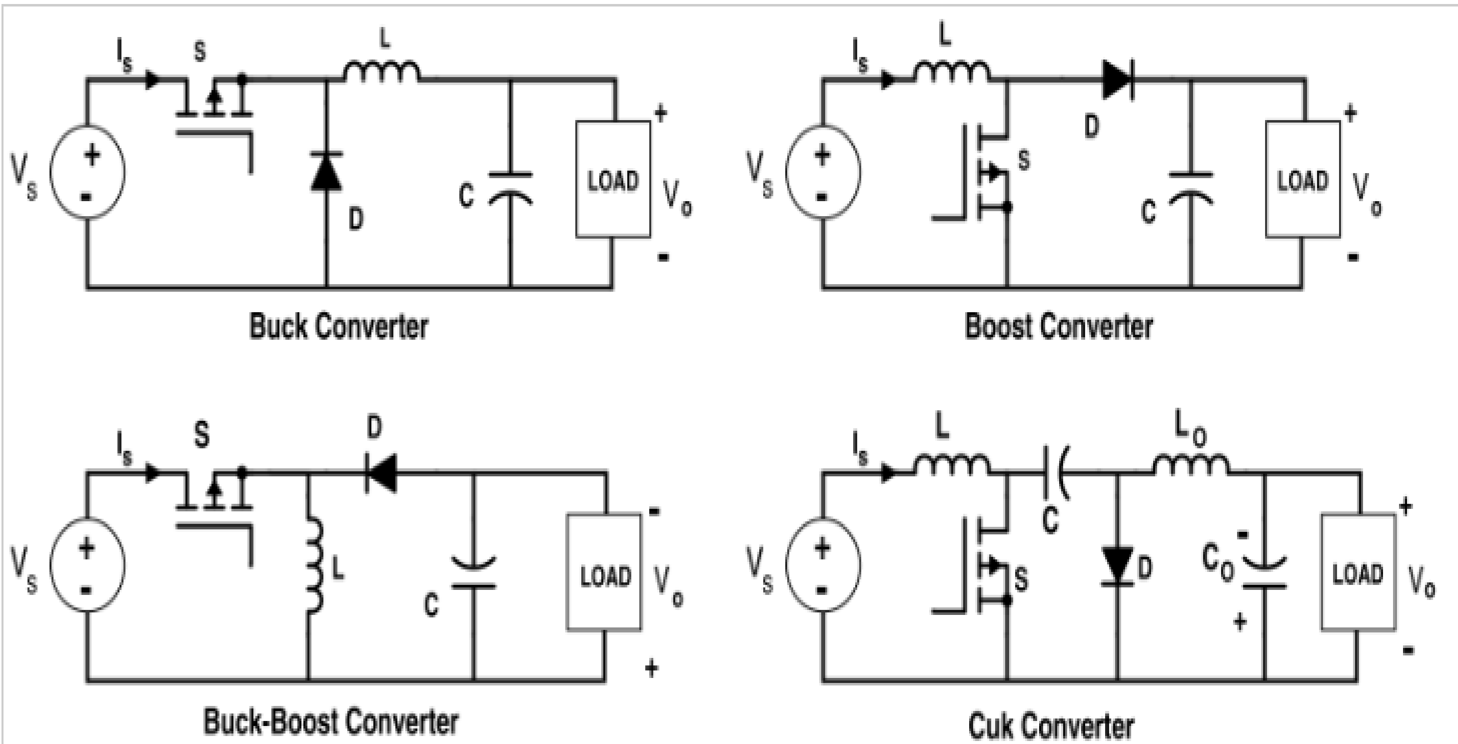
Power electronics lab

DC - DC Converter Buck /Boost /Buck Boost Converter

Eng :Eman Abu Hany



Is
S
L
VS
+
-
D
C
LOAD
Vo
Buck Converter
Boost Converter
Buck-Boost Converter
LO
CO
Cuk Converter

The Pulse Width Modulation

The type of control most frequently used for DC generators and DC voltage converters is the pulse width modulation (PWM). Here the arithmetic average of a square wave voltage is influenced by the on-time ton being changed within a fixed period T. Another name for this method is pulse duration modulation

If, for example, you control the voltage on a load with this method, the arithmetic average of the load current IL will change according to the duty factor D. The following applies: $D = ton/T$

With a simple operational amplifier circuit, a drive circuit for generating a pulse modulation can be set up an operational amplifier compares the delta AC voltage U_D with the control DC voltage U_{ctr}. The operational amplifier is circuited as a comparator.

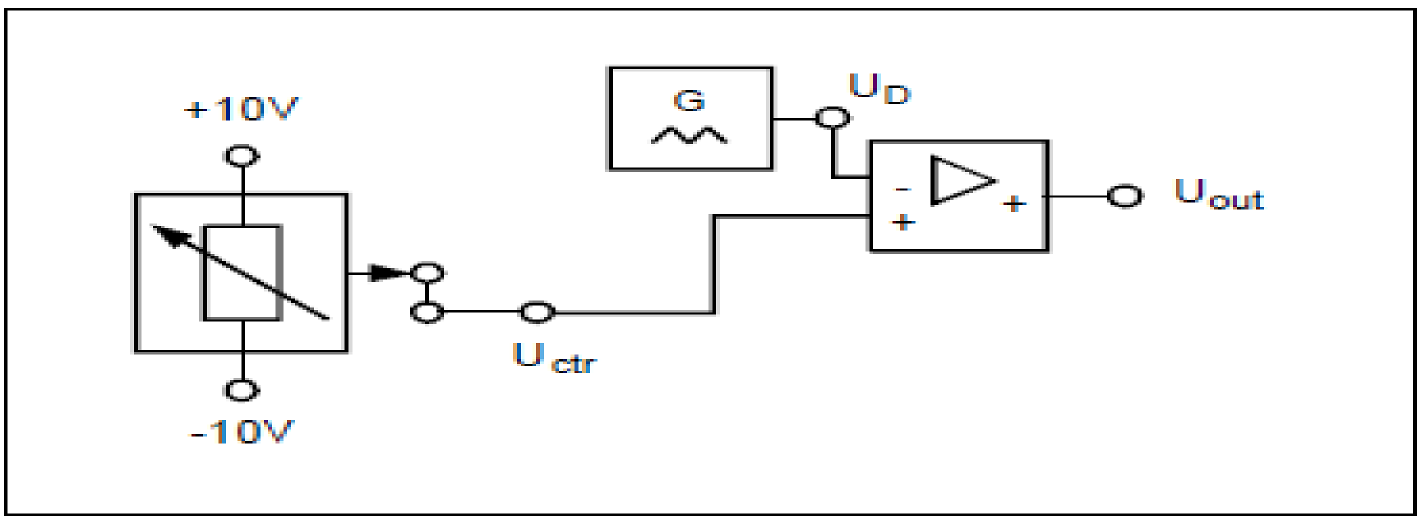
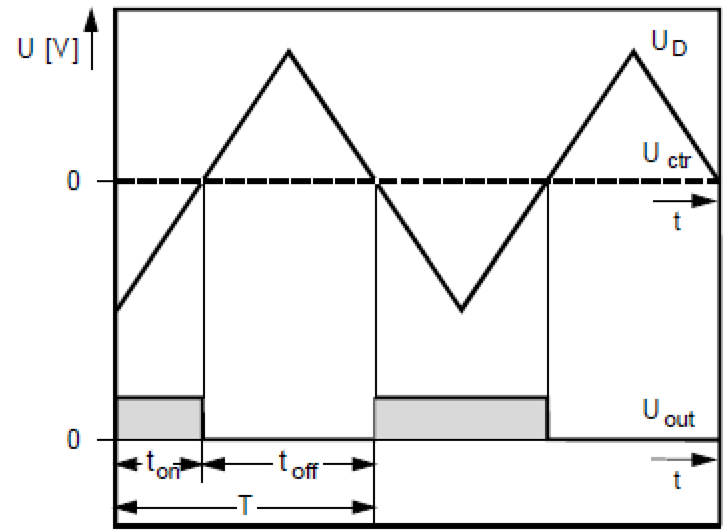


