# Caratteristiche dinamiche dei convertitori cc/cc

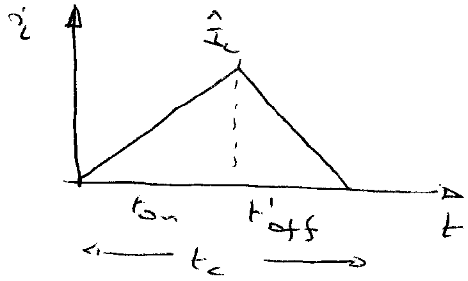


## BUCK CCM

$$\frac{\Delta U_o}{\Delta \delta} = \frac{U_i}{1 + \frac{sL}{R} + s^2 LC}$$

## BUCK DCM

: Si vede che $\Delta\delta \to \Delta \hat{I}_L,\ \Delta t_c,\ \Delta U_o$

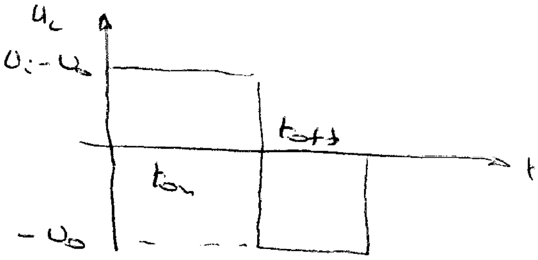



A regime: $\bar{i}_L = \hat{I}_L \frac{(t_{on}+t'_{off})}{2T_s} = \frac{\hat{I}_L t_c}{2T_s}$

Se si applica una variazione $\Delta\delta$ ($\Delta t_{on}$):

$$\bar{i}_L + \Delta \bar{i}_L = (\hat{I}_L + \Delta \hat{I}_L)\frac{(t_c + \Delta t_c)}{2T_s}$$

$$\boxed{\Delta \bar{i}_L = \frac{\hat{I}_L}{2T_s}\Delta t_c + \Delta \hat{I}_L \frac{t_c}{2T_s}}$$




A regime: $(U_i - U_o)\, t_{on} = U_o\, t'_{off}$

$\Downarrow$

$$U_i\, t_{on} = U_o (t_{on} + t'_{off}) = U_o t_c$$

Se si applica $\Delta\delta$:

$$U_i (t_{on} + \Delta t_{on}) = (U_o + \Delta U_o)(t_c + \Delta t_c)$$

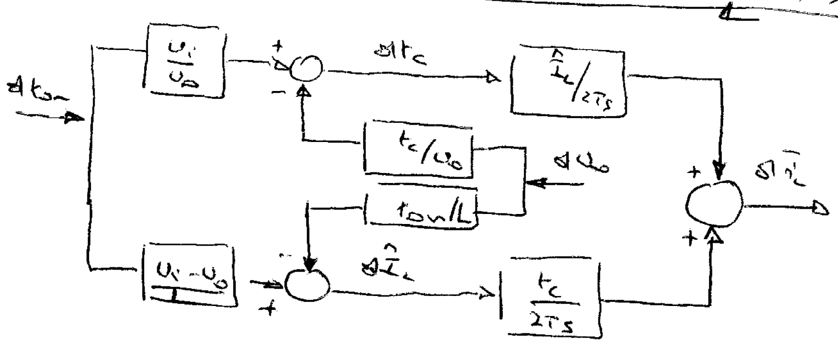
$\Downarrow$

$$U_i \Delta t_{on} = U_o \Delta t_c + \Delta U_o\, t_c$$

Dunque: $\boxed{\Delta t_c = \frac{U_i}{U_o}\Delta t_{on} - \frac{t_c}{U_o}\Delta U_o}$

Infine: $\hat{I}_L + \Delta \hat{I}_L = [U_i - (U_o + \Delta U_o)](t_{on} + \Delta t_{on})/L$

$$\boxed{\Delta \hat{I}_L = -\frac{\Delta U_o\, t_{on}}{L} + \frac{(U_i - U_o)}{L}\Delta t_{on}}$$

