High Output Voltage Based Multiphase Step-Up DC-DC Converter Topology with voltage doubler rectifiers

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Abstract

High Output Voltage Based Multiphase Step-Up DC-DC Converter topology with voltage doubler rectifiers is presented in this paper. High output voltage is obtained due to the series combination of voltage doubler rectifiers on the secondary side of high frequency transformers. This topology is useful in the application where the output voltage is greater than the input. The two loop control strategy has been developed in order to analyze the stable and effective working of the converter topology. Therefore the working mode analysis of the converter topology has been described in detail. The multiphase step-up DC-DC converter topology is first simulated on MATLAB and then a prototype has been designed in order to verify the simulation and experimental results. Finally the simulation and experimental results are found to be satisfactory.

Keywords*: DC-DC converter, High frequency transformers (HFTs), Multiphase, Voltage doubler rectifiers (VDRs).*

1. Introduction

Nowadays multiphase step-up DC-DC converter plays an important role in the field of power electronics and control. Therefore different topologies have been proposed [1-16] for high power and high voltage applications. Some of those topologies are of current fed type [1-5] and few of them are of voltage fed type [6-10]. The first multiphase DC-DC converter has a limitation of switching frequency because soft commutation was not introduced in it [6]. Active clamp technique has been introduced to compensate the duty cycle loss, reduces circulating current and suppresses surge voltage [9]. V6 converter becomes beneficial for high power applications but at the cost of increased number of switches [10]. Multiphase DC-DC converter has number of benefits over single phase DC-DC converter. The primary advantage is the reduced current stress on the devices due to the fact that currents are shared among the phases. This paper presents the multiphase step-up DC-DC converter topology with voltage doubler rectifier. A comprehensive multiphase DC-DC converter topology is designed to increase output voltage; therefore voltage doubler rectifiers in series conFigureuration have been connected at the secondary side of high frequency transformers. As compared to the input DC voltage, High output DC voltage is obtained and is considered to be the main advantage of the proposed topology. Furthermore, the efficiency is improved due to the reduced number of switches and the voltage step-up characteristic. The output filter volume reduces along with a high switching frequency.

2. Proposed Multiphase Step-up DC-DC Converter Topology

2.1 Circuit Description

The multiphase step-up DC-DC converter topology with voltage doubler rectifiers (VDRs) is represented in Figure. 1 The topology consists of dc input voltage source, three input inductors and three MOSFETs on the primary side of high frequency transformers (HFTs), whereas the voltage doubler rectifiers (VDRs) in series combination are connected on the secondary side of high frequency transformers (HFTs). The main purpose of connecting voltage

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doubler rectifiers (VDRs) in series combination at the secondary side of high frequency transformers (HFTs) is to obtain high output voltage. The main characteristics of multiphase step-up DC-DC converter topology are: Same reference is shared by only three switches, featuring simplicity to the drive and a control circuits; Amount of voltage at the switches is decreased because of the employed transformer.

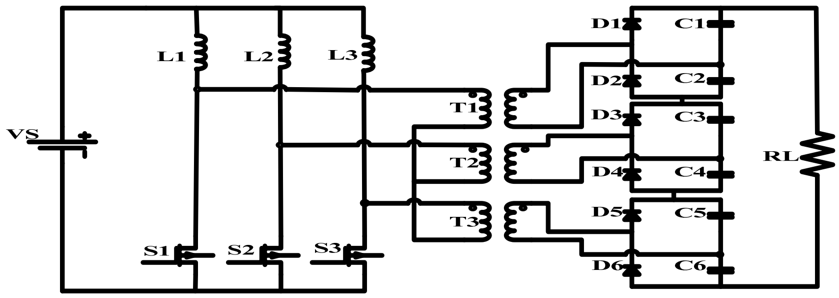


Figure 1. Multiphase Step-up DC-DC Converter

2.2 Control Strategy

Control strategy of multiphase step-up DC-DC converter topology with voltage doubler rectifiers (VDRs) is shown in Figure 2. The control strategy consisting of two loops, one of them is called output voltage loop and the other one is said to be input current loop. Output voltage loop needs to sense the output voltage V_o, then added/subtracted with the reference value Vref and generates the error signal. The error signal is given as an input signal to the PI_1-controller. The output of the PI_1-controller acts as the reference current Iref for the input current loop. Similarly the input current Iin is sensed by input current loop and is added/subtracted with the reference current Iref in order to generate the error signal as an input to the PI_2-controler. The output of the PI_2-controler is given to PWMs in order to generate the driving signals for the gates of three switches.