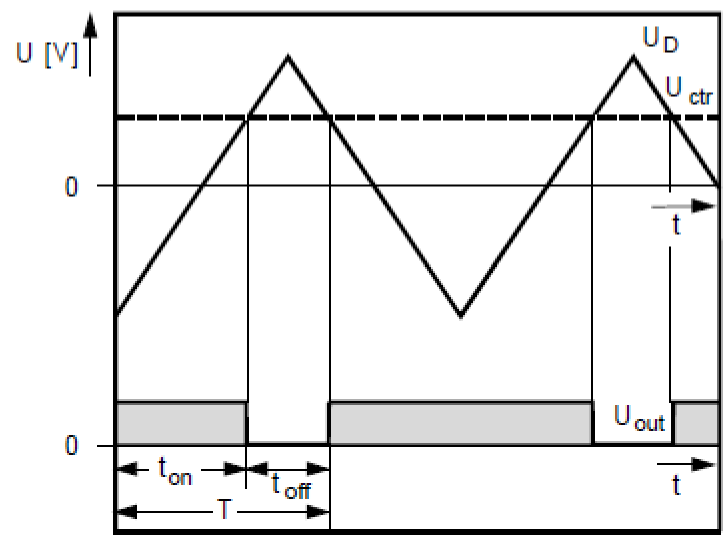
Fig. 5.1.1.2 Drive for PWM

If the value of the control voltage U_{ctr} is greater than the value of the delta voltage U_D, the output of the OP switches to „high". If the control voltage U_{ctr} drops below the delta voltage U_D, the OP switches to „low". U_{out} is therefore a squarewave pulse sequence, whereby the pulse always appears in the time slot in which the delta voltage U_D is smaller than the control voltage U_{ctr}.



At U_{ctr} = 0 V this results in a pulse sequence with $t_{on} = ½ \cdot T$ or $t_{on} = t_{off}$.

The duty factor is $D = \frac{t_{on}}{T} = 0.5$.



If U_{ctr} is made more positive, the pulses get wider, the pauses narrower, the duty factor approaches the value 1 (DC voltage).

If U_{ctr} is made more negative, the pulses get narrower, the pauses wider and the duty factor smaller. The voltage U_{out} therefore serves as a basis for controlling a power final stage.

DC Regulators

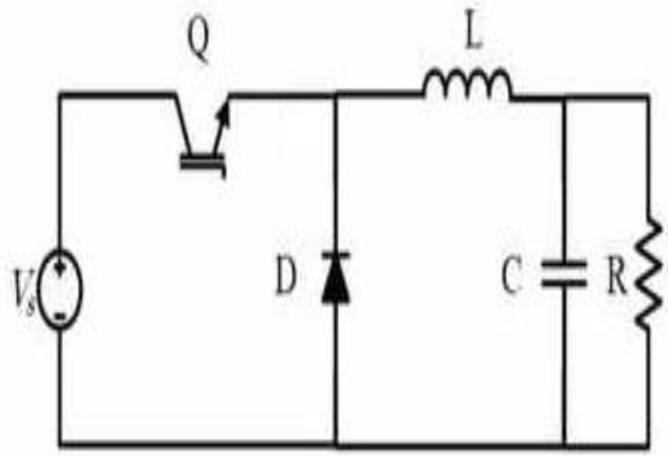
- Convert a DC voltage, normally unregulated, to a regulated DC output voltage
- Achieved by pulse width modulation at fixed frequency
- Used power BJT, power MOSFET or IGBT

- In all converter types
  - LC filter: used to produce DC output with less ripple content
  - Freewheeling Diode: used to provide a path for inductor current when the main switch is open

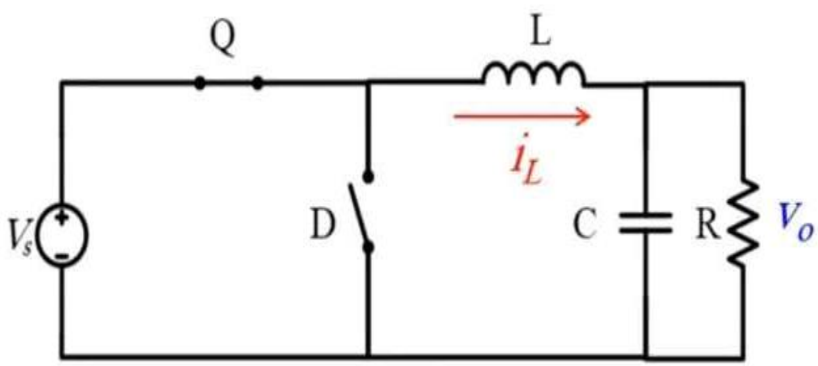
DC Regulators…

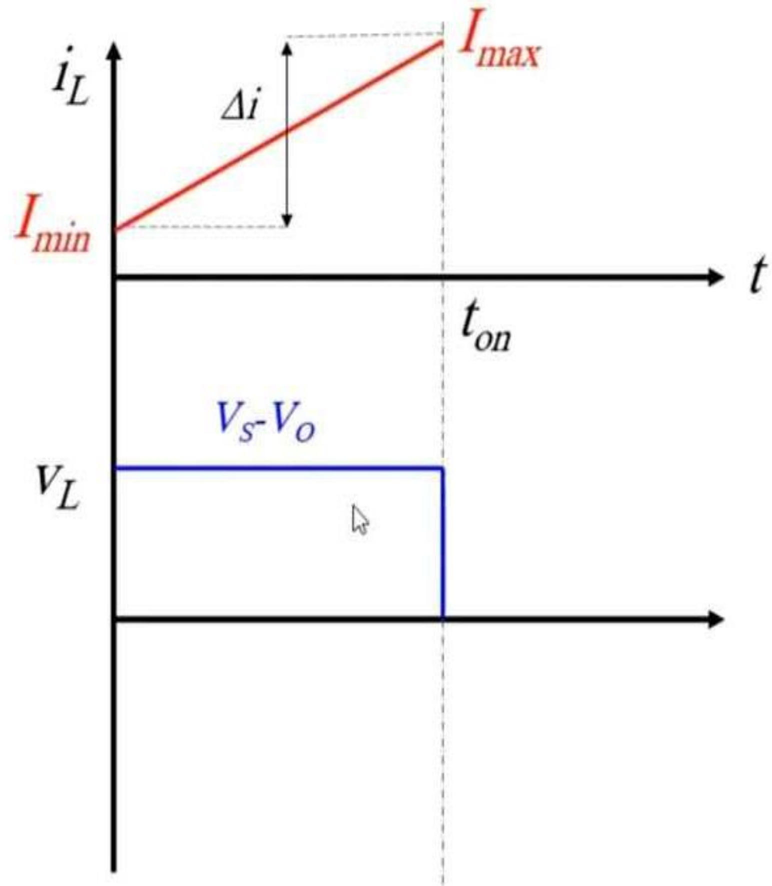
- The following assumptions are adopted before analysis of any type of DC regulators
  1) The circuit is operating in steady-state
  2) The inductor current is continuous
  3) The capacitor is very large and the output voltage is held constant
  4) The components are ideal

