DC-DC Boost converter / Step-up chopper:-

It's main application is in regulated DC power supplies and regenerative braking of DC motors. As the name implies, the o/p voltage is always greater than the i/p voltage.

Fig. (a) shows the realization of a Boost converter using an SPDT switch and Fig. (b) shows the practical realization of Boost converter, replacing SPDT switch by a power semiconducting device, S and diode, D.

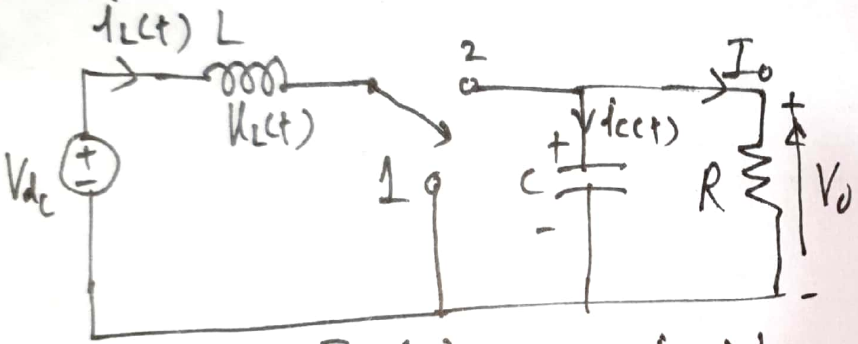


Fig (a).

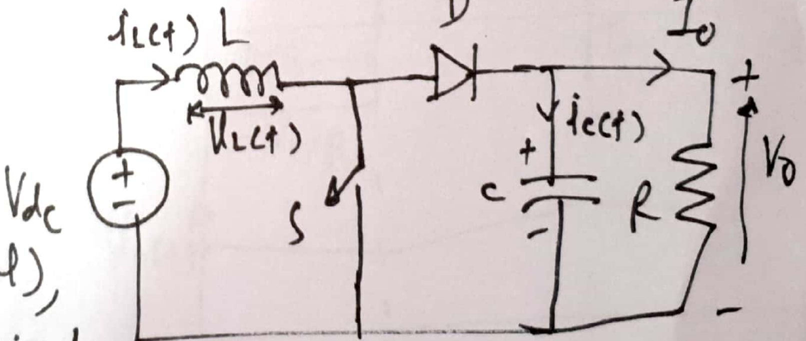
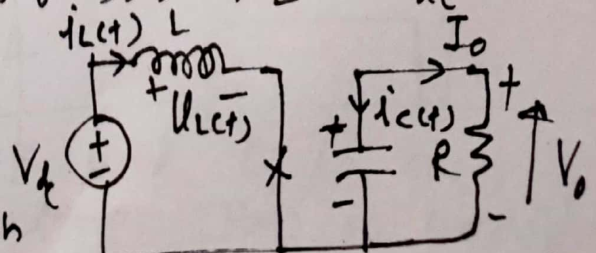


Fig (b).

During sub-interval 1 (Energy storage interval), with switch in position 1, ~~$v_L = V_{dc}$~~ (w.r.t. fig (a))

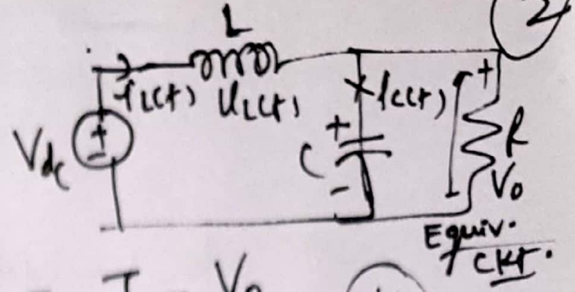
or with S ON (w.r.t. fig (b)), $v_L = V_{dc}$ — (1)

$i_c = -V_o/R$ — (2)



