The Open University of Sri Lanka
Faculty of Engineering Technology
Department of Mechanical Engineering

Study Programme	:	Bachelor of Science Honours in Engineering
Name of the Examination	:	Final Examination
Course Code and Title	:	**DMX5313/ DMX5570 Power Electronics and Motor Drives**
Academic Year	:	2022/2023
Date	:	18th of February 2024
Time	:	09.30-12.30
Duration	:	**3 hours**

General Instructions

1. Read all instructions carefully before answering the questions
2. This question paper consists of **Five (5)** questions in Five (5) pages.
3. Answer all **Five (5)** questions. All questions carry equal marks.
4. Answer for each question should commence from a new page.
5. This is a Closed Book Test (**CBT**).
6. The symbols used in this paper have their usual meanings.
7. Clearly state any assumptions that you may make.
8. Answers should be in clear handwriting.
9. Do not use a red pen.

Question 01

In the field visit to a Wind Power Plant (WPP), you were able to understand the working principle behind the wind turbines. With that knowledge answer the following questions.

a. State generator types used in WPPs. [2 marks]
b. Draw a block diagram of a synchronous generator wind turbine configuration and briefly describe its operation. [3 marks]
c. A 1.5 MW three-phase (3-ph) delta connected synchronous generator has a rated voltage of 2.5 kV at a power factor 0.8. Find the line current when operating in the full load. [3 marks]

Using the knowledge you gained about power electronics associated with inverters used for power conversion in the WPP, answer the questions from (d) to (g) regarding a full-bridge single-phase (1-ph) inverter shows in Figure Q1.1. The inverter (with RL load) is controlled to give an output V_o with the waveform as shown in Figure Q1.2. [12 marks]

The Fourier expansion of the output voltage (V_o) is given by $V_o = \sum_n b_n \sin(n\omega t)$, where $b_n = \frac{4V_{dc}}{n\pi} \sin(n\beta)$ *and* $n = 1,3,5\ldots$

d. Sketch the gate signals to be given to devices Q1-Q4.
e. Calculate the angle β required to eliminate the most dominant harmonic component of the output.
f. Calculate percentage of Total Harmonic Distortion (%THD) of the output for the case (e) above.
g. The calculated angle β for the case (e) above is used with the inverter to supply a fundamental rms voltage of 230V at the output. Calculate the average voltage V_{dc} that required.

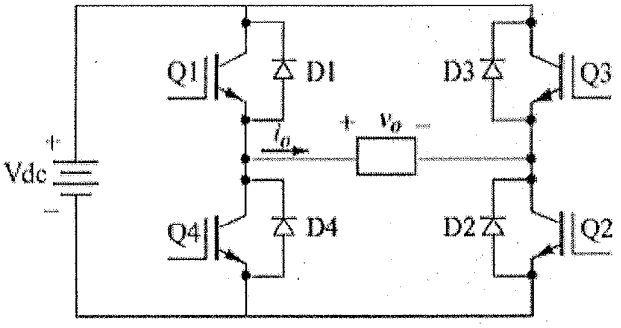

Figure Q1.1

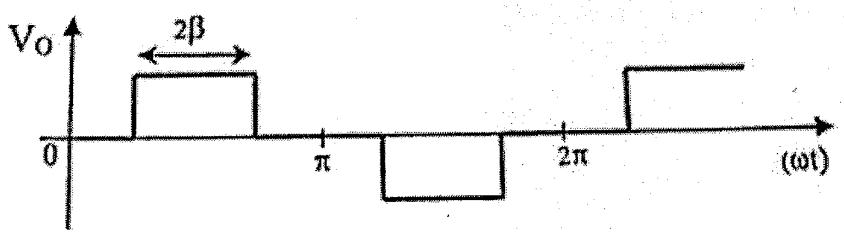

Figure Q1.2

Question 02

a. List down three (3) advantages of using controlled rectifiers over uncontrolled rectifiers. [3 marks]
b. A single-phase (1-ph) bridge rectifier (with parallel R-C load) is given in Figure Q2.1.
   i.) Draw the voltage and current waveforms on the same graph: V_s, V_{out}, V_d, i_s, and i_d *(indicate diode number where necessary).*
   ii.) Explain working mechanism of the rectifier with help of wave forms. [7 marks]