Buck converter



Buck converter





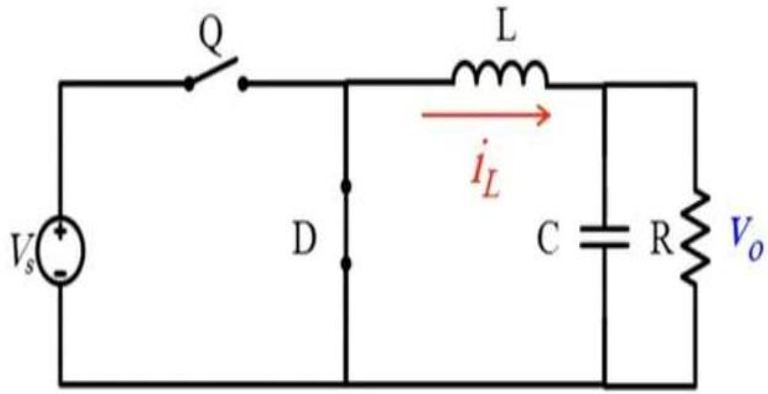
When the switch Q is closed $0 \le t \le t_{on}$

$$V_S = V_L + V_O \qquad L\frac{di_L}{dt} = V_S - V_O$$

$$\frac{\Delta i_L}{t_{on}} = \frac{V_S - V_O}{L} \qquad \boxed{\Delta i_{L(closed)} = \left(\frac{V_S - V_O}{L}\right) DT}$$

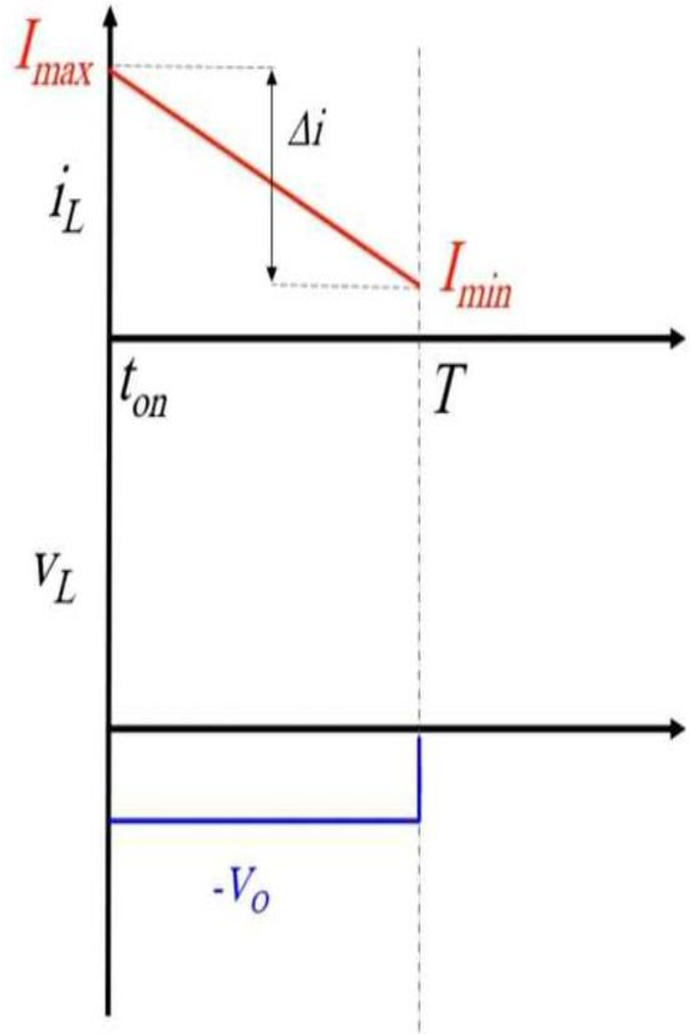
Buck converter

When the switch Q is opened $\quad t_{on} \leq t \leq T$



$$V_L = -V_O \qquad L\frac{di_L}{dt} = -V_O$$

$$\frac{\Delta i_L}{T - t_{on}} = \frac{-V_O}{L} \qquad \Delta i_{L(opened)} = \left(\frac{-V_O}{L}\right)(1-D)T$$



Buck converter

$$\left(\Delta i_L\right)_{closed} + \left(\Delta i_L\right)_{opened} = 0$$

$$\left(\frac{V_s - V_o}{L}\right)DT + \left(\frac{-V_o}{L}\right)(1-D)T = 0$$

The output voltage $V_o = DV_s$

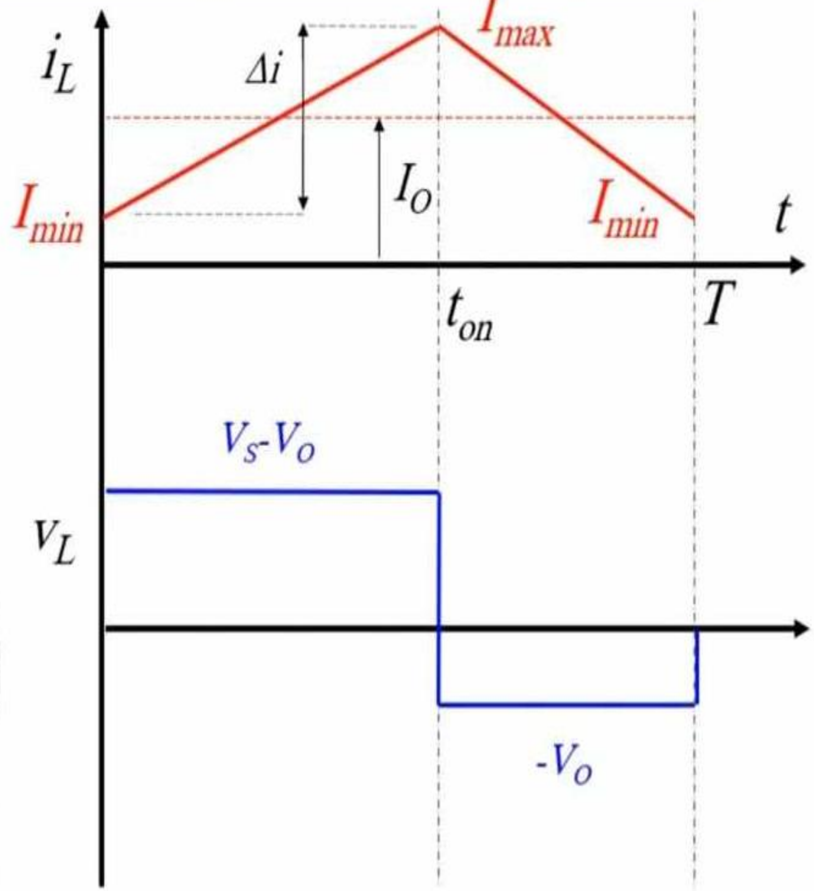
The output current/inductor current

$$I_L = I_o = \frac{V_o}{R} = \frac{DV_s}{R}$$

Max. and Min. of the inductor current

$$\mathrm{I}_{max} = I_L + \frac{\Delta i_L}{2} = \frac{V_o}{R} + \left(\frac{V_s - V_o}{2L}\right)DT = V_o\left(\frac{1}{R} + \frac{(1-D)}{2Lf}\right)$$

$$\mathrm{I}_{min} = I_L - \frac{\Delta i_L}{2} = \frac{V_o}{R} - \left(\frac{V_s - V_o}{2L}\right)DT = V_o\left(\frac{1}{R} - \frac{(1-D)}{2Lf}\right)$$



