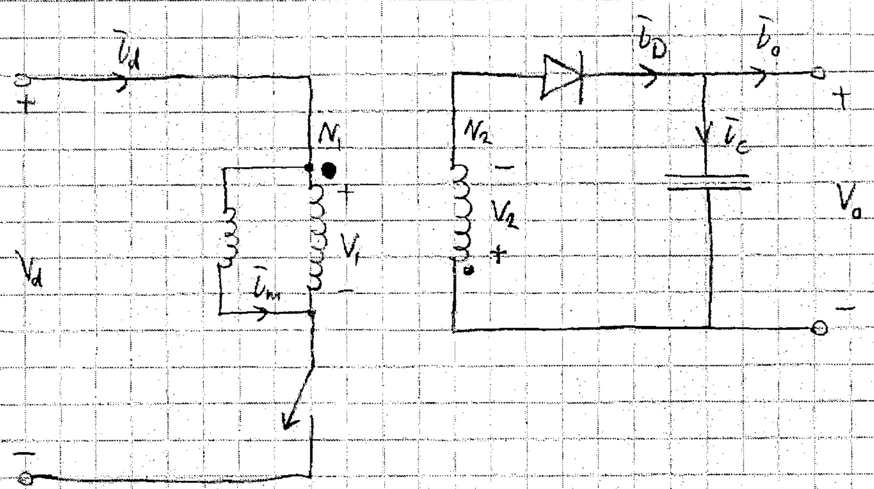
10-3

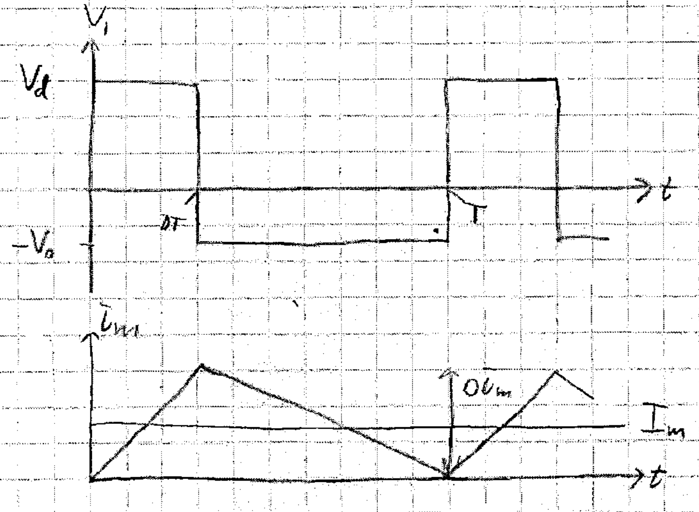


$N_1 = N_2$, $V_o = 12V$ V_d is $12-24V$

$P_{load} = 6-60W$ · $f_s = 200\ kHz$

Calculate the maximum L_m that can be used if the converter is always required to operate in a complete demagnetization mode (DCM).

We assume steady-state operation and draws the waveforms on the border between CCM and DCM.



for DCM we know that

$\Delta i_m \geqslant 2I_m$

$\Delta i_m = \frac{V_o(1-D)}{L_m f_s}$ ← this is only valid at the border (use $V_L = L\frac{di_L}{dt}$ and the time the switch is open)

We know that in steady-state

$$0 = I_C = \frac{1}{T}\int_0^T i_D - i_o \, dt = \frac{1}{T}\int_0^T i_D \, dt - \frac{1}{T}\int_0^T i_o \, dt = I_D - I_o \Rightarrow$$

$$I_D = I_o \qquad 0 = V_L = \frac{1}{T}\left(V_d DT - V_o(1-D)T\right) \Rightarrow V_o = \frac{D}{1-D} V_d$$

$$I_o = I_D = \frac{1}{T}\int_0^T i_D \, dt = \frac{1}{T}\int_{DT}^T i_m \, dt = \frac{(1-D)T}{T} \underbrace{\frac{1}{(1-D)T}\int_{DT}^T i_m \, dt}_{= I_m} = (1-D) I_m$$

$$\Delta i_m \geqslant 2 I_m \Rightarrow$$

$$\frac{V_o(1-D)}{L_m f_s} \geqslant 2 I_m = 2\frac{I_o}{1-D} = 2\frac{P_o}{V_o}\frac{1}{1-D} \Rightarrow$$

$$L_m \leqslant \frac{V_o^2(1-D)^2}{2 f_s P_o}$$

We must now find D and P_o within the operation interval that gives the lowest value of $\frac{V_o^2(1-D)^2}{2 f_s P_o}$

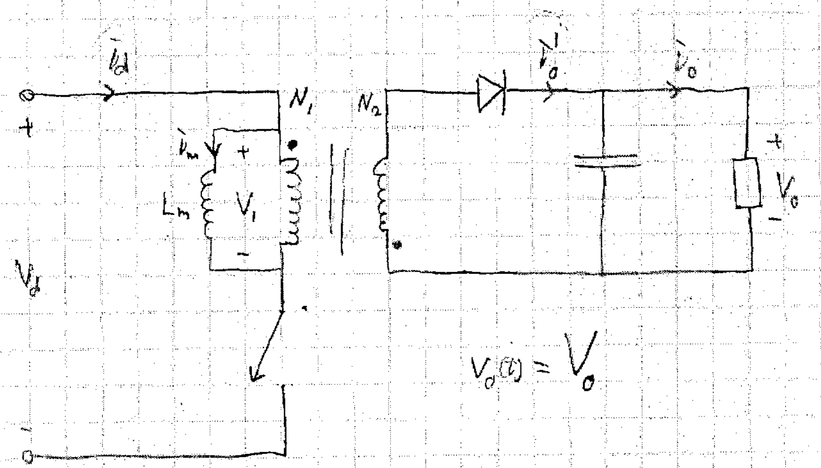
This due to the fact that this is the highest value of L_m that guarantee DCM operation within the interval