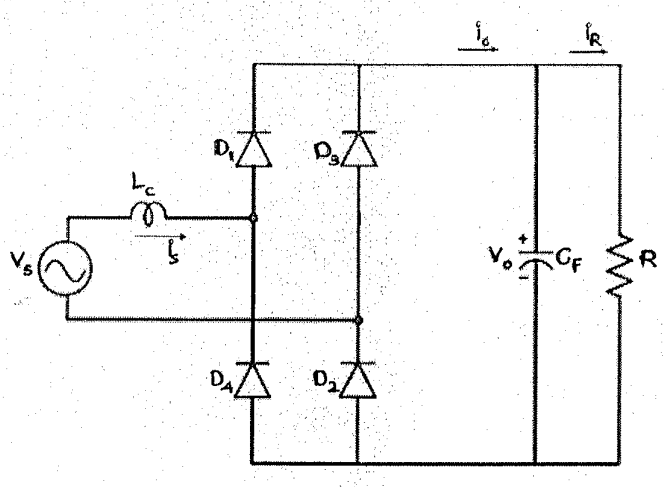

Figure Q2.1

c. A half wave-controlled rectifier circuit is shown in Figure Q2.2. The load circuit consists of a dc source 'E' in addition to a resistor and inductor. [10 marks]

i.) Draw the voltage and current waveforms: v_0 and i_0 *(indicate necessary values)*.

ii.) Explain the working mechanism of the DC source 'E' with help of wave forms you drew in (i)

iii.) Derive an expression for load current: i_0

iv.) Derive an expression for average voltage: $V_{o(dc)}$ *(Clearly mention boundary conditions where necessary)*.

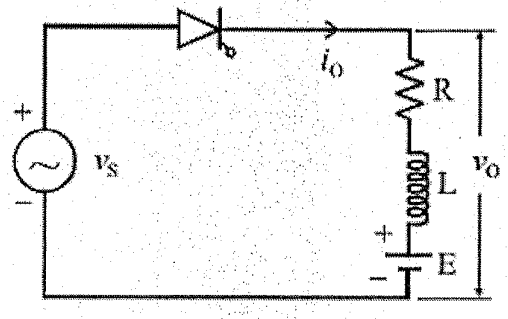

Figure Q2.2

Question 03

Power transistors are generally of five types: BJTs, MOSFETs, SITs, IGBTs and COOLMOS. BJTs are current-controlled devices and parameters are sensitive to junction temperature. MOSFET are voltage-controlled devices and require very low gating power and their parameters are less sensitive to junction temperature. IGBTs, which combine the advantages of BJTs and MOSFETs, are voltage-controlled devices and have low on-state voltage like BJTs.

a. Compare BJTs, IGBTs and MOSFETs by considering their characteristics, working principles, advantages, and limitations. [6 marks]

b. A bipolar transistor is operated as a chopper switch at a frequency of $f_s = 10$ kHz as shown in Figure Q3.1. Specifications are given below.

DC voltage of the chopper is $V_s = 220$ V
Load current is $I_L = 100$ A
Switching times:
Delay time $(t_d) = 0$, Rise time $(t_r) = 3$ µs and Fall time $(t_f) = 1.2$ µs.

