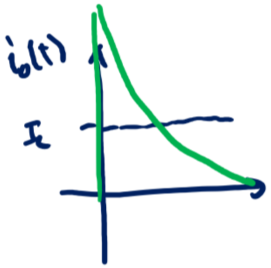
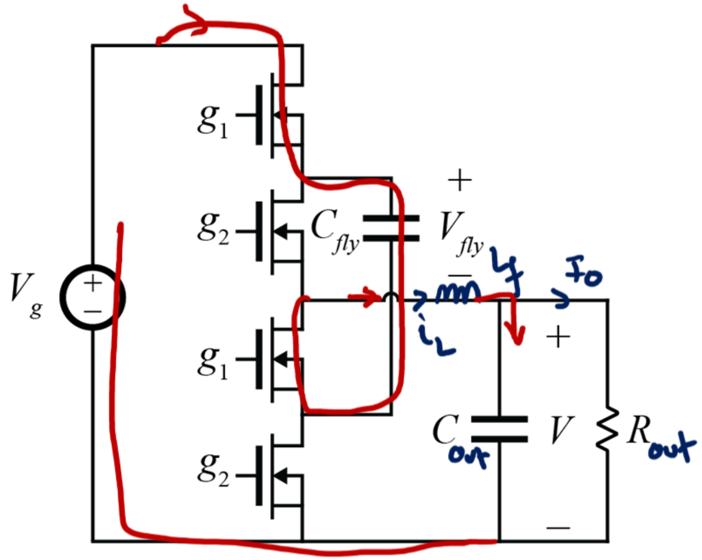
2:1 – Current Loaded





- 2:1 SC converter with current load
- 3-level buck converter
- Flying capacitor multilevel (FCML) buck converter

$L_f \to$ Large, filter inductor, $i_L \simeq I_L$

from previous results

$$E_{loss} = \begin{cases} \text{I} \quad \frac{1}{2} C_{fly} (V_2 - V_1)^2 \frac{2RC_{fly}}{t_c} \\ \text{II} \quad \frac{1}{2} C_{fly} (V_2 - V_1)^2 \frac{2RC_{fly}}{t_c} \end{cases}$$

$R = 2 \times r_{on} + ESR_{C_{fly}} + R_L + R_{par} + ESR_{out}$

$t_c = \frac{T_s}{2}$

$$E_{loss} = \underbrace{C_{fly}^2 (V_2 - V_1)^2}\ \frac{4R}{T_s}$$

$$C_{fly}(V_2 - V_1) = C_{fly} \Delta V_c = \Delta Q_{fly} = I_L \frac{T_s}{2}$$

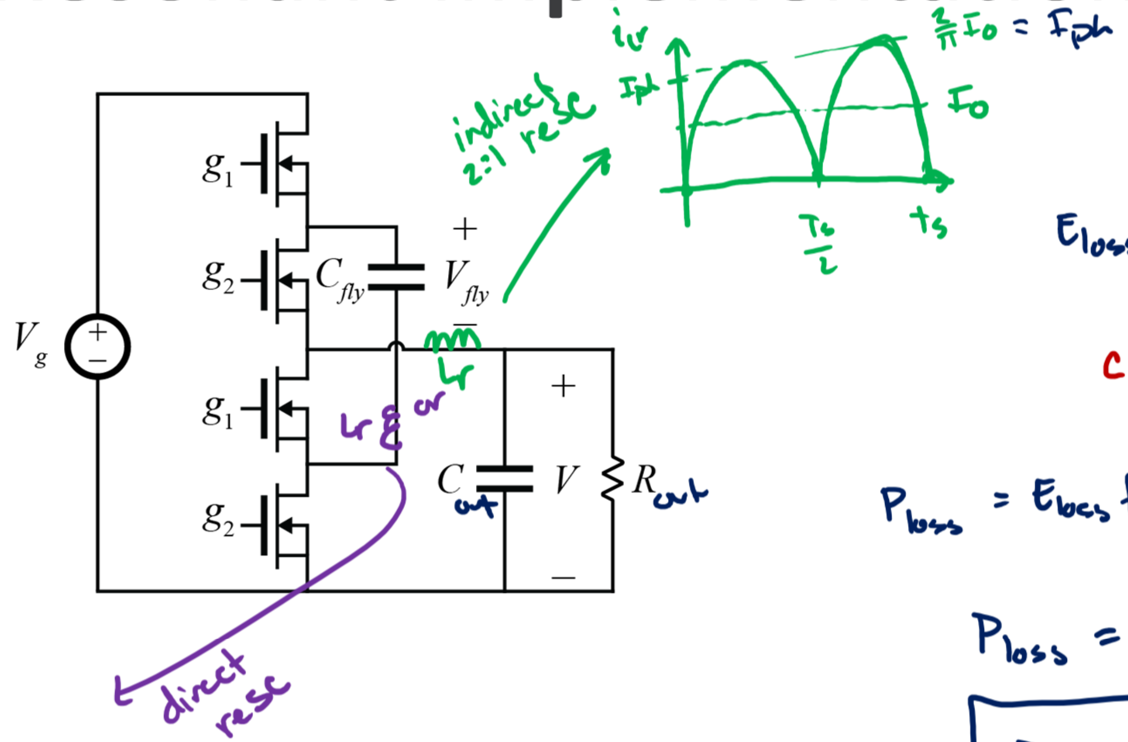
$$E_{loss} = \left(I_L \frac{T_s}{\cancel{2}}\right)^2 \frac{\cancel{4}R}{\cancel{T_s}}$$