Buck converter

The rms current of the inductor current

$$I_{L,rms} = \sqrt{I_L^{\,2} + \left(\frac{\Delta i_L}{2\sqrt{3}}\right)^2}$$

The switches currents

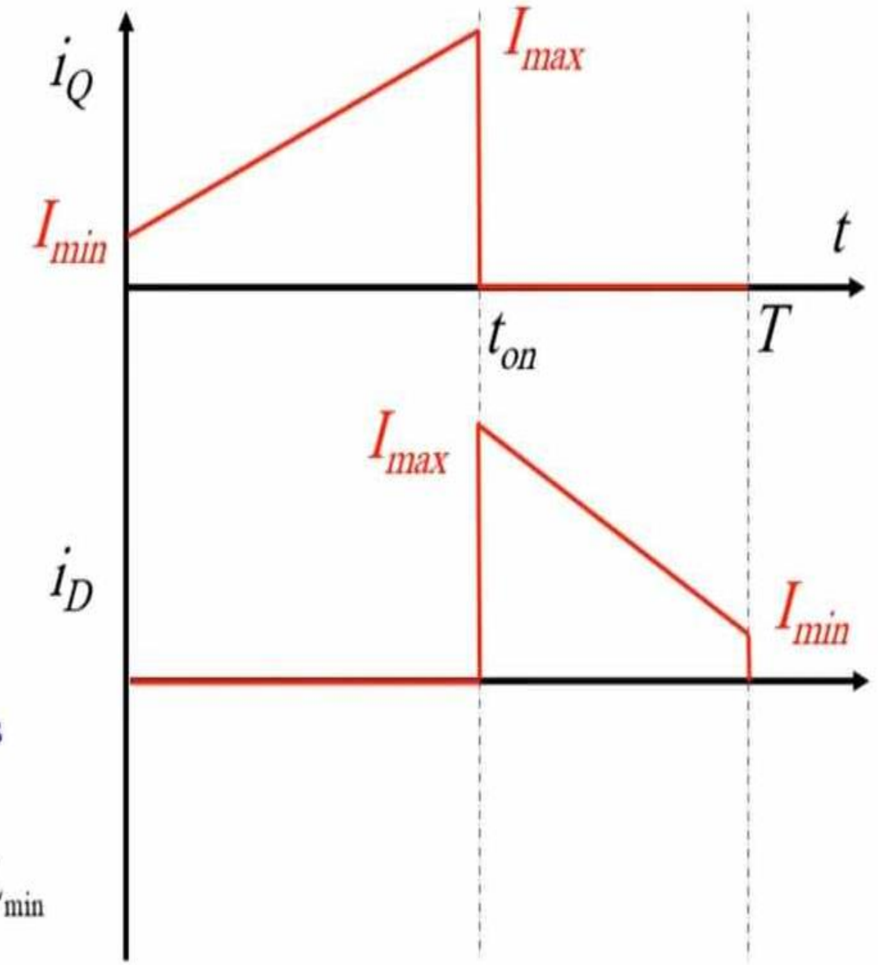
$$I_{Q,avg} = DI_L = I_S \qquad I_{Davg} = (1-D)I_L$$

$$I_{Q,rms} = \sqrt{D}\,I_{L,rms} = I_{S,rms} \qquad I_{D,rms} = \sqrt{(1-D)}\,I_{L,rms}$$

The minimum value of the inductance required for continuous current Operation

$$I_{min} = 0$$

$$L_{min} = \frac{(1-D)R}{2f} \qquad L_{des} = 1.25 * L_{min}$$



Buck converter

$$I_C = I_L - I_O$$

$$Q = CV_O$$

$$\Delta Q = C\Delta V_O$$

The ripple voltage

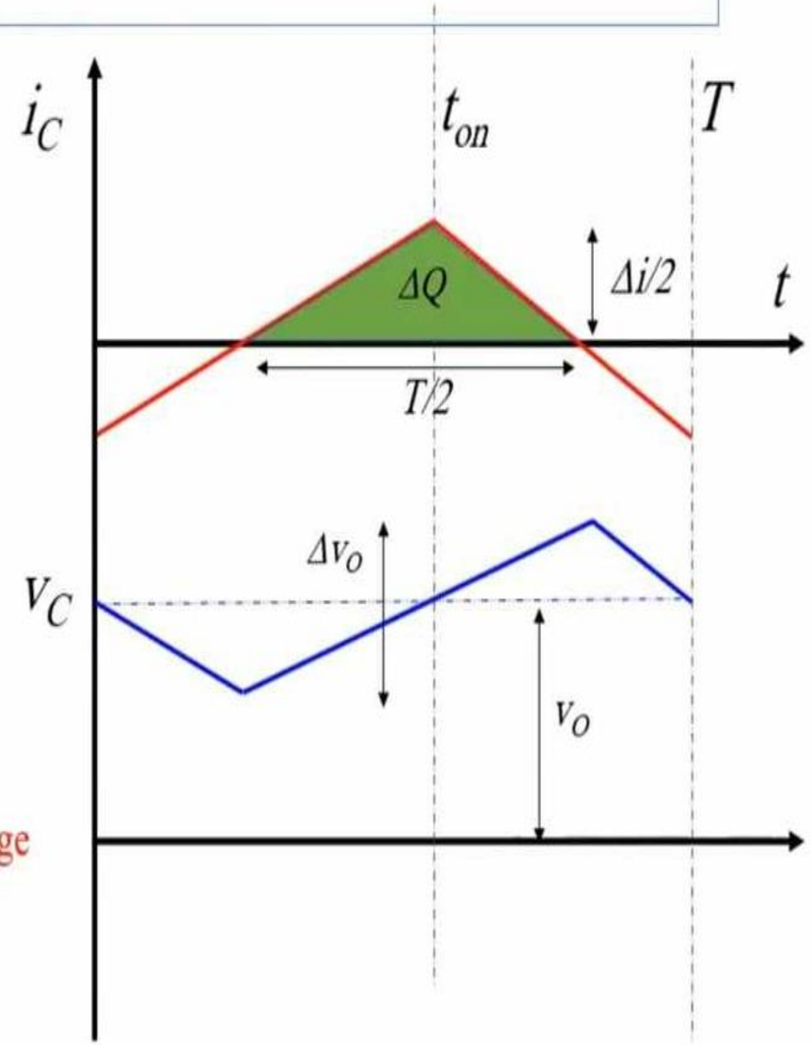
$$\Delta V_O = \frac{\Delta Q}{C} = \frac{1}{C}\left[\frac{1}{2} * \frac{T}{2} * \frac{\Delta i_L}{2}\right]$$

$$\Delta V_O = \frac{TV_O(1-D)T}{8LC} = \frac{V_O(1-D)}{8LCf^2}$$

The ripple factor $RF = \frac{\Delta V_o}{V_o}$

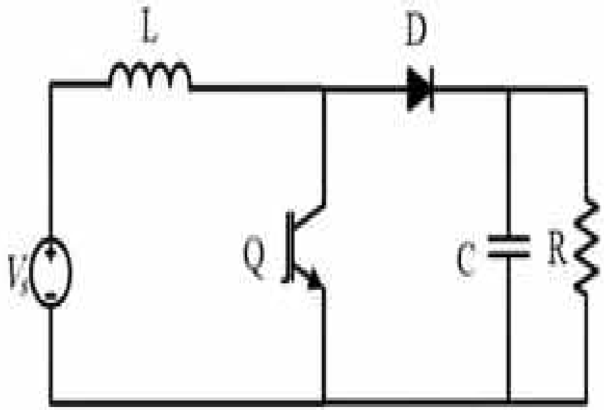
The capacitor can be chosen according to the ripple voltage

The rms value of the capacitor current $I_{C,rms} = \frac{\Delta i_L}{2\sqrt{3}}$

