Introduction-DC-DC Converters

There are two basic types of dc-dc converter circuits, termed as Step up and step down chopper.

- In all of these circuits, a power device is used as a switch.
- In all these circuits, the thyristor is connected in series with load to a dc supply, or a positive (forward) voltage is applied between anode and cathode terminals. The thyristor turns off, when the current decreases below the holding current, or a reverse (negative) voltage is applied between anode and cathode terminals. So, a thyristor is to be force-commutated, for which additional circuit is to be used, where another thyristor is often used.
- Later, GTO's came into the market, which can also be turned off by a negative current fed at its gate, unlike thyristors, requiring proper control circuit. The turn on and turn-off times of GTOs are lower than those of thyristors. So, the frequency used in GTO based choppers can be increased, thus reducing the size of filters.
- Earlier, dc-dc converters were called 'choppers', where thyristors are used. It may be noted here that converter (dc-dc) is a 'step-up chopper'. With the advent of bipolar junction transistor (BJT), which is termed as self- commutated device, it is used as a switch, instead buck converter (dc-dc) is called as 'step-down chopper', whereas boost of thyristor, in dc-dc converters. This device (NPN transistor) is switched on by a positive current through the base and emitter, and then switched off by withdrawing the above signal. The collector is connected to a positive voltage.

- Now-a days, MOSFETs are used as a switching device in low voltage and high current applications. It may be noted that, as the turn-on and turn- off time of MOSFETs are lower as compared to other switching devices, the frequency used for the dc-dc converters using it (MOSFET) is high, thus, reducing the size of filters as stated earlier.

- These converters are now being used for applications, one of the most important being Switched Mode Power Supply (SMPS). Similarly, when application requires high voltage, Insulated Gate Bi-polar Transistors (IGBT) are preferred over BJTs, as the turn-on and turn-off times of IGBTs are lower than those of power transistors (BJT), thus the frequency canbe increased in the converters using them. So, mostly self-commutated devices of transistor family as described are being increasingly used in dc- dc converters.

DEFINITION:

- Converting the unregulated DC input to a controlled DC output with a desired voltage level.

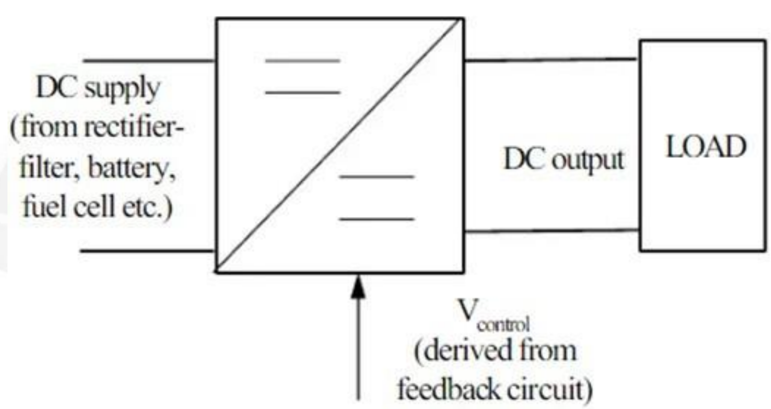

Figure. 1 Block diagram of DC/DC Converter

[Source: "Power Electronics" by P.S.Bimbra, Khanna Publishers]

- **DC to DC converter** is very much needed nowadays as many industrial applications are dependent upon DC voltage source. The performance of these applications will be improved if we use a variable DC supply. It will help to improve controllability of the equipments also. Examples of such applications are subway cars, trolley buses, battery operated vehicles etc.

We can control and vary a constant DC voltage with the help of a chopper. Chopper is a basically static power electronics device which converts fixed DC voltage/power to variable DC voltage or power. It is nothing but a high speed switch which connects and disconnects the load from source at a high rate to get variable or chopped voltage at the output.

