2

CHALMERS	Anonymous code / Anonym kod: ENM061	Points for question (to be filled in by teacher) / Poäng på uppgiften (ifylles av lärare)	Consecutive page no. / Löpande sid nr: 1 — Question no. / Uppgift nr: 1 (a),(b)

(a)

	MOSFET	IGBT
Conduction:	high R_{on} (high loss)	low R_{cond} (low loss)
Switching:	fast (low loss)	medium (high loss
Blocking:	no reverse blocking	reverse blocking
	low forward voltage blocking	medium forward voltage blocking

3

(b)

	Flyback	forward	half bridge
Core excitation:	unipolar	unipolar	bipolar
Core type:	air gap	no air gap	no air gap
transformer use:	storage & isolation voltage scaling	isolation voltage scaling	isolation voltage scaling
magnetizing current:	high	low	low

3

CHALMERS	Anonymous code / Anonym kod: ENM061	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: 2a) b) c) d) e)

(a) $N_1 : N_2 : N_3 = 1:1:1$

$V_o = 12\,V$

$P_o = 48\,W$

$V_d = 20\,V$

$f_{sw} = 20\,kHz$

Boundary condition $\Rightarrow \dfrac{\Delta \hat{i}_L}{2} = I_L = I_o = \dfrac{P_o}{V_o} = \dfrac{48}{12}\,A = \underline{\underline{4A}}$

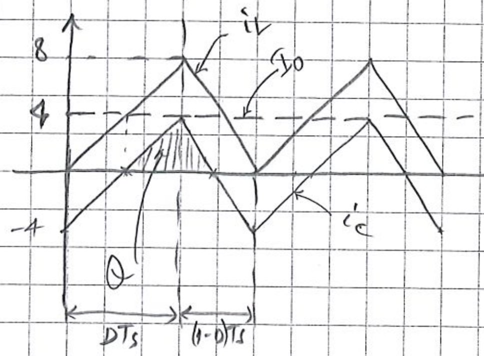
$\Rightarrow \Delta \hat{i}_L = \underline{\underline{8A}}$

$\Rightarrow V_o = DV_d \Rightarrow D = 12/20 = \underline{0.6}$

$\Rightarrow$ During off period, $V_L = -V_o = \dfrac{-L\Delta \hat{i}_L}{(1-D)T_s} = \dfrac{-L\Delta \hat{i}_L \cdot f_{sw}}{1-D}$

$\Rightarrow L = \dfrac{V_o(1-D)}{\Delta \hat{i}_L \cdot f_{sw}} = \dfrac{12(0.4)}{8(20)(10^3)}\,H = \underline{\underline{0.03\,mH}}$ (2)

(b) $i_c = i_L - I_o \Rightarrow$



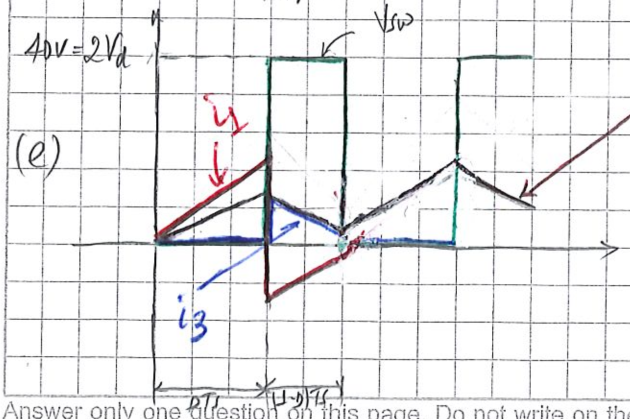
(2)

(c) $\Delta V_o \leq 0.1 V_o = 1.2 \Rightarrow \dfrac{Q}{C} = \left[\tfrac{1}{2}\left(\tfrac{T_s}{2}\right)\left(\Delta \hat{i}_L/2\right)\right]/C = \dfrac{\Delta \hat{i}_L}{8 f_{sw} C} \leq 0.1 V_o$

$\Rightarrow C \geq \dfrac{\Delta \hat{i}_L}{0.1 V_o (8 f_{sw})} = \underline{\underline{0.0417\,mF}}$ (2)

