TSTE19

Power Electronics

Examination (TEN1)

Time:	Wednesday 30th March 2016 at 8:00 – 12:00
Place:	TER4
Responsible teacher:	Tomas Jonsson
	Will visit the exam location at 8:45 and 10.
Number of tasks:	6
Number of pages:	10
Allowed aids:	Calculator
Total points:	70
Notes:	A pass on the exam requires approx. 30 points.
	Describe your calculations clearly and detailed, explaining your methods, assumptions and equations used. When a question is dependent on result from an earlier question which you fail to complete, then its better to assume some value for this result in order to present the calculation methodology.

Question 1

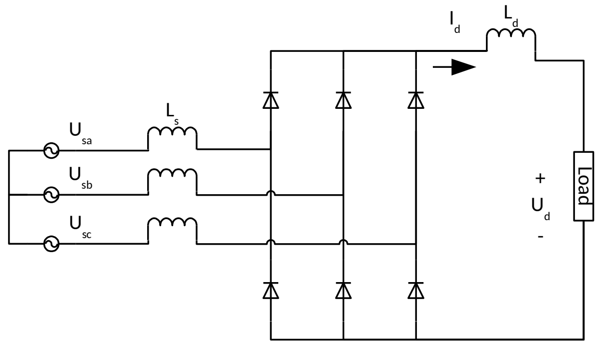


Figure 1

a) A three-phase diode rectifier according to Figure 1 is connected to the sinusodial ac-voltages U_{sa}, U_{sb} and U_{sc}. The ac-voltages have 120 degree phase shift in the order a-b-c. Define the order in which the diodes will conduct by assigning numbers (1-6) to each diode. (2)

b) A diode rectifier according to Figure 2: has an inductance, L, and a voltage source E_d on the dc-side. How will the current, i, change if the dc-voltage E_d is increased. (2)

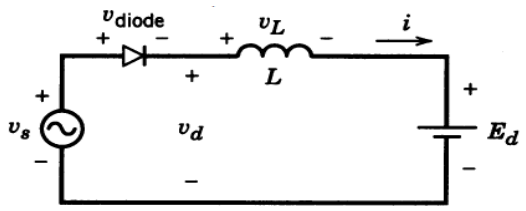


Figure 2:

c) A full-bridge inverter is producing an output voltage, υ_o, with the harmonic spectra according to Figure 3, where m_f is the frequency modulation index. Draw the voltage waveform and state the name of the PWM switching scheme used. (2)

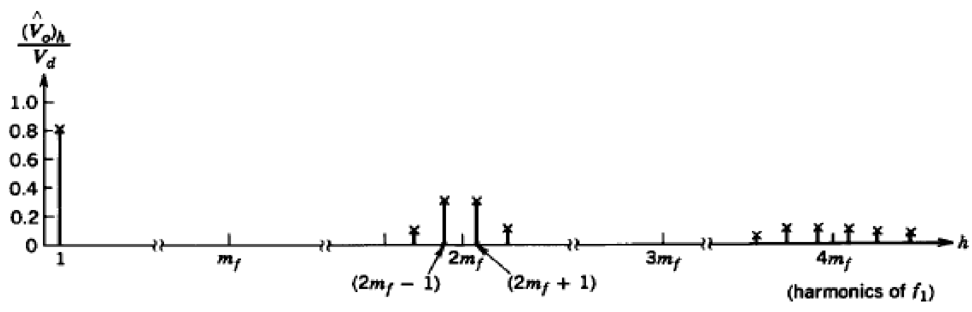
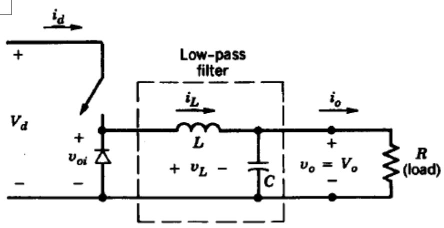


Figure 3

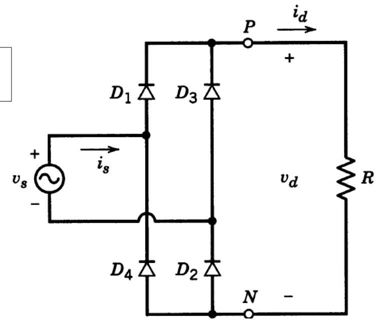
d) List three types of semiconductors which has the capability to turn-off current by the action of a dedicated control input. (3)

e) For each of the four converter circuits below find the corresponding waveform figure that presents the main voltage and/or current. One wave form for each circuit only. (3)