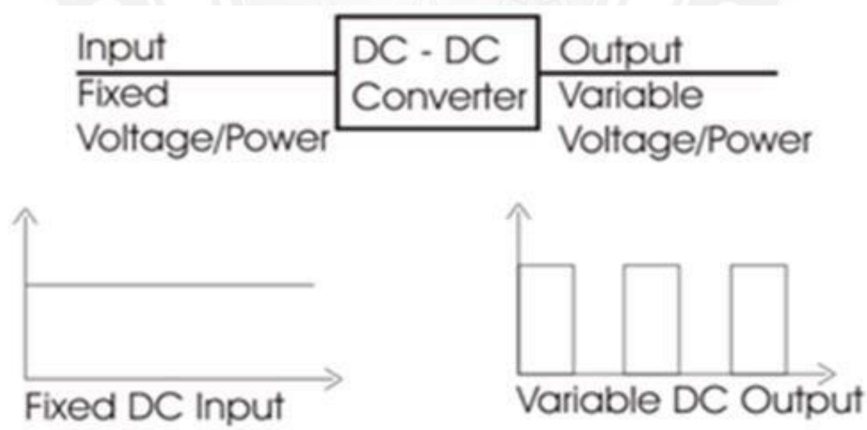

Figure.2 DC-DC Power conversion block diagram

[Source: "Power Electronics" by P.S.Bimbra, Khanna Publishers]

DC-DC converters types

- ❖ Vo<Vin - Buck converter
- ❖ Vo>Vin - Boost converter
- ❖ Vo<Vin or Vo>Vin - Buck-Boost converter,

APPLICATIONS

DC to DC converters are applied for many applications such as in

- Switched Mode Power Supply System.
- DC motors as speed controllers.
- DC voltage boosters,Battery chargers.
- Railway systems, Electric cars etc…

Switched Mode Regulators

Switched Mode Regulators provide much greater power efficiency inDC-to-DC conversion than linear regulators, which are simpler circuits that lower voltages by dissipating power as heat, but do not step up output current. Switched mode regulators consists of energy storage elements along with dc-dc chopper circuits.To reduce voltage ripple, filters made of capacitors (or capacitors in combination with inductors) are normally added to such a converter's output (load-side filter)and input (supply-side filter.

Switched Mode Regulators are classified into Buck, Boost, Buck-Boost converter

BUCK converter

A buck converter (step-down converter) is a DC-to-DC power converter which steps down voltage while stepping up current from its input (supply) to its output (load).

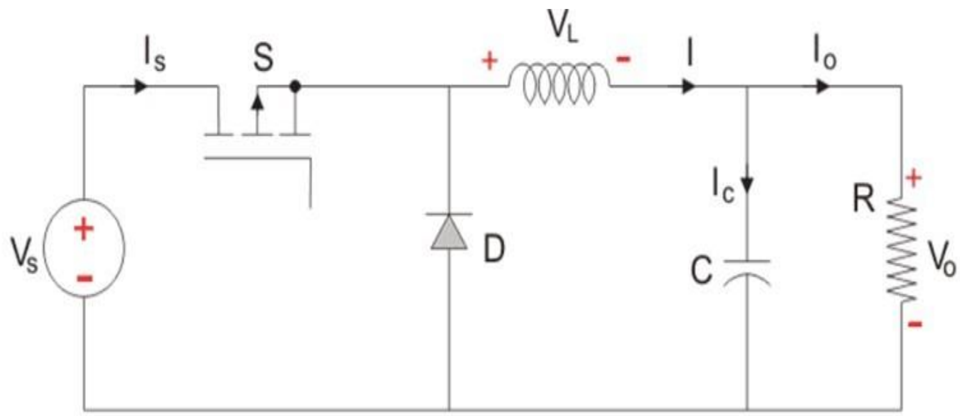

Figure 3. BUCK CONVERTER

[Source: "Power Electronics" by P.S.Bimbra, Khanna Publishers]

