

## 5.3 DC TO DC CONVERTER

- Step-down and step-up chopper
- control strategy
- Forced commutated chopper
- Voltage commutated, Current commutated, Load commutated, Switched mode regulators
- Buck, boost, buck- boost converter
- Introduction to Resonant Converters.

## DC-DC Converters

There are three basic types of dc-dc converter circuits, termed as buck, boost and buck-boost. In all of these circuits, a power device is used as a switch. This device earlier used was a thyristor, which is turned on by a pulse fed at its gate. 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 or GTOs are used. It may be noted here that buck converter (dc-dc) is called as 'step-down chopper', whereas boost converter (dc-dc) is a 'step-up chopper'. In the case of chopper, no buck-boost type was used.

With the advent of bipolar junction transistor (BJT), which is termed as self-commutated device, it is used as a switch, instead 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 can be increased in the converters using them. So, mostly self-commutated devices of transistor family as described are being increasingly used in dc-dc converters.

## Buck Converters (dc-dc)

A buck converter (dc-dc) is shown in Fig. a. Only a switch is shown, for which a device as described earlier belonging to transistor family is used. Also a diode (termed as free wheeling) is used to allow the load current to flow through it, when the switch (i.e., a device) is turned off. The load is inductive (R-L) one. In some cases, a battery (or back emf) is connected in series with the load (inductive). Due to the load inductance, the load current must be allowed a path, which is provided by the diode; otherwise, i.e., in the absence of the above diode, the high induced emf of the inductance, as the load current tends to decrease, may cause damage to the switching device. If the switching device used is a thyristor, this circuit is called as a step-down chopper, as the output voltage is normally lower than the input voltage. Similarly, this dc-dc converter is termed as buck one, due to reason given later.