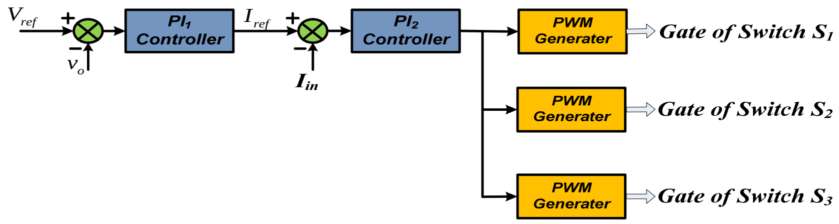


Figure 2. Control Strategy

2.3 Working Mode Analysis

The proposed multiphase step-up DC-DC converter topology has three different operation areas. Each one varies from other by the number of switches ON at the same time. Duty cycle from 0 to 33.33% is the first area and is denoted by A_1. Duty cycle from 33.33% to 66.67% is the second area and is represented by A_2. Duty cycle from 66.67% to 100% is the third area and is indicated as A_3. At least one switch must be ON because the input of the converter is current source, therefore A_1 is forbidden. Figure 3 shows the working modes and equivalent circuits of each mode when the duty cycle is in A_2 and are described for one switching period as under:

Mode 1: S_1 start to conduct, direction of current at primary of T_1 is altered and becomes negative; D_2 starts to conduct and C_1 begins to discharge.

Mode2: Gate pulse of S_3 is removed and the primary current direction of T_3 is altered and becomes positive value; D_5 starts to conduct and C_6 begins to discharge.

Mode3: S_2 start to conduct, direction of current at primary of T_2 is altered and becomes negative; D_4 starts to conduct and C_3 begins to discharge.
Mode4: Gate pulse of S_1 is removed and the direction of current at primary of T_1 is altered and becomes positive; D_1 starts to conduct and C_2 begins to discharge.
Mode5: S_3 start to conduct, direction of current at primary of T_3 is altered and becomes negative; D_6 starts to conduct and C_5 begins to discharge.
Mode6: Gate pulse of S_2 is removed and direction of current at primary of T_2 is altered and becomes positive; D_3 starts to conduct and C_4 begins to discharge.

