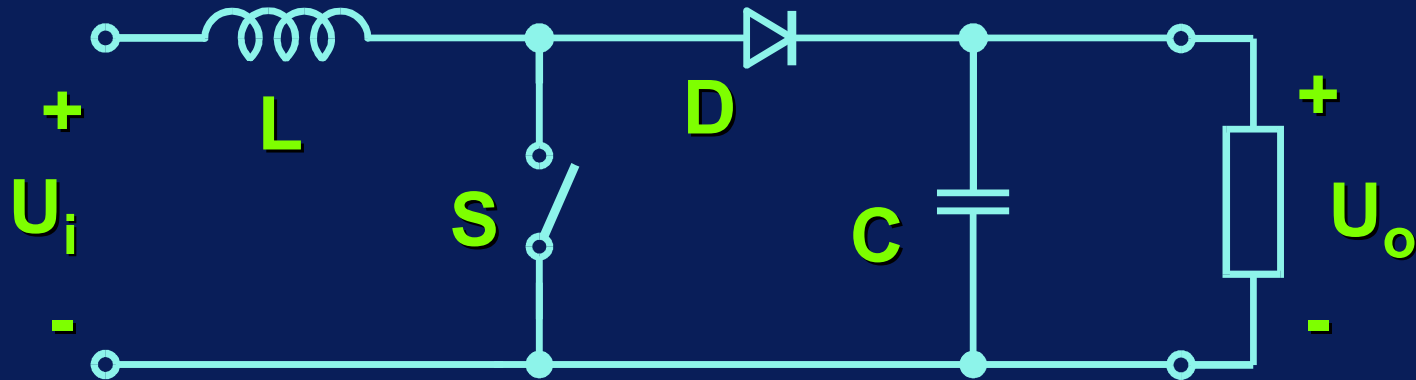


Corso di **ELETRONICA INDUSTRIALE**

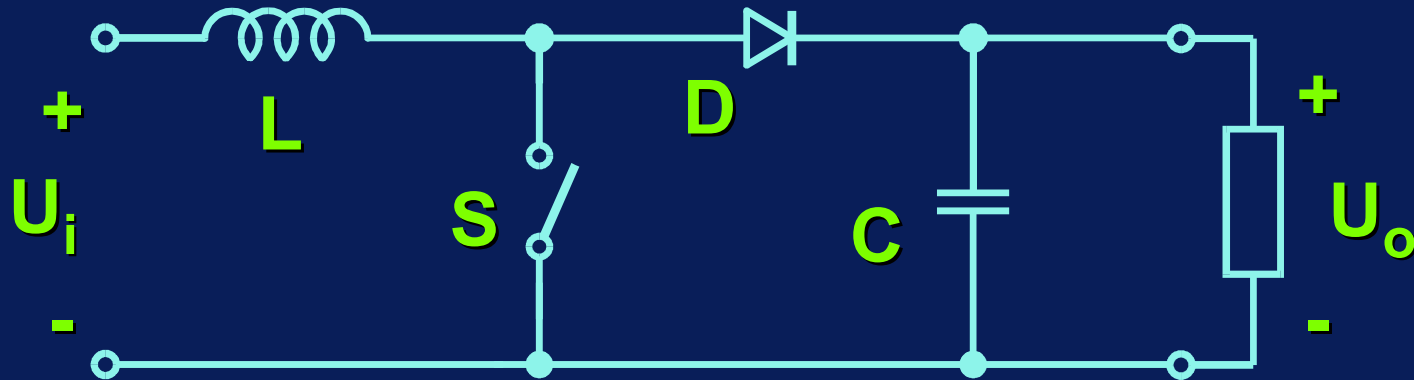
“Convertitore Boost”

Convertitore innalzatore di tensione (boost)

Convertitore innalzatore di tensione (boost)



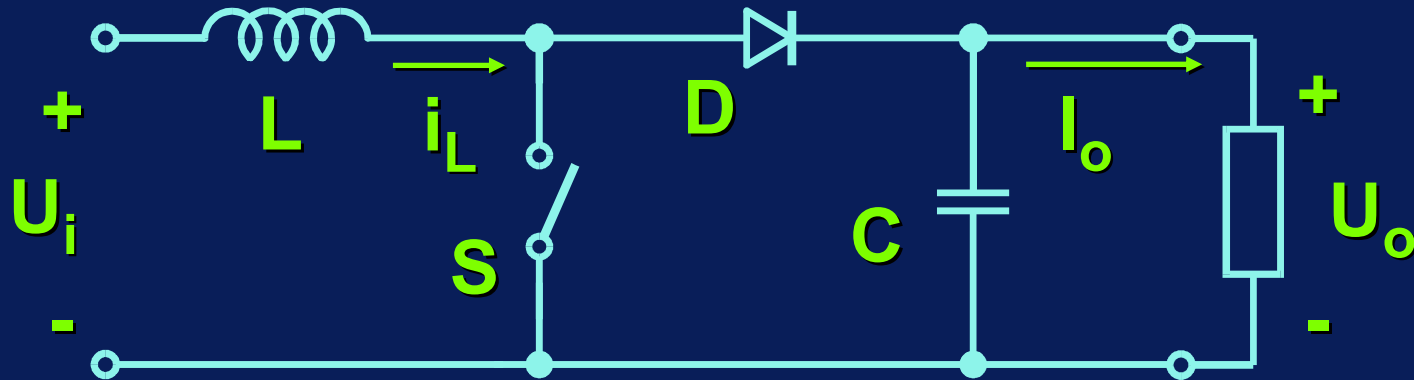
Convertitore innalzatore di tensione (boost)



Note:

- 1) Il diodo D collega direttamente ingresso e uscita e impone che sia $U_o \geq U_i$
- 2) La corrente assorbita dall'alimentazione é filtrata dall'induttanza L

Convertitore innalzatore di tensione (boost)



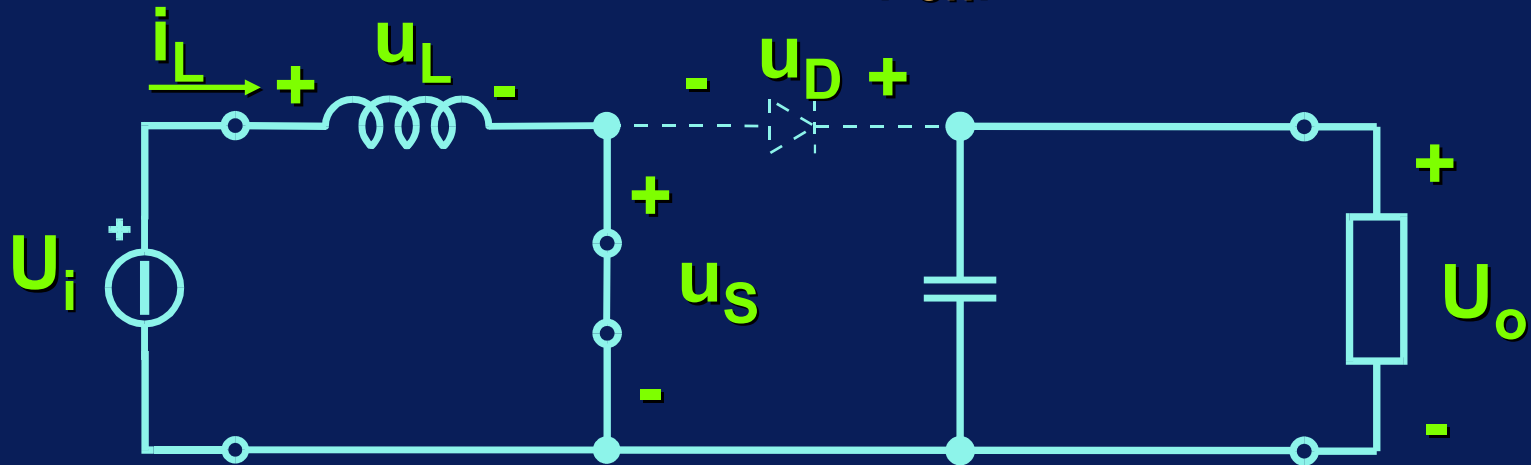
Ipotesi per lo studio:

- interruttore ideale ($u_{son}=0$, $i_{soff}=0$, $t_{swon}=t_{swoff}=0$)
- diodo ideale ($u_{son}=0$, $i_{soff}=0$, $t_{swon}=t_{swoff}=0$)
- L, C ideali ($R_L=0$, $ESR=0$, $ESL=0$)
- $u_i = U_i = \text{costante}$
- $u_o = U_o = \text{costante}$
- $i_o = I_o = \text{costante}$

Analisi del funzionamento continuo (CCM)

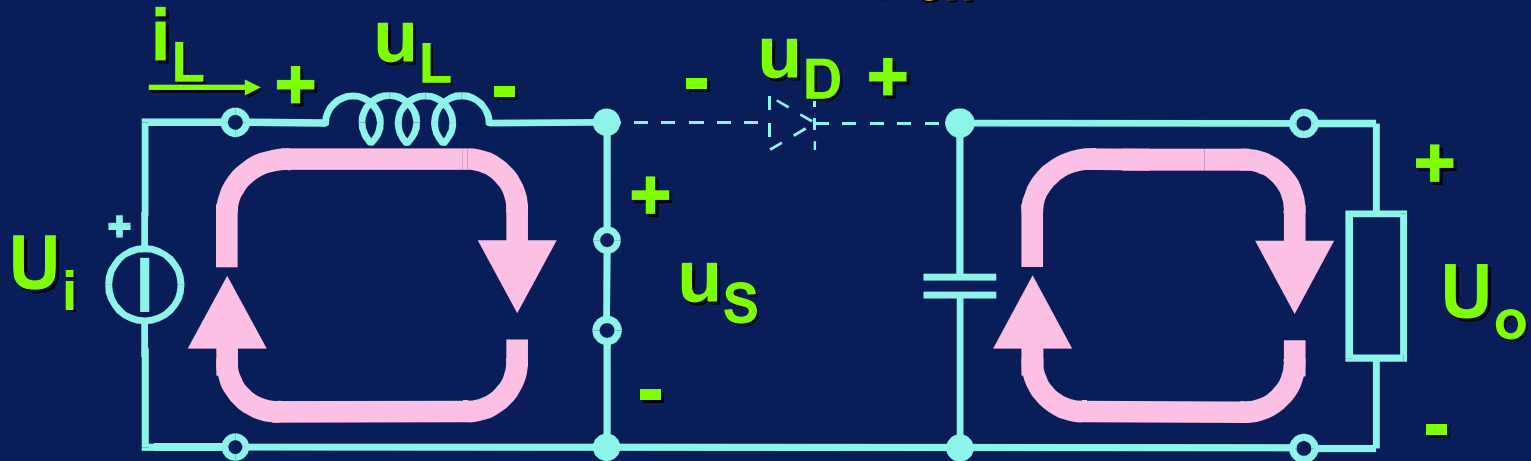
Analisi del funzionamento continuo (CCM)

Tempo di chiusura di S (t_{on}) S on - D off



Analisi del funzionamento continuo (CCM)

Tempo di chiusura di S (t_{on}) S on - D off

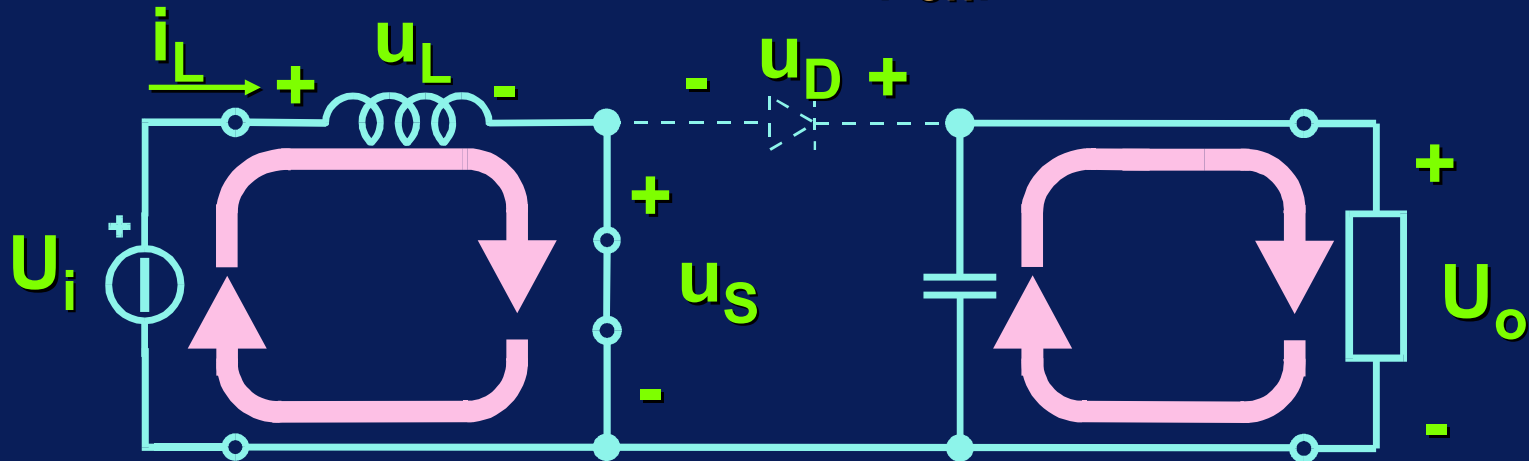


$$u_L = U_i$$

$$u_D = U_o$$

Analisi del funzionamento continuo (CCM)

Tempo di chiusura di S (t_{on}) S on - D off



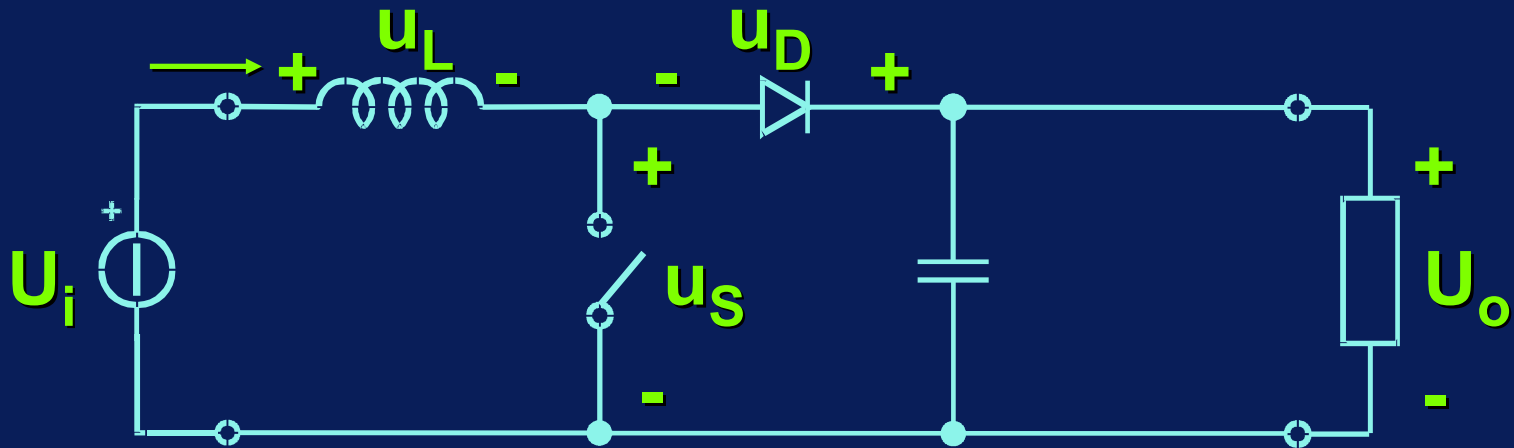
$$u_L = U_i$$

$$u_D = U_o$$

Durante questa fase viene trasferita energia dall'alimentazione all'induttanza

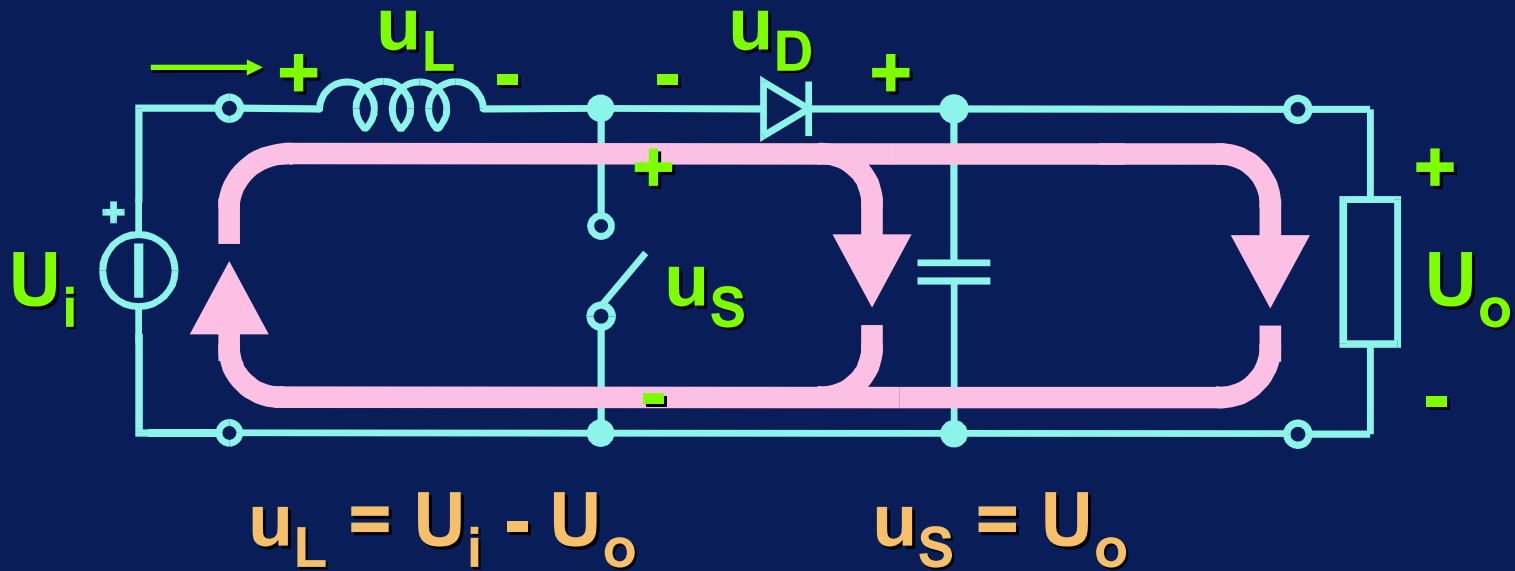
Analisi del funzionamento continuo (CCM)

