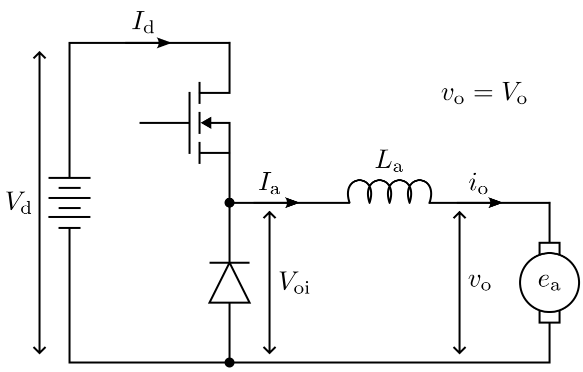
Försättsblad till skriftlig tentamen vid Linköpings Universitet

Datum för tentamen	2023-10-20
Sal	TER1, TERD, TERF
Tid	14-18
Kurskod	TSTE25
Provkod	TEN1
Kursnamn	Effektelektronik (Power Eectronics)
Institution	ISY
Antal uppgifter som ingår i tentamen	5
Antal sidor på tentamen (inkl. försättsbladet)	5
Jour/kursansvarig	Lars Eriksson
Telefon under skrivtid	079-061 20 73 (Arvind)
Besöker salen ca.	15 och 17
Tillåtna hjälpmedel	Vetenskaplig räknare, miniräknare, 1 A4 medformler och information
Övrigt	Betygsgränser: 20 poäng = godkänd

1. (a) (1 point) Draw the ideal characteristics for the Diode.
   (b) (2 points) Draw the MOSFET drain current and the drain-to-source voltage when a positive pulse voltage is applied across the gate-source terminal.
   (c) (2 points) When are the ideal characteristics used, and when are the more complicated characteristics (non-ideal) used?

2. The switched dc-dc step-down converter shown in Figure 1 controls a dc machine with an armature inductance $L_a = 0.2\,\text{mH}$. The armature resistance can be neglected. The armature current i_o is 5 A. The switching frequency $f_{sw} = 30\,\text{kHz}$ and the duty cycle, $D = 0.8$. Consider all the components to be ideal.

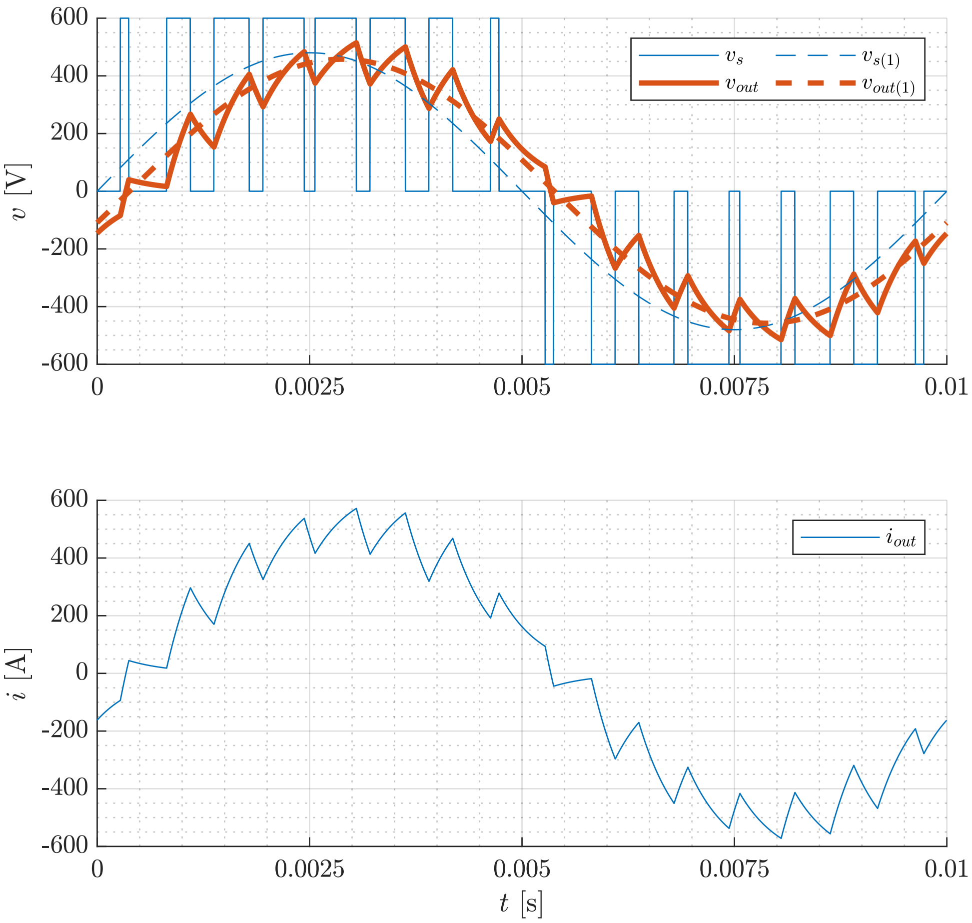


Figur 1: Step-down DC-DC converter.

