ALMERS	Anonymous code / Anonym kod: MeStn ENM060/061	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) c)

(a) diode - uncontrolled: Conducts when forward biased

thyristor - semi controlled: turns on when a gate signal is applied and they are forward biased.

- turns off with a reverse voltage

(2)

MOSFET - turns on & off with a gate-source voltage

(b) with an air gap in the inductor, the inductance is given by

$$L = \frac{N^2}{R_c + R_g} \quad (1)$$

R_c = reluctance of core
R_g = reluctance of airgap

For a given saturating (maximum) flux density in the core,

$$N i_{sat} = B_{sat} A_c (R_g + R_c) \quad \text{(Ampere's law)}$$

(2)

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

air gap increases saturating current and hence operating range.

using (1) & (2), it is possible to show that $W = \frac{1}{2} L \cdot i_{sat}^2$ increases with air gap

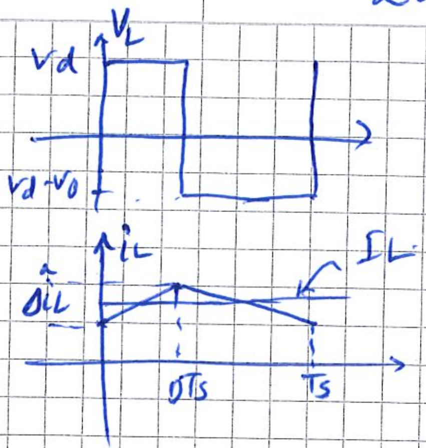
(c) - avoiding circulating currents
- safety
- multiple outputs
- different turns ratio

(2)

2

CHALMERS	Anonymous code / Anonym kod: Melstu ENM060/061	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: 2 a) b)

$V_d = 12V$ Stepup Converter
$P_0 = 40W$
$V_0 = 20V$
$f_{sw} = 20kHz$



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

From $V_d I_L = V_0 I_0 = P_0$

we have $I_L = 40/12\,A = \underline{3.33A}$

CCM $\Rightarrow$ $V_0 = \dfrac{V_d}{1-D}$ (derive this expression !!)

$\Rightarrow D = 1 - V_d/V_0 = \underline{0.4}$

$\Rightarrow$ when the switch is on, $V_L = V_d = 12V$

$$V_L = \frac{L\Delta\hat{i}_L}{\Delta t} = \frac{L\Delta\hat{i}_L}{DT_s} = \frac{Lf_{sw}\cdot\Delta\hat{i}_L}{D} = V_d$$ (2)

$$\frac{\Delta\hat{i}_L}{2} \leq I_L \Rightarrow \frac{DV_d}{2Lf_{sw}} \leq I_L = \frac{P_0}{V_d}$$

$$\Rightarrow L \geq \frac{DV_d^2}{2f_{sw}P_0} = 36\mu H$$

$\Rightarrow L_{min} = \underline{36\mu H}$ for CCM

(b) $\Delta\hat{i}_L = 0.1 I_0 = 0.1P_0/V_0 \Rightarrow V_L = V_d = \dfrac{L\Delta\hat{i}_L}{DT_s}$

$$\Rightarrow V_d = \frac{L(0.1P_0/V_0)f_{sw}}{D}$$ (2)

$$\Rightarrow L = \frac{DV_dV_0}{0.1P_0f_{sw}} = \underline{1.2\,mH}$$

2

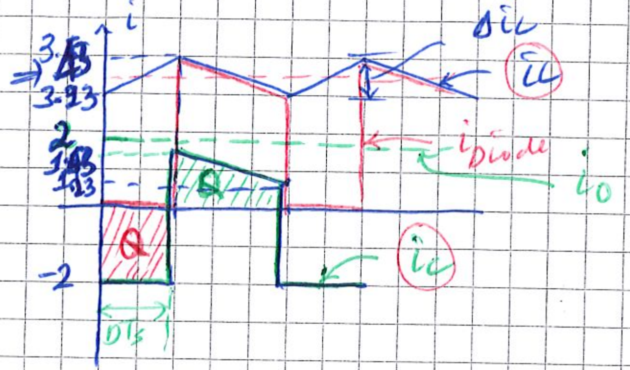
CHALMERS	Anonymous code / Anonym kod: MC8tn / ENM060/061	Points for question (to be filled in by teacher) / Poäng på uppgiften (ifylles av lärare)	Consecutive page no. / Löpande sid nr: 3 — Question no. / Uppgift nr: 2 c) d)

