**EEE4117F QUIZ 1** **TOTAL MARKS: 30**
**DATE: 8 MAY 2020** **TIME: 1 HOUR**

## PART A: MACHINES Marks: 15

### QUESTION 1 [4 MARKS]

State the three main factors you would consider when matching a power electronics converter to a motor and explain how the motor current ripple can be reduced. **[4]**

### QUESTION 2 [11 MARKS]

A **3-phase** AC motor equipped with a flywheel which operates at a constant speed of $1000\ rpm$ (shown in **Fig. 1**), is to supply a constant load torque of $1000\ Nm$ for 10 secs, followed by a light load period of $200\ Nm$ which lasts for 20 secs. After this period, the motor runs to a standstill for another 10 secs. This cycle of operation is repeated for another period of 40 secs. Answer the following:

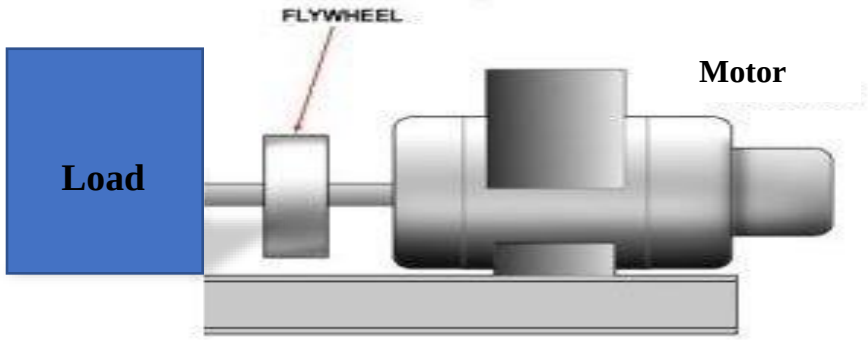



**Fig. 1**

1.1. Draw the torque profile of the motor-load system, showing the three regions of operation. **[4]**

1.2. Calculate the RMS torque of the motor and its approximate power rating. **[3]**

1.3. Calculate the average resistive power loss ($P_{CU}$) and the total power loss ($P_{loss}$), if the rotational loss ($P_{rot}$) is approximately $10\%$ of the power rating of the motor. The RMS torque and current of the motor is related by a constant $k = 4\ Nm/A$, and the winding resistance of the motor, $R_m = 0.267\Omega/$ phase. **[4]**

## PART B: POWER ELECTRONICS Marks: 15

### QUESTION 1 [10 MARKS]

**Fig. 2** shows a simple transistor switch used to connect a 24 V DC supply across a relay coil (inductor), which has a DC resistance of 200Ω. An input pulse of 0 to 5V amplitude is applied through a series base resistor $R_B$ at the base to turn on and off the transistor switch. Saturation voltage of the collector-emitter of the transistor, $V_{CE}(sat)$ = 0.2 V while Saturation voltage of the base-emitter $V_{BE}(sat)$ = 0.7 V. The $\beta$ (dc current gain) of a BJT varies from 25 to 40.

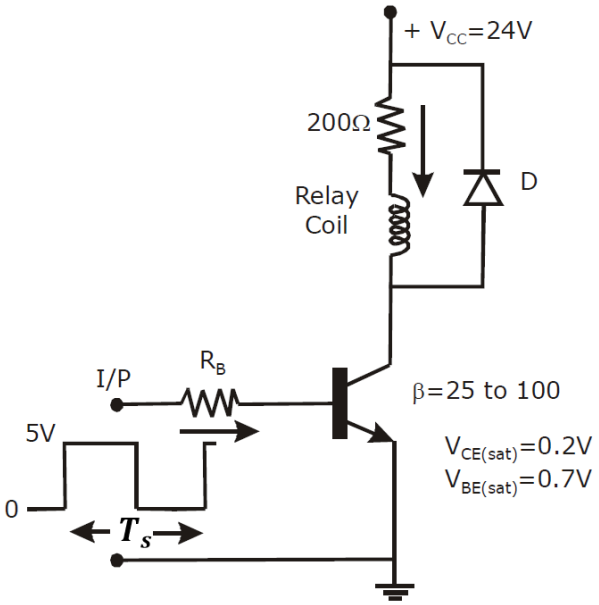



**Fig. 2**

1.1 What is the function of diode *D* in the operation of the circuit shown in **Fig. 2**? **[1]**

1.2. Sketch the device current (or collector current) waveform with reference to the input pulse for a single switching period ($T_s$). **[2]**

1.3 Sketch the general input characteristics curve of a bipolar junction transistor? **[1]**

1.4. Calculate the collector saturation current ($I_{C(sat)}$). **[1]**

1.5. Calculate the value of resistor ($R_b$), required to obtain over drive factor of three. **[3]**

1.6. Total power dissipation in the transistor that occurs during the ON state. **[2]**

**QUESTION 2 [5 MARKS]**

Assume that the **Fig. 3** shows the harmonics magnitude spectrum of the supply current ($i_s$) of a diode rectifier converter, where *h* is the harmonic number. $I_{sh}$ is rms current of the harmonic *h* and $I_{s1}$ is the rms current of the fundamental component.