(d) $f_{corner} = \dfrac{1}{2\pi\sqrt{LC}} = 4.45\,kHz > \dfrac{f_{sw}}{10} = 2\,kHz$! L & C are low for filtering the harmonics due to the switching. [L or C should increase] (2)

(e)



i_m: No enough time for complete demagnetization.

during DT_s: $V_d = L_m \dfrac{di_m}{dt}$ $(0.6T_s)$

(2) during $(1-D)T_s$: $-V_d = -L_m \dfrac{di_m}{dt}$ $(0.4T_s)$

but if L_m is very big, $i_m \rightarrow 0$!

(a) $N_1 : N_2 : N_3 = 1 : 2 : 2$

$V_d = 20\,V$

$f_{sw} = 20\,kHz$

$D = 0.3$

$L_m = 100\,\mu H$

$R_{load} = 40\,\Omega$

Assume CCM $\Rightarrow$ $V_0 = \frac{N_3}{N_1} \cdot \frac{D}{1-D} V_d = \frac{2}{1} \cdot \frac{0.3}{1-0.3} \cdot 20\,V = \underline{\underline{17.143\,V}}$

$V_{0,max} = \frac{N_3}{N_2} V_d = 20\,V > V_0$ (N_2-winding not used)

$\Rightarrow I_D = \frac{V_0}{R_{load}} = \frac{17.143}{40} A = \underline{\underline{0.429\,A}}$

During on period: $\frac{L_m \Delta \hat{i}_m}{DT_S} = V_d$

$\Rightarrow \Delta \hat{i}_m = \frac{DV_d}{L_m f_{sw}} = 3A$

But, $I_m = I_d + \frac{N_3}{N_1} I_D$ & $V_d I_d = V_0 I_D \Rightarrow I_d = V_0 I_D / V_d = \underline{\underline{0.367}}$

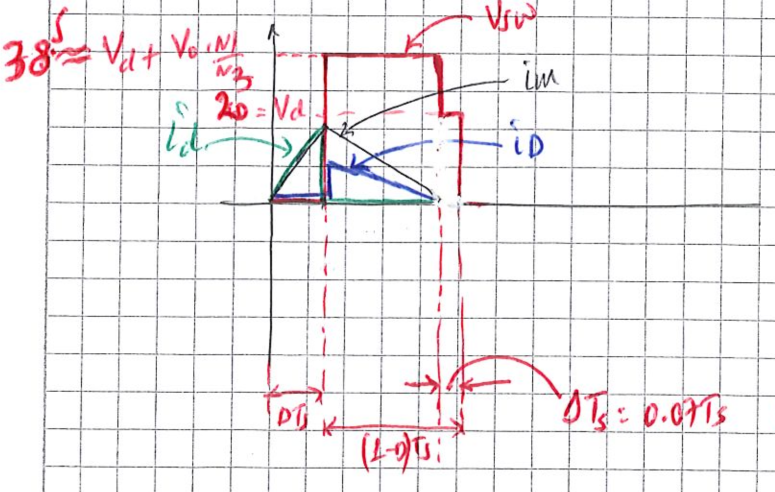
$\Rightarrow I_m = 0.367 + \frac{2}{1}(0.429) = \underline{\underline{1.223\,A}}$

Here $\frac{\Delta \hat{i}_m}{2} = 1.5A > I_m \Rightarrow$ Converter is in DCM mode

$\Rightarrow V_0 = D\sqrt{\frac{R_{load}}{2L_m f_{sw}}} \cdot V_d \le V_{0,max} = 20$

$\Rightarrow V_0 = 0.3\sqrt{\frac{40}{2(0.1)(20)}} \cdot 20 = \underline{\underline{18.97\,V}}$

(4)



; $V_d \cdot DT_S = \frac{N_1}{N_3} V_0 \cdot \Delta T_S \Rightarrow \Delta \approx 0.067$

2

CHALMERS	Anonymous code / Anonym kod: ENM061	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: 3b)

(b) Rload: V_0 results DCM mode.

