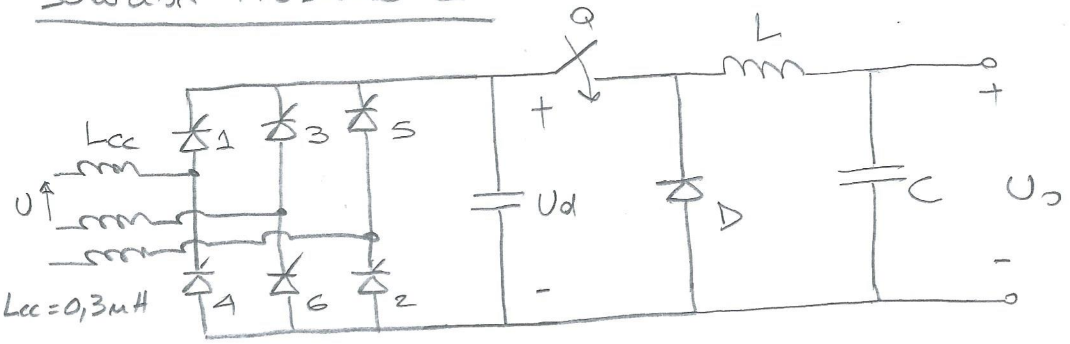
Examen Electrónica de Potencia - Febrero 2021

Solución Problema 2



$U = 230 \pm 20\%$

$U_{d\,min} = 170V$

$U_{d\,máx} = 264$

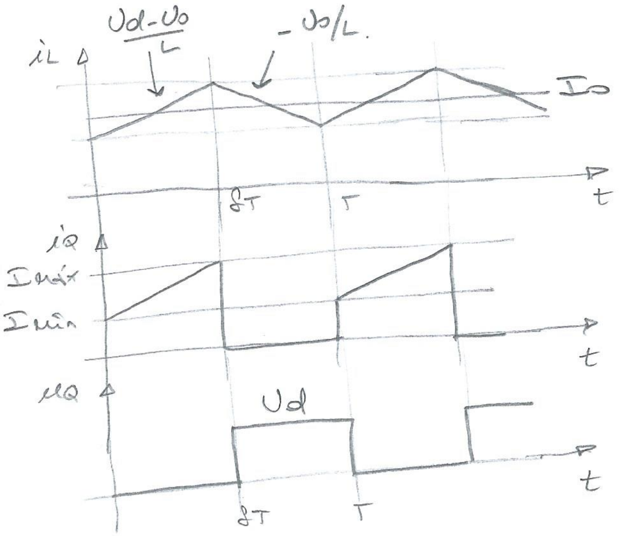
$P_{o\,máx} = 2500W$

$U_o = 110V$

$f = 100kHz$

$T_{j\,máx} = 100°C$

a) Determinar L para MCC $\forall$ $P_o \geq 0,1 P_{o\,máx}$



$P_{oLcc} = 0,1\,P_{o\,máx} = 250W$

$$I_{oLcc} = \frac{P_{oLcc}}{U_o} = \frac{250}{110} = 2,27A$$

→ Impongo Lcc para $U_d = U_{d\,máx}$

$$I_{oLcc} = \frac{1}{2} T . \frac{U_{d\,máx} - U_o}{L} . \delta T . \frac{1}{T}$$

$$I_{oLcc} = \frac{(U_{d\,máx} - U_o)\,\delta}{2Lf}$$

$$\frac{U_o}{U_{d\,máx}} = \delta = \frac{110}{264} = 0,417$$

$$L = \frac{(U_{d\,máx} - U_o)\,\delta}{2\,I_{oLcc} . f} = \frac{(264-110).0,417}{2.2,27.100\times10^3} \Rightarrow \boxed{L = 141,45\mu H}$$

b) La tensión de salida del rectificador está determinada por:

$$\langle v_o \rangle = U_d = \frac{3}{\pi} U\sqrt{2}\cos\alpha - \frac{3}{\pi}\omega L_{cc} . I$$

Donde U es la tensión compuesta de la red e I sería la corriente media de entrada del Buck.