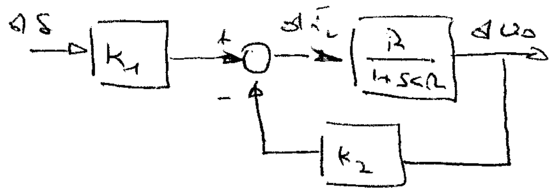



Sovrapp. effetti:

$$\Delta \bar{i}_L = K_1 \Delta\delta - K_2 U_o$$

ove $K_1$ e $K_2$ sono $> 0$ e dipendono dal punto di lavoro

Lo schema a blocchi complessivo è:




$$\frac{\Delta U_o}{\Delta \delta} = K_1 \frac{\frac{R}{1+sCR}}{\frac{K_2 R}{1+sCR}+1} = \frac{K_1 R}{1+K_2R+sCR}$$

Infine: $\boxed{\frac{\Delta U_o}{\Delta\delta} = \frac{K_1 R}{1+K_2R}\,\frac{1}{1+s\frac{CR}{1+K_2R}}}$

La f.d.t. è del 1° ordine e dipende dal punto di lavoro

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BOOST CCM: Introducendo una perturbazione $\Delta\delta$ si ha la comparsa di uno sbilanciamento $\Delta\bar{u}_L$.

$$\Delta\bar u_L = \frac{U_i(t_{on}+\Delta t_{on}) - (U_o+\Delta U_o - U_i)(t_{off}+\Delta t_{off})}{T_s} =$$

$$= \frac{U_i t_{on} + U_i\Delta t_{on} - (U_o-U_i)(t_{off}+\Delta t_{off}) - \Delta U_o t_{off}}{T_s} =$$

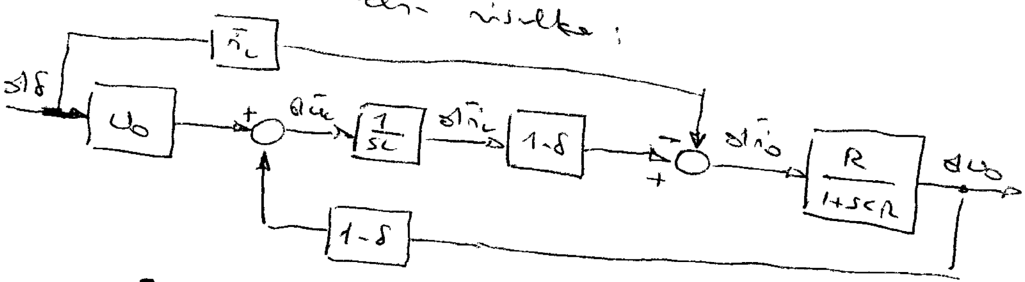
$$= \frac{U_i\Delta t_{on} - (U_o-U_i)\Delta t_{off} - \Delta U_o t_{off}}{T_s} = \frac{U_i(\Delta t_{on}+\Delta t_{off}) - U_o\Delta t_{off} - \Delta U_o t_{off}}{T_s}$$

Posto che $\Delta t_{on} = -\Delta t_{off}$ si ha: $\Delta\bar u_L = \frac{U_o\Delta t_{on} - \Delta U_o t_{off}}{T_s} = U_o\Delta\delta - \Delta U_o(1-\delta)$

Inoltre: $\Delta\bar i_L = \frac{\Delta \bar u_L}{sL}$

e: $\bar i_o + \Delta\bar i_o = \frac{(\bar i_L+\Delta\bar i_L)(t_{off}+\Delta t_{off})}{T_s} \Rightarrow \Delta\bar i_o = \Delta\bar i_L(1-\delta) - \bar i_L\Delta\delta$

Lo schema a blocchi risulta:



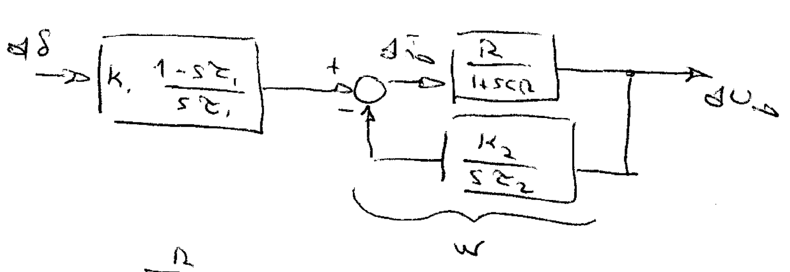

Note: $\frac{\Delta\bar i_o}{\Delta\delta} = \frac{U_o(1-\delta)}{sL} - \bar i_L = \frac{U_o(1-\delta) - sL\bar i_L}{sL} = K_1\frac{1-s\tau_1}{s\tau_1} = \bar i_L \frac{1-s\tau_1}{s\tau_1}$

