UNIVERSITY OF TORONTO
FACULTY OF APPLIED SCIENCE AND ENGINEERING

FINAL EXAMINATION, DECEMBER 1997
Third Year - Program 5

ECE359F - Industrial Electronics and Energy Conversion
Exam Type: C
Examiner : R. Bonert

A complete examination paper consists of the answers to all three problems.
All three problems cary an equal weight of 25 points each.
An aid sheet may be used.

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(1) DC/DC power supply

A car radio with a tape recorder requires a 7.5 V DC-voltage . The maximum power consumption is 30 W, the minimum power consumption is 5 W.
A DC to DC power supply provides this power from the 12 V car battery. The DC-voltage of the car battery can differ from the nominal voltage by +20% to -10%.
The senior design engineer gives the directive to use a switching power supply with a fixed switching frequency of 20 kHz, and specifies the output current should be continuous over the full load range and the output voltage ripple should not exceed 2%.

a) What type of converter circuit has to be used ? Which major components are needed to build the power supply ? Representing the radio by a resistive load, draw the circuit of the power supply including the battery and the load.

b) Determine the required minimum and maximum duty ratio D for the converter.

c) Determine the value of the components of the LC-filter required for such power supply to meet the required specifications.

d) For minimum battery voltage and maximum output power draw to scale:
   1) The control signal for the switch
   2) The voltage across the switch
   3) The voltage across the diode
   4) The current in the inductor
   5) The current through the switch
   6) The current through the diode
   7) The current through the capacitor

(2) Single phase full wave controlled rectifier charging a battery

A single phase full wave controlled rectifier is used to charge a battery for an emergency supply of a computer centre. The battery is rated at 150 V and can supply 50 A of DC-current.
The controlled rectifier is connected to 240 V single phase AC-line with 60 Hz.
The battery resistance is specified to be 0.2 Ohm, the other charging circuit components including an inductor have a resistance of 0.2 Ohm.
An inductor is connected on the DC-side to reduce the ripple of the charging current.

a) Draw the electric circuit diagram showing the described system.

b) Determine the inductance required to smooth the DC-side current. Assume that a smoothing time constant three times as high as the period of the lowest DC-side voltage harmonic is sufficient for the required filtering.
Assume then for the following calculations c) to g) that the DC-side current is continuous and virtually constant.

c) Determine the required output voltage and the required control angle α of the rectifier to charge the battery
1. with its rated current
2. with 2% of its rated current to maintain the charge

d) Determine the input power factor PF and the input displacement power factor DPF for the two cases of operation described in c).

e) Determine the rms value of the first two line side current harmonics. Calculate the total harmonic distortion THD based on these harmonics.

f) What could be done to eliminate these line side current harmonics and prevent them from entering the hydro system.

g) For test purposes the battery has to be discharged once in a while with 50 A for ten minutes. What has to be done to do this with the available phase controlled bridge and which control angle α has to be set to control the current to 50 A discharge current ?

(3) Dynamometer testing of an Induction Motor operating with variable frequency and voltage

A three phase induction motor with a squirrel cage rotor has the following rated data:

3 phase AC 480 V, 60 Hz, 16.8 A, 10 kW, 1152 rpm,

for inverter operation the maximum frequency is 90 Hz

The motor is supplied by a 3-phase voltage source inverter (DC/AC converter) with variable frequency and voltage.The inverter is connected to a 600 V DC supply. The inverter operates with sinusoidal PWM and therefore only the fundamentals of voltage and current have to be considered for the operation.

For the test the induction motor is coupled to a dynamometer which is using a DC-machine operated with constant and rated field using the same 600 V DC-supply as the inverter. The data of the DC-machine are :

400 V, 50A, 2000 rpm, 18 kW

the armature resistance is 0.4 Ohm , maximum speed 2500 rpm (mechanical limit)

The armature of the dynamometer is connected to a variable resistor which can be adjusted between zero and 20 Ohms.

Neglect for the following calculations the mechanical losses of both machines.

a) Draw a diagram showing the test set-up with the machines, the inverter and the dynamometer load included.

b) Draw as a preparation for the following questions c)...f) a speed torque diagram to show the characteristic and the operating points of the induction machine and the dynamometer. Use 100 rpm/ square and 5 Nm/ square on the attached graph paper.

c) Determine the value of the variable resistor connected to the dynamometer to operate the induction motor at its rated point. Determine the load torque of the dynamometer in per-cent of the rated torque of the DC-machine. Draw the characteristic of the induction motor and the characteristic of the dynamometer onto the diagram prepared in b).

d) Determine speed of the induction motor, if it is supplied with maximum inverter frequency of 90 Hz and loaded with the maximum torque for continuous operation at this higher speed. Determine also the required value of the variable resistor of the dynamometer to operate the induction motor at this point of operation. Draw the characteristic of the induction motor and the characteristic of the dynamometer onto the diagram prepared in b).

e) Determine the lowest speed the induction machine can be tested with the given set up, if the induction machine operates at that speed at rated torque. What operation of the inverter is required to operate the induction machine at that point ? Draw the characteristic of the induction motor and the characteristic of the dynamometer onto the diagram prepared in b).

f) Mark onto the diagram drawn in b) the possible range of operation for which it is possible to test the induction motor with the given set up. Describe the limits restricting the range of operation as shown on the graph.