Tempo di apertura di S (t_{off}) S off - D on



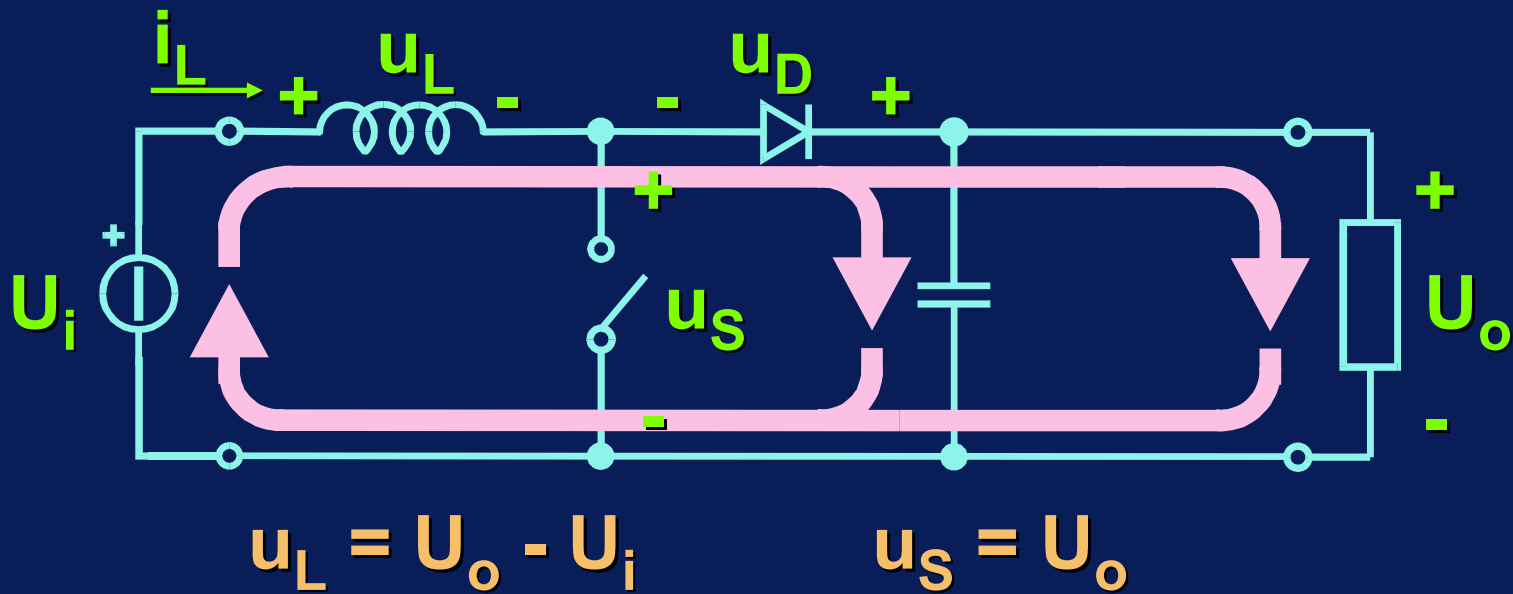
Analisi del funzionamento continuo (CCM)

Tempo di apertura di S (t_{off}) S off - D on



Analisi del funzionamento continuo (CCM)

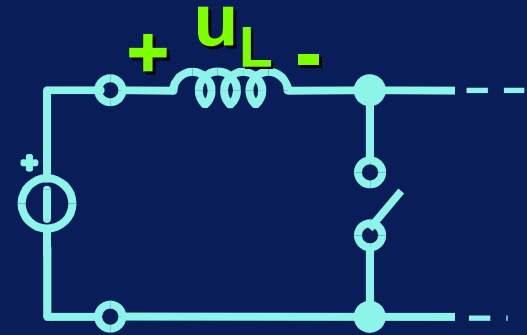
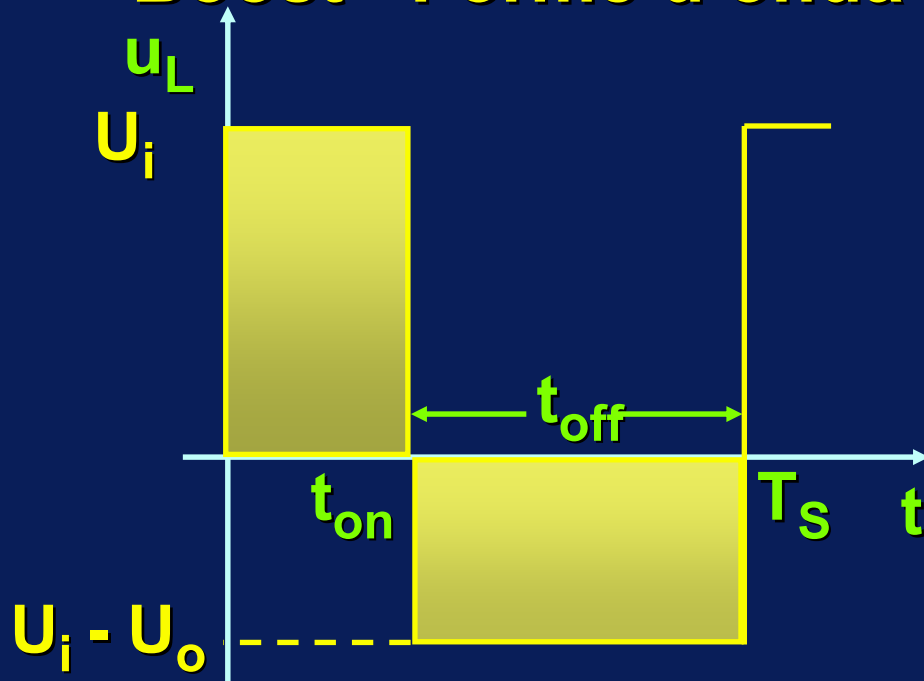
Tempo di apertura di S (t_{off}) S off - D on



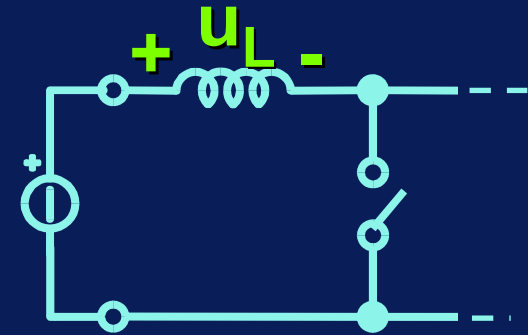
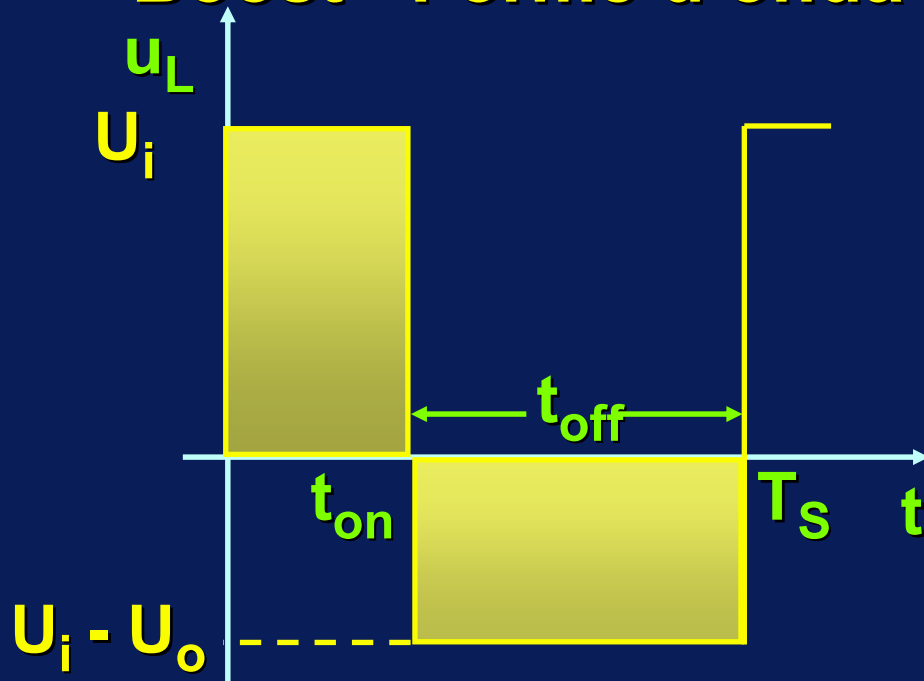
Durante questa fase la sorgente e l'induttanza forniscono energia allo stadio di uscita

Boost - Forme d'onda in CCM: u_L

Boost - Forme d'onda in CCM: u_L

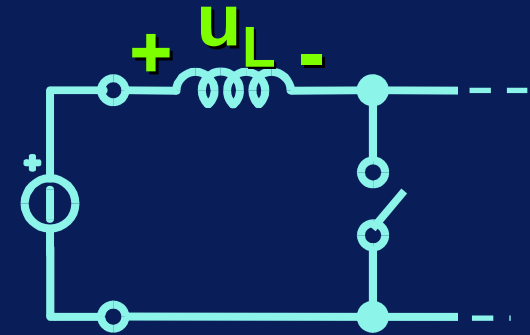
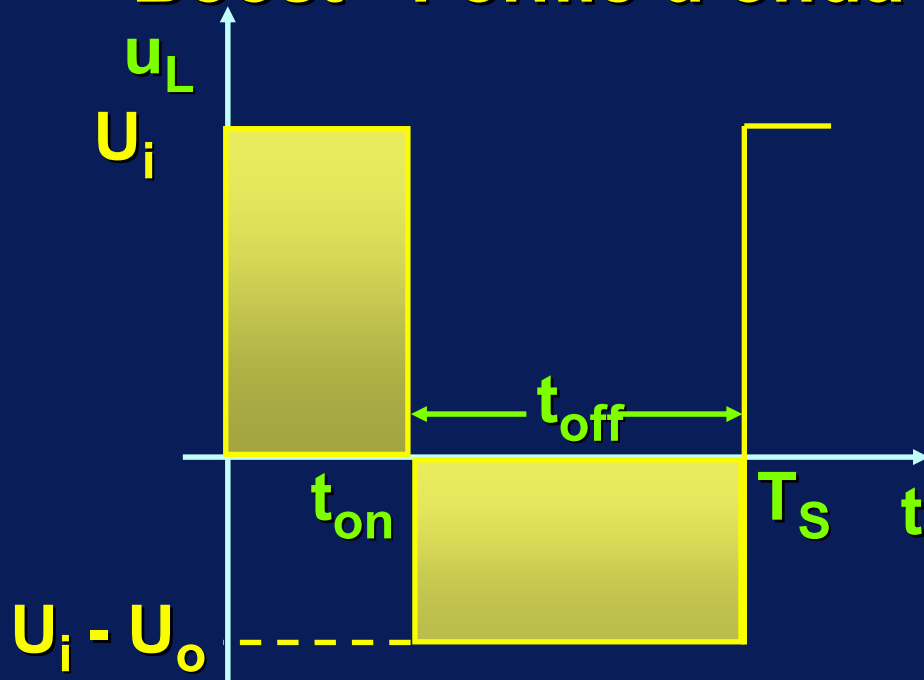


Boost - Forme d'onda in CCM: u_L



$$U_i \cdot t_{on} = (U_o - U_i) \cdot t_{off}$$

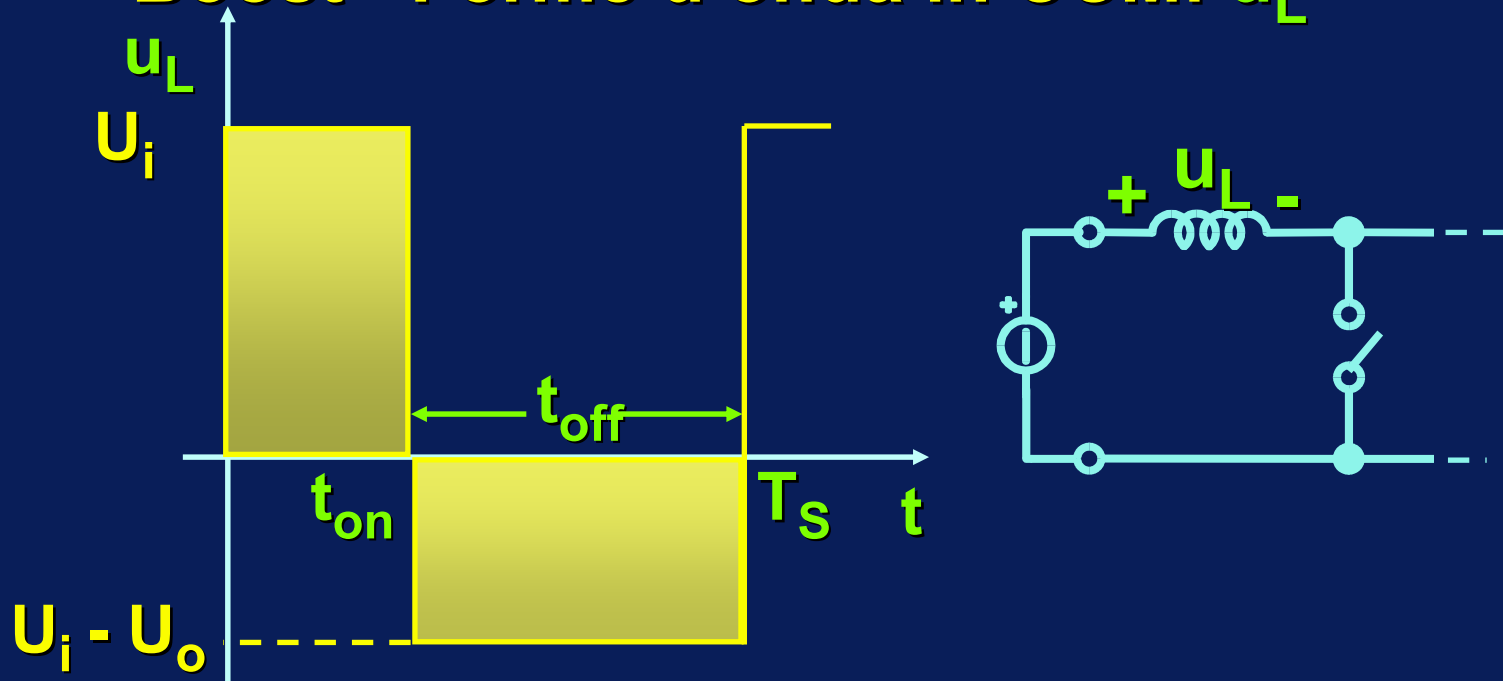
Boost - Forme d'onda in CCM: u_L



$$U_i \cdot t_{on} = (U_o - U_i) \cdot t_{off}$$

$$U_i \cdot T_s = U_o \cdot t_{off}$$

Boost - Forme d'onda in CCM: u_L

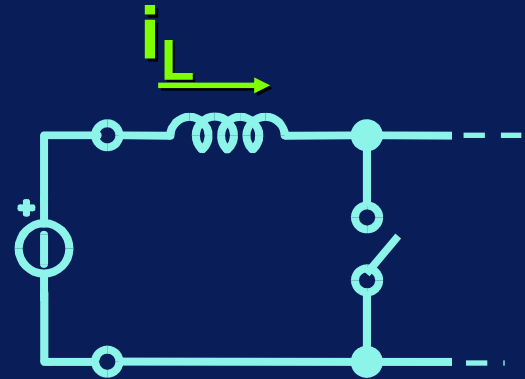
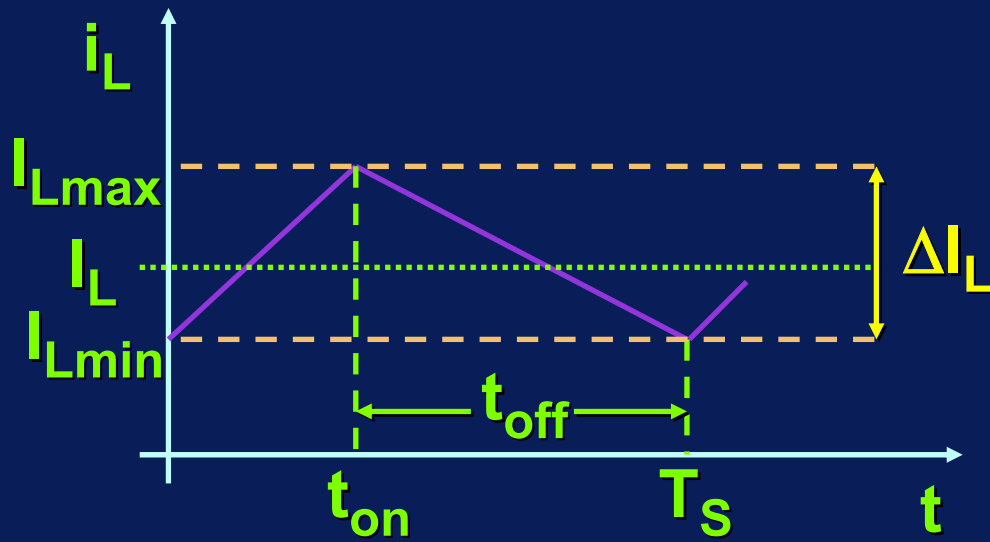