We directly see that the highes value of D and the highest value of P_o gives the highest value

$$V_o = \frac{D}{1-D} V_d \Rightarrow D_{max} = \frac{V_o}{V_o + V_{d,min}} = \frac{12}{12+12} = \frac{1}{2}$$

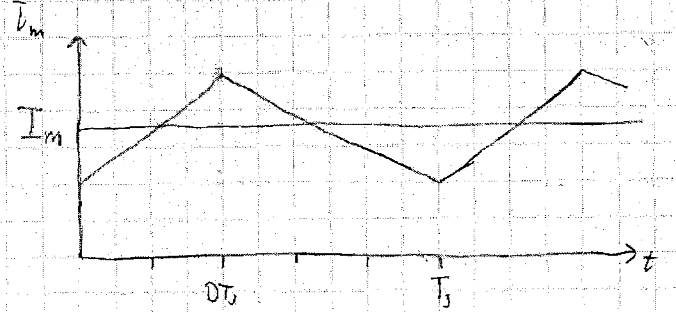
$$\underline{\underline{L_{m,max}}} = \frac{12^2(1-\frac{1}{2})^2}{2 \cdot 200 \cdot 10^3 \cdot 60} = \underline{\underline{1{,}5 \, \mu H}}$$

10-4 One converter

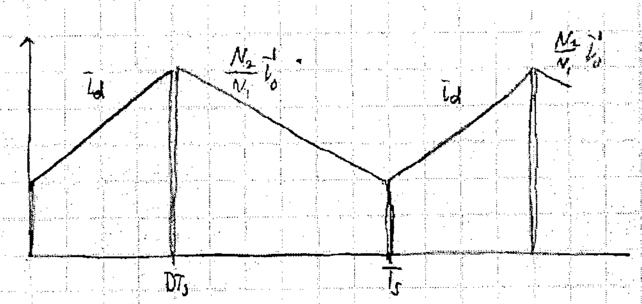


$v_o(t) = V_o$

$D = 0,4$



$V_o = \frac{N_2}{N_1} \frac{D}{1-D}$



$I_d = D I_m$

$$\hat{i}_d = I_m + \frac{1}{2} \frac{\Delta i_m}{\Delta t} t_{on} = \frac{I_d}{D} + \frac{1}{2} \frac{V_d}{L_m} DT_s = 2,5 I_d + 0,2 \frac{V_d}{L_m} T_s$$

$$I_o' = I_o = (1-D) I_m \frac{N_1}{N_2}$$

$$\hat{i}_o = \frac{N_1}{N_2} I_m + \frac{N_1}{N_2} \frac{1}{2} \left| \frac{\Delta i_m}{\Delta t} \right| t_{off} = \frac{I_o}{1-D} + \frac{N_1}{N_2} \frac{1}{2} \frac{N_1}{N_2} \frac{V_o}{L_m} (1-D) T_s =$$

$$= \left[L_m \left(\frac{N_2}{N_1}\right)^2 = L_s \right] = \frac{I_o}{1-D} + \frac{1}{2} \frac{V_o}{L_s} (1-D) T_s = 1,67 I_o + 0,3 \frac{V_o}{L_s} T_s$$

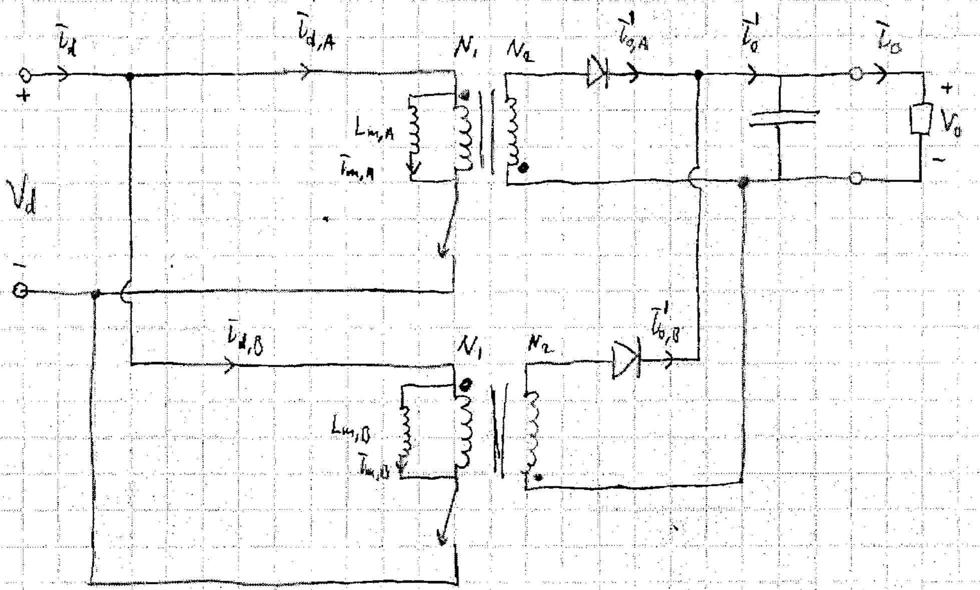
10-4 cont. Two converters in parallel.

