<table>
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<tr>
<th><strong>PROGRAM</strong></th>
<th>BACCALAUREUS TECHNOLOGIAE</th>
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<tbody>
<tr>
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<td>ENGINEERING: ELECTRICAL</td>
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<tr>
<td><strong>SUBJECT</strong></td>
<td>POWER ELECTRONICS IV</td>
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<tr>
<td><strong>CODE</strong></td>
<td>EEP 411</td>
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<tr>
<td><strong>DATE</strong></td>
<td>SUPPLEMENTARY EXAMINATION 28 JULY 2016</td>
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<tr>
<td><strong>DURATION</strong></td>
<td>08:00 - 11:00</td>
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<tr>
<td><strong>WEIGHT</strong></td>
<td>40:60</td>
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<tr>
<td><strong>TOTAL MARKS</strong></td>
<td>105</td>
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<td><strong>FULL MARKS</strong></td>
<td>100</td>
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**EXAMINER** : JOHAN VENTER

**MODERATOR** : ADRIAAN DE KAMPER

**NUMBER OF PAGES** : 4 PAGES (THIS PAGE INCLUDED) AND 1 ANNEXURES

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

**REQUIREMENTS** : ONE ANSWER SHEET PER CANDIDATE.
QUESTION 1 [32]

1.1 A series excited DC motor is driven by a power control chopper drive connected to a 50 V battery supply. The armature winding resistance is 0.12 Ω and the field winding resistance is 0.18 Ω. The machine voltage constant is 10 mV/A-rad/s and the chopper frequency is 8 kHz. The chopping switch is on for 50 μs with a volt drop across the switch of 1.4 V. The measured speed of the driven DC motor is 3000 RPM.

1.1.1 Draw the power control chopper drive circuit. (2)
1.1.2 Calculate the average voltage across the dc motor terminals. (3)
1.1.3 Calculate the average DC motor current. (3)
1.1.4 Calculate the efficiency of the power control chopper drive circuit. (3)
1.1.5 Calculate average output power developed by the series excited DC motor. (3)
1.1.6 What is the efficiency of the series excited DC motor? (2)

1.2 A three-phase full-converter is used to control a 15 kW, 440 V, 1900 RPM separately excited DC motor. The field current is also controlled by a three-phase full-converter. The AC input to the armature and field converters is a three-phase, star connected, 380 V, 50 Hz line voltage. The armature winding resistance is 0.25 Ω, the field winding resistance is 130 Ω and the machine voltage constant is 1.4 V/A-rad/s. The viscous friction, motor no-load losses and converter losses are negligible. Also the inductance of the armature and field windings are sufficient to ensure ripple free continuous current. When the armature delay angle is set to 70°, the average measured armature current is 15 A and the motor reaches a constant measured speed of 650 RPM.

1.2.1 Determine the field converter delay angle setting. (9)
1.2.2 Determine the output power developed by the motor. (4)
1.2.3 For the same load demand, determine the new armature converter delay angle to achieve a 50% increase of the current motor speed. (3)

QUESTION 2 [30]

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 Calculate the constant ripple free armature current. 

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

QUESTION 3 [18]

3 Design a buck-boost converter to produce an output power of 2 W at a constant negative output voltage of 13 V. The voltage ripple must not exceed 0.25 % of the output voltage. The input DC supply voltage is 5 V and the switching period must be 50 μs. 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 Draw and label the circuit diagram of a buck-boost converter. 
3.2 Determine the duty cycle ratio, the output resistance, the value of the inductor and capacitor. 
3.3 For the selected inductor value, what will the inductor ripple current be? 
3.4 What is the average current through the switching device and diode? 
3.5 What peak current must the switching device be able to handle?

QUESTION 4 [6]

4 To avoid possible dynamic latch-up, an external resistance of 12 Ω is connected between the driver and MOSFET gate as indicated in figure 1. The selected gate drive voltage for the IRFP140 power MOSFET is 12 V with a drain to source voltage of 50 V. To reduce the 50 kHz switching frequency losses, the required turn on and off time must be 100 ns. For the given QG vs VGS voltage curve, determine the maximum RDson of the driver output and the power dissipation of the MOSFET driver.