c) When switch on, $i_{Diode} = 0$, $i_c = -i_0 = -I_0$

When switch off, $i_{Diode} = i_L$, $i_c = i_{Diode} - i_0 = i_L - I_0$

$I_L = 3.333\,A$, $\Delta i_L = 0.1 I_0 = 0.2A$

$I_0 = P_0/V_0 = 2A$



(2)

d) $\Delta V_0 = 0.01 V_0 = 0.01(20) = 0.2V$

$$\Delta V_0 = \frac{Q}{C} = \frac{I_0 \cdot DT_s}{C} = \frac{I_0 \cdot D}{f_{sw} \cdot C} \le 0.01 V_0, \quad I_0 = P_0/V_0$$

$$\Rightarrow C \ge \frac{P_0 D}{0.01 V_0^2 f_{sw}} = 0.2mF$$

(2)

$$\Rightarrow C_{min} = 0.2mF$$

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2

CHALMERS	Anonymous code / Anonym kod: Mebtu, ENM060/061	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: 3-i

$N_1 : N_2 : N_3 = 1:2:1$

$V_d = 20\ V$

$f_{sw} = 20\ kHz$

$D = 0.2$

$L_m = 100\ \mu H$

$R_{load} = 30\,\Omega$

$V_0 = ?$ $\quad V_{sw}, i_d$ & i_D

Assume Converter is in CCM

$\Rightarrow V_0 = \frac{D}{1-D} V_d = \frac{0.2}{1-0.2} \cdot 20\,V = \underline{\underline{5V}}$ (if derived good!!)

$\Rightarrow I_0 = \frac{V_0}{R_{load}} = \frac{5}{30} A = 1/6\,A = \underline{\underline{0.167\,A}}$

When the switch S is off, D conducts $\Rightarrow I_D = I_0$

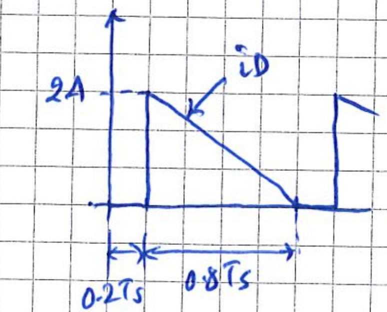
But $I_0 = I_D = \frac{V_0}{R_{load}} = 0.167\,A$

During off period, the magnetizing current decreases proportional to the diode current.

For a continuous conduction mode we have

$\frac{L \Delta \hat{i}_m}{(1-D)T_s} = +V_0 \Rightarrow \Delta \hat{i}_m = \frac{(1-D)V_0}{L f_{sw}}$ (2)

$\Rightarrow \Delta \hat{i}_D = \frac{N_1}{N_3} \Delta \hat{i}_m = \frac{1}{1} \cdot \frac{(1-D)V_0}{L f_{sw}} = \underline{\underline{2A}}$

$\Rightarrow$ 

$\Rightarrow \underset{(\text{for CCM})}{I_{D,min}} = \frac{1/2 (\Delta \hat{i}_D)(1-D)T_s}{T_s} = 0.8\,A$

But $I_0 = I_D = 0.167 < I_{D,min} = 0.8\,A \Rightarrow$ Converter in DCM

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CHALMERS	Anonymous code / Anonym kod: Melsta ENM060/061	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: 3 – ii, iii

$\therefore$ For DCM, $\frac{V_0}{V_d} = D\sqrt{\frac{RT_s}{2L_m}}$ (from energy conservation)

(the expression should be derived !!)

$\Rightarrow V_0 = 0.2\sqrt{\frac{30}{2(100\mu)(20k)}} \cdot 20\text{ V} = \underline{\underline{10.9545\text{ V}}}$ (2)

However due to the turns ratio, $V_{0,max} = \frac{N_3}{N_2}V_d = \underline{\underline{10\text{ V}}}$

$\Rightarrow V_0 = 10\text{V}$, the secondary winding N_2 limits the output voltage

For switch on period, $i_d = i_m$, $V_{sw} = 0$, $i_D = 0$

For switch off period, D_2 conducts due to the fact that $V_0 = V_{0,max}$

$V_{sw} = V_d + \frac{N_1}{N_2}V_d = \underline{\underline{30V}}$ $\Rightarrow$ $i_D = 0$ but $i_{D2} = \frac{N_1}{N_2}i_m = i_m/2$ & $i_d = -i_{D2}$

