Current Doubler Rectifier for High Power and Low Voltage DC/DC Converter Applications

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***Abstract*—The rectifier has important influence on a DC/DC converter's characteristics including the efficiency, the output voltage ripple and the dynamic behavior. By analyzing the difference between the center trapped rectifier and the double current rectifier, this document explains and demonstrates the advantage of the current doubler rectifier for DC/DC converters with especially high power but low output voltage which mean very high output current.**

***Index Terms*—current doubler rectifier, DC/DC converter, high power, low voltage**

I. INTRODUCTION

Along with the development of industry, avigation and spaceflight, there are more and more requirement for high power density DC/DC converters which make the electronic systems smaller, lighter and more efficient. One of the most pivotal factors which restricts the power density of DC/DC converters is efficiency because the heat resulted from the power losses brings serious drawback to the reliability and lifetime of the converters[1], [2]. Rectifier is an integrant part of a DC/DC converter but it produces nearly 40 percent of the powerlosses and also affect the dynamic response. So it is necessary to go deep into the rectifiers especially for the high power, low output voltage and high output current DC/DC converters. Synchronous rectification is quite applicable in high current applications as it can reduce conducting losses largely[3]-[5]. Furthermore the current doubler rectifier gives advantages when the current ripple is low.

The goal of this work is toanalyzing the advantage and disadvantage between center trapped rectifier and current doubler rectifier and find out the more conformable one for high current applications. In this paper, a 500 watts DC/DC converter based on full bridge topology is discussed.

II. HIGH POWER DC/DC CONVERTER BASED ON FULL BRIDGE TOPOLOGY

For the applications when the input voltage is quite high, for example, 300 volts, the full bridge topology is one of the most suited choice because the voltage stress on each switch is equal to the input voltage, which make it able to use lower voltage degree MOSFETs and reduce the power losses.

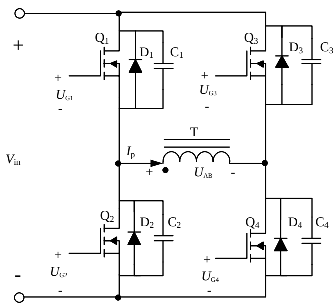

Figure.1 Sketch map of the full-bridge DC/DC converter

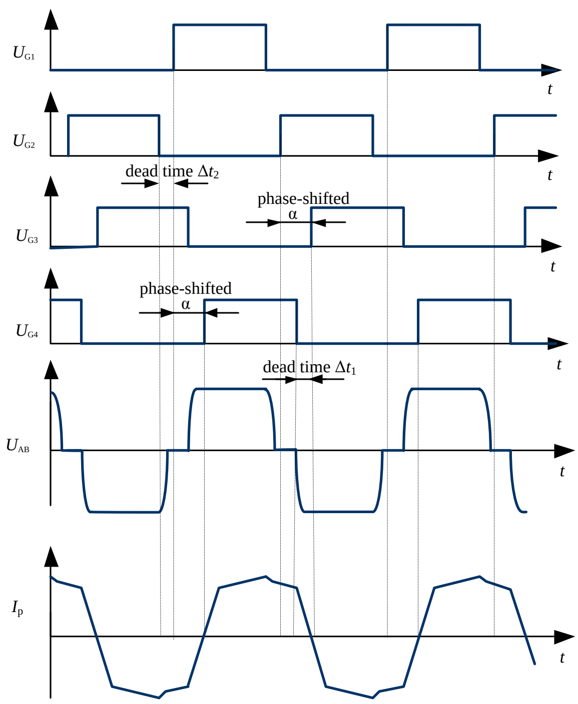

Figure. 2 Typical waveforms of the full-bridge DC/DC converter

A DC/DC converter based on shift-phase full bridge topology is shown in Figure 1[6], where the capacitors C1~C4 are the output capacitance of the MOSFETs Q1~Q4 and the diodes D1~D4 could be the body-diodes or separate diodes. The MOSFETs are drived by a

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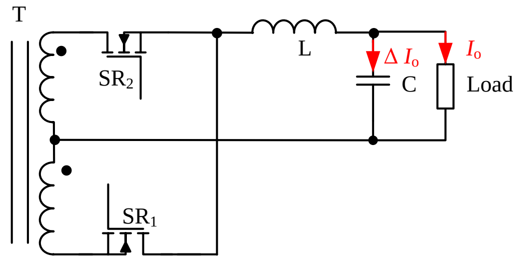
controller that each two on the same leg are 180° phase-shifted and the phase degree between the two MOSFETs catercorner, α, is shifted from 0° to 180° which determines the duty of the full-bridge DC/DC converter. In each cycle, the power transformer T is magnetized bidirectionally and the voltage on the primary side is symmetrical. The typical waveforms of the converter is represented in Fig. 2.

