EE 238

Power Engineering - II

Power Electronics

Lecture 10

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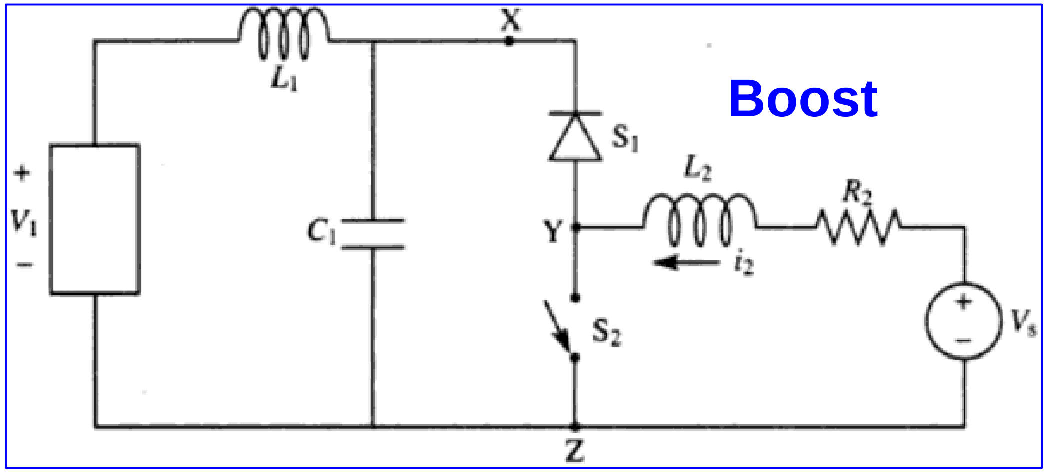
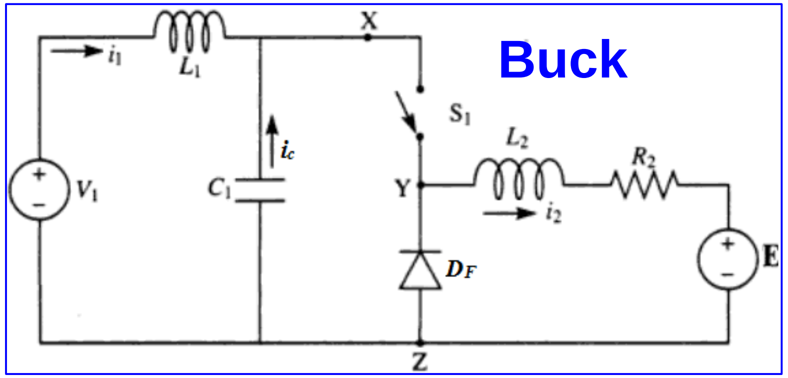
STEP-UP (BOOST) CONVERTER

As the name implies, the output voltage is always greater than the input voltage.



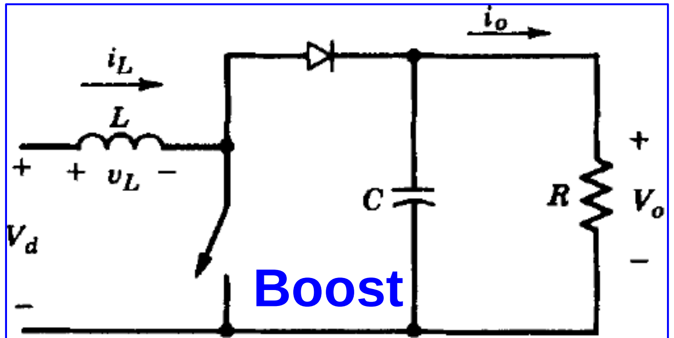
In boost converter, the positions of diode and switch are interchanged as compared to the buck converter circuit.



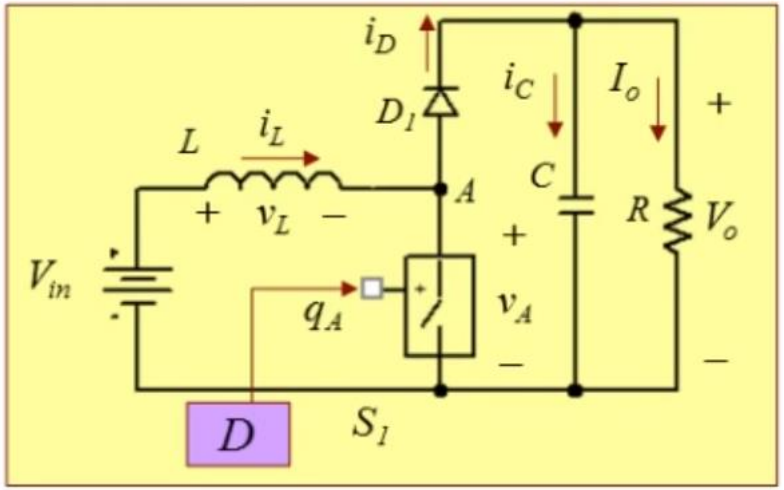
Vs feeds power into the load, which is at a higher voltage V1. C1 and L1 is used on the high voltage side here also. With this filter, the current flowing into the load will have reduced ripple.

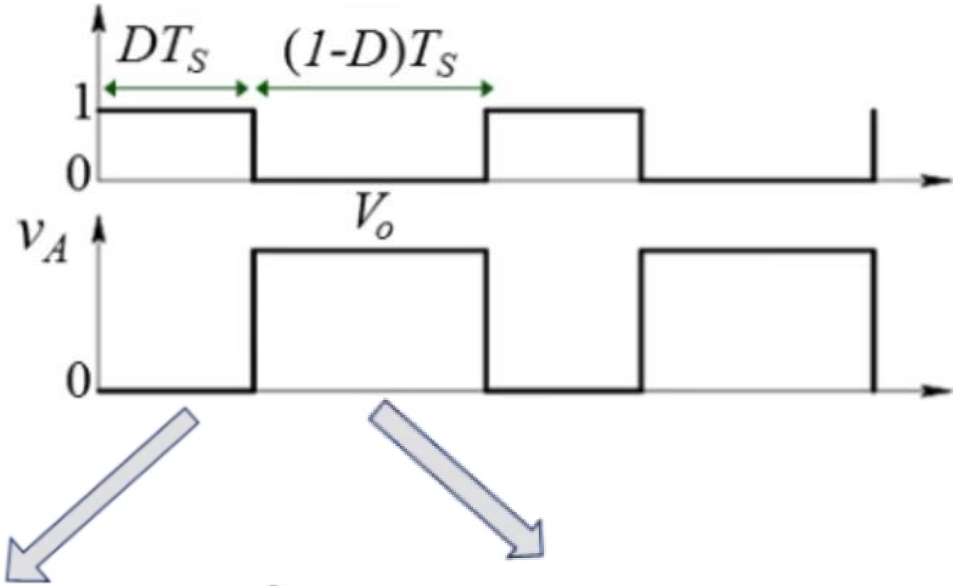
L2 on the low voltage side is similar to the smoothing inductance used on the low voltage side for the buck chopper, to smooth out the low voltage side ripple current. **It is an essential requirement for the step up mode of operation.**

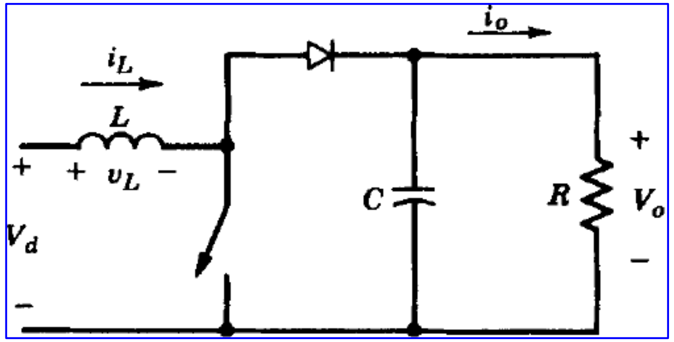
L2 functions as an interim reservoir of energy, drawing energy from the DC source during the ON time, and feeding the same energy into the source at a higher voltage during the OFF time. **It also serves to smooth out ripple current on the low voltage side**, which is the input side.



