2

CHALMERS

Anonymous code / Anonym kod: ENM061 - April 24/2019

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) Component heating ⇒ decide cooling (size) requirement and possible operating power level (1) (1)

(b) Steadystate VI characteristic [check slide notes]

Thyristor ⇒ a threshold voltage needed for conduction (1), reverse recovery

MOSFET ⇒ No threshold voltage (1), no reverse recovery

operation ⇒ Thyristor - semi controlled, high power

MOSFET - fully controlled, low power (1)

(c) Calculate I_{sat} [check slide notes]

$Ni_{sat} = B_{sat}A_c(R_g + R_c)$: Reluctance of core (R_c) & airgap (R_g), inductance (L)

⇒ without air gap $i'_{sat} = \frac{B_{sat}A_c \cdot R_c}{N}$, $\left[\begin{matrix} L'' = N^2/(R_c+R_g) \\ L' = N^2/R_c \end{matrix}\right]$

with airgap $i''_{sat} = \frac{B_{sat}A_c}{N} \cdot (R_c + R_g) > i'_{sat}$ (1)

operating range for energy stored in the inductor

$Energy' = \frac{1}{2}L' i'^2_{sat} = \frac{1}{2}B_{sat}A_c N \cdot I'_{sat} < \frac{1}{2}B_{sat}A_c N \cdot i''_{sat} = \frac{1}{2}L'' i''^2_{sat}$

(1)

$N_1 : N_2 : N_3 = 0.5 : 1 : 1$ Flyback Converter

$V_d = 25$ V

$f_{sw} = 30$ kHz $\Rightarrow T_s = 1/f_{sw}$

$D = 0.4$

$L_m = 120\ \mu H$

(a) $R_{load} = 15/150\ \Omega$, $V_0 = ?$ with N_2, $V_{0,max} = \frac{N_3}{N_2} V_d = \underline{V_d}$

Identify operation Mode CCM/DCM.

For CCM:

$V_0 = \frac{N_3}{N_1} \cdot \frac{D}{1-D} V_d = \frac{1}{0.5} \cdot \frac{0.4}{1-0.4} \cdot V_d = \frac{4}{3} V_d > V_d$ (N2 winding working)

$\Rightarrow$ if CCM, $V_0 = V_d$ (2)

During S on, $L_m \frac{\Delta i_m}{DT_s} = V_1 = V_d$

$\Rightarrow \Delta i_m = \underline{4.17\ A}$

During S off, D_2 conducts $\Rightarrow -L_m \frac{\Delta i_m}{\Delta_1 T_s} = V_2 \frac{N_1}{N_2} = -0.5 V_d$

for $\Delta i_m = 4.17 \Rightarrow$ the demagnetizing time $\Delta_1 = 2D = 0.8$

but $D + \Delta_1 = 1.2 > 1 \Rightarrow$ the magnetizing current keeps increasing

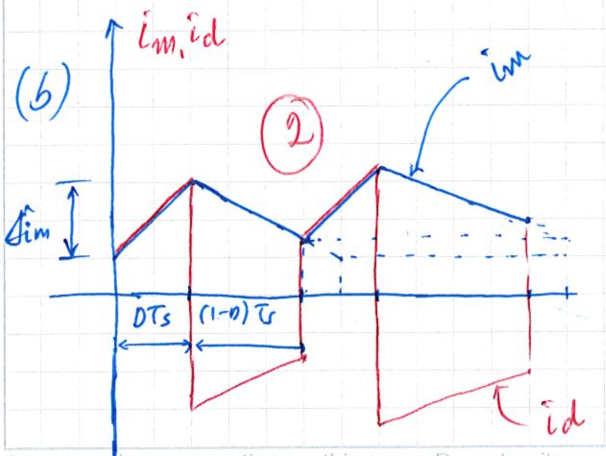
As there is no enough demagnetizing time, the converter works in CCM mode all the time for $R_{load} = 15\Omega / 150\Omega$. (2)

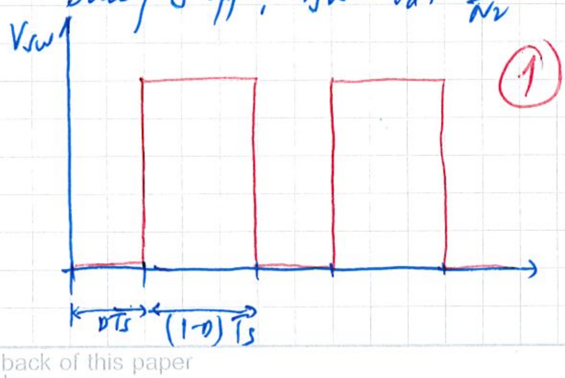
$\Rightarrow V_0 = V_d = 25V. \Rightarrow i_D = 0$