⇒ It should be reduced to get CCM. The maximum Rload to bring the converter to CCM mode is the value to make it operate on the boundary.

$$\Rightarrow \frac{\Delta \hat{i}_m}{2} = I_m = I_d + \frac{N_3}{N_1} I_D = \frac{V_0 I_D}{V_d} + \frac{N_3}{N_1} I_D$$

$$= \left(\frac{V_0}{V_d} + \frac{N_3}{N_1}\right) I_D = \left(\frac{V_0}{V_d} + \frac{N_3}{N_1}\right)\left(\frac{V_0}{R_{load}}\right)$$

At the boundary, $V_0 = \frac{N_3}{N_1} \cdot \frac{D}{1-D} \cdot V_d$

$$\Rightarrow \frac{\Delta \hat{i}_m}{2} = \left(\frac{N_3}{N_1} \cdot \frac{D}{1-D} + \frac{N_3}{N_1}\right)\left(\frac{N_3}{N_1} \cdot \frac{D}{1-D} \cdot \frac{V_d}{R_{load}}\right) = \frac{D V_d}{L_m f_{sw}} \cdot \frac{1}{2} = \frac{\Delta \hat{i}_m}{2}$$

(4)

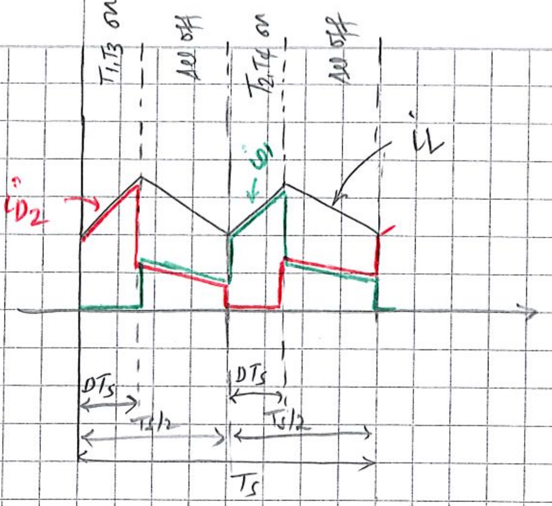
$$\Rightarrow \left(\frac{N_3}{N_1}\right)^2 \left(\frac{D}{1-D} + 1\right)\left(\frac{1}{(1-D) R_{load}}\right) = \frac{1}{2 L_m f_{sw}}$$

$$\Rightarrow R_{load} = \left(\frac{2 L_m f_{sw}}{(1-D)^2}\right)\left(\frac{N_3}{N_1}\right)^2 = \underline{\underline{32.65\ \Omega}}$$

2

CHALMERS	Anonymous code / Anonym kod: ENM061	Points for question (to be filled in by teacher) / Poäng på uppgiften (ifylles av lärare)	Consecutive page no. / Löpande sid nr: 5 Question no. / Uppgift nr: 4 a) b) c)

(a)



(2)

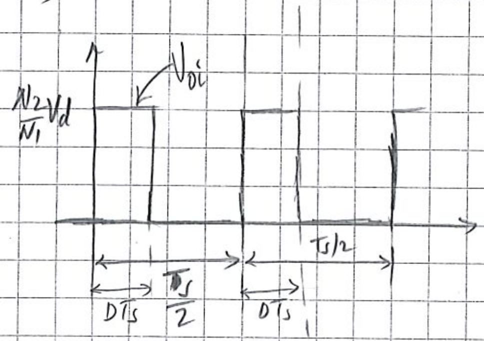
(b)

$$V_0 = \frac{1}{T_s}\int_0^{T_s} V_{oi}\, dt$$

$$= \frac{1}{T_s} \cdot 2DT_s \cdot \frac{N_2}{N_1} V_d$$

$$= 2\frac{N_2}{N_1} \cdot D \cdot V_d$$

$$\Rightarrow \frac{V_0}{V_d} = 2\frac{N_2}{N_1} D$$



(2)

(c) Advantages :-

- ✓ optional DC capacitor
- ✓ twice the output voltage
  - ⇒ higher power output
  - ⇒ less windings for the same voltage output