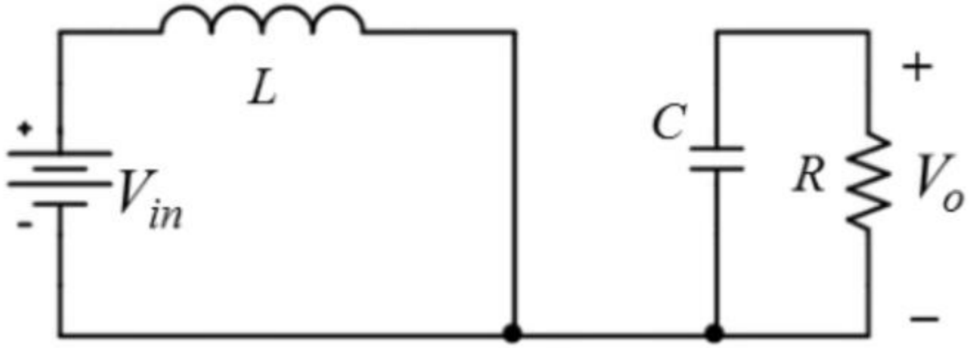
STEP-UP (BOOST) CONVERTER



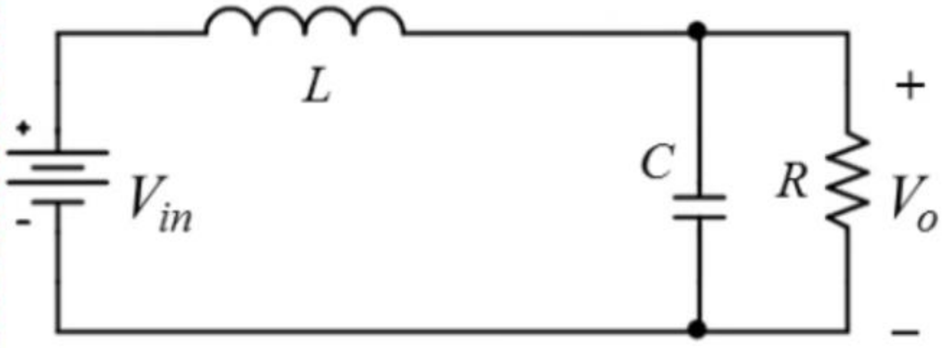




DC Steady-state



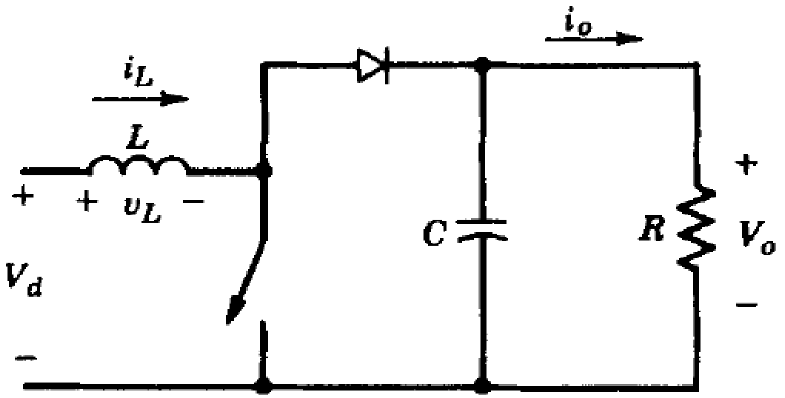
- $v_L = V_{in}$
- i_L and energy stored in L increase
- C supports load and discharges
- C large enough to maintain voltage almost constant (small ripple)

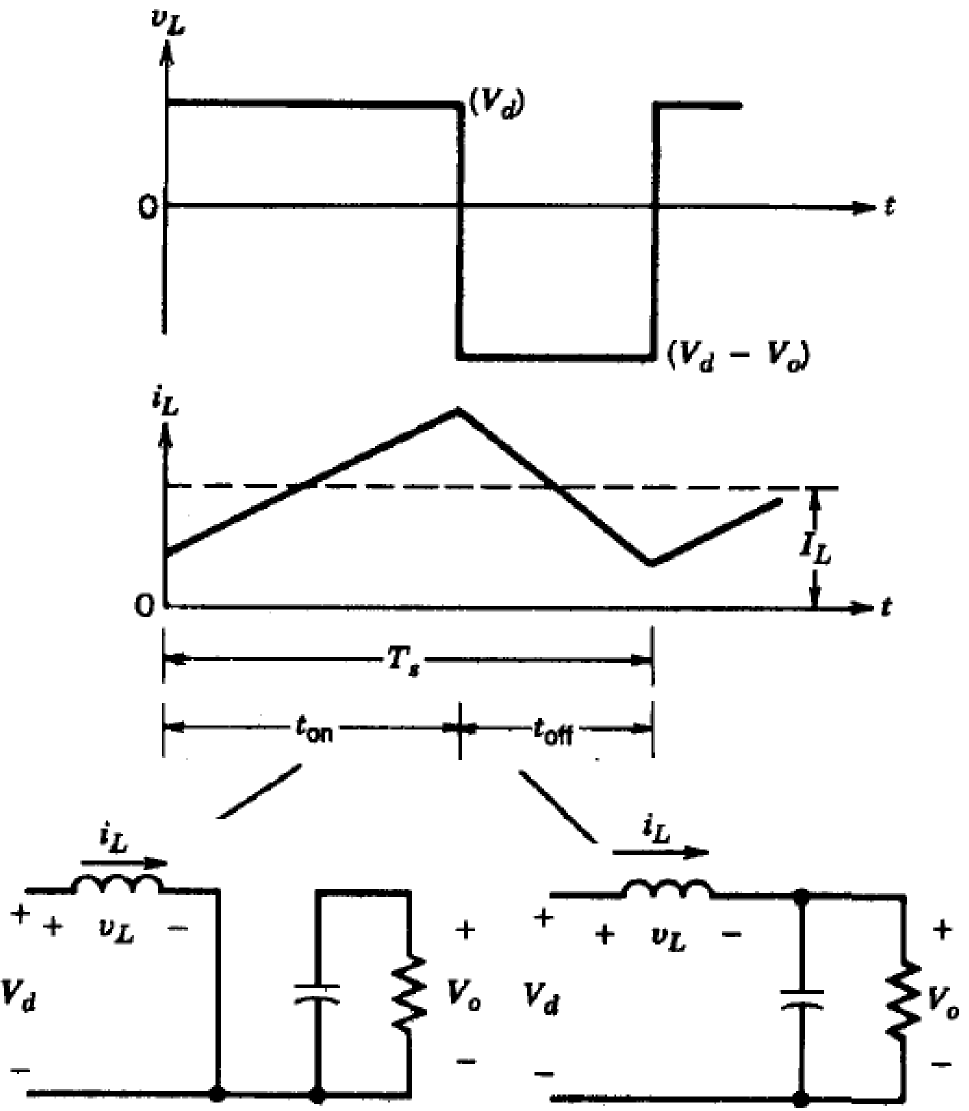


- $v_L = V_{in} - V_o$
- i_L and energy stored in L decrease, energy fed to C and R
- i_C positive and C charges up
- C large enough to maintain voltage almost constant (small ripple)

