2

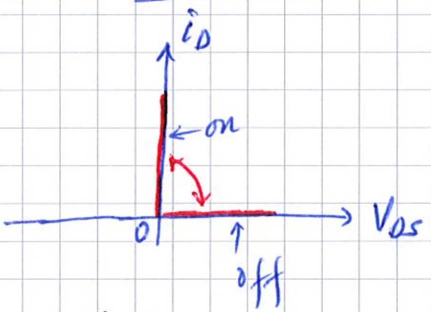
CHALMERS	Anonymous code / Anonym kod: Meftu Bera	Points for question (to be filled in by teacher) / Poäng på uppgiften (ifylles av läraren)	Consecutive page no. / Löpande sid nr: 1 Question no. / Uppgift nr: 1

(a) their main difference depends on the forward voltage drop, reverse recovery time and the blocking voltage.

- Schottky diode : low voltage drop, fast recovery, low reverse blocking
- rectifying diode : low voltage drop, large recovery, high reverse blocking
- switching diodes: high voltage drop, low recovery

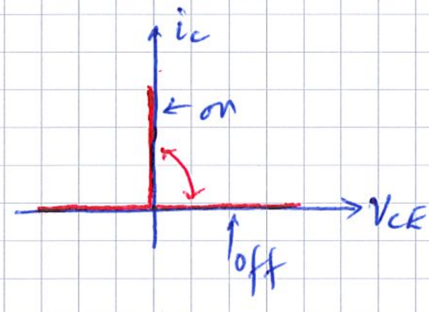
(2 pts)

(b) MOSFET



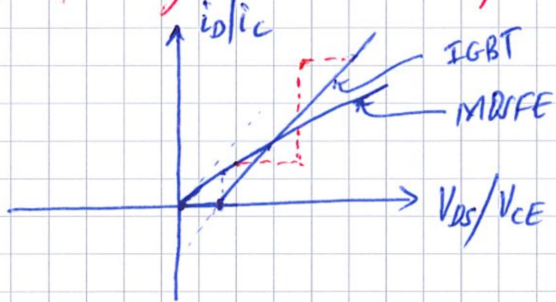
ideal characteristic

IGBT



ideal characteristic

- one difference is reverse blocking for the IGBT when a gate-emitter voltage is not applied.
- Another difference using the simplified i-v characteristics is the absence of a minimum forward voltage for the MOSFET to start conducting when a gate-source voltage is applied.



(2 pts)

(c) the main purpose of an inductor in DC/DC converters is to provide a temporary energy storage given by $W = \frac{1}{2} L i_{max}^2 = \frac{1}{2} L i_{sat}^2$.

If an air gap is used in the inductor design, the inductance value decreases as given by $L = \frac{N^2}{R_c + R_g}$ — reluctance of air gap.

--- (1)

Answer only one question on this page. Do not write on the back of this paper
Behandla endast en uppgift på detta blad. Skriv ej på baksidan

2

CHALMERS	Anonymous code / Anonym kod: Mehta Reza	Points for question (to be filled in by teacher) / Poäng på uppgiften (ifylles av lärare)	Consecutive page no / Löpande sid nr: 2
			Question no. / Uppgift nr: 1

For a given saturated (maximum) flux density in the core, the saturating current is given from Amperes law as

$$N \cdot i_{sat} = \Phi_{sat} \cdot R_{tot}$$

$$= B_{sat} \cdot A_c \cdot (R_g + R_c)$$

$$\Rightarrow i_{sat} = \frac{B_{sat} \cdot A_c \cdot (R_c + R_g)}{N}$$

air gap increases saturating current.

(2)

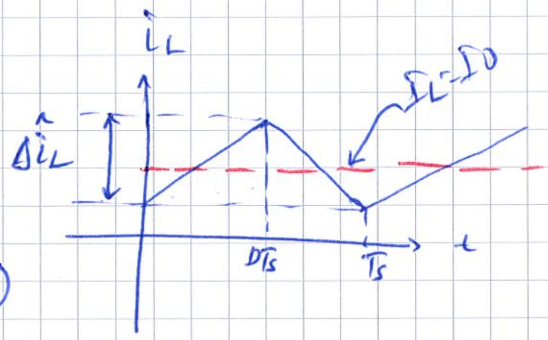
* using (1) + (2), it is possible to show that $W = \frac{1}{2} L \cdot i_{sat}^2$ increases when using an air gap.

