UNIVERSITY OF JOHANNESBURG

PROGRAM	:	BACCALAUREUS TECHNOLOGIAE *ENGINEERING: ELECTRICAL*
SUBJECT	:	**POWER ELECTRONICS IV**
CODE	:	**EEP 411**
DATE	:	MID YEAR SUPPLEMENTARY EXAMINATION 17 JULY 2014
DURATION	:	08:00- 11:00
WEIGHT	:	40 : 60
TOTAL MARKS	:	100

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MODERATOR	:	PROF. D. NICOLAE	
NUMBER OF PAGES	:	4 PAGES AND 1 ANNEXURES	

INSTRUCTIONS	:	ANSWER ALL QUESTIONS NEATLY. ONE NON-PROGRAMMABLE CALCULATOR PER CANDIDATE.
REQUIREMENTS	:	ONE ANSWER SHEET PER CANDIDATE.

QUESTION 1

1.1 An IRFZ44N power MOSFET is used control the speed of a DC motor as indicated in figure 1. The drain to source voltage turn-on delay is 12ns, the rise time is 60ns, the turn-off delay is 44ns and the fall time is 45ns. The drain to source on-resistance is 17,5mΩ and the leakage current is 25uA. When the power MOSFET is fully on, the voltage across the DC motor is 24V and the average current flowing is 8A. If the switching frequency is 20 kHz and the duty cycle is set to 50%, determine:

1.1.1 Power dissipated by the MOSFET during turn on. (3)
1.1.2 Power dissipated by the MOSFET during turn off. (3)
1.1.3 Power dissipated by the MOSFET during conduction time. (3)
1.1.4 Power dissipated by the MOSFET during non-conduction time. (3)
1.1.5 Total power MOSFET switching losses. (1)
1.1.6 Total MOSFET average power dissipation loss. (1)
1.1.7 Maximum switching frequency if the switching losses allowed is 1W. (3)

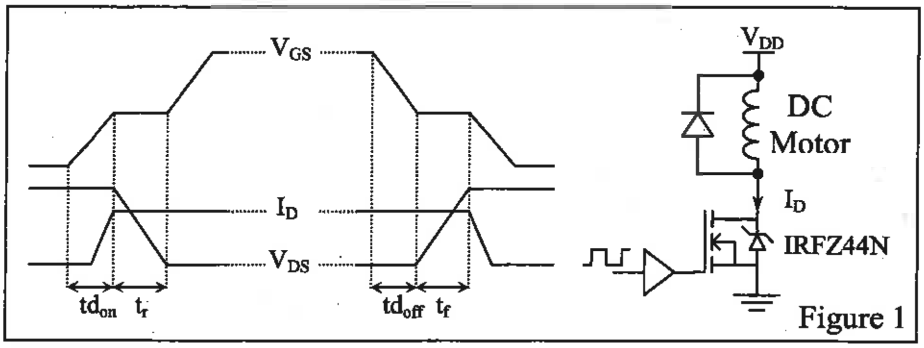

Figure 1

1.2 A 3-phase, 6-pulse, fully controlled bridge rectifier is operated from a 3-phase 380Vrms 50Hz supply. The load is highly inductive and the average load current is 60A with negligible ripple current. If the delay firing angle is set to 60°:

1.2.1 Determine the average output power across the load. (3)
1.2.2 What is the average and peak current through the SCR (tyristors)? (2)
1.2.3 What is the peak inverse voltage across the SCR (tyristors)? (1)
1.2.4 Prove mathematically that the RMS output voltage of the 3-phase, 6-pulse, fully controlled bridge rectifier is given by:

$$V_{RMS} = V_{Lp}\sqrt{\frac{1}{2} + \frac{3\sqrt{3}}{4\Pi} Cos2\alpha}$$

Where α is the delay firing angle and V_{Lp} is peak line to line voltage. (5)

1.2.5 Calculate the value of the RMS voltage across the load? (1)

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QUESTION 2

2.1 A battery powered vehicle is driven by a separately excited DC motor. The armature is connected to a power and rheostatic brake control, two-quadrant DC-DC converter. The field current is constant at 1,7A and machine voltage constant is 100mV/A-rad/s. Initially the motor is driven in power control mode, to a speed of 4000 RPM at a constant armature current of 50A and a duty cycle setting of 70%. The motor is driven by ten 12V batteries connected in series. When power is removed and the motor speed drops to 2000 RPM, it is required to start rheostatic braking of the DC motor. A braking resistor of 2,5Ω is used and the switching losses are negligible.