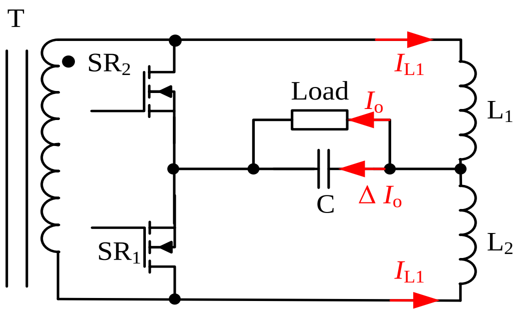
As is shown in Fig. 2, the transformer works symmetrically during each cycle, a rectifier which is able to transfer energy bidirectionally is needed. Either a center trapped rectifier or a current duble rectifier is competent. For high output current applications, the synchronous rectification that make use of low on-resistance MOSFETs instead of Schottky diodes or fast-recovery diodes poduces less conducting losses that is applicable to both the center trapped rectifier and the current duble rectifier.

III. Comparison Between Current Doubler Rectifier and Center Trapped Rectifier

A. Rectifiers Comparison



a) Center trapped rectifier



b) Current doubler rectifier

Figure. 3 Sketch map of the two different rectifiers

A current doubler rectifier and a center trapped rectifier are shown in Fig. 3. The current doubler rectifier is different from the center trapped rectifier by the structure that with only one secondary winding and two separate output inductors which make it three advantages than the center trapped rectifier. Firstly, as two output inductor share the total output current that means IL1 plus IL2 equals Io, during each half cycle the current flows in the secondary winding is just 50% of the center trapped rectifier. Secondly, there are less high current connections in the current doubler rectifier which make it easier for the PCB design and minimize the electro magnetic interference. Thirdly, the two separate inductors share in the high output current so each one is in smaller size and the losses are shared that gives the converter better heat distributing.

For further comparison, a same phase-shifted full bridge DC/DC converter is dicussesd and the duty, the switching frequency, the capacitance ,the input and output voltage are identical and since the two output inductors in the current doubler rectifier are parallel the inductance is two times than that of the center trapped rectifier. The characteristics interrelated with the rectifier include the current ripple, the slew rate and power losses of the inductor and the performance of the transformer and the switches.

B. Inductor Comparison

In steady working mode, the output inductor L of the center trapped rectifier is current-balance as Eq.(1). In the same way, both the inductors L1 and L2 of the current doubler rectifier satisfy Eq.(2). So the voltage on the secondary winding of the current doubler rectifier is two times of that of the center trapped rectifier, Vsec = 2 × Vsec1. It is demonstrated that the total slew rate of current IL1 and IL2 is equal to that of IL, expressed by Eq.(3) to Eq.(8).

$$(V_{\sec 1}-V_o)\times d\times \mathrm{T} = Vo\times(1-2d)\times\frac{\mathrm{T}}{2} \Rightarrow V_o = 2\times V_{\sec 1}d \tag{1}$$

$$(V_{\sec}-V_o)\times d\times \mathrm{T} = Vo\times(1-d)\times \mathrm{T} \Rightarrow V_o = V_{\sec}d \tag{2}$$

$$k_{r(CT)} = \frac{V_{\sec 1}-V_o}{L} = \frac{V_{\sec 1}-2V_{\sec 1}\times d}{L} = \frac{V_{\sec 1}(1-2d)}{L} \tag{3}$$

$$k_{f(CT)} = \frac{V_o}{L} = \frac{2\times V_{\sec 1}d}{L} \tag{4}$$

$$k_{r(L_1、L_2)} = \frac{V_{\sec}-V_o}{L_1} = \frac{V_{\sec}-V_{\sec}\times d}{L_1} = \frac{V_{\sec}(1-d)}{L_1} \tag{5}$$

$$k_{f(L_1、L_2)} = \frac{V_o}{L_1} = \frac{V_{\sec}d}{L_1} \tag{6}$$

$$k_{r(CD)} = k_{r(L_1、L_2)} - k_{f(L_1、L_2)} = \frac{V_{\sec}(1-2d)}{L_1} \tag{7}$$

$$k_{f(CD)} = 2\times k_{f(L_1、L_2)} = \frac{2\times V_{\sec}d}{L_1} \tag{8}$$

where:

$k_{r(CT)}$ = the rising rate of the current of the inductor in center trapped rectifier

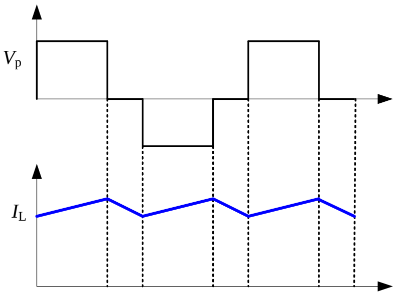
$k_{f(CT)}$ = the falling rate of the current of the inductor in center rectifier

$k_{r(L1、L2)}$ = the rising rate of the current of the inductors in current doubler rectifier

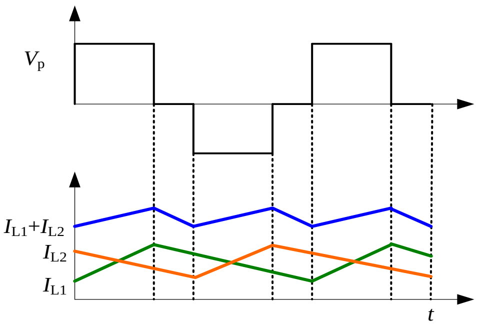
$k_{f(L1、L2)}$ = the falling rate of the current of the inductors in current doubler rectifier