From 10-3 we know that for CCM the magnetizing inductanse must full fill

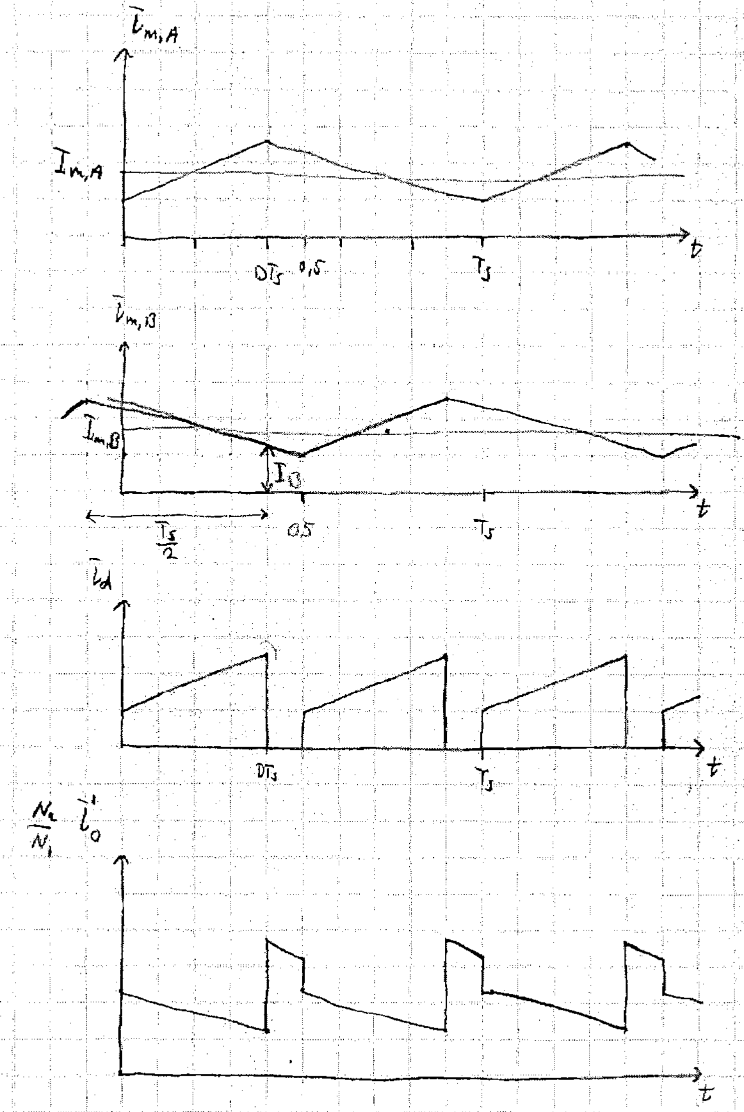
$$L_m = \left(\frac{N_1}{N_2}\right)^2 \frac{T_s}{2 P_{out}} (1-D)^2 V_o^2$$

This gives that if we have tow converters in parallel D is the same but $P_{out,A} = P_{out,B} = \frac{P_{out}}{2}$

This gives that to ensure CCM $L_{m,A} = L_{m,B} = 2 \cdot L_m$



10-4



$$I_d = 2D\, I'_{m,A} = 2D\, I_{m,B}$$

$$\underline{\hat{i}_d} = I_{m,a} + \frac{1}{2}\frac{\Delta i_{m,a}}{\Delta t} t_{on} = \frac{I_d}{2D} + \frac{1}{2}\frac{V_d}{L_{m,a}} D T_s = \frac{I_d}{2D} + \frac{1}{2}\frac{V_d}{2L_m} D T_s = \underline{1{,}25 I_d + 0{,}1 \frac{V_d}{L_m} T_s}$$

$$I_o = 2(1-D)\, I_{m,A} \frac{N_1}{N_2}$$

$$\hat{i}'_{o,A} = I_{m,A}\frac{N_1}{N_2} + \frac{N_1}{N_2}\frac{1}{2}\left|\frac{\Delta i_{m,a}}{\Delta t}\right| t_{off} = \frac{I_o}{2(1-D)} + \frac{N_1}{N_2}\frac{1}{2}\frac{N_1}{N_2}\frac{V_o}{L_{m,A}}(1-D)T_s =$$

$$= \left[L_{m,a}\left(\frac{N_2}{N_1}\right)^2 = L_{S,A} = 2L_S\right] = \frac{I_o}{2(1-D)} + \frac{1}{2}\frac{V_o}{2L_S}(1-D)T_S$$

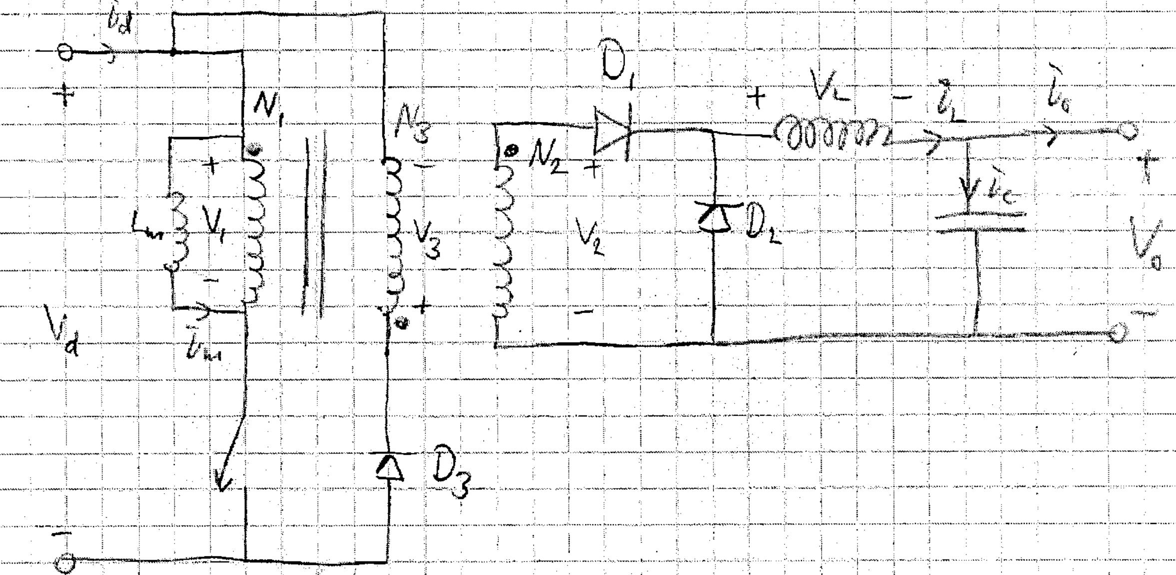
$$I_B = \hat{i}_{o,A} - \frac{N_1}{N_2}\left|\frac{\Delta i_{m,a}}{\Delta t}\right|\frac{T_s}{2} = \hat{i}_{oA} - \frac{N_1}{N_2}\frac{N_1}{N_2}\frac{V_o}{L_{m,a}}\frac{T_s}{2} = \hat{i}_{o,A} - \frac{V_o}{2L_s}\frac{T_s}{2}$$