$\tau_1 = sL\bar i_L / U_o(1-\delta)$ $\quad K_1 = \frac{U_o(1-\delta)}{L}\tau_1 = \bar i_L$

$\frac{\partial \bar i_o}{\partial u_o} = \frac{(1-\delta)^2}{sL} = \frac{K_2}{s\tau_2}$ $\quad \tau_2 = \frac{L}{R}$ $\quad K_2 = \frac{(1-\delta)^2}{R}$

Schema a blocchi complessivo





$$w = \frac{\frac{R}{1+sCR}}{1+\frac{k_2}{s\tau_2}\frac{R}{1+sCR}} = \frac{s\tau_2 R}{s\tau_2 + s^2 CR\tau_2 + k_2 R} = \frac{sL}{(1-\delta)^2 + s\frac{L}{R} + s^2 LC}$$

$$w = \frac{sL}{(1-\delta)^2\left[1+\frac{s^2LC}{(1-\delta)^2}+\frac{sL}{R(1-\delta)^2}\right]}$$

La pulsazione di risonanza è $\frac{1-\delta}{\sqrt{LC}}$, e smorzamento e il guadagno dipendono dal punto di lavoro

Infine:

$$\frac{\partial u_o}{\partial \delta} = \frac{k_1(1-s\tau_1)\frac{L}{\tau_1}}{\dots} = \frac{\frac{\bar{i}_L L}{\bar{i}_L L}\, U_o(1-\delta)(1-s\tau_1)}{\dots}$$

$$\boxed{\frac{\partial u_o}{\partial \delta} = \frac{U_o}{1-\delta}\frac{1-s\tau_1}{1+s^2LC+\frac{sL}{R(1-\delta)^2}} = \frac{U_o}{1-\delta}\frac{1-s\tau_1}{1+\frac{s^2LC}{(1-\delta)^2}+\frac{sL}{R(1-\delta)^2}}}$$

Si nota lo zero a parte reale positiva (introduce un ritardo di fase), possibile fonte d'instabilità

BOOST DCM

Bilanciamento delle aree di tensione nella situazione perturbata

$$U_i(t_{on}+\partial t_{on}) = (U_o+\partial U_o-U_i)(t'_{off}+\partial t'_{off})$$

$$U_i t_{on} + U_i\,\partial t_{on} = (U_o-U_i)(t'_{off}+\partial t'_{off}) + \partial U_o\, t'_{off}$$

$$U_i\,\partial t_{on} = (U_o-U_i)\,\partial t'_{off} + \partial U_o\, t'_{off}$$

Infine: $\boxed{\partial t'_{off} = \partial t_{on}\frac{U_i}{U_o-U_i} - \partial U_o\frac{t'_{off}}{U_o-U_i}}$ $\rightarrow \frac{\partial t'_{off}}{T_s} = \partial\delta\,\frac{U_i}{U_o-U_i} - \frac{\partial U_o}{U_o-U_i}\frac{t'_{off}}{T_s}$

Inoltre:

$$\hat{I}_L + \Delta \hat{I}_L = \frac{U_i\,(t_{on} + \Delta t_{on})}{L} \Rightarrow \boxed{\Delta \hat{I}_L = \frac{U_i\,\Delta t_{on}}{L} = \frac{U_i\,\Delta \delta}{f_s L}}$$

Infine:

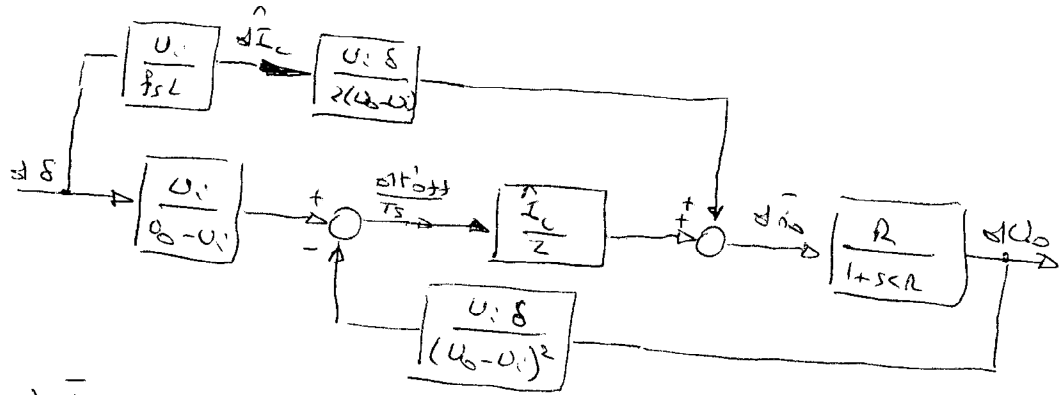
$$\bar{i}_o + \Delta \bar{i}_o = \frac{(\hat{I}_L + \Delta \hat{I}_L)(t'_{off} + \Delta t'_{off})}{2T_s}$$

