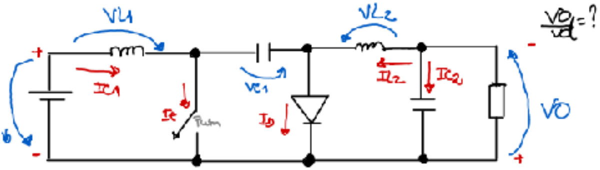
Conversor CuK - exercício

CONVERSOR DC/DC CÚK



DADOS:

$V_D = 50V$
$V_O = 100V$
$P_O \geq 1000W$
$F_S = 100kHz$

A) DEMONSTRE QUE $\frac{V_O}{V_d} = \frac{D}{1-D}$

B) CALCULE L_1 POR FORMA A LIMITAR O "RIPPLE" ΔI_{L1} A 2 A.

C) CALCULE A CORRENTE FORNECIDA PELA FONTE, PARA $I_O = 10A$.

D) CALCULE C_1 PARA LIMITAR O "RIPPLE" ΔV_{C1} A 5 V.

E) CALCULE L_2 DE FORMA A LIMITAR O "RIPPLE" DE CORRENTE ΔI_{L2} A 1 A.

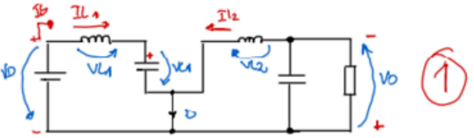
F) CALCULE C_2 DE FORMA A LIMITAR ΔV_O A 1% DE V_O.

G) PARA $P_O = 1000W$ ESBOCE AS TENSÕES V_{L1}, V_{L2}; AS CORRENTES I_{L1}, I_{L2}, I_{C1}, I_{C2}, I_t, I_D.

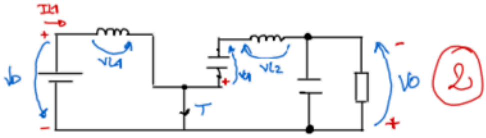
Resolução:

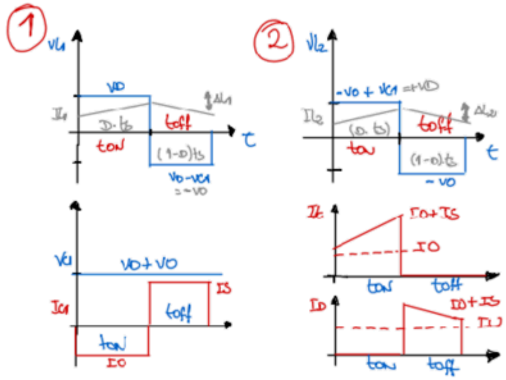
A)

Circuito equivalente em toff $(1-D)\cdot ts$



Circuito equivalente em ton $(D\cdot ts)$





$$V_{L1\,méd} = \frac{1}{ts}\cdot\left(Vd\cdot ton + (Vo - Vc1)\cdot toff\right) = 0$$

$$= \frac{1}{\cancel{ts}}\cdot\left(Vd\cdot D\cdot\cancel{ts} + (Vo - Vc1)\cdot(1-D)\cdot\cancel{ts}\right) = 0$$

$$= D\cdot\cancel{Vo} + V - \cancel{D}\cdot Vo - Vc1 + D\cdot Vc1 = 0$$

$$= VD + Vc1\,(D-1) = 0$$

$$= Vc1 = \frac{VD}{1-D}$$

$$V_{L2\,méd} = \frac{1}{ts}\cdot\left((-Vo + Vc1)\cdot ton - Vo\cdot toff\right) = 0$$

$$= \frac{1}{\cancel{ts}}\cdot\left((-Vo + Vc1)\cdot D\cdot\cancel{ts} - Vo\,(1-D)\cdot\cancel{ts}\right) = 0$$

$$= -D\cdot\cancel{Vo} + D\cdot V1 - Vo + D\cdot\cancel{Vo} = 0$$

$$= D - Vc1 - Vo = 0$$

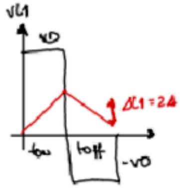
$$= D\cdot Vc1 = Vo$$

$$Vc1 = \frac{Vo}{D}$$

$$\boxed{\frac{VD}{(1-D)} = \frac{Vo}{D} \Rightarrow \frac{Vo}{VD} = \frac{D}{1-D}}$$