Si no hay pérdidas en el Buck: $P_o = U_o . I_o = U_d . I \Rightarrow I = \frac{P_o}{U_d}$

$$\alpha = A\cos\left[\frac{\pi}{3U\sqrt{2}}\left(U_d + \frac{3}{\pi}\omega L_{cc}\frac{P_o}{U_d}\right)\right]$$

Para $P_o = P_{o\,máx}$ la condición más restrictiva puede darse para $U_d = U_{d\,máx}$ o $U_d = U_{d\,mín}$ (respectivamente $U_{máx}$ y $U_{mín}$)

$U_{mín} = 0,8 . 230 = 184V$

$U_{máx} = 1,2 . 230 = 276V$

$$\alpha_1 = Acos\left[\frac{\pi}{3.276.\sqrt{2}}\left(264 + \frac{3}{\pi}.2.\pi.50.0,3\times10^{-3}.\frac{2500}{264}\right)\right]$$

$\alpha_1 = 44,72°$

$$\alpha_2 = Acos\left[\frac{\pi}{3.184.\sqrt{2}}\left(170 + \frac{3}{\pi}2.\pi.50.0,3\times10^{-3}.\frac{2500}{170}\right)\right]$$

$\alpha_2 = 46,41°$

Verifico si α_1 y α_2 resultan en Ud admisibles para el Buck para Pomáx.

$$Ud = \frac{3}{\pi}U\sqrt{2}\cos\alpha - \frac{3}{\pi}\omega L_{cc}\frac{Po}{Ud} \Rightarrow Ud^2 - \frac{3}{\pi}U\sqrt{2}\cos\alpha\, Ud + \frac{3}{\pi}\omega L_{cc}Po = 0$$

$$Ud = \frac{\frac{3}{\pi}U\sqrt{2}\cos\alpha \pm\sqrt{\left(\frac{3}{\pi}U\sqrt{2}\cos\alpha\right)^2 - \frac{12}{\pi}\omega L_{cc}Po}}{2}$$

Si $\alpha=\alpha_1$ pero $U=184V$ ∴ $Ud = \dfrac{\frac{3}{\pi}.184\sqrt{2}\cos44,72 \pm\sqrt{\left(\frac{3}{\pi}184\sqrt{2}\cos44,72\right)^2 - 12.2.50.0,3\times10^{-3}.2500}}{2}$

$Ud = \dfrac{176,56 \pm 174}{2}$ → $Ud = 175,28V > 170V = Ud_{mín}$ ✓ ; → $Ud = 1,28V$ ×

Si $\alpha=\alpha_2$ pero $U=276V$; $Ud = \dfrac{\frac{3}{\pi}.276\sqrt{2}\cos46,41 \pm\sqrt{\left(\frac{3}{\pi}.276.\sqrt{2}.\cos46,41\right)^2 - 12.2.50.0,3\times10^{-3}.2500}}{2}$

$Ud = \dfrac{256,995 \pm 254,355}{2}$ → $Ud = 255,68V < 264 = Ud_{máx}$ ✓ ; → $Ud = 1,32$ ×

El rango de α es $[44,72°; 46,41°]$

c) $P_{MOSFET} = P_{ON} + P_{cond} + P_{OFF}$

$P_{ON} = \frac{1}{2}Ud.I_{mín}.tr.f$

$P_{cond} = R_{DS(on)}I_{Seff}^2$

$P_{OFF} = \frac{1}{2}Ud.I_{máx}.tf.f$

De las hojas de datos:

$tr = 59ns$

$tf = 58ns$

$R_{DS(on)@100°C} = 1,8\times0,27 = 0,486\Omega$

$Io = \frac{2500}{110} = 22,73A \qquad \delta = 0,417$

$$\Delta I = \frac{Uo}{Lf}(1-\delta) = \frac{110(1-0,417)}{141,45\times10^{-6}.100\times10^{3}} = 4,53A$$

$I_{mín} = Io - \frac{\Delta I}{2} = 22,73 - \frac{4,53}{2} = 20,47A$

$I_{máx} = Io + \frac{\Delta I}{2} = 22,73 + \frac{4,53}{2} = 25A$

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$$P_{ON} = \frac{1}{2} 264 \cdot 20{,}47 \cdot 59 \times 10^{-9} \cdot 100 \times 10^3 = 15{,}94\,W$$

$$P_{OFF} = \frac{1}{2} 264 \cdot 25 \cdot 58 \times 10^{-9} \cdot 100 \times 10^3 = 19{,}14\,W$$

$$I_{Q\,eff}^2 = \frac{1}{T}\int_0^T i_Q(\theta)^2 d\theta = \frac{1}{T}\int_0^{\delta T}\left(I_{min} + \frac{\Delta I}{\delta T}\theta\right)^2 d\theta = \frac{1}{T}\left(I_{min}^2 \delta T + 2 I_{min}\frac{\Delta I}{\delta T}\frac{\delta^2 T^2}{2} + \frac{\Delta I^2}{\delta^2 T^2}\frac{\delta^3 T^3}{3}\right)$$

