Department of Power Electronics and Electrical Drives

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Power Electronics

08.09.2014

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.

Good Luck!

Task 1: Boost Converter (25 Points)

Figure 1 shows a boost converter. The input voltage to the converter is $U_1 = 8\,\mathrm{V}$. The average output voltage $\bar{u}_2$ should be $32\,\mathrm{V}$ while delivering a load with a DC content of $4\,\mathrm{A}$. 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 25 kHz. The equivalent series resistance of the capacitor is given as $R_C = 25\,\mathrm{m\Omega}$ and the capacitance as $C = 500\,\mu\mathrm{F}$.

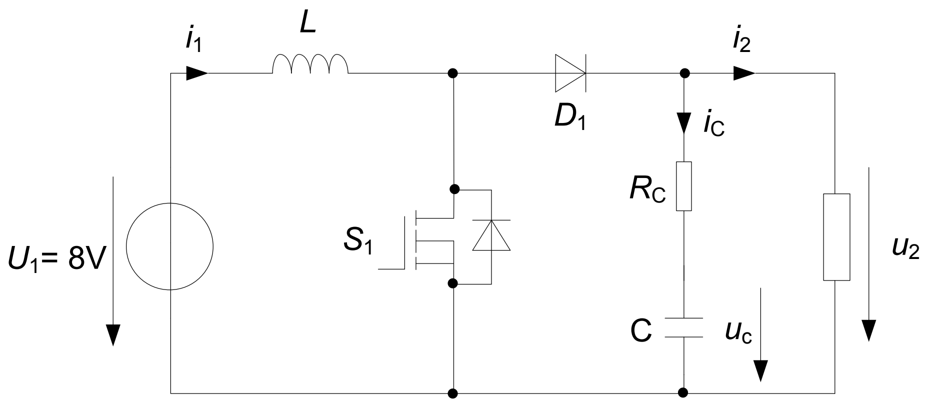


Figure 1: Boost converter

Note: For questions 1.1 to 1.5, R_C can be considered zero.

Estimate the following:

1.1 The DC content of the input current i_1.

1.2 Evaluate the 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 Assume that the above results remain valid even for a small value of $R_C = 25\,\mathrm{m\Omega}$. Evaluate the ripple voltage across R_C.

Task 2: Buck converter (25 Points)

Figure 2 shows a non-ideal buck converter. The source and inductor resistances are represented by R_1 and R_L respectively. The devices 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.

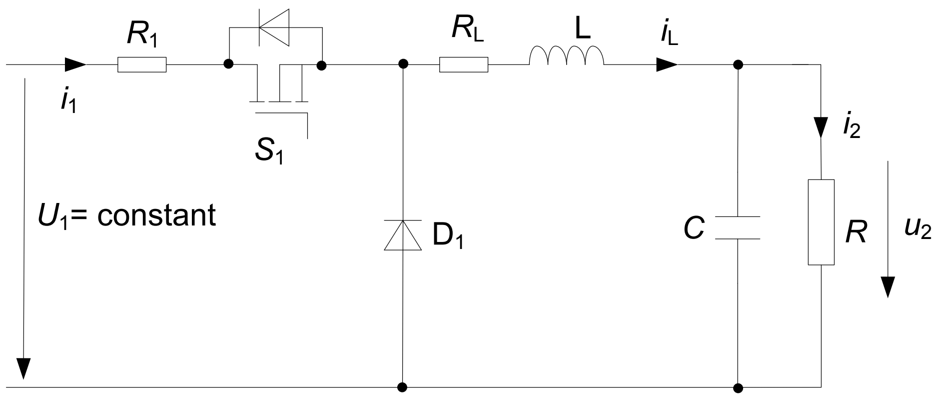


Figure 2: Buck converter

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 matrix notation.

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

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

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.