$$\underline{\hat{i}'_o} = \hat{i}'_{o,A} + I_B = \frac{2I_o}{2(1-D)} + \frac{V_o}{2L_s}(1-D)T_s - \frac{V_o}{2L_s}\frac{T_s}{2} = \underline{1{,}67 I_o + 0{,}05\frac{V_o}{L_s}T_s}$$

10-4
fort

We now notice that the peak values of the input and output current is less for the two parallel fly back konverters and the ripple frequency is doubled.

10-5

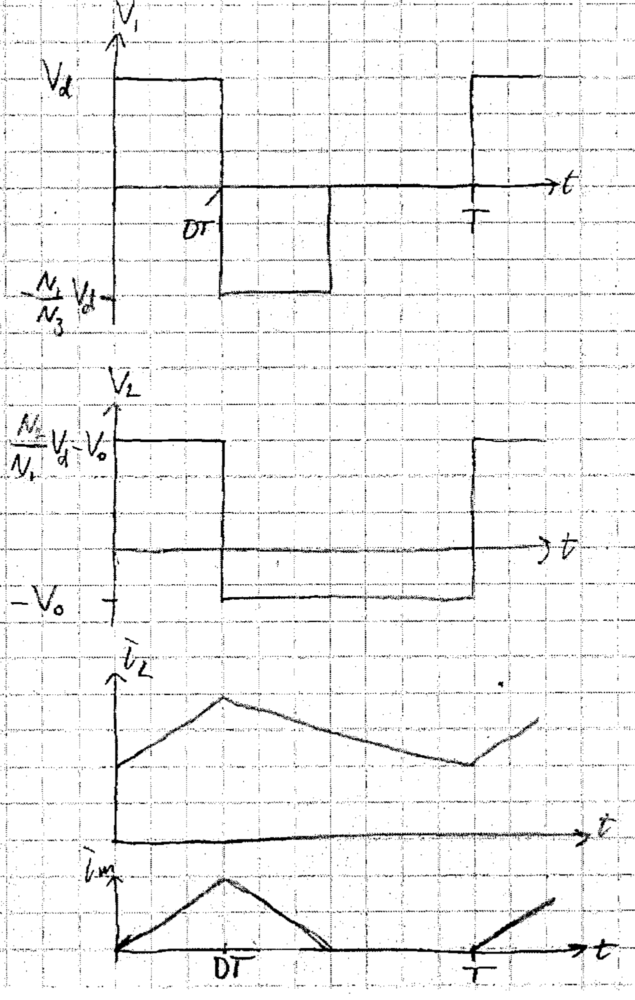


$V_d = 48V \pm 10\%$ $\quad V_o = 5V \quad f_s = 100\,kHz$

$P_o = 15-50\,W \quad N_3 = N_1 \quad CCM$

a) Calculate N_2/N_1 if this turns ratio is desired to be as small as posible

In this case CCM means that $i_L > 0$, we plot the wave forms.



When the switch is closed

$V_1 = V_d \Rightarrow$

$V_3 = \frac{N_3}{N_1}V_d = V_d \Rightarrow D_3$ is blocking

$V_2 = \frac{N_2}{N_1}V_d \Rightarrow$ $\left.\begin{array}{l} D_2 \text{ is blocking} \\ D_1 \text{ is conducting} \end{array}\right\} \Rightarrow$

$V_L = \frac{N_2}{N_1}V_d - V_o$

When the switch is open

at $t = DT$ we have a magnetizing current $\Rightarrow$ when the switch is opend

D_3 will conduct as long as $i_m > 0 \Rightarrow$

$V_3 = -V_d \Rightarrow V_1 = -\frac{N_1}{N_3}V_d = -V_d$

$V_2 = -\frac{N_2}{N_1}V_d \Rightarrow$ $\begin{array}{l} D_1 \text{ is blocking} \\ D_2 \text{ is conducting} \end{array}$

We always want the forward converter to operate with a discontinious magnetizing current. This gives that we must have time to discharge the transformer each period. The longest time we can have for discharge the transformer is $T - DT = (1-D)T$

$$\Rightarrow \Delta I_m = \frac{V_d}{\cancel{L_m}} D_{max} \cancel{T_s} = \frac{N_1}{N_3} \frac{V_d}{\cancel{L_m}} (1 - D_{max}) \cancel{T_s} \Rightarrow$$

$$\underline{\underline{D_{max}}} = \frac{1}{1 + \frac{N_3}{N_1}} = \frac{1}{1+1} = \underline{\underline{\frac{1}{2}}}$$

In steady-state we know that

$$0 = V_L = \frac{1}{T}\left(\frac{N_2}{N_1}(V_d - V_o)DT - V_o(1-D)T\right) \Rightarrow$$

$$V_o = \frac{N_2}{N_1} V_d D \qquad \text{We know that} \quad \begin{matrix} V_o = 5\,V \\ V_d = 48\,V \pm 10\% \end{matrix}$$

We see that if V_d decreases we must increase D but we know that $0 \leq D \leq D_{max}$.

