UNIVERSITY OF TORONTO
FACULTY OF APPLIED SCIENCE AND ENGINEERING

FINAL EXAMINATION, DECEMBER 1998
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 carry an equal weight of 25 points each.
An aid sheet may be used.

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(1) DC/DC power supply

In a remote cottage a 12V battery being charged by a photovoltaic panel is available to power a radio with a CD-player. The radio and the CD-player require 8 V DC-voltage . The maximum power consumption is 32 W, the minimum power consumption is 5 W. The voltage from the battery varies between 10.8 V and 14.4 V.
A DC to DC power supply is needed to convert the battery voltage to the required 8V.

a) What type of converter circuit has to be used ? Which major components are needed to build the power supply ? Assume the radio and the CD-player can be modelled as a resistive load, draw the circuit of the power supply including the battery and the load.
b) Designing the power supply the switching frequency has to be selected. Having the choice between 60Hz, 1 kHz, 10 kHz and 50kHz which frequency would you select and for what reasons ?
c) After choosing the circuit and the frequency the filter has to be designed. What is the common assumption for the filter design and why is it made ? Which further specification beyond the provided data and requirements is needed to design the filter ? Make a reasonable choice for this specification.
d) Determine the values of the components of the LC-filter required for the power supply to meet the required specifications. Determine the components such that the desired operation is guaranteed for the worst case.
e) 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

(2) Electric Car, Battery Charger

Assume you have an electric car in the garage. This car requires a charging facility. Assume it has a battery with a nominal voltage of 160V and requires a charge current of 100 A.
A single phase full wave controlled rectifier connected to the 240 V 60Hz panel in the garage could be used as a charger.
Assume the resistance of the charger circuit is 0.1 Ohm and that an inductor is used on the DC-side to smooth the current.

a) Draw the electric circuit diagram showing the described system.
b) Determine the required inductance to smooth the DC-side current. Assume that a smoothing time constant five times as high as the period of the lowest DC-side voltage harmonic is sufficient for good filtering.

Assume then for the following calculations c) to e) 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 with its rated current at the nominal battery voltage. What is the apparent power the charger draws from the panel in the garage ?
d) Determine whether the charger can charge the battery with full current at its maximum voltage, which is 20% above the nominal voltage.
e) Determine the input power factor PF and the input displacement power factor DPF for operation described in c).
f) Determine the rms value of the first two line side current harmonics. Calculate the total harmonic distortion THD based on these harmonics.
g) Considering the power factor and the harmonics it is unlikely that the above circuit could be used if many electric cars were around. What other power electronic circuits could you think of to be used as chargers for the above application avoiding low PF and high THD ?

(3) Testing of a Race-Car engine with an Induction Machine Dynamometer

An internal combustion engine for a Race-Car has 420hp and a maximum rotational speed of 10500 rpm. The engine has to be tested and electric dynamometer testing has been chosen.
The available dynamometer uses an induction machine (IM). A DC-machine is not possible as such a machine can not be build due to the limitations of the commutator.
To control the IM-dynamometer a DC-link converter is available to provide variable voltage and variable frequency to the IM.
The three phase induction machine with a squirrel cage rotor has the following rated data:

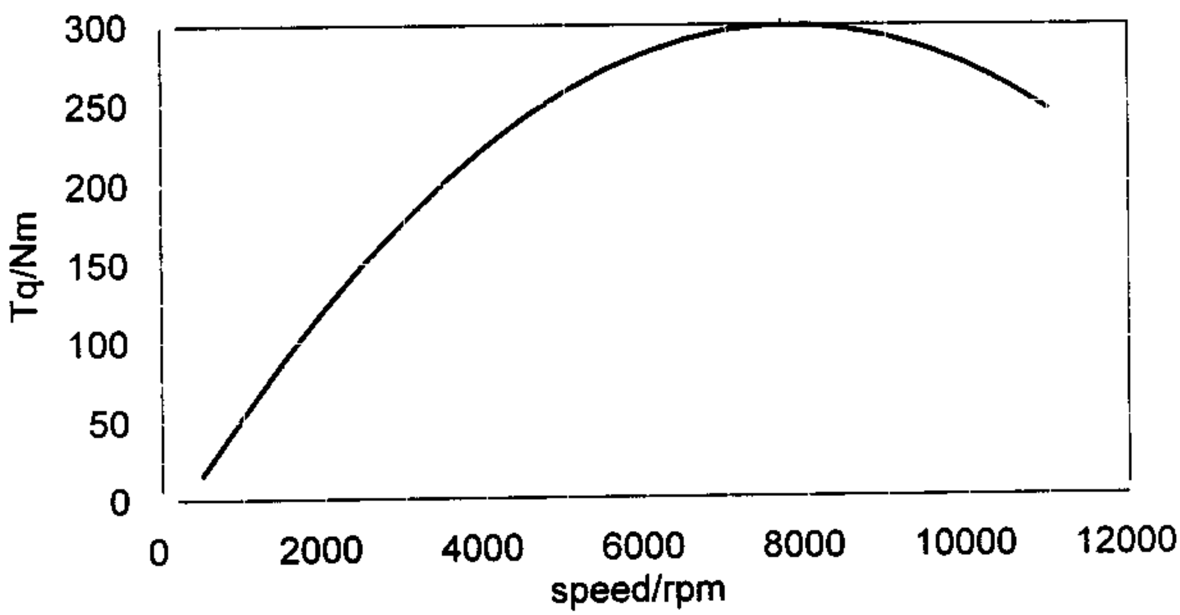
3 phase AC 600 V, 240 Hz, 300 A, 280 kW, 6840 rpm, max speed 11000 rpm
for inverter operation the maximum frequency is 360 Hz

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 950 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.
The torque speed diagram of the engine is shown in Figure 1. It can be described by

$Tq = 300 - (0.022 * \omega m-18)*(0.022 * \omega m-18)$ Nm, with the speed ωm in 1/sec.

Neglect for the following calculations the mechanical losses of the IM

a) Describe the required control settings to test the characteristic of the engine with the IM-dynamometer. The converter output frequency can vary between 20Hz to 360Hz but the converter output line to line AC-voltage can not exceed 600V.
b) Determine the required converter frequency and voltage to achieve operating points of the engine at 3000rpm, 6500 rpm and 10,000 rpm.
c) Draw the speed-torque characteristics of the IM for the operations given in b) onto the engine diagram of the attached sheet and hand it in with your work.



Figurgure 1 : Engine torque in Nm as function of engine speed in rpm