(2 pts)

CHALMERS

Anonymous code / Anonym kod	Points for question (to be filled in by teacher) / Poäng på uppgiften (ifylles av lärare)	Consecutive page no. / Löpande sid nr
Mebtu Reza		3
		Question no. / Uppgift nr: 2

$V_0 = 12\,V$
$P_0 = 48\,W$
$V_d = 20\,V$
$f_{sw} = 20\,kHz$



(a) CCM $\Rightarrow$ $I_L = I_0 \geq \frac{1}{2}\Delta\hat{i}_L$ $\Rightarrow$ ...... (1)

$$I_L = I_0 = \frac{P_0}{V_0} = \frac{48}{12}\,A = \underline{\underline{4A}}$$

CCM $\Rightarrow$ $V_0 = DV_d$ $\Rightarrow$ $D = \frac{12}{20} = \underline{\underline{0.6}}$

when the switch is on, $V_L = V_d - V_0 = (20-12)\,V = \underline{\underline{8V}}$

$$V_L = L\cdot\frac{\Delta\hat{i}_L}{\Delta t} = \frac{L\cdot\Delta\hat{i}_L}{DT_s} = \frac{L\cdot\Delta\hat{i}_L\cdot f_{sw}}{D}$$

$$\Rightarrow \Delta\hat{i}_L = \frac{D\cdot V_L}{L\cdot f_{sw}} \quad \text{......} (2)$$

For CCM, $\frac{1}{2}\Delta\hat{i}_L \leq I_0 = I_L$

$$\Rightarrow \frac{1}{2}\frac{DV_L}{L\cdot f_{sw}} \leq I_0 \Rightarrow 1/L \leq \frac{2I_0\cdot f_{sw}}{DV_L}$$

$$\Rightarrow L \geq \frac{DV_L}{2I_0\cdot f_{sw}}$$

$$\Rightarrow L_{min} = \frac{DV_L}{2I_0\cdot f_{sw}} = \frac{(0.6)(8)}{2(4)(20\cdot10^3)}\,H = \underline{\underline{30\,\mu H}}$$

(2 pts)

(b) Using results above

$$\Delta\hat{i}_L = \frac{DV_L}{L\cdot f_{sw}} = 0.1I_0 \Rightarrow 1/L = \frac{0.1I_0\cdot f_{sw}}{DV_L} = \frac{(0.1)(4)(20\cdot10^3)}{(0.6)(8)}$$

$$\Rightarrow L = \frac{(0.6)(8)}{(0.1)(4)(20\cdot10^3)}\,H = \underline{\underline{0.6\,mH}}$$

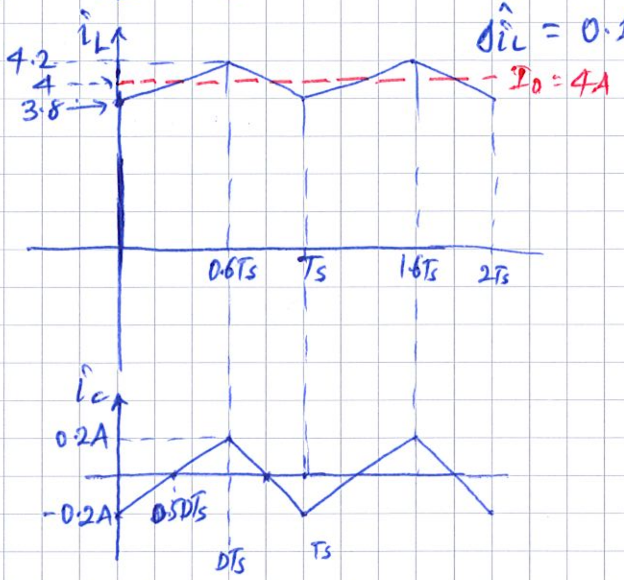
(2 pts)

Answer only one question on this page. Do not write on the back of this paper
Behandla endast en uppgift på detta blad. Skriv ej på baksidan

