Data Provided: None

The University Of Sheffield.

DEPARTMENT OF ELECTRONIC AND ELECTRICAL ENGINEERING

Spring Semester 2014-15 (3.0 hours)

EEE223 Electrical Energy Management

Answer **FOUR** questions. **No marks will be awarded for solutions to a fifth question.** Solutions will be considered in the order that they are presented in the answer book. Trial answers will be ignored if they are clearly crossed out. **The numbers given after each section of a question indicate the relative weighting of that section.**

1. a. i. With the aid of a diagram, give the classical per-phase equivalent circuit of a 3-phase induction motor, explaining what each of the components represents, and how they relate to the motor. **(4)**

ii. Show how the approximate equivalent circuit can be formed from the classical equivalent circuit, explaining the assumptions made to enable this to happen. **(4)**

b. Using the approximate equivalent circuit from part (a) as a starting point, derive an expression for the output torque of a 3-phase induction motor **(6)**

c. A locked rotor test is carried out on a 2-pole, 3-phase star connected induction motor, rated for 50Hz, $415V_{line}$ operation. At the rated motor current of 40A, the power input to the machine was measured to be 200W, with an applied phase voltage of 50V. Given that the winding resistance is measured at 0.02Ω per phase, calculate the maximum pull-out torque for the motor at rated voltage **(6)**

2. **a.** Brushed dc motors typically have 3 rating parameters, T_{stall}, n_{max} and T_{max}.

Explain fully what each of the parameters means, and highlight what influences the rating and how this affects the motor operation. **(4)**

b. With the aid of an annotated diagram, show how a permanent magnet pole may become partially demagnetised within a brushed d.c. motor during operation, and explain how this will be a problem under overload conditions. **(4)**

c.

i. A 200V, 2-pole brushed d.c. shunt motor runs at 3000 rpm and takes an armature current of 28A when driving a certain load. The four field windings are all connected in series across the supply, and draw a field current of 7A. If the armature resistance is equal to 0.1Ω, find the load torque. **(4)**

ii. The four field coils are now connected all in parallel, and the machine is run as a series motor across a 250V supply. Calculate the new speed if the load torque remains the same **(4)**

d. Derive the equations for the operation of a wound field brushed d.c. motor, and explain how the motor may be operated from an a.c. supply, highlighting any other factors which would affect the choice of voltage for the operation of the motor on an a.c. supply. **(4)**

3. **a.** With the aid of a suitable diagram, show that for a linear, non-saturated magnetic system comprising of a coil carrying some current I, the energy stored in the magnetic system, W, is

$$W = \frac{1}{2} L I^2$$

(8)

b. For a particular simple relay shown as figure 1, N = 1200 turns, The cross sectional area A = 100mm^2, and airgap length X = 5mm when the armature is in the open position, and X = 2mm when the armature is in the closed position.

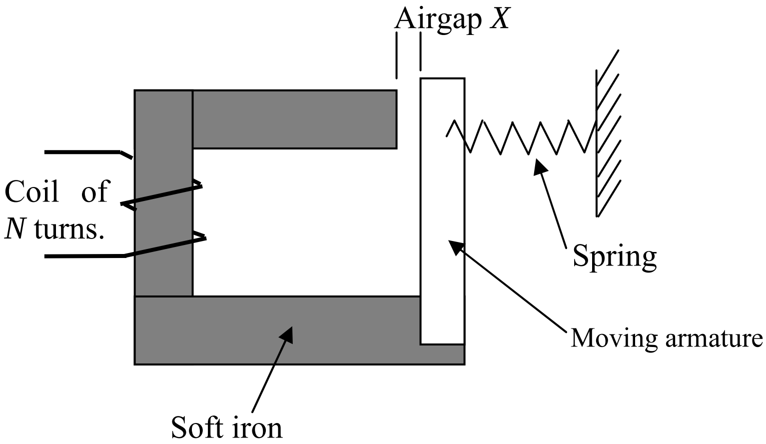


Figure 1 – Simple relay

If the spring exerts a constant force of 1Nm, calculate the current required to close the simple relay, and the current at which the simple relay will re-open. **(6)**

c. (i) Why are the two current levels calculated in part 'b' above not equal? **(3)**