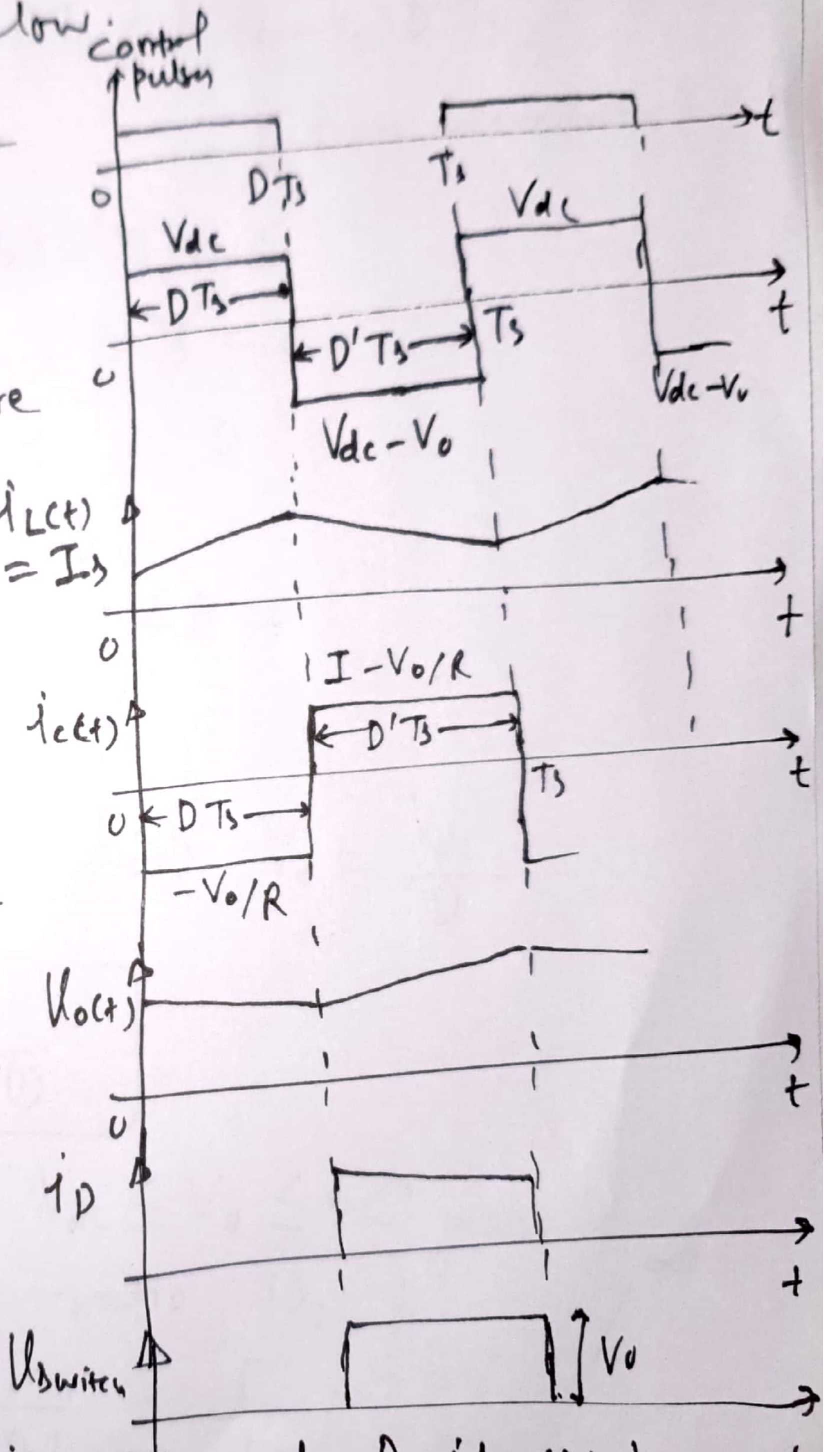
During sub-interval 2 (Energy transfer interval), with switch in position 2 (w.r.t. fig (a)) or diode, D ON (w.r.t. fig (b)),

$$V_L = V_{dc} - V_o \quad (3)$$



$$i_c = i_L - i_o = i_L - \frac{V_o}{R} = I - \frac{V_o}{R} \quad (4)$$

Above eqns. (1) to (4) are used to sketch the waveforms as below.