CHALMERS	Anonymous code / Anonym kod: Mebtu Beza	Points for question (to be filled in by teacher) / Poäng på uppgiften (ifylles av lärare)	Consecutive page no. / Löpande sid nr: 4 — Question no. / Uppgift nr: 2

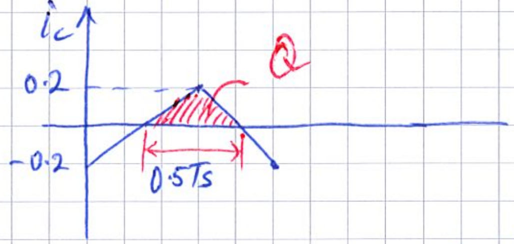
(c) $i_L = I_0 + i_c$; $I_0 = 4A$

$\Delta \hat{i}_L = 0.1 I_0 = 0.4A$



(2 pts)

(d) $V_0 = 12V$, $\Delta V_0 \le 0.01 V_0 = 0.12V$



$$\Delta V_0 = \frac{Q}{C} = \frac{\frac{1}{2}\cdot 0.5T_s \cdot \Delta \hat{i}_L/2}{C} = \frac{\frac{1}{2}\cdot(0.5)(0.2)}{C\cdot f_{sw}} = \frac{0.05}{(20\cdot 10^3)C}$$

$\Delta V_0 \le 0.12V$

$$\Rightarrow \frac{0.05}{(20\cdot 10^3)C} \le 0.12$$

$$\Rightarrow C \ge \frac{0.05}{(0.12)(20\cdot 10^3)} F$$

$$\Rightarrow C_{min} = \frac{0.05}{(0.12)(20\cdot 10^3)} F = \underline{\underline{20.83\ \mu F}}$$

(2 pts)

$N_1 : N_2 : N_3 = 1:1:1$

$V_d = 20V$

$f_{sw} = 20 \text{ kHz}$

$D = 0.3$

$L_m = 100 \, \mu H$

$R_{load} = 20 \, \Omega$

$V_0 : ?$, sketch V_{sw}, i_d, i_D

Find if the Converter is in CCM or DCM mode

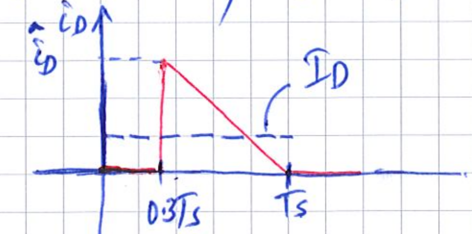
let's start with the assumption that the Converter is in CCM

$\Rightarrow \quad V_0 = \frac{D}{1-D} \cdot V_d = \frac{0.3}{1-0.3} \cdot 20 = \underline{\underline{8.57 \, V}} \quad (N_1 : N_2 : N_3 = 1:1:1)$

$\Rightarrow \quad I_0 = \frac{V_0}{R_{load}} = \frac{8.57}{20} A = \underline{\underline{0.4286 A}}$

when the switch S is off, the diode D conducts and the average diode current is the same as the output current.

at the boundary condition, we have:



$$I_D = \frac{\frac{1}{2} \hat{i}_D \cdot (1-D) T_s}{T_s} = \underline{\underline{0.35 \hat{i}_D}}$$

1

if $0.35 \hat{i}_D = I_D \leq I_0$, the assumption of CCM is Correct.

During the switch S off period, $V_1 = -\frac{N_1}{N_3} V_0 = -L_m \frac{\Delta i_m}{(1-D)T_s}$ but

During switch off period, $i_m = i_D$

$$\Rightarrow \quad V_0 = L_m \cdot \frac{\hat{i}_D}{0.7 T_s} = \frac{L_m (f_{sw}) \cdot \hat{i}_D}{0.7}$$

(2 pts)

$$\Rightarrow \quad \hat{i}_D = \frac{(0.7)(8.57)}{100\mu \cdot 20k} A = \underline{\underline{3A}} \Rightarrow I_D = 0.35 \hat{i}_D = \underline{\underline{1.05A}}$$

However I_D at the boundary is higher that I_0 which disproves 1.