$$U_i \cdot t_{on} = (U_o - U_i) \cdot t_{off} \quad U_i \cdot T_s = U_o \cdot t_{off}$$

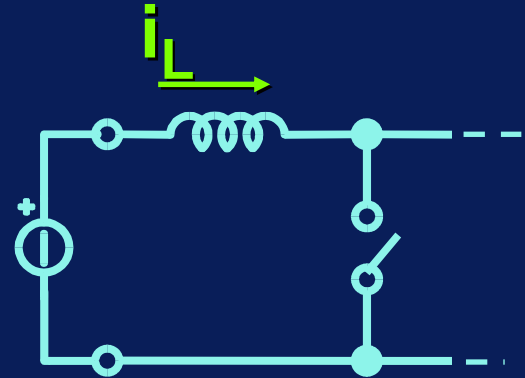
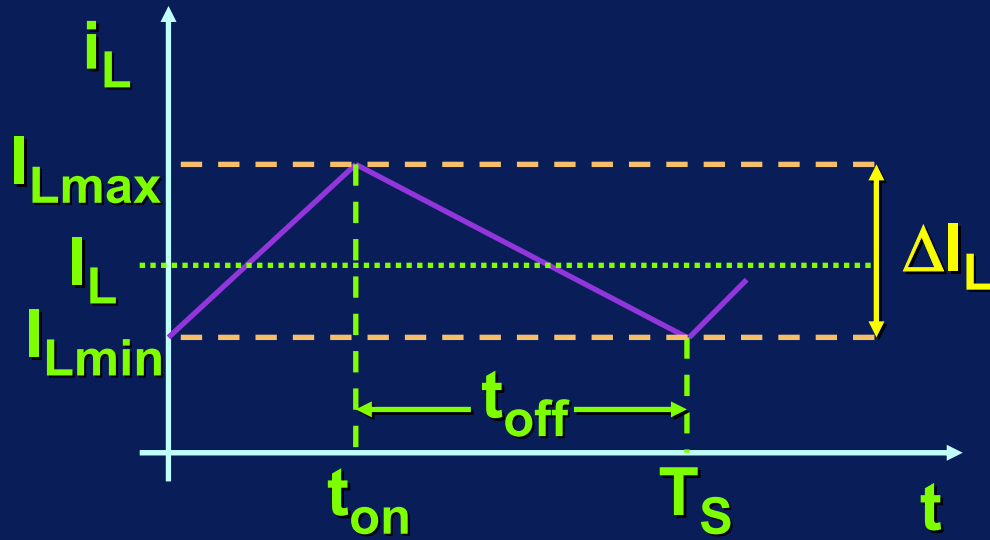
$$M = \frac{U_o}{U_i} = \frac{T_s}{t_{off}} = \frac{1}{1 - \delta} > 1$$

Boost - Forme d'onda in CCM: i_L

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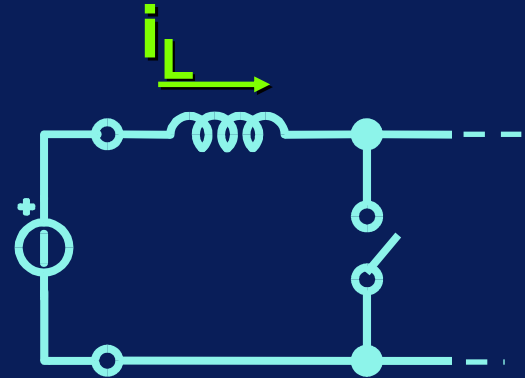
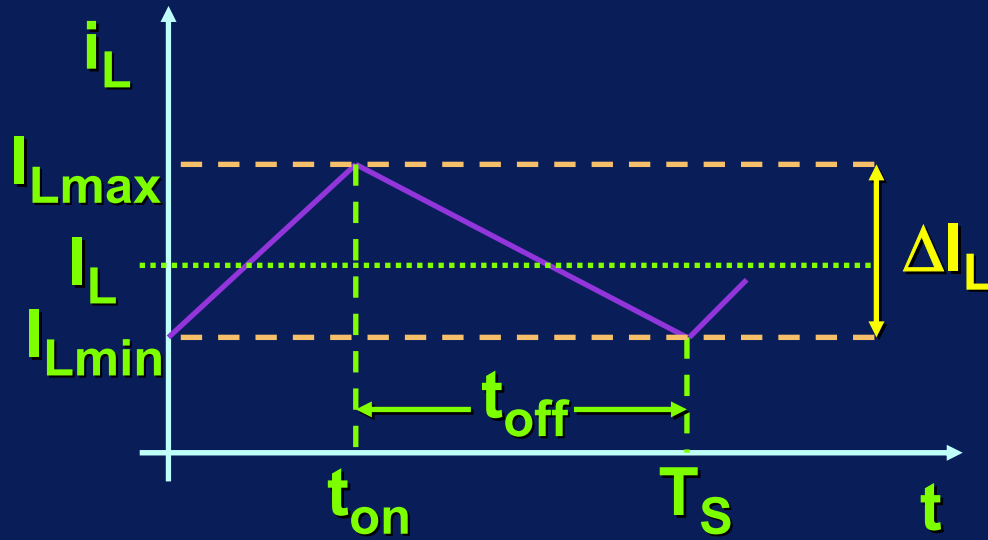


Boost - Forme d'onda in CCM: i_L



A regime:

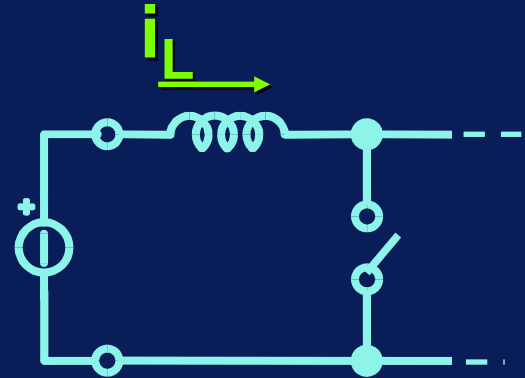
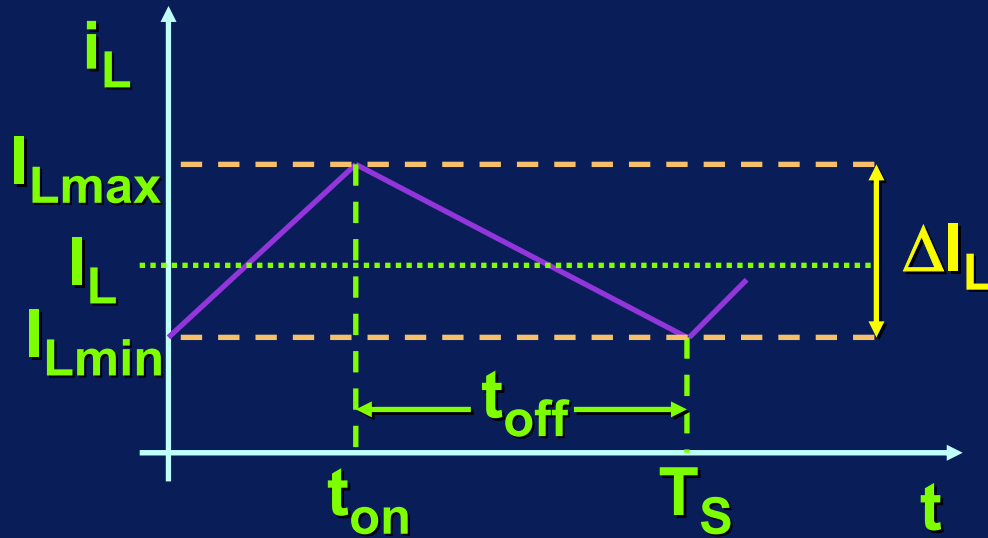
Boost - Forme d'onda in CCM: i_L



A regime:

$$\Delta I_{Lon} = \Delta I_{Loff} = \Delta I_L = \frac{U_i}{L} \cdot t_{on} = \frac{U_o - U_i}{L} \cdot t_{off}$$

Boost - Forme d'onda in CCM: i_L



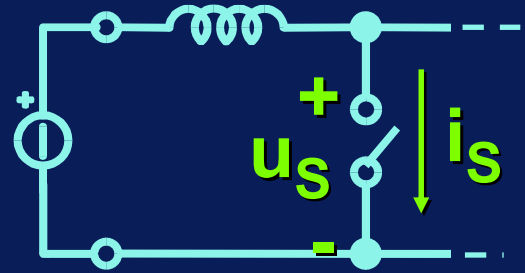
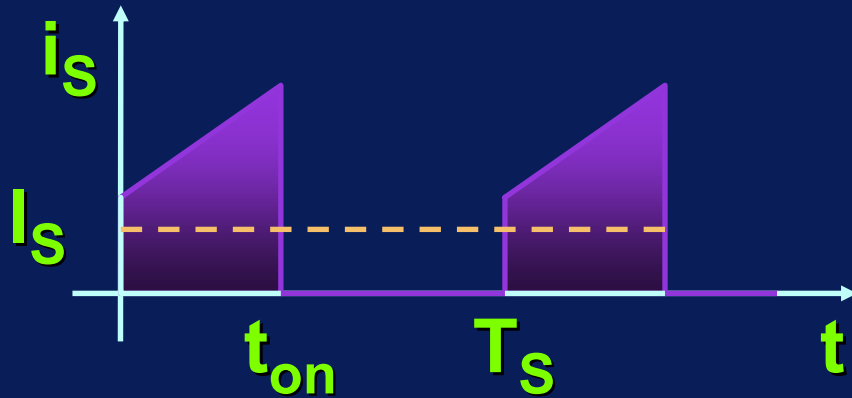
A regime:

$$\Delta I_{Lon} = \Delta I_{Loff} = \Delta I_L = \frac{U_i}{L} \cdot t_{on} = \frac{U_o - U_i}{L} \cdot t_{off}$$

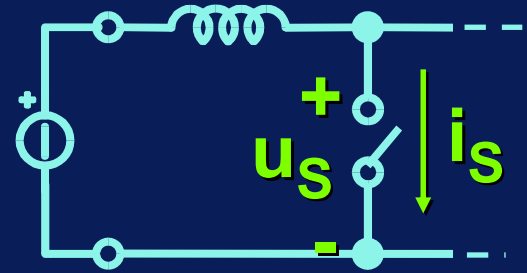
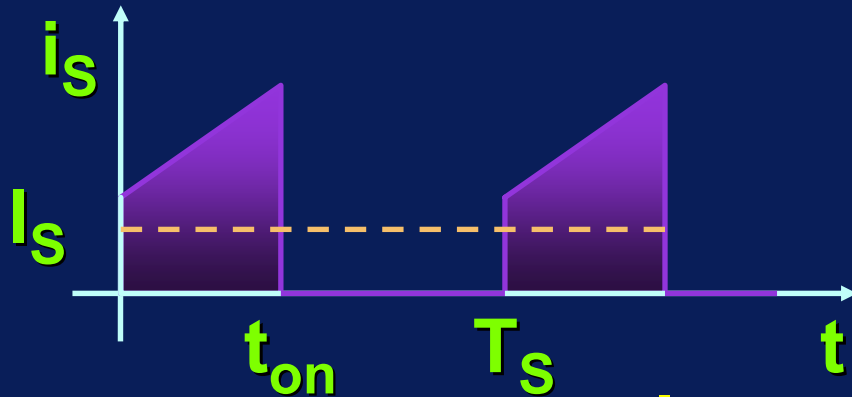
$$M = \frac{U_o}{U_i} = \frac{T_s}{t_{off}} = \frac{1}{1 - \delta} > 1$$

Boost - Forme d'onda in CCM: i_s , u_s

Boost - Forme d'onde in CCM: i_s , u_s

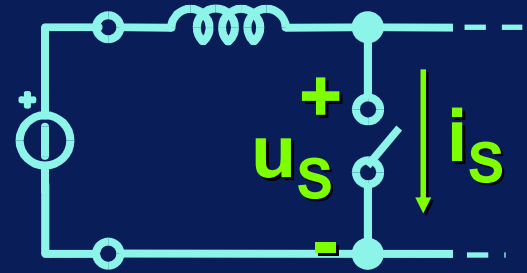
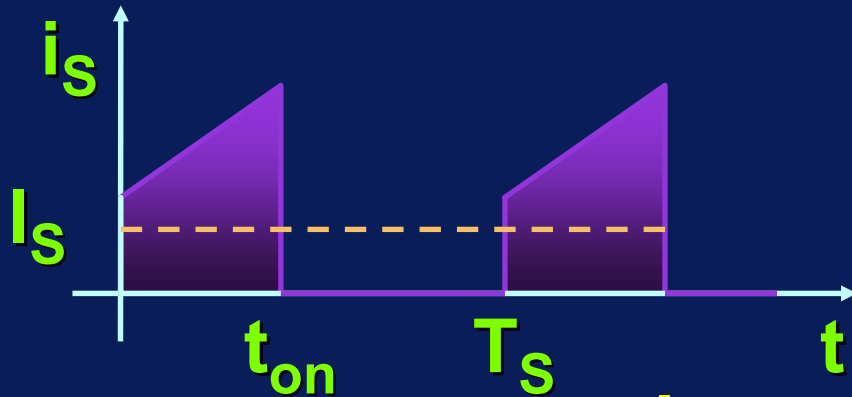


Boost - Forme d'onda in CCM: i_s , u_s

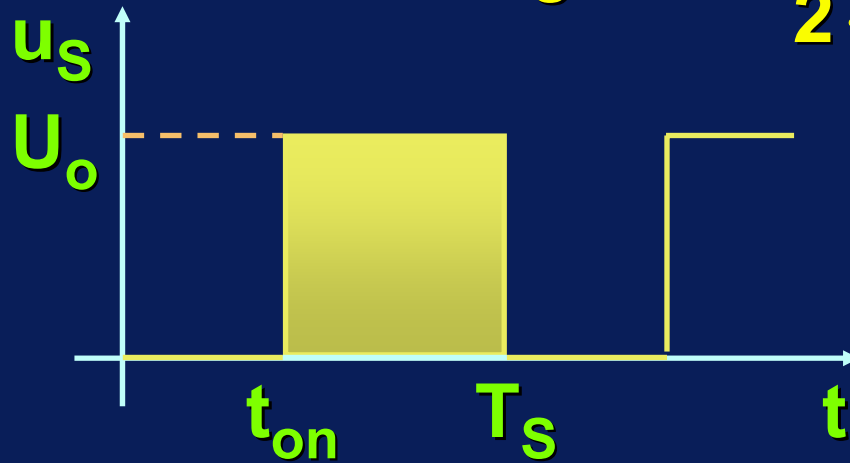


$$I_s = \frac{I_{Lmin} + I_{Lmax}}{2 \cdot T_s} \cdot t_{on} = I_L \cdot \delta$$