During energy storage interval (S ON), $V_L(t)$ is equal to V_{dc} and positive volt-seconds are applied to inductor. Since in steady-state, the total volt-seconds applied over one switching period must be zero, negative volt-seconds must be applied during energy transfer interval (S OFF and D ON), which implies that inductor voltage during second sub-interval (when S is OFF and D is ON) i.e., $V_{dc} - V_o$ must be negative. This is possible only if $V_o > V_{dc}$. Hence it proves that in a boost converter, o/p voltage is always greater than i/p voltage.

Now, total volt-sec. applied to the inductor over one switching period are:

$$\int_0^{T_s} V_L(t)\,dt = (V_{dc})\cdot DT_s + (V_{dc}-V_o)D'T_s = 0$$

(from waveforms)

$$\Rightarrow V_{dc}DT_s + (V_{dc}-V_o)D'T_s = 0$$

$$\Rightarrow V_{dc}D\cancel{T_s} + V_{dc}D'\cancel{T_s} - V_oD'\cancel{T_s} = 0$$

$$\Rightarrow V_{dc}(D+D') - V_oD' = 0$$

Since $D' = 1-D$

$$\therefore D+D' = D+1-D = 1$$

$$\therefore V_{dc} - V_oD' = 0$$

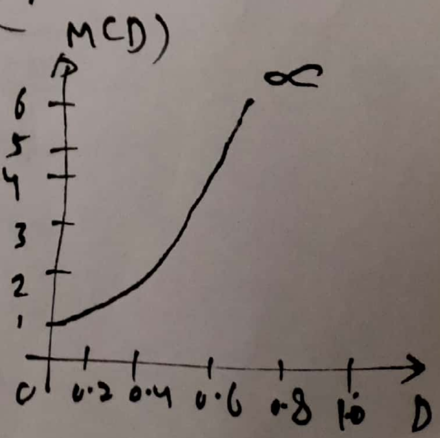
$$\Rightarrow V_oD' = V_{dc} \quad \Rightarrow V_o = \frac{V_{dc}}{D'}$$

$$\Rightarrow \boxed{V_o = \frac{V_{dc}}{(1-D)}}$$

For $0 \le D \le 1$, $V_{dc} \le V_o \le \infty$

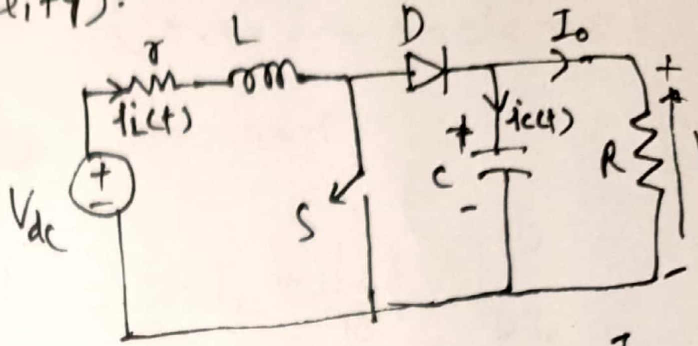
voltage conversion ratio is,

$$M(D) = \frac{V_o}{V_{dc}} = \frac{1}{D'} = \frac{1}{1-D}$$

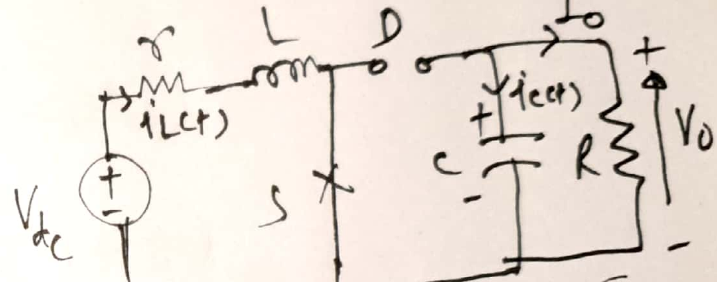


So, an ideal Boost converter is capable of producing any o/p voltage greater than i/p voltage. There are, of course, limits to the o/p voltage due to component non-idealities.