2

$\Rightarrow$ Converter operating in DCM mode

$\Rightarrow \dfrac{V_0}{V_d} = D\sqrt{\dfrac{RT_s}{2L_m}}$ (from energy conservation)

$$\left\{ \begin{array}{l} \frac{1}{2}L_m \hat{i}_m^2 = \frac{V_0^2}{R_{load}} \cdot T_s \\ V_d = \frac{L_m \cdot \hat{i}_m}{DT_s} \\ \Downarrow \\ \frac{V_0}{V_d} = D\sqrt{\frac{RT_s}{2L_m}} \end{array} \right.$$

$\Rightarrow V_0 = (0.3)\sqrt{\dfrac{20}{2(100\mu)(20k)}} \cdot 20\ V$ $\quad (V_0 \simeq V_d)$

$\Rightarrow V_0 = \underline{\underline{13.42\ V}}$ (2 pt)

during the switch S on period, $(i_d = i_m,\ V_{sw} = 0,\ i_D = 0)$

$V_1 = V_d = \dfrac{L_m \cdot \hat{i}_m}{DT_s} = \dfrac{L_m \cdot f_{sw}}{D} \cdot \hat{i}_m$ (i_m starts from 0 DCM)

$\Rightarrow \hat{i}_m = \dfrac{DV_d}{L_m \cdot f_{sw}}\ A = 3A = \hat{i}_D$

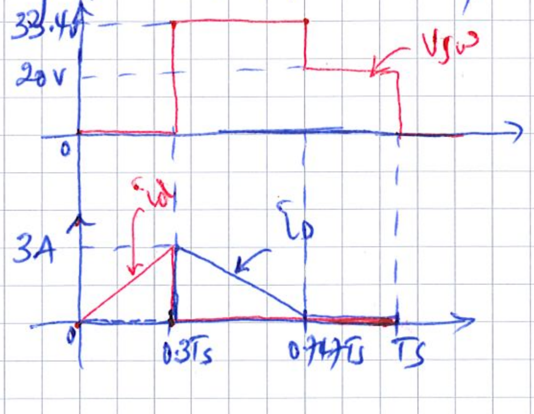
during the switch S off period. $(i_d = 0,\ i_m = i_D,\ V_{sw} = V_d + V_0)$

$V_1 = -V_0 = \dfrac{-L_m \hat{i}_m}{\Delta_1 T_s} \Rightarrow V_0 = \dfrac{L_m f_{sw} \cdot \hat{i}_m}{\Delta_1}$ $\quad (\Delta_1 < (1-D))$

$\Rightarrow \Delta_1 = \dfrac{L_m \cdot f_{sw} \cdot \hat{i}_m}{V_0} = 0.447 < (1-D)$

$\Rightarrow I_D = (0.5)(0.447)(3) = V_0/R_{load}$ (Correct!)

during the discontinuous period $(i_d = 0,\ i_m = 0,\ i_D = 0,\ V_{sw} = V_d)$



(2 pts)

CHALMERS	Anonymous code / Anonym kod: Mebtu Beza	Points for question (to be filled in by teacher) / Poäng på uppgiften (ifylles av lärare)	Consecutive page no. / Löpande sid nr: 7 — Question no. / Uppgift nr: 4

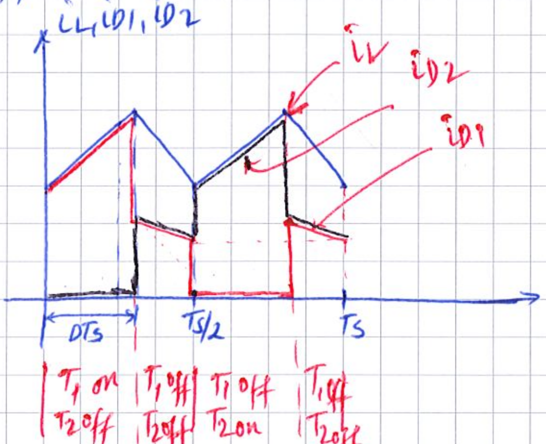
(a) each switch operate for a duty cycle $D<0.5$ in each of the half switching cycle.

$$i_L = i_{D1} + i_{D2}$$

when T_1 is on, $i_{D1} = i_L$ and $i_{D2} = 0$
when T_1 is off, $i_{D1} = i_{D2} = i_L/2$
} for a period of $T_s/2$, T_2 is off in this period