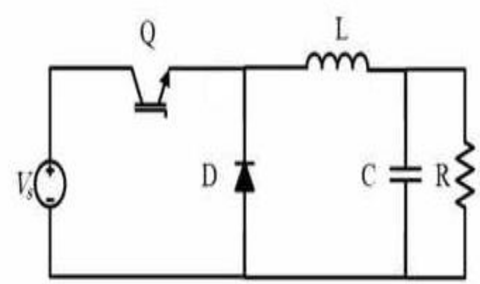


Boost converter

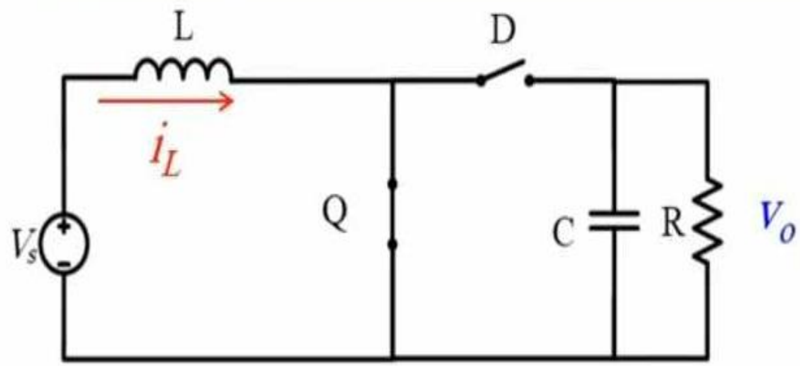
Boost converter

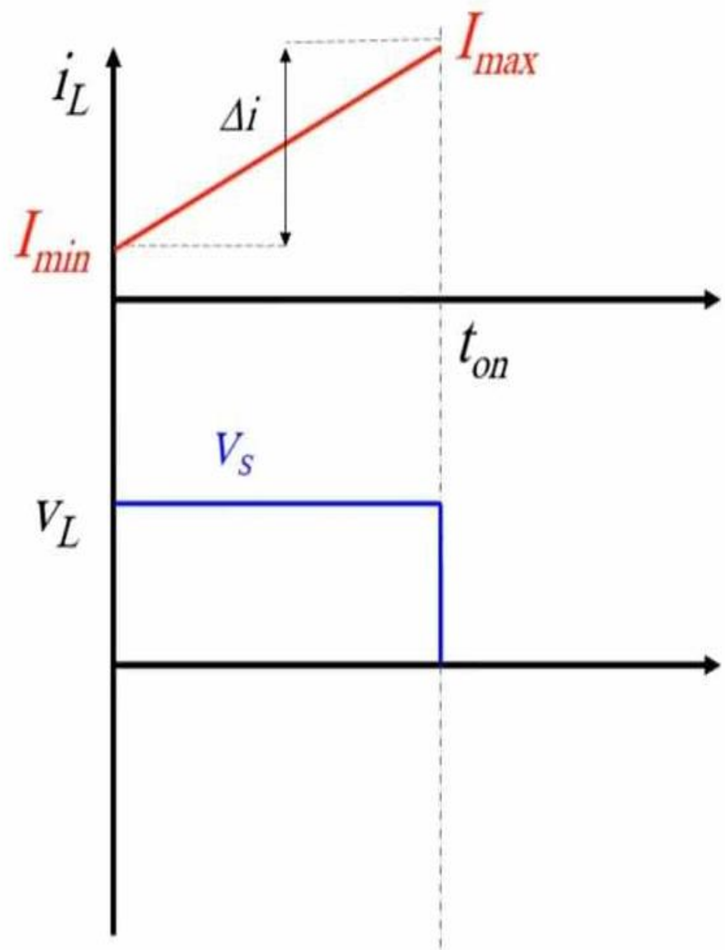


Buck converter



Boost converter





When the switch Q is closed $\quad 0 \le t \le t_{on}$

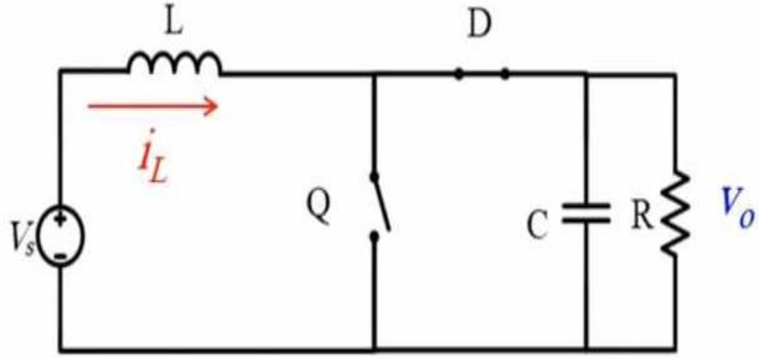
$$V_L = V_S \qquad L\frac{di_L}{dt} = V_S$$

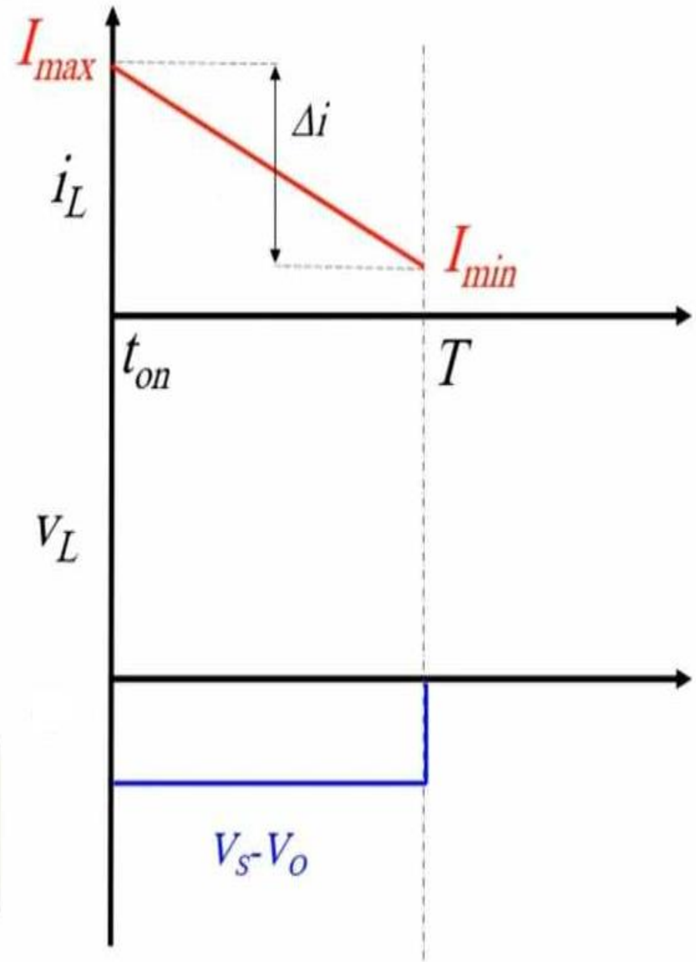
$$\frac{\Delta i_L}{t_{on}} = \frac{V_S}{L}$$

$$\Delta i_{L(closed)} = \left(\frac{V_S}{L}\right)DT$$

Boost converter

When the switch Q is opened $t_{on} \le t \le T$





$$V_L = V_S - V_O$$

$$L\frac{di_L}{dt} = V_S - V_O$$

$$\frac{\Delta i_L}{T - t_{on}} = \frac{V_S - V_O}{L}$$

$$\Delta i_{L(opened)} = \left(\frac{V_S - V_O}{L}\right)(1 - D)T$$

Boost converter

$$\left(\Delta i_L\right)_{closed} + \left(\Delta i_L\right)_{opened} = 0$$

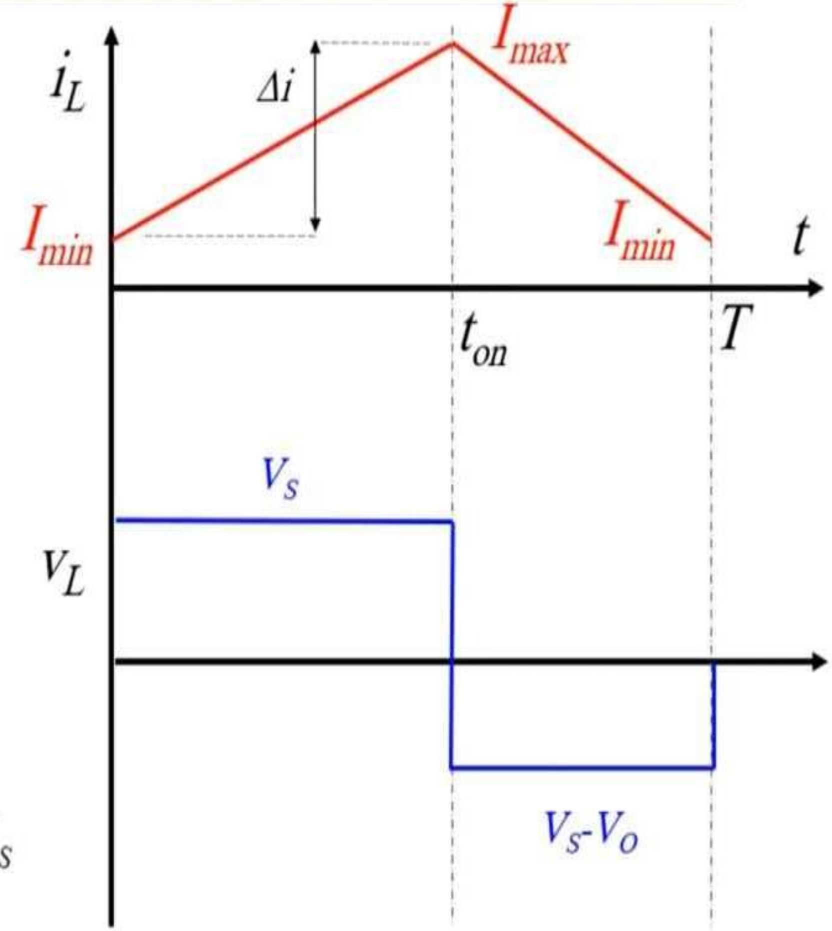
$$\left(\frac{V_S}{L}\right)DT + \left(\frac{V_S - V_O}{L}\right)(1-D)T = 0$$