STEP-UP (BOOST) CONVERTER

$V_0 > V_d$ **Why??**

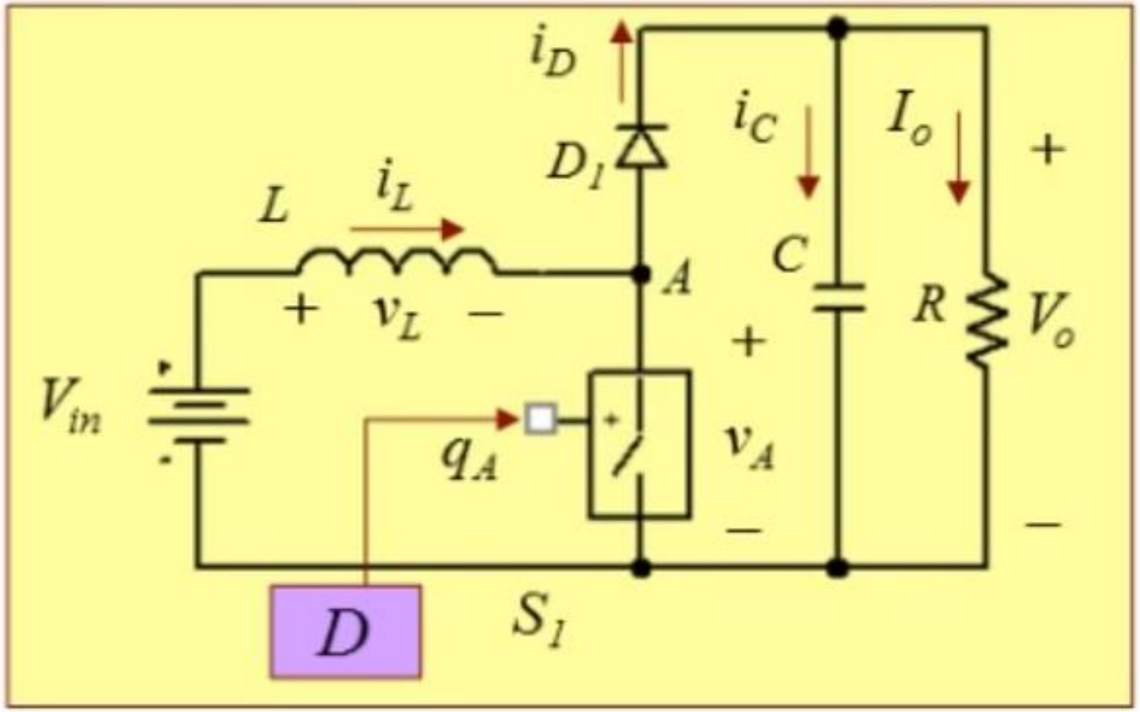




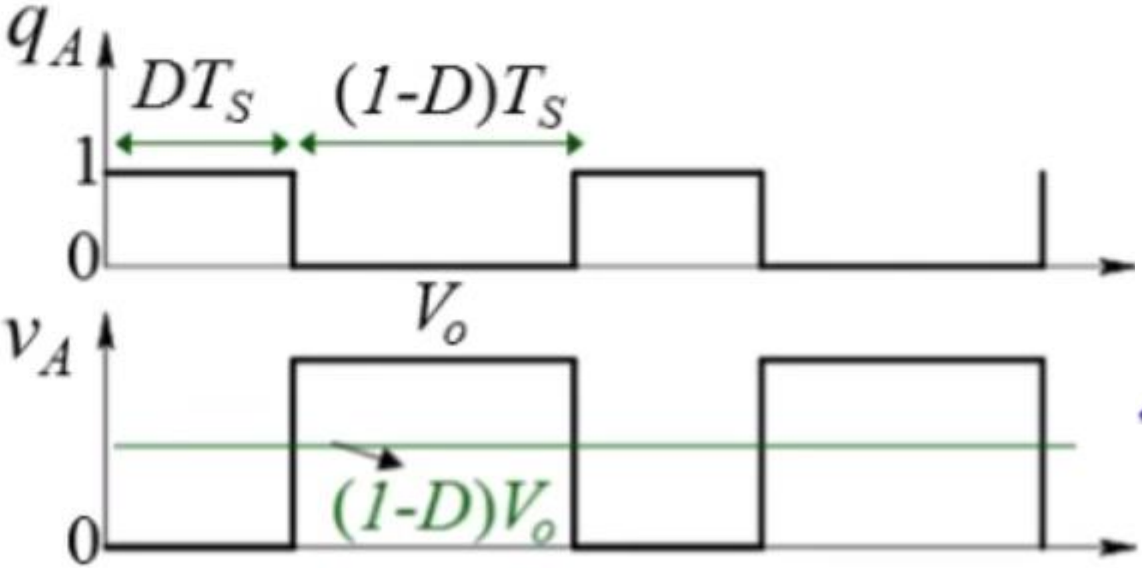
Depending on the circuit parameters and the duty cycle, the current may decay to zero even before the end of the OFF period of the chopper switch (T_{OFF}). In such a case, the current flowing in the voltage source Vd will be discontinuous.

STEP-UP (BOOST) CONVERTER

Input-Output Voltage Relationship: SS operation



$$\bar{v}_A = V_{in} \left(\text{since } \bar{v}_L = 0\right)$$



$$\bar{v}_A = (1 - D)V_o \text{ (from waveform)}$$

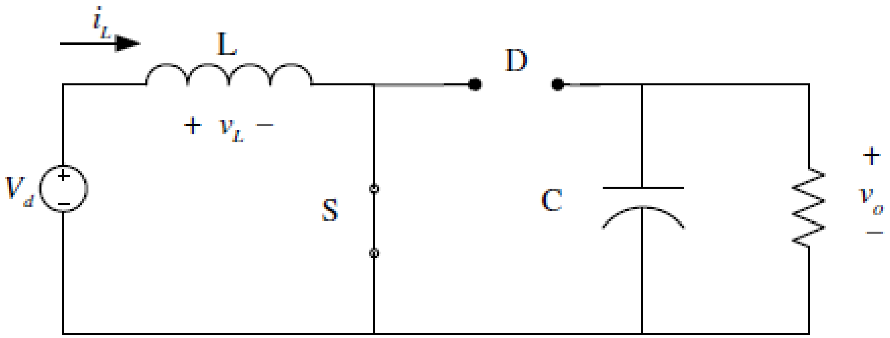
$$\boxed{\frac{V_o}{V_{in}} = \frac{1}{1 - D}}$$