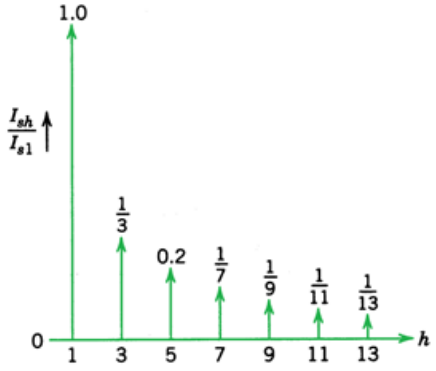



**Fig. 3**

2.1. Determine the total harmonic distortion, THD of supply current ($i_s$). **[3]**

2.2. Determine the power factor of the converter if the displacement power factor of the converter is 1. **[2]**

# SOLUTIONS

**QUESTION 1 [4 MARKS]**

State the three main factors you would consider when matching a power electronics converter to a motor and explain how the motor current ripple can be reduced. **[4]**

**Ans:**

The main considerations in matching the power electronic converter to the motor are: [3]

1. Current rating
2. Voltage rating
3. Switching frequency / motor inductance

The motor current ripple can be reduced by increasing the switching frequency of the converter or by increasing the size of the motor inductance. [1]

## QUESTION 2 [11 MARKS]

A **3-phase** AC motor equipped with a flywheel which operates at a constant speed of 1000 $rpm$ (shown in **Fig. 1**), is to supply a constant load torque of 1000 $Nm$ for 10 secs, followed by a light load period of 200 $Nm$ which lasts for 20 secs. After this period, the motor runs to a standstill for another 10 secs. This cycle of operation is repeated for another period of 40 secs. Answer the following:

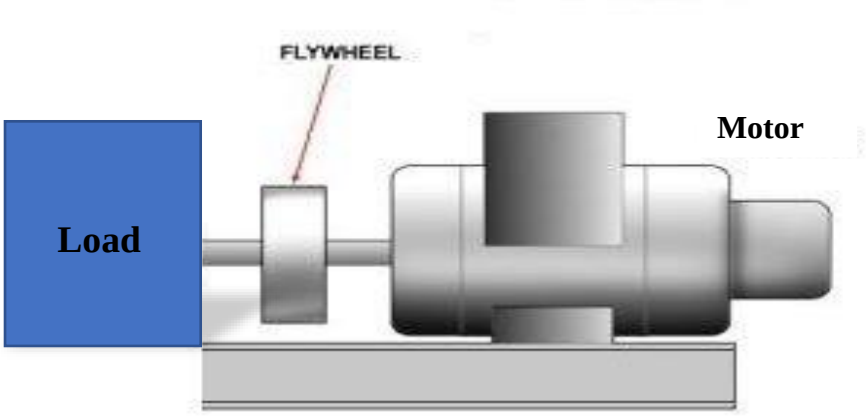
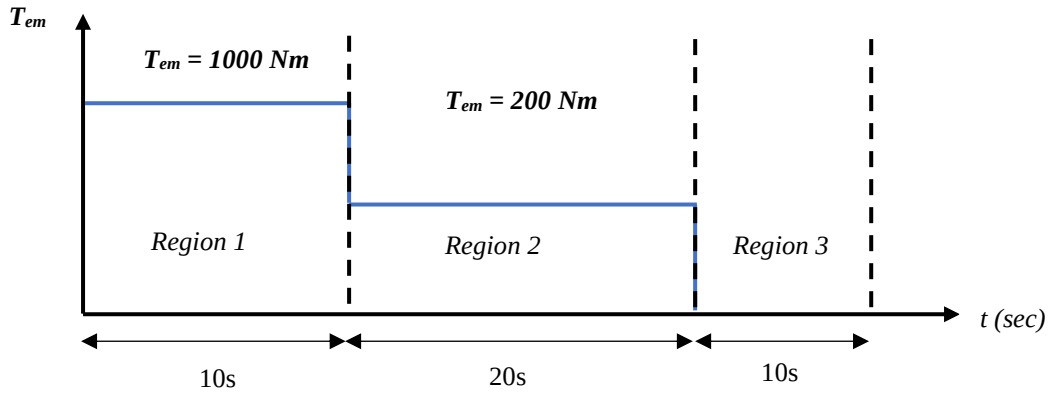