MODE I: SWITCH IS ON, DIODE IS OFF

The voltage across the capacitance in steady state is equal to the output voltage. The switch is on for a time T_{ON} and is off for a time T_{OFF}. We define the time period, T, as T=Ton+Toff, and the switching frequency,

f= 1/T = chopping frequency

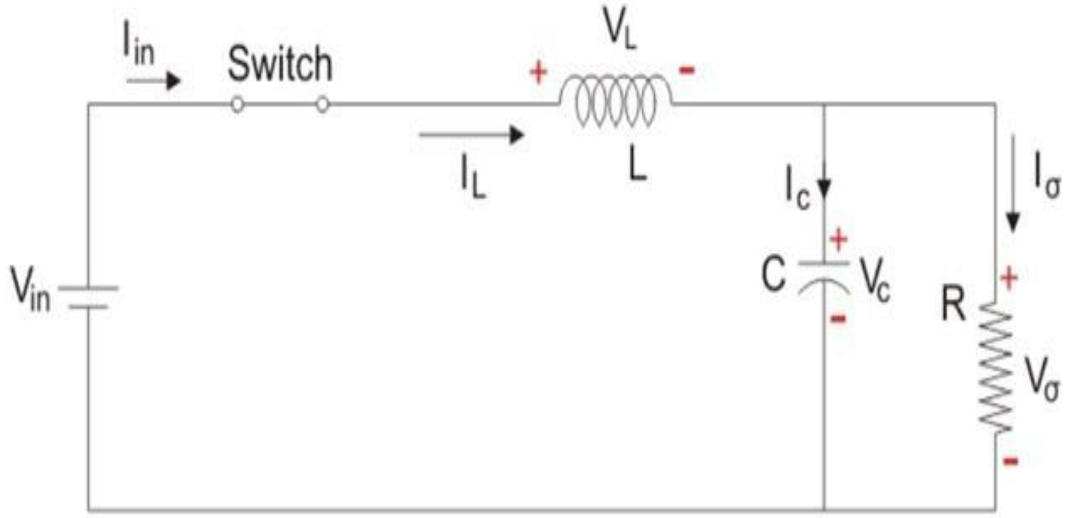

Figure.4 Buck converter- Mode II circuit diagram

[Source: "Power Electronics" by P.S.Bimbra, Khanna Publishers]

MODE II: SWITCH IS OFF, DIODE IS ON

Here, the energy stored in the inductor is released and is ultimately dissipated inthe load resistance, and this helps to maintain the flow of current through the load. But for analysis we keep the original conventions to analyse the circuit using KVL.

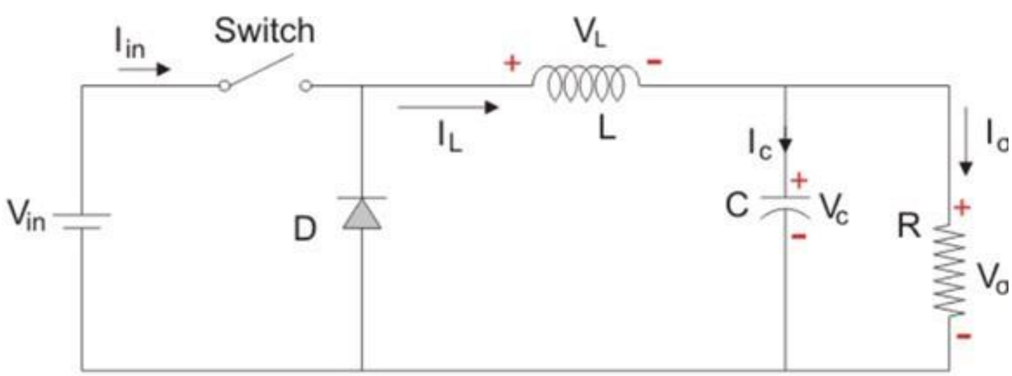

Figure 3.5.3 Buck converter- Mode II circuit diagram

[Source: "Power Electronics" by P.S.Bimbra, Khanna Publishers]