Input-output relationship for boost converter

STEP-UP (BOOST) CONVERTER

Input-Output Voltage Relationship: SS operation

The ΔI method



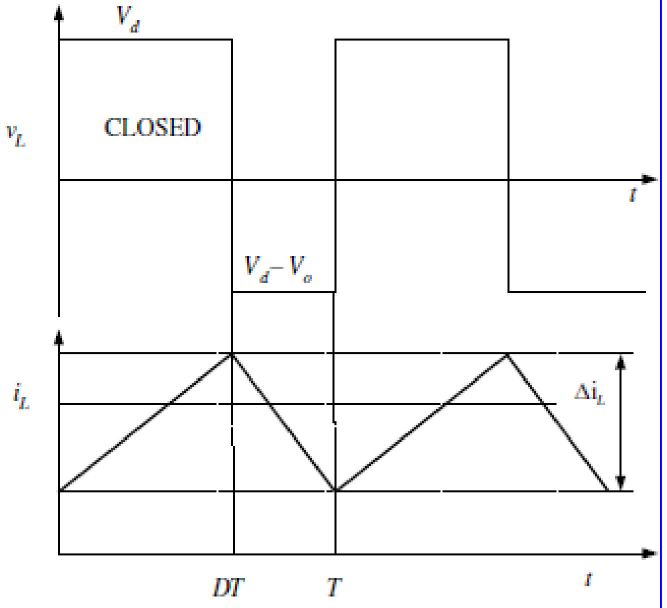
$$v_L = V_d = L\frac{di_L}{dt}$$

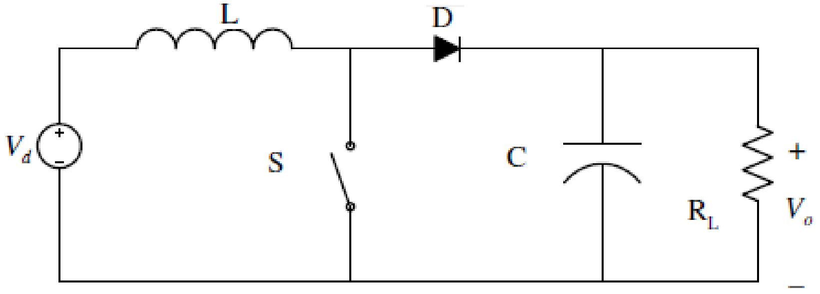
$$\Rightarrow \frac{di_L}{dt} = \frac{V_d}{L}$$

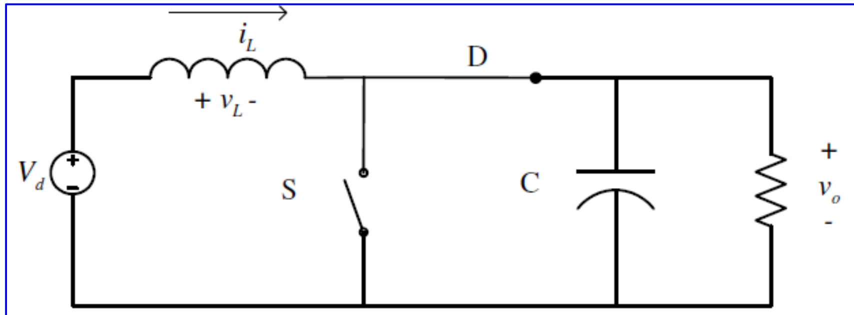
$$\frac{di_L}{dt} = \frac{\Delta i_L}{\Delta t} = \frac{\Delta i_L}{DT}$$

$$\Rightarrow \frac{di_L}{dt} = \frac{V_d}{L}$$

$$(\Delta i_L)_{closed} = \frac{V_d DT}{L}$$



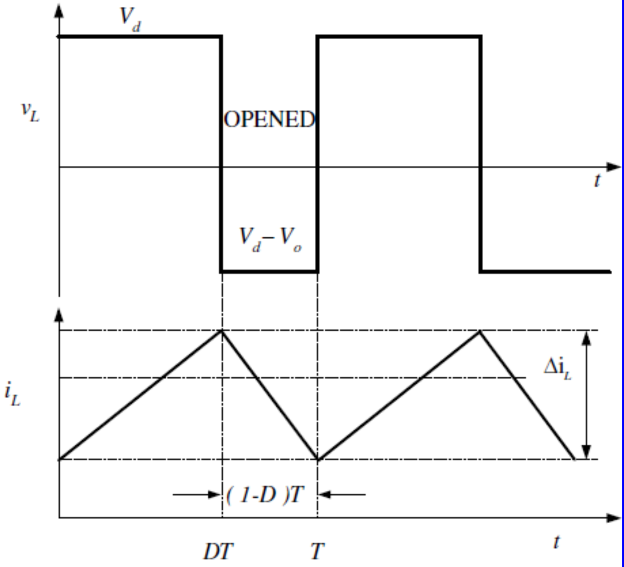




$$v_L = V_d - V_o = L\frac{di_L}{dt}$$

$$\Rightarrow \frac{di_L}{dt} = \frac{V_d - V_o}{L}$$

$$\frac{di_L}{dt} = \frac{\Delta i_L}{\Delta t} = \frac{\Delta i_L}{(1-D)T}$$



$$\Rightarrow \frac{di_L}{dt} = \frac{V_d - V_o}{L}$$

$$\Rightarrow (\Delta i_L)_{opened} = \frac{(V_d - V_o)(1-DT)}{L}$$

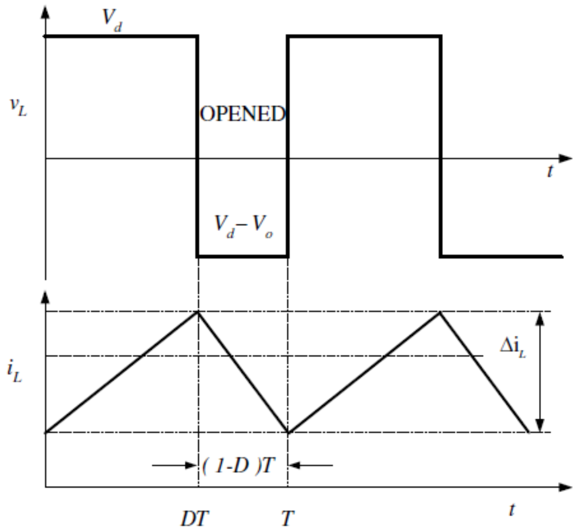
STEP-UP (BOOST) CONVERTER

The ΔI method

Input-Output Voltage Relationship: SS operation

$$\left(\Delta i_L\right)_{closed} = \frac{V_d DT}{L}$$

$$\left(\Delta i_L\right)_{opened} = \frac{(V_d - V_o)(1 - DT)}{L}$$

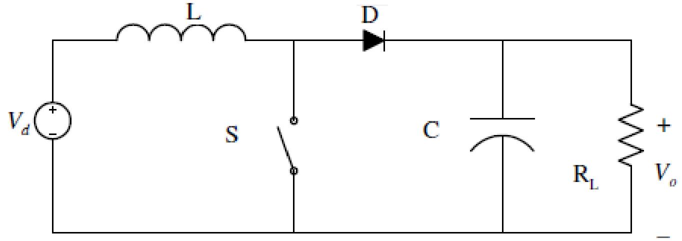


$$\left(\Delta i_L\right)_{closed} + \left(\Delta i_L\right)_{opened} = 0$$

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

$$\Rightarrow V_o = \frac{V_d}{1 - D}$$

Boost converter produces output voltage that is greater or equal to the input voltage.