2.1.1 Sketch the power and rheostatic brake control circuit connected to the separately excited DC motor. (3)

2.1.2 By making use of labeled switches and diodes, explain how the two-quadrant converter operates in the power mode and then in the rheostatic brake mode. (6)

2.1.3 Determine initial duty cycle of the rheostatic brake control switch to maintain a constant average armature current of 20A. (6)

2.2 The armature of a separately excited DC motor is controlled by a three-phase full-converter. The field circuit is controlled by a three-phase semi-converter with a delay angle setting of 80°. A contactor switch is used to reverse the polarity of the field current. The supply to the armature and field converters is 380Vrms, 50Hz line voltage. The armature winding resistance is 0.52Ω, the field winding resistance is 150Ω and the machine voltage constant is 1.84V/A-rad/s. The viscous friction, motor no-load losses and converter losses are negligible. Assume the inductance of the armature and field windings are sufficient to ensure ripple free continuous current. When the delay angle of the armature converter is set to 40° the motor reaches a constant speed of 880 RPM.

2.2.1 Sketch the drive circuit diagram. (2)

2.2.2 Calculate the constant ripple free armature current. (9)

If the polarity of the field current is reversed by the contactor switch, determine:

2.2.3 Initial delay angle of armature converter to ensure a constant current of 50A. (3)

2.2.4 The power fed back to the supply due to regenerative braking of the DC motor. (1)

[30]

QUESTION 3

3.1 Design a buck-boost converter to produce an output power of 2W at a constant negative output voltage of 13V. The voltage ripple must not exceed 0.25% of the output voltage. The input DC supply voltage is 5V and the switching period must be 50us. Ensure that the buck-boost regulator will operate in continuous conduction mode by selecting the inductor value to be 100 times larger than the critical inductor value. Assume the switch and diode losses to be negligible.

3.1.1 Sketch and label the circuit diagram of a buck-boost converter. (2)

3.1.2 Determine the duty cycle ratio, the output resistance, the value of the inductor and capacitor. (8)

3.1.3 For the selected inductor value, what will the inductor ripple current be? (2)

3.1.4 What is the average current through the switching device and diode? (4)

3.1.5 What peak current must the switching device be able to handle? (2)

[18]

QUESTION 4

4.1 The average DC input voltage of a switch mode DC power supply circuit shown in figure 2, is 300V. The output ripple current is negligible and load resistance is 3Ω. The switching frequency is 10 kHz and the duty cycle has been set to 50%. The on state voltage drops of the IGBT and diode is 1.2V and 0.7V respectively. The turns ratio of the transformer (N_S/N_P) is 0.35 and the transformer losses are negligible.

4.1.1 Determine the average input current of the switch mode DC power supply. (9)

4.1.2 Determine the efficiency of the switch mode DC power supply. (2)

4.1.3 Determine the primary magnetizing inductance value of the transformer. (2)

4.1.4 Determine the required peak current withstand rating of the IGBT. (2)

4.1.5 Determine the required open circuit withstand voltage rating of the IGBT. (2)

4.1.6 What is the circuit topology in figure 2, commonly referred to as? (1)

4.1.7 If the required withstand voltage rating is too high for the IGBT switch, what alternative circuit topology can be used to reduce the required withstand voltage rating. Sketch the circuit and explain how the switch withstand voltage is reduced. (5)

