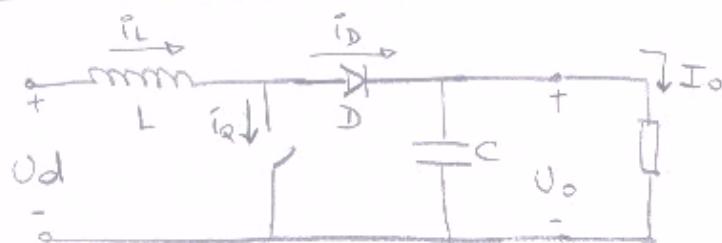


Solución Problema 2

$P_{\text{nom}} = 2 \text{ kW}$

$U_o = 300 \text{ V}$

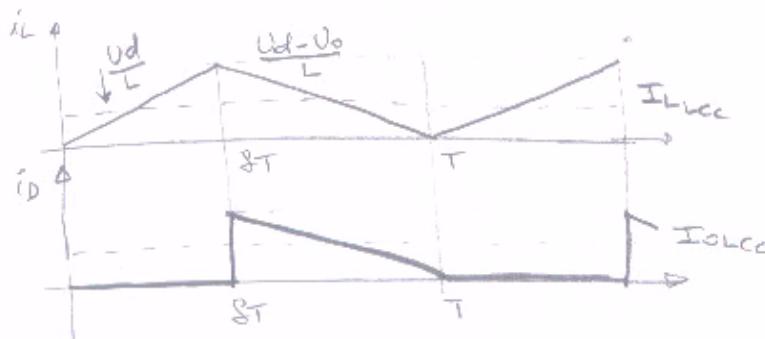
$U_{d\min} = 100 \text{ V}$

$U_{d\max} = 230 \text{ V}$

$f = 500 \text{ kHz}$

$T_{j\max} = 120^\circ \text{C}$

$I_o = \langle i_D \rangle$



$I_{LCC} = \frac{1}{T} \int_0^T i_{LCC}(t) dt = \frac{1}{f} \cdot \frac{1}{2} \cdot \frac{U_d \cdot 8T}{L} = \frac{U_d \cdot 8T}{2L}$

Es válida la transferencia en H.C.C.: $\frac{U_o}{U_d} = \frac{1}{1-\delta} \Rightarrow U_d = (1-\delta) \cdot U_o$

$\Rightarrow I_{LCC} = \frac{U_o \cdot \delta(1-\delta)}{2Lf}$

$\text{Así vez: } I_{OLCC} = \frac{1}{f} \cdot \frac{1}{2} \cdot (1-\delta) \frac{U_d \cdot 8T}{L} = (1-\delta) I_{LCC} = \frac{U_o \cdot \delta(1-\delta)^2}{2Lf}$

$\text{Si impongo que } I_{OLCC\max} = \frac{1}{3} I_{OLCC}$

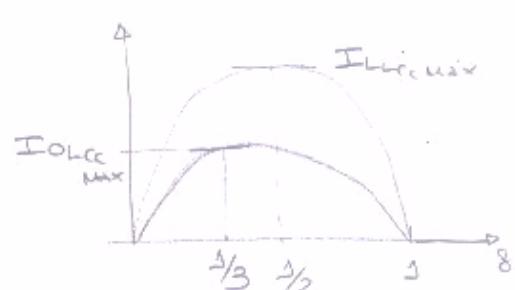
$\Rightarrow f \cdot I_o > \frac{1}{3} I_{OLCC}$ el convertidor opera en H.C.C.

→ Debo verificar que $\delta_{\min} < 1/3$ y $\delta_{\max} > 1/3$

En caso contrario se evita en el que provoque I_{OLCC}

$\frac{U_o}{U_{d\max}} = \frac{1}{1-\delta_{\max}} \Rightarrow 1-\delta_{\max} = \frac{U_{d\max}}{U_o} \Rightarrow \delta_{\max} = 1 - \frac{U_{d\max}}{U_o}$

$$\left. \begin{aligned} \delta_{\min} &= 1 - \frac{230}{300} = 0,23 \\ \delta_{\max} &= 1 - \frac{100}{300} = 0,67 \end{aligned} \right\} \Rightarrow I_{OLCC\max} \text{ se da para } \delta^* = 1/3$$



Solución problema 2 (cont.)

