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A DC-DC Converter Forms an Integral Part of any MPPT System

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ABSTRACT: A DC-to-DC converter is an electronic circuit which converts a source of direct current from one voltage level to another. It is a class of power converter. Electronic switch-mode DC to DC converters operate by storing the input energy temporarily and then releasing that energy to the output at a different voltage and current. Just like a transformer, they essentially just change the input energy into a different impedance level. So whatever the output voltage level, the output power all comes from the input; there's no energy manufactured inside the converter. In fact some energy is used by the converter circuitry and components while doing their job. It is this principle that makes a DC-DC Converter essential for MPPT. A dc-dc converter forms an integral part of any MPPT system. The dc-dc Converter can be a step up converter, in which output voltage is greater than the input voltage. In this, the operation and design of the Boost Converter is described in a very precise manner. Also the simulation of the Boost Converter in MATLAB and the corresponding output waveforms are done.

KEYWORDS: Cognitive Radio, Spectrum Sensing, Efficient Communication, System Security.

I.INTRODUCTION

A dc-dc converter forms an integral part of any MPPT system. The dc-dc Converter can be a step up converter, in which output voltage is greater than the input voltage [18]. In this chapter, the operation and design of the Boost Converter is described in a very precise manner. Also the simulation of the Boost Converter in MATLAB and the corresponding output waveforms are done. A boost converter (step-up converter) is a DC-DC power converter with an output voltage greater than its input voltage. It is a class of switched- mode power supply (SMPS) containing at least two semiconductors switches (a diode and a transistor) and at least one energy storage element, a capacitor, inductor or the two in combination. Filters made of capacitors (sometimes in combination with inductors) are normally added to the output of the converter to reduce output voltage ripple.The converter presents an electrical load to the solar panel that varies as the output voltage of the converter varies. This load variation in turn causes a change in the operating point (current and voltage characteristics) of the panel. Thus by intelligently controlling the operation of the DC-DC converter, the power output of the panel can be intelligently controlled and made to output the maximum possible.

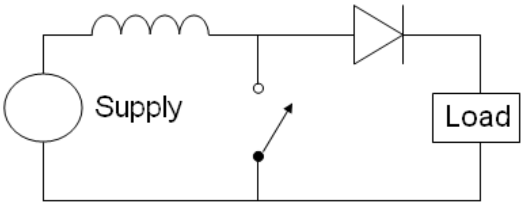

Fig.3 The basic schematic diagram of a boost converter

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II. CIRCUIT ANALYSIS

Operating principle:

The key principle that drives the boost converter is the tendency of an inductor to resist changes in current by creating and destroying a magnetic field. In a boost converter, the output voltage is always higher than the input voltage. A schematic of a boost power stage is shown in Figure 3 (a) When the switch is closed, current flows through the inductor in clockwise direction and the inductor stores some energy by generating a magnetic field. Polarity of the left side of the inductor is positive.(b) When the switch is opened, current will be reduced as the impedance is higher. The magnetic field previously created will be destroyed to maintain the current flow towards the load. Thus the polarity will be reversed (means left side of inductor will be negative now). As a result two sources will be in series causing a higher voltage to charge the capacitor through the diode D.

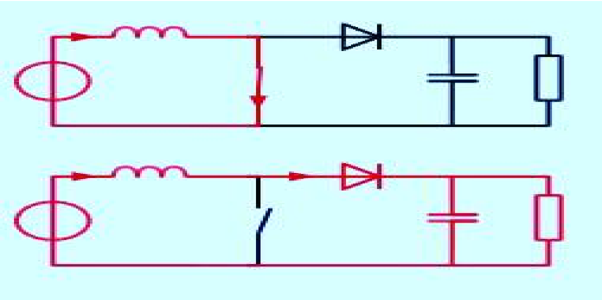

Fig.3.1 the two configurations of a boost converter

If the switch is cycled fast enough, the inductor will not discharge fully in between charging stages, and the load will always see a voltage greater than that of the input source alone when the switch is opened. Also while the switch is opened, the capacitor in parallel with the load is charged to this combined voltage. When the switch is then closed and the right hand side is shorted out from the left hand side, the capacitor is therefore able to provide the voltage and energy to the load. During this time, the blocking diode prevents the capacitor from discharging through the switch. The switch must of course be opened again fast enough to prevent the capacitor from discharging too much.