During S on, $V_{sw} = 0$

During S off, $V_{sw} = V_d + \frac{N_1}{N_2} V_d = 1.5 V_d = 37.5V$

(b)





Forward Converter

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

$V_0 : 20\,v$

$P_0 = 60W$

$V_d = 30V$

$f_{sw} : 30\,kHz \quad , \Rightarrow T_s = 1/f_{sw}$

(a) $\Delta i_L : 0.15 I_L, \quad \Delta i_m : 0.015 I_L \qquad (I_L = I_0)$

$I_L = I_0 = P_0/V_0 = 3A$

$\Rightarrow \Delta i_L = 0.45A \Rightarrow$ During Sw ON, $v_L = \frac{L \Delta i_L}{DT_s} = \frac{N_2}{N_1} V_d - V_0$ ($\Delta i_L \Rightarrow 0.45$, $\frac{N_2}{N_1} \Rightarrow 1$)

$\Delta i_m : 0.045A \Rightarrow$ During Sw on, $v_1 = V_d = L_m \frac{\Delta i_m}{DT_s}$ ($\Delta i_m \Rightarrow 0.045$)

} $D = ?$

$\Delta i_L = 0.45 A \Leftrightarrow \quad \frac{\Delta i_L}{2} = 0.225A < I_L = I_0 = 3A \quad \Rightarrow \quad$ CCM.

$\Rightarrow \quad V_0 = \frac{N_2}{N_1} \cdot D V_d \Rightarrow D = N_1/N_2 \cdot V_0/V_d = \frac{V_0}{V_d} = \underline{0.67 = 2/3}$ (1)

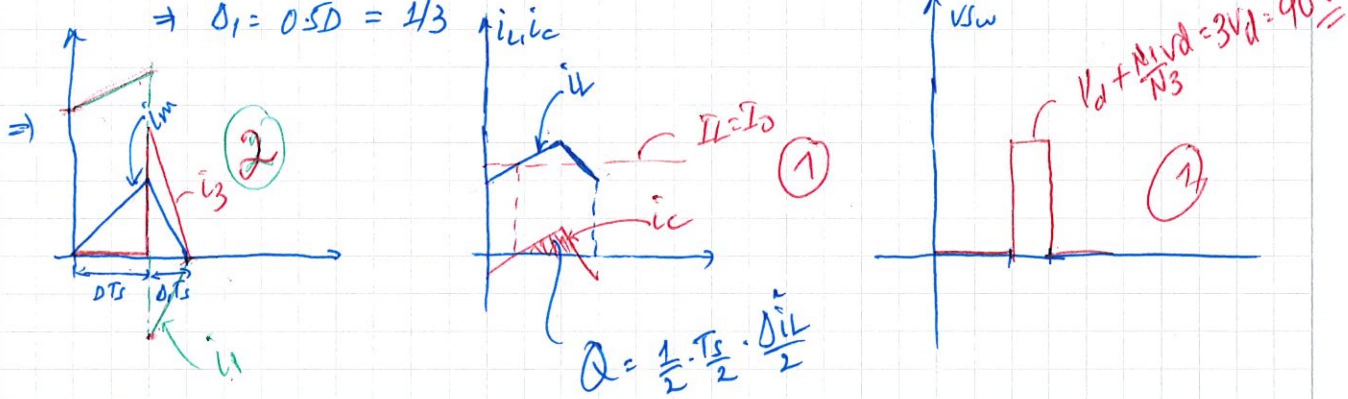
$\therefore \quad L = \frac{DT_s(V_d - V_0)}{\Delta i_L} H = \underline{0.496\,mH}$ (1)

$L_m = \frac{DT_s(V_d)}{\Delta i_m} H = \underline{14.9\,mH.}$ (1)

(b) refer the slide notes for waveforms.

