ET4119 Electronic Power Conversion 2011/2012
Exam 20 April 2012

Remarks:
In front of every question the maximum rating that can be obtained is indicated.

First solve the problems on draft paper and make a neat version subsequently.

Start each problem on a separate piece of paper.

Always show the formulas that you used to make the calculations.

You can give your answers in Dutch or in English.

It is allowed to use a (self-made) single sided piece of paper (1xA4) with formulas and figures from the textbook.

1. Figure 1a shows a single-phase rectifier that is connected to a supply voltage v_s and a battery. The battery is represented by a DC load voltage V_d. The voltage v_s has a block-like shape (Figure 1b) that is produced by some HF inverter (not shown). The rectifier is intended to charge the battery. Depending on the charging state of the battery the voltage V_d may vary. The circuit specifications are as follows:

- $V_{d,nom}$=160V (nominal voltage of V_d)
- V_s=300V (amplitude of v_s as shown in Figure 1b)
- T_s=30µs (period of voltage v_s)
- f_s= $1/T_s$=33.3 kHz (frequency of v_s)
- L_s=20 µH

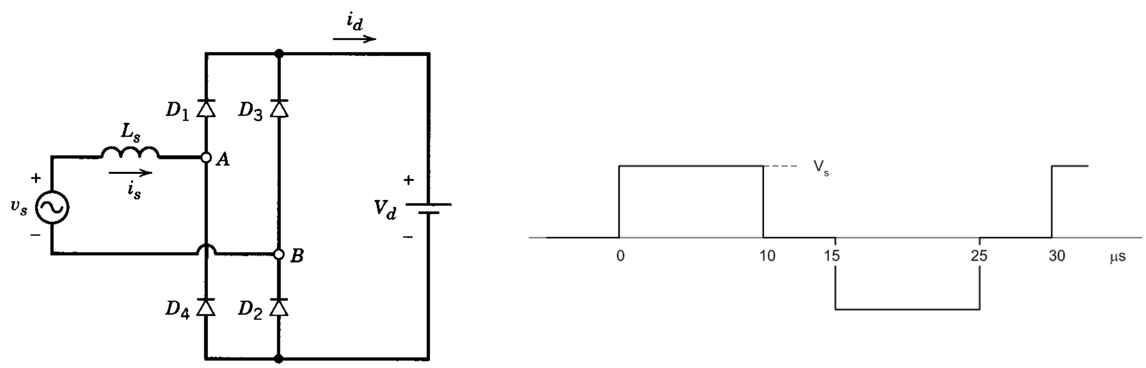

Figure 1 a. rectifier circuit b. input voltage waveform

1.1 (10) Sketch v_L and i_s as a function of time and indicate relevant values for $V_d = V_{d,nom}$.

1.2 (10) Calculate the peak value of i_s, the average current I_d and the average output power P_d for V_d=$V_{d,nom}$.

1.3 (5) What will happen if V_d is increased above 200V?

2. Figure 2 shows a boost converter used in the Toyota Prius hybrid electric vehicle for stepping up the battery voltage from 150-250 V to 500 V. The converter's switching frequency is f_s= 20kHz.

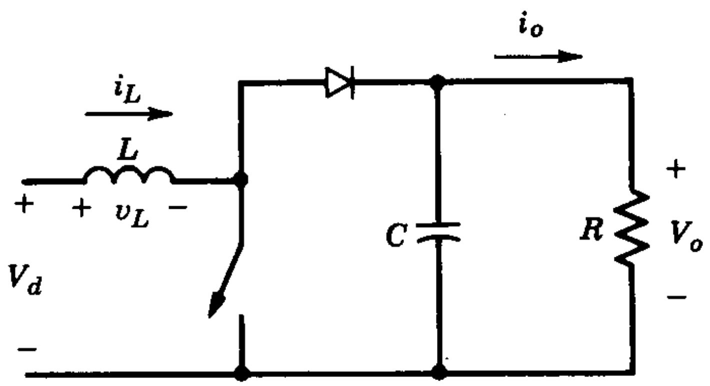

Figure 2 Boost converter

2.1 (10) Calculate the critical (maximum) inductance value of the filter inductor to ensure that the converter operates in the discontinuous conduction mode for the given input voltage range and the load current up to I_o= 10A. Show the derivation of the expression for the inductance (do not use ready-made formulas).

2.2 (5) Given the inductance value obtained in 1.1 calculate the duty cycle range to keep the output voltage V_o constant (500V) for the given range of the input voltage and the nominal current of I_{nom}= 4A.