$$\boxed{\Delta \bar{i}_o = \frac{\Delta \hat{I}_L\, t'_{off} + \hat{I}_L\, \Delta t'_{off}}{2T_s}}$$

Si osserva che:

$$t'_{off} = \frac{U_i\, t_{on}}{U_o - U_i} \rightarrow \frac{t'_{off}}{T_s} = \frac{U_i}{U_o - U_i}\,\delta$$

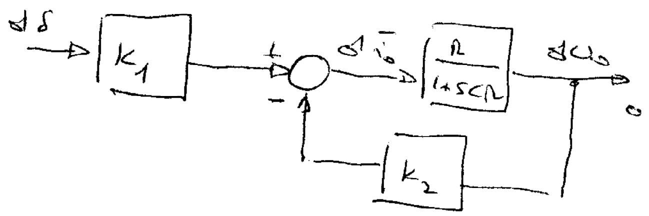
Schema a blocchi:




$$\frac{\partial \bar{i}_o}{\partial \delta} = \frac{U_i}{U_o - U_i}\,\frac{\hat{I}_L}{2} + \frac{U_i^2\,\delta}{2 f_s L\,(U_o - U_i)} = K_1$$

$$\frac{\partial \bar{i}_o}{\partial u_o} = \frac{U_i\,\delta}{(U_o - U_i)^2}\,\frac{\hat{I}_L}{2} = K_2$$

Schema semplificato:




È come il Buck DCM, con valori diversi dei coefficienti $K_1$ e $K_2$.

La risposta è del 1° ordine.
(senza zeri a parte reale positiva)

# BUCK-BOOST CCM

Se si applica $\Delta\delta \rightarrow \Delta\bar{u}_L$

$$\Delta\bar{u}_L = \frac{V_i\,(t_{on}+\Delta t_{on}) - (V_o+\Delta V_o)(t_{off}+\Delta t_{off})}{T_s}$$

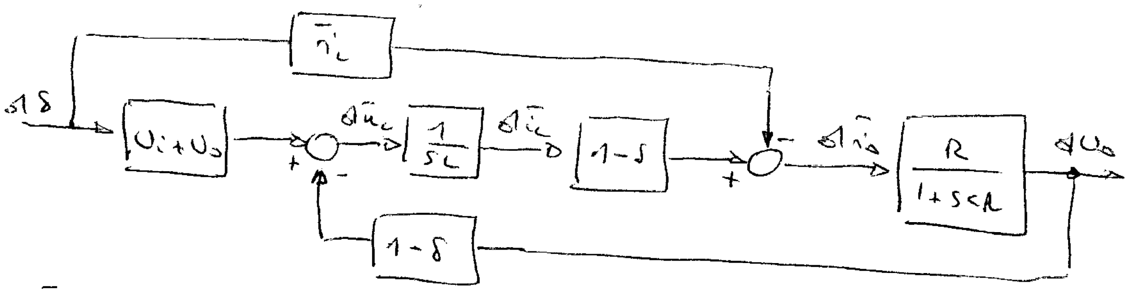
$$\Delta\bar{u}_L = \frac{V_i\,\Delta t_{on} - V_o\,\Delta t_{off} - \Delta V_o\, t_{off}}{T_s} = (V_i+V_o)\,\Delta\delta - \Delta V_o\,(1-\delta)$$

$$\Delta\bar{i}_L = \frac{\Delta\bar{u}_L}{sL}$$

$$\Delta\bar{i}_o + \bar{i}_o = \frac{(\bar{i}_L+\Delta\bar{i}_L)(t_{off}+\Delta t_{off})}{T_s}$$

