Försättsblad till skriftlig tentamen vid Linköpings Universitet

Datum för tentamen	2024-01-05
Sal	TER4
Tid	14-18
Kurskod	TSTE25
Provkod	TEN2
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	013 28 44 09
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. 1 kW, 100 V output step-up converter is to be evaluated. Consider all the components to be ideal. The input voltage is Vd = 48 V, and the switching frequency is $f_{\text{sw}} = 80\,\text{kHz}$.
   (a) (5 points) Calculate the output capacitor C when the output voltage peak-to-peak ripple is 5% of the output voltage $V_{\text{o}} = 100\,\text{V}$.
   (b) (2 points) Consider filter inductance $L = 40\,\mu\text{H}$, calculate $I_{\text{L(peak)}}$. Is the converter in continuous conduction mode?
   (c) (2 points) Consider filter inductance $L = 6\,\mu\text{H}$, calculate $I_{\text{L(peak)}}$. Is the converter in continuous conduction mode?
   (d) (2 points) Determine the conduction losses of the MOSFET if the on-state resistance of the MOSFET is $1\,\text{m}\Omega$.

3. An n-channel power MOSFET, IPD023N04NF2S by Infineon, is to be used in a step-down converter (*datasheet is attached*). The MOSFET conducts an RMS current of 100 A. The switching frequency is 10 kHz, the duty cycle (D) is 0.75 and the input voltage of the converter is 20 V.
   (a) (5 points) Calculate the total MOSFET power losses (assume the same time for voltage and current transients, i.e., $t_{\text{ri}} = t_{\text{fv}} = t_{\text{r}}$ and $t_{\text{fi}} = t_{\text{rv}} = t_{\text{f}}$).
   (b) (2 points) If the internal junction temperature is not to exceed 100°C and the maximum ambient temperature is 35°C, specify the thermal resistance of the required heat sink.
   (c) (2 points) Determine the peak MOSFET drain-to-source voltage during the turn-off transient if the parasitic inductance between the input voltage source and the MOSFET drain-terminal is 3 nH.