Boost - Forme d'onda in CCM: i_s, u_s



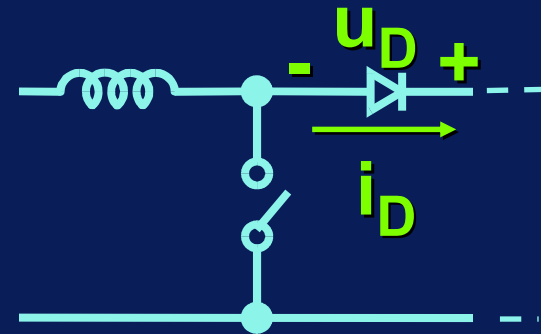
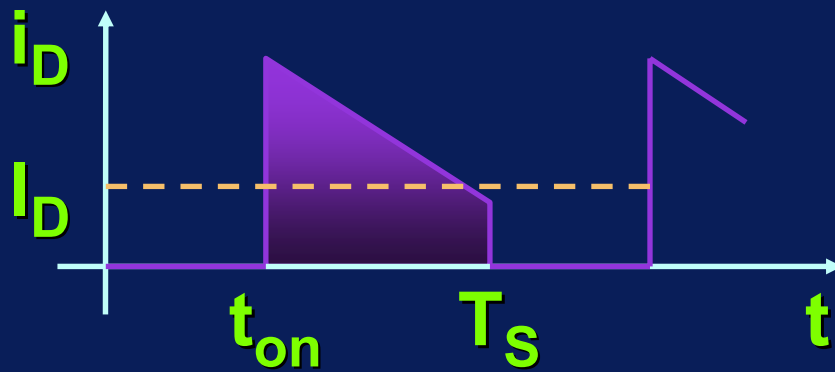
$$I_s = \frac{I_{Lmin} + I_{Lmax}}{2 \cdot T_s} \cdot t_{on} = I_L \cdot \delta$$



$$U_{Smax} = U_o$$

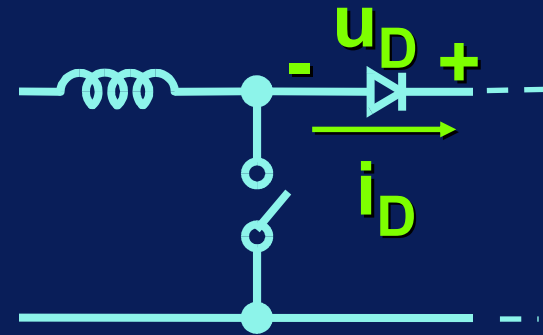
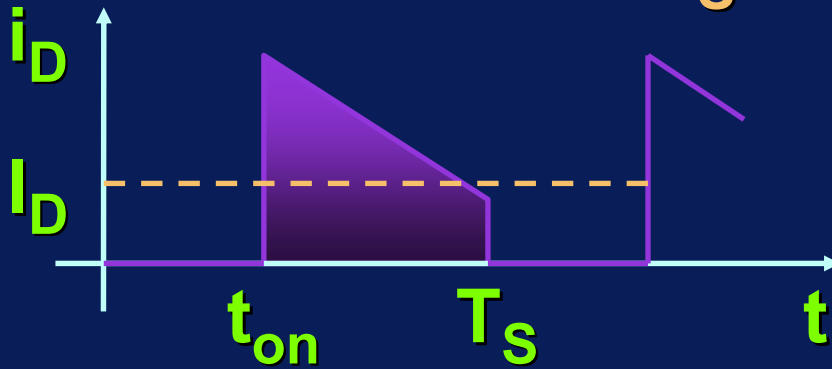
Boost - Forme d'onda in CCM: i_D , u_D

Boost - Forme d'onda in CCM: i_D , u_D



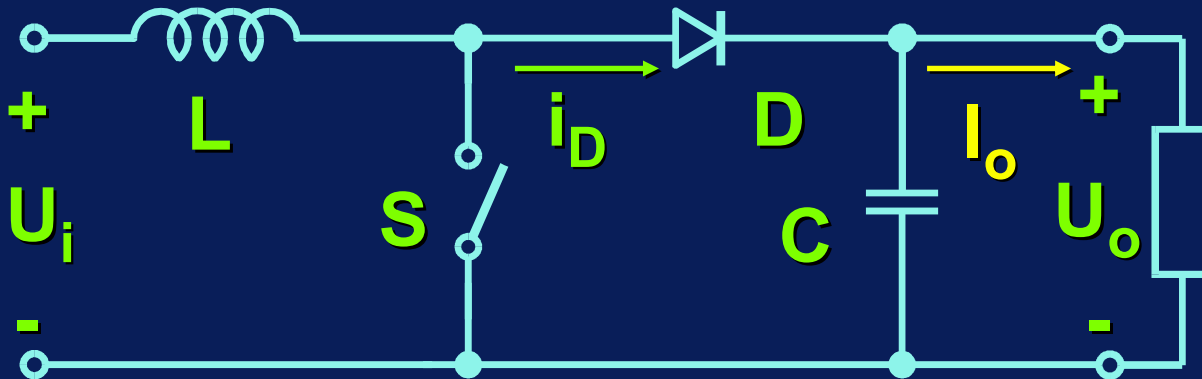
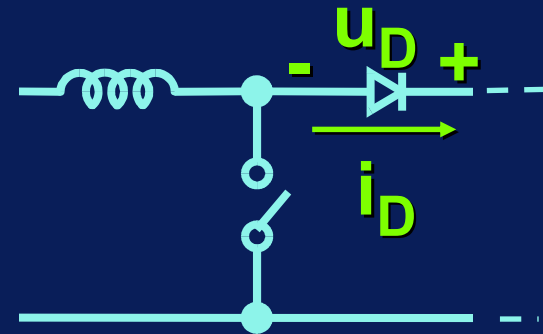
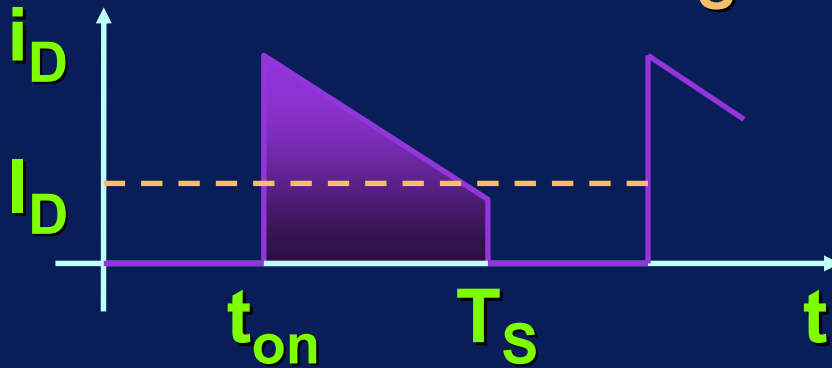
Boost - Forme d'onda in CCM: i_D , u_D

$$I_D = \frac{I_{Lmin} + I_{Lmax}}{2 \cdot T_S} \cdot t_{off} = I_L \cdot (1 - \delta)$$



Boost - Forme d'onda in CCM: i_D , u_D

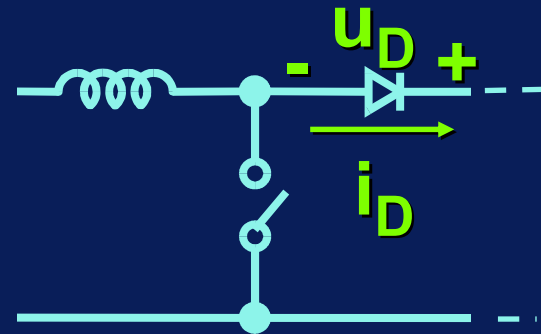
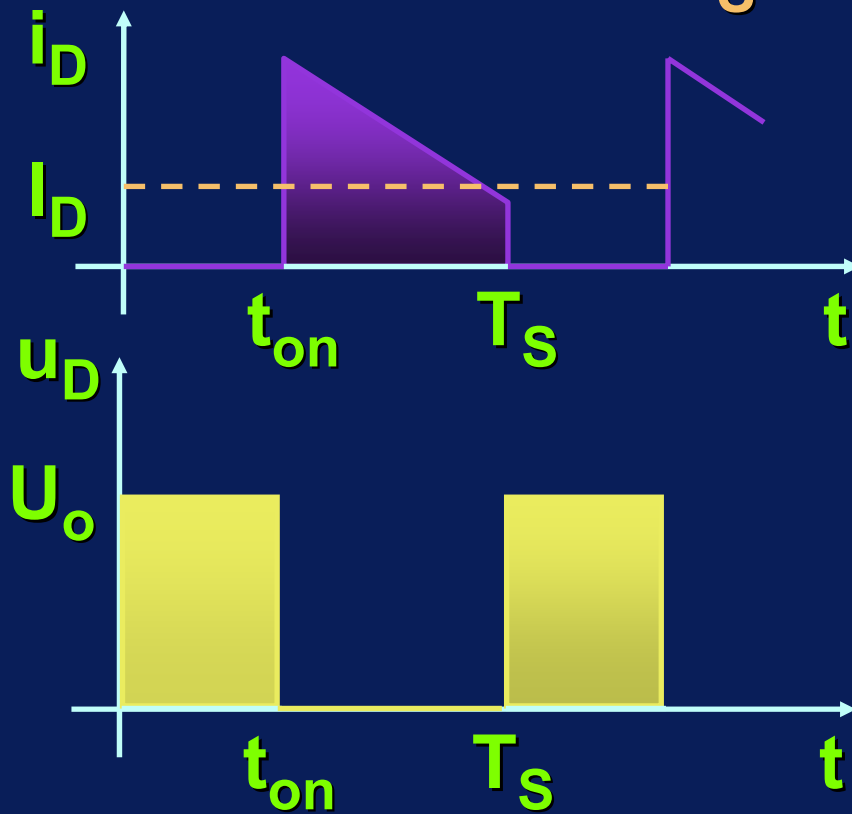
$$I_D = \frac{I_{Lmin} + I_{Lmax}}{2 \cdot T_S} \cdot t_{off} = I_L \cdot (1 - \delta)$$



$$I_D = I_o$$

Boost - Forme d'onda in CCM: i_D , u_D

$$I_D = \frac{I_{Lmin} + I_{Lmax}}{2 \cdot T_S} \cdot t_{off} = I_L \cdot (1 - \delta)$$



$$I_D = I_o$$

$$U_{Dmax} = U_o$$

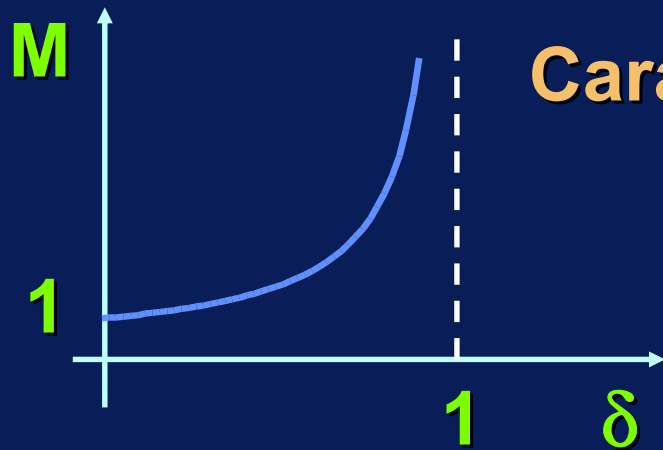
Convertitore boost in CCM

Convertitore boost in CCM

Caratteristica di controllo

$$M = \frac{U_o}{U_i} = \frac{1}{1 - \delta}$$

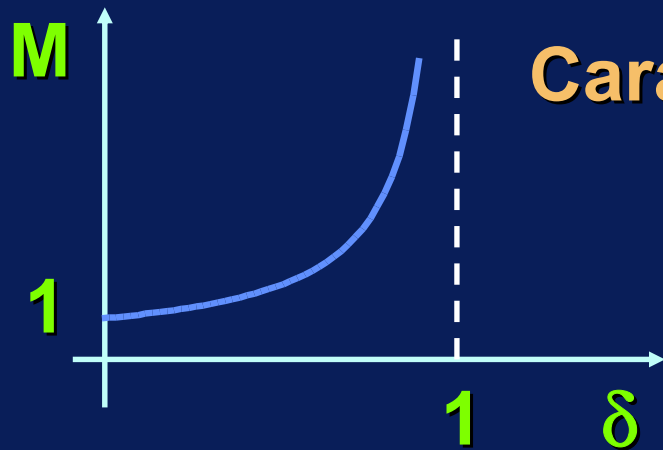
Convertitore boost in CCM



Caratteristica di controllo

$$M = \frac{U_o}{U_i} = \frac{1}{1 - \delta}$$

Convertitore boost in CCM



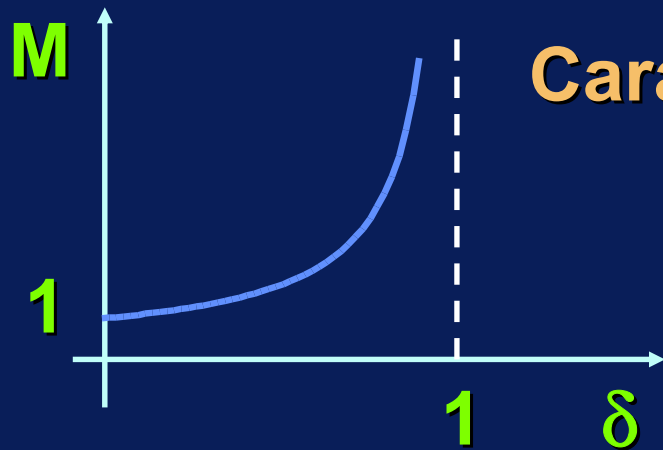
Caratteristica di controllo

$$M = \frac{U_o}{U_i} = \frac{1}{1 - \delta}$$

Ondulazione di corrente

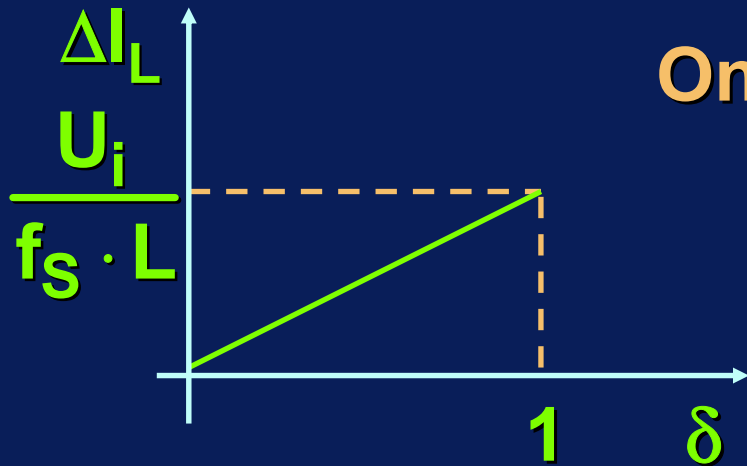
$$\Delta I_L = \frac{U_i}{L} \cdot t_{on} = \frac{U_i \cdot \delta}{f_s \cdot L}$$