   (a) (1 point) The output voltage, $V_o = 200\,\text{V}$. Calculate the input voltage, V_d.
   (b) (2 points) Find the ripple in the armature current.
   (c) (2 points) Calculate the maximum and the minimum value of the armature current.
   (d) (2 points) The load on the machine is reduced. Calculate I_a when the converter is on the boundary between continuous and discontinuous mode.
   (e) (4 points) The load on the DC machine gives $I_a = 2\,\text{A}$. Is the converter in discontinuous mode? Note: The duty-cycle of the converter is changed

3. An n-channel power MOSFET, a VMO 400-02F made by IXYS, is to be used in a converter (*datasheet is attached*). The MOSFET is to conduct a continuous current of 300 A when on and the switching frequency is 10 kHz with a 50% duty cycle. The input voltage is 100 V. The internal junction temperature is not to exceed 100°C and the maximum ambient temperature is 35°C.
   (a) (5 points) Calculate the total MOSFET power losses (assume the same time for voltage and current transients, i.e., $t_{ri} = t_{fv} = t_r$ and $t_{fi} = t_{rv} = t_f$).
   (b) (2 points) Specify the thermal resistance of the required heat sink (Assume that the MOSTFET has no heat transfer paste).
   (c) (2 points) Determine the peak MOSFET drain-to-source voltage during the switching transient if the blocking voltage (MOSFET drain-to-source voltage when it is completely turned off) is 100 V and the parasitic inductance is 100 nH.

4. The output voltages and current of a singe-phase full-bridge inverter are shown in the figure. Determine the following:
   (a) (1 point) Type of modulation (unipolar or bipolar).
   (b) (2 points) Switching frequency.
   (c) (3 points) Inductance.
   (d) (2 points) Peak fundamental current.
   (e) (2 points) Pole-to-pole DC-link voltage (V_d) and modulation index (m_a).
   (f) (2 points) Active power on the load at the fundamental frequency.
   (g) (1 point) Phase angle of the fundamental current with respect to the inverter side voltage.
   (h) (2 points) Active and reactive power on the converter at the fundamental frequency.



Figur 2: Single-phase DC to AC full-bridge inverter output waveforms.

5. The problem with ripple in the output current from a single-phase full bridge converter is to be studied. The first harmonic of the output voltage is given by $V_{o(1)}$ at $f_1 = 50\,\text{Hz}$. The load is given in the figure as $L = 10\,\text{mH}$ in series with an ideal voltage source $e_o(t)$. It is assumed that the converter operates in sinusoidal PWM mode, bipolar modulation.

$$e_o(t) = \sqrt{2}\,220\,\sin(2\pi\, f_1\, t)$$

(a) (1 point) The frequency of the triangular signal is 1050 Hz. Calculate the frequency modulation ratio (or pulse number), m_f.

(b) (1 point) Find the dc-voltage when the converter fundamental RMS output voltage $V_{o(1)}$ is 230 V and modulation index, $m_a = 0.6$.

(c) (2 points) Determine the RMS fundamental output current (i.e., current through the inductor).

(d) (3 points) Determine the RMS and frequency of the highest output ripple current component.

(e) (3 points) If a Unipolar modulation is used, determine the RMS and frequency of the highest output ripple current component.

Note: Ripple here is referred to as distortion, which is the alteration of the original shape of a signal. Here ripple means the alteration of the waveform from an ideal sinusoidal signal.

Tabell 1: Generalized harmonics of a half-bridge inverter output voltage for a large m_f.

$h \downarrow \quad m_a \rightarrow$	0.2	0.4	0.6	0.8	1
1 Fundamental	0.2	0.4	0.6	0.8	1
m_f	1.242	1.15	1.006	0.818	0.6023
$m_f \pm 2$	0.061	0.061	0.131	0.22	0.318
$m_f \pm 4$					0.018
$2m_f \pm 1$	0.19	0.326	0.37	0.314	0.181
$2m_f \pm 3$		0.024	0.071	0.139	0.212
$2m_f \pm 5$				0.013	0.033
$3m_f$	0.335	0.123	0.083	0.171	0.133
$3m_f \pm 2$	0.044	0.139	0.203	0.176	0.062
$3m_f \pm 4$		0.012	0.047	0.104	0.157
$3m_f \pm 6$				0.016	0.044
$4m_f \pm 1$	0.163	0.157	0.088	0.105	0.068
$4m_f \pm 3$	0.012	0.070	0.132	0.115	0.009
$4m_f \pm 5$			0.034	0.084	0.119
$4m_f \pm 7$				0.017	0.05

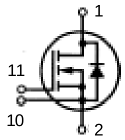
Note: output voltage ($\hat{V}_o$) is $\hat{V}_o = m_a\, V_d/2$.