$$I_{\text{onix}} = \frac{P_{\text{onix}}}{U_0} = \frac{2000}{300} = 6,67 \text{ A}$$

$$\frac{I_{\text{onix}}}{3} = I_{\text{oncmax}} = \frac{U_0 \delta^* (1-\delta^*)^2}{2Lf}$$

$$\Rightarrow L = \frac{U_0 \delta^* (1-\delta^*)^2 \cdot 3}{2f I_{\text{onix}}} = \frac{300 \cdot \frac{1}{3} \cdot (2/3)^2 \cdot 3}{2 \cdot 100 \times 10^3 \cdot 2000/300} \Rightarrow L = 100 \mu \text{H.}$$

b) Corriente por el MOSFET

$$\hat{i}_Q = I_L + \frac{\Delta I_L}{2}$$

$$P_{\text{in}} = P_0 \Rightarrow U_d \cdot I_L = U_0 \cdot I_0$$

$$I_L = \frac{U_0}{U_d}, I_0 = \frac{I_0}{1-\delta}$$

$$\frac{\Delta I_L}{2} = \frac{U_d \cdot \delta f}{2L}$$

$$U_d = U_0 (1-\delta)$$

$$\Rightarrow \frac{\Delta I_L}{2} = \frac{U_0 f}{2L} \delta (1-\delta)$$

$$\Rightarrow \hat{i}_Q = \frac{I_0}{1-\delta} + \frac{U_0 f}{2L} \delta (1-\delta) = I_L + \frac{\Delta I_L}{2} \rightarrow \begin{cases} I_L \text{ fijo.} \\ \Delta I_L \text{ tiene un máximo en } f = \frac{1}{2} \end{cases}$$

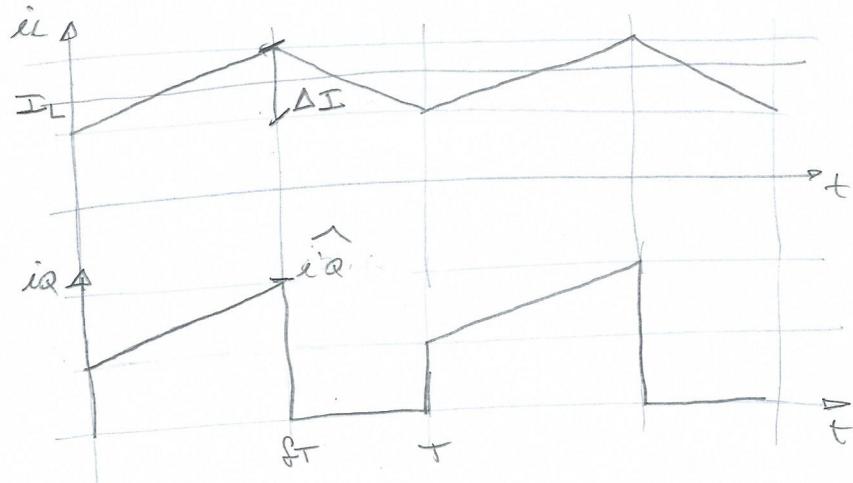
\Rightarrow corresponde analizar \hat{i}_Q en el intervalo $[f_{\text{min}}, f_{\text{mix}}]$, en particular para

$$f = 0,5 \text{ y } f = f_{\text{mix}} = 0,67$$

$$\rightarrow \underline{\underline{f = 0,5}} \rightarrow \hat{i}_Q = \frac{6,67}{1,95} + \frac{300 \cdot 0,5 \cdot 0,5}{2 \times 100 \times 10^{-6} \times 100 \times 10^3} = 17,09 \text{ A}$$

$$\rightarrow \underline{\underline{f = 0,67}} \rightarrow \hat{i}_Q = \frac{6,67}{1-0,67} + \frac{300 \cdot 0,67 \cdot (1-0,67)}{2 \times 100 \times 10^{-6} \times 100 \times 10^3} = 23,53 \text{ A}$$

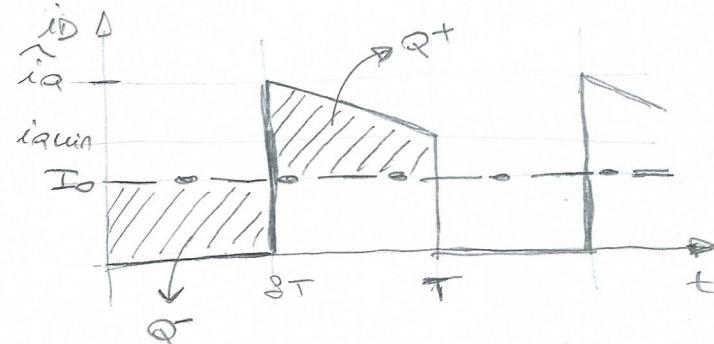
$$\Rightarrow \boxed{\hat{i}_{Q \text{ mix}} = 23,53 \text{ A}}$$