Convertitore boost in CCM



Caratteristica di controllo

$$M = \frac{U_o}{U_i} = \frac{1}{1 - \delta}$$



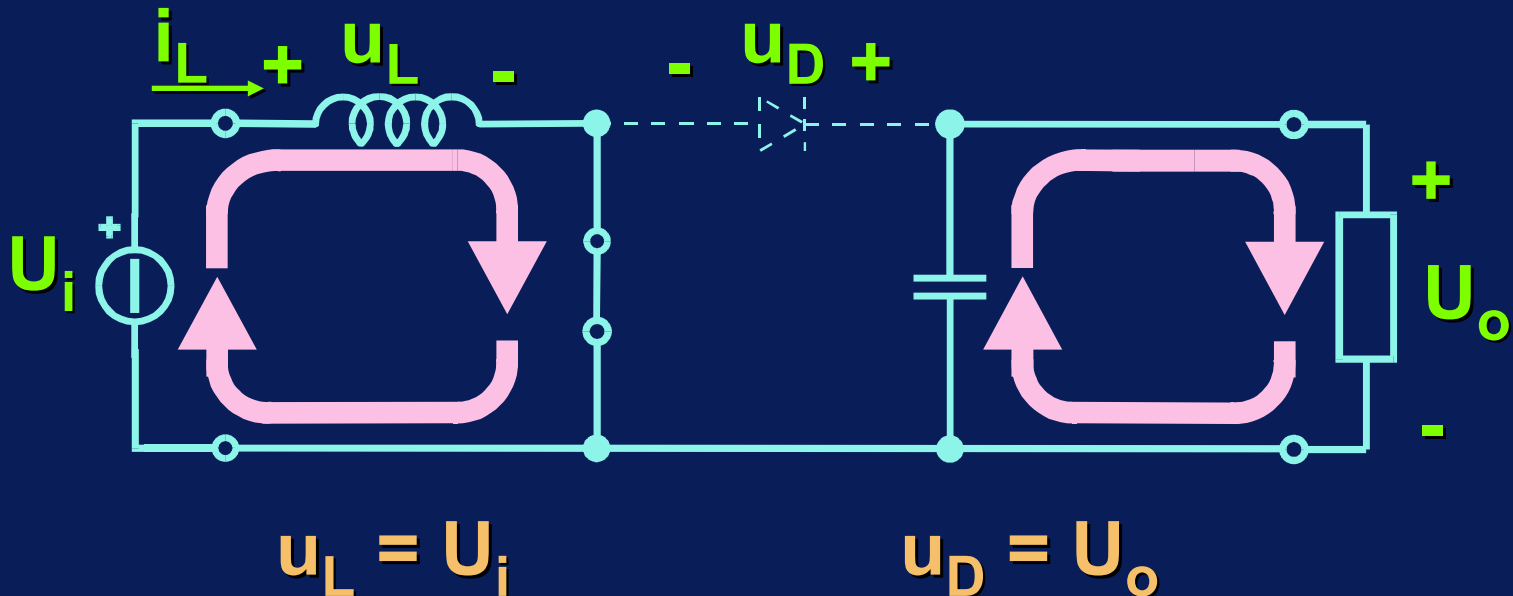
Ondulazione di corrente

$$\Delta I_L = \frac{U_i}{L} \cdot t_{on} = \frac{U_i \cdot \delta}{f_s \cdot L}$$

Analisi del funzionamento discontinuo (DCM)

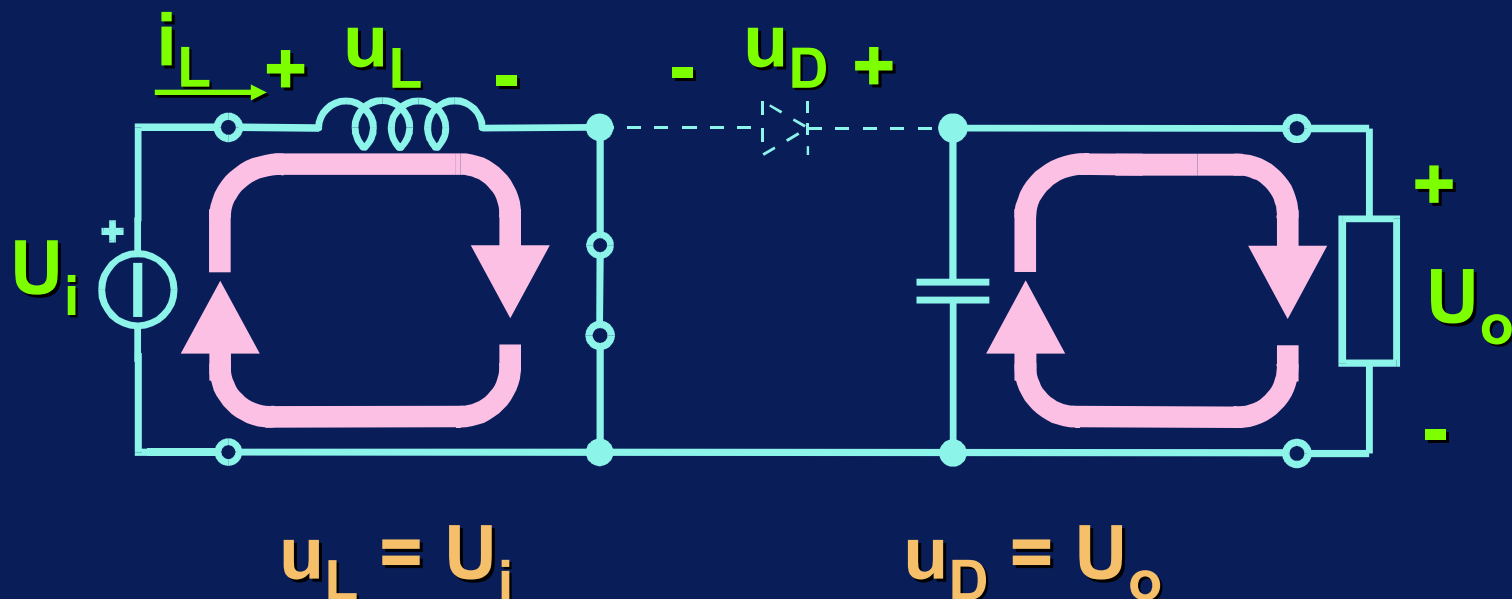
Analisi del funzionamento discontinuo (DCM)

Tempo di chiusura di S (t_{on}) **S on - D off**



Analisi del funzionamento discontinuo (DCM)

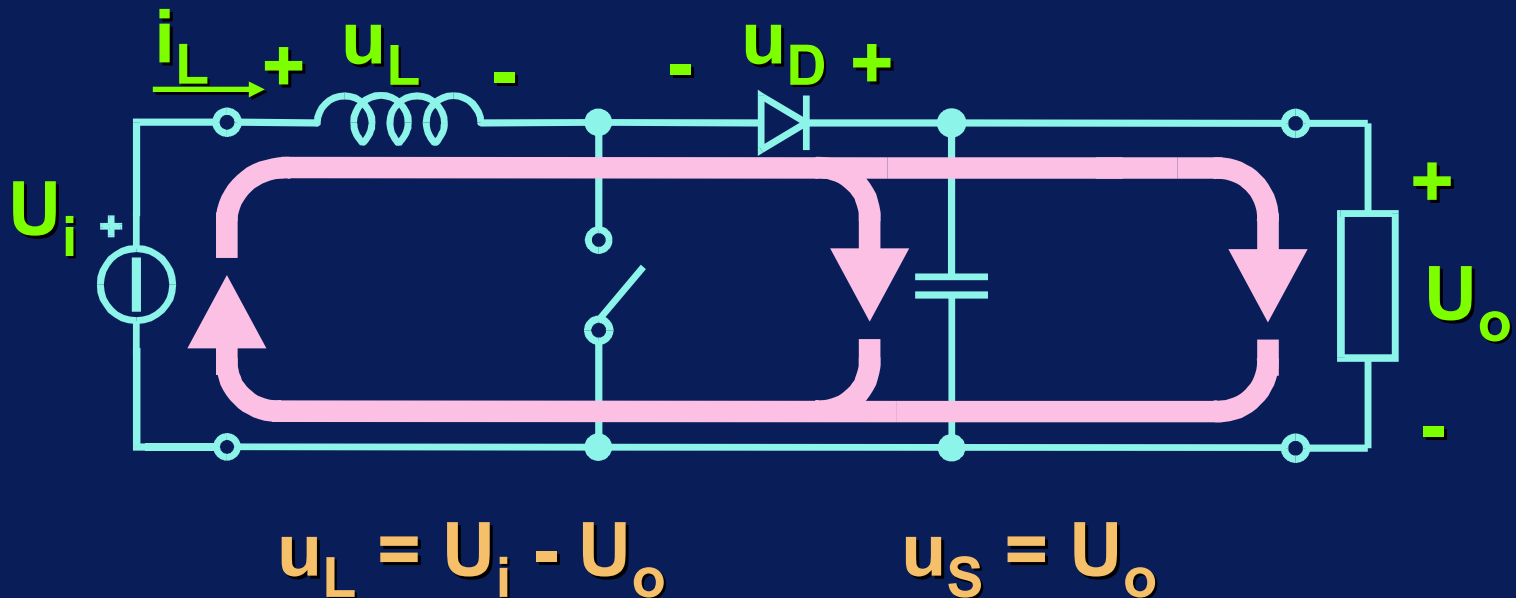
Tempo di chiusura di S (t_{on}) S on - D off



A differenza del funzionamento CCM la corrente i_L inizia con valore nullo.

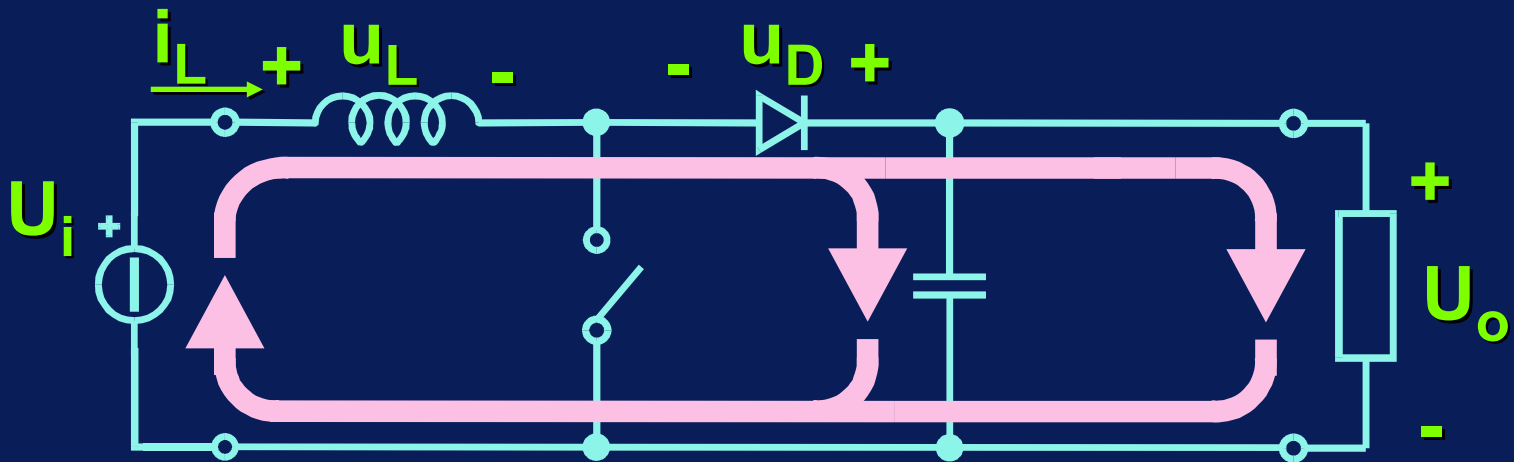
Analisi del funzionamento discontinuo (DCM)

Tempo di apertura di S (t'_{off}) S off - D on



Analisi del funzionamento discontinuo (DCM)

Tempo di apertura di S (t'_{off}) S off - D on



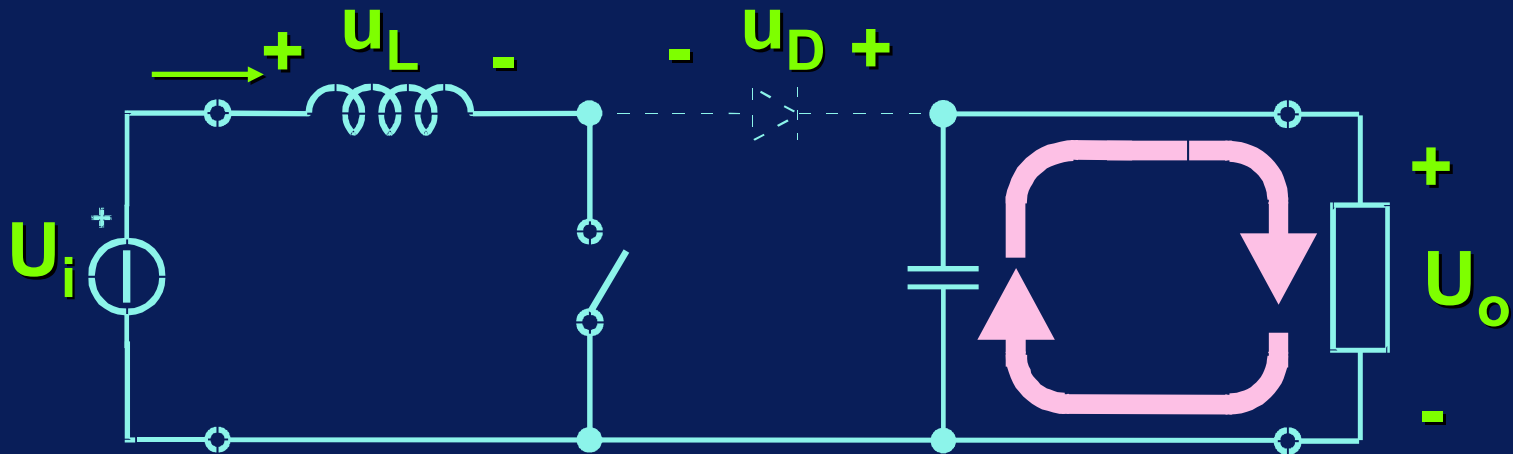
$$u_L = U_i - U_o$$

$$u_S = U_o$$

Alla fine di questa fase la corrente dell'induttanza si annulla

Analisi del funzionamento discontinuo (DCM)

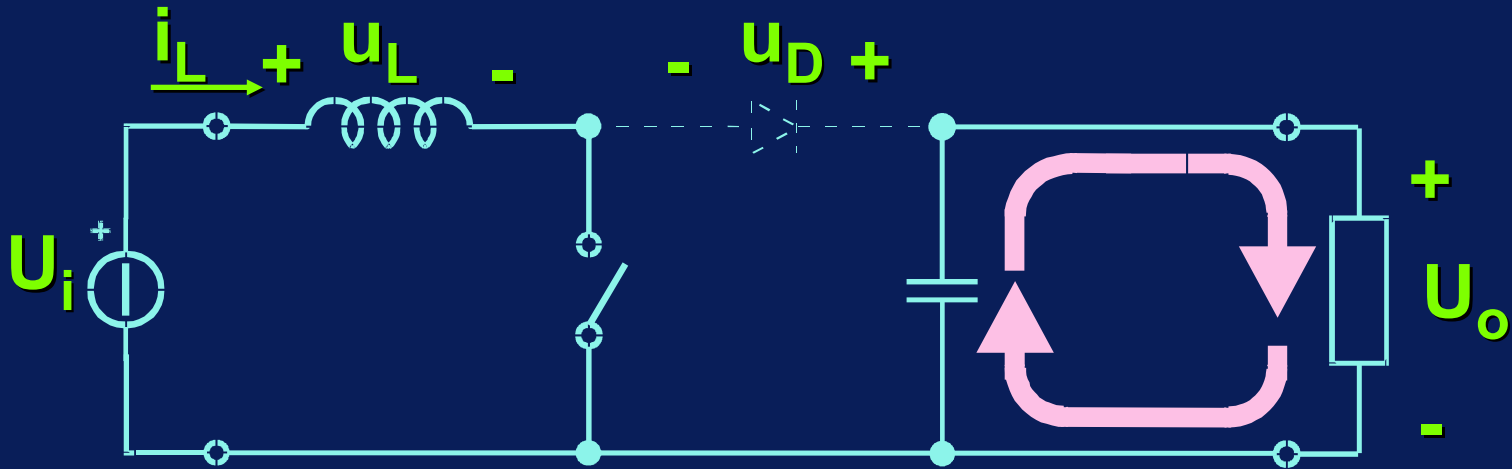
Tempo di apertura di S (t''_{off}) S off - D off



$$u_D = U_o - U_i > 0 \quad u_S = U_i$$

Analisi del funzionamento discontinuo (DCM)