É um Conversor Buck Boost

B)



$$V_{L1} = L \cdot \frac{\Delta I}{\Delta t} \qquad \underline{t_{on}}: \; V_O = L \cdot \frac{\Delta I_{L1}}{t_{on}}$$

$$\cdot \; L_1 = t_{on} \cdot \frac{V_D}{\Delta I_{L1}} = D \cdot t_s \cdot \frac{V_D}{\Delta I_{L1}}$$

$$T_S = \frac{1}{f_s} = \frac{1}{10000} = 10\ \mu S$$

$$D = \frac{V_O}{V_O + V_D} = \frac{100}{100+50} = \frac{2}{3} \qquad \cdot \; L_1 = 167\ \mu H$$

C)

$$P_I = P_O \qquad \Leftrightarrow \; I_S = \frac{V_O \cdot I_O}{V_D} = \frac{100 \times 10}{50} = 20A$$

$$V_D \cdot I_S = V_O \cdot I_O$$

D)

$$I_C = C \cdot \frac{\Delta V}{\Delta t} \longrightarrow t_{off} \longrightarrow I_C = I_S = 20A$$

$$\Delta t = t_{off} = (1-D) \cdot t_s = (1-D) \cdot T_S =$$

$$= \left(1 - \frac{2}{3}\right) \cdot 10 \times 10^{-6} = 3,33\ \mu S$$

$$C_1 \geq \frac{\Delta t \cdot I_C}{\Delta V} \quad \Leftrightarrow \quad C_1 \geq \frac{t_{off} \cdot I_S}{\Delta V_{C1}} = \frac{3.33 \times 10^{-6} \cdot 20}{5}$$

$$C_1 \geq 13,3\ \mu F$$

E)

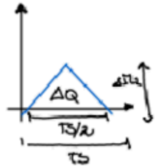
$$V_{L2} = \frac{L_2 \cdot \Delta I_{L2}}{\Delta t}$$

En t_{off}:
$V_{L2} = -V_O$
$\Delta t = (1-D) \cdot T_S$
$\Delta I_{L2} = -1A$

$$L_2 = \frac{-V_O \cdot (1-D) \cdot T_S}{-\Delta I_{L2}}$$

$$L_2 = \frac{-100 \cdot \left(1 - \frac{2}{3}\right) \cdot 10 \times 10^{-3}}{-1} \qquad L_2 = 333,3\ \mu H$$

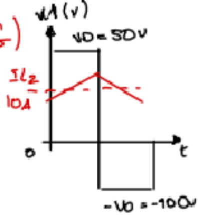
F)

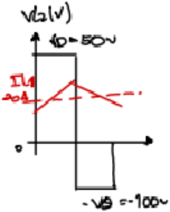


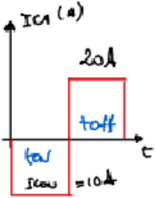
$$\begin{cases} \Delta Q = C_2 \cdot \Delta V_O \\ \Delta Q = \frac{1}{2} \cdot \frac{T_S}{2} \cdot \frac{\Delta I_{L2}}{2} = \frac{t_S \cdot \Delta I_{L2}}{8} \end{cases}$$

$$\begin{cases} C_2 \cdot \Delta V_O = \frac{t_s \cdot \Delta I_{L2}}{8} \\ C_2 = \frac{T_S \cdot \Delta I_{L2}}{8\, \Delta V_O} = \frac{10 \times 10^{-6} \cdot 1}{8 \cdot 0,01 \times 100} = 1,25\ \mu F \end{cases}$$

G)





