Department of Power Electronics and Electrical Drives

Prof. Dr.–Ing. Joachim Böcker

Power Electronics

(Trial Exam)

Family name:	**Student number:**
First name:	
Course of study:	

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

Duration: 120 minutes

Permitted resources:

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

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. Make suitable assumptions.

Good Luck!

Task 1: Buck Converter (25 Points)

Figure 1 shows a buck converter. The input voltage to the converter is U_1 = 20 V. The average output voltage U_2 is 5 V while delivering a load of 2 A. 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 100 kHz. The equivalent series resistance (ESR) of the capacitor is given as R_C = 5 mΩ and the capacitance C = 100 µF.

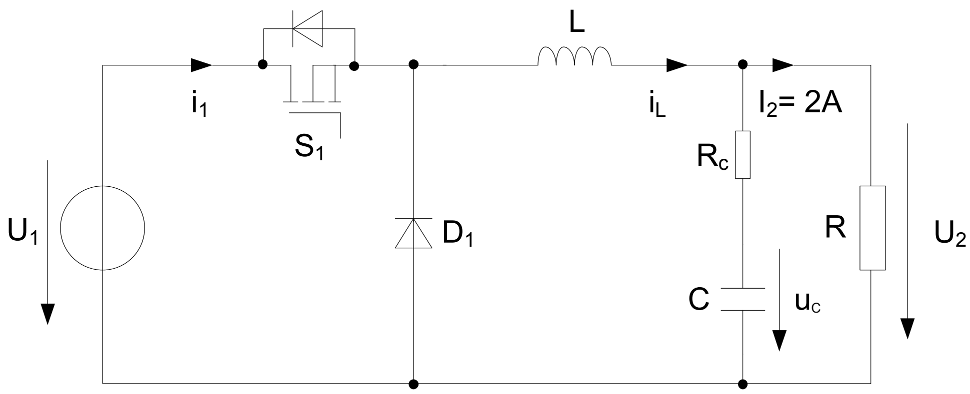

Fig.1: Buck converter

Estimate the following:

1.1 The DC value of the input current

1.2 Evaluate the inductance L to limit the ripple current of i_1 to ± 20%.

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

1.5 Sketch u_C

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

Figure 2 shows a buck-boost converter. 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.

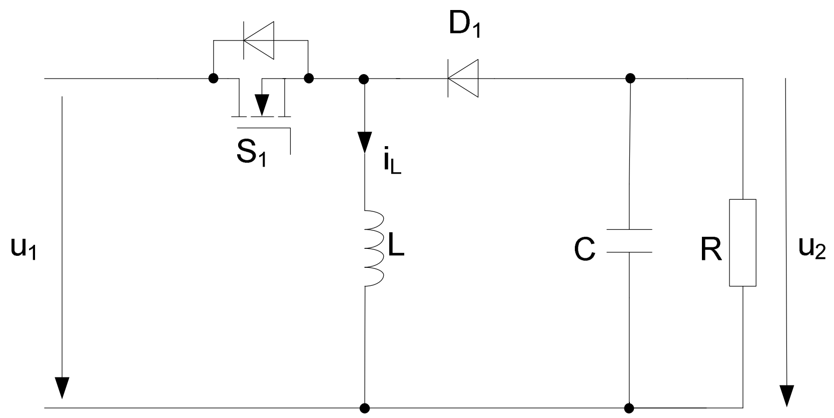

Fig.2 : Buck-Boost converter

2.1 Write down the differential equations of the converter for the two state variables during ON state i.e. when S_1 is ON.

2.2 Write down the differential equations of the converter 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 format.

2.4 Derive the gain U_2/U_1 at steady state in terms of duty cycle.

2.5 Evaluate the efficiency of the converter $\eta = (U_2\, I_2)/(U_1\, I_1)$

Task 3: Four Quadrant Converter (25 Points)

In an electric locomotive, two four-quadrant converters (4QC) are connected via a multi-winding traction transformer to the overhead line. The overhead line delivers a single-phase sinusoidal AC voltage $\boldsymbol{V_{AC}}$ with grid frequency$\boldsymbol{f}$**.** 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.