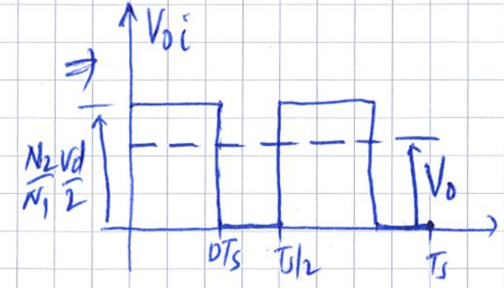
when T_2 is on, $i_{D2} = i_L$ and $i_{D1} = 0$
when T_2 is off, $i_{D2} = i_{D1} = i_L/2$
} for the next $T_s/2$, T_2 is off in this period

For CCM,



(2 pts)

(b) $V_{oi} = \frac{N_2}{N_1} v_1$, when T_1 or T_2 are on, $v_1 = V_d/2$
when T_1 & T_2 are off, $v_1 = 0$



$$\Rightarrow V_o = \frac{1}{T_s}\int_0^{T_s} V_{oi}\,dt = \frac{2 * \frac{N_2}{N_1}\cdot\frac{V_d}{2}\cdot DT_s}{T_s} = \frac{N_2}{N_1} D V_d$$

$$\Rightarrow \underline{\underline{\frac{V_o}{V_d} = \frac{N_2}{N_1} D}}$$

(2 pts)

(c) half bridge DC/DC converter $\Rightarrow$ bipolar core excitation & small magnetizing current (much less than load current)

Flyback converter $\Rightarrow$ unipolar core excitation & larger magnetizing current (in the order of load current). Hence air gap needed to avoid saturation.

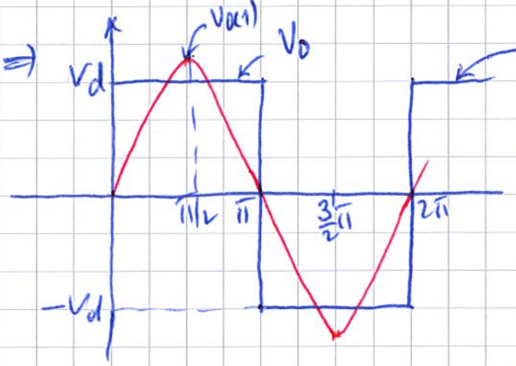
(1 pt)

CHALMERS	Anonymous code / Anonym kod: Mebtn Beza	Points for question (to be filled in by teacher) / Poäng på uppgiften (ifylles av lärare)	Consecutive page no. / Löpande sid nr: 8
			Question no. / Uppgift nr: 5

(a) $V_d = 300$, Squar wave operation

$V_o = V_d$ for half cycle of the fundamental period

$V_o = -V_d/2$ for next half cycle of the fundemental period



$\Rightarrow$ odd quarter wave

$\Rightarrow a_h = 0$

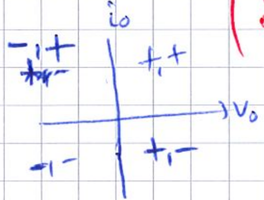
$$b_h = \frac{4}{\pi}\int_0^{\pi/2} V_d \sin(h\theta)\,d\theta \quad \text{for } h \text{ odd}$$

$$= \frac{4V_d}{\pi h}$$

using Fourier calculation the peak of the fundamental component is calculated as

$$\hat{V}_{o(1)} = \frac{4}{\pi} V_d = \underline{\underline{382}}$$

(2pts)



(b) Full bridge $\Rightarrow$ 4 quadrant operation

V_o, i_o	$+,+$	$+,-$	$-,-$	$-,+$
Device conducting	S_1, S_2	D_1, D_2	S_3, S_4	D_3, D_4

(2pts)

(c) $\hat{V}_{o(1)} = m_a \cdot V_d \Rightarrow \hat{V}_{o(1),max} = 1 \cdot 300 = \underline{300V}$

$(m_a \le 1)$

(2pts)

(d)

	advantage	disadvantage
squar wave:	- smaller switching loss - simpler modulation - higher fundamental output	- higher harmonics content - uncontrolled output voltage

(2pts)