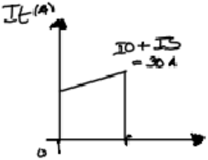


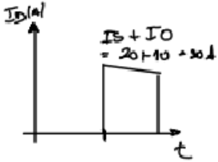
$$20 \times t_{off} = I_{con} \cdot t_{on}$$

$$I_{con} = \frac{20 \times t_{off}}{t_{on}}$$

$$I_{con} = 20 \cdot \frac{\frac{1}{3}}{\frac{2}{3}}$$

$$I_{con} = 10\,A$$





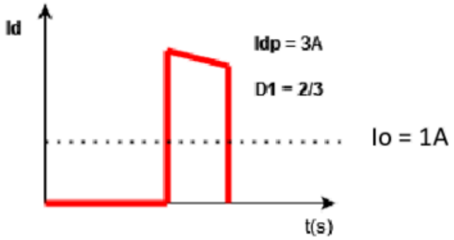
$$I_{tmed} = \frac{1}{t_s} \cdot t_{on} \cdot (I_O + I_S) = \frac{D \cdot t_s}{t_s} \cdot (I_O + I_S)$$

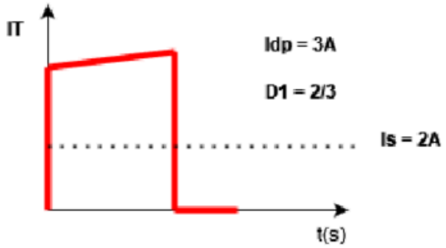
$$I_{tmed} = \frac{2}{3} \cdot (10 + 20) = 20\,A$$

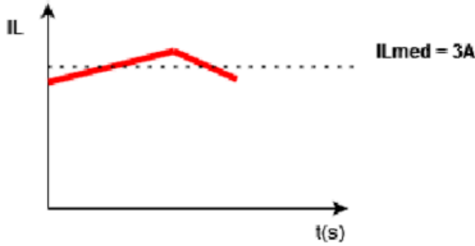
$$I_{Dmed} = \frac{1}{t_s} \cdot t_{off} \cdot (I_O + I_S) = \frac{(1 - D) \cdot t_s}{t_s} \cdot (I_O + I_S)$$

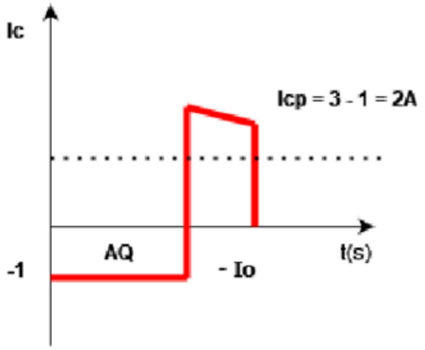
$$I_{Dmed} = \left(1 - \frac{2}{3}\right) \cdot (10 + 20) = 10\,A$$

c)









$$I_0 = \frac{P_0}{V_0} = \frac{16}{16} = 1A$$

$$I_0 = I_{d_{med}} = \frac{1}{T_s} * t_{off} * I_{d_p}$$

$$I_{d_p} = \frac{I_0 * T_s}{t_{off}} = \frac{I_0}{(1 - D_1)} = 3A$$

d)

$$\Delta V_0 = \frac{I_{0 * t_{on}}}{C} = \frac{I_{0 * D * T_s}}{C}$$

$$\Delta V_{0_{max}} = \frac{I_{0 * D_1 * T_s}}{C} = 0{,}133\ V$$

e)

em corrente:

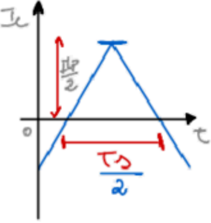
Id = 1 A

It = 2 A

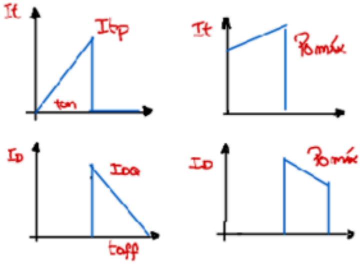
Em tensão:

Em toff - $V_{T_{max}} = V_{d_{max}} - (-V_0) = 40 + 16 = 56\,V$

Em ton - $V_{d_{max}} = -V_0 - V_{d_{max}} = -16 - 40 = -56\,V$



Dimensionamento em corrente dos S.C.P



Transístor:

$P_O = P_I$

$V_O \cdot I_O = V_d \cdot I_t$

$\boxed{I_t = \frac{V_O \cdot I_O}{V_d} = \frac{P_{O\,max}}{V_d}}$ ①

Díodo:

$I_t + I_D = I_O$

$\boxed{I_D = I_O - I_t}$

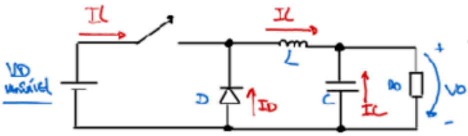
$I_D = \frac{P_{O\,máx}}{V_O} - \frac{P_{O\,máx}}{V_D}$

$\boxed{I_D = (1-D) \cdot I_O}$ ②

① $\boxed{I_t = I_O \cdot D}$

$\boxed{D = \frac{V_O}{V_d}}$

Considerando agora tensão de entrada variável.



$\boxed{V_{d\,mín} \leq V_d \leq V_{d\,máx}}$

$$L \geq \frac{V_O(1-D) \cdot t_s}{2 \cdot I_{O\,mín}}$$

$$L_1 = \frac{V_O(1-D_1) \cdot t_s}{2 \cdot I_{O\,mín}} \qquad D_1 = \frac{V_O}{V_{d\,mín}}$$

$$L_2 = \frac{V_O(1-D_2) \cdot T_s}{2 \cdot I_{O\,mín}} \qquad D_2 = \frac{V_O}{V_{d\,máx}}$$

Como decidir o valor de L a utilizar?

$$I_{O1} = \frac{V_O(1-D_2) \cdot t_s}{2 \cdot L_1} ; \quad I_{O2} = \frac{V_O(1-D_1) \cdot t_s}{2 \cdot L_2}$$

Nota: Rejeitamos a indutância que levaria a uma corrente máxima maior que $\boxed{I_{O\,mín} = \frac{P_{O\,mín}}{V_O}}$

$$C \geq \frac{T_s \cdot I_{O\,mín}}{4 \cdot \Delta V_O}$$

3) $v_L = L \cdot \frac{\Delta I}{\Delta t}$ Em toff: $v_L = -v_O$

$\Delta t = t_{off} = (1-D)\cdot t_s$

$\Delta I = I_{Lp} = -2\, I_{O\,min}$

$$-v_O = L \cdot \frac{-2\, I_{O\,min}}{(1-D)\cdot t_s} \Leftrightarrow \boxed{L = \frac{V_O(1-D)\cdot t_s}{2\cdot I_{O\,min}}}$$

$$L_1 = \frac{V_O(1-D_1)\cdot t_s}{2\, I_{O\,min}}$$

$$L_2 = \frac{V_O(1-D_2)\cdot t_s}{2\, I_{O\,min}}$$

$f_s = 50\,kHz$ $t_s = \frac{1}{50} = 20\mu s$

$D_1 = \frac{V_O}{V_{I\,min}} = \frac{9}{12} = \frac{3}{4}$

$D_2 = \frac{V_O}{V_{I\,max}} = \frac{9}{18} = \frac{1}{2}$

$I_{O\,min} = \frac{P_{O\,min}}{V_O} = \frac{3}{9} = \frac{1}{3}A$

$$L_1 = \frac{9\cdot(1-\frac{3}{4})\cdot 20\times10^{-6}}{2\cdot\frac{1}{3}} = 67{,}5\ \mu H$$

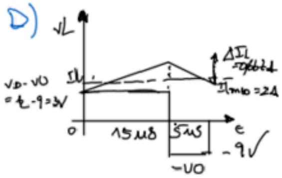
justificar

$$L_2 = \frac{9\cdot(1-\frac{1}{2})\cdot 20\times10^{-6}}{2\cdot\frac{1}{3}} = 135\ \mu H$$

c) $I_S \cdot V_I = V_O \cdot I_O$

$I_{S\,max} = \frac{V_O\cdot I_O}{V_{I\,min}} \Leftrightarrow I_S = \frac{18}{12} = 1{,}5\,A$