(ii) Explain why this is desirable for correct operation of the device. **(3)**

4. The circuit shown in Figure 4 is a simple series voltage regulator circuit, with an adjustable output voltage, V_{out}, which is controlled by varying R_v. The component values associated with this circuit are:

V_{dc}=50V, V_{ref}=1.25V, R_v=47kΩ, R=5.1kΩ

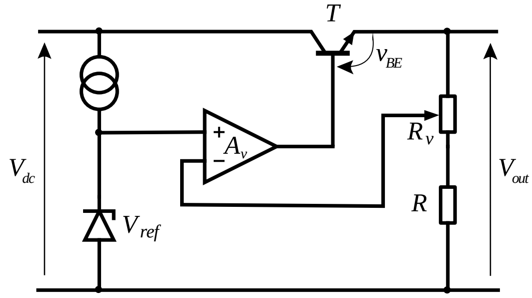


Figure 4

a. Derive an expression for the output voltage, V_{out}, of the circuit shown in Figure 4 in terms of V_{dc}, V_{ref}, R_v and R. You may assume that the setting of R_v can be modelled by two resistors R_{v1} and R_{v2} such that $R_v = R_{v1} + R_{v2}$ = 47kΩ and that the gain of the error amplifier is ideal ($A_v = \infty$).

What are the minimum and maximum output voltages that can be obtained by adjusting R_v? **(5)**

b. By redrawing Figure 4, show how a current limiting capability could be added to the circuit. Explain how your current limiting circuit works.

Choose component values that would achieve a current limit level of $I_{out(lim)}$=10A. **(5)**

c. Determine the efficiency of the regulator circuit if the input is connected across a 40V DC supply and the regulator is to provide an output voltage of 6V across a 0.7Ω load. You should include the effects of the power dissipated by your current limited circuit that you described in part b although you may assume that power dissipated by the feedback network R_v-R and the reference voltage generator are negligible. **(5)**

d. The regulator is operating under the following conditions: V_{dc}=40V, V_{out}=6V, I_{out}=10A, T_{amb}=25°C with a transistor with the following junction-case thermal resistance $R_{j\text{-}c}$=0.1°C/W which is mounted to a heatsink using a thermal washer with a thermal resistance of $R_{c\text{-}h}$=0.08°C/W.

Draw the thermal equivalent circuit for the transistor operating as above explicitly showing the junction and heatsink temperatures.

What is the minimum heatsink thermal resistance ($R_{h\text{-}a}$) required to ensure the semiconductor junction temperature (T_j) remains below 100°C and the heatsink temperature (T_h) remains below 40°C? **(5)**

5. The boost (step-up) converter shown in Figure 5 is designed to provide an output voltage V_{out}=200V DC from a 5V DC input source suitable for driving a radiation detector.

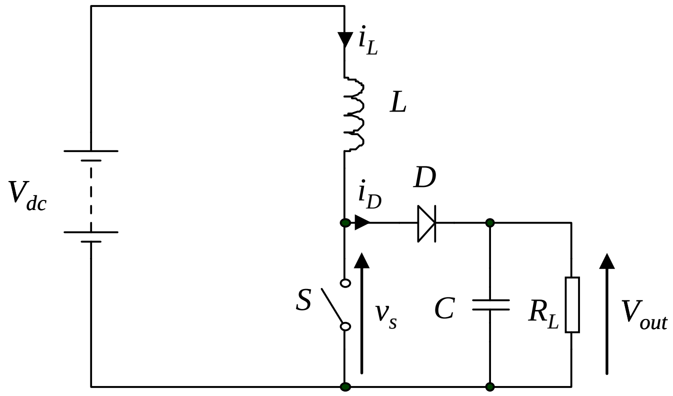


Figure 5

a. Draw the typical waveforms that one would expect to see over a complete cycle for the signals i_L, i_D and v_s. On your v_s waveform label the time period when S is on, V_{out} and V_{dc} voltage levels and on the current waveforms label the peak current I_{pk}. **(6)**