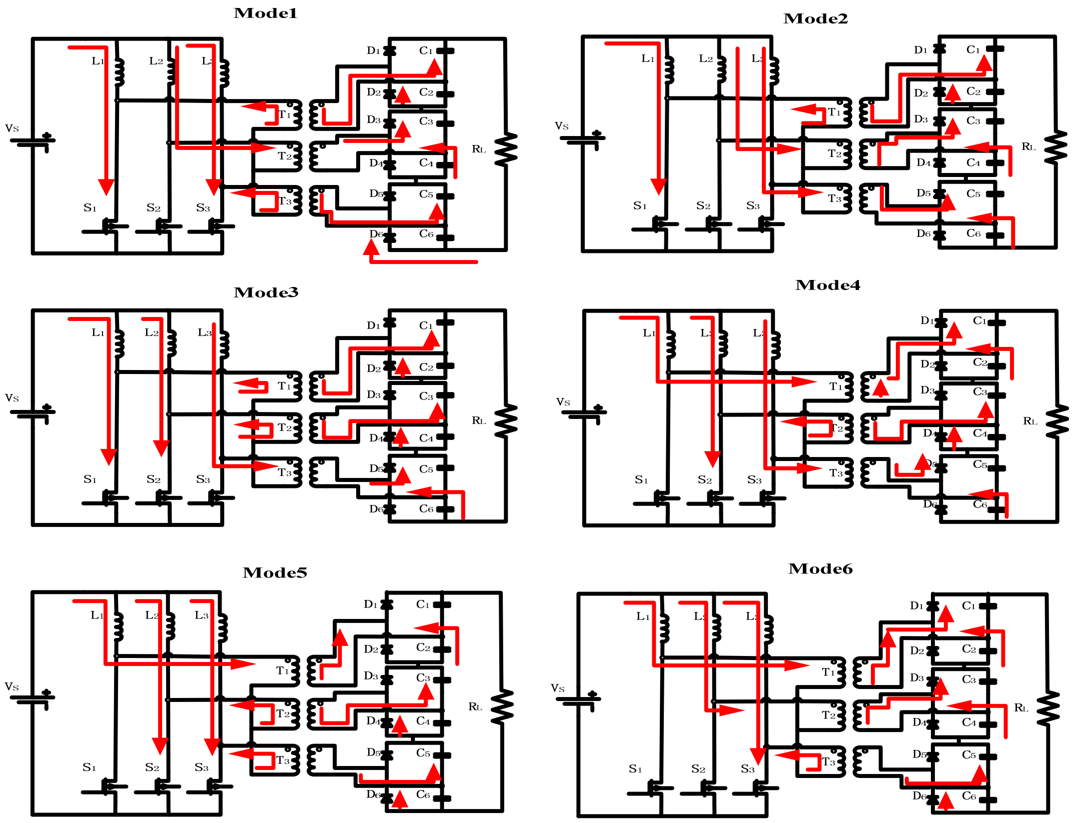


Figure 3. Shows the Working Modes and Equivalent Circuits When Duty Cycle Is In A_2

Mode 1: S_1 start to conduct, the primary current of T_1, T_2 and T_3 become to zero; The diodes of the second sides do not conduct and the capacitances of the second sides begins to discharge together.
Mode2: Gate pulse of S_2 is removed and direction of current at primary of T_2 is altered and becomes positive; at the same time, the primary current direction of T_1 and T_3 is altered and becomes negative; D_2, D_3 and D_4 starts to conduct.
Mode3: Gate pulse of S_3 is removed direction of current at primary of T_3 is altered and becomes positive; D_2, D_3 and D_5 start to conduct.
Mode4: S_2 start to conduct, direction of current at primary of T_2 is altered and becomes negative; D_2, D_4 and D_5 start to conduct.
Mode 5: S_3 start to conduct, the primary current of T_1, T_2 and T_3 become to zero; The diodes of the second sides do not conduct and the capacitances of the second sides begins to discharge together.
Mode6: Gate pulse of S_1 is removed and the primary current direction of T_1 is altered and becomes positive value; at the same time, the primary current direction of T_2 and T_3 is altered and becomes negative value; D_1, D_4 and D6 start to conduct.

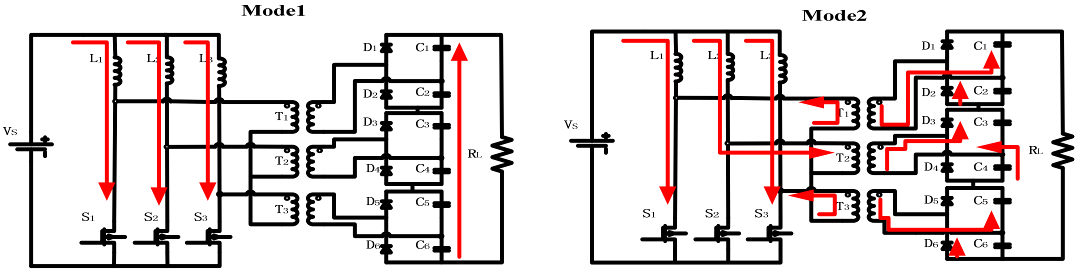
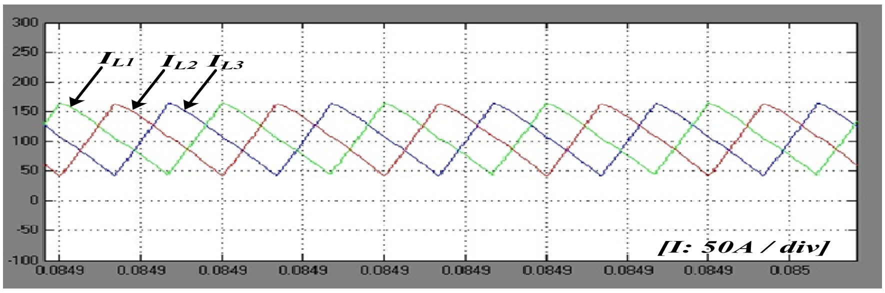