PWM:- advantages:- smaller low order harmonics & controlled output voltage

disadvantage:- higher switching loss, high frequency electromagnetic disturbance,

(e) advantage:- better output voltage waveform interms of harmonics with less switching losses. disadv:- difficult control structure, more component count

(2pts)

$I_d = 20\,A$, $L_s = 0$

50 HZ , 400 V RMS,LL source

(a) 400 V.LL.RMS $\Rightarrow$ $V_{a,peak} = \frac{400}{\sqrt{3}} \cdot \sqrt{2} = 327$

$\Rightarrow$ $V_a = 327 \sin(\omega t)$

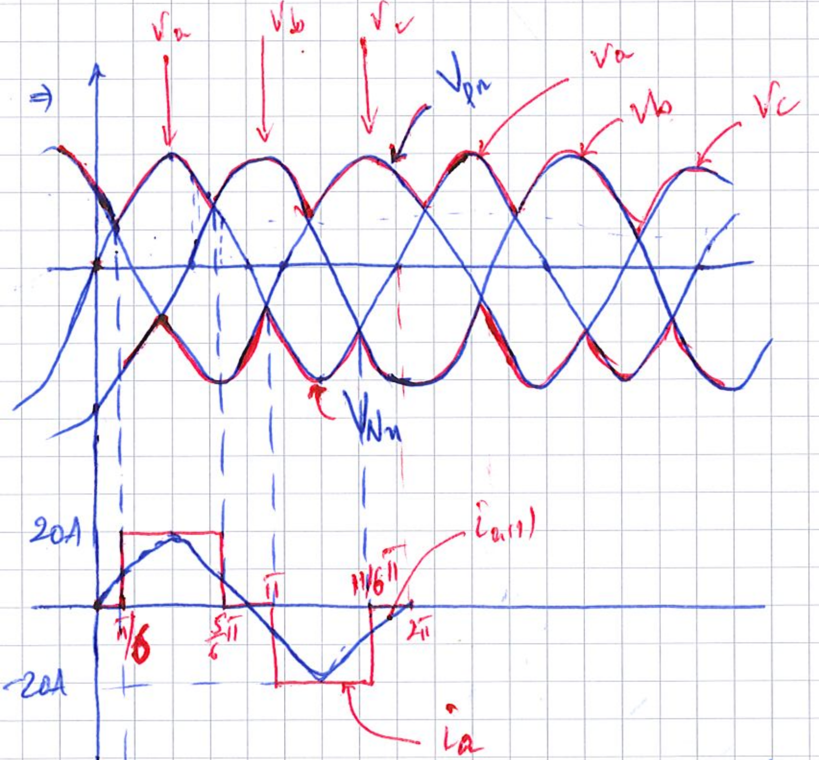
$V_b = 327 \sin(\omega t - 2\pi/3)$

$V_c = 327 \sin(\omega t + 2\pi/3)$

i_a flows when D_1 or D_4 is conducting. that is when V_a is higher than V_b & V_c or V_a is lower than both V_b & V_c. Similarily for i_b & i_c

$\Rightarrow V_d = V_P - V_N = \max(V_a, V_b, V_c) - \min(V_a, V_b, V_c)$

$\Rightarrow$

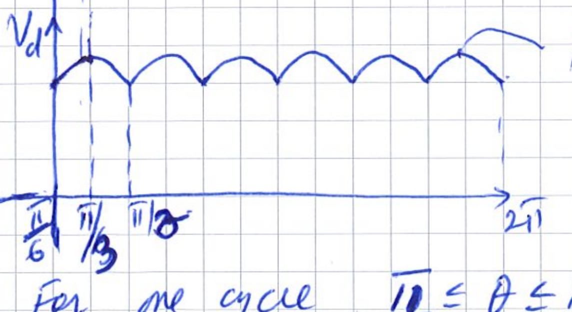


$\Leftarrow$ drawing not to scale

(2 pts)

DPF is ~~zero~~ 1. $DPF = \cos(\varphi) = 1$

(b)



peak value $= 400 * \sqrt{2} = \underline{565.68}$

$V_d = V_{Pn} - V_{Nn}$

For one cycle $\frac{\pi}{6} \leq \theta \leq \pi/2$, $V_d = \sqrt{2} \cdot V_{LL} \cos(\theta - \pi/3)$

