The Open University of Sri Lanka
Faculty of Engineering Technology
Department of Electrical & Computer Engineering

056

Study Programme	: Bachelor of Technology Honours in Engineering
Name of the Examination	: Final Examination
Course Code and Title	**: EEX5453 Power Electronics**
Academic Year	: 2020/21
Date	: 21st January 2022
Time	: 0930 – 1230 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 **Five (5)** pages.
3. Answer all the **Five (5)** questions.
4. Answer for each question should commence from a new page.
5. Relevant charts/ codes are provided.
6. This is a Closed Book Test (CBT).
7. Answers should be in clear handwriting.
8. Do not use Red colour pen.

Question 01 [20 marks]

As the design engineer in a manufacturing company, you are asked to design a **non-isolated voltage step-up** power electronics circuit (Boost converter) which converts 12 V DC in to 24 V DC. You are provided with an adjustable duty cycle PWM generator IC which operates at 30 kHz to be used in this application.

1. Draw the circuit diagram of the boost converter indicating all the necessary components.

   [1 mark]

2. Draw the equivalent circuits for the two operating modes ('on' and 'off' states) of the circuit.

   [2 marks]

3. Derive an expression for the duty cycle (D) of the converter and determine the required duty cycle for this application.

   [5 marks]

4. If the load connected to this circuit is a constant 20 Ω resistor, what is the minimum inductor size required to keep the circuit on Continuous Current Mode (CCM). (Derivation of the equation is not required).

   [2 marks]

5. In the circuit, maximum variation of the inductor current should be ±5% (10% Peak to Peak) from the rated inductor current.

   a. Size the inductor properly to achieve this requirement and select a matching inductor from the chart shown in table 1: Standard Inductor Values. Note that only one inductor can be used.

      [3 marks]

   b. When the selected inductor is used, what will be the peak-to-peak current variation of the inductor?

      [2 marks]

6. The voltage ripple at the output should not exceed 1% of the rated output voltage. Calculate the minimum capacitor size accordingly to achieve this requirement.

   [5 marks]

Table 1: Standard inductor values

nH	nH	nH	μH	μH	μH	mH	mH	mH
1	10	100	1.0	10	100	1.0	10	100
1.2	12	120	1.2	12	120	1.2	12	
1.5	15	150	1.5	15	150	1.5	15	
1.8	18	180	1.8	18	180	1.8	18	
2	20	200	2.0	20	200	2.0	20	
2.2	22	220	2.2	22	220	2.2	22	
2.7	27	270	2.7	27	270	2.7	27	
3	33	330	3.3	33	330	3.3	33	
4	39	390	3.9	39	390	3.9	39	
5	47	470	4.7	47	470	4.7	47	
6	51	510	5.1	51	510	5.1	51	
7	56	560	5.6	56	560	5.6	56	
8	68	680	6.8	68	680	6.8	68	
9	82	820	8.2	82	820	8.2	82	

Question 02 [20 marks]

You have a multilevel inverter with **3 independent sources** with source voltage Vdc = 50 V each. Determine the following.

1. How many voltage levels you can obtain using a 3-source inverter? draw the general output waveform indicating all the voltage levels.

[04 marks]

2. Fourier coefficients of output voltage up to 9th harmonic, if $\alpha_1 = 10°$, $\alpha_2 = 25°$ and $\alpha_3 = 40°$.

[06 marks]

3. Calculate the Modulation Index (M_i)

[04 marks]

4. Determine α_1, α_2 and α_3 to eliminate the 3rd harmonic and to keep modulation index at 0.846 approximately.
Hint: Test with 5° increments and decrements from the current operating point.

[06 marks]

Question 03 [20 marks]

A full-bridge inverter is used to produce a 50 Hz voltage across a series *RL* load using bipolar PWM. The DC input to the bridge is 100 V, the amplitude modulation ratio m_a is 0.70, and the frequency modulation ratio m_f is 21 [$(f_{carrier} = 21 \times 50 = 1050 \text{ Hz})$. The load has a resistance of $R = 10\ \Omega$ and a series inductance $L = 20\ mH$.