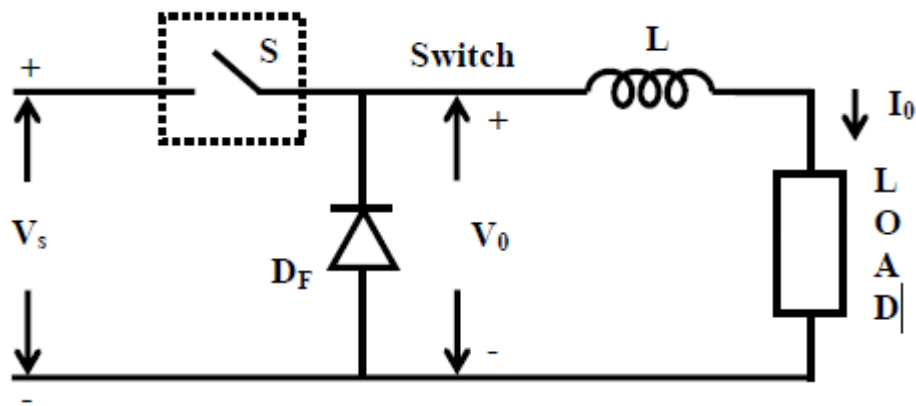


Fig. (a); Buck converter (dc-dc),

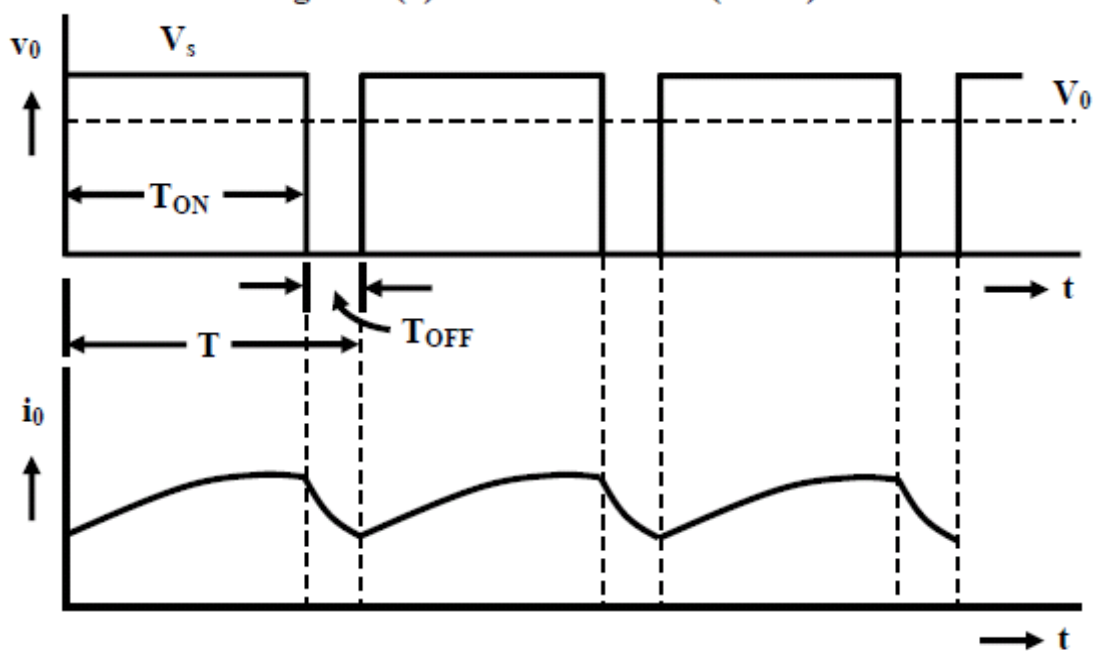


Fig. (b): Output voltage and current waveforms

The output voltage and current waveforms of the circuit (Fig. a) are shown in Fig. b. The output voltage is same as the input voltage, i.e.,  $v_0 = V_s$ , when the switch is ON, during the period,  $T_{ON} \geq t \geq 0$ . The switch is turned on at  $t = 0$ , and then turned off at  $t = T_{ON}$ . This is

called ON period. During the next time interval,  $T \geq t \geq T_{ON}$ , the output voltage is zero, i.e.,  $v_0 = 0$ , as the diode,  $D_F$  now conducts. The OFF period is  $T_{OFF} = T - T_{ON}$ , with the time period being  $T = T_{ON} + T_{OFF}$ . The frequency is  $f = 1/T$ . With T kept as constant, the average value of the output voltage is,

$$V_0 = \frac{1}{T} \int_0^T v_0 dt = \frac{1}{T} \int_0^{T_{ON}} V_s dt = V_s \left( \frac{T_{ON}}{T} \right) = k V_s$$

Normally, due to turn-on delay of the device used, the duty ratio (k) is not zero, but has some positive value. Similarly, due to requirement of turn-off time of the device, the duty ratio (k) is less than 1.0. So, the range of duty ratio is reduced. It may be noted that the output voltage is lower than the input voltage. Also, the average output voltage increases, as the duty ratio is increased. So, a variable dc output voltage is obtained from a constant dc input voltage. The load current is assumed to be continuous as shown in Fig. b. The load current increases in the ON period, as the input voltage appears across the load, and it (load current) decreases in the OFF period, as it flows in the diode, but is positive at the end of the time period, T.

## Boost Converters (dc-dc)

A boost converter (dc-dc) is shown in Fig.a. Only a switch is shown, for which a device belonging to transistor family is generally used. Also, a diode is used in series with the load. The load is of the same type as given earlier. The inductance of the load is small. An inductance, L is assumed in series with the input supply. The position of the switch and diode in this circuit may be noted, as compared to their position in the buck converter (Fig.a).

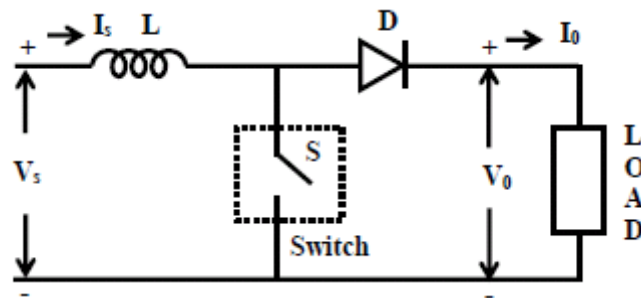


Fig. 17.2(a): Boost converter (dc-dc)