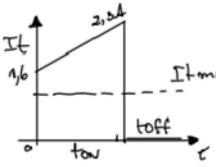
D)

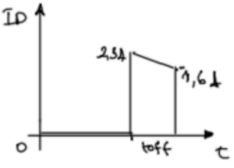


$v_{O\,min} = D_1 = \frac{3}{4}$

$t_{on} = 20\mu s \cdot \frac{3}{4} = 15\mu s$

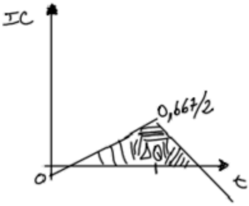
$t_{off} = 5\mu s$





$I_O = I_L - I_t$

$2A - 1{,}5 = 0{,}5A$



$I_C = I_L - I_O$

$I_C =$

E) $\begin{cases} \Delta Q = C \cdot \Delta V_O \\ \Delta Q = \dfrac{1}{2} \cdot \dfrac{t_S}{2} \cdot \dfrac{\Delta I}{2} = \dfrac{t_S \cdot \Delta I}{8} = \dfrac{t_S \cdot 2 I_{Omin}}{8} \end{cases}$

$$= \frac{t_S \cdot I_{Omin}}{4}$$

$$\begin{cases} \Delta Q = C \cdot \Delta V_O \\ \Delta Q = \dfrac{T_S \cdot I_{Omin}}{4} \end{cases}$$

$$C \cdot \Delta V_O = \frac{t_S \cdot I_{Omin}}{4}$$

$$C \geqslant \frac{t_S \cdot I_{Omin}}{4 \cdot \Delta V_O}$$

$$C \geqslant \frac{20 \times 10^{-6} \cdot \frac{1}{3}}{4 \cdot 0{,}01 \cdot 9} = 18{,}52\ \mu F$$

B) $C \geq \frac{I_{Omin} \cdot t_s}{4 \cdot \Delta V_O} = \frac{100 \times 10^{-3} \times 10 \times 10^{-6}}{4 \times (0{,}1 \times 6)} = 4{,}17\ \mu A$

C) $P_O = P_I$

$P_O = V_O \cdot I_O$

$P_I = V_D \cdot I_t$

$\boxed{\underline{\underline{\text{OBSERVAÇÃO}}} \quad I_O = \frac{P_O}{V_O} = \frac{12}{6} = 2A}$

$V_O \cdot I_O = V_D \cdot I_t$

$I_{t_{max}} = \frac{V_O}{V_{Dmin}} \cdot I_O$ $\qquad I_{tmax} = 1\ A$

$I_{tmax} = \frac{6}{12} \cdot 2$

D) Perdas de condução no transístor

$P_{cond_T} = V_{ton} \cdot I_{tmed}$ $\qquad I_{tmed} = I_{Omáx} \cdot D$

$I_{tmed} \to I_{tmed_1} = 2 \times 0{,}5 = 1\ A$

$I_{tmed} \to I_{tmed_2} = 2 \times \frac{1}{3} = \frac{2}{3}\ A$

Perdas de comutação no díodo

$P_{cond_D} = V_{Don} \cdot I_{Dmed}$ $\qquad I_{Dmed} = I_{Omáx} \cdot (1 - D)$

$I_{Dmed} \to I_{Dmed_1} = 2 \times (1 - 0{,}5) = 1\ A$

$I_{Dmed} \to I_{Dmed_2} = 2 \times (1 - \frac{1}{3}) = \frac{4}{3}\ A$

$D1: P_{cond} = P_{cond_T} + P_{cond_D} = 0{,}5 \times 1 + 0{,}3 \times 1 = 0{,}8W$

$D2: P_{cond} = P_{cond_T} + P_{cond_D} = 0{,}5 \times \frac{2}{3} + 0{,}3 \times \frac{4}{3} = 0{,}733W$

$\eta = \frac{P_O}{P_O + P_{cond}} \times 100 = \frac{12}{12 + 0{,}8} \times 100 = 94\%$