The output voltage $$V_O = \frac{V_S}{1-D}$$

The output current $$I_O = \frac{V_O}{R}$$

The inductor current/ Supply current

$$I_L = \frac{I_O}{(1-D)} = \frac{V_O}{R(1-D)} = \frac{V_S}{R(1-D)^2} = I_S$$



Boost converter

Max. and Min. of the inductor current

$$I_{max} = I_L + \frac{\Delta i_L}{2} = \frac{V_S}{R(1-D)^2} + \frac{V_S D}{2Lf}$$

$$I_{min} = I_L - \frac{\Delta i_L}{2} = \frac{V_S}{R(1-D)^2} - \frac{V_S D}{2Lf}$$

The rms current of the inductor current

$$I_{L,rms} = \sqrt{I_L^{\,2} + \left(\frac{\Delta i_L}{2\sqrt{3}}\right)^2}$$

Boost converter

The switches currents

$$I_{Q,avg} = DI_L \qquad I_{Davg} = (1-D)I_L$$

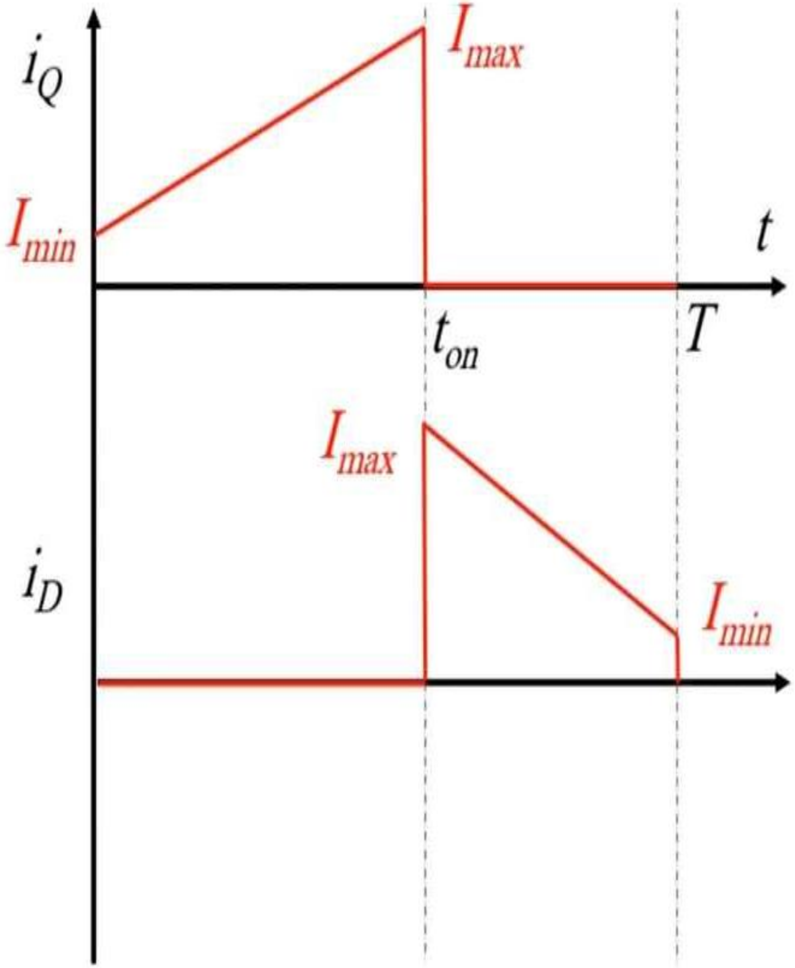
$$I_{Q,rms} = \sqrt{D}I_{L,rms} \qquad I_{D,rms} = \sqrt{(1-D)}I_{L,rms}$$

The minimum value of the inductance required for continuous current Operation

$$I_{min} = 0$$

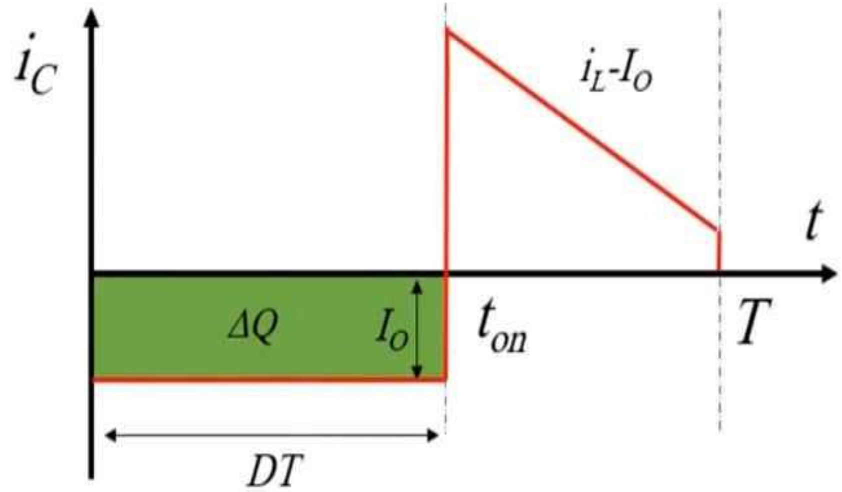
$$L_{\min} = \frac{D(1-D)^2 R}{2f}$$

$$L_{des} = 1.25 * L_{\min}$$



Boost converter

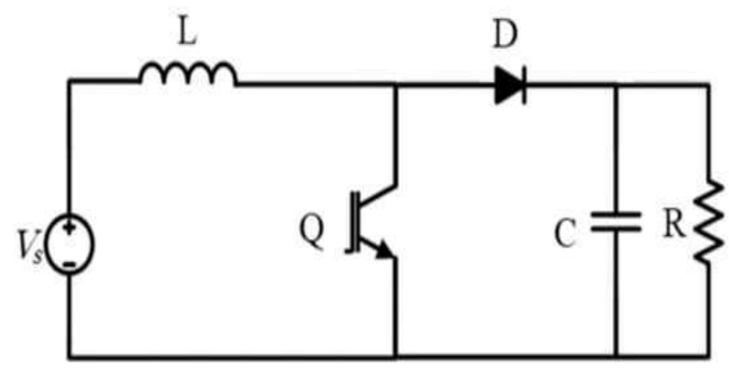
$$Q = CV_O$$
$$\Delta Q = C\Delta V_O$$



The ripple voltage

$$\Delta V_O = \frac{\Delta Q}{C} = \frac{I_O DT}{C} = \frac{V_O D}{RCf}$$

The ripple factor $RF = \frac{\Delta V_o}{V_o}$



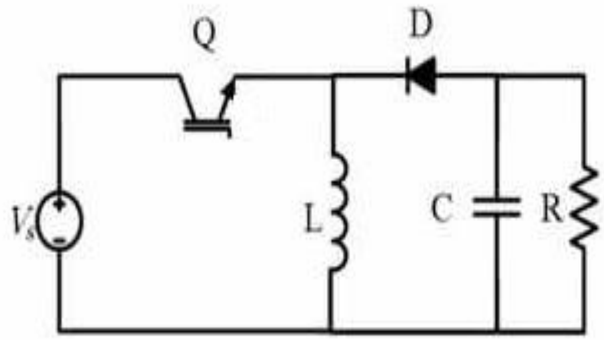
The capacitor can be chosen according to the ripple voltage