Disadvantages

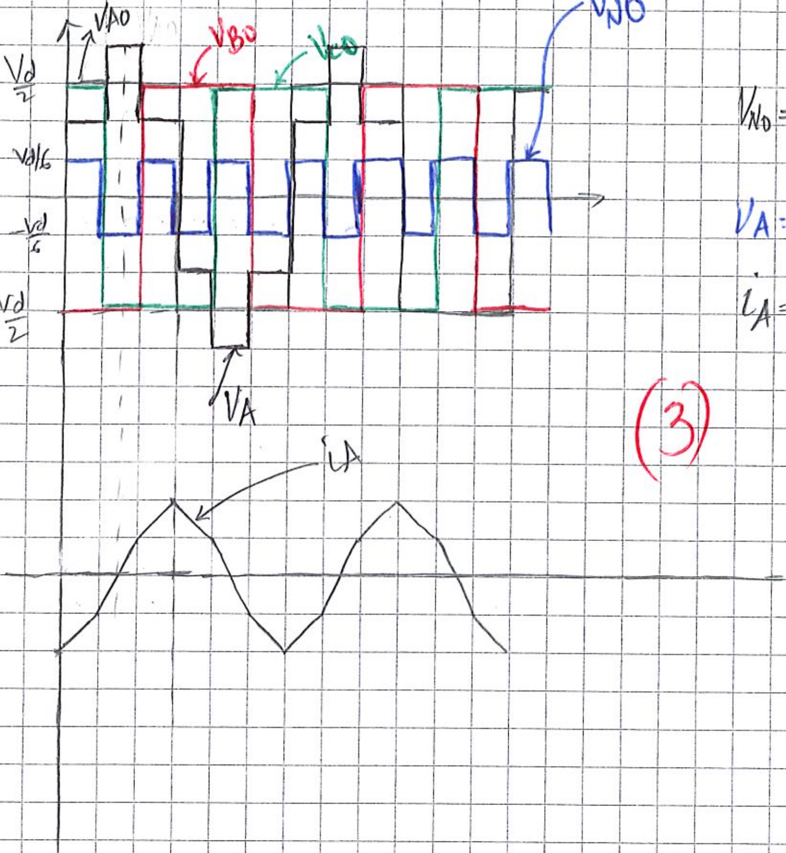
- ✓ more components count
- ✓ more conduction loss ⇒ less economical for lower power rating

(2)

2

CHALMERS	Anonymous code / Anonym kod: ENM061	Points for question (to be filled in by teacher) / Poäng på uppgiften (ifylles av lärare)	Consecutive page no. / Löpande sid nr: 6 Question no. / Uppgift nr: 5a) b) c)

(a) $V_d = 300V \Rightarrow \pm\frac{V_d}{2} = \pm 150V$



$V_{NO} = \frac{V_{AO}+V_{BO}+V_{CO}}{3}$

$V_A = V_{AO} - V_{NO}$

$i_A = i_{A0} + \frac{1}{L}\int_0^t V_A d\tau$

(3)

(b) $I_d = 0$ due to an inductive load

i_d harmonics are at $6n$ for $n = \pm 1, \pm 2, \pm 3$ (3)

i_d harmonics for pwm are around the switching frequency, $n m_f$, $n = \pm 1, \pm 2$

where m_f = is the frequency modulation ratio.

(c) PWM: $\hat{V}_{A(1)} = m_a \cdot \frac{V_d}{2} = \underline{\underline{150V}}$ $(m_a \leq 1)$ (3)

square wave $\hat{V}_{A(1)} = \frac{4}{\pi} \cdot \frac{V_d}{2} = \underline{\underline{191V}}$ (using Fourier Analysis)

(For the fundamental component, $\hat{V}_{A(1)} = \hat{V}_{AO(1)}$ because $\hat{V}_{NO(1)} = 0$)