III. MODES OF BOOST CONVERTER

Boost converter operates in two modes depending upon inductor current they are :

a) Continuous conduction mode of operation

b) Discontinuous conduction mode of operation

1) (A) Continuous conduction mode of operation:

When a boost converter operates in continuous mode, the current through the inductor (I_L) never falls to zero. The output voltage can be calculated as follows, in the case of an ideal converter (i.e. using components with an ideal behavior) operating in steady conditions. During the On-state, the switch S is closed, which makes the input voltage (V_i) appear across the inductor, which causes a change in current (I_L) flowing through the inductor during a time period (t) by the formula:

$$\frac{\Delta I_L}{\Delta t} = \frac{V_i}{L} \qquad (3.6)$$

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At the end of the On-state, the increase of I_L is therefore:

$$\Delta I_{L\,On} = \frac{1}{L}\int_0^{DT} V_i dt = \frac{DT}{L} V_i \tag{3.7}$$

D is the duty cycle. It represents the fraction of the commutation period T during which the switch is On. Therefore D ranges between 0 (S is never on) and 1 (S is always on). During the Off-state, the switch S is open, so the inductor current flows through the load. If we consider zero voltage drop in the diode, and a capacitor large enough for its voltage to remain constant, the evolution of I_L is:

$$V_i - V_o = L\frac{dI_L}{dt} \tag{3.8}$$

Therefore, the variation of I_L during the Off-period is:

$$\Delta I_{L\,Off} = \int_{DT}^{T} \frac{(V_i - V_O)dt}{L} = \frac{(V_i - V_O)(1-D)T}{L} \tag{3.9}$$

As we consider that the converter operates in steady-state conditions, the amount of energy stored in each of its components has to be the same at the beginning and at the end of a commutation cycle. In particular, the energy stored in inductor is given by:

$$E = \frac{1}{2} L I_L^2 \tag{3.10}$$

So, the inductor current has to be the same at the start and end of the commutation cycle. This means the overall change in the current (the sum of the changes) is zero:

$$\Delta I_{L\,On} + \Delta I_{L\,Off} = 0 \tag{3.11}$$

Substituting $\Delta I_{L\,On}$and$\Delta I_{L\,Off}$by their expressions yields:

$$\Delta I_{L\,On} + \Delta I_{L\,Off} = \frac{V_i DT}{L} + \frac{(V_i - V_O)(1-D)T}{L} = 0 \tag{3.12}$$

This can be written as:

$$\frac{V_O}{V_i} = \frac{1}{1-D} \tag{3.13}$$

Which in turn reveals the duty cycle to be :

$$D = 1 - \frac{V_i}{V_O} \tag{3.14}$$

The above expression shows that the output voltage is always higher than the input voltage (as the duty cycle goes from 0 to 1), and that it increases with D, theoretically to infinity as D approaches 1. This is why this converter is sometimes referred to as a step-up converter.