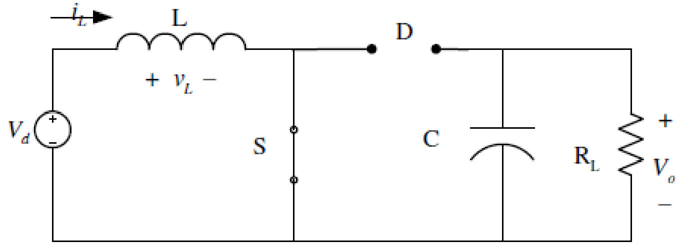
CIRCUIT OF BOOST CONVERTER

Alternative explanation:

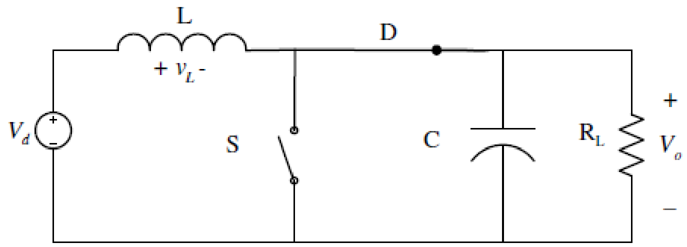
– when switch is closed, diode is reversed. Thus output is isolated. The input supplies energy to inductor.

– When switch is opened, the output stage receives energy from the input as well as from the inductor. Hence output is large.

– Output voltage is maintained constant by virtue of large C.