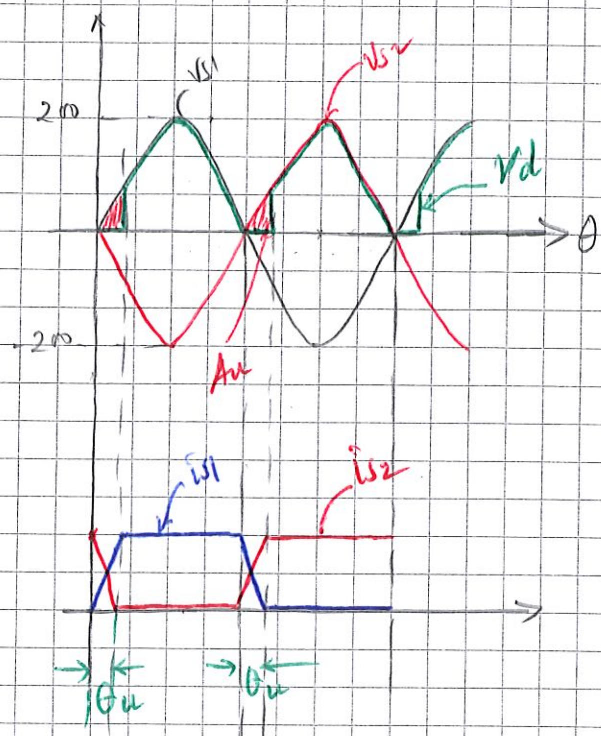
2

CHALMERS	Anonymous code ENM061	Points for question (to be filled in by teacher)	Consecutive page no. Löpande sid nr 7
	Anonym kod	Poäng på uppgiften (ifylles av lärare)	Question no. Uppgift nr 6a) b)

(a), (b) $v_{s1} = 200\sin(2\pi f t)$, $\omega = 2\pi f = 100\pi$, $L_s = 15\text{ mH}$, $I_d = 12\text{ A}$

$v_{s2} = 200\sin(2\pi f t - 180°)$

(2) + (3)



$v_{s1} > v_{s2}$ after commutation, $i_{s1} = I_d$, $i_{s2} = 0$, $V_d = V_{s1}$

$v_{s2} > v_{s1}$ after commutation, $i_{s1} = 0$, $i_{s2} = I_d$, $V_d = v_{s2}$

during commutation $i_{s1}, i_{s2} \neq 0$ and from T_1 to T_2

$i_{s1} = I_d - i_u$, $i_{s2} = i_u$

$$V_d = v_{s2} - v_{L2} = v_{s2} - L_s\frac{di_u}{dt} = v_{s1} - v_{L1} = v_{s1} + L_s\frac{di_u}{dt}$$

$$\Rightarrow L_s\frac{di_u}{dt} = \frac{v_{s2} - v_{s1}}{2} = v_{L2}$$

$$\Rightarrow V_d = \frac{v_{s1} + v_{s2}}{2} \text{ during commutation}$$

$$= \underline{0}.$$

i_u commutates from 0 to I_d

$$\Rightarrow L_s\frac{di_u}{dt} = \frac{v_{s2} - v_{s1}}{2} = v_{s2},$$

$$\Rightarrow L_s\int_0^{I_d} di_u = \int_0^{\theta_u} 200\sin\theta \cdot d\theta/\omega$$

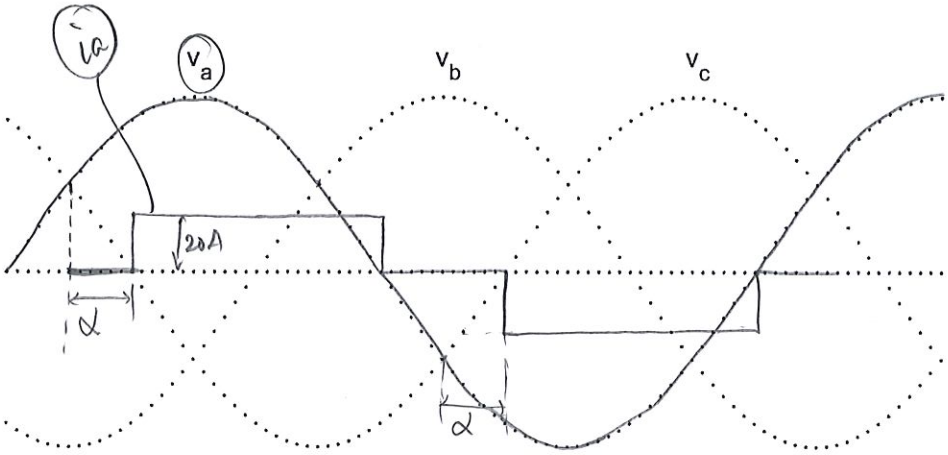
$$L_s\omega I_d = [-200\cos\theta]\Big|_0^{\theta_u} = 200(1 - \cos\theta_u)$$