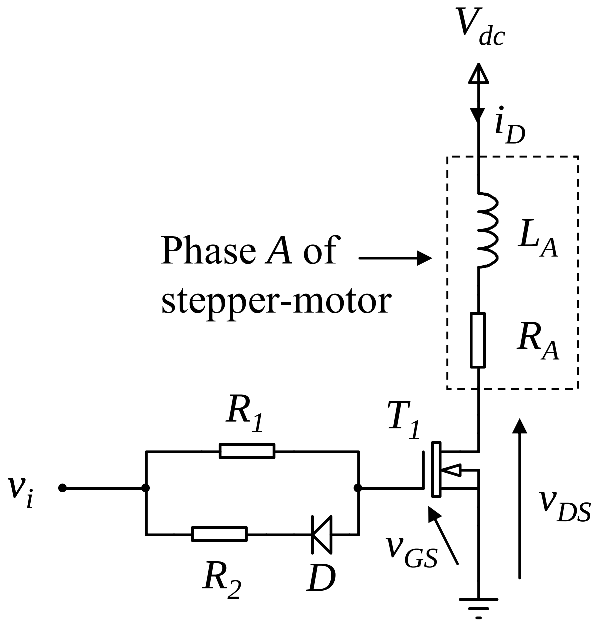
b. Derive an expression for the output voltage V_{out} of the boost converter for a given switch on-time t_{on}. **(4)**

c. If t_{on}=12μs, R_L=10kΩ and the switching frequency of S is 60kHz, what value of L is required to obtain the 200V output voltage required? **(2)**

d. What is the peak current through L and what is the maximum energy transferred from L to C each cycle? **(3)**

e. What output voltage would be obtained if the circuit was operated at the boundary between continuous and discontinuous current through L? **(5)**

6. The circuit shown in Figure 6 forms part of a drive system for a 3-phase stepper-motor, where L_A and R_A represent the inductance and resistance respectively of phase *A*. The rotation of the motor is controlled by applying individual pulses to the phases *A*, *B* and *C* with the direction of rotation being controlled by the order in which the phases *A*, *B* and *C* are switched (i.e. *ABC*=forward *ACB*=reverse). The position of the motor is held constant by holding one of the phases active. In order to minimise the power dissipation in the motor each phase must be switched-off before another is switched-on, the components R_1, R_2, and *D* in Figure 6 fulfil this purpose.



Stepper-motor specifications:

L_A=1mH

R_A=30Ω

MOSFET specifications:

C_{GS}=600pF

C_{DG}=175pF

V_{TH}=5V

V_{DSMAX}=60V

r_{DSON}=15mΩ

Figure 6: Stepper-motor drive system

a. Assuming that L_A has a negligible effect on the switching times and that *D* is ideal, sketch the waveforms you would expect for v_{GS}, v_{DS} and i_D given v_i is a uni-polar rectangular waveform with an amplitude of 10V and a mark-to-space ratio of unity. Show at least one complete cycle. Explain what is happening at each stage in the switching cycle. **(6)**

b. What is the turn-on delay and turn-on switching time if R_1=1.5kΩ, V_{dc}=36V and v_i has an amplitude of 10V? **(4)**

c. Assuming *D* is ideal, what is the maximum value for R_2 that can be employed to ensure that two phases are not switched on simultaneously? **(6)**

d. When the MOSFETs in the drive system are switched-off, the stepper-motor's phase inductance may cause v_{DS} to exceed rating of the switching device. Therefore, to ensure this does not happen a free-wheeling diode with a series resistor is placed in parallel with the motor's phase winding to limit v_{DS} to a maximum of 60V. What value of resistance is required to achieve this? Assume the free-wheeling diode is ideal. **(4)**

DAS/MPF/MO