Tempo di apertura di S (t''_{off}) S off - D off

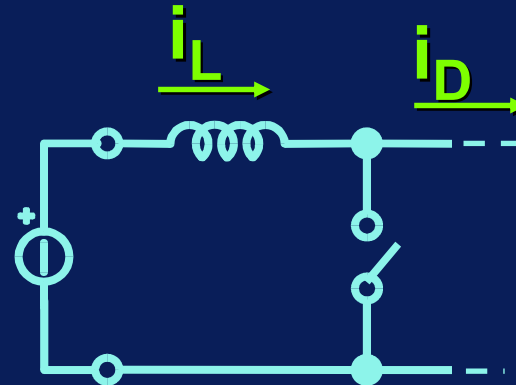
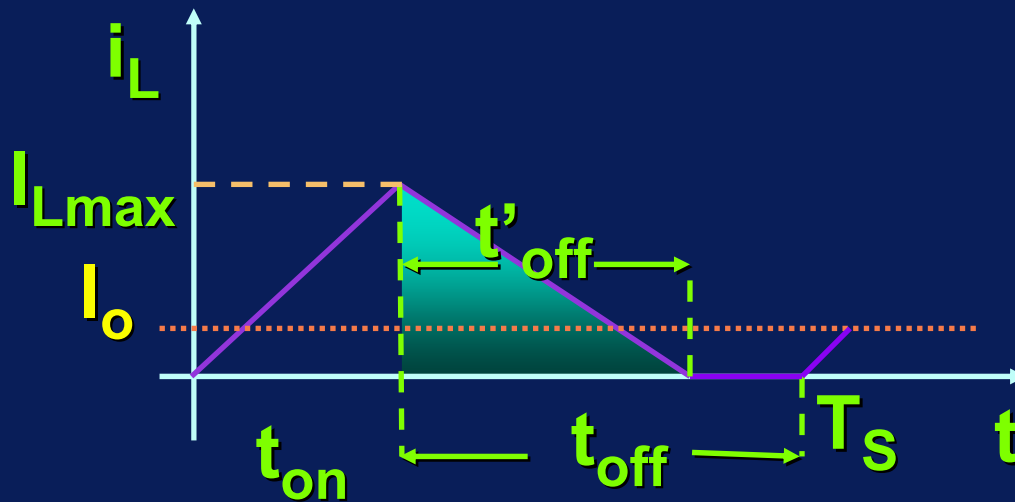


$$u_D = U_o - U_i > 0 \quad u_S = U_i$$

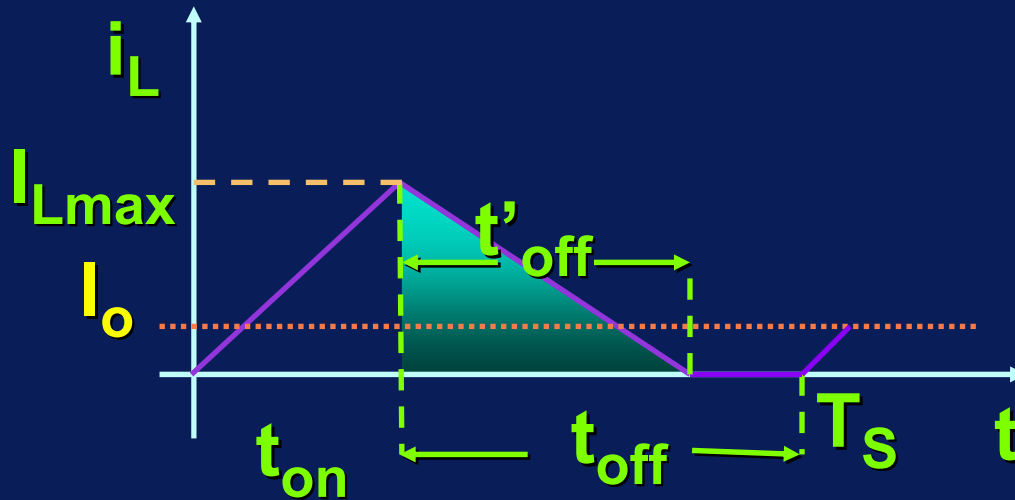
Durante questa fase il solo condensatore
fornisce energia al carico

Boost - Forme d'onda in DCM: i_L

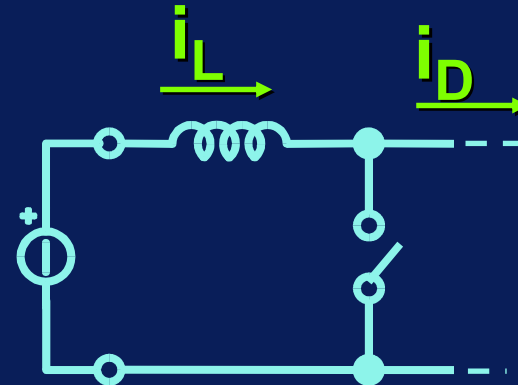
Boost - Forme d'onda in DCM: i_L



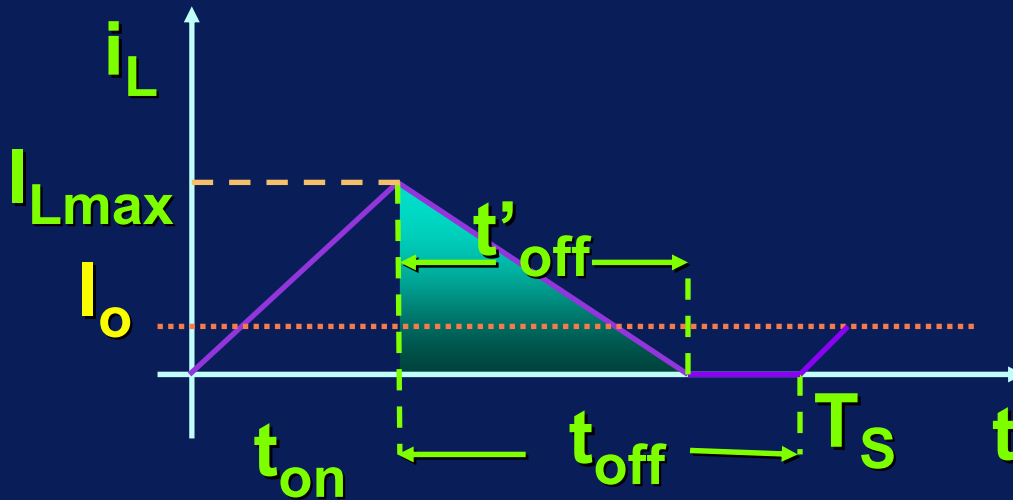
Boost - Forme d'onda in DCM: i_L



$$I_{Lmax} = \frac{U_i}{L} \cdot t_{on}$$

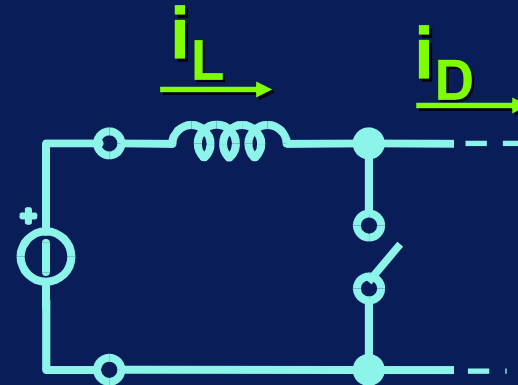


Boost - Forme d'onda in DCM: i_L



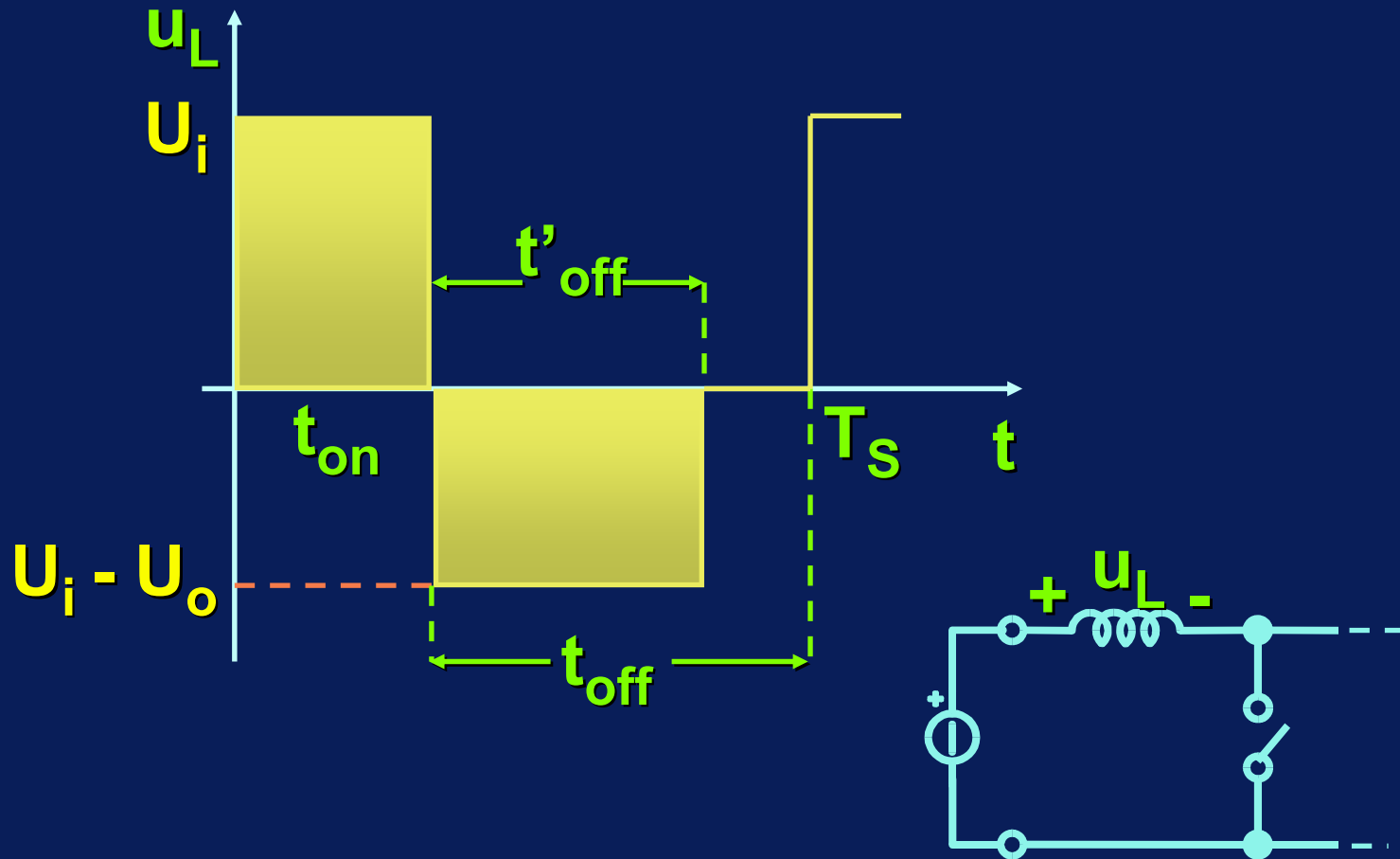
$$I_{Lmax} = \frac{U_i}{L} \cdot t_{on}$$

$$I_o = I_D = \frac{I_{Lmax} \cdot t'_{off}}{2 \cdot T_s}$$

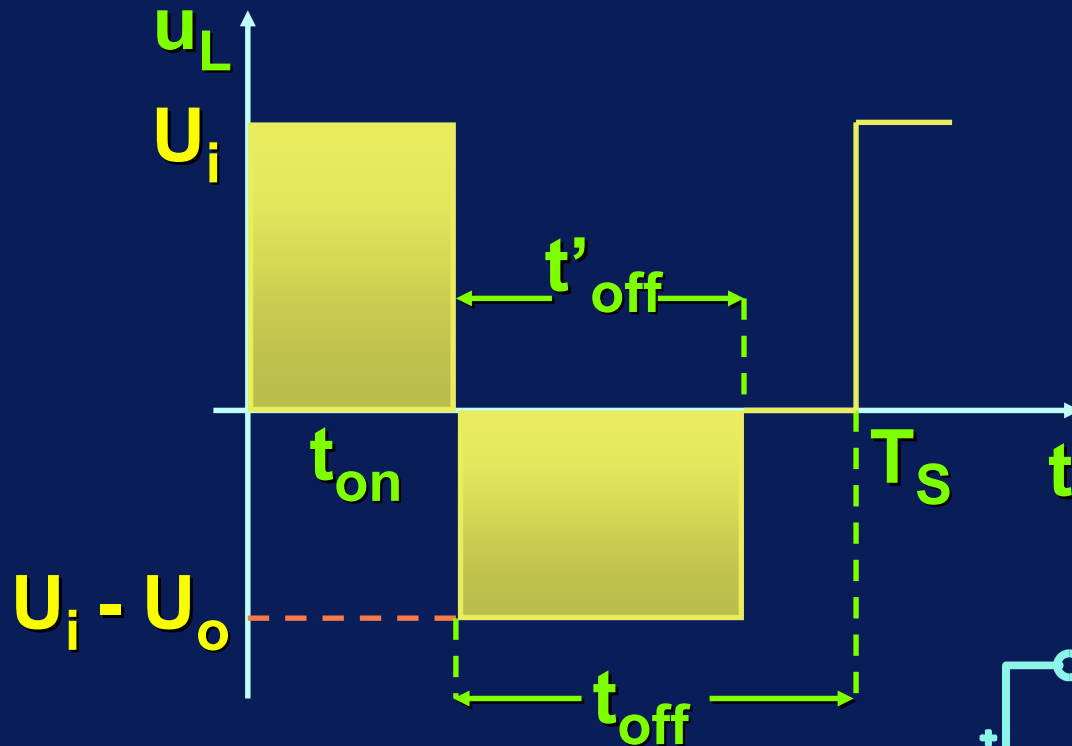


Boost - Forme d'onda in DCM: u_L

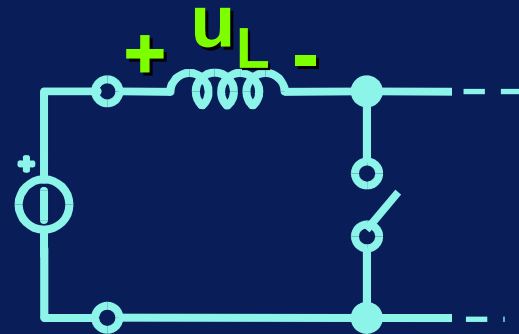
Boost - Forme d'onda in DCM: u_L



Boost - Forme d'onda in DCM: u_L



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



Boost: Caratteristica di controllo in DCM

Boost: Caratteristica di controllo in DCM

$$I_o = \frac{I_{L\max} \cdot t'_{\text{off}}}{2 \cdot T_s}; \quad I_{L\max} = \frac{U_i}{L} \cdot t_{\text{on}};$$

$$t'_{\text{off}} = \frac{U_i}{U_o - U_i} \cdot t_{\text{on}}$$

Boost: Caratteristica di controllo in DCM

$$I_o = \frac{I_{L\max} \cdot t'_{\text{off}}}{2 \cdot T_S}; \quad I_{L\max} = \frac{U_i}{L} \cdot t_{\text{on}};$$

$$t'_{\text{off}} = \frac{U_i}{U_o - U_i} \cdot t_{\text{on}}$$

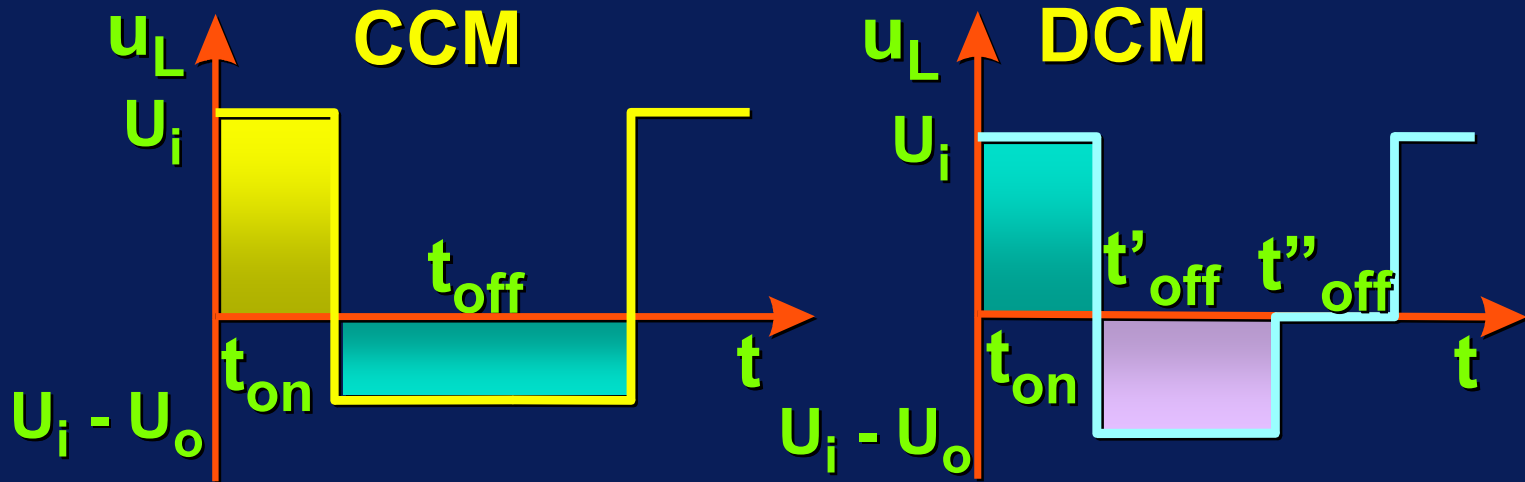


$$M = \frac{U_o}{U_i} = 1 + \delta^2 \cdot \frac{U_i}{2 \cdot f_S \cdot L \cdot I_o} = 1 + \delta^2 \cdot \frac{I_N}{I_o}$$

