UNIVERSITI TEKNOLOGI PETRONAS

FINAL EXAMINATION
JANUARY 2025 SEMESTER

COURSE	**:**	**EEB3033/EFB3033 - POWER ELECTRONICS**
DATE	**:**	**19 APRIL 2025 (SATURDAY)**
TIME	**:**	**9.00 AM - 12.00 NOON (3 HOURS)**

INSTRUCTIONS TO CANDIDATES

1. Answer **ALL** questions in the Answer Booklet.
2. Begin **EACH** answer on a new page in the Answer Booklet.
3. Indicate clearly answers that are cancelled, if any.
4. Where applicable, show clearly steps taken in arriving at the solutions and indicate **ALL** assumptions, if any.
5. **DO NOT** open this Question Booklet until instructed.

Note :

i. There are **EIGHT (8)** pages in this Question Booklet including the cover page and appendix.

ii. **DOUBLE-SIDED** Question Booklet.

1. A power electronics engineer is tasked with selecting an appropriate switching device for a high-frequency, high-power converter application.

a. Explain the switching characteristics for power semiconductor devices (MOSFET, IGBT, SCR) with respect to switching speed, conduction losses, voltage handling capability, and suitability for high-frequency applications.

[6 marks]

b. Using the characteristics explained in **part (a)**, outline the most suitable for the high-frequency, high-power converter application. Support your answer with appropriate reasoning.

[4 marks]

c. A large industrial manufacturing plant requires a precise and controlled DC power source to operate a heavy-duty industrial motor. To achieve this, a three-phase fully controlled full-wave rectifier is used to convert 410-V_{RMS} L-L, 50 Hz into a variable DC output voltage that can be adjusted by controlling the delay angle, α, as shown in **FIGURE Q1.**

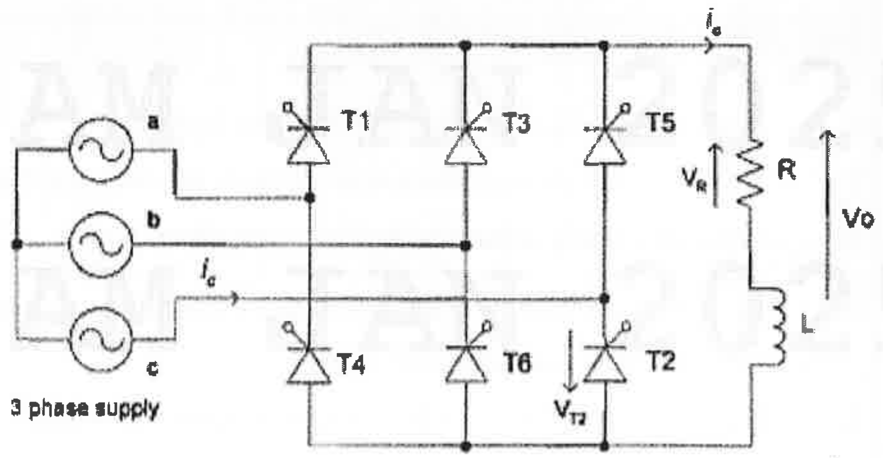

FIGURE Q1: Three Phase Diode Rectifier

The load consists of an industrial DC motor, modelled as a series R-L circuit with $R = 10\,\Omega$ and $L = 85\ mH$. Assume the phase sequence is *abc*, and the output current is ripple-free.

i. If the rectifier operates at a delay angle of $\alpha = 45°$, determine the average output DC voltage, V_o, supplied to the motor. Identify the effects of increasing the delay angle on the motor's performance, particularly in terms of torque, speed, and power delivery.

[8 marks]

ii. Sketch the dc output voltage, V_o, the current across the thyristor T_1 to T_4, and the phase current and the phase voltage of 'phase c'.

[7 marks]

2. DC-DC converters are essential in renewable energy systems, where efficient voltage regulation ensures proper energy storage and power conversion. Your task is to design, analyse, and evaluate DC-DC converter circuits for two different renewable energy applications, ensuring appropriate voltage regulation, efficiency, and continuous operation under the given specifications.

a. A renewable energy system requires a DC-DC converter to regulate power delivery to a storage system with the following specifications:

$$V_{in} = 75\text{ V},\ V_o = 24\text{ V},\ P_{load} = 130\text{ W},\ f_s = 96\text{ kHz},$$
$$\Delta I_o/I_o \text{ to} \leq 3\ \%\text{ and } \Delta V_o/V_o \text{ to} \leq 1\ \%$$

With the aid of a diagram, analyse the DC-DC converter circuit to meet the given specifications to indicate converter in Continuous Conduction Mode (CCM) by performing relevant calculations.