For the discontinious period, $i_m = i_{D2} = i_d = i_D = 0$, $V_{sw} = V_d$

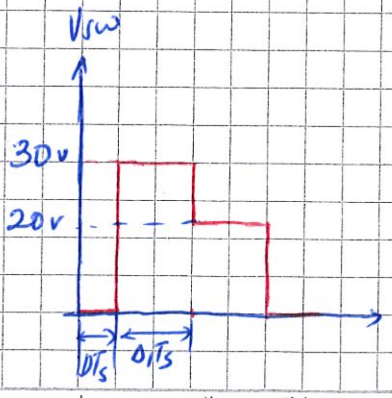
the interval the current goes off is $v_1 = L\frac{\Delta i_m}{\Delta t} \Rightarrow \frac{N_1}{N_2}V_d = \frac{L\Delta i_m}{\Delta_1 T_s}$

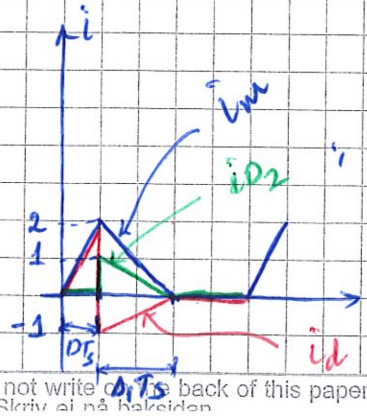
but $V_d = \frac{L\Delta i_m}{DT_s}$ (during switch on)

$\Rightarrow \Delta_1 = 2D = \underline{\underline{0.4}}$

i_D is only a transient current to account for capacitor loss and charge the voltage to $\underline{10V}$.

$\Delta i_m = \frac{V_d \cdot DT_s}{L} = 2A$ (2)





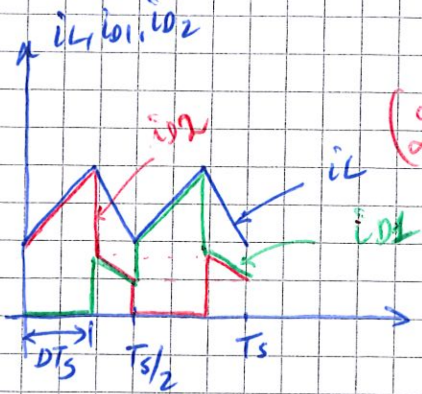
; $i_D = 0$ all the time in steadystate

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
Melstn		6
ENM060/061		Question no. / Uppgift nr: 4 a) b) c)

(a)

(b)



(2)

$D \leq 0.5$

$i_L = i_{o2} + i_{D1}$

$\left.\begin{array}{l} T_1, T_2, \text{on} \\ T_3, T_4, \text{off} \end{array}\right\} \Rightarrow i_{o2} = i_L,\ i_{o1} = 0$

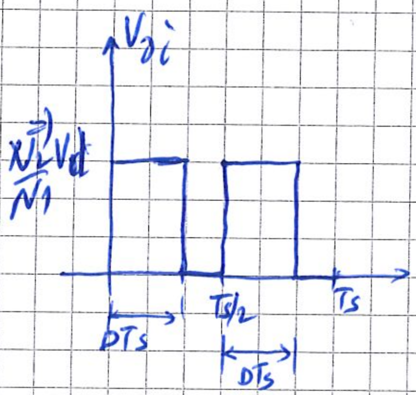
$\Rightarrow V_{oi} = \frac{N_2}{N_1} V_d$

$T_1, T_2, T_3, T_4 \text{ off} \} \Rightarrow i_{o2} = i_{o1} = i_L/2$

$V_{oi} = 0$

$\left.\begin{array}{l} T_1, T_2, \text{off} \\ T_3, T_4, \text{on} \end{array}\right\} \Rightarrow i_{o1} = i_L,\ i_{o2} = 0$

$V_{oi} = V_d \cdot \frac{N_2}{N_1}$



$$\Rightarrow V_o = \bar{V}_{oi} = \frac{1}{T_s}\left\{ 2 * DT_s * \frac{N_2}{N_1} V_d \right\} = \frac{2N_2 D}{N_1} \cdot V_d$$

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

(2)

(c)

+, Capacitor at the dc bus optional unlike half-bridge

+, twice the output voltage of a half bridge

$\Rightarrow$ higher power rating

$\Rightarrow$ possible to use less windings for the same V_o

−, more component count

−, more conduction loss $\Rightarrow$ less economical for lower power rating

(2)