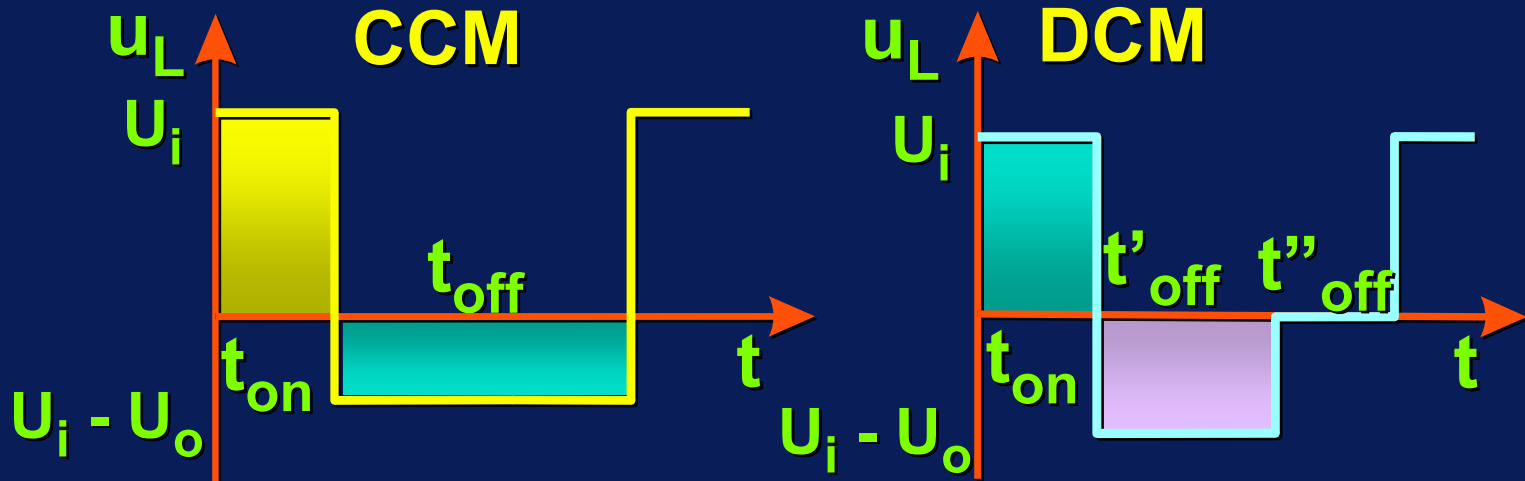
dove: $I_N = \frac{U_i}{2 \cdot f_S \cdot L}$

Nota: $U_{oDCM} > U_{oCCM}$

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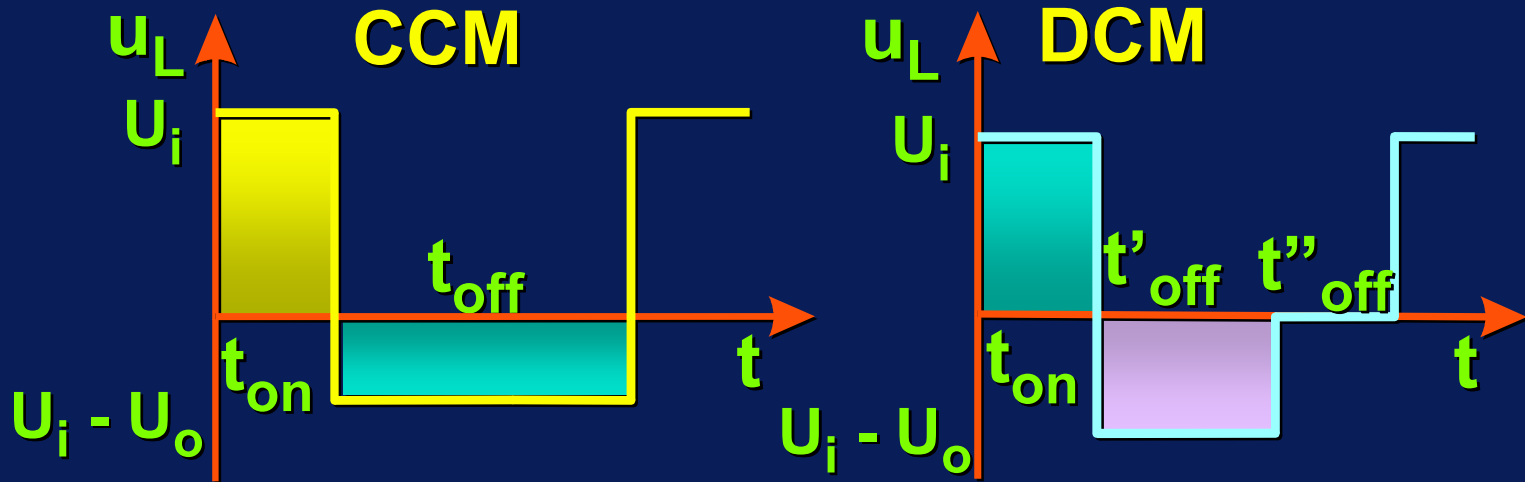


Nota: $U_{oDCM} > U_{oCCM}$



$$U_i t_{on} = (U_{oCCM} - U_i)t_{off} = (U_{oDCM} - U_i)t'_{off}$$

Nota: $U_{oDCM} > U_{oCCM}$



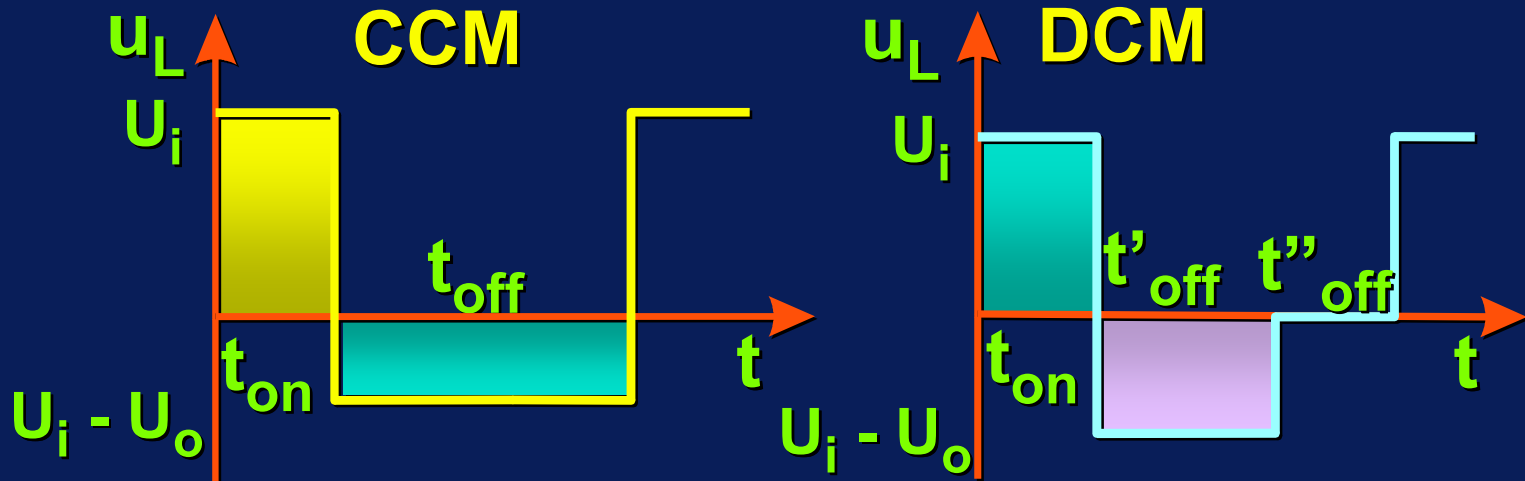
$$U_i t_{on} = (U_{oCCM} - U_i) t_{off} = (U_{oDCM} - U_i) t'_{off}$$

$$\frac{U_{oDCM} - U_i}{U_{oCCM} - U_i} = \frac{t_{off}}{t'_{off}} > 1$$



$$U_{oDCM} > U_{oCCM}$$

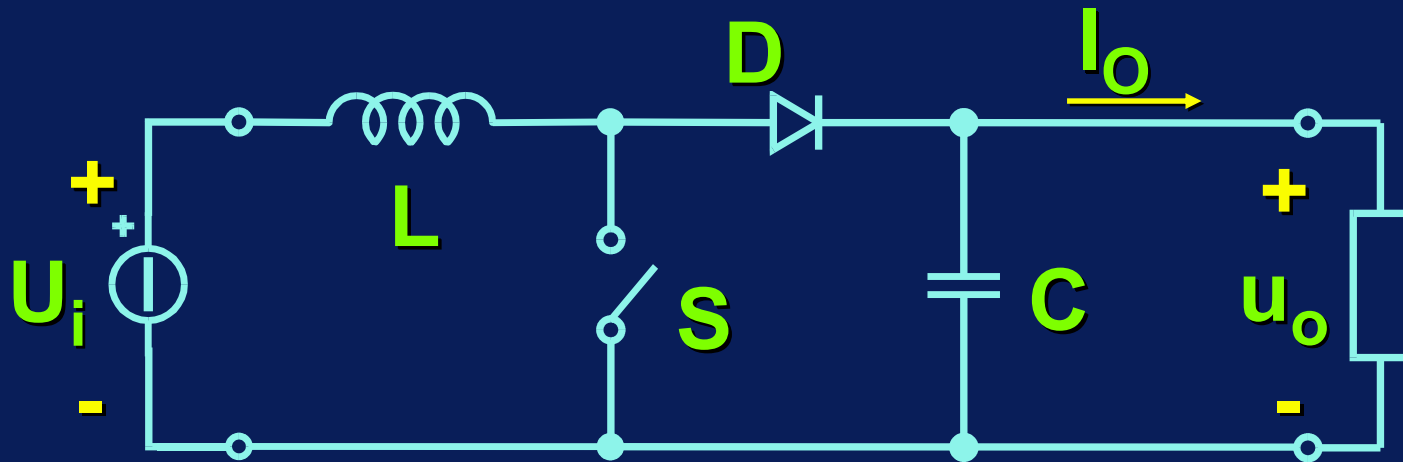
Nota: $U_{oDCM} > U_{oCCM}$



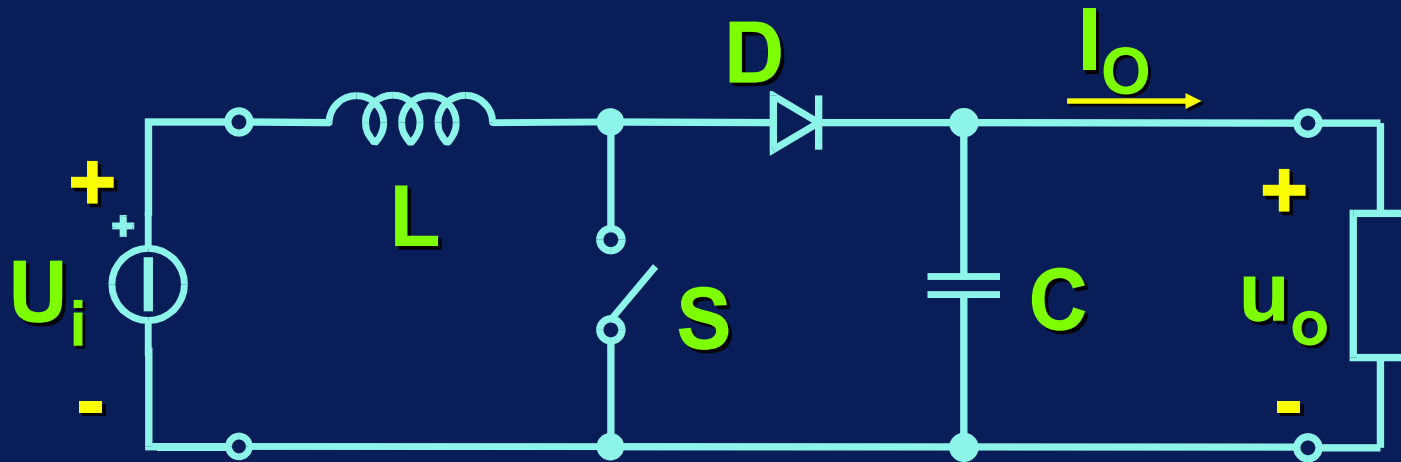
$$U_i t_{on} = (U_{oCCM} - U_i) t_{off} = (U_{oDCM} - U_i) t'_{off}$$

$$\frac{U_{oDCM}}{U_{oCCM}} = 1 + \frac{t_{on} t''_{off}}{T_s t'_{off}} > 1$$

NOTA: A vuoto ($I_o = 0$) il convertitore non è controllabile



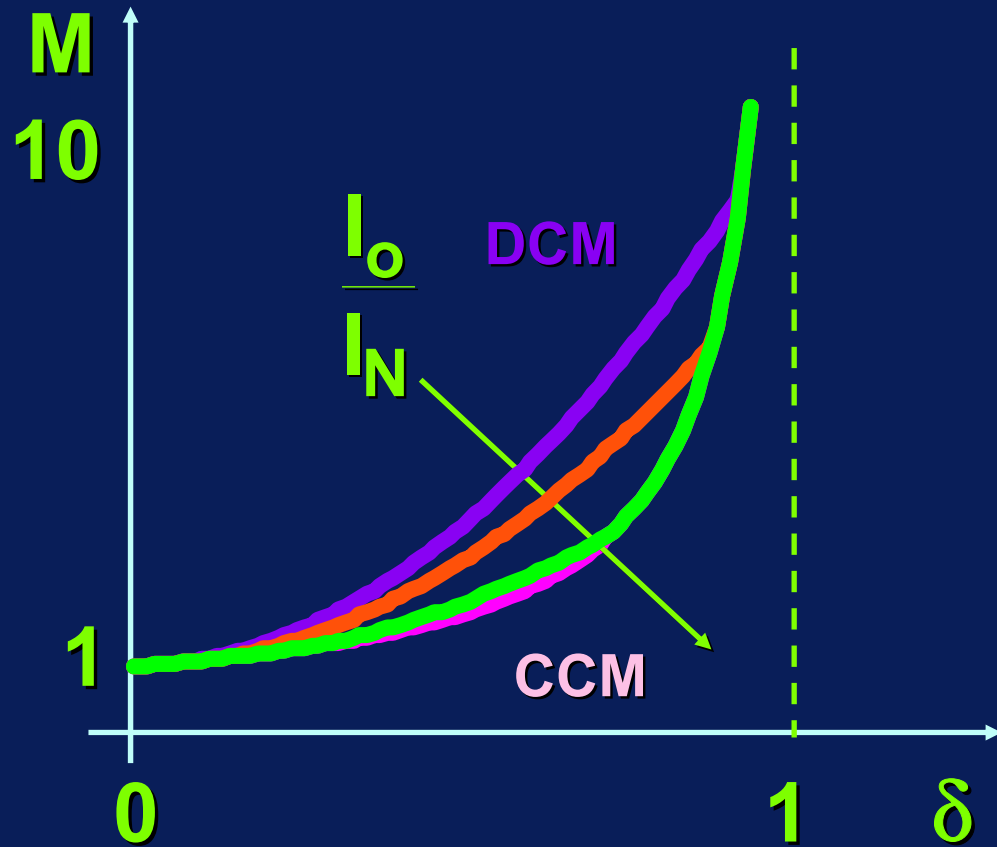
NOTA: A vuoto ($I_o = 0$) il convertitore non è controllabile



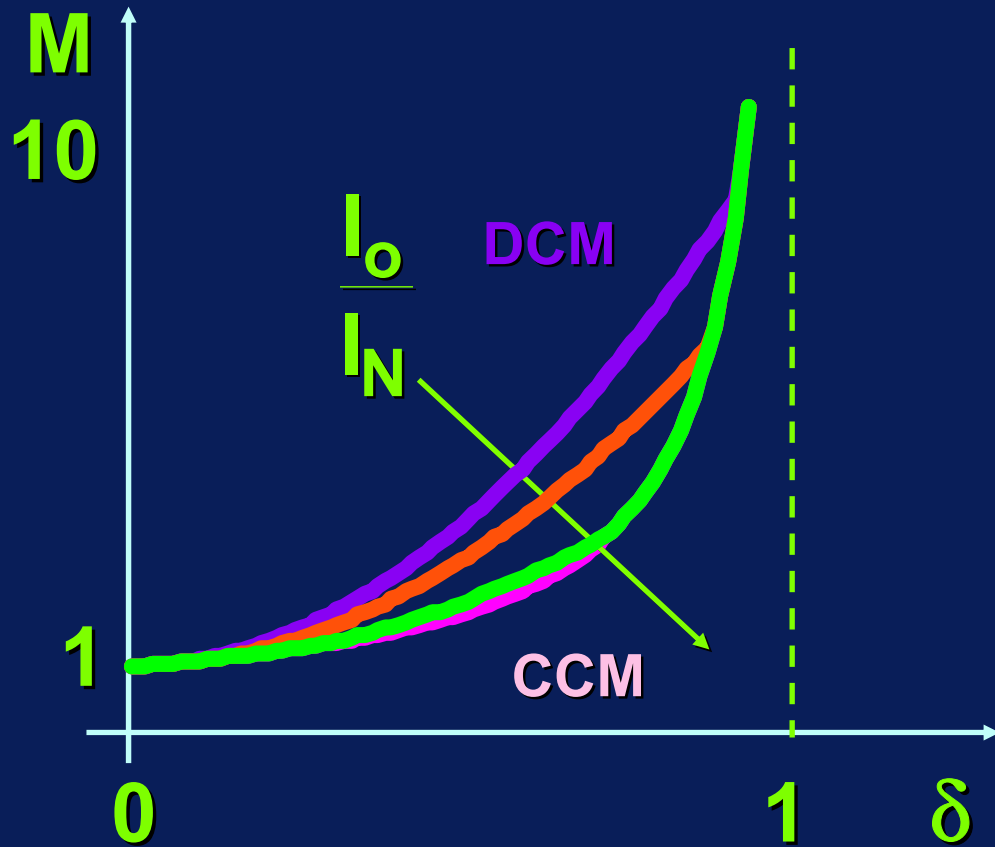
Se $I_o = 0$ non c'è assorbimento di energia dal carico. L'energia fornita dall'alimentazione si accumula progressivamente nel condensatore C , la cui tensione U_o cresce indefinitamente.

