CHALMERS

2

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Solution ENM061

Points for question (to be filled in by teacher) / Poäng på uppgiften (ifylles av lärare)

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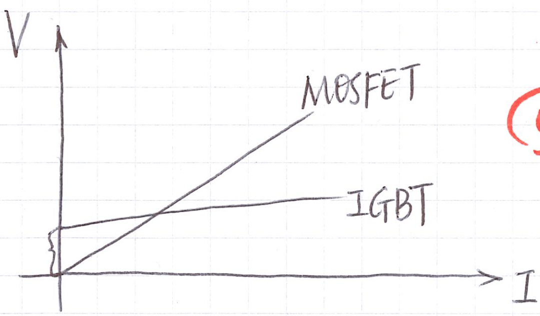
Q # 1.

(a) Fourier components represent sinusoidal components with frequencies multiples of the signal frequency of a periodic signal. (1)

We need to calculate them to know the harmonic content (THD) of a signal to design the corresponding filters and avoid electromagnetic interference (EMI). (1)

(b) IGBT : smaller R_{on}, non-zero threshold conduction voltage. (1)

MOSFET : higher R_{on}, zero threshold conduction voltage.



(1)

Q #2.

(a) $N_1 : N_2 : N_3 = 1:2:2$, $V_d = 20V$, $f_{sw} = 20\,kHz$.

$D = 0.3$, $L_m = 100\,\mu H$, $R_{load} = 20\Omega, 60\Omega$. V_o?

First identify CCM or DCM.

Assume CCM.

$$\Rightarrow \frac{V_o}{V_d} = \frac{N_3}{N_1} \cdot \frac{D}{1-D}.$$

$$\Rightarrow V_o = \frac{2}{1} \cdot \frac{0.3}{0.7} \cdot 20V = 17.14V < \frac{N_3}{N_2} \cdot V_d = 20V$$

$$\Rightarrow I_o = \frac{V_o}{R_{load}} = \begin{cases} 0.857\,A & \text{for } R_{load} = 20\Omega \\ 0.286\,A & \text{for } R_{load} = 60\Omega. \end{cases}$$

$$P_{in} = P_{out} \Rightarrow V_d I_d = V_o \cdot I_o.$$

$$\Rightarrow I_d = \begin{cases} 0.734\,A & \text{for } R_{load} = 20\Omega. \\ 0.244\,A & \text{for } R_{load} = 60\Omega. \end{cases}$$

$$I_m = I_d + I_o \frac{N_3}{N_1} = \begin{cases} 2.45A & \text{for } R_{load} = 20\Omega \\ 0.82A & \text{for } R_{load} = 60\Omega. \end{cases}$$ 1

$$\frac{\Delta i_m}{2} = \frac{D \cdot V_d}{2 \cdot L_m \cdot f_{sw}} = 1.5A.$$

$$\begin{cases} \frac{\Delta i_m}{2} < I_m & \text{for } R_{load} = 20\Omega \quad \text{CCM.} \\ \frac{\Delta i_m}{2} > I_m & \text{for } R_{load} = 60\Omega \quad \text{DCM.} \end{cases}$$ 1 1

for $R_{load} = 20\Omega$ $\Rightarrow$ CCM $\Rightarrow$ $V_o = \frac{N_3}{N_1} \cdot \frac{D}{1-D} V_d = 17.14V$

$< \frac{N_3}{N_2} \cdot V_d = 20V$

$\Rightarrow$ winding N_2 not used.

for $R_{load} = 60\Omega$ $\Rightarrow$ DCM.