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CHALMERS

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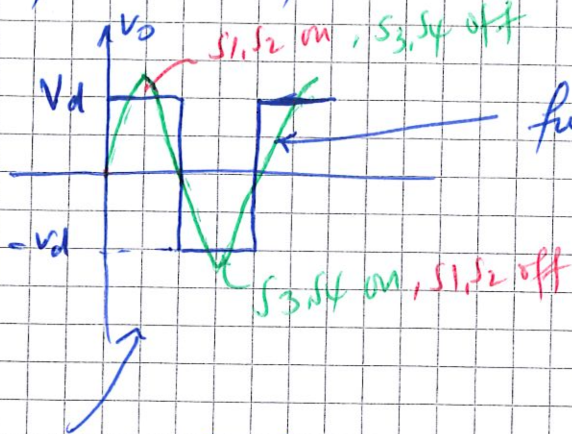
Mebtu ENM060/061		7
		Question no. / Uppgift nr: 5 a) b)

$V_d = 300V$

(a) square-wave operation



(2)

odd quarter wave $\Rightarrow a_h = 0$ for all h

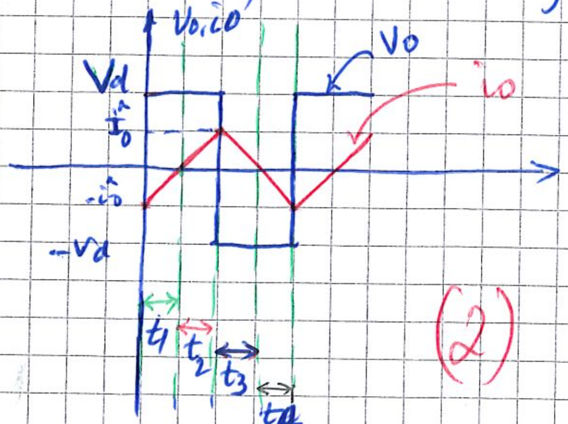
$b_h = \frac{4}{\pi h} V_d$ for h odd

$\Rightarrow b_1 = \frac{4}{\pi} V_d = \underline{\underline{382V}}$

$\Rightarrow \hat{V}_{o(1)} = 382V$, $V_{o(1)_{RMS}} = \underline{\underline{270V}}$

(b) $V_o = L\frac{di}{dt} \Rightarrow i_L = \frac{1}{L}\int_0^t V_o(\tau)d\tau$; being in Ac, $\bar{I}_L = 0$

$\Rightarrow$ i_L increases & decreases from an average value of 0.
Since V_o is squarewave, i_L increases/decreases linearly when V_o is positive and negative respectively.



4 quadrant operation possible

(2)

time	Device conducting
t1	D1, D2
t2	S1, S2
t3	D3, D4
t4	S3, S4

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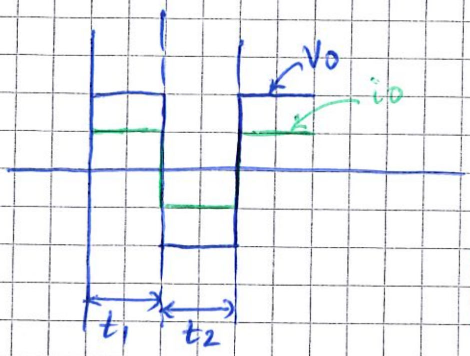
2

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 8
			Question no. / Uppgift nr 5 c) d) e) f)

(c) For a purely resistive load

$v_0 = R i_0 \Rightarrow i_0 = v_0/R$



time	Device Conducting
t_1	S_1, S_2
t_2	S_3, S_4

(2)

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

$(m_a \leq 1)$

$V_{o(1)_{RMS}} = \frac{300}{\sqrt{2}} V = \underline{\underline{212\,V}}$

(2)

(e) Square wave

+	−
✓ smaller switching loss	✓ higher low order harmonics
✓ simpler modulation	✓ uncontrolled output voltage
✓ higher fundamental output	

PWM operation

+	−
✓ smaller low order harmonics	✓ higher switching loss
✓ controlled output voltage	✓ complex control
	✓ electromagnetic disturbance

(2)

(f) three-phase :-

+

✓ low harmonics
✓ higher power output

−

✓ more component count ⇒ expensive
✓ more losses ⇒ less economical for lower power output & single phase loads

(2)

CHALMERS

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MeAu ENM060/061		9
		Question no. / Uppgift nr 6 a) b)

(a) $V_{LL} = 300V$, $I_d = 10A$, $50Hz$

current flows in phase a when V_a is higher or lower than both V_b and V_c.