1. Explain the effect of varying the frequency modulation ratio of a PWM inverter and what benefits can be achieved from it.

[4 marks]

2. Explain the effect of varying the Amplitude Modulation ratio of a PWM inverter and what benefits can be achieved from it.

[4 marks]

3. Using the details given in the question text and the Normalised Fourier Coefficients given in table 2, determine the following measurement at the output. (Consider only up to the first three harmonics $m_f, m_f + 2, m_f - 2$).
   a. The amplitudes of voltage and current of the 50 Hz component and the harmonics.
   b. The power absorbed by the load resistor.
   c. The Total Harmonic Distortion (THD) of the load current.

[4 x 3 = 12 marks]

Table 2: Normalised Fourier Coefficients of Bipolar PWM

	$m_a=1$	0.9	0.8	0.7	0.6	0.5	0.4	0.3	0.2	0.1
$n=1$	1.00	0.90	0.80	0.70	0.60	0.50	0.40	0.30	0.20	0.10
$n=m_f$	0.60	0.71	0.82	0.92	1.01	1.08	1.15	1.20	1.24	1.27
$n=m_f\pm2$	0.32	0.27	0.22	0.17	0.13	0.09	0.06	0.03	0.02	0.00

Question 04 [20 marks]

Figure 1 shows an ideal half-wave rectifier circuit with a pure resistive load equal to R.

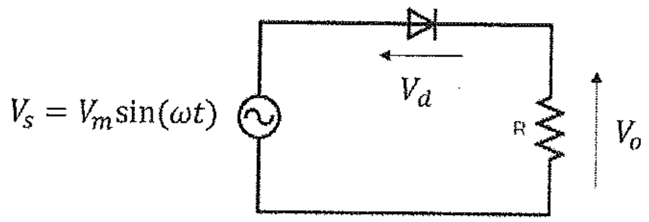

Figure 1

1. If the supply voltage $V_s = V_m \sin(\omega t)$, Draw a sketch of the voltage waveforms of output voltage (V_o) and the voltage across the diode (V_d) in a common time scale. Indicate all the voltage levels and phase angles. [4 marks]

2. From the first principles, prove the following measurements of the output.

   a. $V_{avg} = \frac{V_m}{\pi}$ [2 marks]

   b. $I_{rms} = \frac{V_m}{2R}$ [2 marks]

3. If the Ideal rectifier in consideration is supplied with a sinusoidal voltage with a rms value of $230\ V$ and if $R = 10\ \Omega$, calculate the following.

   a. Average Current flow through the load.
   b. V_{rms} across the load.
   c. Power Absorbed by the load.
   d. Power factor of the power supply.

[3 x 4 = 12 marks]

Question 05 [20 marks]

This question consists of two parts (A and B). Answer both parts.

Part A

A single-phase AC voltage controller has a $100\ V_{rms}$, $50\ Hz$ source. The load is purely resistive, and the resistance value is $6\ \Omega$. Determine the following.

1. The Delay angle of the controller to deliver 600 W power to the Load. (Use the normalized amplitude curve shown in figure 3 at the end of this question) [6 marks]
2. Source rms current. [2 marks]
3. Power factor. [2 marks]

Part B

Consider the circuit shown in figure 2. S_1 and S_2 are two identical Silicon Controlled Rectifiers (SCR).

