

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 Power Electronics and Motor Drives
Academic Year : 2023/2024
Date : 17th of March 2025
Time : 13.30-16.30 hrs
Duration : 3 hours

General Instructions

1. Read all instructions carefully before answering the questions
2. This question paper consists of **Five (5)** questions in ~~Four (4)~~ ^{Five (5)} pages.
3. Answer all the 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.

Question01

(20 Marks)

Suppose that a ^{10MW} solar power plant requires a three-phase inverter system to convert DC power from the solar arrays to AC power for grid connection. The DC link voltage from the solar arrays is 1500V DC.

- a. Describe the architecture of a grid-connected solar power plant, highlighting the role of power electronic converters at different stages. [4 marks]

- b. For a three-phase Voltage Source Inverter (VSI) using Sinusoidal Pulse Width Modulation (SPWM):
- Draw the circuit diagram and explain its principle of operation. [4 marks]
 - Calculate the fundamental RMS line-to-line output voltage if the modulation index is 0.8 and the switching frequency is 5 kHz. [3 marks]
- c. The inverter needs to be synchronized with the grid (400V, 50Hz). Explain the importance of the Phase-Locked Loop (PLL) technique for grid synchronization. [3 marks]
- d. Calculate the rating of each power semiconductor device (IGBTs) in the inverter if the plant operates at full capacity (10MW) with a power factor of 0.95. Assume an equal distribution of current among parallel modules if needed. [3 marks]
- e. Discuss the challenges in harmonic mitigation for grid-connected inverters and explain any TWO techniques to reduce the Total Harmonic Distortion (THD). [3 marks]

Question 02

(20 Marks)

- a. Compare single-phase and three-phase uncontrolled rectifiers regarding output voltage ripple, power factor, and harmonic content. Include relevant waveforms in your answer. [6 marks]
- b. A three-phase fully controlled bridge rectifier is connected to a 400V (line-to-line) 50Hz supply and feeds a load consisting of a resistance of 20Ω in series with a large inductance that makes the load current continuous and ripple-free. The firing angle (α) is set to 30° . [10 marks]
- Draw the circuit diagram of the rectifier.
 - Calculate the average output voltage.
 - Calculate the average and RMS load current.
 - Calculate the input displacement power factor.
- c. Discuss the methods to improve the power factor in controlled rectifiers and explain how active Power Factor Correction (PFC) circuits work. [4 marks]

Question 03

(20 Marks)

- a. Explain the following switching losses in power electronic devices with appropriate diagrams. [6 marks]

- i. Turn-on losses
- ii. Turn-off losses
- iii. Conduction losses

- b. A power IGBT is switching a load with the following parameters:

DC bus voltage: 600V	Turn-on time: 200 ns
Load current: 50A	Turn-off time: 300 ns
Switching frequency: 20 kHz	On-state voltage drop: 2.5V

Calculate:

[4 marks]

- i. The turn-on energy loss per switching
 - ii. The turn-off energy loss per switching
 - iii. The conduction losses
 - iv. The total power loss in the IGBT.
- c. Design an RCD (Resistor, Capacitor, Diode) turn-off snubber circuit for the IGBT in **part b**. Calculate appropriate values for the snubber resistor and capacitor. The snubber should reduce the voltage rise rate to $600\text{V}/\mu\text{s}$ during turn-off. [5 marks]
- d. The IGBT has a junction-to-case thermal resistance of $0.2^\circ\text{C}/\text{W}$. If the maximum junction temperature is limited to 125°C and the ambient temperature is 40°C . Calculate the required thermal resistance of the heat sink if the case-to-sink thermal resistance is $0.1^\circ\text{C}/\text{W}$. [5marks]

Question 04

(20 Marks)

DC-DC converters are widely used in applications such as regulated DC power supplies and DC motor drives. Suppose that a buck converter is designed to supply a resistive load of 10Ω with an output voltage of 24V. The input voltage is 48V, and the switching frequency is 50 kHz.

- Draw the buck converter circuit diagram and explain its operation modes. [5 marks]
- Calculate the duty cycle required to achieve the desired output voltage. [2 marks]
- Calculate the minimum inductance required if the converter operates in continuous conduction mode (CCM). Assume the current ripple is limited to 10% of the average output current. [4 marks]
- Calculate the value of the output capacitor if the output voltage ripple needs to be limited to 0.5% of the output voltage. [4 marks]
- Determine the peak current through the switching device and the freewheeling diode. [3 marks]
- If the converter's efficiency is 95%, calculate the input power and the power loss in the converter. [2 marks]

Question 05

(20 Marks)

In one of the practical sessions, you used the thyristor bridge panel to control a DC shunt motor for various cases. With that knowledge, answer the following questions.

A separately excited DC shunt motor has the following parameters:

Armature resistance (R_a) = $0.5\ \Omega$

Field resistance (R_f) = $200\ \Omega$

Rated armature voltage = 230 V

Rated field voltage = 230 V

Rated speed = 1500 rpm

Rated armature current = 25 A

Motor constant (k) = $1.2\ \text{V}\cdot\text{s}/\text{rad}$

The motor is controlled using a thyristor-based DC drive with a firing angle range of 0° to 180° . The drive is connected to a 300 V DC source.

- a. Draw a clear schematic diagram showing a thyristor-based DC drive configuration for the shunt motor, labeling all key components. Explain the purpose of each component in your schematic. [4marks]
- b. If the firing angle of the thyristor converter is adjusted to 30° , calculate: [4marks]
 - i. The armature voltage supplied to the motor
 - ii. The motor speed at rated load torque
- c. The motor is now operated with field weakening control: [4marks]
 - i. Explain the principle of field weakening in DC shunt motors
 - ii. If the field current is reduced to 80% of its rated value, calculate the new speed of the motor at the rated armature current and voltage
- d. The motor is required to brake regeneratively: [4marks]
 - i. Calculate the range of firing angles required for regenerative braking when the motor is rotating at 1200 rpm
 - ii. Determine the power fed back to the supply during regenerative braking at this speed with an armature current of 15 A
- e. Discuss how the torque-speed characteristics of the DC shunt motor are affected by the following cases. Include appropriate sketches of the characteristics in your answer. [4 marks]
 - i. Armature voltage control
 - ii. Field control

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