Solución problema 2 (cont.)c) t tal que $\Delta U_0 < 0,01 U_0$

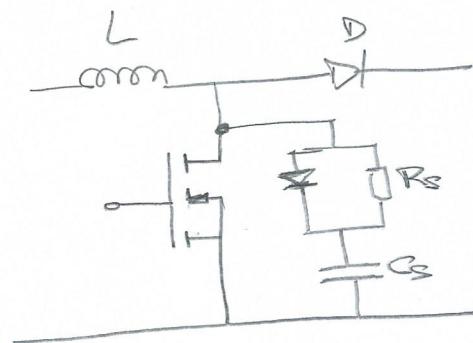
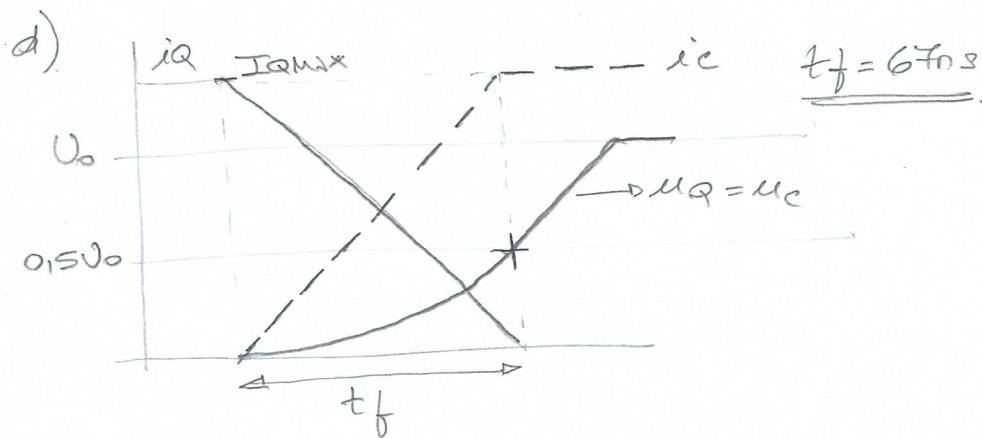
$$\Delta U_0 = \frac{Q^-}{C} = \frac{Q^+}{C}$$

$$Q^- = I_0 \cdot 8T$$



$$\Rightarrow \Delta U_{0\text{mix}} = \frac{Q_{\text{mix}}}{C} = \frac{I_0 S_{\text{mix}} T}{C}$$

$$\Rightarrow C = \frac{I_0 S_{\text{mix}} T}{\Delta U_{0\text{mix}}} = \frac{6,67 \times 0,67}{0,01 \cdot 300 \cdot 100 \times 10^3} \Rightarrow C = 14,9 \mu F.$$



$$\Delta u_c = \frac{Q}{C_S}$$

$$Q = \int_0^{t_f} i_C(t) dt$$

$$i_C(t) = \frac{I_{\text{mix}}}{t_f}, t$$

$$\Rightarrow C_S = \frac{23,53 \cdot 67 \times 10^{-9}}{2 \cdot 0,5 \cdot 300} \Rightarrow C_S = 5,3 nF$$

$$Q = \frac{I_{\text{mix}}}{t_f} \frac{t_f}{2} = \frac{I_{\text{mix}} \cdot t_f}{2}$$

$$\Rightarrow \Delta u_c = \frac{I_{\text{mix}} \cdot t_f}{2 C_S}$$

$$C_S = \frac{I_{\text{mix}} \cdot t_f}{2 \Delta u_c}$$

Tiempo mínimo de descarga del condensador: $S_{\text{mix}} \cdot T$

$$\Rightarrow 3R_S C_S \leq S_{\text{mix}} T \Rightarrow R_S \leq \frac{S_{\text{mix}} T}{3 C_S} = \frac{0,23}{3 \cdot 5,3 \times 10^{-9} \cdot 100 \times 10^3}$$

$$\Rightarrow R_S = 144,7 \Omega$$

Solución Problema 2. (cont.2)

$$P_{RS} = \frac{E_C}{T} = \frac{1}{T} \frac{1}{2} C_S V^2 = \frac{5,3 \times 10^{-9} \cdot 300^2 \times 100 \times 10^3}{2}$$

$$\boxed{P_{RS} = 23,85 \text{ W.}}$$

$$e) \eta = \frac{P_0}{P_0 + P_{\text{perd.}}}$$

Si solo considero las pérdidas en la llave P_{RS} el peor caso:

$$P_{\text{perd.}} = P_{on} + P_{cond} + P_{off}.$$

$$P_{on} = \frac{1}{2} U_o, I_{Q\min} \cdot t_r \cdot f$$

$$I_{Q\min} = I_L - \frac{\Delta I_L}{2} = \frac{6,67}{1-0,67} - \frac{300 \cdot 0,67 (1-0,67)}{2 \times 100 \times 10^6 \times 100 \times 10^3}$$