[13 marks]

b. A different renewable energy system requires a DC-DC converter to efficiently convert power from an energy storage source under the following conditions:

$$V_{in} = 20\text{ V},\ V_o = 48\text{ V},\ P_{load} = 75\text{ W},\ f_s = 84\text{ kHz},\ I_{in,max} = 6\text{ A, and}$$
$$\Delta V_o/V_o \text{ to } 5\ \%$$

With the aid of a diagram, design and evaluate the DC-DC converter circuit that meets the given specifications. Justify the given specifications to indicate converter in Continuous Conduction Mode (CCM) by performing relevant calculations.

[12 marks]

3. Engineers must analyse the performance of inverters under different operating conditions and evaluate critical design parameters to ensure reliability and efficiency.

   a. A half-bridge inverter is used in an industrial power system, where the circuit consists of the following parameters:

$$V_{dc} = 408 \text{ V},\ R = 6\ ,\ f_s = 60 \text{ Hz},\ L = 20 \text{ mH}$$

   Consider the half-bridge inverter as shown in **FIGURE Q3** where the system operates with a lagging power factor due to the inductive load.

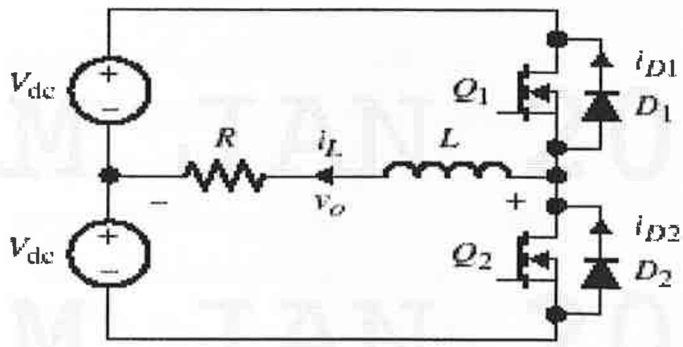

FIGURE Q3: Half-Bridge Inverter

   i. Solve for the average diode and transistor currents, the average power delivered to the load, and the ripple current. Show all relevant calculations and illustrate the relationships between these parameters.

[12 marks]

   ii. Analyse the differences between Voltage Source Inverters (VSI) and Current Source Inverters (CSI) in terms of their operating principles, load dependence, and commutation requirements. Include how these differences impact their applications in motor drives and renewable energy systems.

[8 marks]

   b. Distinguish the role of dead-time implementation in inverters, including its impact on switching performance, efficiency, and overall system reliability.

[5 marks]

4. In power electronics, snubber circuits and soft-switching techniques such as Zero-Voltage Switching (ZVS) and Zero-Current Switching (ZCS) are essential in applications like converters, inverters, and motor drives.

   a. Compare the benefits and limitations of implementing Zero-Voltage Switching (ZVS) and Zero-Current Switching (ZCS) in a high-frequency inverter used for motor drives on complexity, system performance, thermal management, and switching losses, providing a comparative analysis of both techniques.

   [8 marks]

   b. As an engineer, you are required to design a ZCS-QRC boost converter DC-DC converter having the specifications as follows: Input voltage, $V_{in} = 10\ V$, output power, $P_o = 30\ W$, nominal switching frequency, $f_{ns} = 0.52$, switching frequency, $f_s = 250\ kHz$ and output ripple voltage level, $\Delta V_o/V_o$ is expected to be $5\ \%$. It is also determined that the duty ratio, $D = 0.7$. You are also given a diagram of control characteristics curve, M vs nominal switching frequency, f_{ns} for your reference as shown in **FIGURE Q4**. With the aid of diagram, sketch and indicate all the computed parameter values on the converter.

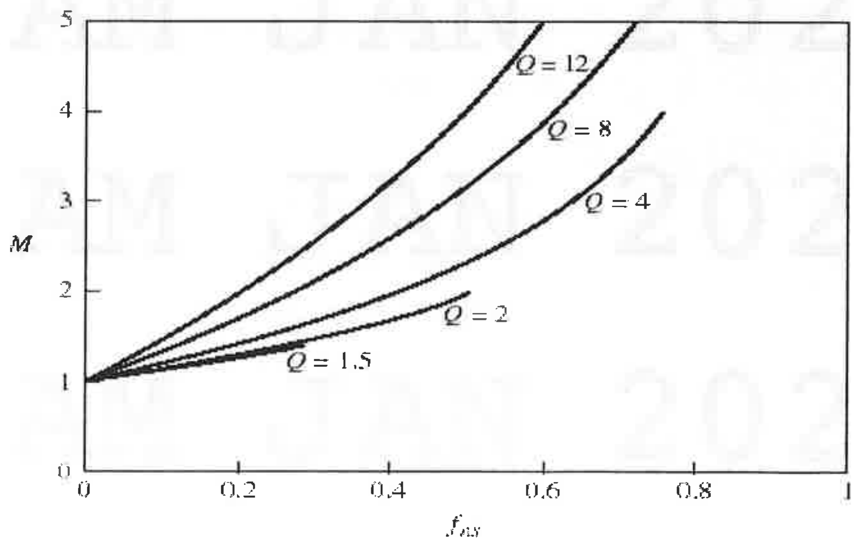

FIGURE Q4: M Vs F_{ns} Control Characteristics Curve

[17 marks]