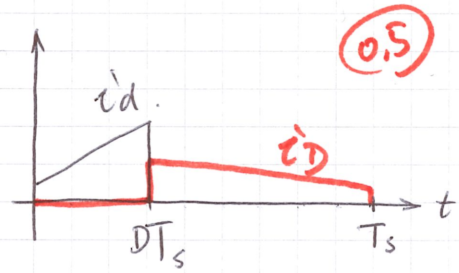
$\Rightarrow V_o = D \cdot \sqrt{\frac{R_{load}}{2L_m f_{sw}}} \cdot V_d = 23.24V > \frac{N_3}{N_2} V_d = 20V$

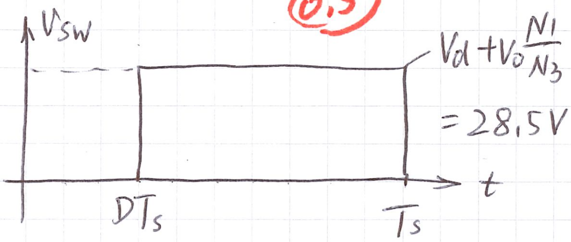
$\Rightarrow V_o = V_{o,max} = \frac{N_3}{N_2} V_d = 20V$ 1

$\Rightarrow$ winding N_2 is conducting.

(b) $R_{load} = 20\Omega$, CCM. $\Delta i_m = 3A$, $I_m = 1.591A$.

0.5 0.5

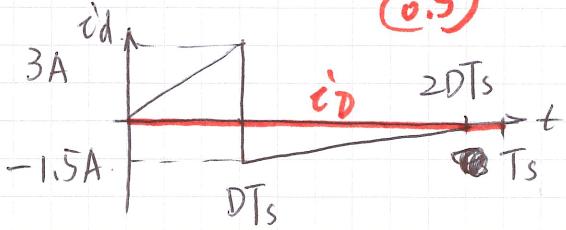


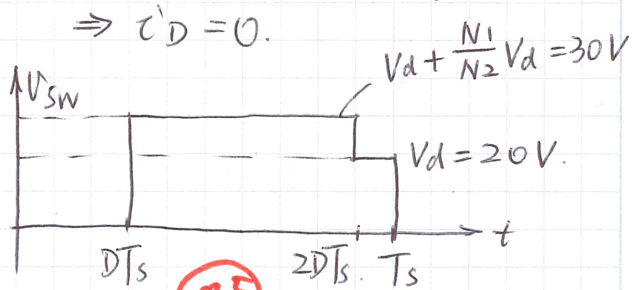


$R_{load} = 60\Omega$. DCM. $\Delta i_m = 3A$. winding N_2 conducting.

0.5

$\Rightarrow i_D = 0$.





0.5

(c) Unipolar core excitation. 1

Core with airgap as the transformer is used for energy storage. 1

Q #3. $N_1 : N_3 : N_2 = 1 : 0.5 : 1$. $V_o = 15V$, $P_o = 50W$.

$V_d = 25V$ $f_{sw} = 20\,kHz$.

(a). $I_o = \frac{P_o}{V_o} = \frac{50}{15} = 3.33A = I_L$.

$\Rightarrow \Delta i_L = 0.1 I_o = 0.333A \Rightarrow \frac{\Delta i_L}{2} < I_L \Rightarrow$ CCM.

$\frac{V_o}{V_d} = \frac{N_2}{N_1} \cdot D \Rightarrow D = 0.6$. 1

During on period. $v_L = \frac{N_2}{N_1} V_d - V_o = V_d - V_o = \frac{L \cdot \Delta i_L}{DT_s}$. 1.

$L = \frac{D \cdot (V_d - V_o)}{\Delta i_L \cdot f_{sw}} = \frac{0.6 \cdot (25V - 15V)}{0.333A \cdot 20kHz} = 0.9\,mH$.

