Department of Power Electronics and Electrical Drives

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# Power Electronics

31.03.2015

| Surname: | Student number: |
|---|---|
| First name: | |
| Course of study: | |

| Task: (Points) | 1 (25) | 2 (25) | 3 (25) | 4 (25) | | Total (100) | | Mark |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | | |

**Duration: 120 minutes**

**Permitted resources:**

- a non-programmable calculator without graphic display
- drawing materials (compasses, protractor, ruler, pens ...)

**Please note:**

- Please prepare your student ID card (with photo) on your desk for the attendance check.
- Please label each exam sheet with your name and student number. Use a new exam sheet for each task. Do not use pencils or red pens.
- With numerical calculations, the units must be considered in every step. Not following that rule will result in deduction of points.
- All solutions must be clearly documented and wherever required explained! The entry of a mere final result without any approach will not be counted.
- You can only take part in the exam, if you are registered in the PAUL system. If you take part without registration, the exam result will not be considered.

# Good Luck!

**Task 1: Buck-Boost Converter (25 Points)**

Figure 1 shows a converter which can be called buck-boost converter. The input voltage to the converter is $U_1 = 10$ V. The converter supplies a DC load current of 5 A at the output. The power switches are assumed to be ideal during conduction and blocking states (0 V during conduction and 0 A in blocking). The converter is operated at a switching frequency of 10 kHz. The capacitance of the capacitor $C$ is 100 µF.

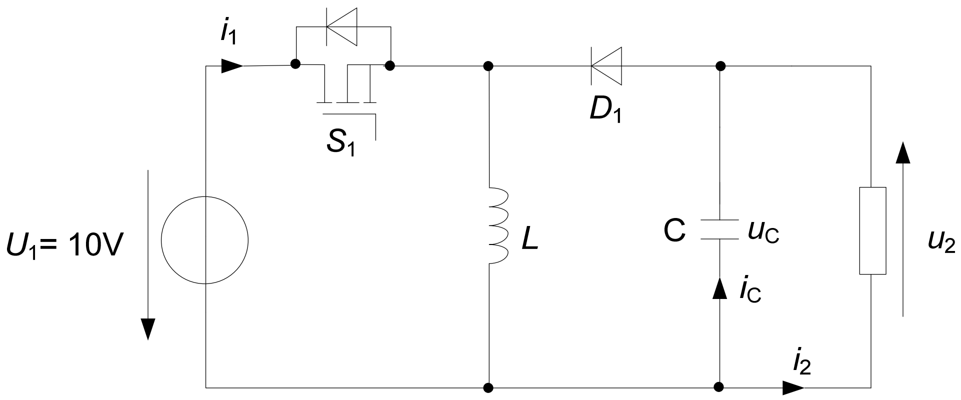



**Figure 1: Buck-Boost converter**

If the duty cycle of switch $S_1$ is chosen as 0.25, estimate the following:

1.1 The DC contents of the input current $i_1$ and of the output voltage $u_2$.

1.2 Evaluate the required inductance $L$ to limit the ripple current of $i_1$ to 20% of the DC content (assume the output voltage approximately constant).

1.3 For what value of the inductance $L$ does the converter operate at the boundary between continuous and discontinuous conduction modes?

1.4 Sketch the current through the capacitor $C$ (assume the load current approximately constant)

1.5 Sketch $u_C$

1.6 Determine the peak-to-peak voltage ripple across the capacitor C.

**Task 2: Boost converter (25 Points)**

Figure 2 shows a non-ideal boost converter. The source and inductor resistances are represented by $R_1$ and $R_L$ respectively. The switches $S_1$ and $D_1$ are assumed to be ideal. The state variables are the inductor current $i_L$ and capacitor voltage $u_2$. The circuit is to be operated in continuous conduction mode.

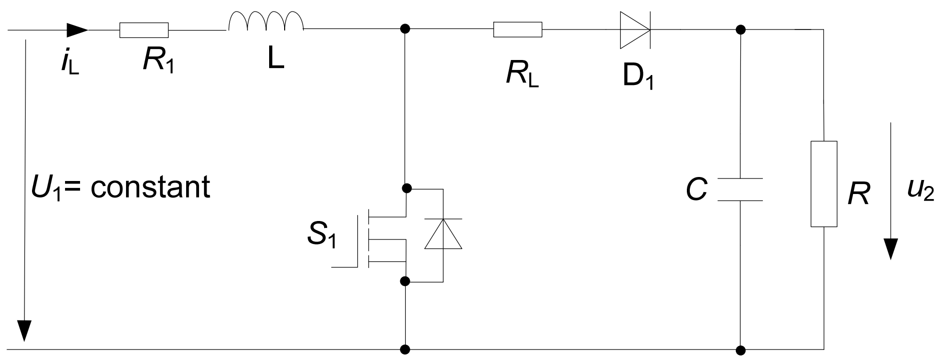



**Figure 2: Boost converter**

**2.1** Write down the differential equations of the complete system for the two state variables during ON state, i.e. when $S_1$ is ON.

