UNIVERSITY OF JOHANNESBURG

PROGRAM	:	BACCALAUREUS TECHNOLOGIAE *ENGINEERING: ELECTRICAL*
SUBJECT	:	**POWER ELECTRONICS IV**
CODE	:	**EEP 411**
DATE	:	MID-YEAR EXAMINATION – **MAIN EXAM** JUNE 5TH 2018 at 12:30pm
DURATION	:	3 hours
WEIGHT	:	40 : 60
TOTAL MARKS	:	**140**
FULL MARKS	:	**100%**

EXAMINER	:	Dr. KA Ogudo
MODERATOR	:	Prof. AA Yusuff
NUMBER OF PAGES	:	5 PAGES AND 2 ANNEXURE

INSTRUCTIONS	:	ANSWER ALL QUESTIONS NEATLY.
	:	ONE NON-PROGRAMMABLE CALCULATOR PER CANDIDATE.
REQUIREMENTS	:	AT MOST: TWO ANSWER SHEETS PER CANDIDATE.

QUESTION 1 (Power & Energy) [16]

Voltage and current waveforms across a device is shown in the figure 1, determine:

1.1 The energy absorbed by the device in one period (W_e). (4)
1.2 The average power absorbed by the device in one period. (4)
1.3 The rms voltage across the device. (3)
1.4 The rms current through the device. (3)
1.5 The power factor of the device. (2)

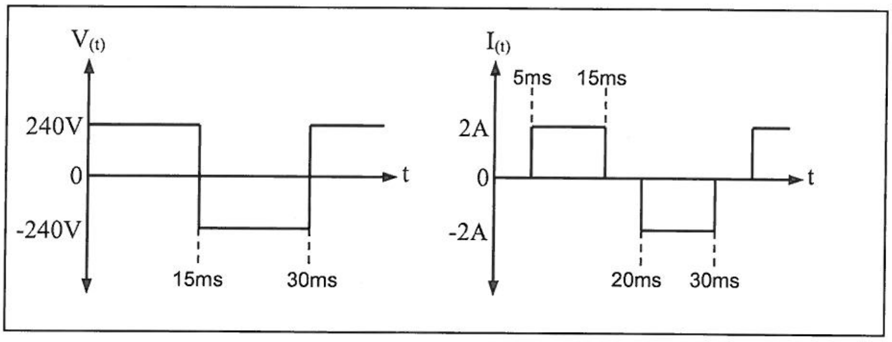

Figure 1

QUESTION 2 (DC-DC converter) [16]

A circuit diagram of DC-DC converter shown in figure 2 has a resistive load of 10 Ω with an average voltage of 24V measured across the resistor. The converter switch has a volt drop of V_{ch} = 0.7 V when conducting. If the chopping frequency is 10 kHz and the duty cycle is set to 25 %:

2.1 Determine the peak input current (I_{i-pk}) provided by the input voltage. (4)
2.2 Analyze and find the average input current (I_{i-ave}). (2)
2.3 Evaluate the equivalent input resistance (R_{i-eq}). (2)
2.4 Calculate the converter efficiency (η). (3)
2.5 Now, consider that the duty cycle varies between 25 % and 50 %. The output resistance is 10 Ω, the input voltage is 48 V and same chopper voltage drop of 0.7 V. Analyze and calculate the range of the average output current (I_{o-ave}) (5)

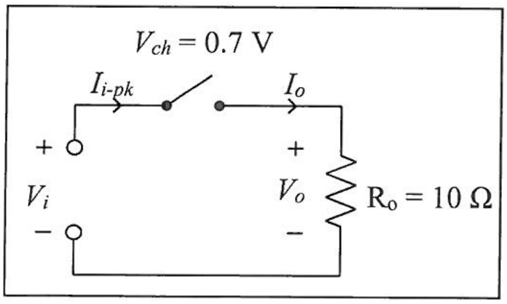

Figure 2

QUESTION 3 (Chopper converter) [16]

A step-down converter has a resistive load of 4.7 Ω with a peak input current of 9 A. The converter switch has a volt drop of 0.7 V when conducting. If the chopping frequency is 3 kHz and the duty cycle is set to 50%, determine:

3.1 The average voltage across the load resistor. (3)
3.2 The peak input voltage. (3)
3.3 The peak input and output power. (4)
3.4 The average input and output power. (4)
3.5 The converter efficiency. (2)

QUESTION 4 (Separately excited controlled motor by 3ø full-converter) [27]

The armature current of a separately excited motor is controlled by a three-phase full-converter with a 525 V/50 Hz source. A three-phase semi-converter (set to the maximum possible output) using the same source controls the field current. The armature resistance is R_a = 0.2 Ω, the field resistance is R_f = 200 Ω, and the motor voltage constant is K_v = 0.68 V/A-rad/sec. The load torque is T_L = 180 N·m at 1200 rpm. The viscous friction and no-load losses are negligible. The inductances of the armature and field circuits are large enough to make the armature and field currents continuous and ripple-free.

4.1 Evaluate the field current (I_f). (3)
4.2 Analyse and find the armature current (I_a). (3)
4.3 Evaluate the armature DC voltage (V_a). (3)
4.4 Analyse and determine the armature delay angle (α_a). (2)
4.5 Evaluate the true power delivered by the armature converter ($P_{a\text{-}rms}$). (4)
4.6 Analyse and find the rms current drawn by the armature converter (I_{sa}). (2)
4.7 Evaluate the true power delivered by the field converter ($P_{f\text{-}rms}$). (3)
4.8 Analyse and find the rms current drawn by the field converter (I_{sf}). (2)
4.9 Calculate the current drawn by this DC drive from the three-phase supply. (2)
4.10 Determine the power factor of the drive (PF). (3)

QUESTION 5 (Boost regulators) [22]

Consider a **boost** regulator and the measured waveforms in figure 3.

5.1 Draw the diagram of the boost regulator. (5)

5.2 Find the duty cycle (K). (3)

5.3 Determine the average output voltage (V_o). (3)

5.4 Calculate the average input current (I_s). (3)

5.5 Evaluate the values of the inductor (L). (4)

5.6 Find the capacitor (***C***). (3)

5.7 Calculate the resistive load (***R***). (1)

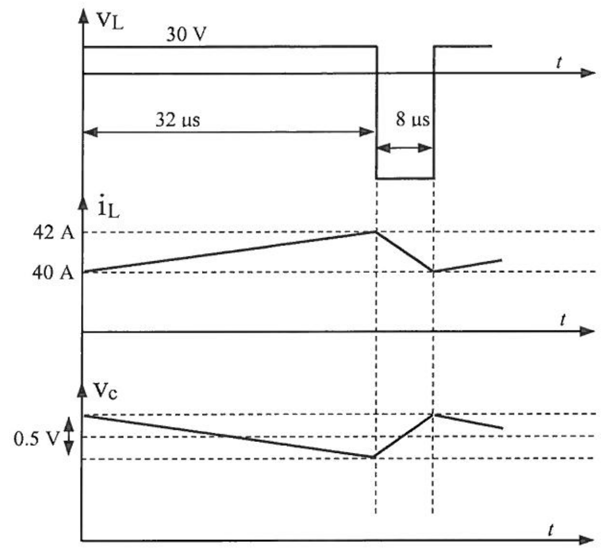

Figure 3

QUESTION 6 (Single face full-wave converter) [10]

The speed of a separately excited dc motor is controlled by a single phase full-wave converter. The field circuit is also controlled by a full converter and the field current is set to the maximum possible value. The AC supply to the armature and field converters is 240 V, 50 Hz. The armature resistance is 0.25 Ω, the field resistance is 175 Ω and the motor voltage constant is 1.4 V/A rad/s. The armature current corresponding to the current load demand is 25 A. The viscous friction and no-load losses are negligible. The inductance of the armature and field are sufficient to ensure ripple free continuous current. If the delay angle of the armature converter is set to 40° determine:

6.1 The torque developed by the motor. (4)

6.2 The actual speed of the motor in revelation per minute (rpm.) (6)

QUESTION 7 (Silicon control rectifier) [12]

An SCR operating from a sinusoidal ac mains supply ($V_s = 230$ V) with a resistive load of 2.7 Ω is fired at an angle $\boldsymbol{\alpha}$ so that the peak value of the load current is 85 A and the average value of the load current is 20 A. Calculate:

7.1 The firing angle α. (4)

7.2 The rms value of the load current, show derivation steps. (4)

7.3 The average power absorbed by the load. (2)

7.4 The power factor of the circuit. (2)

QUESTION 8 (Separately excited DC motor control systems) [21]

The control system block diagram of a separately excited DC motor is given in the figure 4. The separately excited DC motor develops an output power of 55 kW at 3000 rpm with a constant field current I_f = 1.6 A. The armature resistance is 0.32 Ω and the machine voltage constant is k_v = 0.76 V/A-rad/s. The viscous friction of the bearings and load is calculated to be approximately B = 0.56 N·m/rad/s. The speed sensor "K_1" amplification is 120 mV/rad/s and the power control "K_2" gain is 100.

8.1 Derive the steady state transfer function of the change in speed due to a step change in the applied reference voltage "Vr". (3)

8.2 Create the closed-loop block diagram for "T_L" step change input. (4)

8.3 Derive the steady state transfer function of the change in speed due to a step change in the applied load torque "T_L". (3)

8.4 If the load torque applied is T_L = 150 N·m and the reference voltage is set to 12.5V, evaluate the DC motor output rpm speed. (3)

8.5 For the same load and reference voltage setting, determine the armature current. (4)

8.6 Evaluate the efficiency of this DC motor drive control system? (4)

(Hint: The block diagram of the DC motor control system was built based on the basic equations of the motor written in Laplace where "p" is the Laplace operator.)