**Fig. 1**

1.1. Draw the torque profile of the motor-load system, showing the three regions of operation. **[4]**

**Ans:**




**[4]**

1.2. Calculate the RMS torque of the motor and its approximate power rating. **[3]**

**Ans:**

$$T_{rms} = \sqrt{\frac{T_1^2 \cdot t_1 + T_2^2 \cdot t_2 + T_3^2 \cdot t_3}{t_1 + t_2 + t_3}} = \sqrt{\frac{1000^2 \cdot 10 + 200^2 \cdot 20 + 0^2 \cdot 10}{10 + 20 + 10}} = \mathbf{519.6\ Nm}$$ [2]

$$P_{rating} = T_{rms} \cdot \omega = 519.6 \times \left(1000 \times \frac{2\pi}{60}\right) = 54.4\ kW$$ [1]

1.3. Calculate the average resistive power loss ($P_{CU}$) and the total power loss ($P_{loss}$), if the rotational loss ($P_{rot}$) is approximately 10% of the power rating of the motor. The RMS torque and current of the motor is related by a constant $k = 4\ Nm/A$, and the winding resistance of the motor, $R_m = 0.267\Omega$/ phase. **[4]**

**Ans:**

$$I_{rms} = \frac{T_{rms}}{k} = \frac{519.6}{4} = 129.9\ A$$ [1]

$$P_{CU} = 3 \cdot I_{rms}^2 \cdot R_m = 3 \cdot 129.9^2 \cdot 0.267 = 13516.1\ W$$ [1]

$$P_{rot} = 0.1 \times 54400 = 5440\ W$$ [1]

$$P_{loss} = P_{CU} + P_{rot} = 13516.1 + 5440 = 18956.1\ W$$ [1]

## PART B: POWER ELECTRONICS Marks: 15

### QUESTION 1 [10 MARKS]

**Fig. 2** shows a simple transistor switch used to connect a 24 V DC supply across a relay coil (inductor), which has a DC resistance of 200Ω. An input pulse of 0 to 5V amplitude is applied through series base resistor $R_B$ at the base to turn on and off the transistor switch. Saturation voltage of the collector-emitter of the transistor, $V_{CE}$(sat) =0.2 V, Saturation voltage of the base-emitter $V_{BE}$(sat) =0.7 V. The $\beta$ (dc current gain) of a BJT varies from 25 to 40.

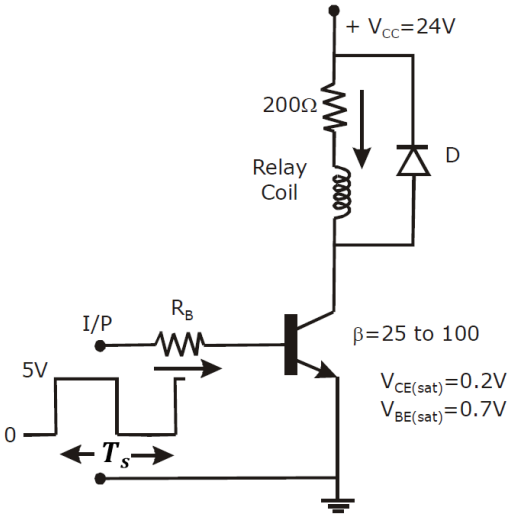


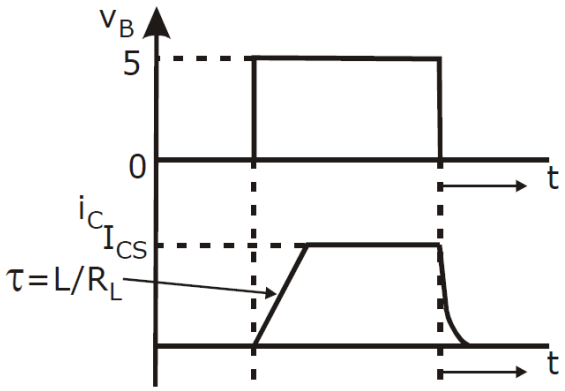

**Fig. 1**

1.2 What is the function of diode *D* in the operation of the circuit shown in **Fig. 2**? **[1]**

Ans: The transistor allows currents in one direction when switched ON. During the transistor's switch-off state, the current through the coil will circulate through the diode (or discharging of the inductor)