**2.2** Write down the differential equations of the complete system for the two state variables during OFF state, i.e. when $S_1$ is OFF.

**2.3** Using the above, write down the averaged dynamic model of the converter in state space matrix notation.

**2.4** Derive the gain $\bar{u}_2/U_1$ at steady state as a function of duty cycle.

**2.5** Evaluate the efficiency of the converter based on the average modeling, $\eta = (\bar{u}_2\, \bar{\imath}_2)/(U_1\, \bar{\imath}_1)$

**Task 3: Four-Quadrant Converter (25 Points)**

A four-quadrant converter (4QC) is connected to the single-phase grid. The overhead line delivers a single-phase sinusoidal AC voltage $V_{AC}$ with grid frequency $f$. The two four-quadrant converters are operated in interleaving operation to minimize the current ripple. The traction transformer has two primary windings connected in parallel and two secondary windings.

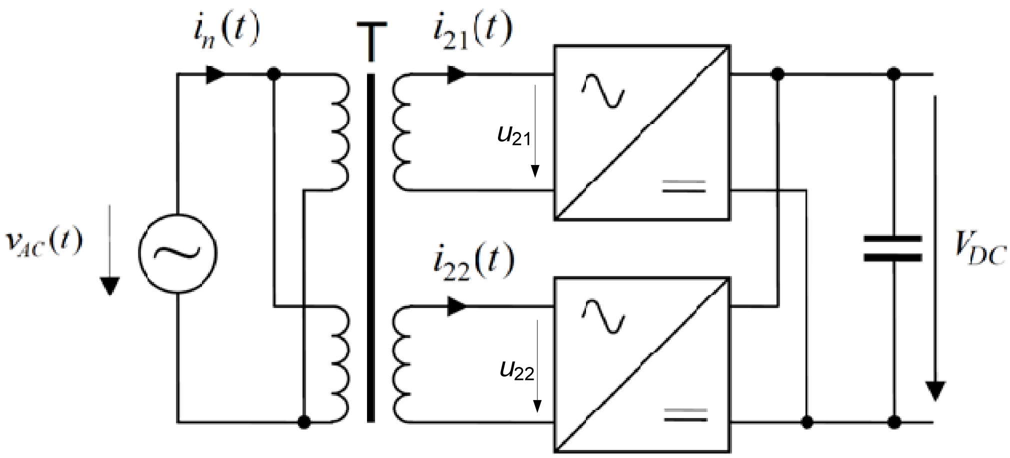



**Figure 3: Power supply for an electric locomotive**

| | | | |
|---|---|---|---|
| Nominal output voltage | $V_{\mathrm{DC}} = 1.8\ \mathrm{kV}$ | Relative short circuit voltage (each secondary) | $u_{\mathrm{k}} = 19\%$ |
| Nominal output power | $P_{\mathrm{N}} = 2.4\ \mathrm{MW}$ | Switching frequency | $f_{\mathrm{S}} = 500\ \mathrm{Hz}$ |
| Grid voltage | $V_{\mathrm{AC}} = 25\ \mathrm{kV}$ | Grid frequency | $f = 50\ \mathrm{Hz}$ |

**3.1** Draw the circuit diagram of a four-quadrant converter, where the semiconductors are treated as ideal switches.

**3.2** Draw qualitatively the switching functions of the 4QC-switches of two parallel four-quadrant converters in interleaving operation. Draw the transformer secondary voltages resulting from the two four-quadrant converters for a fundamental period.

**3.3** Calculate the leakage inductances of the transformer. Assume that the primary leakage inductances can be neglected. Assume that the apparent power of the transformer is 2.6 MVA.

**3.4** The two four-quadrant converters should be controlled that way that only active power is supplied from the grid (target power factor mode). Determine the phase angle of the required fundamental phasors of $u_{21}$ , $u_{22}$. Consider the case of rated load at nominal input voltage.

**3.5** Calculate the minimum required transformer winding ratio $\alpha = \frac{N_1}{N_2}$ for the case of 3.4.

**3.6** Calculate the peak voltage stress in the transistors and the diodes of the 4QC. Explain in words what has to be done to calculate the peak current stress (calculation not mandatory).

**Task 4: Line-Commutated Converter (25 Points)**

A 3-pulse thyristor controlled converter is connected to the 3-phase grid via a Dy-transformer configuration and supplies a DC-motor. The motor can be represented by an equivalent circuit consisting of a DC-voltage $U_g$ and a resistor $R$ of 2.8 Ω. The nominal value of the line voltage on the primary and secondary is 400 V.