Average load Voltage is given by

- $V_0 = T_{on}/(T_{on} + T_{off}) * V_s = (T_{on}/T)\ V = D$
- $V_s T_{on}$: on -time T_{off} : off- time
- Thus the load voltage can be controlled by varying the duty cycle D

$$\mathbf{V_0 = f.\, T_{on}\, .V_s}$$

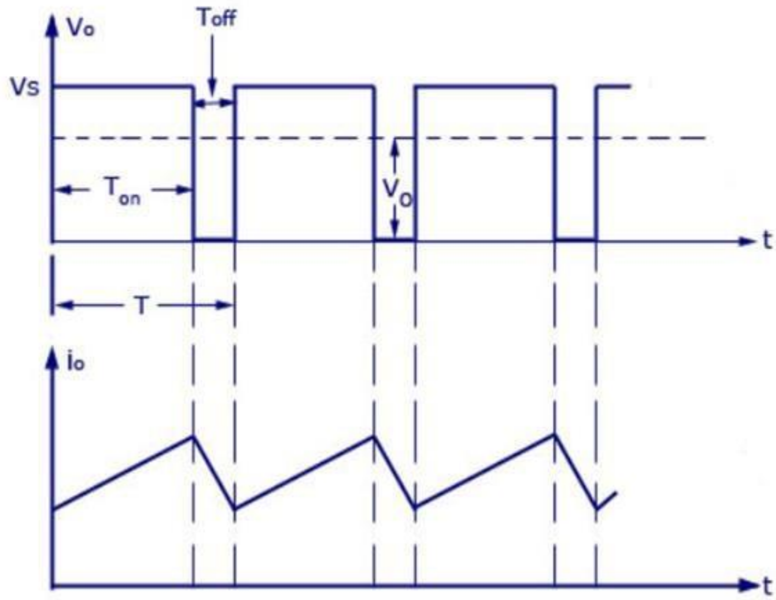

Figure.5 Buck converter Output Voltage and Current Waveforms
[Source: "Power Electronics" by P.S.Bimbra, Khanna Publishers]

BOOST CONVERTER

- Boost converter which increases the input DC voltage to a specified DC output voltage. A typical Boost converter is shown below.
- Step-up chopper works as a step-up transformer on DC current.
- The working principle of a step up chopper can be explained from the above diagram. In the circuit, a large inductor L is connected in series to the supply voltage. Capacitor maintains the continuous output voltage to the load. The diode prevents the flow of current from load to source.