We want $\frac{N_2}{N_1}$ to be as small as possible, but when $\frac{N_2}{N_1}$ decreases D must also increase $\Rightarrow$

$$\underline{\left(\frac{N_2}{N_1}\right)_{min}} = \frac{V_o}{V_{d,min} \, D_{max}} = \frac{5}{48 \cdot 0{,}9 \cdot 0{,}5} = \underline{0{,}231}$$

b) Calculate L_{min} that gives CCM

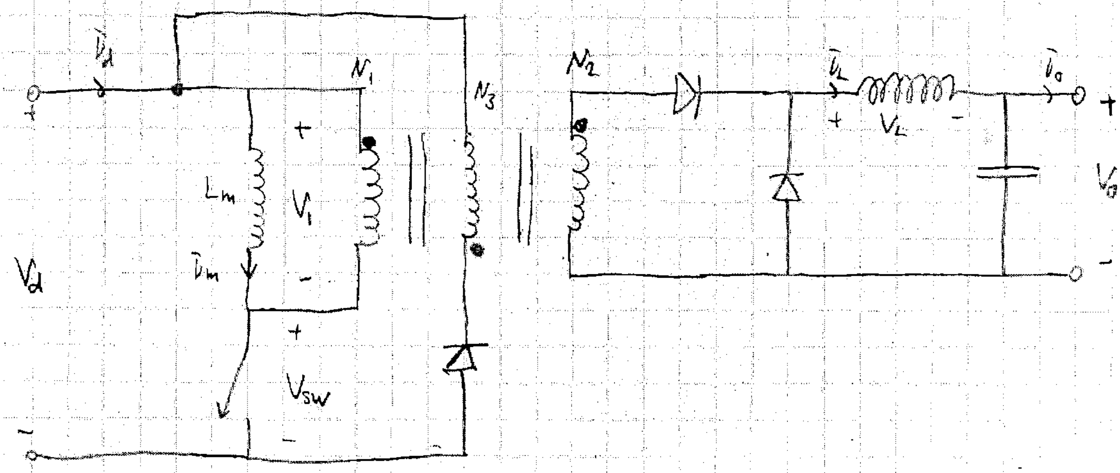
For CCM we know that $\Delta i_L \leq 2 I_m$

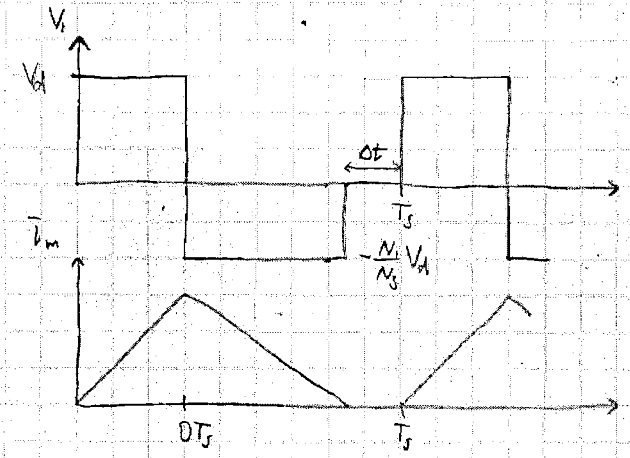
$$\left.\begin{matrix} I_m = I_o = \frac{P_o}{V_o} \\ \\ \Delta i_L = \frac{V_o(1-D)}{L f_s} \end{matrix}\right\} \Rightarrow \frac{V_o(1-D)}{L f_s} \leq 2 \frac{P_o}{V_o} \Rightarrow$$

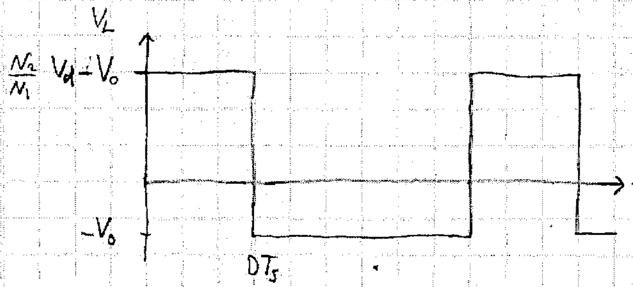
$$L \geq \frac{V_o^2(1-D)}{2 f_s P_o} \qquad \text{The lowest } D \text{ and } P_o \text{ gives the highest value} \Rightarrow$$

$$L_{min} = \frac{V_o^2\left(1 - \frac{N_1}{N_2}\frac{V_o}{V_{d,max}}\right)}{2 f_s P_{o,min}} = \frac{5^2\left(1 - \frac{1}{0{,}231}\frac{5}{48 \cdot 1{,}1}\right)}{2 \cdot 100 \cdot 10^3 \cdot 15} = 4{,}92\,\mu H$$

10-6







At D_{max} the magnetizing inductance is presicly discharged $\Rightarrow \Delta t = 0$

$$\Rightarrow \quad \cancel{V_d} D_{max} = \frac{N_1}{N_3} \cancel{V_d} (1 - D_{max}) \Rightarrow \frac{N_1}{N_3} = \frac{D_{max}}{1 - D_{max}}$$