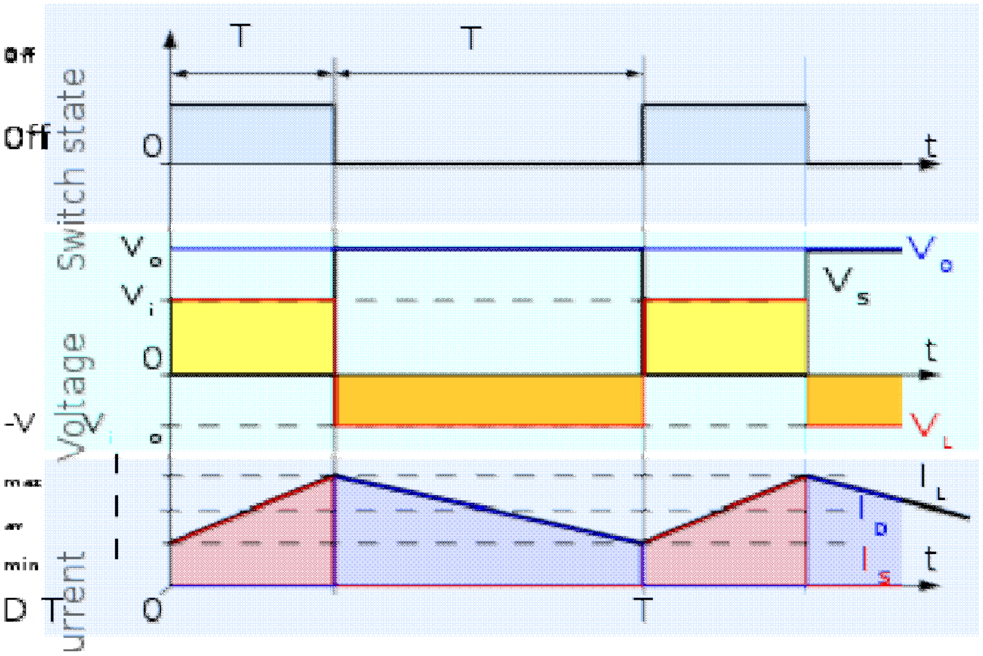

Fig.3.8 Waveforms of current and voltage in a boost converter

2) (B) Discontinuous conduction mode of operation:

If the ripple amplitude of the current is too high, the inductor may be completely discharged before the end of a whole commutation cycle. This commonly occurs under light loads. In this case, the current through the inductor falls to zero during part of the period (see waveforms in figure.3.8). Although slight, the difference has a strong effect on the output voltage equation. It can be calculated as follows, As the inductor current at the beginning of the cycle is zero, its maximum valueI_{Lmax} (at $t=DT$) is

$$I_{L\,Max} = \frac{V_i DT}{L} \qquad (3.15)$$

During the off-period, I_L falls to zero after δT:

$$I_{L\,Max} + \frac{(V_i - V_o)\delta T}{L} = 0 \qquad (3.16)$$

Using the two previous equations, δ is:

$$\delta = \frac{V_i D}{V_o - V_i} \qquad (3.17)$$

The load current I_o is equal to the average diode current (I_D). As can be seen on figure 3.9, the diode current is equal to the inductor current during the off-state. Therefore the output current can be written as:

$$I_o = I_D = \frac{I_{L\,Max}}{2}\delta \qquad (3.18)$$

Replacing I_{Lmax} and δ by their respective expressions yields:

$$I_o = \frac{V_i DT}{2L} \cdot \frac{V_i D}{V_o - V_i} = \frac{V_i^2 D^2 T}{(V_o - V_i)} \qquad (3.19)$$

Therefore, the output voltage gain can be written as follows:

$$\frac{V_o}{V_i} = 1 + \frac{V_i D^2 T}{2LI_o} (3.20)$$

Compared to the expression of the output voltage for the continuous mode, this expression is much more complicated. Furthermore, in discontinuous operation, the output voltage gain not only depends on the duty cycle, but also on the inductor value, the input voltage, the switching frequency, and the output current.