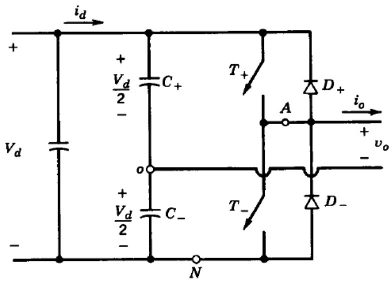
C1



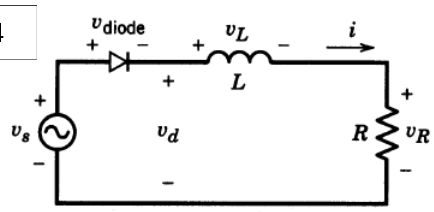
C2



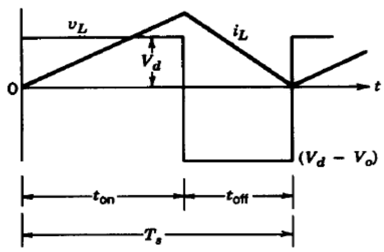
C3



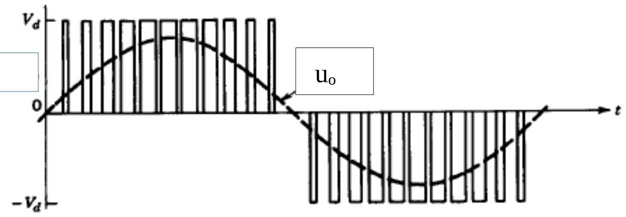
C4



W1



W2



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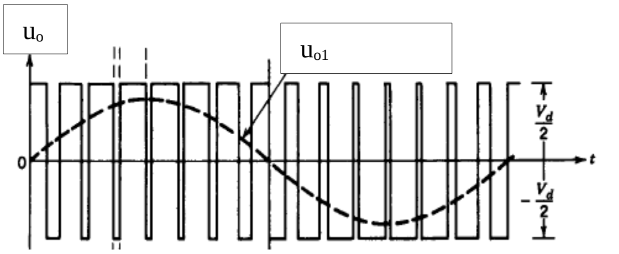

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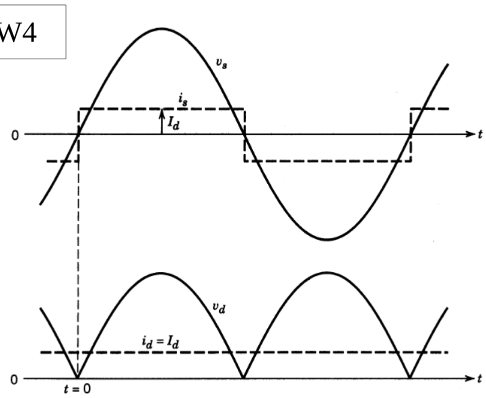
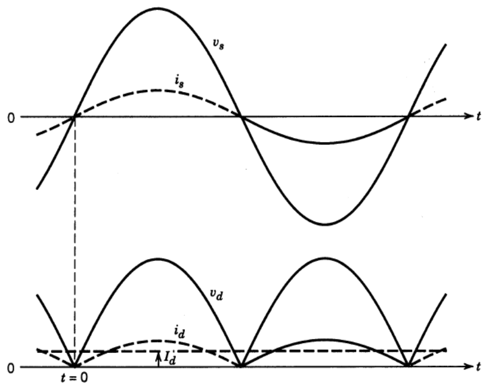
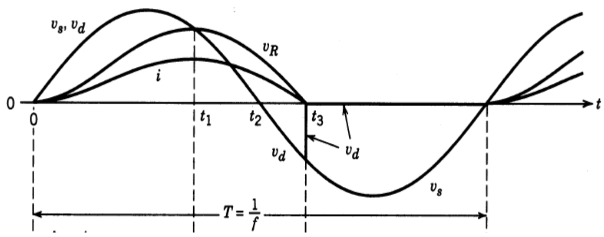