4. The output voltages and current of a single-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.

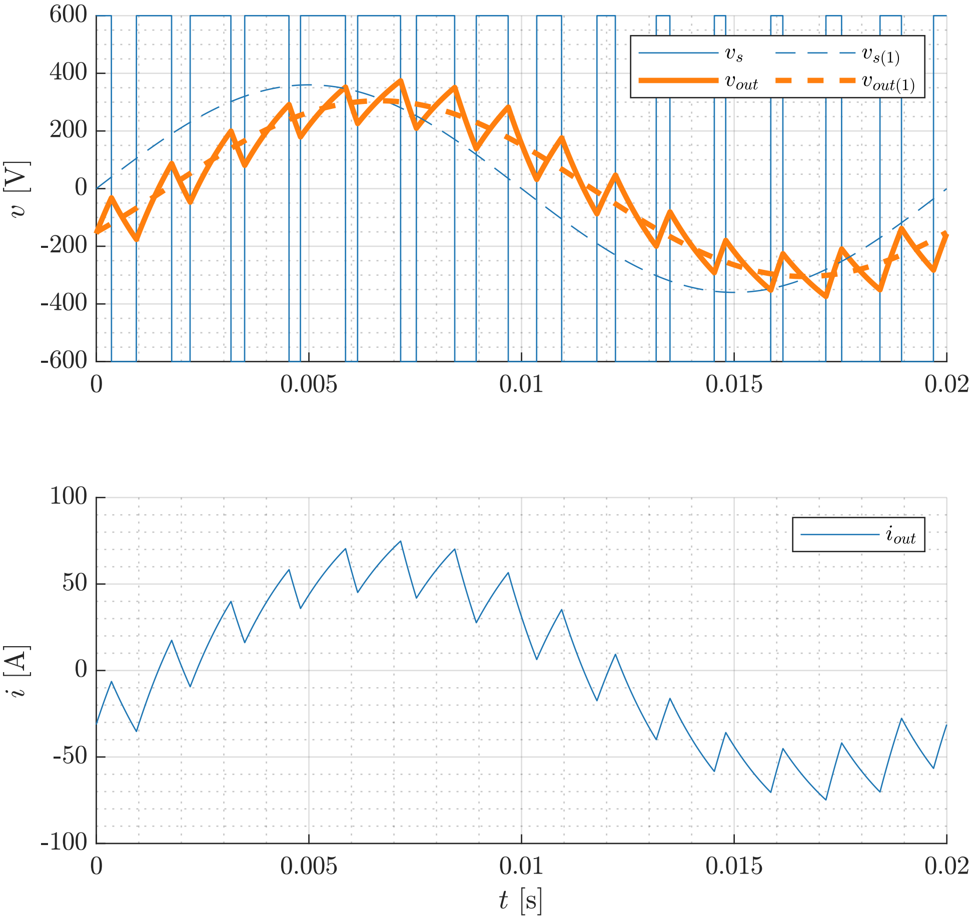

Figure 1: Single-phase DC to AC full-bridge inverter output waveforms.

5. For a full-bridge inverter with unipolar modulation, the RMS fundamental (at 150 Hz) output voltage and current are 1 kV and 180 A respectively. The inverter incorporates a filter inductor with inductance 100 μH and it operates with a modulation index of 0.8 with a switching frequency of 10 kHz.

   (a) (4 points) Determine the dc-link voltage of the inverter.

   (b) (6 points) Calculate the magnitude (in RMS) and frequency of the largest component of the output current for a modulation index of 0.8. Assume that the magnitude of all the other components of the output voltage is zero.

Table 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 $\hat{V}_o = m_a V_d/2$.

1 Maximum ratings

at T_A=25 °C, unless otherwise specified

Table 2 Maximum ratings

Parameter	Symbol	Values			Unit	Note / Test Condition
		Min.	Typ.	Max.		
Continuous drain current[1]	I_D	- - -	- - -	143 110 27	A	V_{GS}=10 V, T_C=25 °C V_{GS}=10 V, T_C=100 °C V_{GS}=10 V, T_A=25 °C, R_{THJA}=50 °C/W[2]
Pulsed drain current[3]	$I_{D,pulse}$	-	-	572	A	T_A=25 °C
Avalanche energy, single pulse[4]	E_{AS}	-	-	167	mJ	I_D=70 A, R_{GS}=25 Ω
Gate source voltage	V_{GS}	-20	-	20	V	-
Power dissipation	P_{tot}	- -	- -	150 3.0	W	T_C=25 °C T_A=25 °C, R_{THJA}=50 °C/W[2]
Operating and storage temperature	T_j, T_{stg}	-55	-	175	°C	-

2 Thermal characteristics

Table 3 Thermal characteristics

Parameter	Symbol	Values			Unit	Note / Test Condition
		Min.	Typ.	Max.		
Thermal resistance, junction - case	R_{thJC}	-	-	1.0	°C/W	-
Thermal resistance, junction - ambient, 6 cm² cooling area[2]	R_{thJA}	-	-	50	°C/W	-
Thermal resistance, junction - ambient, minimal footprint	R_{thJA}	-	-	75	°C/W	-

[1] Rating refers to the product only with datasheet specified absolute maximum values, maintaining case temperature as specified. For other case temperatures please refer to Diagram 2. De-rating will be required based on the actual environmental conditions.
[2] Device on 40 mm x 40 mm x 1.5 mm epoxy PCB FR4 with 6 cm² (one layer, 70 µm thick) copper area for drain connection. PCB is vertical in still air.
[3] See Diagram 3 for more detailed information
[4] See Diagram 13 for more detailed information