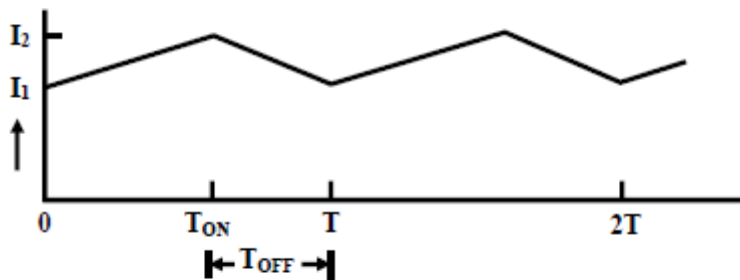


Fig. (b): Waveforms of source current ( $i_s$ )

The operation of the circuit is explained. Firstly, the switch, S (i.e., the device) is put ON (or turned ON) during the period,  $T_{ON} \geq t \geq 0$ , the ON period being  $T_{ON}$ . The output voltage is zero ( $v_0 = 0$ ), if no battery (back emf) is connected in series with the load, and also as stated earlier, the load inductance is small. The current from the source ( $i_s$ ) flows in the inductance L. The value of current increases linearly with time in this interval, with  $(di/dt)$  being positive. As the current through L increases, the polarity of the induced emf is taken as say, positive, the left hand side of L being +ve. The equation for the circuit is,

$$V_s = L \frac{di_s}{dt} \quad \text{or,} \quad \frac{di_s}{dt} = \frac{V_s}{L}$$

The switch, S is put OFF during the period,  $T \geq t \geq T_{ON}$ , the OFF period being  $T_{OFF} = T - T_{ON}$ . ( $T = T_{ON} + T_{OFF}$ ) is the time period. As the current through L decreases, with its direction being in the same direction as shown (same as in the earlier case), the induced emf reverses, the left hand side of L being -ve. So, the induced emf (taken as -ve in the equation given later) is added with the supply voltage, being of the same polarity, thus, keeping the current ( $i_s = i_0$ ) in the same direction. The current ( $i_s = i_0$ ) decreases linearly in the time interval,  $T_{OFF}$ , as the output voltage is assumed to be nearly constant at  $v_0 \approx V_0$ , with  $(di_s/dt)$  being negative, as  $V_s < V_0$ , which is derived later.

The equation for the circuit is,

$$V_s = V_0 + L \frac{di_s}{dt} \quad \text{or,} \quad \frac{di_s}{dt} = \frac{(V_s - V_0)}{L}$$

In this case, the output voltage is higher than the input voltage, as contrasted with the previous case of buck converter (dc-dc). So, this is called boost converter (dc-dc), when a self-commutated device is used as a switch. Instead, if thyristor is used in its place, this is termed as step-up chopper. The variation (range) of the output voltage can be easily computed.

The source current waveform is shown in Fig. 17.2b. As stated earlier, the current varies linearly from  $I_1$  ( $I_{\min}$ ) to  $I_2$  ( $I_{\max}$ ) during the time interval,  $T_{ON}$ .

So, using the expression for  $di_s/dt$  during this time interval,

$$I_2 - I_1 = I_{\max} - I_{\min} = (V_s / L) T_{ON}.$$

Similarly, the current varies linearly from  $I_2$  ( $I_{\max}$ ) to  $I_1$  ( $I_{\min}$ ) during the time interval,  $T_{OFF}$ .

So, using the expression for  $di_s/dt$  during this time interval,

$$I_2 - I_1 = I_{\max} - I_{\min} = [(V_0 - V_s) / L] T_{OFF}.$$

Equating the two equations,  $(V_s / L) T_{ON} = [(V_0 - V_s) / L] T_{OFF}$ , from which the average value of the output voltage is,

$$V_0 = V_s \left( \frac{T}{T_{OFF}} \right) = V_s \left( \frac{T}{T - T_{ON}} \right) = V_s \left( \frac{1}{1 - (T_{ON} / T)} \right) = V_s \left( \frac{1}{1 - k} \right)$$

The time period is  $T = T_{ON} + T_{OFF}$ , and the duty ratio is,

$k = (T_{ON} / T) = [T_{ON} / (T_{ON} + T_{OFF})]$ , with its range as  $1.0 \geq k \geq 0.0$ . The ON time interval is  $T_{ON} = kT$ . As stated in the previous case, the range of  $k$  is reduced. This is, because the minimum value is higher than the minimum (0.0), and the maximum value is lower than the maximum (1.0), for reasons given there, which are also valid here. As shown, the source current is assumed to be continuous. The expression for the output voltage can be obtained by using other procedures.