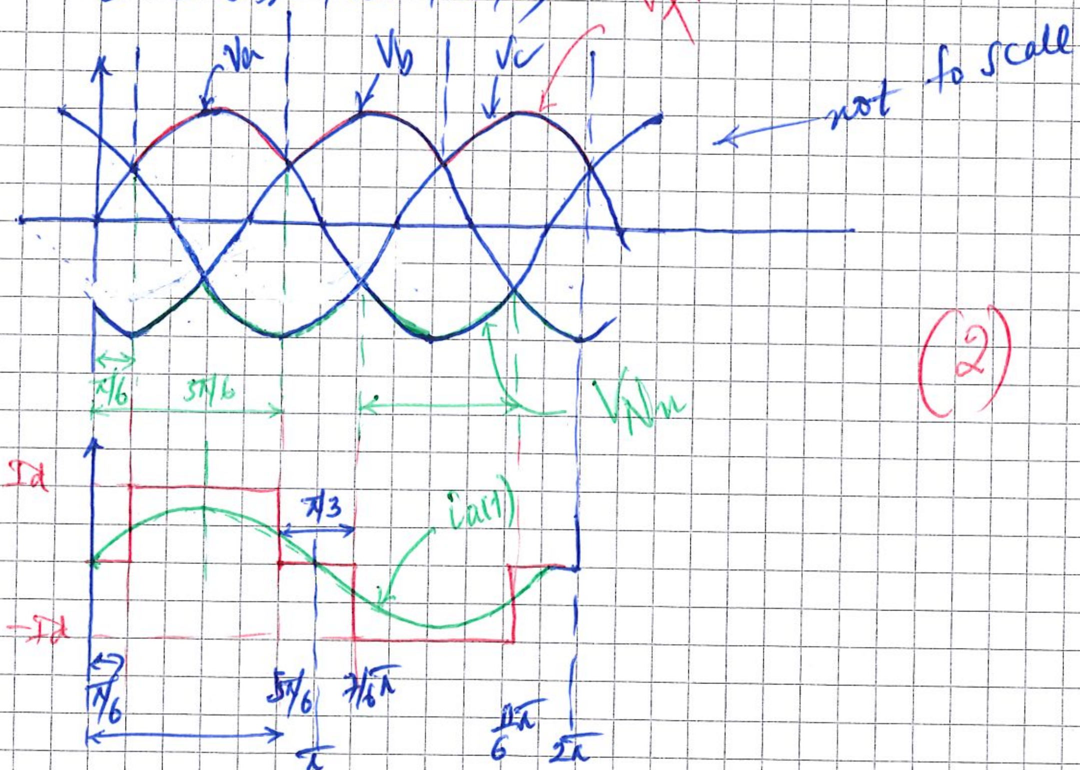
the output voltage $V_d = \max(V_a, V_b, V_c) - \min(V_a, V_b, V_c) = V_{Pn} - V_{Nn}$

$300\ LL \Rightarrow \hat{V}_a = \frac{300\sqrt{2}}{\sqrt{3}} = 245V$

$\Rightarrow V_a = 245\sin(\omega t)$

$V_b = 245\sin(\omega t - 2\pi/3)$

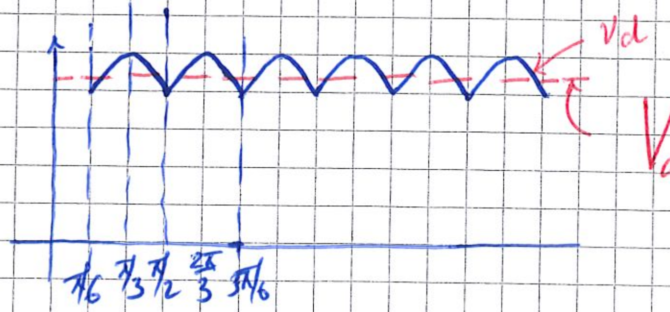
$V_c = 245\sin(\omega t + 2\pi/3)$



(2)

No phase shift between V_a & $i_{a(1)}$ $\Rightarrow$ $\underline{\underline{DPF = 1}}$

(b)



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For one cycle, $\pi/6$ to $\pi/2$, $v_d = (V_{LL}\sqrt{2})\cos(\theta - \pi/3)$

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

(2)

$$= \frac{3}{\pi}\int_{-\pi/6}^{\pi/6} \sqrt{2}V_{LL}\cos\theta \cdot d\theta = \frac{3\sqrt{2}}{\pi}V_{LL}\sin\theta\Big|_{-\pi/6}^{\pi/6} = \frac{3\sqrt{2}}{\pi}V_{LL} = \underline{\underline{405V}}$$

(c) Source inductance adds a commutation angle, u.