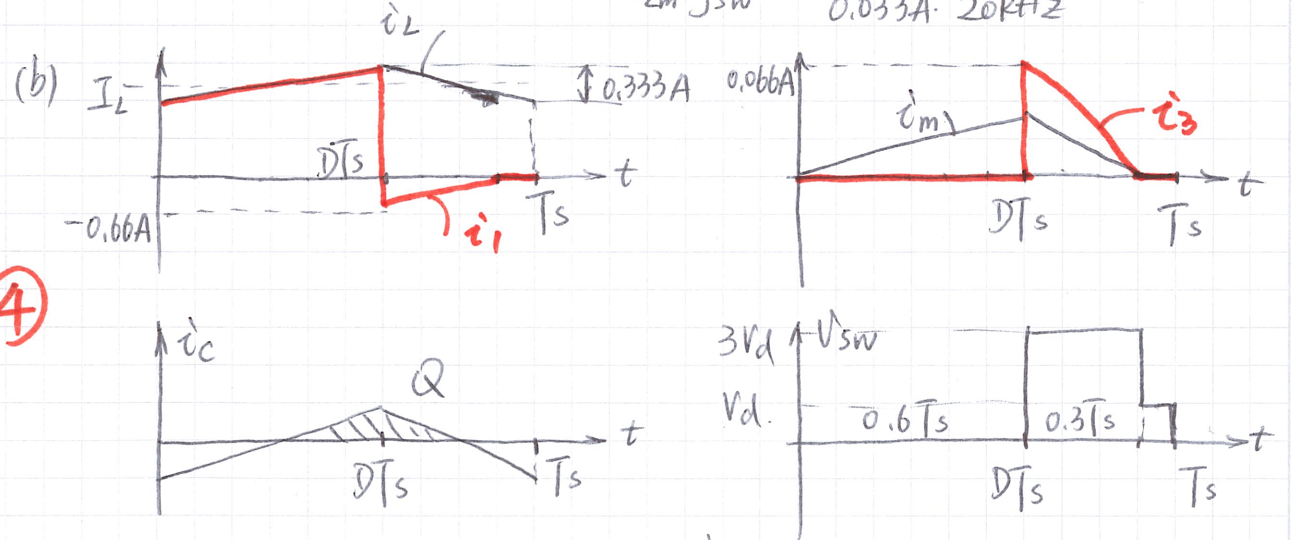
$\Delta i_m \ll \Delta i_L$

$\Rightarrow \Delta i_{Lm} = 0.01 I_o = 0.033A$.

During on period. $v_1 = V_d = L_m \frac{\Delta i_{Lm}}{DT_s}$. 1

$L_m = \frac{D \cdot V_d}{\Delta i_{Lm} \cdot f_{sw}} = \frac{0.6 \cdot 25V}{0.033A \cdot 20kHz} = 22.52\,mH$

(b)



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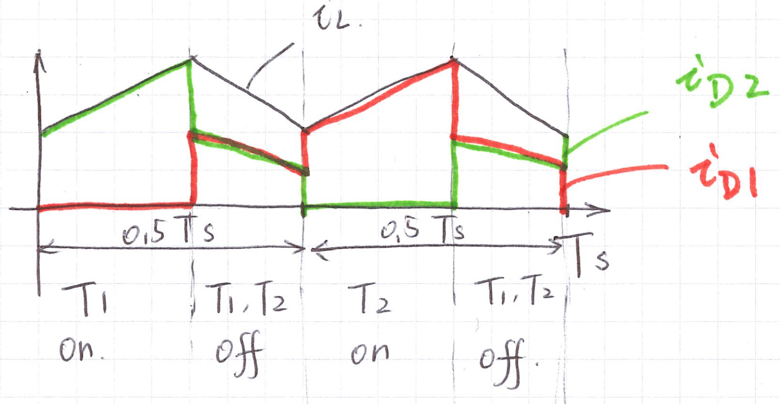
(c) $\Delta V_o = 0.01 V_o = 0.15V = \frac{Q}{C} = \frac{\frac{1}{2} \cdot \frac{\Delta i_L}{2} \cdot \frac{T_s}{2}}{C} \Rightarrow C = 13.9\,\mu F$. 2

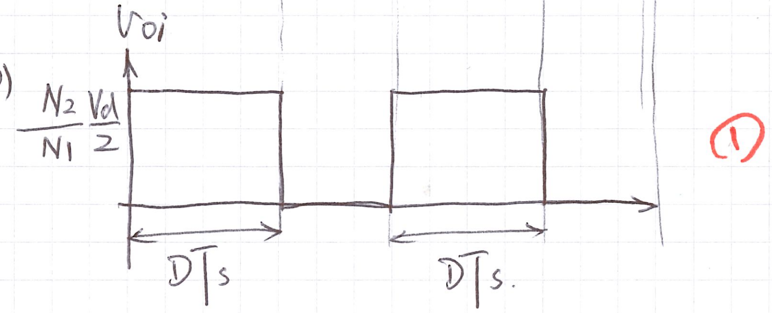
(d). Unipolar core excitation. No air gap as L_m should be large so i_m is small. The transformer is not used for energy storage as there is another inductance. 2

Q # 4.