$k_{r(CD)}$ = the rising rate of the total current ripple in center trapped rectifier

$k_{f(CD)}$ = the falling rate of the total current ripple in center rectifier

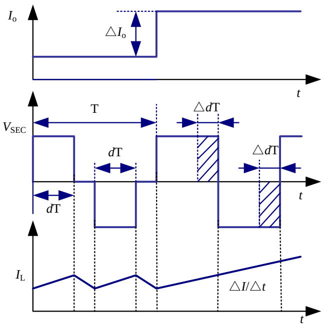


a) Center trapped rectifier

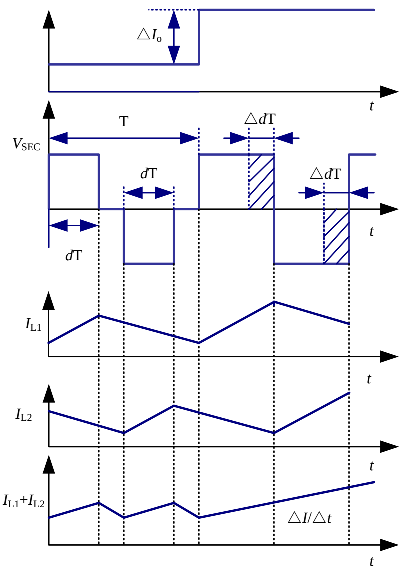


b) Current doubler rectifier

Figure 4. Current ripple of the two rectifiers



a) Center trapped rectifier



b) Current doubler rectifier

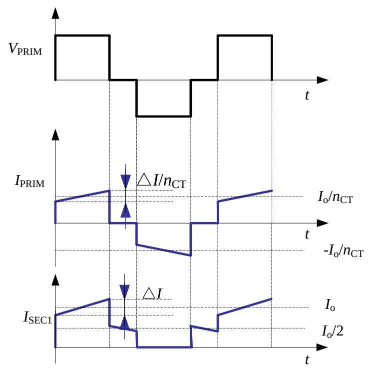
Figure 5. Load step response of the two rectifiers

It is proved that by the equations above that the total current ripple waveforms and load step response are identical in both the center trapped rectifier and the current doubler rectifier which are shown in Fig. 4 and Fig. 5.

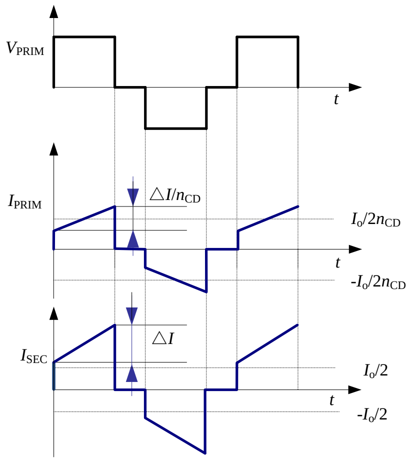
To emphasize the differences of power losses of the inductors in each rectifier, we build FEA(finite element analysis) models of the inductors in which high frequency effects are regarded. On the assumption that the area and volume with each rectifier are similar, several specifications of $\Delta I/I_o$ such as 5A/10A, 5A/50A, 1A/10A, 1A/25A are computed and the results show that there are lower losses in center trapped rectifier for most cases and only for very low $\Delta I/I_o$ ratios like 5A/50A the current doubler rectifier present less losses.

C. *Transformer Comparison*

The losses of the transformer relate to the turns and the configuration of the windings and the current flowing in. As introduced before, the frenquency, duty and size of the transformers are consistant in both the current doubler rectifier and the center trapped rectifier so the magnetism flux and the core losses are almost equal. As is shown in Fig. 6, with the same average value but the AC current in the current doubler rectifier is larger than that of the certer trapped rectifier which means larger AC losses. On the other hand, it is more possible to achieve better interleaving configuration and higher coupling coefficient in the current doubler rectifier which reduce the current ringing at each switching time[7].



a) Center trapped rectifier



b) Current doubler rectifier

Figure 6. Current waveforms of the rectifiers

Accordingly the inferior position due to the AC losses of the transformer and the turn-off losses of the MOSFETs in the current doubler rectifier would be compensated when the output current is extramly high and the current ripple ΔI_o is low. For example, I_o = 25 A and ΔI_o = 2A.

IV. Conclusion

For high power and high current DC/DC converters the rectifier is one of the major parts that has important effect on the converter including the efficiency, current ripple, dynamic response, size, configuration, EMI and lifetime. Both the two synchronours rectifiers are commended in high output current applications and the current doubler rectifier is more applicable when low current ripple is required. It is demonstrated that while the current ripple and dynamic characteristics are identical, a better interleaving transformer can be achieved and reduce the turn-off losses and AC losses in the current doubler rectifier. Futhermore the two parallel inductors sharing the output current produce less losses and ameliorate the heat distributing which make a smaller size possible.

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