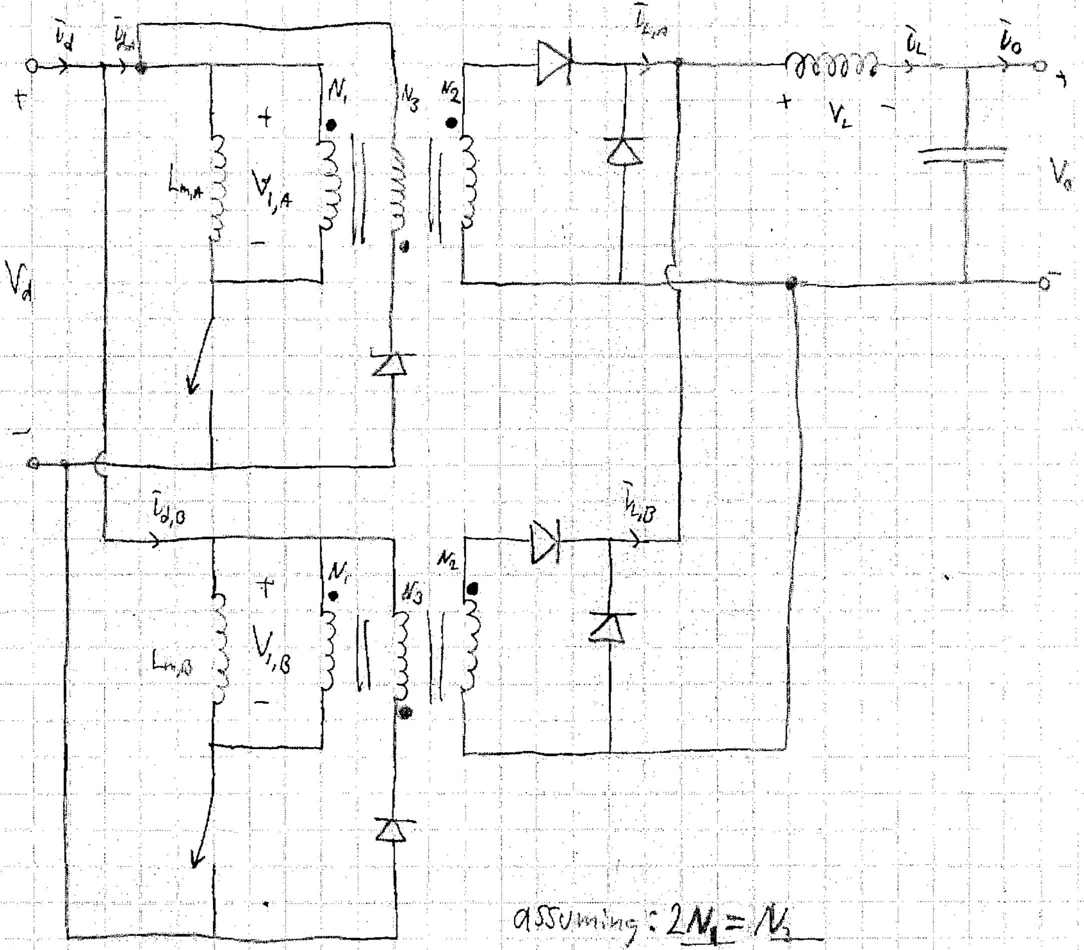
The voltage rating of the switch:

The maximum voltage over the switch is reached during the discharging of the transformer $\Rightarrow$

$$\hat{V}_{sw} = V_d + \frac{N_1}{N_3} V_d = \left(1 + \frac{D_{max}}{1 - D_{max}}\right) V_d = \frac{1}{1 - D_{max}} V_d = \frac{1}{1 - 0{,}7} V_d = \underline{\underline{3{,}33\, V_d}}$$

1-(5)