Let 'r' be the internal resistance of boost inductor, L (Non-ideality).



Equiv. ckt. during Energy storage interval ($0 < t < DT_s$) is as shown below:



Equiv. ckt. during energy storage interval

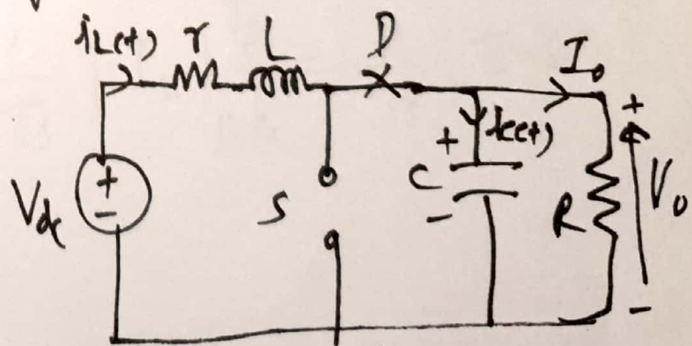
By KVL,

$$V_{dc} = r i_L + L\frac{di_L}{dt} \quad -(1)$$

By KCL,

$$C\frac{dV_o}{dt} + \frac{V_o}{R} = 0 \quad -(2)$$

Equiv. circuit during Energy transfer interval ($DT_s < t < T_s$) is as:



Equiv. ckt. during energy transfer interval

By KVL,

$$V_{dc} = r i_L + L\frac{di_L}{dt} + V_o \quad -(3)$$

By KCL,

$$C\frac{dV_o}{dt} + \frac{V_o}{R} = i_L \quad -(4)$$

Now,

$$V_{dc} = r I_L + L\left(\frac{di_L}{dt}\right) + \frac{1}{T_s}\int_{DT_s}^{T_s} V_o\,dt \quad -(5)$$

$$C\left(\frac{dv_o}{dt}\right) + \frac{V_o}{R} = \frac{1}{T_s}\int_{DT_s}^{T_s} i_L\,dt \quad -(6)$$

Now, Average values :

$$V_L = L\int_0^{T_s} \frac{di_L}{dt} = 0$$ (Average inductor voltage over one cycle = 0)

$$I_c = C\int_0^{T_s} \frac{dV_o}{dt} = 0$$ (Average capacitor current over one cycle = 0)

$\therefore$ From eqns. 5, we have

$$V_{dc} = \gamma I_L + \frac{1}{T_s}\int_{DT_s}^{T_s} V_o dt = \gamma \cdot I_L + \frac{1}{T_s}\left| V_o \right|_{DT_s}^{T_s}$$

$$V_{dc} = \gamma \cdot I_L + \frac{V_o}{T_s}(T_s - DT_s)$$

$$= \gamma I_L + \frac{V_o}{\cancel{T_s}} \cdot \cancel{T_s}(1-D)$$

$$\Rightarrow V_{dc} = \gamma \cdot I_L + V_o(1-D) \quad \text{— } 7$$

From eqn. 6, we have

$$\frac{V_o}{R} = \frac{1}{T_s}\int_{DT_s}^{T_s} i_L d(t) = \frac{1}{T_s}\left| I_L \right|_{DT_s}^{T_s} = \frac{I_L}{T_s}(T_s - DT_s)$$

$$\frac{V_o}{R} = \frac{I_L \cdot T_s}{T_s}(1-D)$$

$$\Rightarrow \frac{V_o}{R} = I_L(1-D) \quad \text{— } 8$$

Multiplying eqn. 7 by $(1-D)$, we get

$$V_{dc}(1-D) = \gamma \cdot I_L(1-D) + V_o(1-D)^2$$

Using eqn. 8, we get

$$V_{dc}(1-D) = r \cdot \frac{V_o}{R} + V_o(1-D)^2$$

$$V_o\left[\frac{r}{R} + (1-D)^2\right] = V_{dc}(1-D)$$

$$\Rightarrow \boxed{V_o = \frac{V_{dc}(1-D)}{r/R + (1-D)^2}}$$

This is the modified expression for average o/p voltage of a practical Boost converter with non-linearities.