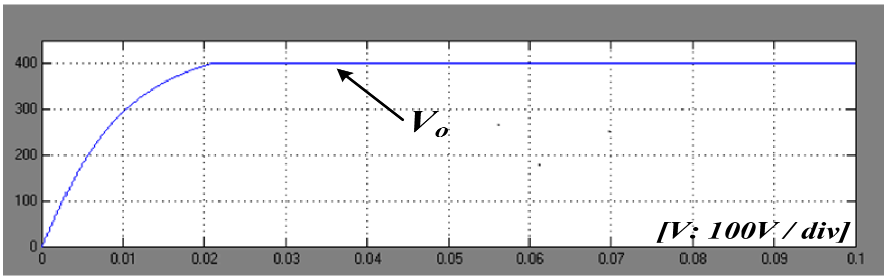
Figure 4. Shows the Working Modes and Equivalent Circuits When Duty Cycle Is In A_3

3. Simulation and Experimental Results

Multiphase step-up DC-DC converter topology along with the voltage doubler rectifiers has been simulated on SimPower tool of MATLAB in order to obtained high output voltage. The specifications for simulation model of above said conFigureuration are shown in Table 1. The simulation results are represented in Figure 5, whereas Figure. 5(a) shows input inductor currents, Figure 5(b) represents output voltage and Figure 5(c) shows voltage at each voltage doubler rectifier.



(a)



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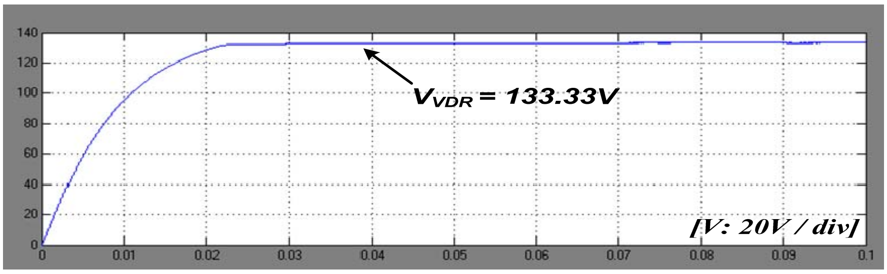

(c)

Figure 5. Simulation Results (a) Inductor Currents; (b) Output Voltage or load Voltage; (c) Voltage at each VDR

Table 1. Specifications for Simulation

Parameter	Value
P_o	5KW
V_{in}	50V
V_o	400V
F	40KHz
L_1 to L_3	1µH
C_1 to C_6	8µF

Table 2. Specifications for Experiment

Parameter	Value
P_o	2KW
V_{in}	35V
V_o	200V
F	40KHz
L_1 to L_3	160µH
C_1 to C_6	45µF

2KW Laboratory prototype has been design to verify the working mode and the control strategy of proposed DC-DC converter topology. The specifications for experimental model of above said conFigureuration are shown in Table 2.

Figure 6 shows the experimental results for the input inductors and output voltage.

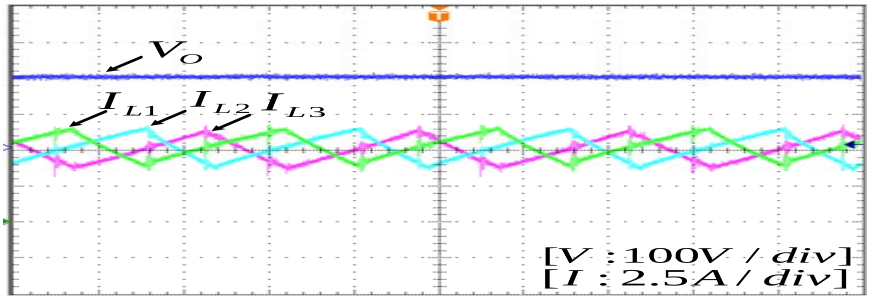

Figure 6. Experimental Results of Output Voltage and Inductor currents

4. Conclusion

High output voltage based multiphase step-up DC-DC converter topology with voltage doubler rectifiers has been proposed in this paper. In the proposed topology two loop control strategy has been applied. Based on simulation and experimental results, the working modes of above said topology are explained in detail. Moreover, it can also be concluded that the high output voltage can be obtained by connecting series voltage doubler rectifiers at the secondary side of high frequency transformers. The converter topology is useful where the input DC voltage is less than the output DC voltage.

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