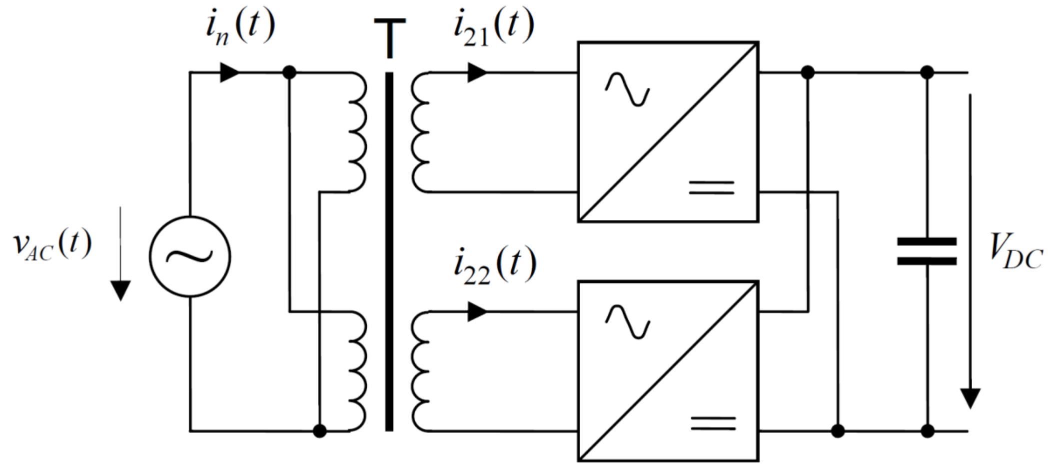

Figure 3: Power supply for an electric locomotive

Nominal output voltage	$V_{\mathrm{DC}} = 2.5\,kV$	Relative short circuit voltage	$u_{\mathrm{k}} = 20\%$
Nominal output power	$P_{\mathrm{N}} = 2\,\mathrm{MW}$	Switching frequency	$f_{\mathrm{S}} = 300\,\mathrm{Hz}$
Grid voltage	$V_{\mathrm{AC}} = 15\,\mathrm{kV}$	Interlocking time	$\tau_{\mathrm{S}} = 5\,\mu\mathrm{s}$
Grid frequency	$f = 16.67\,\mathrm{Hz}$	DC Link capacitance	$C = 12mF$

3.1 Explain that the 4QC could operate as both Buck and Boost converter.

3.2 Draw a simple diagram to explain the interleaving operation for a single 4QC.

3.3 Calculate the leakage inductance of the secondary windings, assuming that the primary leakage inductance of the traction transformer can be ignored.

3.4 Assuming that both 4QCs are lossless and that the main inductance and primary leakage inductance of the traction transformer can be ignored, derive the state-space equations describing the dynamics of the circuit system in figure 3 by using the simplified star formed equivalent circuit of the traction transformer.

3.5 Calculate the maximal ripple of the primary transformer current.

3.6 Please explain the purpose of interlocking time with the help of a circuit diagram. How does the interlocking time affect the transformer currents?

3.7 In the practical application it was found out that the DC-Link voltage oscillates at twice the grid frequency, please explain this phenomenon and design a countermeasure and complete the figure 1 with your design.

Task 4: Line Commutated Converter (25 Points)

Fig 4 below shows a M3 circuit feeding a load with constant DC current I_d.

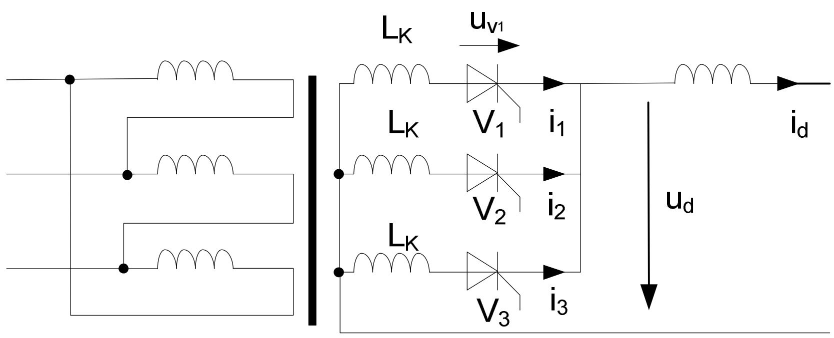

Fig 4: Line commutated converter in M3 configuration

4.1 Sketch qualitatively the resulting waveforms for thyristor currents i_1, i_2, i_3 , the thyristor voltage u_{V1} and the output voltage u_d for a control angle of α = 30° assuming ideal commutations.

4.2 Draw an equivalent circuit for a commutation of V_3 to V_1.

4.3 Derive a general formula for the current during commutation i_K, its amplitude i_K and the initial commutation/overlapping angle κ_0.

4.4 Calculate the relative inductive voltage drop.

4.5 Calculate the maximum control angle α_{max}, if the commutating inductor is L_c =1 mH, the output current is I_d = 50A, the recovery time of the thyristor is t_c = 300µs, the turns ratio of primary to secondary is 1:1 and the line voltage amplitude is 400 V.