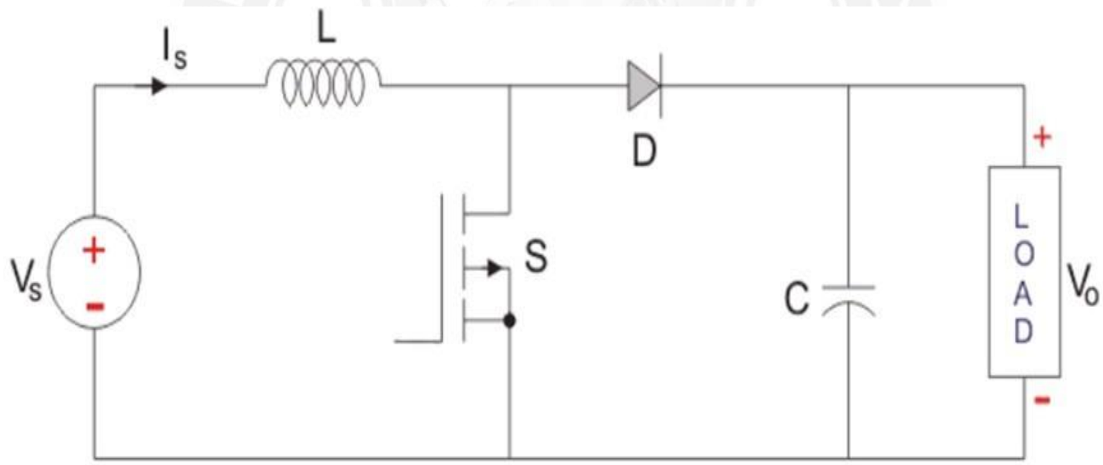

Figure. 6 Block diagram of Boost converter

[Source: "Power Electronics" by P.S.Bimbra, Khanna Publishers]

- The input voltage source is connected to an inductor. The solid-state device which operates as a switch is connected across the source. The second switch used is a diode. The diode is connected to a capacitor, and the load and the two are connected in parallel as shown in the figure above.

- The inductor connected to input source leads to a constant input current, and thus the Boost converter is seen as the constant current input source. And the load can be seen as a constant voltage source. The controlled switch is turned on and off by using Pulse Width Modulation(PWM). PWM can be time-based or frequency based. Frequency-based modulation has disadvantages like a wide range of frequencies to achieve the desired control of the switch which in turn will give the desired output voltage. Time-based Modulation is mostly used for DC-DC converters. It is simple to construct and use. The frequency remains constant in this type of PWM modulation.

The Boost converter has two modes of operation.

The first mode is when the switch is on and conducting.

MODE I : SWITCH IS ON, DIODE IS OFF

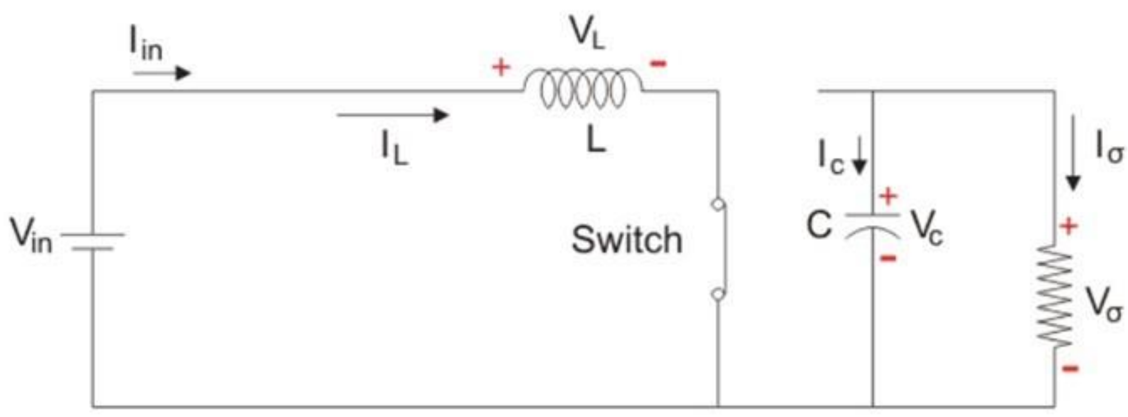

Figure.7 Boost converter- Mode I circuit diagram

[Source: "Power Electronics" by P.S.Bimbra, Khanna Publishers]

- The Switch is ON and therefore represents a short circuit ideally offering zero resistance to the flow of current so when the switch is ON all the current will flow through the switch and back to the DC input source. Let us say the switch is on for a time T_{ON} and is off for a time T_{OFF}. We define the time period, T, as T=Ton + Toff.

- When the chopper is turned ON the current through the inductance L will increase from I_1 to I_2. As the chopper is on the source voltage is applied to L that is $v_L = V_S$.