2.3 (10) Calculate the required capacitance value of the output filter capacitor to ensure that at the nominal input voltage (V_{d_nom} = 200V) and the output current of 12A the output voltage ripple is less than 2% of the nominal output voltage (V_o). Show the derivation of the expression for the inductance (do not use ready-made formulas).

3. A switch-mode power supply is to be designed with the following specifications:

- V_d=48V±10%
- V_o=5V (regulated)
- f_s=100kHz
- P_{load}=15-50W

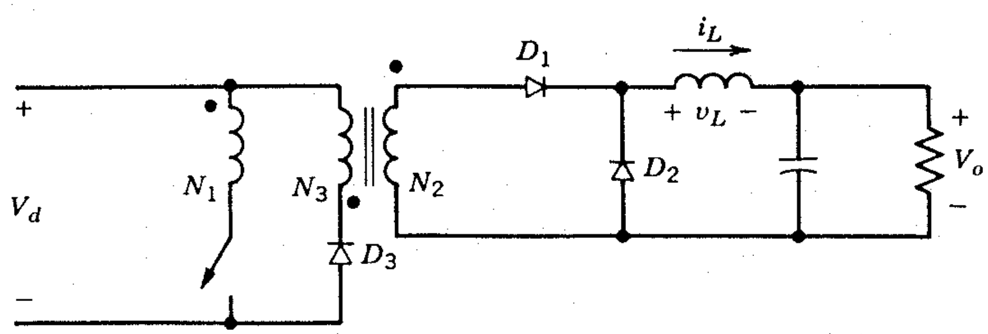

Figure 3 Forward converter

A forward converter topology shown in Figure 3 operating in a continuous conduction mode with a demagnetising winding (N_3=N_1) is chosen. Assume all components to be ideal except for the presence of transformer magnetising inductance.

3.1 (5) Sketch the operating waveforms of the converter.
3.2 (10) Calculate N_2/N_1 if this turns ratio is desired to be as small as possible.
3.3 (10) Calculate the minimum value of the filter inductance.

4. Given is a single-phase full bridge dc/ac voltage source converter that is connected to a single phase induction motor with counter emf e_0, as shown in Figure 4. The output voltage v_0 of the inverter is obtained by bipolar voltage switching. To obtain a low distortion linear modulation is applied.

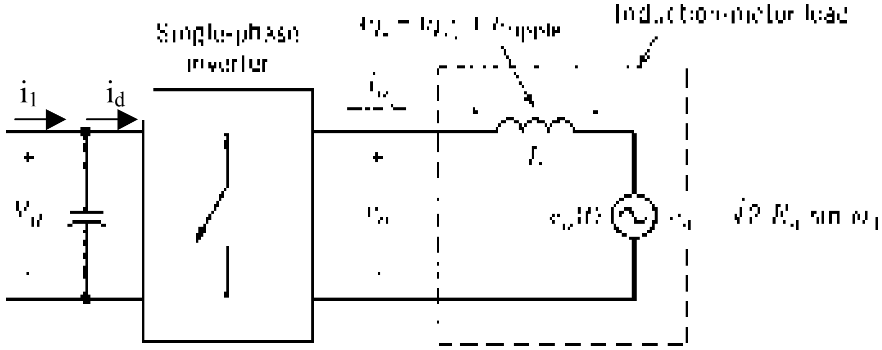

Figure 4 Full bridge inverter

Given is further:

- $V_d = 350V$ (DC link voltage)
- $\omega_{1,nom} = 2\pi 60$ rad/s (nominal value of ω_1)
- $V_{01,nom} = 230$ V (nominal rms value of fundamental of v_0)
- $L = 30$ mH (inductance of machine)
- $f_s = 7.5$ kHz (frequency of triangular carrier v_{tri})
- $C_d = 1$ mF (capacitance of input filter)
- At nominal speed and nominal voltage the input power of the loaded drive is 1 kW at $\cos \varphi_1 = 0.8$

4.1 (5) Calculate the rms value of the fundamental of i_0 when the machine runs at rated speed and rated power. Sketch a phasor diagram with the phasors of e_0, v_0 and i_0.

4.2 (5) Define the modulation ratio ma and give the relation between V_{o1}, m_a and V_d, where V_{o1} is the rms value of the fundamental of the output voltage. Calculate the modulation ratio ma such that the machine runs at nominal speed and nominal voltage.

4.3 (5) Calculate the expression for and sketch the instantaneous power $p_0(t)$ that is transmitted by the fundamental current i_0 and voltage v_0

4.4 (10) Calculate the low-frequency (<1 kHz) peak-to-peak voltage ripple ΔV_d assuming that the current i_1 is constant.