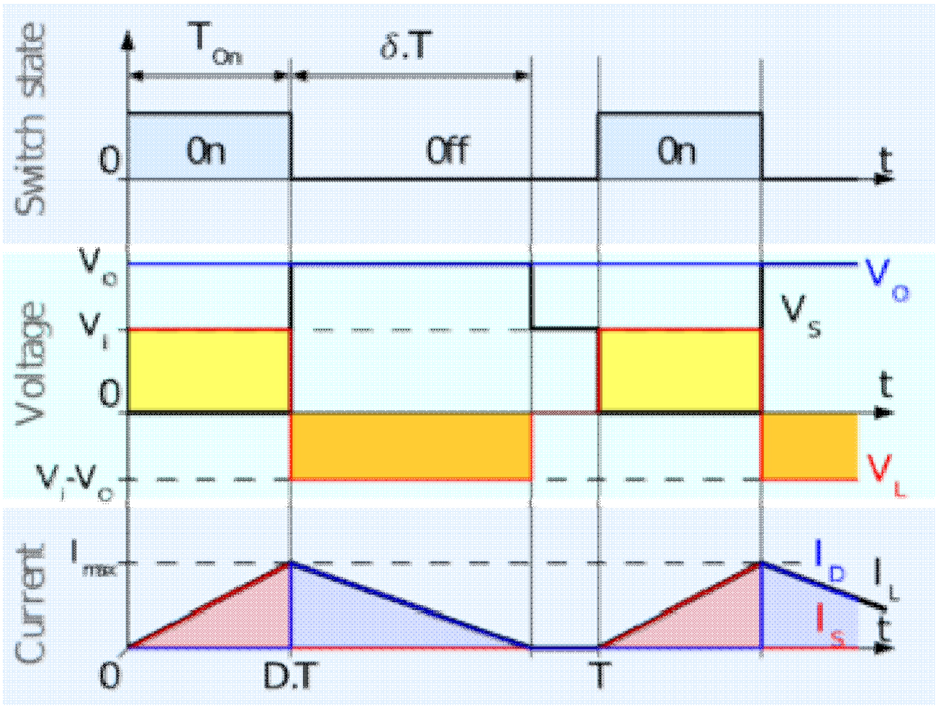

Fig.3.9 Waveforms of current and voltage in a boost converter

IV. DESIGN OF DC-DC BOOST CONVERTER (CONTINUOUS CONDUCTION MODE)

3) (A) Inductor design

L_{CRIT} = Critical value of inductor $= \frac{R \times T}{2} \times (1 - D)^2 \times D$ (3.21)

If $L > L_{CRIT}$ then boost converter operates in continuous conduction mode

If $L < L_{CRIT}$ then boost converter operates in discontinuous conduction mode

Converter losses are very small so output power almost equals to input power when the PV array operates at its maximum capacity 5 Watts. Therefore the output current can be calculated by using the eqn.

$$Po=Vo\times Io \qquad (3.22)$$

Vo=12 V

$$Io = \frac{Po}{Vo} = \frac{5}{12} = 0.41667A$$

The amplitude of the inductor current ripple can be varying between 10% and 20% of its dc value. If the converter is assumed operating at frequency of 1 kHz (T = 1ms), and the inductor current is assumed to be equal to the output current and its current ripple is 10% = 0.041 A).

Eqn. for inductor ripple is given by

$$\Delta i_L = \frac{V_{in}\times D\times T}{2\times L} \qquad (3.23)$$

$$L = \frac{V_{in}\times D\times T}{2\times \Delta i_L} \qquad (3.24)$$

From Eqn. (3.13)

$$D = 1 - \frac{V_{in}}{V_o} = 1 - \frac{10}{12} = 0.1667$$

$$L_{CRIT} = \frac{71.985\times(10)^{-3}\times(1-0.1667)^2\times 0.1667}{2} = 4.166mH$$

$$L = \frac{10\times 0.1667\times 10^{-3}}{2\times 0.041667} = 20mH$$

Hence in the proposed system, the Inductor value has been chosen as 20mH.

Here $R = \frac{V_o}{I_o} = \frac{12}{0.41667} = 71.985\Omega$

Here $L > L_{CRIT}$, Boost converter will operate in continuous conduction mode.

4) (B) Capacitor Design:

Toobtain a desired output voltage ripple, the right value of capacitance is required. Eqn. for voltage ripple is given by

$$\Delta V_O = \frac{I_O\times D\times T}{C} \qquad (3.25)$$

$$C = \frac{I_O\times D\times T}{\Delta V_O} \qquad (3.26)$$

If we take the output ripple voltage 2% then the capacitance of capacitor is given by

$$C = \frac{0.41667 \times 0.1667 \times 10^{-3}}{0.24} = 289.5\mu F$$

Here$\Delta V_O = 12 \times 0.02 = 0.24V$

In the proposed system, the capacitor value has been chosen as 330μF.

VI.CONCLUSION

A dc-dc converter forms an integral part of any MPPT system. The dc-dc Converter can be a step up converter, in which output voltage is greater than the input voltage. In this chapter, the operation and design of the Boost Converter is described in a very precise manner. Also the simulation of the Boost Converter in MATLAB and the corresponding output waveforms are done.

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