

Analysis of Flying Capacitor Boost Converter

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ABSTRACT- This paper analyzes the working principle of flying capacitor boost converter and its different variants such as synchronous flying capacitor boost converter and n-level flying capacitor boost converter. The circuit diagram and analysis of different waveforms have been provided. Voltage conversion ratio of different converters have been provided. The lower voltage conversion ratio (VCR), higher voltage stress, and low efficiency of the boost converter at higher duty cycle levels are the primary limitations of the device. Magnetic coupling components are employed to boost the VCR, but the rating is reduced as a result. The leakage current stored in the magnetic component causes unwanted voltage spikes to occur in the switches as a result of the leakage current. For the purpose of addressing these difficulties, several active and passive clamping switches are employed. Three-level boost converters are an excellent alternative to conventional boost converters, but they have a number of disadvantages that must be considered before using them.

Keywords: Flying capacitor boost converter, Voltage conversion ratio, Flying capacitor, Boost converter.

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1. INTRODUCTION

DC-DC boost converter is one of the widely used DC-DC converter. It is widely used in variety of applications such as renewable power generation, electric vehicle etc. The major limitation of boost converter is lower voltage conversion ratio (VCR), higher voltage stress and low efficiency at higher values of duty cycle. To increase the VCR, magnetic coupling components are used but the rating goes up. The leakage current stored in the magnetic component gives rise of unintended voltage spikes in the switches. To eliminate these issues, different active and passive clamping switches are used. Three-level boost converter is one of the impressive alternatives of classical boost converter but there are different drawbacks of classical three-level boost converter.

Flying capacitor boost converter (FCBC) has been conceptualized by [1] where an additional switch, diode and a capacitor is placed in the boost converter. The use of flying capacitor boost converter reduces the size of the converter which makes the converter modular in nature. For an N-level FCBC, the minimum rating of flying capacitor has been deduced in [3]. High power density FCBC has been designed in [4]. Minimized component FCBC has been discussed in [5]. L2CD network based flying capacitor has been discussed in [6-9]. Control method of FCBC in CCM and DCM has been discussed in [10]. Capacitor voltage balancing control

technique of three-level FCBC has been provided in [11]. This paper also provides the average behavior circuit model. Parameter design of flying capacitor boost converter has been discussed in [12-14]. A comparative analysis of different DC-DC converter topologies has been discussed in [13]. Flying capacitor three level bipolar bidirectional DC-DC converter and its modulation strategy has been proposed in [12, 18-20]. Soft-switched asymmetrical flying capacitor boost converter with synchronous rectification has been proposed in [14]. Design and control aspects of 3-level boost converter under discontinuous conduction mode has been presented in [15-18].

This paper provides the working principle of different variants of FCBC. Different variants such as synchronous FCBC and n-level FCBC. Comparative analysis of VCR of different converters have been provided [19-23]. *Section II* provides the detailed circuit analysis of classical boost converter. *Section III* provides different variants of FCBC. *Section IV* shows simulation results and *Section V* concludes the paper.

2. BOOST DC-DC CONVERTOR

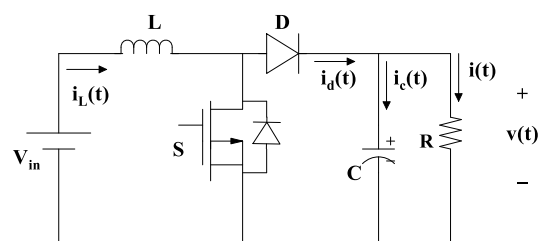


Figure 1: Circuit diagram of boost converter

The voltage conversion ratio (VCR) of boost converter can be written as Flying Capacitor Boost DC-DC Converter

$$\frac{V_o}{V_{in}} = \frac{1}{1-d} \quad (1)$$

Figure 2(a) illustrates circuit diagram of FCBC and its relevant waveforms. Figure 2(b) shows the switching characteristics of flying capacitor boost converter.