10-7

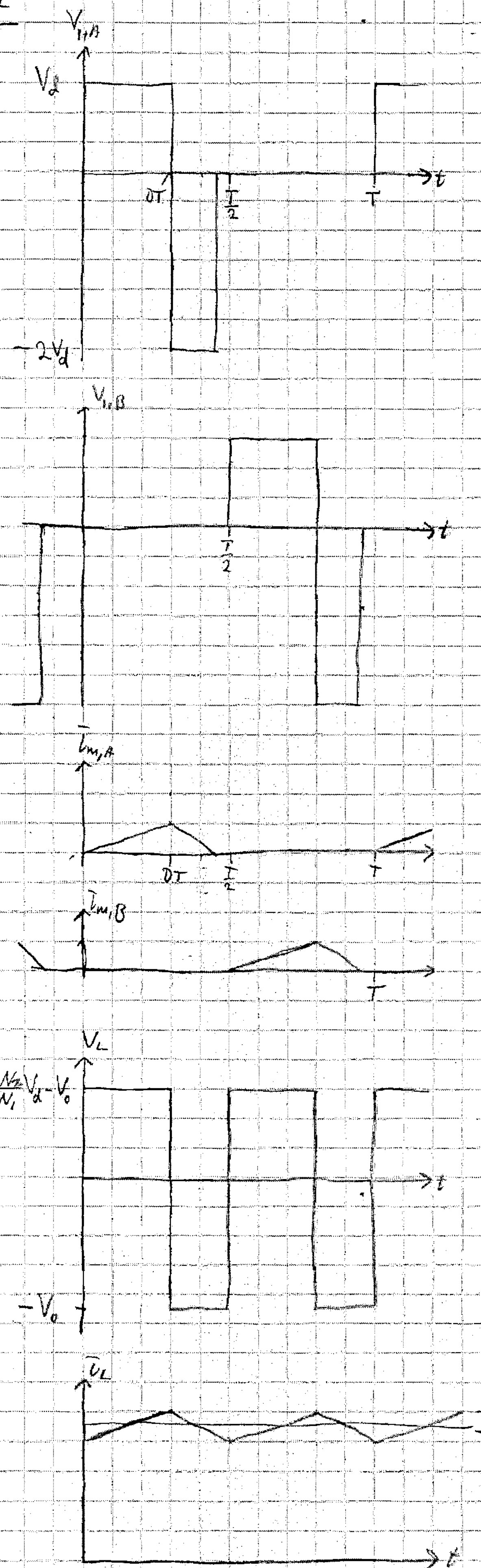


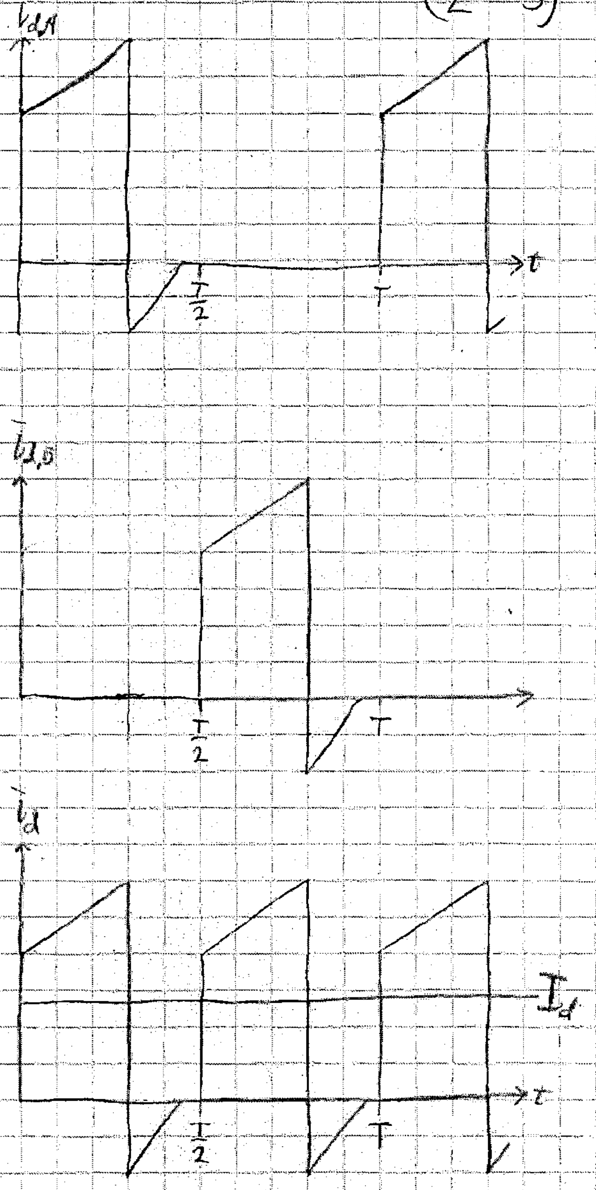
assuming: $2N_1 = N_3$

draw i_d and i_L waveforms if each converter is operating at a duty ratio of 0.3 in CCM.

Compare these two waveforms with those if a single forward converter (with twice the power rating but with the same value of the output filter inductance) is used. Assume $v_o(t) = V_o$

10-7





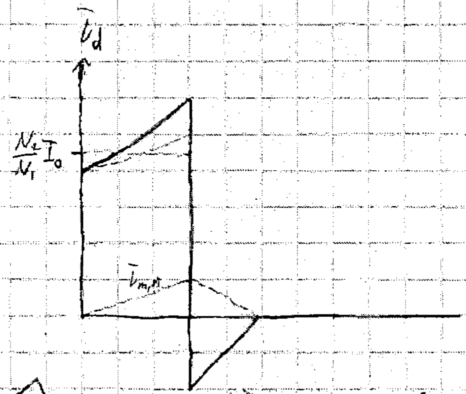
$$V_L = 0 = 2\left(\frac{N_2}{N_1}V_d - V_o\right)D + 2\left(-V_o\left(\frac{T}{2} - DT\right)\right) =$$

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

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

$P_{in} = P_o \Rightarrow$

$V_d I_d = V_o I_o \Rightarrow \quad \underline{\underline{I_d}} = \frac{V_o I_o}{V_d} = \underline{\underline{2 \frac{N_2}{N_1} I_o D}}$



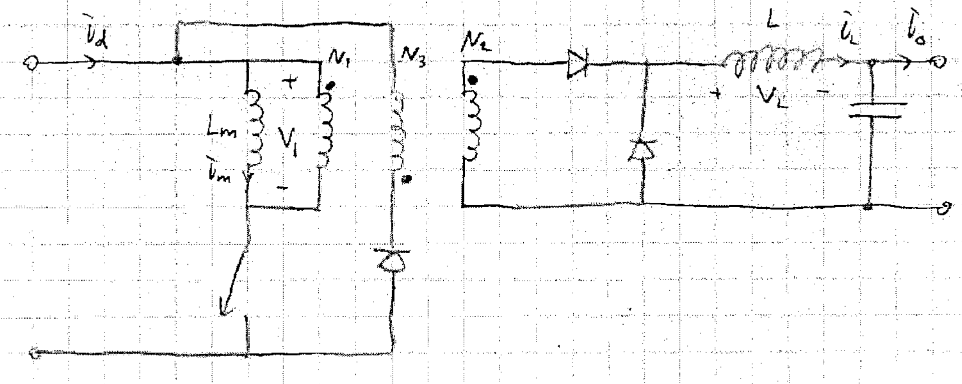
$$\underline{\underline{\hat{i}_L}} = I_o + \frac{1}{2} \frac{\Delta i_L}{\Delta t} t_{off} = I_o + \frac{1}{2} \frac{V_o}{L} (0{,}5T - DT) = \underline{\underline{I_o + 0{,}1 \frac{V_o}{L} T}}$$

$$\underline{\underline{\hat{i}_d}} = \frac{N_2}{N_1} \hat{i}_L + \hat{i}_{m,x} = \frac{N_2}{N_1} \left(I_o + 0{,}1 \frac{V_o}{L} T \right) + \frac{\Delta i_{m,x}}{\Delta t} DT =$$

$$= \frac{I_d}{2D} + 0{,}1 \cdot 2 \cdot \left(\frac{N_2}{N_1}\right)^2 \frac{V_d}{L} DT + \frac{V_d}{L_m} DT = \underline{\underline{1{,}67 I_d + 0{,}06 \left(\frac{N_2}{N_1}\right)^2 \frac{V_d}{L} T + 0{,}3 \frac{V_d}{L_m} T}}$$