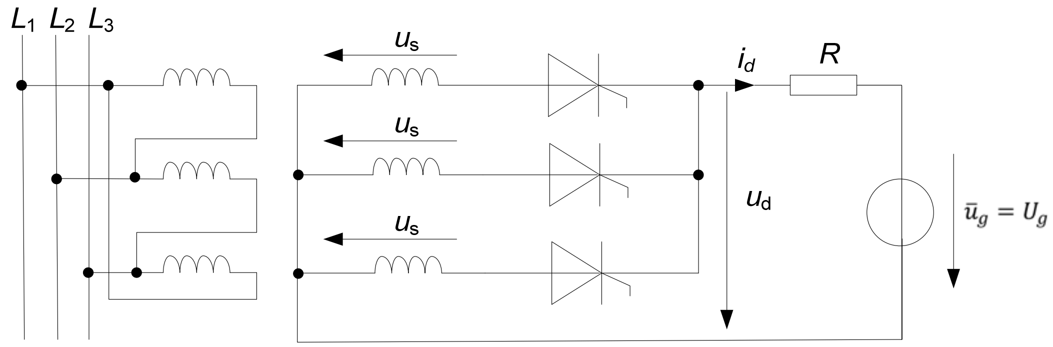



**Figure 4 : Line-commutated converter in M3 configuration**

Assuming negligible losses and ideal commutations answer the following.

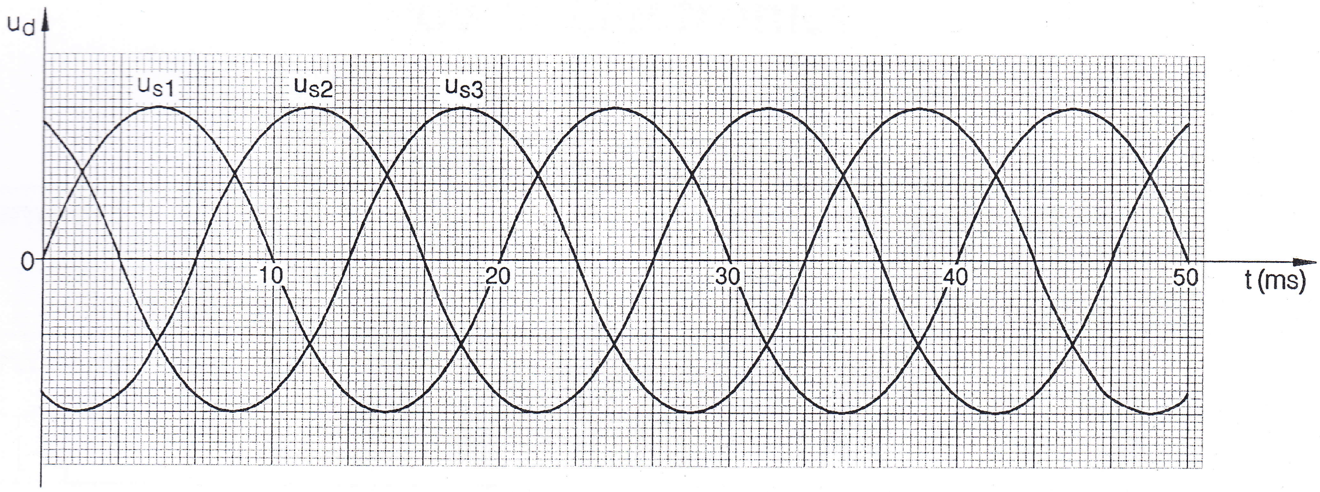
**4.1** Assume steady state condition and DC load voltage is zero.
a) Sketch the voltage $u_d$ for a control angle $\alpha = 45°$. Use the solution sheet in next page for the sketch.
b) Calculate the maximum and average value of the load current at $\alpha = 45°$.

**4.2** Assuming a DC output voltage $U_g$ which is not zero but approximately constant $u_g = U_g$, calculate $U_g$ :
a) for the case of a load current $i_d$, which is at the border between continuous and discontinuous conduction mode at a control angle of $\alpha = 45°$.
b) which ensures an average load current of $I_d$ = 70 A at the maximum output voltage.

**4.3** Consider the start-up of the system. The control angle is constantly $\alpha = 0°$, the gate is first triggered at $\omega t = 30°$ (refer to solution page).
Sketch on the solution page the instantaneous load current $i_d$(t) in the interval from $t$ = 0 to $t$ = 45 ms, if the counter voltage $u_g$(t) rises as show in the figure. Assume that the commutations are ideal and instantaneous, and the initial condition is $i_d$(0) = 0.

## Lösungsblatt zu Aufgabe 4

zu 4.1 a




zu 4.3