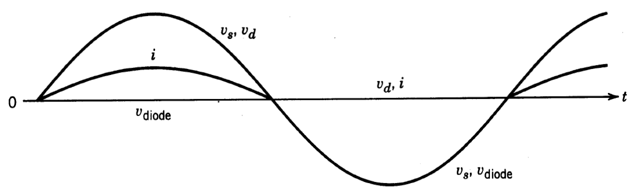
W5



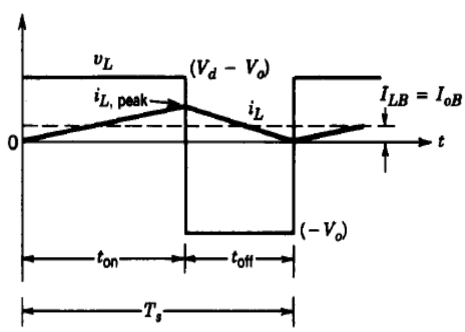
W6



W7



W8



Question 2

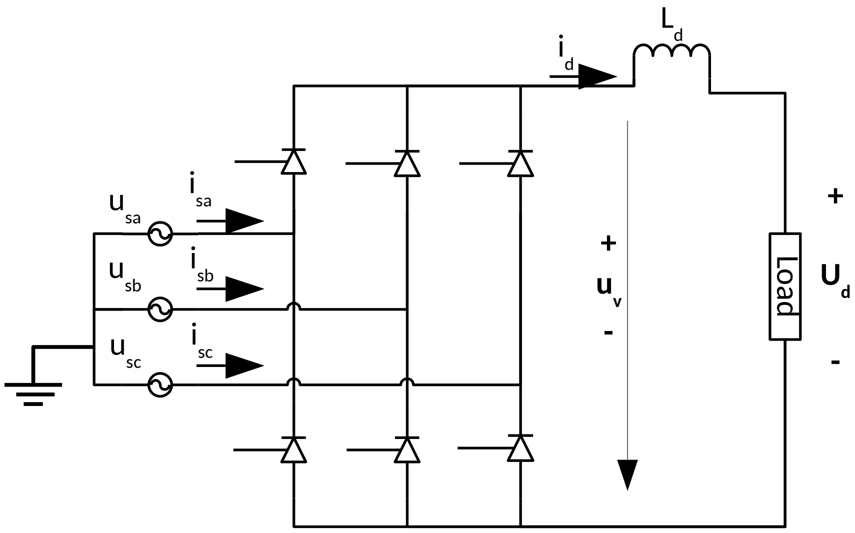


Figure 4

A three phase thyristor rectifier as shown by Figure 4 is connected to a voltage source with a phase-ground voltage U_s=240 Vrms. The commutation inductance can be neglected and the dc-side current considered smooth through the inductance L_d.

a) Calculate the average dc-load voltage, U_d, for a firing angle α=20 deg. (2)

b) Determine the average dc-current considering a resistive load of 4 kW. (2)

c) Determine the displacement power factor. (2)

d) Calculate the ac-side fundamental frequency rms current (i_{sa}). Assume zero losses of the thyristor converter. (2)

e) Draw the waveform of the three phase source currents, i_{sa}, i_{sb} and i_{sc}. (2)

f) Determine the reactive power. (2)

Question 3

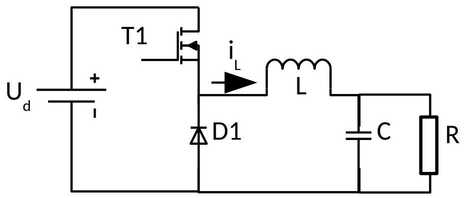


Figure 5

In the buck converter in Figure 5 which is feeding a resistive load, R=2 ohm, the current, $i_{L,}$ should be continuous. The MOSFET T1 is operated with a switching frequency f_{sw} = 120 kHz and a duty cycle of 0.75. The input voltage U_d = 12 V.

a) Determine the average output voltage, U_o, across the load resistance. (3)

b) Determine the average current through the inductance L. (2)

c) Determine the minimum inductance related to continuous current and calculate the peak current through the inductance L. Assume the output capacitance C is large enough to get a smooth voltage. (4)

d) Draw the waveforms of the inductor voltage, inductor current and MOSFET current during one switching cycle considering the minimum inductance for continuous current. (2)

