Boost Converter Theory

Introduction

A **Boost Converter**, also known as a step-up converter, is a DC-to-DC power converter that steps up the input voltage to a higher output voltage while stepping down the current. The main components of a boost converter are:

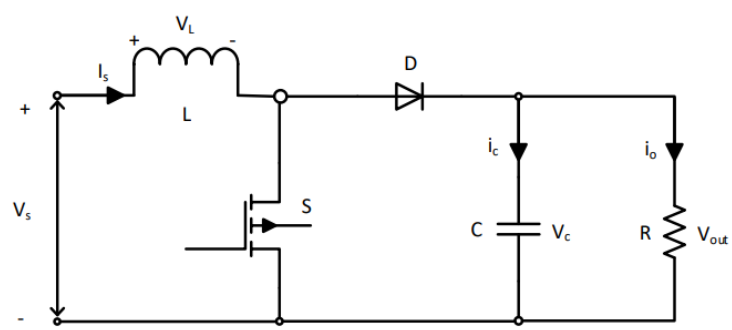
1. **Inductor (L):** Stores energy when the switch is ON and releases it to the load when the switch is OFF.
2. **Switch (usually a MOSFET):** Controls the flow of current through the inductor.
3. **Diode (D):** Ensures current flows in the correct direction.
4. **Capacitor (C):** Smoothens the output voltage to reduce ripples.

Working Principle

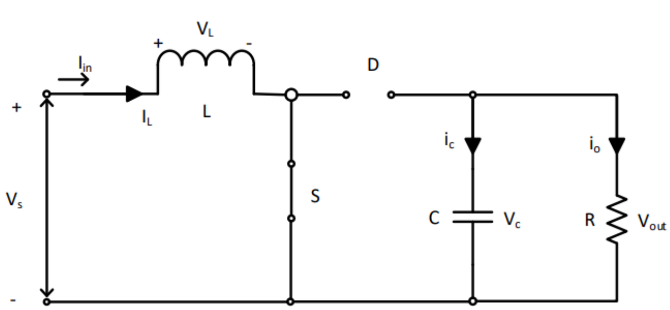
The operation of the boost converter can be divided into two main states:

1. **Switch ON (0<t<DT):**
   - The MOSFET conducts, and the inductor stores energy from the source.
   - The load is powered by the energy stored in the capacitor.
2. **Switch OFF (DT<t<T):**
   - The MOSFET turns OFF, causing the inductor to release its stored energy to the load via the diode.
   - The combined energy from the input source and the inductor is transferred to the load, increasing the output voltage.

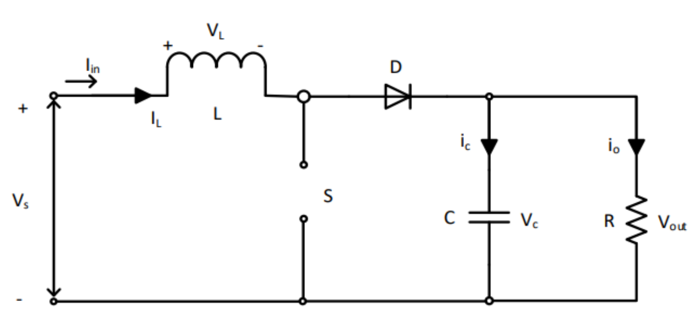
Circuit



Switch ON:



Switch OFF:



By volt-sec balance: $\int V_L.dt = 0$

For 0<t<DT,
$V_L = V_s$

For DT<t<T,
$V_L = V_s - V_o$

So,
$\Rightarrow V_s \times DT + (V_s - V_o) \times (T - DT) = 0$
$\Rightarrow V_s(DT + T - DT) = V_o(T - DT)$
$\therefore V_o = \dfrac{V_s}{1 - D}$
Here, $(1 - D) < 1$, so $V_o > V_s$ always.

By ampere-sec balance: $\int i_c.dt = 0$
For 0<t<DT,
$i_c = -i_o$

For DT<t<T,
$i_c = i_L - i_o$

So,
$\Rightarrow -i_o \times DT + (i_L - i_o)(T - DT) = 0$
$\Rightarrow i_L(1 - D) = i_o$
$\therefore i_L = \dfrac{i_o}{1 - D}$
Note: This i_L is the average inductor current. So, $i_L = i_L(avg)$.

Some Important Parameter

- Ripple in Inductor Current: $\Delta i_L = \frac{DV_s}{fL}$
- RMS Inductor Current: $i_L(rms) = \sqrt{i_L^2 + \left(\frac{\Delta i_L}{2\sqrt{3}}\right)^2}$
- Source Current: $i_s = i_L$ (always)
- Switch or MosFET Current: $i_{sw}(avg) = Di_L$ and $i_{sw}(rms) = \sqrt{D}i_L(rms)$ and this works only for time 0 to DT.
- Diode Current: $i_D(avg) = (1 - D)i_L$ and $i_D(rms) = \sqrt{(1 - D)}i_L(rms)$ and works only for time DT to T.
- Ripple in Output Voltage: $\Delta V_o = \frac{Di_o}{fC}$
- Critical Inductance(L_c): Value of inductance at which converter operates at boundary of continuous and discontinuous conduction. $L_c = \frac{D(1-D)^2R}{2f}$
- Critical Capacitance: $C_c = \frac{D}{2fR}$

Efficiency and Losses

Boost converter efficiency (η) is the ratio of output power (P_{out}) to input power (Pin) :

$$\eta = \frac{\mathrm{P_{out}}}{P_{in}}$$

Losses can be minimized through careful component selection and optimized design. Key types of losses include:

- **Conduction Losses:** Caused by the resistance in inductors, switches, and diodes. Using components with low resistance can reduce these losses.
- **Switching Losses:** Occur during MOSFET state transitions. Minimizing on-state resistance and optimizing switching speeds can help reduce these.
- **Diode Reverse Recovery Losses:** Due to reverse current during state transitions. Selecting diodes with short reverse recovery times, like Schottky diodes, mitigates these losses.
- **Magnetic Core Losses:** Result from energy dissipation in the inductor core. These can be minimized by choosing suitable core materials and reducing magnetic flux density.
- **Capacitor Losses:** Caused by the Equivalent Series Resistance (ESR) of capacitors. Using low-ESR capacitors improves efficiency.

Applications

Boost converters are widely used to step up input voltage in various fields:

- **Power Supplies:** Provide stable output voltages for portable devices, laptops, and power banks.
- **LED Lighting:** Ensure consistent brightness in LEDs by regulating current, especially in automotive systems.
- **Solar Power Systems:** Enhance energy extraction by stepping up panel voltage in MPPT controllers.
- **Electric Vehicles:** Supply higher voltages for traction motors and auxiliary systems to ensure optimal performance.
- **Telecommunications:** Stabilize voltages for RF transmitters and communication equipment.
- **Sensor Systems:** Provide stable voltage for sensitive components like ADCs in battery-operated or energy-harvesting devices.