For Δi_m, D_1 = demagnetizing time = ? For Sw off, $V_1 = \frac{N_1}{N_3} V_3 = \frac{N_1}{N_3} V_d = -2V_d$

$\Rightarrow D_1 = 0.5D = 1/3$



(c) $\Delta V_0 = 0.02 V_0 = 0.4V = \frac{1/2 (\Delta \hat{i}_{Lm}/2)(T_s/2)}{C_{min}} = Q_{Area}/C_{min}$ (2)

$\Rightarrow C_{min} = \frac{1/8 (\cdot \Delta \hat{i}_{Lm})(1/f_{sw})}{\Delta V_0} = \frac{1/8 (0.45)(1/30(10^3))}{0.4} F = 4.69\ \mu F$

(d) $f_c = \frac{1}{2\pi}\sqrt{\frac{1}{LC}}\ Hz = \frac{1}{2\pi}\sqrt{\frac{1}{0.496(10^{-3})(4.69(10^{-6}))}}\ Hz = 3.3\ kHz$ (1)

$f_c \ll f_{sw} = 30\ kHz \Rightarrow$ good filtering of harmonics can be achieved! (1)

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(a) ac-current harmonics : 3, 5, 7, 9, 11 --- 2n±1
dc-current harmonics : 2, 4, 6, ---- 2n
} 1-phase (2)

ac-current harmonics : 5, 7, 11, 13 ---- 6n±1
dc-current harmonics : 6, 12, --- 6n
} 3-phase (2)

(b) advantage :- higher fundamental output voltage
: easy modulation (1)
: less switching losses

disadvantages :: uncontrolled output voltage
: low order harmonics (1)

(c) Use PWM modulation with higher frequency of the triangular waveform (2)

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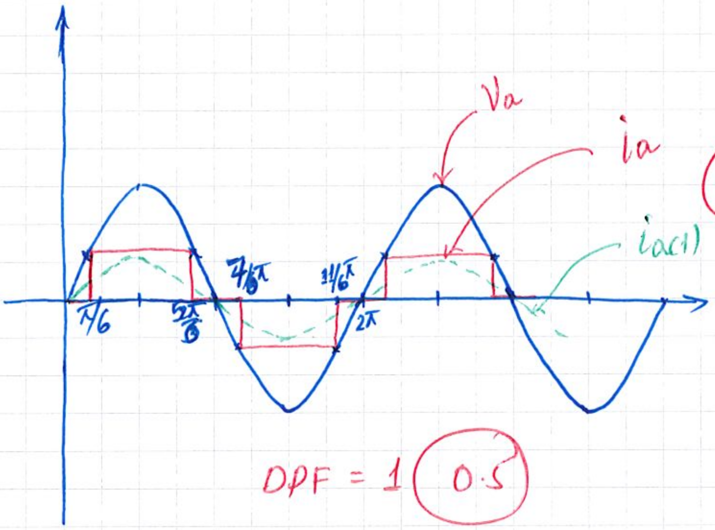
Question no. / Uppgift nr: 5a) b)

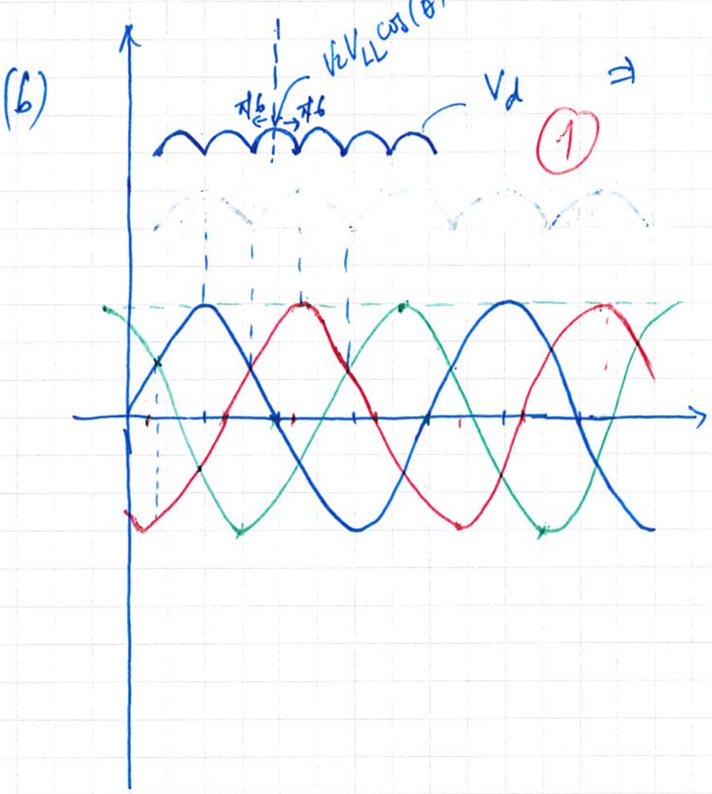
(a) $I_d = 15A$, 50Hz , $V_{LL} = 400V$



1.5

DPF = 1 (0.5)

(b)