1.2. Sketch the device current (or collector current) waveform with reference to the input pulse for a single switching period ($T_s$). **[2]**

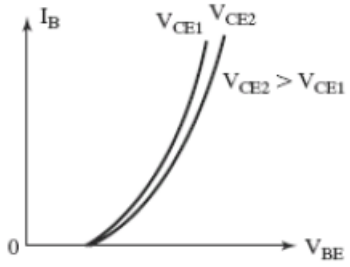
**Ans:**




[1] mark each for identifying the two slopes (delay in current rise and delay in current fall)

1.3 Sketch the general input characteristics curve of a bipolar junction transistor? **[1]**

**Ans:**




Input Characteristics

**One** $V_{CE}$ curve is acceptable.

1.4. Calculate the collector saturation current ($I_{C(sat)}$). **[1]**

**Ans:**

$I_{C(sat)}= \frac{V_{CC}-V_{CE(sat)}}{R_C} = \frac{24-0.2}{200} = 0.119\ A$ [1]

1.5. Calculate the value of resistor ($R_b$), required to obtain over drive factor of three. **[3]**

**Ans:**

$I_{B(sat)} = \frac{I_{C(sat)}}{\beta_{min}} = \frac{0.119}{25} = 4.76\ mA$ [1]

$I_B = ODF\ x I_{B(sat)} = 3\ x\ 4.76 = 14.28\ mA$ [1]

$R_B = \frac{V_B - V_{BE(sat)}}{I_B} = \frac{5-0.7}{14.28} = 301.11\Omega$ [1]

1.6. Total power dissipation in the transistor that occurs during the ON state. **[2]**

**Ans:**

$P_T = V_{BE(sat)} x I_B + V_{CE(sat)} x I_{C(sat)}$ [1]

$P_T = 0.7x14.28 + 0.2x0.119 = 0.0338\text{W}$ [1]

**QUESTION 2 [5 MARKS]**

Assume that the **Fig. 3** shows the harmonics magnitude spectrum of the supply current ($i_s$) of a diode rectifier converter, where $h$ is the harmonic number. $I_{sh}$ is rms current of the harmonic $h$ and $I_{s1}$ is the rms current of the fundamental component.

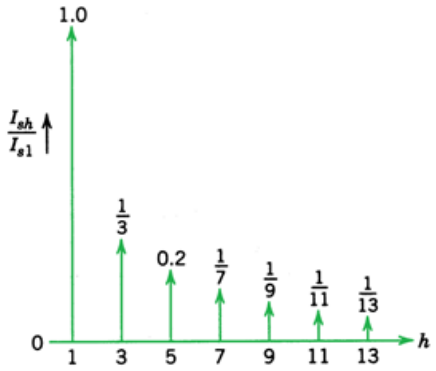



**Fig. 2**

2.1. Determine the total harmonic distortion, THD of supply current ($i_s$). **[3]**

**Ans:.**

$h=3$

$$\left(\frac{I_{S3}}{I_{S1}}\right) = \left(\frac{1}{3}\right)$$

$h=5$

$$\left(\frac{I_{S5}}{I_{S1}}\right) = 0.2$$

$h=7$

$$\left(\frac{I_{S7}}{I_{S1}}\right) = 1/7$$

$h=9$

$$\left(\frac{I_{S9}}{I_{S1}}\right) = 1/9$$

$h=11$

$$\left(\frac{I_{S11}}{I_{S1}}\right) = 1/11$$

$h=13$

$$\left(\frac{I_{S11}}{I_{S1}}\right) = 1/13$$

$$THD = \sqrt{\left(\frac{I_{S3}}{I_{S1}}\right)^2 + \left(\frac{I_{S5}}{I_{S1}}\right)^2 + \left(\frac{I_{S7}}{I_{S1}}\right)^2 + \left(\frac{I_{S9}}{I_{S1}}\right)^2} * 100\% \quad \textbf{[2]}$$

$$THD = \sqrt{\left(\frac{1}{3}\right)^2 + (0.2)^2 + \left(\frac{1}{7}\right)^2 + \left(\frac{1}{9}\right)^2 + \left(\frac{1}{11}\right)^2 + \left(\frac{1}{13}\right)^2} * 100\%$$

$$THD = 44.50\% \quad \textbf{[1]}$$

2.2. Determine the power factor of the converter if the displacement power factor of the converter is 1. **[2]**

**Ans:**

$$PF = \frac{1}{\sqrt{1+THD_i^2}} DPF \quad [1]$$

$$\mathrm{PF} = \frac{1}{\sqrt{1+0.4450^2}}(1) = 0.9136 \qquad [1]$$