Question 4

A buck converter as in Figure 5, is operated at the limit between continuous and discontinuous current with a peak inductor current of 20 A. The converter is operated with a switching frequency f_{sw} = 50 kHz and a duty cycle of 0.75 which gives an output voltage of 12 V.

a) Calculate the RMS value of the MOSFET T1 current. (4)

b) <u>Calculate the conduction losses</u> in the MOSFET T1 if the on-state resistance $R_{ds(on)}$ = 0.05 ohm. (3)

c) <u>Determine the efficiency</u> of the converter assuming switching losses and diode losses to be negligible. (2)

d) Determine the required thermal resistance of the heatsink (R_{thHA}) for the MOSFET T1 in order to keep the heatsink temperature, $T_H \leq 70$ °C and the junction temperature, $T_J \leq 100$ °C. The MOSFET has a thermal resistance R_{thJH} = 12.0 °C/W. The ambient temperature, T_A = 25 °C. (4)

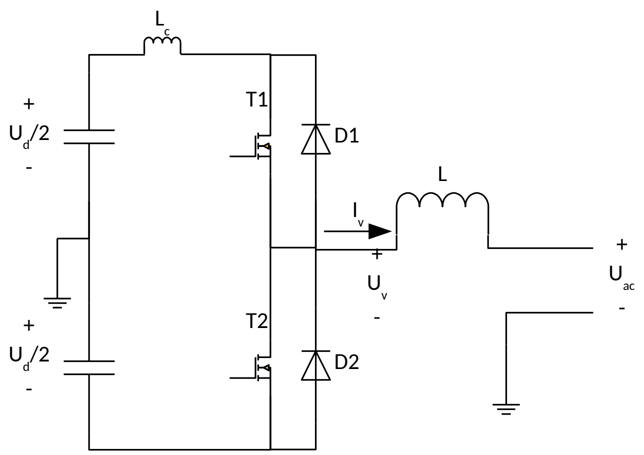


Figure 6

Question 5

A half-bridge voltage source converter is connected between a dc-source and an ac-load as shown by Figure 6. The dc-side has a parasitic inductance L_c = 70 nH. The control of the switched output voltage is done through pulse width modulation (PWM) with a switching frequency f_{sw}=950 Hz, in order to obtain a 50 Hz voltage component with a defined magnitude.

a) What is the maximum amplitude modulation ratio, m_a, for a dc-side voltage, U_d=48 V when the rms magnitude of the 50 Hz component, U_{v1}, shall be controllable between 10 Vrms and 15 Vrms. (4)

b) Consider an interval during switching where initially Diode D2 is conducting and consequently the current I_v is positive. Draw the waveforms of current and voltage of T1, D1, T2 and D2 for the switching sequence listed below. Assume the current Iv is constant during this interval. Consider the rise and fall times for both current and voltage to be 1 µs. (3)

- t = 1 µs, T2 turn-off
- t = 5 µs, T1 turn-on
- t = 10 µs, T1 turn-off
- t = 15 µs, T2 turn-on

c) Determine the rate-of-rise of current through a MOSFET at turn-on, considering very fast gate control causing the voltage across the MOSFET to fall to zero instantaneously. E.g. consider the case when D2 is conducting, T2 is off and T1 is turning on. The dc-voltage U_d shall be considered to be constant, related to a large capacitance. (3)

Question 6

A gate drive shall be designed for the half-bridge converter in Figure 6. An equivalent circuit to analyze the switching of the MOSFET T1 is shown in Figure 7. Here the MOSFET is represented by the capacitances C_{gd}=150 pF, C_{gs}=1.5 nF and a current source I_{ds}. Figure 8 shows the switching waveforms of the voltages and current through the MOSFET. The gate is controlled by the voltage V_{GG} which switches instantaneously from 0 V to 15 V at turn-on. The current I_v can be considered to be constant, and flowing out of the converter.