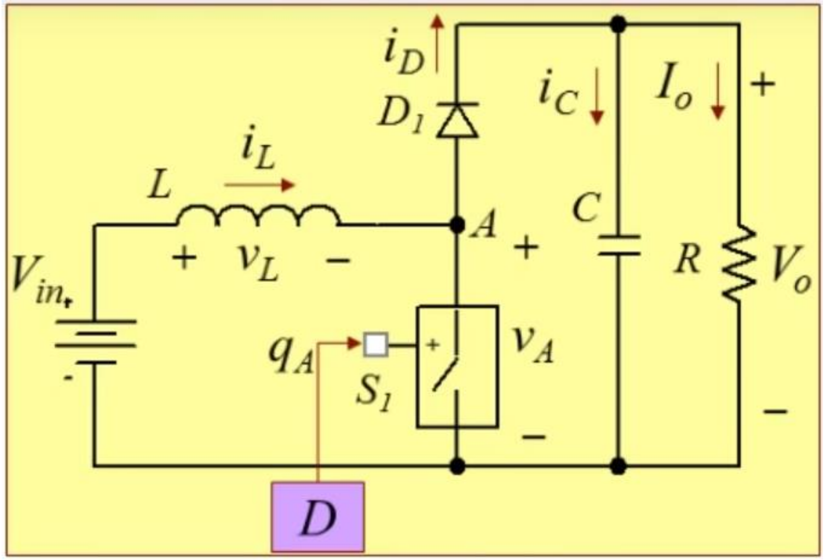


CIRCUIT WHEN SWITCH IS CLOSED



CIRCUIT WHEN SWITCH IS OPENED

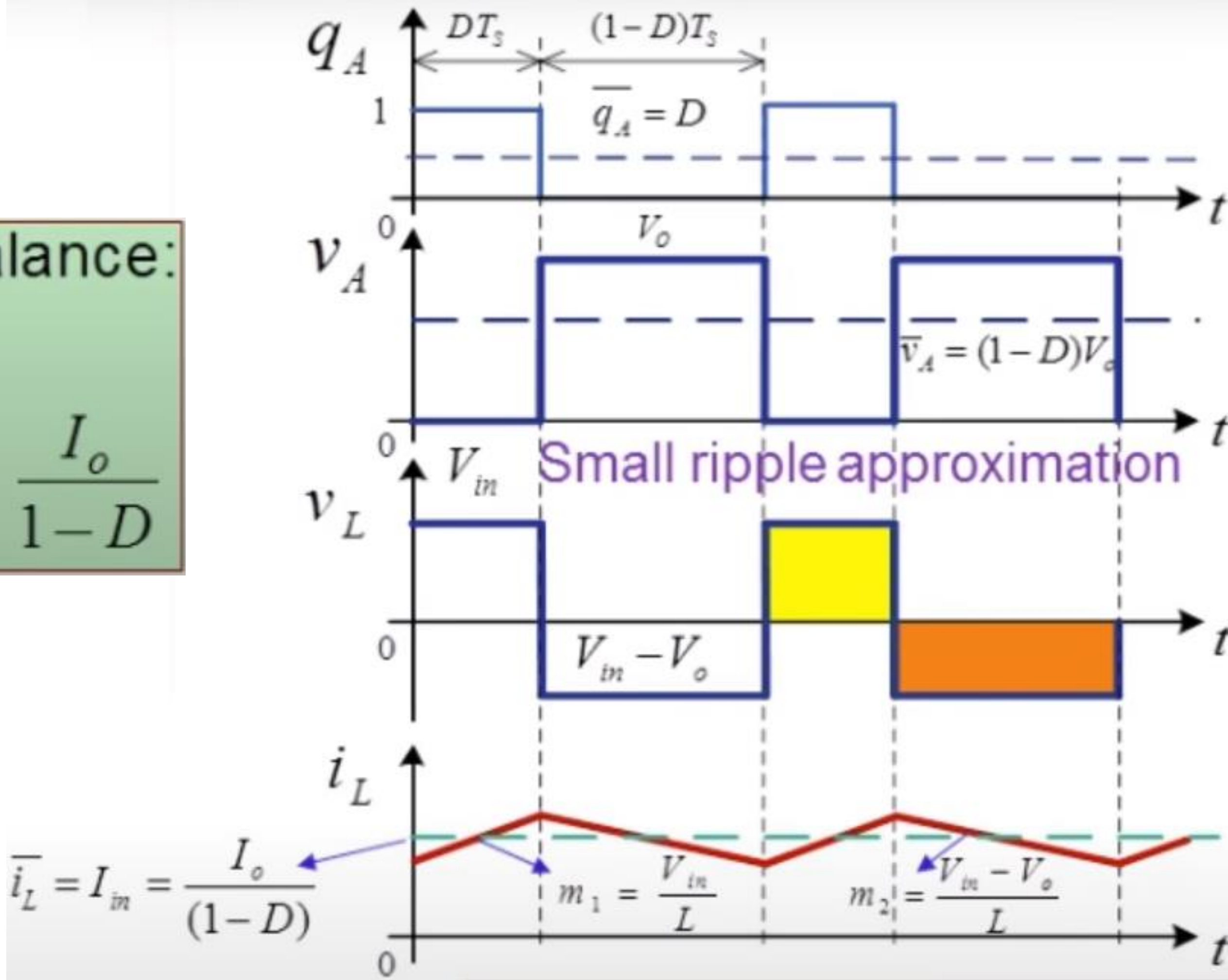
Boost Converter Waveforms

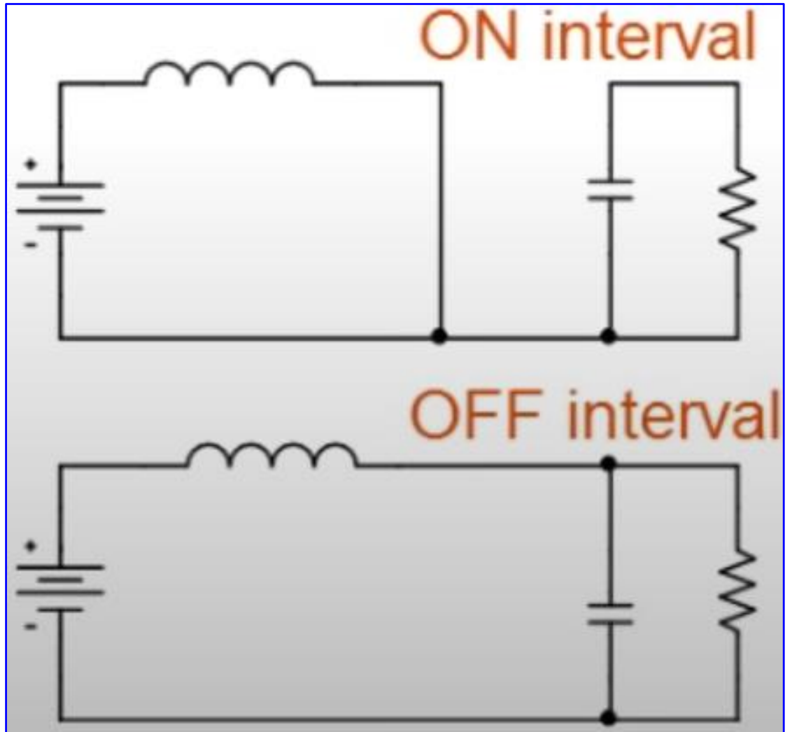


By power balance:

$$V_{in} I_{in} = V_o I_o$$

$$I_{in} = \frac{V_o}{V_{in}} I_o = \frac{I_o}{1-D}$$





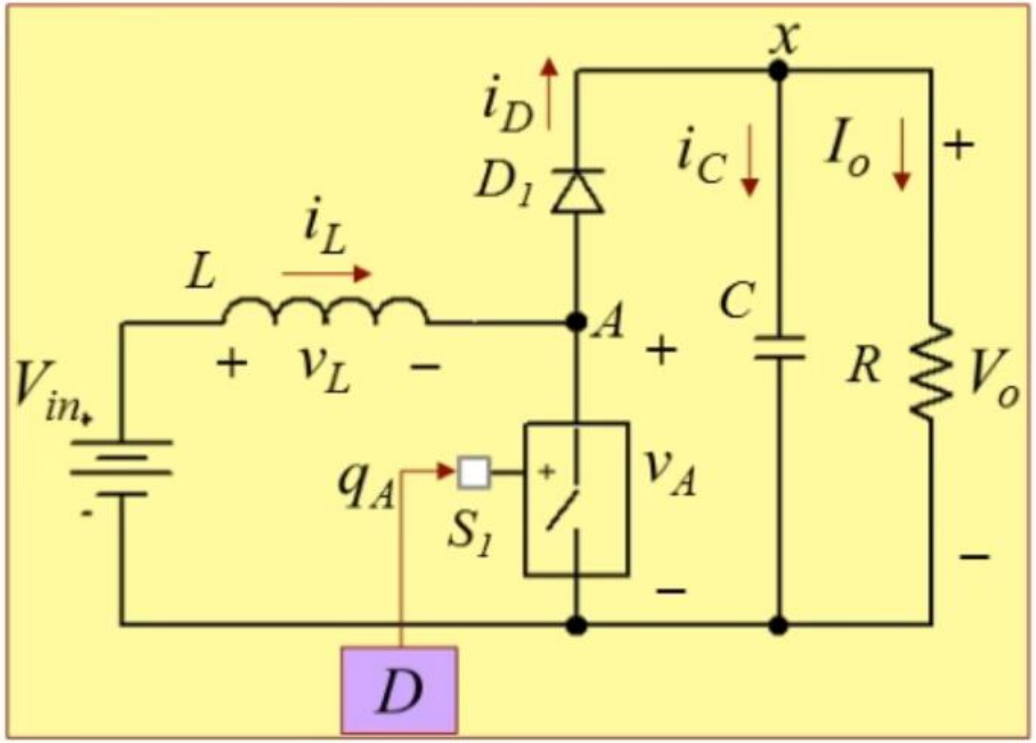
Volt-sec balance for L

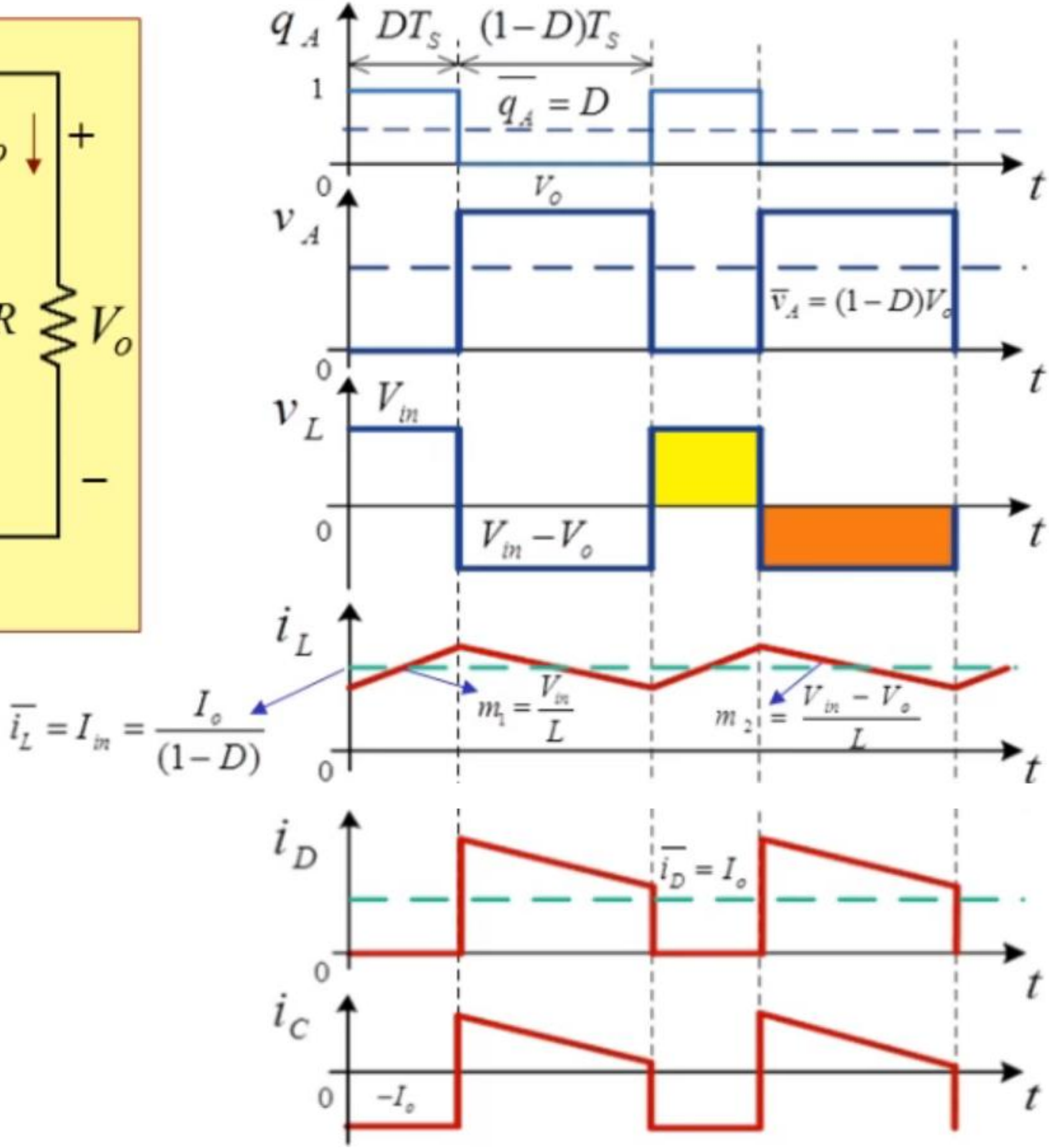
$$V_{in} DT_s + (V_{in} - V_o)(1-D)T_s = 0$$