CHALMERS	Anonymous code / Anonym kod: Mebta Bera	Points for question (to be filled in by teacher) / Poäng på uppgiften (ifylles av lärare)	Consecutive page no. / Löpande sid nr: 10 — Question no. / Uppgift nr: 6

$$\Rightarrow V_d = \frac{1}{\pi/3} \int_{\pi/6}^{\pi/2} \sqrt{2} V_{LL} \cos(\theta - \pi/3)\, d\theta)$$

$$= \frac{3}{\pi} \int_{-\pi/6}^{\pi/6} \sqrt{2} V_{LL} \cos(\theta)\, d\theta$$

$$= \frac{3}{\pi} \cdot \sqrt{2} V_{LL} \sin\theta \Big|_{-\pi/6}^{\pi/6} = \frac{6\sqrt{2}}{\pi} V_{LL} \sin(\pi/6) = \frac{3\sqrt{2}}{\pi} \cdot V_{LL}$$

$$\Rightarrow \underline{\underline{V_d = 540\,V}}$$

(2 pts)

(c) Source inductance reduces both the average output voltage and the DPF.

$DPF = \cos(u/2)$ where u = commutation angle.

(2 pts)

CHALMERS	Anonymous code / Anonym kod: Mebtu Beza	Points for question (to be filled in by teacher) / Poäng på uppgiften (ifylles av lärare)	Consecutive page no / Löpande sid nr: 11
			Question no. / Uppgift nr: 7