-END OF PAPER-

APPENDIX

$C_{in} = \frac{\Delta Q}{\Delta V}$	$V_{gs} = V_p \times (1 - e^{-\frac{t}{RC_{in}}})$	$\Delta Q_g = i_g \times t_{fv}$
$I_{no} = \frac{\omega \times L_s \times I_o}{V_s}$	$\omega_0 = \frac{1}{\sqrt{L \times C}}$	$Q_0 = \frac{R_o}{\sqrt{\frac{L}{C}}}$

$I_{avg} = 2\frac{I_p}{\pi}$	$I_{avg} = \frac{I_p}{2\pi}\int_{\theta_1}^{\theta_2} \sin(x)dx$
$k = \frac{T_0}{T}$	$k = 1 - \frac{t_1}{T}$
$V_o = \frac{V_s}{\pi}$	$V_{rms} = \frac{V_s}{2}$
$V_o = \frac{V_s}{2\pi}(1 - \cos \omega t_2)$	$\lvert Z \rvert = \sqrt{(\omega L)^2 + R^2}$
$\tau = L/R$	$\theta = \tan^{-1}\frac{\omega L}{R}$
$I_1 = \frac{V_s}{\lvert Z \rvert}\sin\theta \frac{1 + e^{-T/2\tau}}{1 - e^{-T/\tau}}$	$i_{o1}(t) = \frac{V_s}{\lvert Z \rvert}\sin(\omega t - \theta) + I_1 e^{-t/\tau}$
$i_{o1}(t) = \frac{V_s}{\lvert Z \rvert}\sin(\omega t - \theta) + I_2 e^{\frac{t-T/2}{\tau}}$	$I_{RF} = (i_{max} - i_{min})/I_0$
$FF = \frac{V_{rms}}{V_s}$	$RF = \frac{V_{ac}}{V_{dc}} = \sqrt{FF^2 - 1}$
$V_{dc} = \frac{3\sqrt{3}V_m}{\pi}\cos\alpha$	$\frac{V_o}{V_{in}} = \frac{I_{in}}{I_o} = D$
$P = IV = I^2R = \frac{V^2}{R}$	$L_{crit} = (\frac{1-D}{2})TR$
$\Delta I_L = \Delta I_o = \frac{1}{L}[V_{in}T(1-D)D]$	$\Delta i_L = \frac{V_oT(1-D)}{L}$
$I_{L,min} = DV_{in}\left(\frac{1}{R} - \frac{T(1-D)}{2L}\right)$	$I_{L,max} = DV_{in}\frac{1}{L}[T(1-D)]$
$\Delta V_c = \Delta V_o = \frac{I_o(1-D)}{f_sC}$	$\Delta V_o = \frac{I_o(1-D)}{f_sC}$
$\frac{\Delta V_o}{V_o} = \frac{1-D}{8LCf^2}$	$D = 1 - \frac{V_o}{V_{in}}$
$\Delta I_L = \frac{V_oDT(1-D)}{L} = \frac{(1-D)V_{in}T}{L}$	$L_{crit} = \left(\frac{RT}{2}\right)(1-D)^2D$
$M = \frac{V_o}{V_{in}}$	$f_o = \frac{f_s}{f_{ns}}$

$Q = \frac{R_o}{Z}$	$Lr = \frac{Z_o}{2\pi f_o}$
$Cr = \frac{1}{Z_o \omega_o}$	$\frac{\Delta v_o}{V_0} = \frac{D}{f_s R_0 C_0}$
$Z = \sqrt{(\omega L)^2 + R^2}$	$\theta = tan^{-1} \frac{\omega L}{R}$
$I_{Q,avg} = \frac{I_{o1}}{2\pi}(1 + \cos\theta)$	$I_{D,avg} = \frac{I_{o1}}{2\pi}(1 - \cos\theta)$
$P_{o,avg} = \frac{2V_{dc}{}^2}{\pi^2 \lvert Z \rvert} \cos\theta$	$I_{o1} = \frac{2V_{dc}}{\pi \lvert Z \rvert}$
$V_{o1} = \frac{2V_{dc}}{\pi}$	$I_{in,rip} = \frac{\sqrt{2}V_{dc}}{\pi \lvert Z \rvert}$