The rms value of the capacitor current

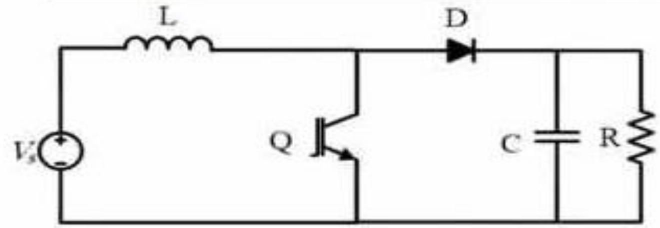
$$I_{C,rms} = \sqrt{I_{D,rms}^2 - I_{O,rms}^2} \qquad I_{O,rms} = I_O$$

Buck-Boost converter

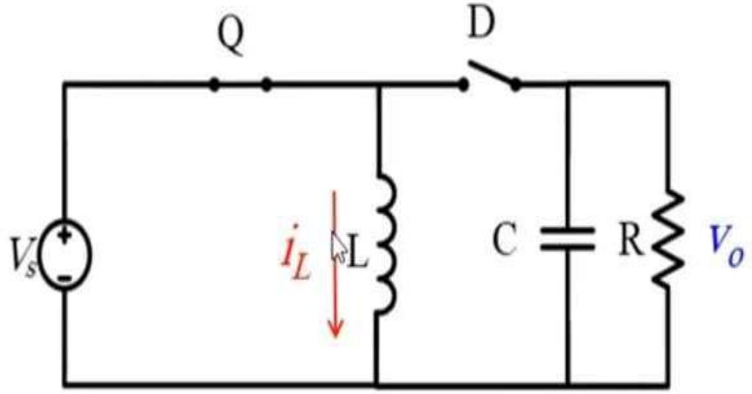
Buck-Boost converter



Boost converter



Buck-Boost converter

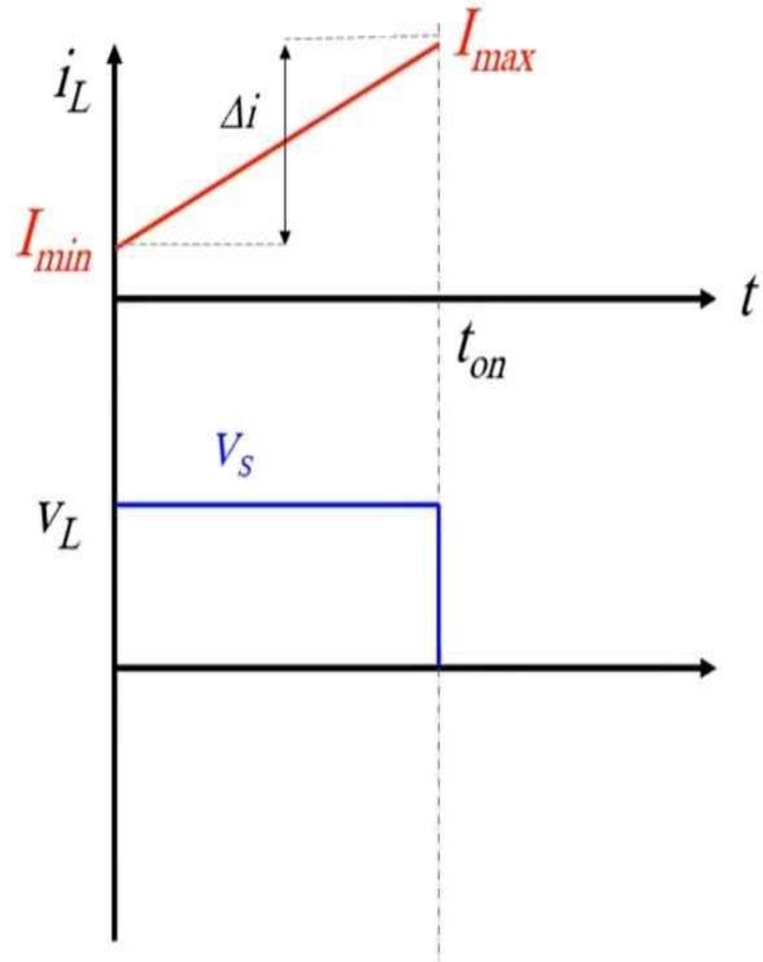


When the switch Q is closed $\quad 0 \le t \le t_{on}$

$$V_S = V_L \qquad L\frac{di_L}{dt} = V_S$$

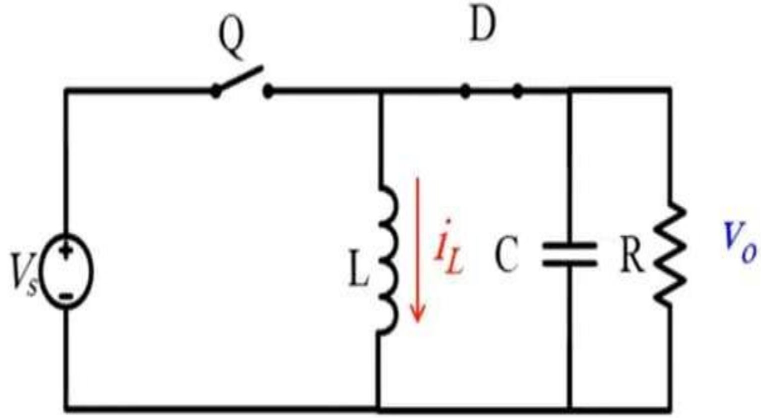
$$\frac{\Delta i_L}{t_{on}} = \frac{V_S}{L}$$

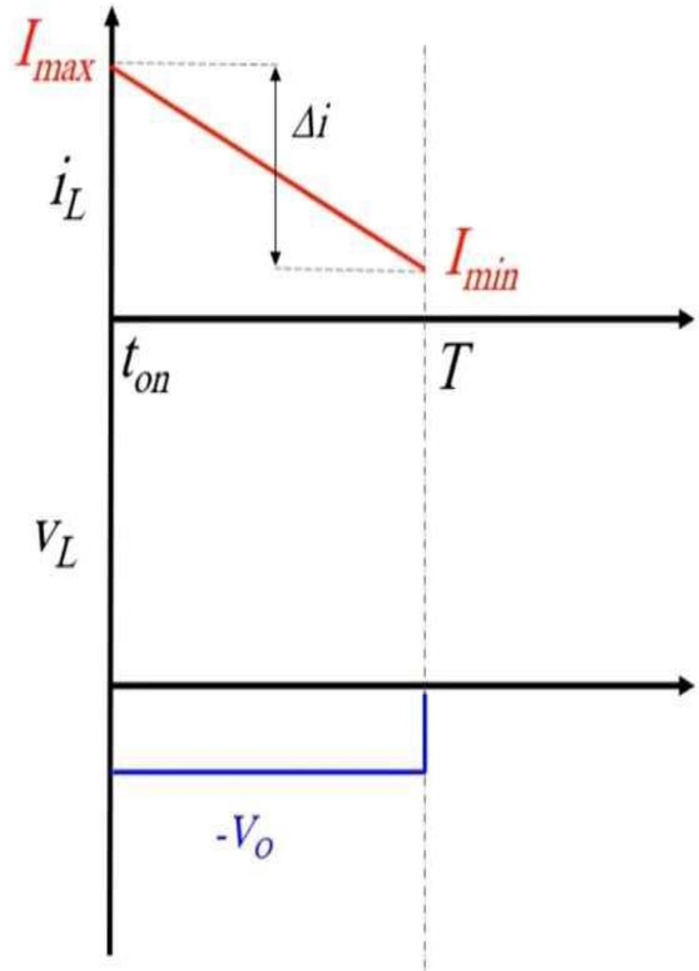
$$\Delta i_{L(closed)} = \left(\frac{V_S}{L}\right)DT$$