MODE II : SWITCH IS OFF, DIODE IS ON

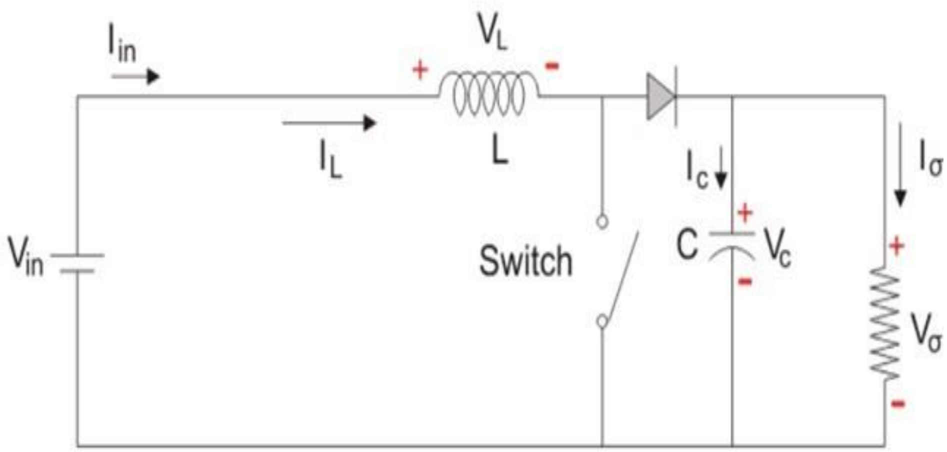

Figure.8 Boost converter- Mode II circuit diagram

[Source: "Power Electronics" by P.S.Bimbra, Khanna Publishers]

When the chopper is OFF, the KVL can be written as $v_L - V_0 + V_S = 0$ or $v_L = V_0 - V_S$

where v_L is the voltage across L. Variation of source voltage v_S , source current I_S , load voltage v_0 and load current i_O is sketched in the fig .

Let us assume that the variation of output current is linear, the energyinput to inductor from the source, during the time period T_{on} , is

$$W_{in}= V_s (I_1+I_2/2)\, T_{on}$$

During the time T_{off} the chopper is off, so the energy released bythe inductor to the load is

$$W_{off} = (V_0-V_s)(I_1+I_2/2).T_{off}$$

Let us assume that the system is lossless, then the two energiessay W_{in} and W_{off} are equal.

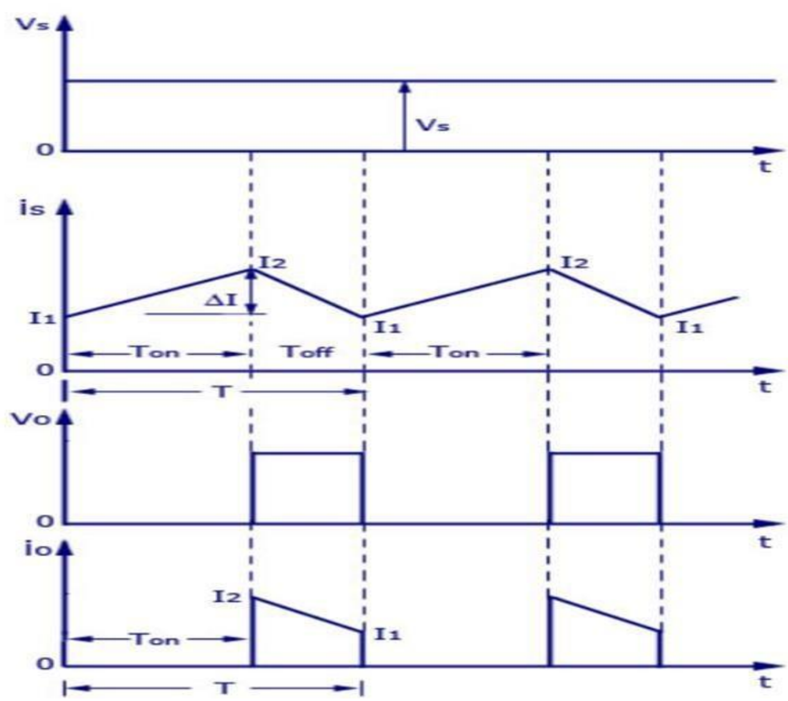

Figure.9 Boost converter Waveforms

[Source: "Power Electronics" by P.S.Bimbra, Khanna Publishers]