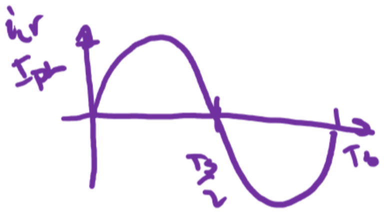
$$= I_L^2 R T_s$$

$$\boxed{P_{loss} = I_L^2 R}$$

$I_L = I_o$

2:1 – Resonant Implementation





$$E_{loss} = C_{fly}(V_2 - V_1)^2 \frac{\pi^2 R C_{fly}}{4 t_e}, \quad t_e = \frac{T_s}{2}$$

$$C_{fly}(V_2 - V_1) = \Delta Q_{fly} = I_o \frac{T_s}{2}$$

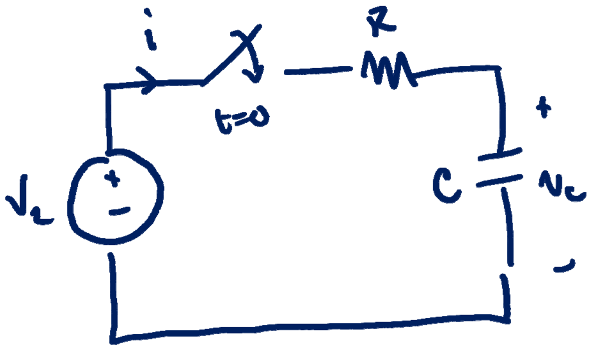
$$P_{loss} = E_{loss} f_s = \left(I_o \cancel{\frac{T_s}{2}}\right)^2 \frac{\pi^2 R}{4 \cancel{\frac{T_s}{2}}} \cancel{f_s}$$