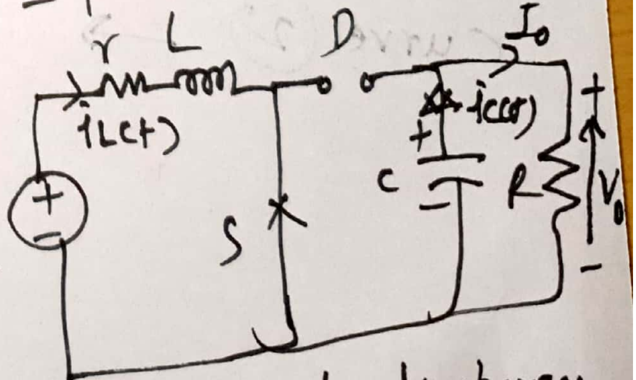
For $D=0$, $\boxed{V_o = \frac{V_{dc}}{r+R} \times R}$

For ideal case ($r=0$),

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

Question? Why $V_o = 0$ for $D=1$ (practically) and $V_o \neq \infty$ for $D=1$

For $D=1$, equiv. ckt. is as shown ⟶



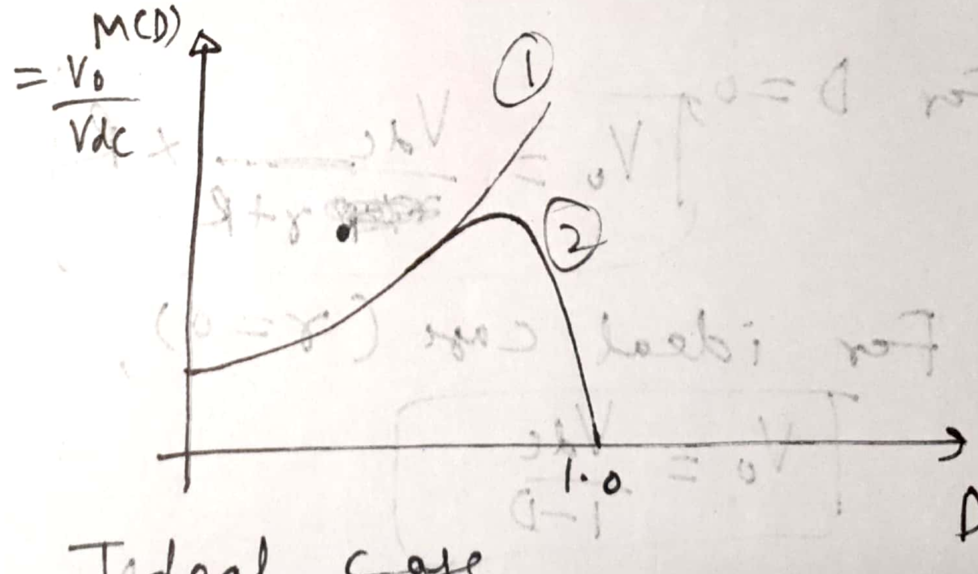
In this case, V_{dc} is predominantly shorted through L (r) and 'C' continuously supplied power to load and discharges.

$$i_C(t) = -I_o = -V_o/R$$

$\Rightarrow$ Capacitor voltage gradually decreases and finally becomes zero (i.e., $V_o = 0$).

On supply side, V_{dc} is applied across L. So, $L\frac{di_L}{dt}$ is +ive which means inductor current keeps on increasing and we may soon see smoke coming out of the circuit due to the failure or burning of either boost inductor, L or source, V_{dc} or switch, S or all of them as

$$I_{dc} = \frac{V_{dc}}{r} \text{ is very large.}$$



Curve (1) ⟶ Ideal case.

Curve (2) ⟶ Practical case.