Boost converter Output Voltage

So equating these two we will get

$$V_s (I_1+I_2/2) T_{on} = (V_0-V_s)(I_1+I_2/2).T_{off}$$

$$V_s T_{on} = (V_0-V_s) T_{off}$$

$$V_0T_{off} = V_s (T_{off} + T_{on}) = V_s .T$$

$$V_0 = V_S (T/T_{off}) = V_S \quad (T/T-T_{on}) = V_S (1/(1-D)$$

From the above equation , we can see that the average voltage across the load can be stepped up by varying the duty cycle.

We know that D varies between 0 and 1. But as we can see from the equation above that if D = 1 then the ratio of output voltage to input voltage at steady state goes to infinity.

BUCK -BOOST CONVERTER

- **Buck Boost converter** which can operate as a DC-DC Step-Down converter or a DC-DC Step-Up converter depending upon the duty cycle. A typical Buck-Boost converter is shown below.

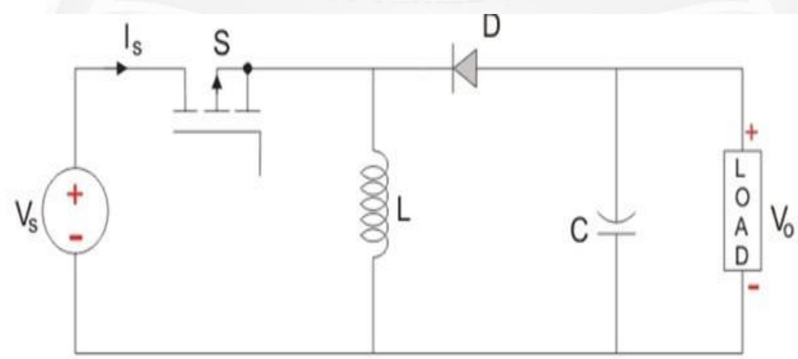

Figure. 10 Buck- Boost converter circuit diagram

[Source: "Power Electronics" by P.S.Bimbra, Khanna Publishers]

- The input voltage source is connected to a solid state device. The second switch used is a diode. The diode is connected, in reverse to the direction of power flow from source, to a capacitor and the load and the two are connected in parallel as shown in the figure above.

- The controlled switch is turned on and off by using Pulse Width Modulation (PWM). PWM can be time based or frequency based. Frequency based modulation has disadvantages like a wide range of frequencies to achieve the desired control of the switch which in turn will give the desired output voltage. Time based Modulation is mostly used for DC-DC converters. It is simple to construct and use. The frequency remains constant in this type of PWM modulation.

The Buck Boost converter has two modes of operation.