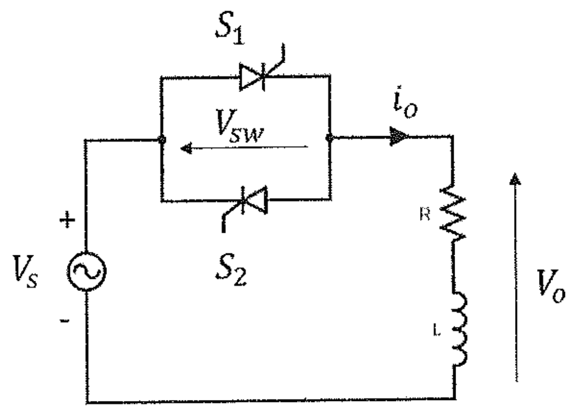

Figure 2

For the single-phase voltage controller shown in figure 2, the source is $120\ V_{rms}$ at $60\ Hz$, and the load is a series RL combination with $R = 20\ \Omega$ and $L = 50\ mH$. The delay angle $\alpha = 90°$ and the extinction angle $\beta = 220°$.

1. Draw the waveforms V_S, V_o, i_o, V_{sw} for two cycles, in a common time scale. [3 marks]
2. Derive an expression for the instantaneous load current (i_o) of this circuit. You may modify the equation provided at the end of this question. Verify that the conduction angle is within the controllable limits. [2 marks]
3. Using the expression, you have obtained above, determine the following.
   a. rms load current.
   b. rms SCR current.
   c. Average SCR current.
   d. Active power delivered to the load.
   e. Power factor.

[1 x 5 = 5 marks]

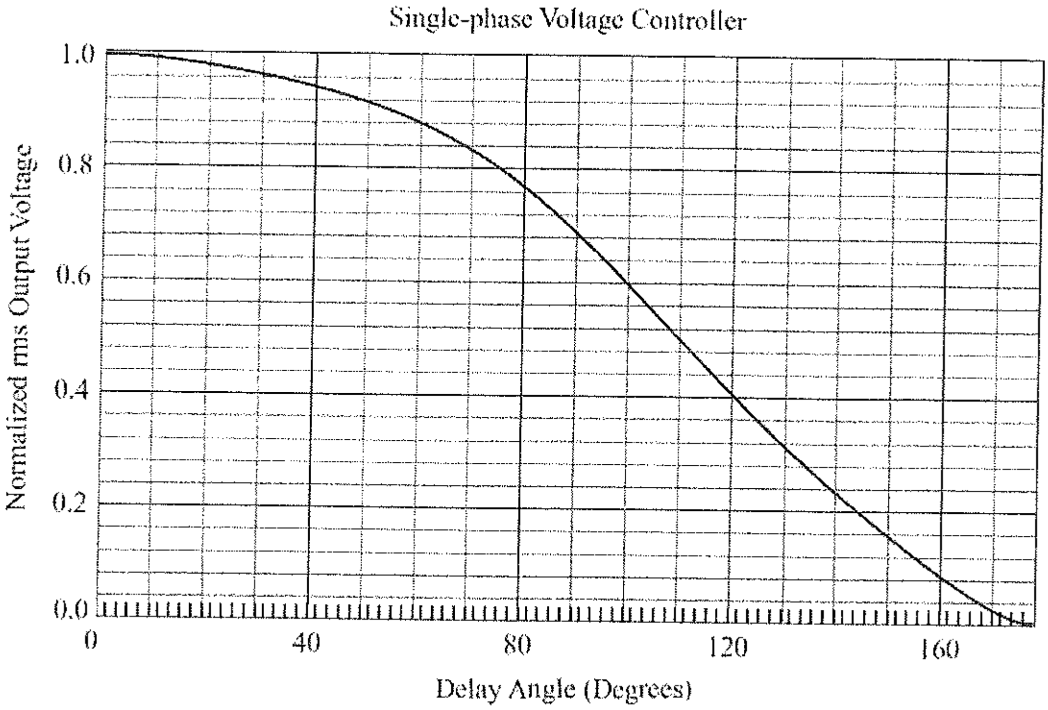

Figure 3: Normalised Delay Angle Amplitude Curve

$$i_o(\omega t) = \frac{V_m}{Z}\left[\sin(\omega t - \theta) - \sin(\alpha - \theta)\,.\,e^{\left(\frac{\alpha - \omega t}{\omega \tau}\right)}\right]; for\ \alpha \leq \omega t \leq \beta$$

All the symbols have conventional meanings.