Boost: Caratteristiche di controllo

Boost: Caratteristiche di controllo

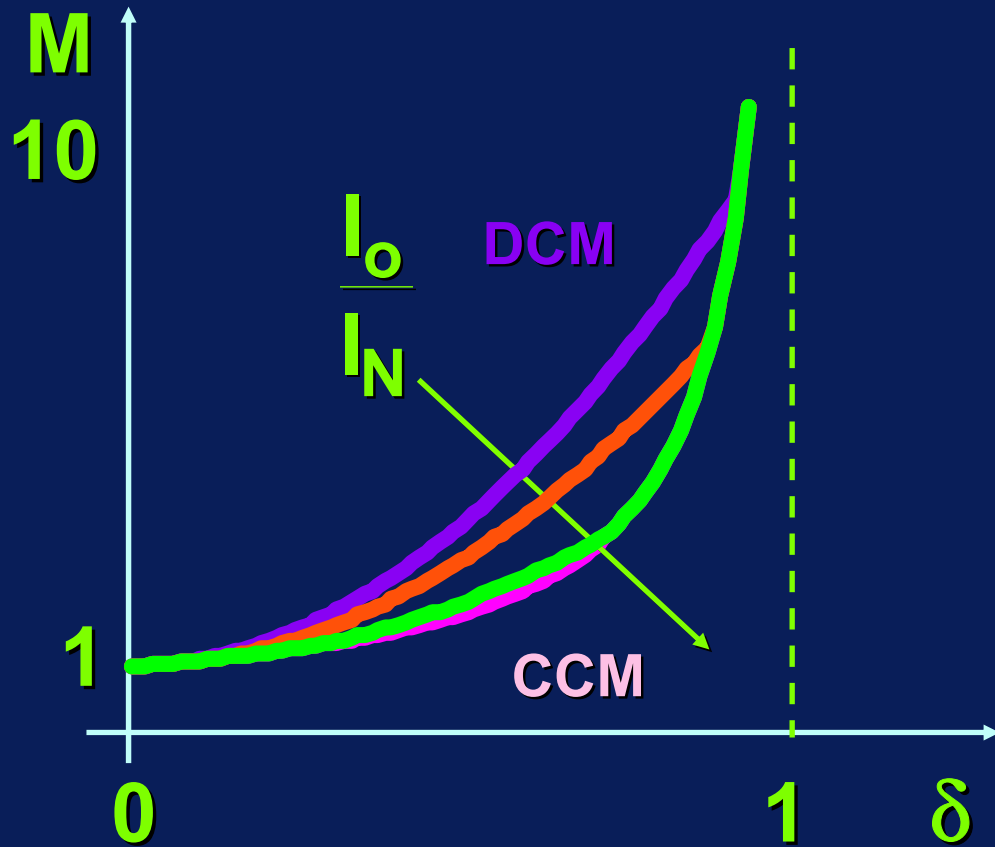


Boost: Caratteristiche di controllo



Anche in questo caso valgono le curve che danno tensione d'uscita più elevata

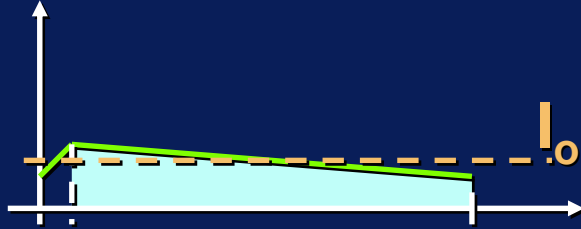
Boost: Caratteristiche di controllo



Il funzionamento è continuo per valori di δ estremi, discontinuo per valori intermedi

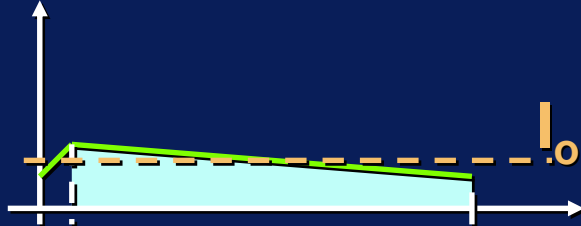
Ondulazione di corrente

Ondulazione di corrente

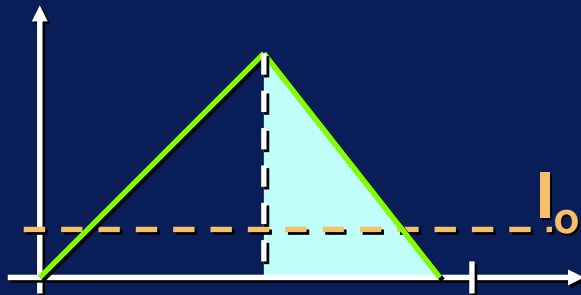


δ piccolo

Ondulazione di corrente

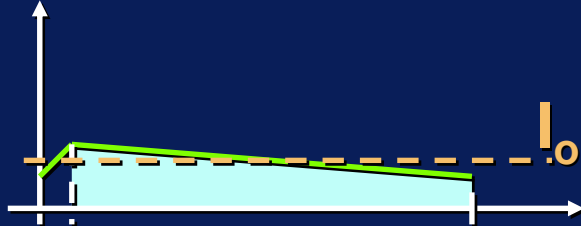


δ piccolo

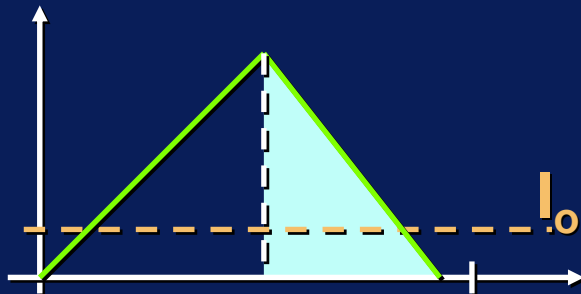


δ intermedio

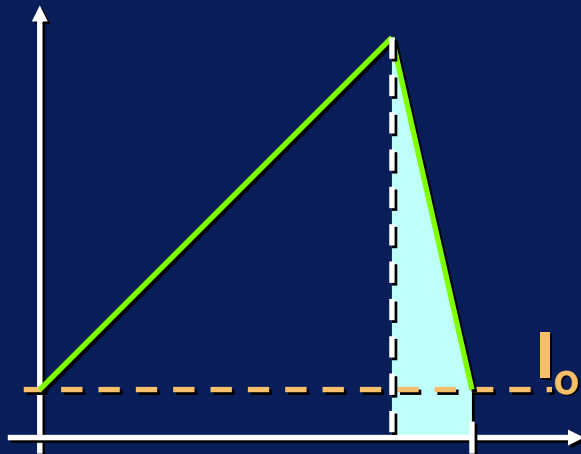
Ondulazione di corrente



δ piccolo

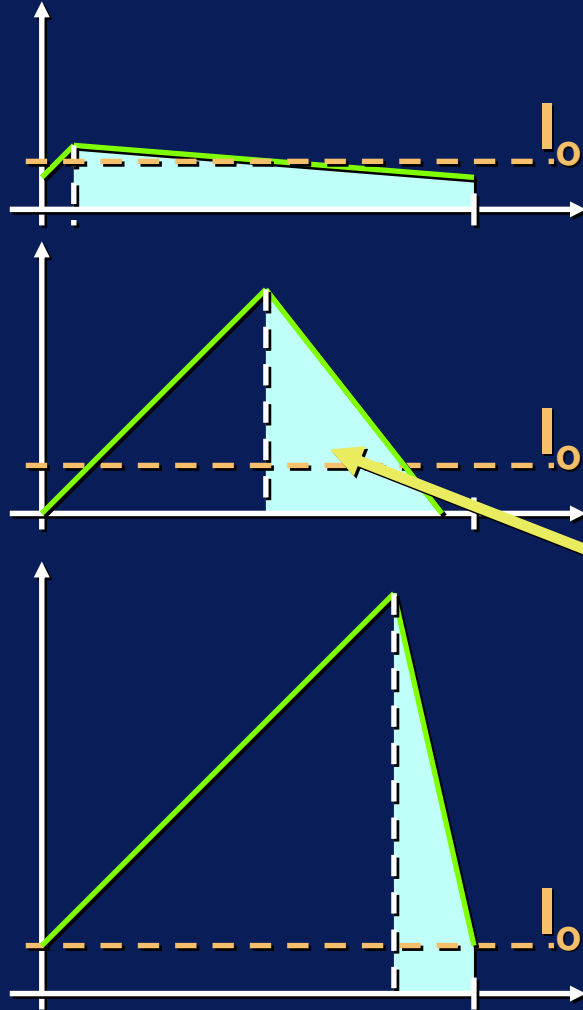


δ intermedio



δ elevato

Ondulazione di corrente

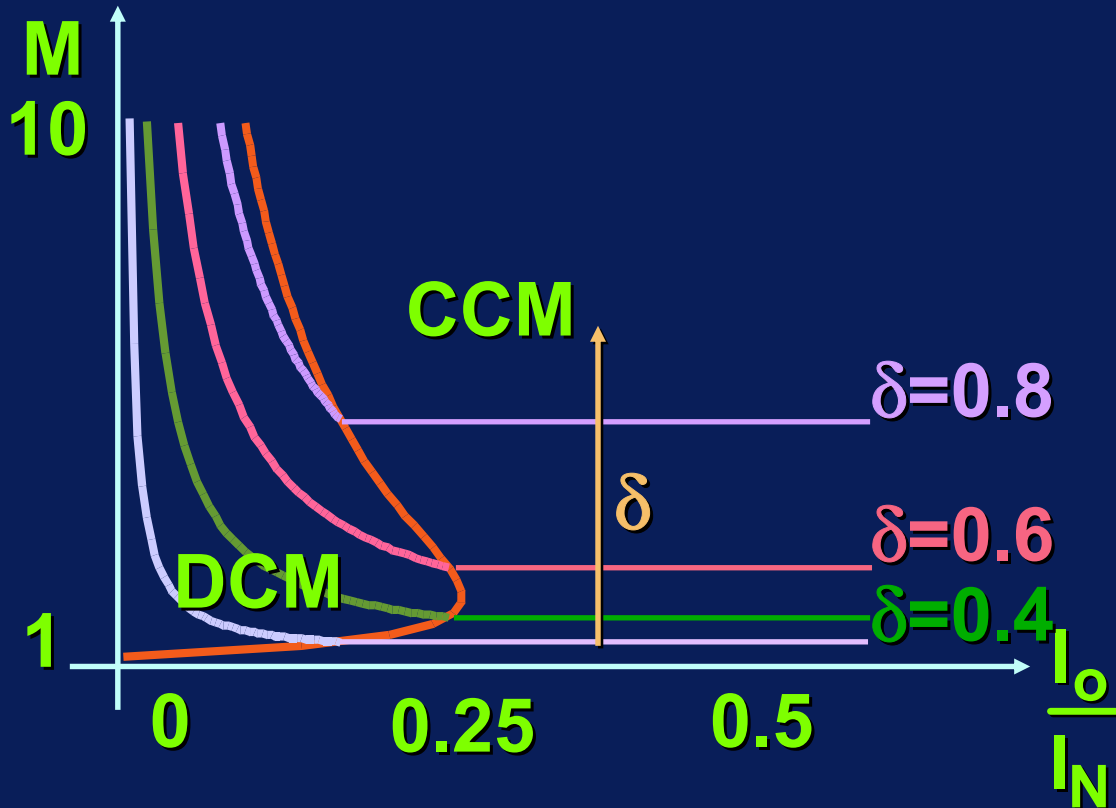


δ piccolo

A parità di I_o
l'intermittenza
si può avere
per $\delta \cong 0.5$

Boost: Caratteristiche d'uscita

Boost: Caratteristiche d'uscita



Curva limite:
$$\frac{I_o}{I_N} = \frac{1}{M} \cdot \left(1 - \frac{1}{M}\right)$$

Caratteristica di controllo in DCM per carico resistivo

Caratteristica di controllo in DCM per carico resistivo

$$M = \frac{1}{2} + \sqrt{\frac{1}{4} + \frac{\delta^2}{k}}$$

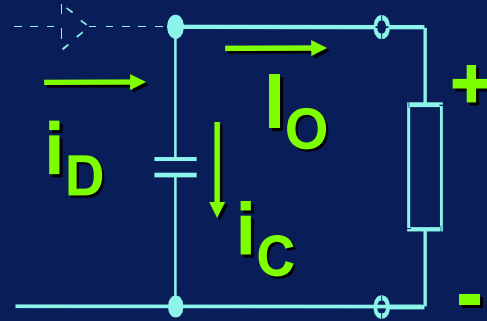
dove:

$$k = \frac{2 \cdot f_s \cdot L}{R_o}$$

Corrente del condensatore di filtro: i_C

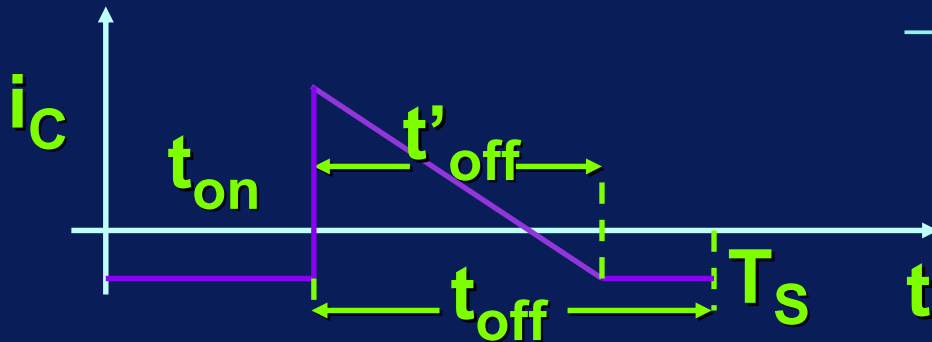
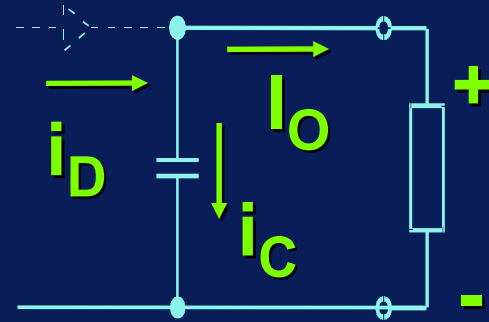
Corrente del condensatore di filtro: i_C

$$i_C = i_D - I_o$$



Corrente del condensatore di filtro: i_C

$$i_C = i_D - I_o$$



i_C ha fronti ripidi; l'induttanza parassita di C (ESL) deve quindi essere minima

Note

- Le tecniche di controllo sono le stesse del convertitore Buck
- La risposta dinamica è però difficile da dominare (caratteristica statica nonlineare, modello ai piccoli segnali a parametri variabili e zero a parte reale positiva)
- Schemi a trasformatore basati sulla topologia boost risultano complessi e sono poco usati