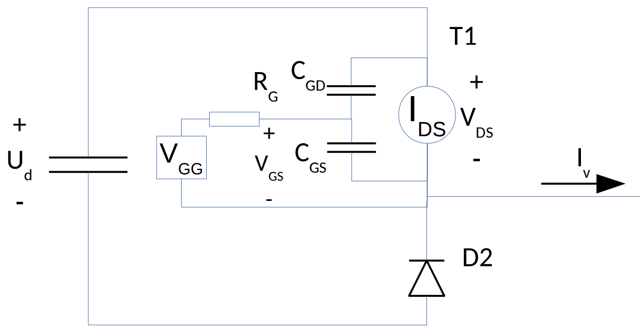


Figure 7

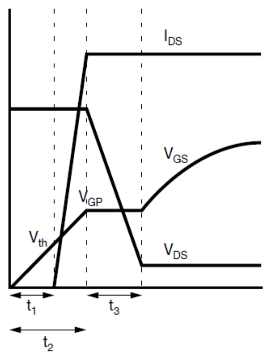


Figure 8

a) Determine the turn-on delay, t_1 of the MOSFET, from the time when V_{GG} switches from 0 V to 15 V to the time when the current I_{ds} starts rising. R_g = 680 ohm, V_{th} = 3 V. (4)

b) Determine the total delay, t_2 of the MOSFET, until full current I_v = 12 A is reached. Consider a rate of rise of drain current dI_{ds}/dt = 10 A/µs. (3)

c) Determine the rate of decay of the voltage across the MOSFET, dV_{ds}/dt, during the time when the gate voltage V_{GS} is constant at the plateau level V_{GP} = 7 V. (5)

Formula collection TSTE19 Power Electronics

Fourier series coefficients using symmetry,

Even	$f(-t) = f(t)$	$b_h = 0$	$a_h = \frac{2}{\pi}\int_0^{\pi} f(t)cos(h\omega t)d(\omega t)$
Odd	$f(-t) = -f(t)$	$a_h = 0$	$b_h = \frac{2}{\pi}\int_0^{\pi} f(t)sin(h\omega t)d(\omega t)$
Half-wave	$f(t) = -f\left(t+\frac{1}{2}T\right)$	$a_h = b_h = 0$ for even h	
		$a_h = \frac{2}{\pi}\int_0^{\pi} f(t)cos(h\omega t)d(\omega t)$ for odd h	
		$b_h = \frac{2}{\pi}\int_0^{\pi} f(t)sin(h\omega t)d(\omega t)$ for odd h	
Even quart-wave	Even and half-wave	$b_h = 0$ for all h	
		$a_h = \frac{4}{\pi}\int_0^{\frac{\pi}{2}} f(t)cos(h\omega t)d(\omega t)$ for odd h, $a_h = 0$ for even h	
Odd quarter-wave	Odd and half-wave	$a_h = 0$ for all h	
		$b_h = \frac{4}{\pi}\int_0^{\frac{\pi}{2}} f(t)sin(h\omega t)d(\omega t)$ for odd h, $b_h = 0$ for even h	

Undamped resonant circuits

Even	$f(-t) = f(t)$	$b_h = 0$	$a_h = \frac{2}{\pi}\int_0^{\pi} f(t)cos(h\omega t)d(\omega t)$
Odd	$f(-t) = -f(t)$	$a_h = 0$	$b_h = \frac{2}{\pi}\int_0^{\pi} f(t)sin(h\omega t)d(\omega t)$
Half-wave	$f(t) = -f\left(t+\frac{1}{2}T\right)$	$a_h = b_h = 0$ for even h	
		$a_h = \frac{2}{\pi}\int_0^{\pi} f(t)cos(h\omega t)d(\omega t)$ for odd h	
		$b_h = \frac{2}{\pi}\int_0^{\pi} f(t)sin(h\omega t)d(\omega t)$ for odd h	
Even quart-wave	Even and half-wave	$b_h = 0$ for all h	
		$a_h = \frac{4}{\pi}\int_0^{\frac{\pi}{2}} f(t)cos(h\omega t)d(\omega t)$ for odd h, $a_h = 0$ for even h	
Odd quarter-wave	Odd and half-wave	$a_h = 0$ for all h	
		$b_h = \frac{4}{\pi}\int_0^{\frac{\pi}{2}} f(t)sin(h\omega t)d(\omega t)$ for odd h, $b_h = 0$ for even h	

Integration rules

$\int_a^b f(x)dx = \int_A^B f(g(t))g'(t)dt$ if $a = g(A)$, $b = g(B)$ and g is monotone in [A,B]

$\int_a^b sin(x)dx = [-cos(x)]_a^b$

$\int_a^b cos(x)dx = [sin(x)]_a^b$