$$P_{loss} = \left(I_o \frac{1}{\sqrt{2}} \frac{\pi}{2}\right)^2 R$$

$$\boxed{P_{loss} = I_{L,rms}^2 R}$$

$$R = 2r_{on} + R_L + ESR_{Cfly} + \cdots$$

Slow and Fast Switching Limits

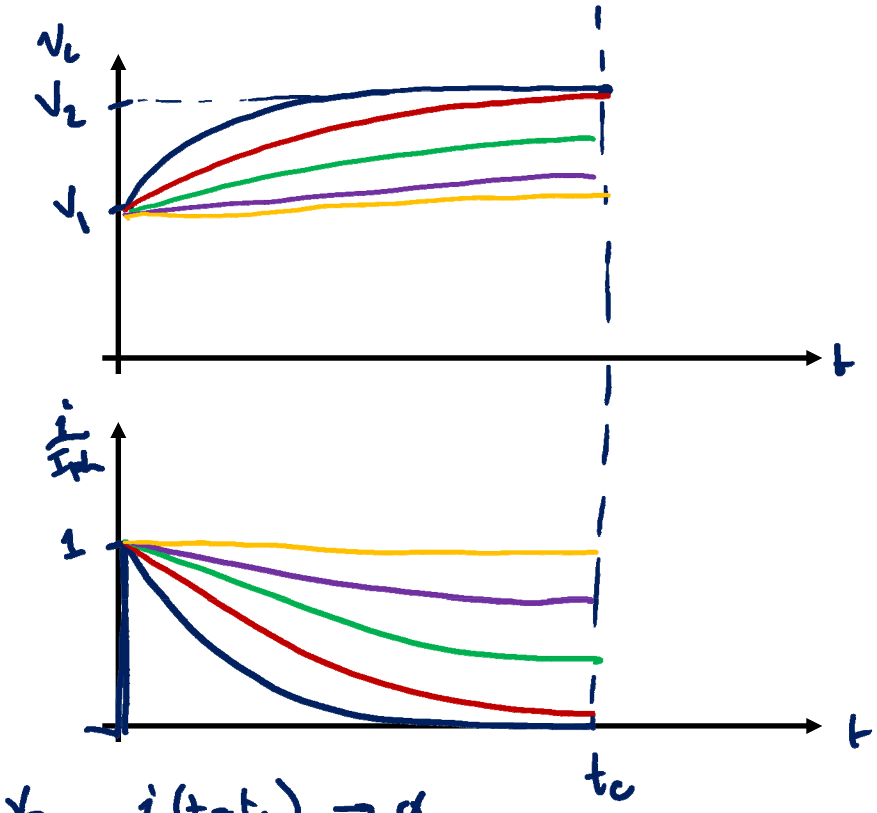


$$v_c(t=0) = V_1$$

$$v_c(t) = V_1 + (V_2 - V_1)\left(1 - e^{-\frac{t}{RC}}\right)$$

$\frac{t_c}{\tau}$	$\frac{\Delta v_c}{V_2 - V_1}$
∞	100 %
3	95%
1	63%
1/2	39%
$\frac{1}{10}$	9.5%

$$I_{pk} = \frac{V_2 - V_1}{R}$$



if $t_c \gg \tau \rightarrow v_c(t=t_c) = V_2 \quad i(t=t_c) \rightarrow \emptyset$

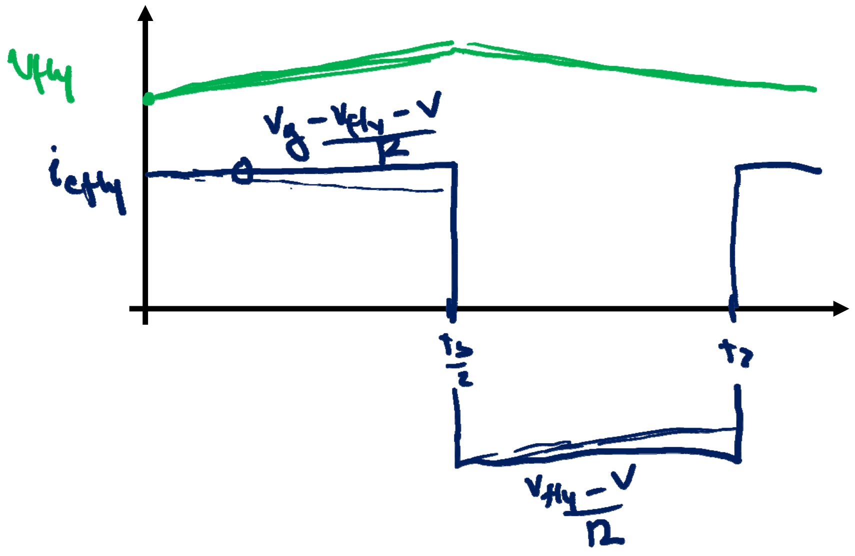
slow switching limit (SSL)

if $t_c \ll \tau \rightarrow v_c(t=t_c) < V_2 \quad i_c(t=t_c) > \emptyset$

Fast switching limit (FSL)