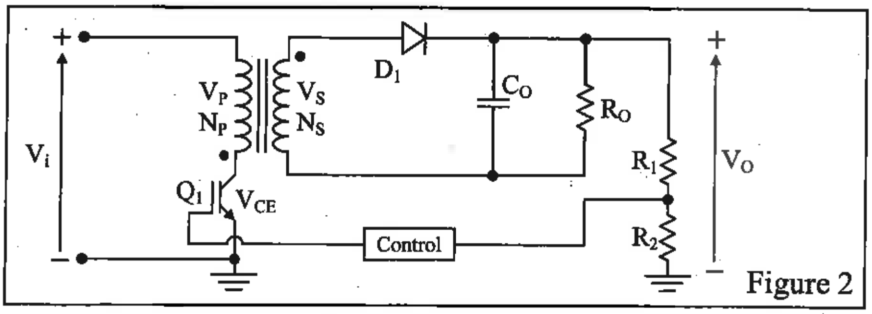

Figure 2

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TOTAL [100]

EQUATIONS

$$Vce_{off} = Vi_{max} + V_p \frac{N_p}{N_r}$$

$$Vo_{ave} = K\,Vs_{pk}$$

$$\frac{Ii_{pk}}{Io_{ave}} = \frac{Vo_{ave}}{Vi_{pk}} = \frac{K}{1-K}$$

$$V_f = R_f\,I_f$$

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

$$Vb_{ave} = Ia_{pk}(1-k)R_b$$

$$Vce_{off} \geq 2Vi_{max}$$

$$Is_{ave} = K\,Ia_{ave}$$

$$I_L = Vi_{pk}K\left(\frac{1}{R_O(1-K)^2} \pm \frac{T}{2L}\right)$$

$$T_d = B\omega + T_L$$

$$L_{crit} = \frac{R_O(1-k)^2}{2f}$$

$$P_{AVE} = \int_{t0}^{T} v_{(t)} i_{(t)}\,dt$$

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

$$P_d = E_g\,I_a$$

$$P_b = Ia_{pk}^2(1-k)R_b$$

$$f = \frac{1}{2RC\ln(3)}$$

$$Ib_{ave} = Ia_{pk}(1-k)$$

$$Rs = \frac{Ro}{k}$$

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

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

$$Ic_{max} = \frac{N_s}{N_p} I_{L1} + \frac{V_p KT}{L_p}$$

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

$$P_{ch} = Vch_{on}\,Ia_{pk}\,K$$

$$\frac{Ii_{pk}}{Io_{ave}} = \frac{Vo_{ave}}{Vi_{pk}} = \frac{K}{1-K}$$

$$Io_{ave} = K\,Is_{pk}$$

$$Ic_{ave} = K Ii_{pk}$$

$$Ip_{pk} = \frac{V_p K}{f L_p}$$

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

$$R_{eq} = \frac{V_s}{K\,Ia_{Aave}}$$

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

$$V_O = KV_s$$

$$Vo_{ave} = \frac{Vs_{pk}}{1-K}$$

$$T_d = K_t\,I_f\,I_a$$

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

$$Io_{rms} = \sqrt{K}\,Is_{pk}$$

$$V_a = E_g \pm R_a I_a$$

$$Po_{ave} = Vo_{ave}\,Is_{pk}$$

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

$$Ic_{max} \geq Ii_{pk}$$

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

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

$$Ich_{ave} = Ia_{pk}\,K$$

$$E_g = K_v\,\omega\,I_f$$

$$\Delta I_L = \frac{Vo_{ave}(1-K)KT}{L}$$

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

$$\Delta I_L = \frac{Vi_{ave}K}{fL}$$

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

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

$$I_L = Vi_{pk}\left(\frac{1}{R_O(1-K)^2} \pm \frac{KT}{2L}\right)$$

$$Po_{ave} = Vs_{PK}\,Io_{ave}$$

$$L_{crit} = \frac{R_O T}{2}(1-k)^2 K$$

$$P_d = T_d\omega$$

$$Vo_{rms} = \sqrt{K}\,Is_{pk}$$

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

$$\Delta V_c = \frac{KVo_{ave}}{R_O C f}$$

$$Vce_{off} \geq 2Vi_{max}$$

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

$$Ic_{max} \geq \frac{2P_{Lp}}{V_p K}$$

$$P_f = \frac{P_{AVE}}{V_{rms}\,I_{rms}}$$

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

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

$$W_{AVE} = \int_{t0}^{T} p_{(t)}\,dt$$

$$f = \frac{1}{2RC\ln(3)}$$

$$Vch_{off} = (1-K)\,V_s$$