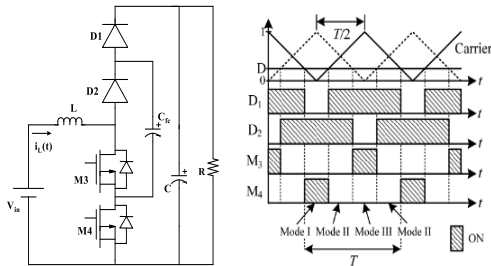


Figure 2: (a) Circuit diagram of FCBC (b) Switching pulses of FCBC

In FCBC, two MOSFET and two diodes are used along with a flying capacitor and inductor. One of the advantages of FCBC is that the input inductor rating is very small and it mitigates any inrush current. The energy is transferred from the flying capacitor to output side. The inductor of flying capacitor boost converter can be represented as

$$L_{FCBC} = 0.25L_{boost}$$

The volume of the flying capacitor boost converter is also reduced due to the size reduction of inductor. The volume of the flying capacitor boost converter can be represented as

$$Vol_{(3-level)} = 0.35Vol_{conventional}$$

From the above expression it can be found that the flying capacitor boost converter is modular and takes lower rating of magnetic devices which makes it more efficient and compact. The VCR of FCBC can be represented as and the inductor current ripple of FCBC can be represented as

$$\Delta i_L = \frac{V_{in}(V_o - 2V_{in})}{2Lf_{sw}V_o} \quad (2)$$

The value of inductor and capacitor of FCBC can be represented as

$$L = \frac{V_{in}d}{4\Delta I_{in}f_{sw}} \quad (3)$$

$$C = \frac{V_o}{2R\Delta V_c f_{sw}} \quad (4)$$

3. SYNCHRONOUS FLYING CAPACITOR BOOST CONVERTER

Figure 3(a) illustrates the circuit diagram of synchronous FCBC where MOSFET are used for synchronous operation. Though it increases the number of switches and control as well as gate complexity, the VCR increases as well as efficiency increases. Figure 3(b) shows the switching waveforms of synchronous flying capacitor boost converter.

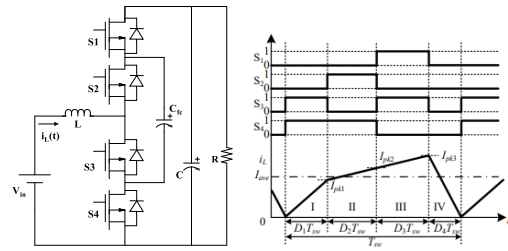


Figure 3: (a) Circuit diagram of synchronous FCBC (b) Waveforms of synchronous FCBC

The duty ratio in heavy load is expressed as

$$D_1 = -\frac{2V_{in}}{V_{dc}} + 1 + \frac{V_{in} - \sqrt{-V_{in}^2 + V_{in}V_{dc} - 2I_{avg}Lf_{sw}V_{dc}}}{V_{dc}} \quad (6)$$

The average current is represented as

$$I_{avg} = \frac{2LI_{avg}f_{sw}V_o}{V_{in}(V_{dc} - V_{in})} \quad (7)$$

N-level Flying Capacitor Boost Converter:

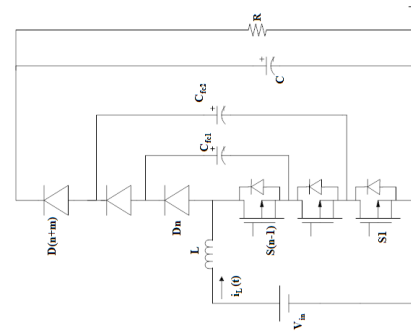


Figure 4: Circuit diagram of n-level FCBC

Figure 4 illustrates the circuit diagram of n-level FCBC where up to n-level can be accommodated. So, number of components increases drastically. In n-level flying capacitor, the inductor value can be represented as

$$L_{(n-level)} = \frac{L_{conventional}}{(n-1)^2} \quad (8)$$

The volume of n-level flying capacitor boost converter can be represented as

$$Vol_{(n-level)} = \left(\frac{1}{(n-1)^2} \right)^{0.75} Vol_{conventional} \quad (9)$$