Buck-Boost converter

When the switch Q is opened $t_{on} \leq t \leq T$





$$V_L = -V_O$$

$$L\frac{di_L}{dt} = -V_O$$

$$\frac{\Delta i_L}{T - t_{on}} = \frac{-V_O}{L}$$

$$\Delta i_{L(opened)} = \left(\frac{-V_O}{L}\right)(1-D)T$$

Buck-Boost converter

$$(\Delta i_L)_{closed} + (\Delta i_L)_{opened} = 0$$

$$\left(\frac{V_S}{L}\right)DT + \left(\frac{-V_O}{L}\right)(1-D)T = 0$$

The output voltage

$$V_O = \frac{-DV_S}{(1-D)}$$

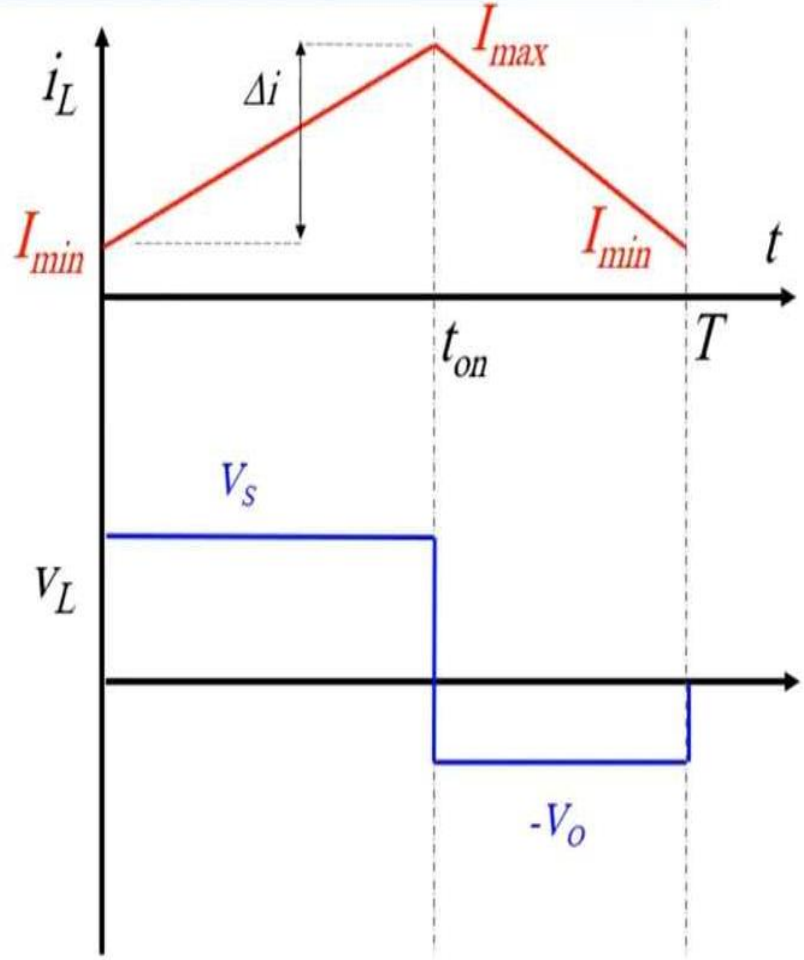
$D > 0.5$	*Boost*
$D < 0.5$	*Buck*

The output current

$$I_O = \frac{V_O}{R}$$

The inductor current

$$I_L = \frac{I_O}{(1-D)} = \frac{V_O}{R(1-D)} = \frac{DV_S}{R(1-D)^2}$$



Buck-Boost converter

Max. and Min. of the inductor current

$$I_{max} = I_L + \frac{\Delta i_L}{2} = \frac{DV_S}{R(1-D)^2} + \frac{V_S D}{2Lf}$$

$$I_{min} = I_L - \frac{\Delta i_L}{2} = \frac{DV_S}{R(1-D)^2} - \frac{V_S D}{2Lf}$$

The rms current of the inductor current

$$I_{L,rms} = \sqrt{I_L^{\,2} + \left(\frac{\Delta i_L}{2\sqrt{3}}\right)^2}$$

Buck-Boost converter

The switches currents

$$I_{Q,avg} = DI_L = I_{S,avg}$$

$$I_{Davg} = (1-D)I_L$$

$$I_{Q,rms} = \sqrt{D}\,I_{L,rms} = I_{S,rms}$$

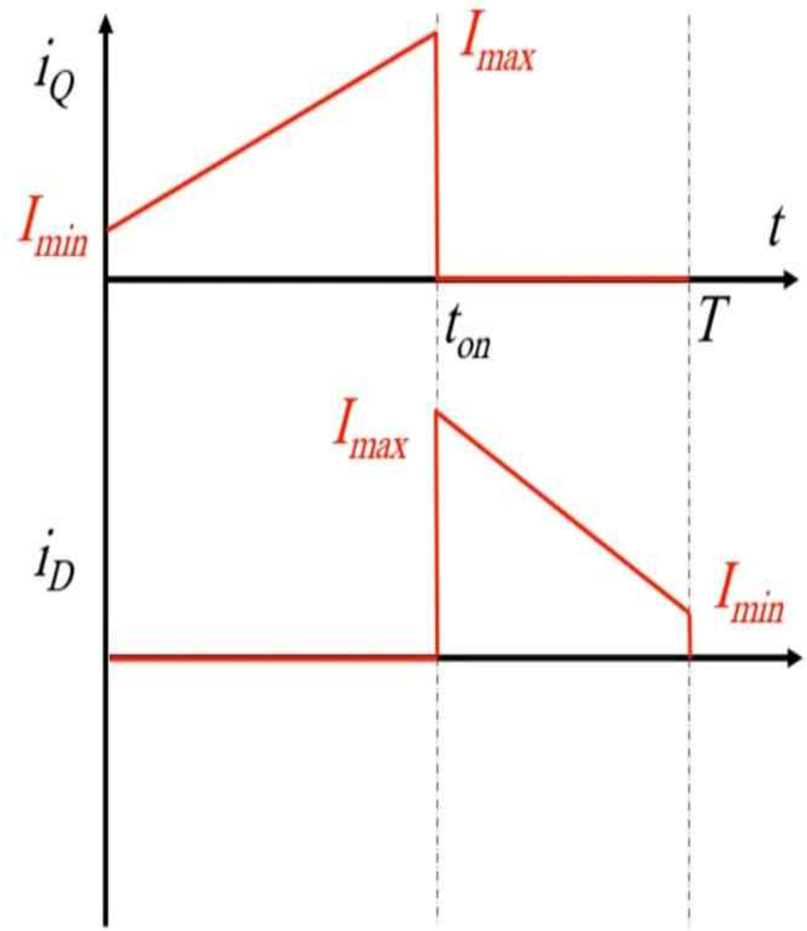
$$I_{D,rms} = \sqrt{(1-D)}\,I_{L,rms}$$

The minimum value of the inductance required for continuous current Operation

$$I_{min} = 0$$

$$L_{\min} = \frac{(1-D)^2 R}{2f}$$

$$L_{des} = 1.25 * L_{\min}$$



Buck-Boost converter

$$Q = CV_O$$

$$\Delta Q = C\Delta V_O$$

The ripple voltage

$$\Delta V_O = \frac{\Delta Q}{C} = \frac{I_O DT}{C} = \frac{V_O D}{RCf}$$

The ripple factor $RF = \frac{\Delta V_o}{V_o} = \frac{D}{RCf}$

The capacitor can be chosen according to the ripple voltage