(1)

$$\Rightarrow V_d = \frac{1}{\pi/3}\int_{-\pi/6}^{\pi/6} \sqrt{2}V_{LL}\cos(\theta)\,d\theta = \frac{1}{\pi/6}\int_{0}^{\pi/6} \sqrt{2}V_{LL}\cos(\theta)\,d\theta$$

$$= \frac{3\sqrt{2}}{\pi} V_{LL} \;\; v = \underline{\underline{540V}}$$

(2)

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$L_s = 5mH$, $f = 50Hz$

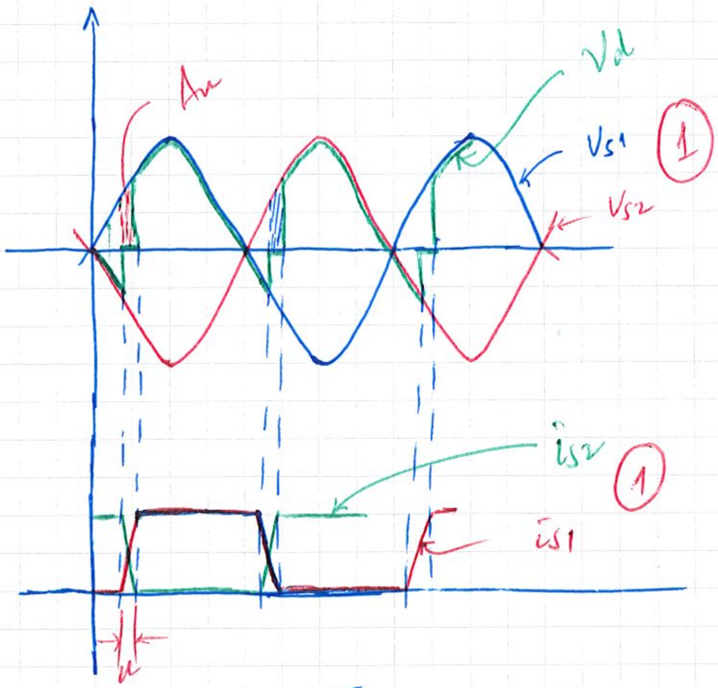
$I_d = 15A$

$V_{s1} = 180 \sin(\theta)$

$V_{s2} = 180 \sin(\theta - \pi)$

$\alpha = 30° = \pi/6$ rad

(a)



(1) (1)

$$V_d = \frac{1}{\pi}\left[\int_{\alpha}^{\alpha+\pi} v_d \, d\theta - A_u\right] \quad ; \quad V_d = V_{s1} = 180 \sin(\theta)$$

$A_u = ?$ $\quad v_{s1} - v_{s2} - L_s \frac{di_{s1}}{dt} + L_s \frac{di_{s2}}{dt} = 0$ during Commutation

$\Downarrow$

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

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

$$\Rightarrow L_s \frac{di_{s1}}{dt} = \frac{1}{2}\{v_{s1} - v_{s2}\}$$

$$A_u = \int_0^{\theta u} \frac{1}{2}(v_{s1} - v_{s2}) \, d\theta = \int_0^{I_d} L_s \frac{di_s}{dt} \cdot d\theta = \int_0^{I_d} \omega L_s \frac{di_s}{dt} \cdot dt = \underline{\omega L_s I_d}$$

(2)

$$\Rightarrow V_d = \frac{1}{\pi}\int_{\alpha}^{\alpha+\pi} 180 \sin(\theta) d\theta - \frac{\omega L_s I_d}{\pi} = \frac{180[2\cos(\alpha)] - \omega L_s I_d}{\pi} = \underline{91.7V}$$

(b) $\alpha = 150° \Rightarrow V_d = [180[2\cos(150°)] - \omega L_s I_d]/\pi = \underline{-106.7V}$ (2)

(c) $\alpha = 0°$, $L_s = 0 \Rightarrow A_u = 0 \Rightarrow$ plot i_{s1}, i_{s2} with $\alpha = 0$, $u = 0$ & V_d. (1) $\quad V_d = 180[2]/\pi = \underline{114.6V}$ (1)

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$P = 2.5W$

$T_a = 20°c$

$R_{thja} = 62°c/w$

(a) $T_j = T_a + P[R_{thja}] = 20° + 2.5(62)° = \underline{\underline{175}}°c > T_{jmax}$

heatsink needed

(2)

(b) $T_{jmax} = 100 = T_a + P[R'_{thja_{max}}] = 20° + 2.5[R'_{thja_{max}}]$

$\Rightarrow R'_{thja_{max}} = \frac{100° - 20°}{2.5w} = \underline{\underline{32°c/w}}$

(2)