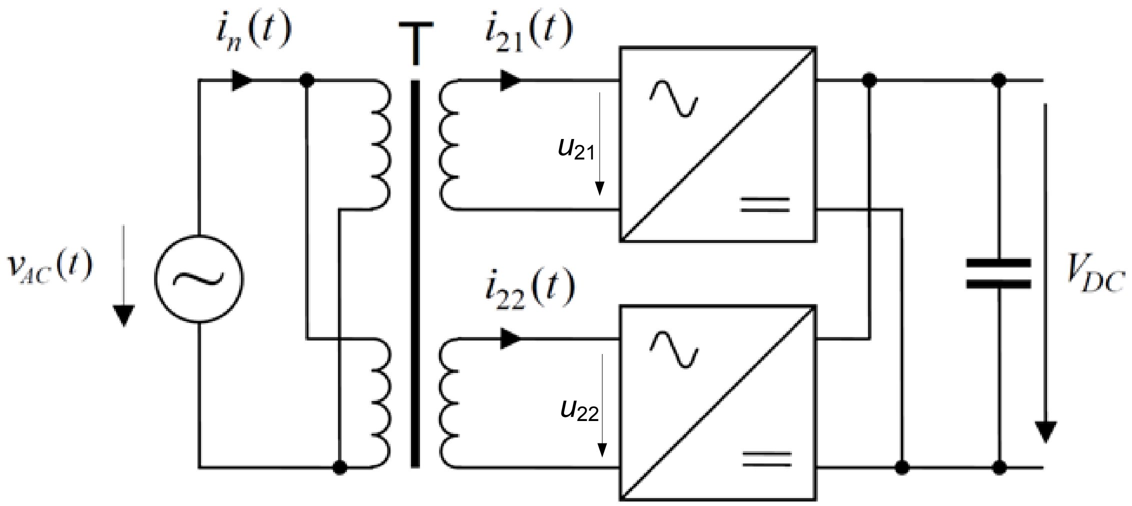


Figure 3: Power supply for an electric locomotive

Nominal output voltage	$V_{\mathrm{DC}} = 1.8\ \mathrm{kV}$	Grid voltage	$V_{\mathrm{AC}} = 25\ \mathrm{kV}$
Nominal output power	$P_{\mathrm{N}} = 2.4\ \mathrm{MW}$	Grid frequency	$f = 50\ \mathrm{Hz}$
Transformer's nominal apparent power	$S_{\mathrm{N}} = 2.6\ \mathrm{MVA}$	Switching frequency	$f_{\mathrm{S}} = 500\ \mathrm{Hz}$
Transformer's short circuit voltage	$\mathrm{u_k} = 19\%$		
(each secondary)			

3.1 Draw the circuit diagram of a four-quadrant converter with the semiconductors treated as ideal switches.

3.2 Draw qualitatively the switching functions of the 4QC-switches of the 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.

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 nominal 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 line-commutated converter in M2-configuration supplies a DC-motor with a well smoothed armature current shown in figure below.