The output voltage of a n-level flying capacitor voltage is expressed as

$$V_{fcx(n-level)} = \frac{x}{n-1} V_o \quad (10)$$

The voltage ripple of n-level flying capacitor can be expressed as

$$\Delta V_{fcx(n-level)} = \frac{P_{in} D}{V_{in} C_{fcx(n-level)} f_{sw}} \quad (11)$$

The minimum value of capacitor for n-level flying capacitor can be expressed as

$$C_{fcx(n-level)} = \frac{(n-1)P_{in} D}{(2(n-1)V_{fcx(n-level)} - 2xV_o)V_{in} f_{sw}} \quad (12)$$

4. EVALUATION RESULT AND DISCUSSION

Figure 5(a) provides the voltage conversion ratio of boost converter and 3-level flying capacitor boost converter. As can be seen from the simulation results, the flying capacitor boost converter has more VCR from boost converter. Figure 5(b) provides the comparative analysis of VCR of different converters and it is found that flying capacitor boost converter provides superior VCR than other converters.

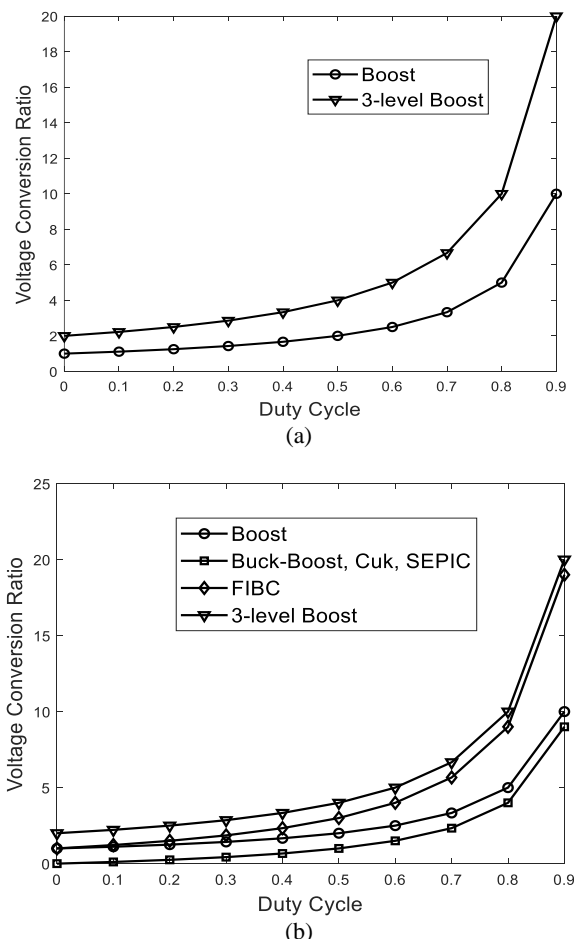


Figure 5: (a) Comparative analysis of VCR of boost converter and flying capacitor boost converter (b) Comparative analysis of VCR of different converter

5. CONCLUSION

This paper provides a comprehensive idea about different variants of FCBC which is used to step-up the DC voltage from

one voltage to other voltage. FCBC, synchronous FCBC and, n-level FCBC have been discussed in this paper. Comparative analysis and detailed circuit analysis as well as switching signal have been discussed. A decreased voltage conversion ratio (VCR), increased voltage stress, and worse efficiency at higher duty cycle levels are the primary drawbacks of boost converters, which are often used in power supplies. Magnesium coupling components are utilised to raise the VCR's rating, however the effect is negligible. Inadvertent voltage spikes are caused by leakage current stored in the magnetic component that is used to connect the switches. Clamping switches, both active and passive, are employed to solve these problems. But there are certain downsides to the standard three-level boosting converter as well as advantages.

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