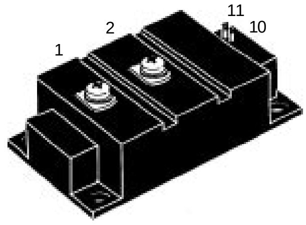
MegaMOS™FET Module

VMO 400-02F

V_{DSS} = 200 V
I_{D25} = 418 A
$R_{DS(on)}$ = 4.2 mΩ

N-Channel Enhancement Mode





1 = Drain 2 = Source
10 = Kelvin Source 11 = Gate

Symbol	Test Conditions	Maximum Ratings	
V_{DSS}	T_J = 25°C to 150°C	200	V
V_{DGR}	T_J = 25°C to 150°C; R_{GS} = 10 kΩ	200	V
V_{GS}	Continuous	±20	V
V_{GSM}	Transient	±30	V
I_{D25}	T_K = 25°C	418	A
I_{DM}	T_K = 25°C, t_P = 10 µs	1672	A
P_D	T_C = 25°C T_K = 25°C	2450 1640	W W
T_J		-40 ...+150	°C
T_{JM}		150	°C
T_{stg}		-40 ... +125	°C
V_{ISOL}	50/60 Hz t = 1 min I_{ISOL} ≤ 1 mA t = 1 s	3000 3600	V~ V~
M_d	Mounting torque (M6) Terminal connection torque (M5)	2.25-2.75/20-25 2.5-3.7/22-33	Nm/lb.in. Nm/lb.in.
Weight	typical including screws	250	g

Symbol	Test Conditions	Characteristic Values (T_J = 25°C, unless otherwise specified) min.	typ.	max.	
V_{DSS}	V_{GS} = 0 V, I_D = 12 mA	200			V
$V_{GS(th)}$	V_{DS} = 20 V, I_D = 120 mA	3		6	V
I_{GSS}	V_{GS} = ±20 V DC, V_{DS} = 0			±500	nA
I_{DSS}	V_{DS} = V_{DSS}, V_{GS} = 0 V T_J = 25°C V_{DS} = 0.8 • V_{DSS}, V_{GS} = 0 V T_J = 125°C			2.5 12	mA mA
$R_{DS(on)}$	V_{GS} = 10 V, I_D = 0.5 • I_{D25} Pulse test, t ≤ 300 µs, duty cycle d ≤ 2 %			4.2	mΩ

Features

- International standard package
- **D**irect **C**opper **B**onded Al_2O_3 ceramic base plate
- Isolation voltage 3600 V~
- Low $R_{DS(on)}$ HDMOS™ process
- Low package inductance for high speed switching
- Kelvin Source contact for easy drive

Applications

- AC motor speed control for electric vehicles
- DC servo and robot drives
- Switched-mode and resonant-mode power supplies
- DC choppers

Advantages

- Easy to mount
- Space and weight savings
- High power density
- Low losses

IXYS reserves the right to change limits, test conditions, and dimensions.

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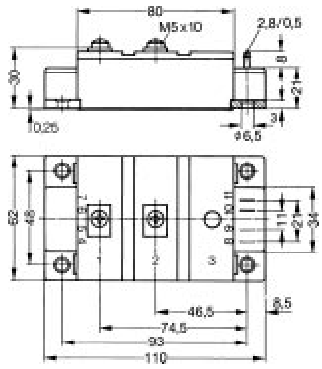
Tel: +49-6206-5030 Fax: +49-6206-503629

Symbol	Test Conditions	Characteristic Values (T_J = 25°C, unless otherwise specified) min.	typ.	max.	
g_{fs}	V_{DS} = 10 V; I_D = 0.5 • I_{D25} pulsed		380		S
C_{iss}	V_{GS} = 0 V, V_{DS} = 25 V, f = 1 MHz		53		nF
C_{oss}			9.6		nF
C_{rss}			3.4		nF
$t_{d(on)}$	V_{GS} = 10 V, V_{DS} = 0.5 • V_{DSS}, I_D = 0.5 • I_{D25}; R_G = 1 Ω (External)		210		ns
t_r			500		ns
$t_{d(off)}$			900		ns
t_f			350		ns
Q_g	V_{GS} = 10 V, V_{DS} = 0.5 • V_{DSS}, I_D = 0.5 • I_{D25}		2300		nC
Q_{gs}			420		nC
Q_{gd}			1150		nC
R_{thJC}				0.051	K/W
R_{thJK}	with 30 µm heat transfer paste			0.076	K/W

Dimensions in mm (1 mm = 0.0394")



Source-Drain Diode

Symbol	Test Conditions	Characteristic Values (T_J = 25°C, unless otherwise specified) min.	typ.	max.	
I_S	V_{GS} = 0 V			418	A
I_{SM}	Repetitive; pulse width limited by T_{JM}			1672	A
V_{SD}	I_F = I_S; V_{GS} = 0 V, Pulse test, t ≤ 300 µs, duty cycle d ≤ 2 %		0.9	1.2	V
t_{rr}	I_F = I_S, -di/dt = 1200 A/µs, V_{DS} = 100 V		600		ns

IXYS MOSFETS and IGBTs are covered by one or more of the following U.S. patents:
4,835,592 4,881,106 5,017,508 5,049,961 5,187,117 5,486,715
4,850,072 4,931,844 5,034,796 5,063,307 5,237,481 5,381,025