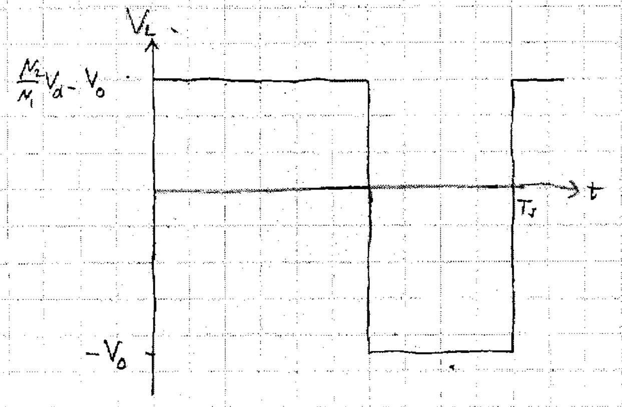
10-7 One single forward converter

$$\frac{V_1}{N_1} = \frac{V_2}{N_2} = \frac{V_3}{N_3}$$



- We assume that the winding ratio of N_1, N_2 and N_3 is the same for the single converter as for the two and that $L_{m,A} = L_{m,B} = L_m$.
- We should use the same value of the output filter inductance L

We now start by drawing the voltage over the output inductor L



in steady state

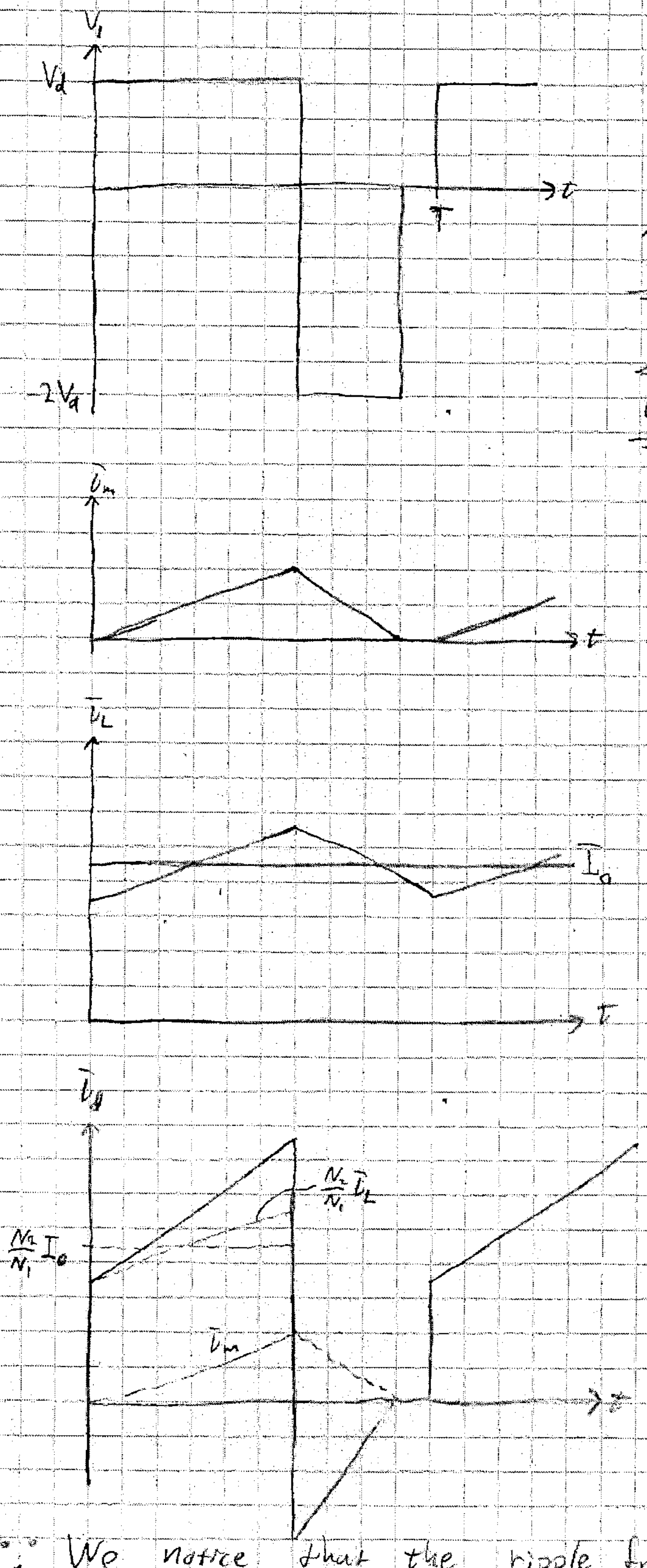
$$V_L = 0 = \left(\frac{N_2}{N_1}V_d - V_o\right)D - V_o(1-D) =$$

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

$$I_d = \frac{N_2}{N_1} I_o D$$

We now se that the single converter must operate at a duty ratio twice as high as the two converter configuration

$$\Rightarrow \quad \underline{D_{one}} = 2 \cdot D_{two} = 2 \cdot 0{,}3 = \underline{0{,}6}$$



In the same way as for two converters:

$$\underline{\hat{i}_L} = I_o + \frac{1}{2}\frac{V_o}{L}(T - DT) = \underline{I_o + 0{,}2\frac{V_o}{L}T}$$

$$\underline{\hat{i}_d} = \frac{N_2}{N_1}\hat{i}_L + \hat{i}_m = \frac{N_2}{N_1}\left(I_o + 0{,}2\frac{V_o}{L}T\right) + \frac{V_d}{L_m}DT =$$

$$= \frac{I_d}{D} + 0{,}2\left(\frac{N_2}{N_1}\right)^2 \frac{V_d}{L}DT + \frac{V_d}{L_m}DT =$$

$$= \underline{1{,}67\, I_d + 0{,}12\left(\frac{N_2}{N_1}\right)^2 \frac{V_d}{L}T + 0{,}6\frac{V_d}{L_m}T}$$

∴ We notice that the ripple frequency for the single converter is half of the ripple frequency of the two converter case.

We also notice that the peak values is higher for the one converter case.