$$\Delta\bar{i}_o = \Delta\bar{i}_L\,(1-\delta) - \bar{i}_L\,\Delta\delta$$

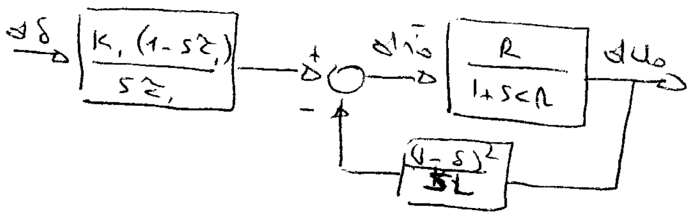
Schema a blocchi:




$$\frac{\Delta\bar{i}_o}{\Delta\delta} = \frac{(V_i+V_o)(1-\delta)}{sL} - \bar{i}_L = \frac{K_1\,(1-s\tau_1)}{s\tau_1}$$

$$\frac{\Delta\bar{i}_o}{\Delta V_o} = \frac{(1-\delta)^2}{sL}$$

Schema semplificato




La proprietà sono le stesse del boost CCM, con valori diversi dei parametri. In particolare la pulsazione di risonanza vale ancora $\omega_r = \frac{1}{\sqrt{LC}}$

## BUCK-BOOST DCM

$$\bar{i}_o + d\bar{i}_o = \frac{(\hat{I}_L + d\hat{I}_L)(t'_{off} + dt'_{off})}{2T_S}$$

$$d\bar{i}_o = \hat{I}_L \frac{dt'_{off}}{2T_S} + d\hat{I}_L \frac{t'_{off}}{2T_S}$$

$$\frac{t'_{off}}{T_S} = \frac{U_i\, t_{on}}{U_o\, T_S} = \frac{U_i}{U_o}\delta$$

$$\boxed{d\bar{i}_o = \hat{I}_L \frac{dt'_{off}}{2T_S} + d\hat{I}_L \frac{U_i}{U_o}\frac{\delta}{2}}$$

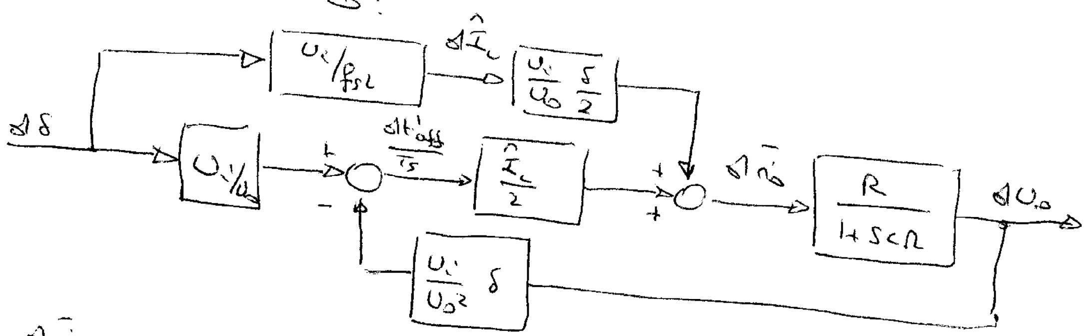
$$\boxed{d\hat{I}_L = \frac{U_i}{L} dt_{on} = \frac{U_i}{f_s L} d\delta}$$

$$U_i (t_{on} + dt_{on}) = (U_o + dU_o)(t'_{off} + dt'_{off})$$

$$U_i\, dt_{on} = U_o\, dt'_{off} + dU_o\, t'_{off}$$

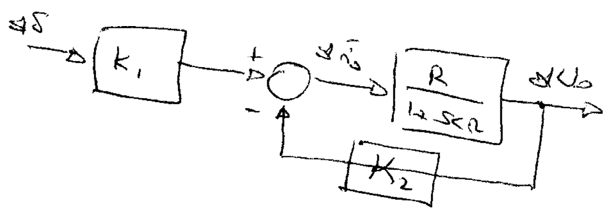
$$\boxed{\frac{dt'_{off}}{T_S} = \frac{U_i}{U_o} d\delta - \frac{dU_o}{U_o}\frac{U_i}{U_o}\delta}$$

Schema a blocco:




$$\frac{d\bar{i}_o}{d\delta} = \frac{U_i}{U_o}\frac{\hat{I}_L}{2} + \frac{U_i}{f_s L}\frac{U_i}{U_o}\frac{\delta}{2} = K_1$$

$$\frac{d\bar{i}_o}{dU_o} = \frac{U_i}{U_o^2}\delta\frac{\hat{I}_L}{2} = K_2$$




Come nel caso di boost DCM