(a)

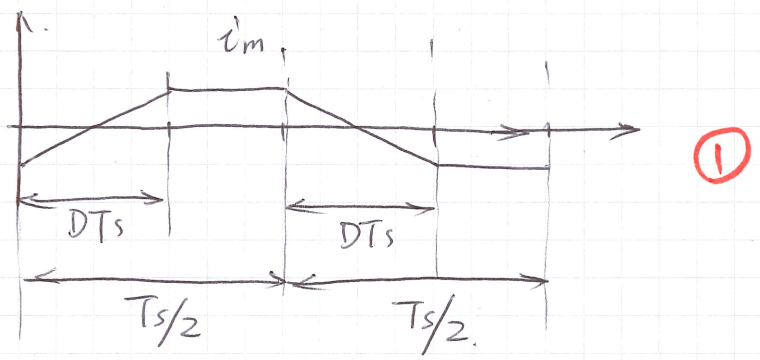


(b)



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

(c)



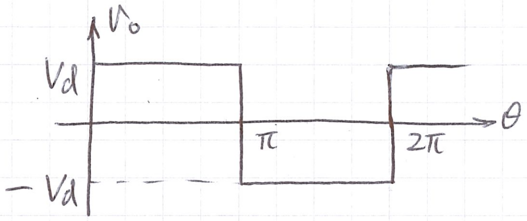
bipolar core exitation ⇒ higher operating range. 1

⇒ core saturation can be avoided.

2

Q #5.

(a)



1

$$\hat{V}_{o,1} = \frac{4}{\pi}\int_0^{\frac{\pi}{2}} V_d \cdot \sin\theta \cdot d\theta = V_d \cdot \frac{4}{\pi} \cdot (-\cos\theta)\Big|_0^{\frac{\pi}{2}} = \frac{4}{\pi} V_d.$$

1

$$V_{o,rms} = \sqrt{\frac{1}{2\pi}\int_0^{2\pi} V_d^2 \cdot d\theta} = V_d.$$

$$V_{o,1,rms} = \frac{4}{\pi} V_d \cdot \frac{1}{\sqrt{2}} = \frac{2\sqrt{2}}{\pi} V_d.$$

$$\Rightarrow THD = \frac{\sqrt{V_{o,rms}^2 - V_{o,1,rms}^2}}{V_{o,1,rms}} \times 100\%.$$

$$= \frac{\sqrt{1-(2\sqrt{2}/\pi)^2}}{2\sqrt{2}/\pi} \times 100\% = 48.3\%.$$ 1

(b) current harmonics

$$\begin{cases} \text{1-phase} : & 2n \pm 1 = 3, 5, 7, 9, \cdots \\ \text{3-phase} : & 6n \pm 1 = 5, 7, 11, 13, \cdots \end{cases}$$ 1 1

3-phase removes odd harmonics that are multiples of 3. 1

(c) Using PWM instead of square-wave – by using a high frequency triangular wave for modulation, the low-order harmonics are pushed higher up. 2

(d) Multilevel: advantages. ⇒ better harmonics performance.
⇒ lower switching losses. 1

disadvantages. ⇒ more components.
⇒ more complicated design. 1

Q #6. $v_{s1} = 230V \frac{\sqrt{2}}{\sqrt{3}} \sin\theta = 230V \cdot \frac{\sqrt{2}}{\sqrt{3}} \sin(2\pi \cdot 50Hz \cdot t)$