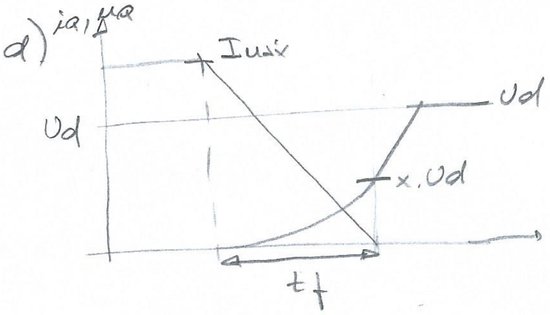
$$I_{Q\,eff}^2 = \left(I_{min}^2 + I_{min}\Delta I + \frac{\Delta I^2}{3}\right)\delta = \left(20{,}47^2 + 20{,}47 \cdot 4{,}53 + \frac{4{,}53^2}{3}\right) \cdot 0{,}416 = 215{,}73\,A^2$$

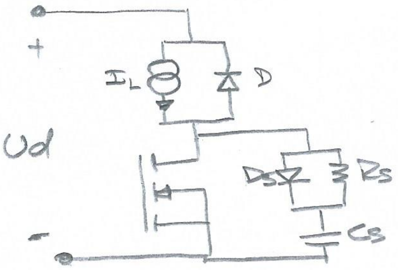
$$P_{cond} = 0{,}486 \cdot 215{,}73 = 104{,}84\,W$$

$$P_{MOSFET} = 15{,}94 + 104{,}84 + 19{,}14 = 139{,}92\,W$$

$$\eta = \frac{2500}{2500 + 139{,}92} \Rightarrow \boxed{\eta = 0{,}945}$$

d)





$$P_{OFF} = 0{,}3 \cdot 19{,}14 = 5{,}74\,W$$

$$P_{OFF} = \int_0^{t_f} u_Q(\theta)\, i_Q(\theta)\, d\theta$$

$$i_Q(t) = I_{máx} - \frac{I_{máx}\, t}{t_f}$$

$$u_Q(t) = \frac{1}{C_s}\int_0^t i_C(\theta)d\theta$$

$$i_C(t) = \frac{I_{máx}}{t_f} \cdot t$$

$$\Rightarrow u_Q(t) = \frac{I_{máx}\, t^2}{2 C_s t_f}$$

$$P_{OFF} = \frac{1}{T}\int_0^{t_f} \frac{I_{máx}\,\theta^2}{2 C_s t_f}\left(I_{máx} - \frac{I_{máx}\,\theta}{t_f}\right)d\theta = \frac{1}{T}\int_0^{t_f}\left(\frac{I_{máx}^2\,\theta^2}{2 C_s t_f} - \frac{I_{máx}^2\,\theta^3}{2 C_s t_f^2}\right)d\theta$$

$$P_{OFF} = \frac{1}{T}\left(\frac{I_{máx}^2}{2 C_s t_f}\frac{t_f^3}{3} - \frac{I_{máx}^2}{2 C_s t_f^2}\frac{t_f^4}{4}\right) = \frac{I_{máx}^2 \cdot f}{2 C_s}\left(\frac{t_f^2}{3} - \frac{t_f^2}{4}\right)$$

$$\Rightarrow C_s = \frac{I_{máx}^2 \cdot f}{2 P_{OFF}}\left(\frac{t_f^2}{3} - \frac{t_f^3}{4}\right) = \frac{25^2 \cdot 100 \times 10^3}{2 \cdot 5{,}74}\left(\frac{(58 \times 10^{-9})^2}{3} - \frac{(58 \times 10^{-9})^3}{4}\right)$$

$$\Rightarrow \boxed{C_s = 6{,}1\,nF}$$

$$3 R_s C_s \le \delta T \Rightarrow R_s = \frac{0{,}417}{3 \cdot 6{,}1 \times 10^{-9} \cdot 100 \times 10^3} \Rightarrow \boxed{R_s = 227{,}95\,\Omega}$$

$$P_{RS} = \frac{1}{2} C \cdot U_d^2 \cdot f = \frac{1}{2} 6{,}1 \times 10^{-9} \cdot 264^2 \cdot 100 \times 10^3 \Rightarrow \boxed{P_{RS} = 21{,}26\,W}$$

Al incorporar el snubber se bajan las pérdidas en el apagado del MOSFET a 5,74 W pero la resistencia del snubber disipa más de 20 W adicionales ⇒ el rendimiento complexivo del convertidor empeora.