$$\Rightarrow \theta_u = \cos^{-1}\left[1 - \frac{L_s\omega I_d}{200}\right] = \underline{\underline{25.1°}} \; (0.43726\text{ rad})$$

$$V_d = \frac{1}{\pi}\int_{\theta_u}^{\pi} 200\sin(\theta)\cdot d\theta = \frac{1}{\pi}\Big[200\cos\theta\Big]_{\pi}^{\theta_u} = \frac{200\cos\theta_u + 200}{\pi} = \underline{\underline{121.33\text{ V}}}$$

Dot paper for Question 7 (*give a page number and put this paper together with your answer sheets if you use it for your answers. The distance between the dots in the voltage plots is 5°.*)

1) Phase-voltage and current plot for part 7.a.

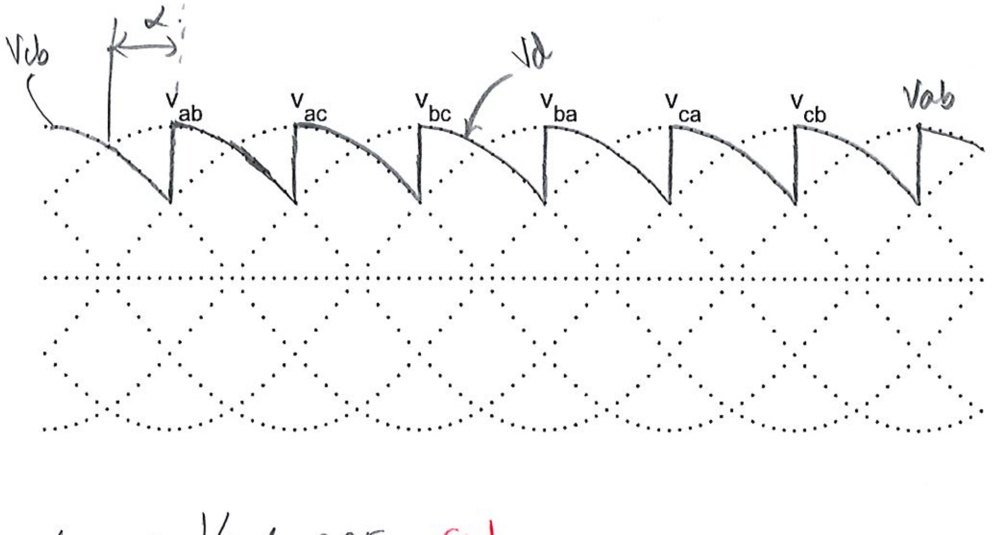


(2)

$DPF = \cos(30^\circ) = \underline{0.866}$

2) Phase-current plot for part 7.a.

3) Output dc-voltage plot for part 7.b.



$$V_d = \frac{1}{\pi/3}\int_{0}^{\pi/6+\alpha} \hat{V}_{LL}\cos(\theta)\,d\theta$$

$$= 3/\pi \int_{0}^{\pi/6+\alpha} 300\sqrt{3}\cos(\theta)\,d\theta$$

$$= \frac{3}{\pi}\{300\sqrt{3}\}\sin(\pi/6+\alpha)$$

$$= \underline{429.72V}$$

(2)

OR

$$V_d = \frac{3\sqrt{2}}{\pi} V_{LL}\cos\alpha$$

$$= \frac{3\sqrt{2}}{\pi}\left(\frac{300\cdot\sqrt{3}}{\sqrt{2}}\right)\cos\alpha$$

$$= \underline{429.72}$$

(c) decrease V_d & DPF. (1)

$DPF = \cos(\alpha + u/2)$; θ_u = commutation angle!