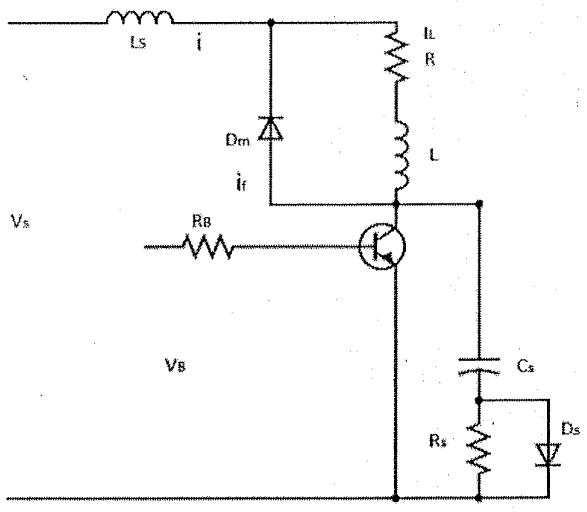

Figure Q3.1

i.) Describe how the given circuit is working with the help of wave forms.
ii.) Determine L_S, C_S, R_S for critically damped condition.
iii.) Find R_S, if the discharge time is limited to one-third (1/3) of switching period.
iv.) Find R_S, if the peak discharge current is limited to 10% of load current.
v.) Calculate the power loss due to RC snubber. (*Neglect the effect of inductor L_S on the voltage of snubber capacitor C_S).*

[14 marks]

Question 04

DC-DC converters are widely used in applications such as regulated DC power supplies and in DC motor drives. Input to these converters are unregulated DC voltage mainly obtained by rectification of single-phase (1-ph) or three-phase (3-ph) AC supply voltage at line frequency. Alternatively, it could be from a battery. The main function of the DC-DC converters is to convert the unregulated DC voltage into a regulated (stabilized) DC output voltage which can be maintained constant at the desired value irrespective of the supply voltage or load variations.

a. State different types of choppers depending on the voltage output and explain the working operation for one of them using appropriate circuit diagrams and wave forms. [5 marks]
b. List down classification of choppers depending upon the direction of the output current and voltage. [3 marks]

c. The average output voltage can be controlled by varying the Duty Cycle of the switching pulses in a DC-DC converter. What are the two (2) ways can be used to vary duty cycle? Explain them using appropriate diagrams. [6 marks]

d. A step-up chopper has an input voltage of 150 V. The voltage output needed is 450 V. Given, that the thyristor has a conducting time of 150 μs. Calculate: [6 marks]
   i.) chopping frequency (f)
   ii.) output voltage (V_0).

Question 05

a. A full converter is a two-quadrant converter in which the output voltage can be bipolar, but the current will be unidirectional since the thyristors are unidirectional. A full converter feeding a separately excited DC motor is shown in Figure Q5.1.

   Explain the operation of the full controller considering thyristors T_1 and T_3 that are simultaneously triggered at a firing angle of α and thyristors T_2 and T_4 are triggered at firing angle (π+α) *(Use appropriate waveforms:* ***e, e_{LA}, i_a, and i_s).*** [8 marks]

b. A separately excited DC motor is fed from a 230 V, 50 Hz supply via a single-phase (1-ph), half-controlled bridge rectifier. Armature parameters are:
   Inductance 0.06 H
   Resistance 0.3 Ω
   Motor voltage constant is (K_a) = 0.9 V/A rad/s
   Field resistance is (R_F) = 104 Ω
   Load torque (T_L) = 50 N.m at 800 rpm

   The filed current is also controlled by a semi converter and is set to the maximum possible value. The inductances of the armature and field circuits are sufficient enough to make the armature and filed current continuous and ripple free. Calculate:
   i.) Field current
   ii.) Firing angle of the converter in the armature circuit.

   [12 marks]

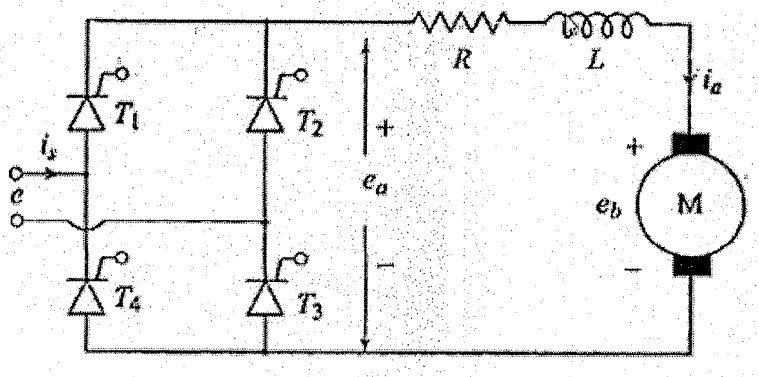

Figure Q5.1

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