$$V_{in}(D + 1 - D) = V_o(1-D)$$

$$\frac{V_o}{V_{in}} = \frac{1}{1-D}$$

Boost Converter Waveforms





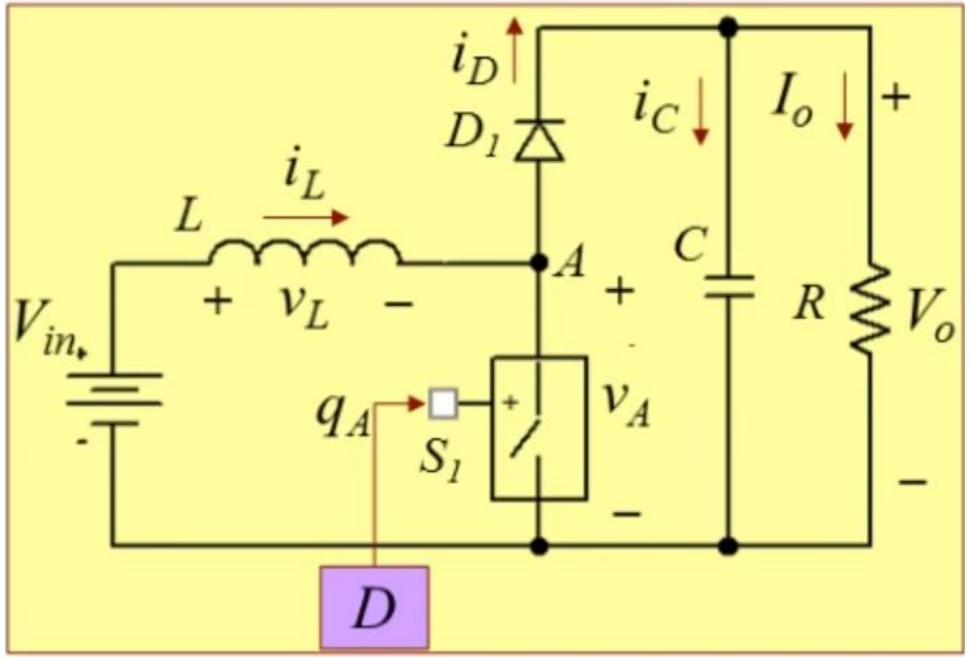
Average KCL at node x

$$\overline{i_D} = \overline{i_C} + I_o = I_o$$

KCL at node x instantaneously

$$i_C = i_D - I_o$$

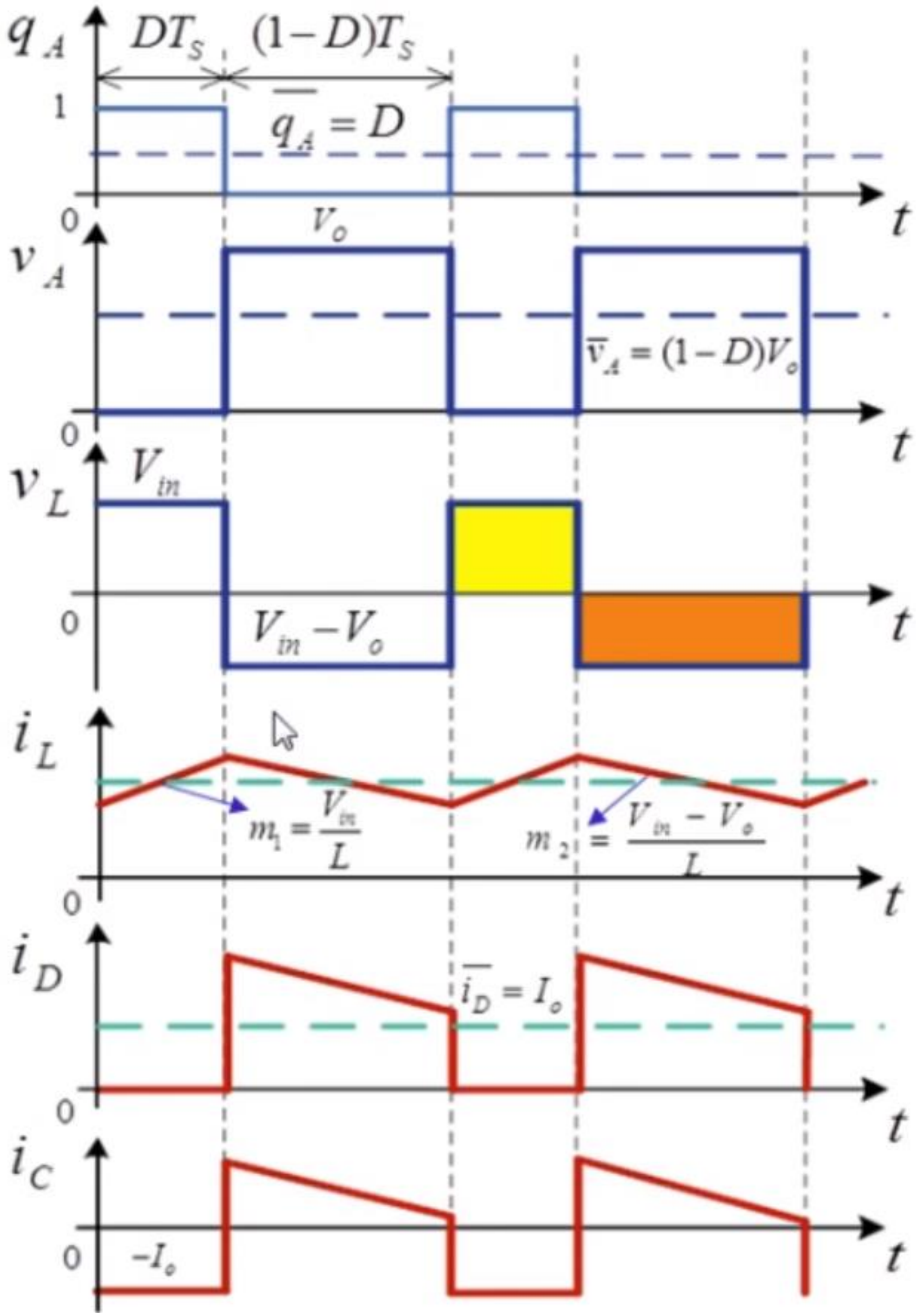
Boost Converter Waveforms



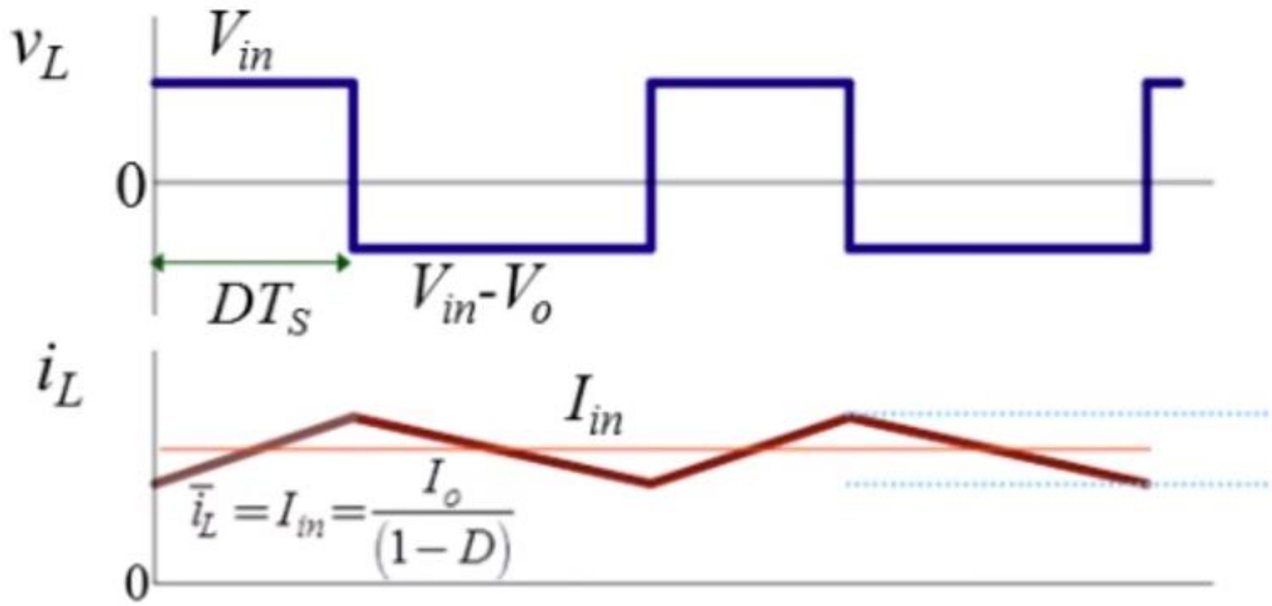
$$\frac{V_o}{V_{in}} = \frac{1}{1-D} \Rightarrow D = 1 - \frac{V_{in}}{V_o}$$

For constant output voltage and variable input voltage applications

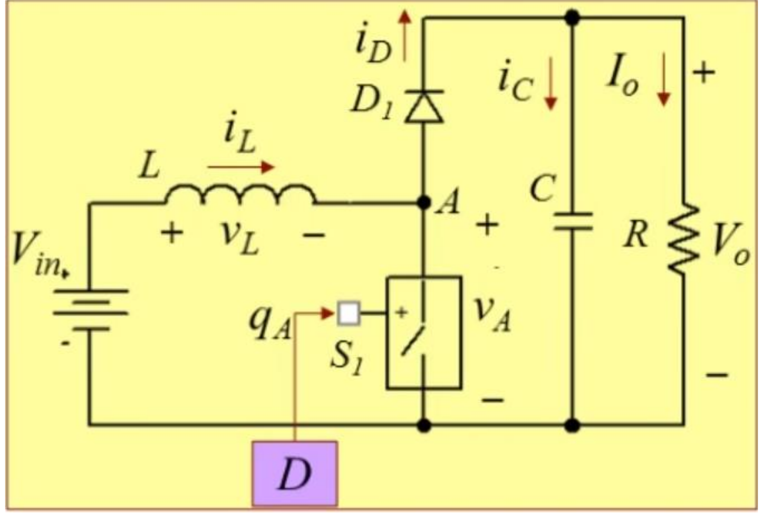
$$\left(1 - \frac{V_{in,max}}{V_o}\right) \le D \le \left(1 - \frac{V_{in,min}}{V_o}\right)$$



Selection of L



ΔI_L Peak-peak ripple in inductor current



- L selected to limit peak-peak inductor current ripple to a chosen value
  - For example, 10-20% of max. I_{in}
  - Specifications on input current ripple
  - CCM considerations
- Choice of L does not significantly affect capacitor selection

Consider the T_{ON} interval

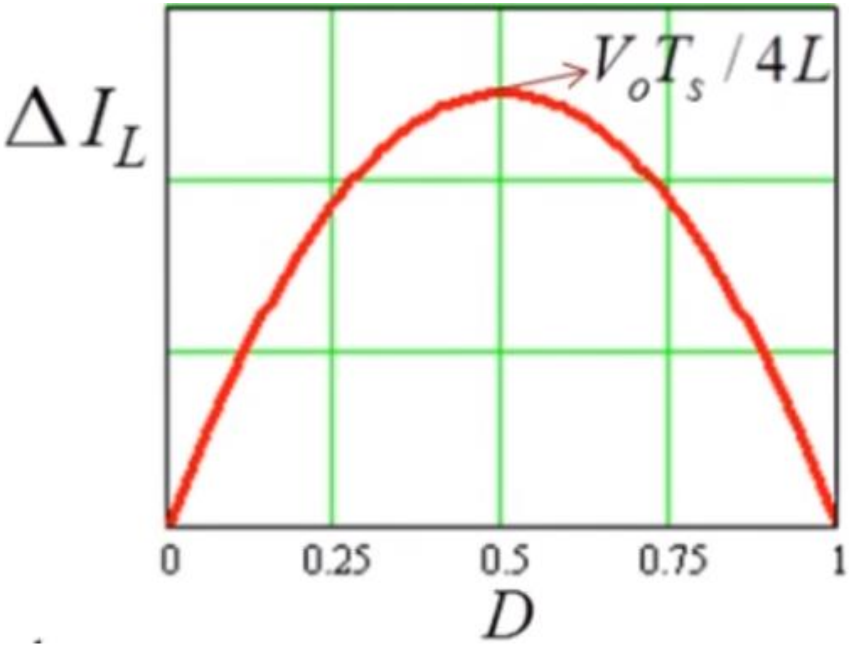
$$L\frac{\Delta I_L}{DT_S} = V_{in} = V_o(1-D)$$

$$\boxed{L = \frac{V_o D(1-D)T_S}{\Delta I_L}}$$

Selection of L

- Design for **worst case condition**

$$L = \frac{V_o D(1-D)T_S}{\Delta I_L}$$



Worst case condition for constant output voltage applications

$$\frac{dL(D)}{dD} = \frac{V_o T_S}{\Delta I_L}(1-2D) = 0$$

$\Rightarrow D = 0.5$ (or closest to 0.5 in the operating range of D)