3 Electrical characteristics

at T_j=25 °C, unless otherwise specified

Table 4 Static characteristics

Parameter	Symbol	Values			Unit	Note / Test Condition
		Min.	Typ.	Max.		
Drain-source breakdown voltage	$V_{(BR)DSS}$	40	-	-	V	V_{GS}=0 V, I_D=1 mA
Gate threshold voltage	$V_{GS(th)}$	2.2	2.8	3.4	V	V_{DS}=V_{GS}, I_D=81 µA
Zero gate voltage drain current	I_{DSS}	- -	0.1 10	1 100	µA	V_{DS}=40 V, V_{GS}=0 V, T_j=25 °C V_{DS}=40 V, V_{GS}=0 V, T_j=125 °C
Gate-source leakage current	I_{GSS}	-	10	100	nA	V_{GS}=20 V, V_{DS}=0 V
Drain-source on-state resistance	$R_{DS(on)}$	- -	1.9 2.2	2.3 3.1	mΩ	V_{GS}=10 V, I_D=70 A V_{GS}=6 V, I_D=35 A
Gate resistance	R_G	-	3.0	-	Ω	-
Transconductance[1]	g_{fs}	125	-	-	S	$\|V_{DS}\|\geq 2\|I_D\|R_{DS(on)max}$, I_D=70 A

Table 5 Dynamic characteristics

Parameter	Symbol	Values			Unit	Note / Test Condition
		Min.	Typ.	Max.		
Input capacitance	C_{iss}	-	4800	-	pF	V_{GS}=0 V, V_{DS}=20 V, f=1 MHz
Output capacitance	C_{oss}	-	1800	-	pF	V_{GS}=0 V, V_{DS}=20 V, f=1 MHz
Reverse transfer capacitance	C_{rss}	-	98	-	pF	V_{GS}=0 V, V_{DS}=20 V, f=1 MHz
Turn-on delay time	$t_{d(on)}$	-	16	-	ns	V_{DD}=20 V, V_{GS}=10 V, I_D=70 A, $R_{G,ext}$=1.6 Ω
Rise time	t_r	-	15	-	ns	V_{DD}=20 V, V_{GS}=10 V, I_D=70 A, $R_{G,ext}$=1.6 Ω
Turn-off delay time	$t_{d(off)}$	-	35	-	ns	V_{DD}=20 V, V_{GS}=10 V, I_D=70 A, $R_{G,ext}$=1.6 Ω
Fall time	t_f	-	15	-	ns	V_{DD}=20 V, V_{GS}=10 V, I_D=70 A, $R_{G,ext}$=1.6 Ω

Table 6 Gate charge characteristics[2]

Parameter	Symbol	Values			Unit	Note / Test Condition
		Min.	Typ.	Max.		
Gate to source charge	Q_{gs}	-	21	-	nC	V_{DD}=20 V, I_D=70 A, V_{GS}=0 to 10 V
Gate charge at threshold	$Q_{g(th)}$	-	13.5	-	nC	V_{DD}=20 V, I_D=70 A, V_{GS}=0 to 10 V
Gate to drain charge	Q_{gd}	-	13	-	nC	V_{DD}=20 V, I_D=70 A, V_{GS}=0 to 10 V
Switching charge	Q_{sw}	-	20	-	nC	V_{DD}=20 V, I_D=70 A, V_{GS}=0 to 10 V
Gate charge total[1]	Q_g	-	68	102	nC	V_{DD}=20 V, I_D=70 A, V_{GS}=0 to 10 V
Gate plateau voltage	$V_{plateau}$	-	4.3	-	V	V_{DD}=20 V, I_D=70 A, V_{GS}=0 to 10 V
Gate charge total, sync. FET	$Q_{g(sync)}$	-	61	-	nC	V_{DS}=0.1 V, V_{GS}=0 to 10 V
Output charge	Q_{oss}	-	76	-	nC	V_{DS}=20 V, V_{GS}=0 V

[1] Defined by design. Not subject to production test.
[2] See ″Gate charge waveforms″ for parameter definition

Question:	1	2	3	4	5	Total
Points:	5	11	9	15	10	50
Score:						