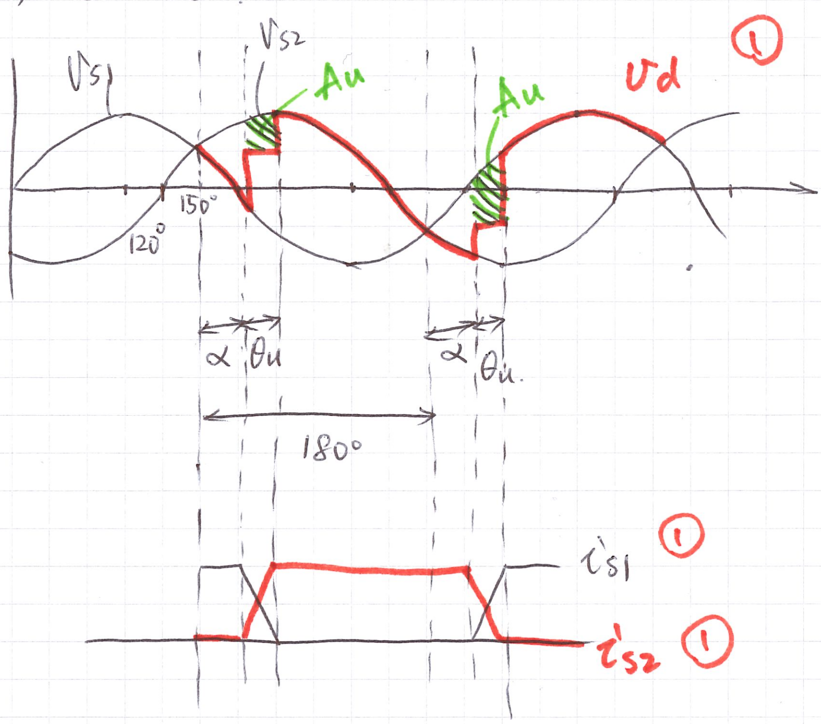
$v_{s2} = 230V \cdot \frac{\sqrt{2}}{\sqrt{3}} \cdot \sin(\theta - \frac{2}{3}\pi) = 230V \cdot \frac{\sqrt{2}}{\sqrt{3}} \sin(2\pi \cdot 50Hz\, t - \frac{2}{3}\pi)$

$\uparrow$ 120°.

$L_s = 5mH$.

$I_d = 10A$.

(a) $\alpha = 35°$.



(1) $V_d = \frac{1}{2\pi}\left(\int_{\alpha+150°}^{\alpha+\pi+150°} v_{s2} \cdot d\theta + \int_{\alpha+\pi+150°}^{\alpha+\pi+150°+\pi} v_{s1} \cdot d\theta\right) - \frac{2A_u}{2\pi}$

$= \frac{1}{2\pi}\left[\int_{\alpha+\frac{\pi}{6}}^{\alpha+\frac{\pi}{6}+\pi} v_{s1} \cdot d\theta + \int_{\alpha+\pi+5\pi/6}^{\alpha+\pi+5\pi/6+\pi} v_{s1} \cdot d\theta\right] - \frac{2A_u}{2\pi}$

(1) $A_u = ?$ $\quad v_{s1} - v_{s2} - L_s \frac{di_{s1}}{dt} + L_s \frac{di_{s2}}{dt} = 0. \quad i_{s1} = I_d - i_u$

$i_{s2} = i_u$.

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

$A_u = \frac{1}{2}\int (v_{s2} - v_{s1}) \cdot d\theta = L_s \omega I_d$.

(b). $\alpha = 145°$. $\Rightarrow$ average output voltage will be negative. 1

use previous expression.

$$V_d = \frac{1}{2\pi}\left[\int_{\alpha+\pi/6}^{\alpha+\pi/6+\pi} U_{s1}\, d\theta + \int_{\alpha+5\pi/6+\pi}^{\alpha+5\pi/6+2\pi} U_{s1}\, d\theta\right] - \frac{2L_s w I_d}{2\pi}$$

2

$$\alpha = \frac{145}{180}\cdot\pi$$

(c). in this case $\alpha = 0$.

$L_s = 0 \Rightarrow A_u = 0$.

use previous expression and no commutation in the plots.

i_{s1}, i_{s2} plots. 1

V_d plot. 1

V_d calculation. 1

$$V_d = \frac{1}{2\pi}\left[\int_{\pi/6}^{\pi/6+\pi} U_{s1}\, d\theta + \int_{5\pi/6+\pi}^{5\pi/6+2\pi} U_{s1}\, d\theta\right].$$