MODE I : SWITCH IS ON, DIODE IS OFF

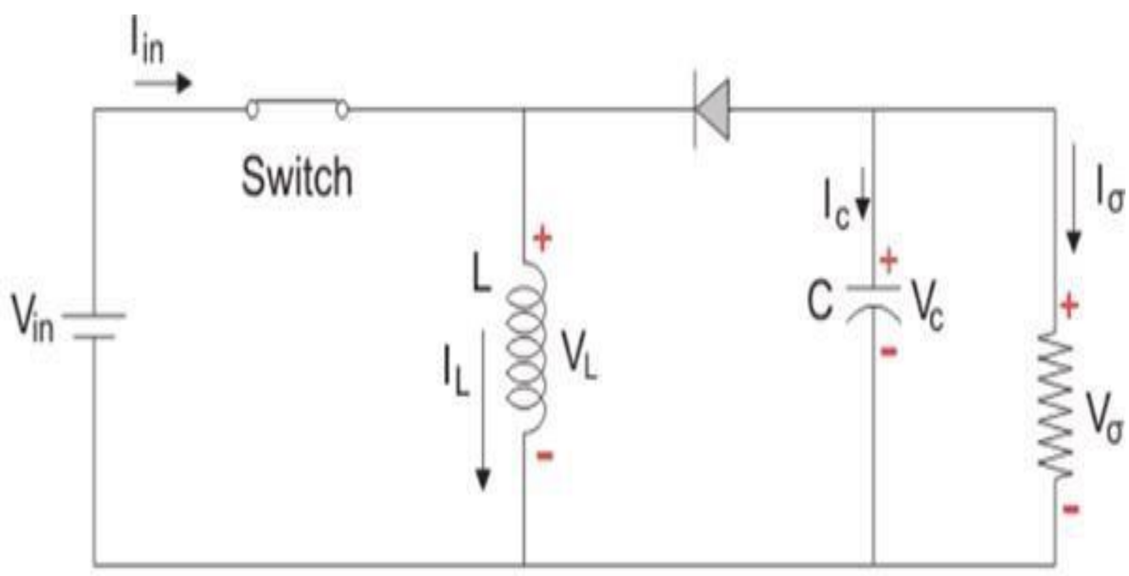

Figure.11 Buck- Boost converter- Mode I circuit

[Source: "Power Electronics" by P.S.Bimbra, Khanna Publishers]

- The Switch is ON and therefore represents a short circuit ideally offering zero resistance to the flow of current so when the switch is ON all the current will flow through the switch and the inductor and back to the DC input source. The inductor stores charge during the time the switch is ON and when the solid state switch is OFF the polarity of the Inductor reverses so that current flows through the load and through the diode and back to the inductor.
- So the direction of current through the inductor remains the same.

MODE II : SWITCH IS OFF, DIODE IS ON

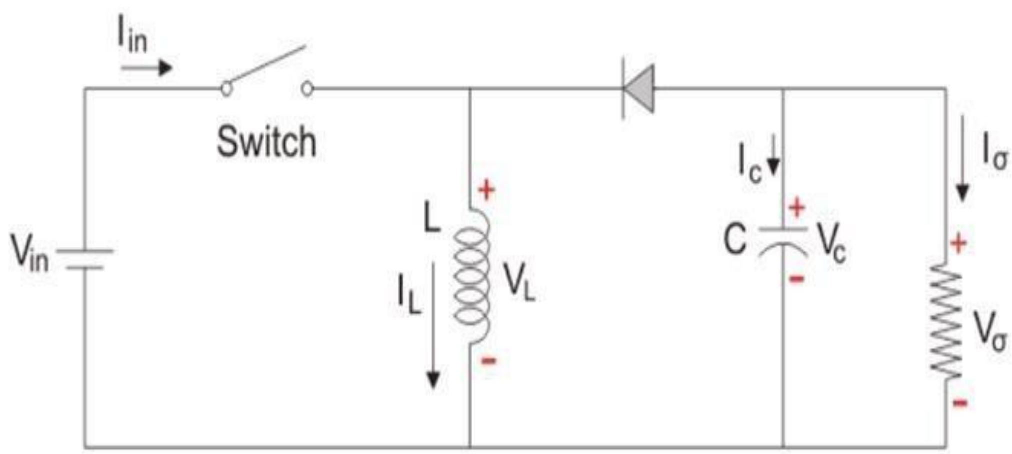

Figure.12 Buck- Boost converter- Mode II circuit diagram

[Source: "Power Electronics" by P.S.Bimbra, Khanna Publishers]

In this mode the polarity of the inductor is reversed and the energy stored in the inductor is released and is ultimately dissipated in the load resistance and this helps to maintain the flow of current in the same direction through the load and also step-up the output voltage as the inductor is now also acting as a source in conjunction with the input source.