature current, and K=0.02 V/(A rpm). At a certain operating point, the dc machine operates in motor mode running at 500 rpm. The measured armature current at this operating point is 30 A. Assume the ideal conditions for the converter, and the armature inductance is sufficiently large so that the armature current can be considered to be constant.

i) Draw a circuit diagram to illustrate the converter and the connection of the armature of the motor.

ii) Calculate the required firing angle of the converter.

iii) Calculate the rms values of the harmonic phase currents for harmonic numbers h=2, 3, 4, 5, 6, 7 at the ac side of the converter.

iv) Draw a phasor diagram to illustrate the phasor relationship between the fundaental-frequency phase voltage and fundaental-frequency phase current at the ac side of the converter.

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

vi) Is it possible to revese the direction of rotation of the dc series machine using this type of power electronic converter? Explain your answer using suitable performance equations of the converer and the dc machine.

[6 Marks]

Q2 a)

i) Draw the power circuit for the single-switch step-up (boost) dc-dc converter.

ii) Using necessary steady-state waveforms, obtain the input/output voltage and input/output current relationships, in terms of the switch duty ratio D for the continuous-conduction mode of operation of the step-up dc-dc converter you have drawn in i). State clearly the assumptions you made.

iii) Show that at the edge of the continuous-conduction, the average output current I_{oB} can be expressed as

$$I_{oB} = \frac{T_s V_o}{2L} D(1-D)^2$$

Note that all the symbols have their usual meaning.

[6 Marks]

b) In a step-up converter, the duty ratio is adjusted to regulate the output voltage V_o at 15 V. The input voltage varies in a wide range from 5 V to 10 V. The minimum power output from the converter is 7.5 W. The switching frequency is 20 kHz. It is required that the converter always operate in a continuous-conduction mode. Calculate the minimum value of inductance L_{min} that can be used in the converter.

[4 Marks]

Q3 a)

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

ii) A buck-boost converter operates at 12.5 kHz switching frequency. The inductance of the converter's inductor is L=0.05 mH and the capacitance of the converter's capacitor is sufficiently large so that the output voltage to be a constant. The input voltage to the converter is 20 V and the output voltage of the converter is to be regulated at 10 V. The converter is supplying a load of 20 W. Under these conditions, determine whether the converter operates in continuous or discontinuous conduction mode.
[Note that for a single-switch buck-boost type dc-dc converter

$$I_{oB} = \frac{T_s V_o}{2L}(1-D)^2,$$

where all the symbols have their usual meaning.]

[3.5 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 $R_a = 0.1\ \Omega$ and the motor's back emf constant is 0.05 V/rpm. The motor is connected to a constant load and the armature current is constant at 100 A. The dc input voltage of the converter is 150 V and the switching frequency of the converter is 250 Hz. The converter employs PWM with unipolar 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 the following two speeds can be achieved in the motor.

  I) 2200 rpm

  II) -2200 rpm

[6.5 Marks]

Q4 The single-phase full-bridge inverter shown in Figure Q4 uses PWM with bipolar voltage switching to obtain ac output voltage. The dc input voltage to the inverter is 500 V and the switching frequency is 750 Hz.

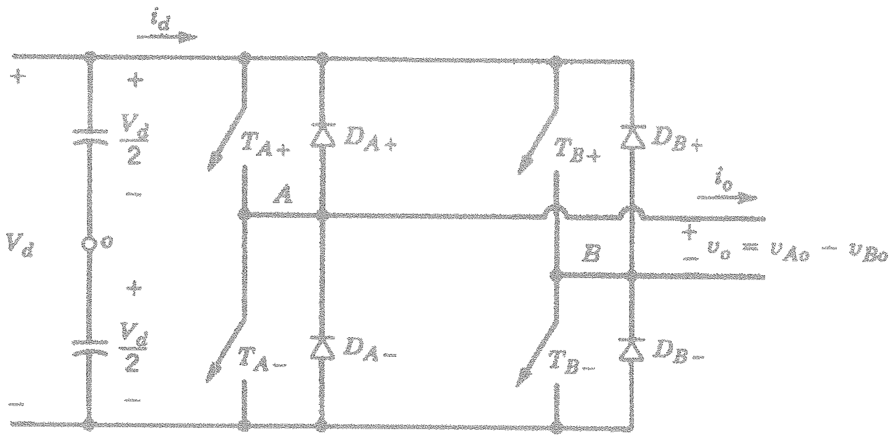

Figure Q4: Single-phase full-bridge inverter.

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

ii) Define the following terms associated with this inverter.

  (I) Amplitude modulation ratio (m_a)

  (II) Frequency modulation ratio (m_f)

  (III) Overmodulation

iii) From this inverter, it is required to obtain a 50 Hz ac output voltage with the rms value of 240 V.

  (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?

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

v) For one cycle, draw the waveform of v_{AB} when the inverter is operated in square-wave mode to obtain a 50 Hz ac output voltage. On the waveform, indicate the switches that are conducting.

vi) Explain the main advantage of using PWM with unipolar voltage switching instead of PWM with bipolar voltage switching in this inverter.

[10 Marks]

Q5 a) A three-phase load is supplied by a three-phase inverter. The dc input voltage to the inverter is 600 V.

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

v) If the inverter is operated in square-wave mode, calculate the rms values of the harmonic line to line voltages for harmonic numbers h=2, 3, 4, 5, 6, 7.

[5 Marks]

b) A single-phase, phase-angle controlled, ac voltage controller is shown in Figure Q5. The input voltage $v_s = 325 \sin \omega t$, and the delay angles of thyristors T_1 and T_2 are $\pi/3$ and $\pi+(\pi/3)$, respectively. It has a resistive load of R = 10 Ω. Assume that the thyristors in the circuit have ideal characteristics.

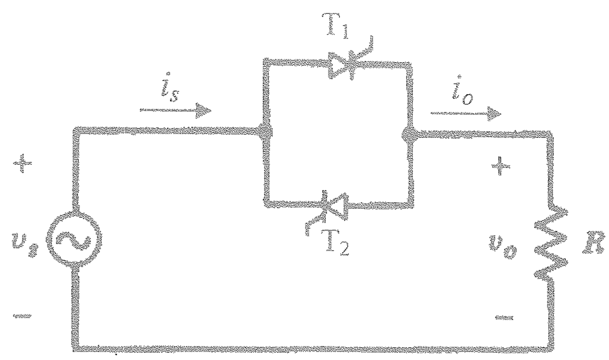

Figure Q5: ac voltage controller.

i) For one period of v_s, draw the waveforms of the output voltage v_o, output current i_o and the input current i_s.

ii) Calculate the rms value of the input current i_s.

iii) Calculate the input power of the circuit.

iv) For one period of v_s, draw the anode to cathode voltage and current waveforms of the thyristor T_1.

[5 Marks]