![Figure 1](image-url)
The control system block diagram of a separately excited DC motor is given in figure 2. The separately excited DC motor develops an output power of 55 kW at 3000 RPM with a constant field current of 1.6 A. The armature resistance is 0.32Ω and the machine voltage constant is 0.76 V/A-rad/s. The viscous friction of the bearings and load is calculated to be approximately 0.56 N·m/rad/s. The speed sensor “K₁” amplification is 120 mV/rad/s and the power control “K₂” gain is 100.

5.1 Derive the steady state transfer function of the change in speed due to a step change in the applied reference voltage “Vᵣ”.

5.2 Derive the steady state transfer function of the change in speed due to a step change in the applied load torque “Tₗ”.

5.3 If the load torque applied is 150 N·m and the reference voltage is set to 12.5 V, determine the DC motor output RPM speed.

5.4 For the same load and reference voltage setting, determine the armature current.

5.5 What is the efficiency of this DC motor drive control system?

5.6 What is the speed regulation percentage achieved by the drive control system.

\[
\text{TOTAL MARKS = 105}
\]
\[ V_{ce_{off}} = V_{i_{max}} + V_p \frac{N_p}{N_r} \]
\[ V_{O_{ave}} = K V_{s_{pk}} \]
\[ \frac{I_{pk}}{I_{o_{ave}}} = \frac{V_{o_{ave}}}{V_{i_{pk}}} = \frac{K}{1-K} \]
\[ V_f = R_f I_f \]
\[ R_{eq} = \frac{V_i}{I_a}(1-K) + R_m \]
\[ V_{b_{ave}} = I_{a_{pk}}(1-k)R_b \]
\[ V_{ce_{off}} \geq 2V_{i_{max}} \]
\[ I_{s_{ave}} = K I_{a_{ave}} \]
\[ I_a = I_{a_{pk}}(1-k) \]
\[ R_s = \frac{R_o}{k} \]
\[ I_{c_{max}} = \frac{N_z}{N_p} I_{s_{pk}} + \frac{V_p KT}{L_p} \]
\[ Q_{gt} = Q_{gg} T_{gg} \]
\[ P_{ch} = V_{ch_{on}} I_{a_{pk}} K \]
\[ \frac{I_{pk}}{I_{o_{ave}}} = \frac{V_{o_{ave}}}{V_{i_{pk}}} = \frac{K}{1-K} \]
\[ I_{o_{ave}} = K I_{s_{pk}} \]
\[ I_{c_{ave}} = K I_{i_{pk}} \]
\[ I_{p_{pk}} = \frac{V_p K}{f L_p} \]
\[ V_{dc} = \frac{V_m}{2\pi} \frac{(1 + \cos \alpha)}{\cos \alpha} \]
\[ V_o = K V_i \]
\[ V_{o_{ave}} = \frac{V_{s_{pk}}}{1-K} \]
\[ R_{eq} = K \frac{I_{a_{ave}}}{L_p} \]
\[ V_{dc} = \frac{V_m}{2\pi} \frac{(1 + \cos \alpha)}{\cos \alpha} \]
\[ \omega_{min} = \frac{R_m I_a}{K_v I_f} \]
\[ \omega_{max} = \frac{V_s}{K_v I_f} + \frac{R_m I_a}{K_v I_f} \]
\[ \Delta I_L = \frac{V_{i_{ave}} K}{f L} \]
\[ \Delta L = \frac{V_{o_{ave}}(1-K)KT}{L} \]
\[ P_{o_{ave}} = V_{s_{pk}} I_{o_{ave}} \]
\[ L_{crit} = \frac{R_o T}{2} (1-k)^2 K \]
\[ P_d = T_d \omega \]
\[ V_{o_{rms}} = \sqrt{K} I_{s_{pk}} \]
\[ P_{lp} = \frac{(V_p K)^2}{2 f L_p} \]
\[ \Delta V_c = \frac{K V_{o_{ave}}}{R_o C f} \]
\[ V_{ce_{off}} \geq 2V_{i_{max}} \]
\[ P_f = \frac{P_{AVE}}{V_{rms} I_{rms}} \]
\[ P_d = C_{gt} V_{gs}^2 f \]
\[ V_{ch_{off}} = (1-K) V_i \]