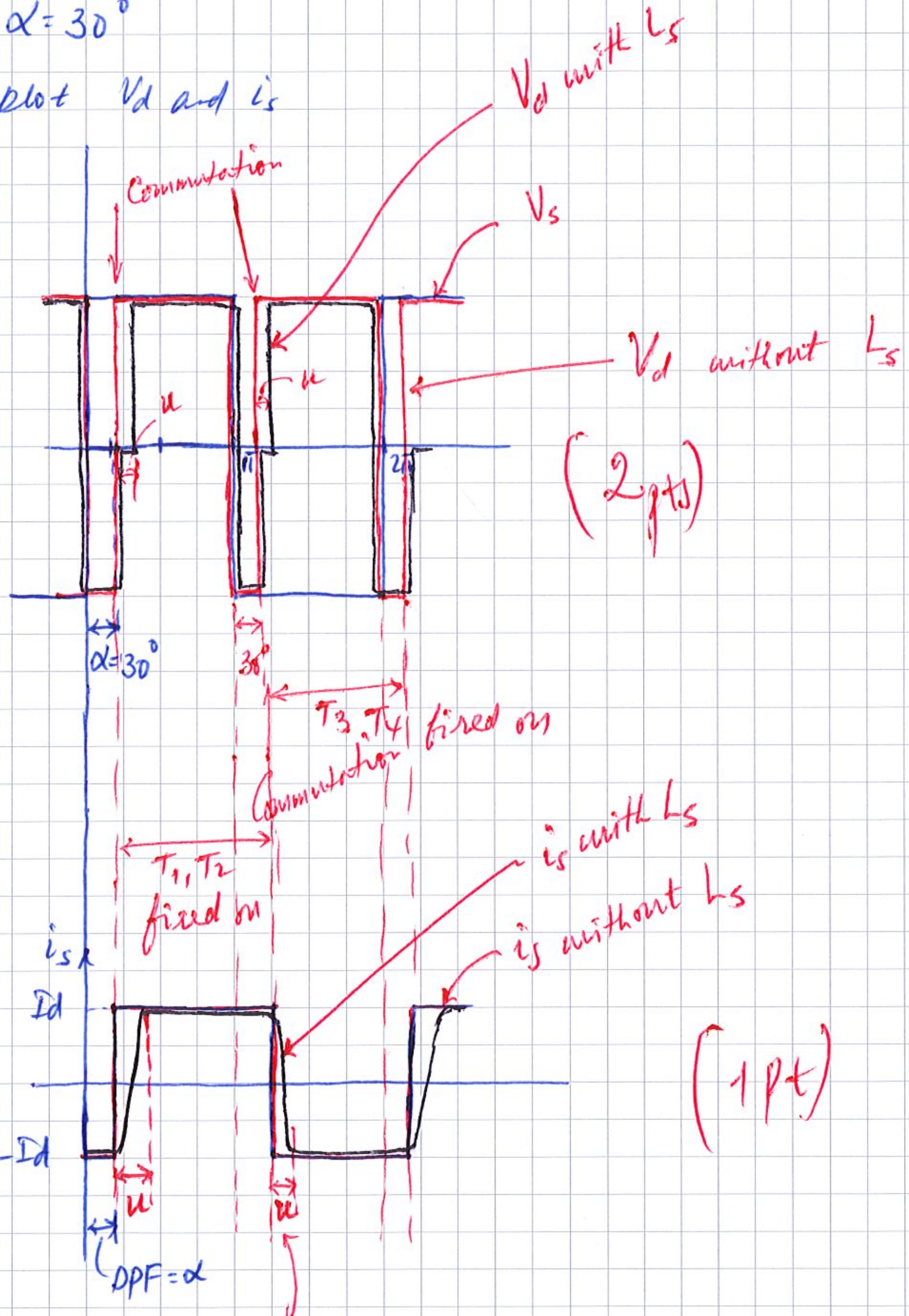
$L_s = 5mH$

$V = \pm 100V$, $50Hz$

$i_d = 10A$

$\alpha = 30^\circ$

(a) plot V_d and i_s



during 2 commutations $V_d = 0$

for $2 \times 30^\circ$, $V_d = -100V$

for other intervals $V_d = 100V$

CHALMERS | Anonymous code / Anonym kod: Mebtu Beza | Points for question (to be filled in by teacher) / Poäng på uppgiften (ifylles av lärare) | Consecutive page no. / Löpande sid nr: 12 | Question no. / Uppgift nr: 7

2

(b) Find u, is increases from $-I_d$ to I_d in the interval of u. $V_d = 0$ during commutation.

$\Rightarrow$ $V_s = L_s \dfrac{di_s}{dt}$ where $V_s = 100$

$\Rightarrow$ $V_s = L_s \cdot \dfrac{di_s}{d\theta} \cdot \dfrac{d\theta}{dt} = L_s \dfrac{di_s}{d\theta} \cdot \omega = L_s\omega \cdot \dfrac{di_s}{d\theta}$

$\Rightarrow$ $V_s d\theta = L_s\omega \cdot di_s$

$\Rightarrow$ $\int_0^u V_s d\theta = L_s\omega \int_{-I_d}^{I_d} di_s$

$\Rightarrow$ $100 \cdot u = L_s\omega \cdot 2I_d$

$\Rightarrow$ $u = \dfrac{2L_s\omega \cdot I_d}{100}$ rad $= \dfrac{2(5\cdot10^{-3})(2\pi\cdot50)(10)}{100} = \underline{\underline{0.3142 \text{ rad}}}$

$\Rightarrow$ $V_d = \dfrac{1}{2\pi}\left(2(-100)(\underset{\alpha}{\pi/6}) + 2(0)(\underset{u}{0.3142}) + 2(100)(\underset{\pi-\alpha-u}{\pi - \pi/6 - 0.3142})\right)$

$\Rightarrow$ $V_d = \dfrac{100}{\pi}\left(\pi - 2\pi/6 - 0.3142\right) = \underline{\underline{56.67 \text{ V}}}$

(2pts)

Answer only one question on this page. Do not write on the back of this paper
Behandla endast en uppgift på detta blad. Skriv ej på baksidan

(a) $P = 3W$

$T_a = 25^\circ c$

$R_{thja} = 62^\circ c/W$

$T_j = T_a + P \cdot R_{thja}$ (2 pts)

$= 25^\circ c + 3w \cdot 62^\circ c/w$

$\Rightarrow \underline{\underline{T_j = 211^\circ c}}$ the junction temperature is very high and a heat sink is needed.

(b) $T_{j,max} = 100^\circ c$

$\Rightarrow T_j = 25^\circ c + 3w * R_{thja} \leq 100^\circ c$

$\Rightarrow R_{thja} \leq \frac{100^\circ c - 25^\circ c}{3w} = 25^\circ c/w$

$\Rightarrow R_{thja,max} = \underline{\underline{25^\circ c/w}}$ (2 pts)