2:1 SC – FSL Model

in FSL, $t_c \ll \tau = RC$



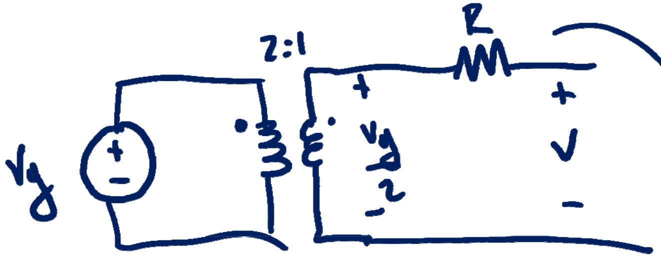
$$P_{out} = \frac{1}{T_s}\int_0^{T_s} V \cdot i_o(t)\,dt$$

$$= V \cdot \frac{1}{T_s}\left[\underbrace{\frac{V_g - \cancel{V_{fly}} - V}{R}\,\frac{T_s}{2}}_{\mathrm{I}} + \underbrace{\frac{\cancel{V_{fly}} - V}{R}\,\frac{T_s}{2}}_{\mathrm{II}}\right]$$

$$= V \cdot \frac{1}{\cancel{T_s}}\left[\frac{V_g - 2V}{R}\,\frac{\cancel{T_s}}{2}\right]$$

$$P_{out} = V \cdot \frac{\frac{V_g}{2} - V}{R}$$

$R = 2 \times r_{on} + ESR_c + \ldots$

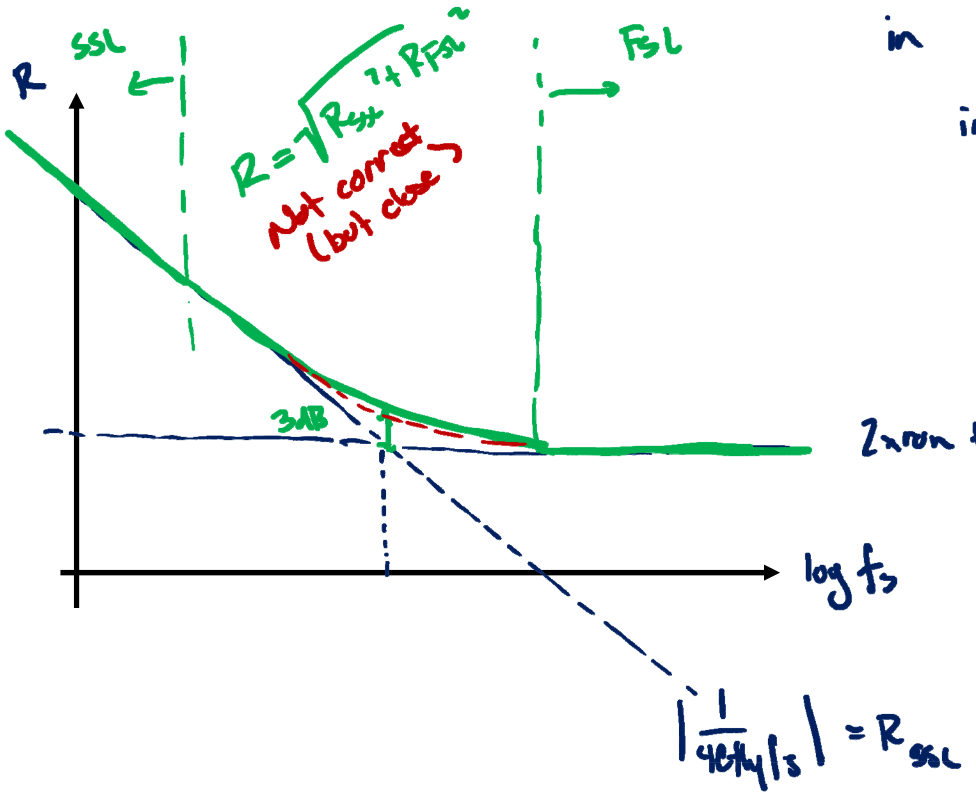


$$R = \begin{cases} \frac{1}{4C_{fly}f_s}, & SSL \ (t_c \gg \tau) \\ 2r_{on} + ESR_c + R_{par}, & FSL, \ (t_c \ll \tau) \end{cases}$$

SC Output Resistance

in SSL $R = \frac{1}{4C_{fly} f_s}$

in FSL $R = 2 \times r_{on} + ESR_c + \ldots$



$R = \frac{1}{4C_{fly} f_s}$

$RC_{fly} = \tau = \frac{T_s}{4} = \frac{t_c}{2}$