$\Rightarrow$ DPF $= \cos(u/2) \Rightarrow$ decreases

this also reduces the average output voltage.

(2)

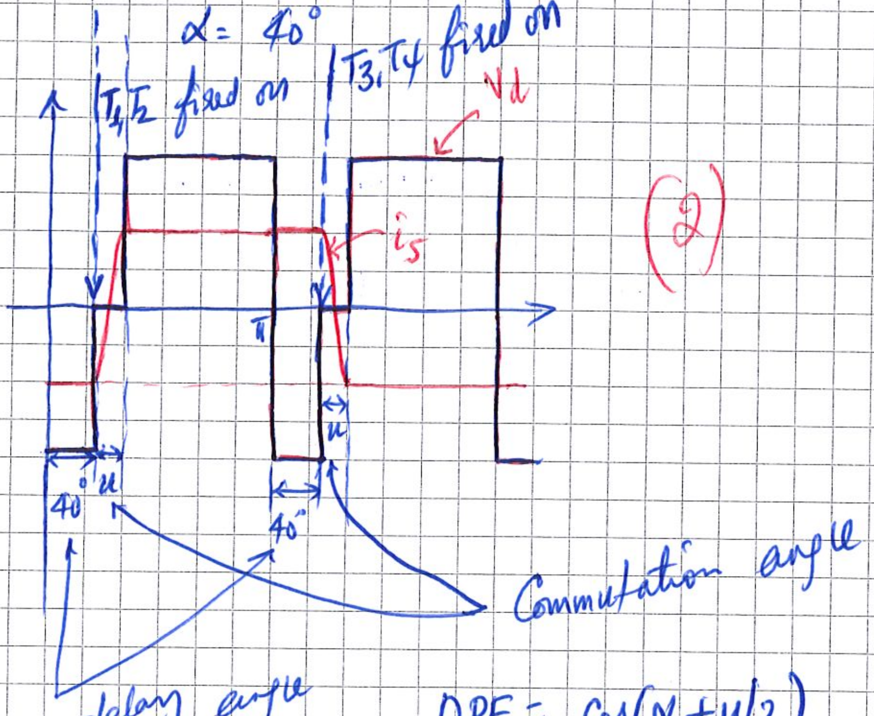
CHALMERS	Anonymous code / Anonym kod	Points for question (to be filled in by teacher) / Poäng på uppgiften (ifylles av lärare)	Consecutive page no. / Löpande sid nr
	Mehtn ENM060/061		11
			Question no. / Uppgift nr: 7 a) b)

(a) $L_s = 5mH$, 50Hz system

$i_d = I_d = 20A$

$v_s = \pm 150\,V$

$\alpha = 40°$



(2)

$DPF = \cos(\alpha + u/2)$

(b) during 2 commutations, $V_d = 0$ $(2 \times u)$

during $2 \times 40°$, $V_d = -150\,V$ $(2 \times 40°)$

for other intervals, $V_d = 150\,V$ $(360° - 2 \times 40 - 2 \times u)$

$$\Rightarrow V_d = \frac{(360 - 2\times 40° - 2\times u)150 - (2\times 40°)150 + (2\times u)0}{360}$$

$$\Rightarrow V_d = \frac{360 - 160 - 2u}{360} \cdot 150 \quad , \quad u \text{ in degrees.}$$

Find u = ?

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i_s increases from $-I_d$ to I_d in interval of u

$\Rightarrow V_s = L_s \frac{di_s}{dt}$ where $V_s = 150V$

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

(2)

$\Rightarrow \int_0^u V_s d\theta = L_s\omega \int_{-I_d}^{I_d} di_s = 2L_s\omega I_d$

$\Rightarrow V_s \cdot u = 150u = 2L_s\omega I_d$

$\Rightarrow u = \frac{2L_s\omega I_d}{150}$ rad $= \frac{2L_s\omega I_d}{150} * \frac{180}{\pi}$ degrees $= \underline{\underline{24^\circ}}$

$\Rightarrow V_d = \frac{360-160-2\times24}{360} \cdot 150 = \underline{\underline{63.3V}}$

(c) the source inductance results in $V_d = 0$ during the commutation angle. this results in a reduction of the average voltage by

$\frac{2\times24}{360^\circ} * 150V = \underline{\underline{20V}}$

(2)

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