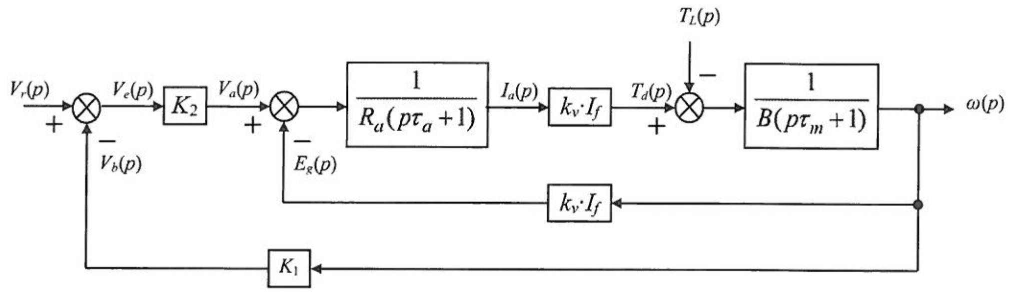

Figure 4

TOTAL MARK: 140
FULL MARK=100%

EEP411 FORMULA SHEET

$$W = \int_{t_1}^{t_2} p(t)dt$$

$$P_{ave} = \frac{1}{T}\int_{t_o}^{t_o+T} v(t)i(t)dt$$

$$\theta_J = P_D\left(R_{JC} + R_{CS} + R_{SA}\right) + \theta_A$$

$$R_{eq} = \frac{V_s}{I_a}(1-K) + R_m$$

$$V_{rms} = \sqrt{\frac{1}{T}\int_0^T v^2(t)dt}$$

$$I_{b-ave} = I_{a-pk}(1-k)$$

$$I_{L-max} = V_i \cdot K\left[\frac{1}{R_o(1-K)^2} + \frac{T}{2L}\right]$$

$$I_{Cmax} = \frac{N_s}{N_p}I_{L1} + \frac{V_p \cdot K \cdot T}{L_p}$$

$$I_{o-ave} = K \cdot I_{s-pk}$$

$$R_{eq} = \frac{V_s}{K \cdot I_{a-ave}}$$

$$T_d = K_t I_f I_a$$

$$P_{o-ave} = V_{o-ave} I_{s-pk}$$

$$V_{dc} = \frac{3\sqrt{2}V_L}{\pi}\cos\alpha$$

$$V_{dc} = \frac{2V_m}{\pi}\cos\alpha$$

$$Q_{gt} = C_{gt}V_{gs}$$

$$V_{o-rms} = \sqrt{K} \cdot V_{s-pk}$$

$$V_{o-ave} = K \cdot V_{s-pk}$$

$$V_{b-ave} = I_{a-pk}(1-K)R_b$$

$$T_d = B \cdot \omega + T_L$$

$$P_d = E_g \cdot I_a$$

$$R_s = R_o / K$$

$$Q_{gt} = I_{gq}T_{gq}$$

$$I_{c-ave} = K \cdot I_{ipk}$$

$$V_{dc} = \frac{3\sqrt{2}V_L}{2\pi}(1+\cos\alpha)$$

$$V_{dc} = \frac{2V_m}{\pi}(1+\cos\alpha)$$

$$I_{ch-ave} = K \cdot I_{apk}$$

$$\Delta I_L = \frac{V_{i-ave} \cdot K}{f \cdot L}$$

$$P_{o-ave} = V_{s-pk} I_{o-ave}$$

$$P_{Lp} = \frac{\left(V_p \cdot K\right)^2}{2f \cdot L_p}$$

$$I_{c-max} \geq \frac{2P_{Lp}}{V_p \cdot K}$$

$$\frac{I_{i-pk}}{I_{o-ave}} = \frac{V_{o-ave}}{V_{i-pk}} = \frac{K}{1-K}$$

$$V_{ce-off} \geq 2V_{i-max}$$

$$L_{crit} = \frac{R_o(1-K)^2}{2f}$$

$$P_b = I_{a-pk}^2(1-K)R_b$$

$$K_{max} = \frac{1}{1 + N_r / N_p}$$

$$P_{ch} = V_{ch-on} \cdot I_{a-pk} \cdot K$$

$$I_{p-pk} = \frac{V_p \cdot K}{f \cdot L_p}$$

$$V_o = K \cdot V_s$$

$$I_{o-rms} = \sqrt{K} \cdot I_{s-pk}$$

$$I_{c-max} \geq I_{i-pk}$$

$$E_g = K_v \cdot \omega \cdot I_f$$

$$C_{crit} = \frac{(1-K)}{16Lf^2}$$

$$\Delta V_c = \frac{K \cdot V_{o-ave}}{R_o \cdot C \cdot f}$$

$$f = \frac{1}{2 \cdot R \cdot C \cdot ln(3)}$$

$$V_f = R_f \cdot I_f$$

$$I_{s-ave} = K \cdot I_{a-ave}$$

$$P_g = I_a V_s (1-K)$$

$$V_{dc} = \frac{V_m}{2\pi}(1+\cos\alpha)$$

$$V_a = E_g \pm R_a \cdot I_a$$

$$\omega_{min} = \frac{R_m \cdot I_a}{K_v \cdot I_f}$$

$$\Delta I_L = \frac{V_{o-ave}(1-K)K}{f \cdot L}$$

$$R_{eq} = R_b(1-K) + R_m$$

$$P_d = T_d \cdot \omega$$

$$V_{ce-off} \geq 2 \cdot V_{i-max}$$

$$P_d = C_{gt}V_{gs}^2 f$$

$$V_{ch-off} = (1-K)V_s$$

$$m_a = \frac{V_{pk-ref}}{V_{pk-carrier}}$$

$$m_f = \frac{f_{carrier}}{f_{output}}$$

$$V_{o-rms} = V_{dc}\sqrt{\frac{\delta}{\pi}}$$

$$V_n = \frac{4 \cdot V_{dc}}{n \cdot \pi}\sin\left(\frac{n\delta}{2}\right)$$

$$I_{L-min} = V_i \cdot K\left[\frac{1}{R_o(1-K)^2} - \frac{T}{2L}\right]$$

$$I_{dc} = \frac{I_{pk}}{2\pi}(1+\cos\alpha)$$

$$PF = \frac{P_{ave}}{V_{rms}I_{rms}}$$

$$V_{rms-fc} = \sqrt{3}\times V_m \times \sqrt{\frac{1}{2} + \frac{3\times\sqrt{3}\times\cos(2\alpha)}{4\pi}}0$$

$$V_{o-ave} = \frac{V_{s-pk}}{1-K}$$

$$\omega_{max} = \frac{V_s}{K_v \cdot I_f} + \frac{R_m \cdot I_a}{K_v \cdot I_f}$$

$$V_{rms-sc} = \sqrt{3}\times V_m \times \sqrt{\frac{1}{2} + \frac{3\times\sqrt{3}\times\cos^2\alpha}{4\pi}}$$