$$\underline{t_r = 79 \text{ ns}}$$

$$\underline{I_{Q\min} = 16,9 \text{ A.}}$$

$$\Rightarrow P_{on} = \frac{1}{2} \cdot 300 \cdot 16,9 \cdot 79 \times 10^{-9} \cdot 100 \times 10^3 \Rightarrow \underline{P_{on} = 20,03 \text{ W.}}$$

$$P_{cond} = R_{DS(on)} \cdot I_{Q\text{eff}}^2$$

$$T_j = 120^\circ\text{C} \Rightarrow R_{DS(on)} = 2,2 \cdot 0,20 \Rightarrow R_{DS(on)} = 0,44 \Omega$$

$$I_{Q\text{eff}}^2 = \frac{1}{T} \int_0^T i_Q^2(t) dt$$

$$i_Q(t) = I_{Q\min} + \frac{\Delta I}{8T} \cdot t \Rightarrow i_Q^2(t) = I_{Q\min}^2 + \frac{\Delta I^2}{8T^2} t^2 + \frac{2 I_{Q\min} \cdot \Delta I \cdot t}{8T}$$

$$I_{Q\text{eff}}^2 = \frac{1}{T} \int_0^{8T} \left(I_{Q\min}^2 + \frac{\Delta I^2 t^2}{8T^2} + \frac{2 I_{Q\min} \Delta I t}{8T} \right) dt =$$

$$= \frac{I_{Q\min}^2 \cdot 8T}{T} + \frac{\Delta I^2 \cdot 8T^3}{384T} + \frac{2 I_{Q\min} \Delta I \cdot 8T^2}{28T} =$$

$$= \left(I_{Q\min}^2 + \frac{\Delta I^2}{3} + I_{Q\min} \cdot \Delta I \right) \cdot 8 = \left(16,9^2 + \frac{3,32^2}{3} + 16,9 \cdot 3,32 \right) \cdot 0,67$$

$$I_{Q\text{eff}}^2 = 231,41 \text{ A}^2$$

$$\boxed{P_{cond} = 0,44 \cdot 231,41 = \underline{\underline{201,8 \text{ W}}}}$$

Solución Problema 2 (cont. 3)P_{off}:

→ Sin snubber:

$$P_{off} = \frac{1}{2} U_o \cdot I_{aux} \cdot t_f \cdot f = \frac{300 \cdot 23,53 \cdot 67 \times 10^{-9} \cdot 100 \times 10^3}{2}$$

$$\underline{\underline{P_{off} = 23,65W}}$$

→ Con snubber:

$$P_{off} = \frac{1}{T} \int_0^{t_f} u_Q(t) i_Q(t) dt$$

$$i_Q(t) = I_{aux} - \frac{I_{aux}}{t_f} \cdot t$$

$$u_Q(t) = \frac{1}{C} \int_0^t i_C(\theta) d\theta = \frac{1}{C} \int_0^t \frac{I_{aux} \cdot \theta}{t_f} d\theta = \frac{I_{aux} \cdot t^2}{2t_f \cdot C}$$

$$i_C(\theta) = \frac{I_{aux} \cdot \theta}{t_f}$$

$$P_{off} = \frac{1}{T} \int_0^{t_f} \frac{I_{aux} \cdot t^2}{2t_f \cdot C} \left(I_{aux} - \frac{I_{aux} \cdot t}{t_f} \right) dt =$$

$$= \frac{1}{T} \frac{I_{aux}^2}{2t_f \cdot C} \int_0^{t_f} \left(t^2 - \frac{t^3}{t_f} \right) dt = \frac{1}{T} \frac{I_{aux}^2}{2t_f \cdot C} \left(\frac{t_f^3}{3} - \frac{t_f^3}{4} \right)$$

$$= \frac{I_{aux}^2 \cdot t_f^2 \cdot f}{2C} \left(\frac{1}{3} - \frac{1}{4} \right) = \frac{23,53^2 \cdot 67 \times 10^{-9}^2 \cdot 100 \times 10^3}{2 \cdot 5,3 \times 10^{-9}} \left(\frac{1}{3} - \frac{1}{4} \right)$$

$$\underline{\underline{P_{off} = 1,95W}}$$

En este caso, para el cálculo de la eficiencia del convertidor se debe tener en cuenta las pérdidas en la resistencia del snubber: P_{RS} = 23,85W

$$\Rightarrow \text{sin snubber: } \eta = \frac{2000}{2000 + 20,03 + 103,8 + 23,65} = 0,932$$

$$\text{con snubber: } \eta = \frac{2000}{2000 + 20,03 + 103,8 + 1,95 + 23,85} = 0,931$$

El rendimiento es el mismo. El snubber baja mucho las pérdidas en el apagado pero ocasiona pérdidas considerables en la resistencia.

Podría establecerse un criterio de tensión sobre la llave no tan exigente, del orden de 0,8 U_o, lo que reduciría el C_s y en consecuencia, bajaría las pérdidas en R_S.