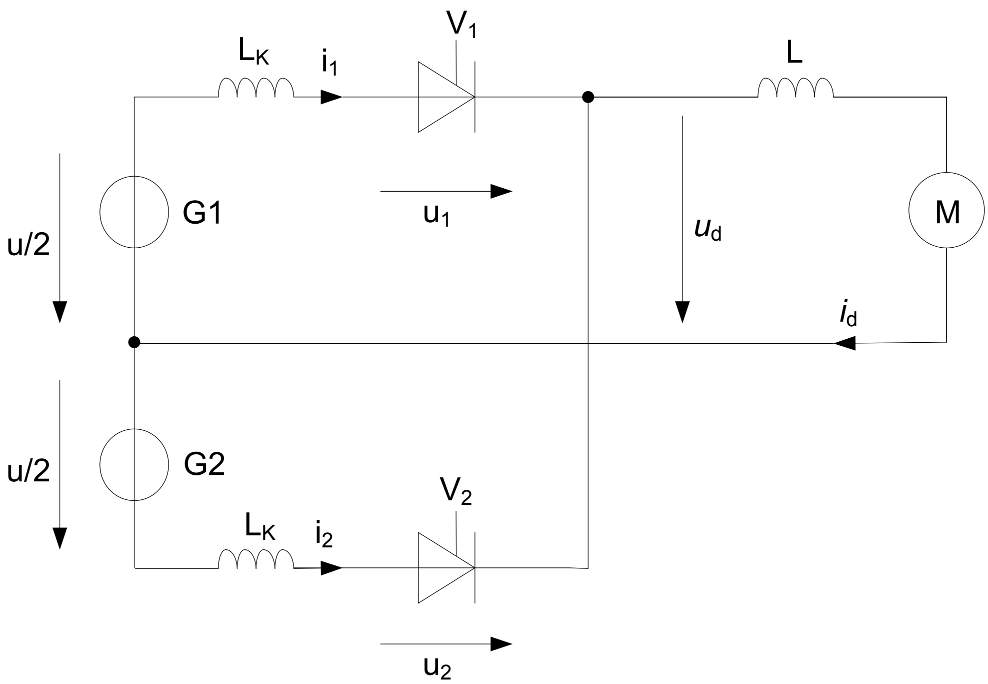


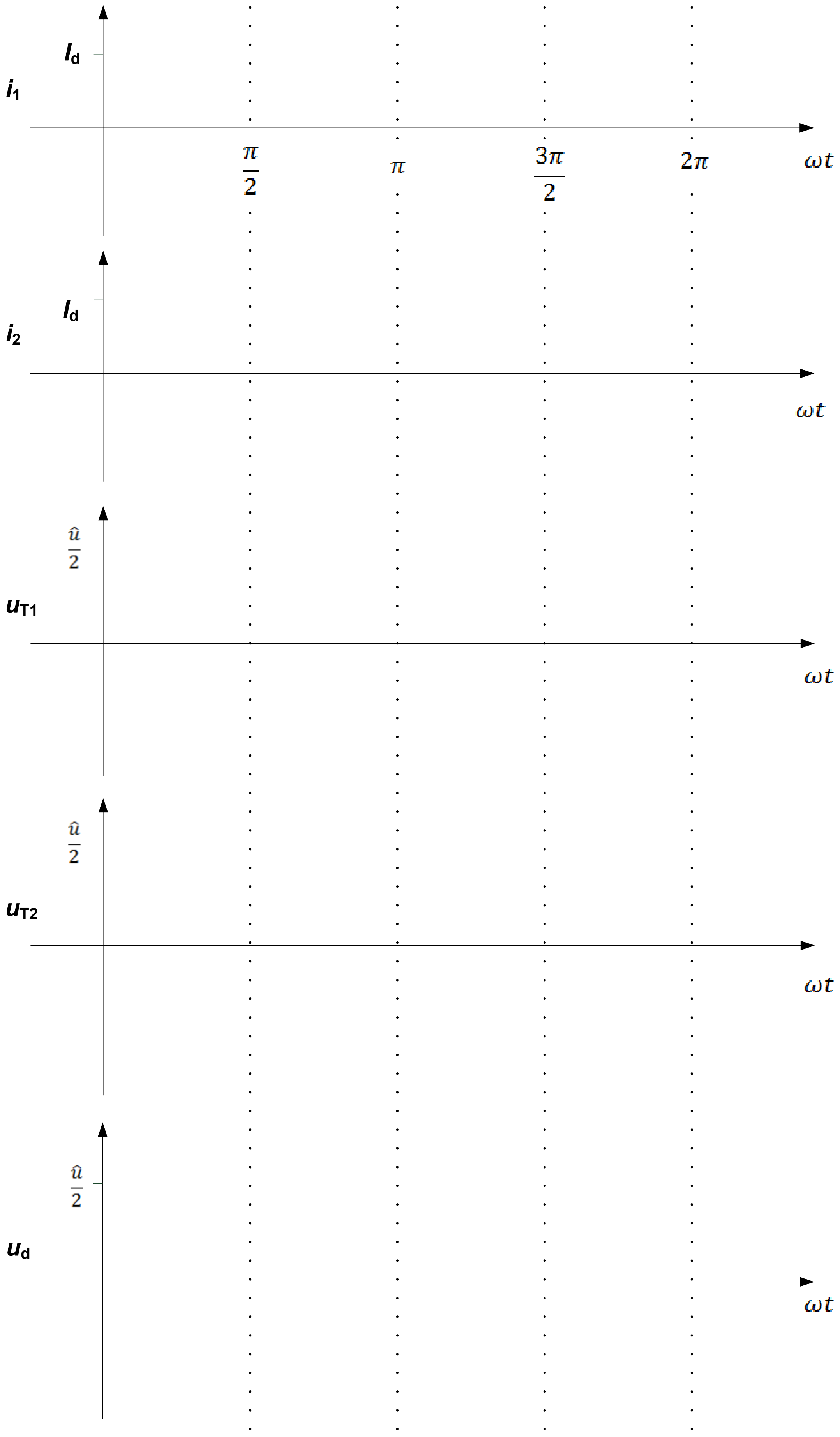
Figure 4: Line-commutated converter in M2-configuration

4.1 Sketch qualitatively the resulting waveforms for thyristor currents i_1, i_2, the thyristor voltages u_{T1}, u_{T2} and the output voltage u_d for a control angle of α = 45° assuming ideal commutations.

4.2 Derive a formula for the current i_1 during commutation for $\alpha = 0$.

4.3 Calculate the inductive voltage drop due to the commutation.

4.4 Calculate the maximum control angle α_{max}, if the commutating inductors are $L_K = 1\ \mathrm{mH}$, the output current is $I_d = 50\ \mathrm{A}$, the recovery time of the thyristors to block the recurring positive voltage is $t_c = 300\mu\mathrm{s}$ and the line voltage amplitude is 400 V.


I_d
i_1
$\frac{\pi}{2}$
π
$\frac{3\pi}{2}$
2π
ωt
I_d
i_2
ωt
$\frac{\hat{u}}{2}$
u_{T1}
ωt
$\frac{\hat{u}}{2}$
u_{T2}
ωt
$\frac{\hat{u}}{2}$
u_d
ωt