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DC-DC Bi-Directional Converter for Automotive Application with RLE load

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Abstract: *This paper presents MATLAB simulation of DC-DC Bi-directional converter for automotive applications with RLE load. A PCMC implemented phase shifted full bridge (PSFB) with synchronous rectification controls power flow from a high voltage bus/battery to the low voltage battery in step-down mode, while a push-pull stage controls the reverse power flow from the low voltage battery to the high voltage bus/battery in boost mode. An active clamp circuit is used to limit transient voltage overshoot on the push-pull switches in boost mode. The proposed method is modeled and its performance is studied with MATLAB software. The simulation is done using MATLAB/SIMULINK and the desired results are obtained.*

Keywords: Bi-directional converter, Buck mode, Boost mode, Matlab, Simulink.

I INTRODUCTION

With increasing concerns on energy crisis and Environmental protection, the electric vehicles (EVs) are attracting more and more attention in recent years. The use of DC-DC converters is essential in hybrid vehicles and electric vehicles. Bi-directional DC-DC converters are frequently used in applications where bi-directional power flow may be required. In hybrid electric vehicles (HEV) and electric vehicles (EV) these bi-directional converters are useful to charge a low voltage (6V) battery during normal operation (buck mode) and charge or assist the high voltage (12V) battery/bus when needed (boost mode). A typical system consists of a full-bridge power stage on the high voltage (HV) side, which is isolated from a full-bridge or a push-pull stage on the low voltage (LV) side. In the system there are four MOSFET switches that form a full-bridge on the HV side of the isolation transformer and two MOSFET switches on the center-tapped LV side that work as synchronous rectifiers in buck mode and as push-pull switches in boost mode. Closed loop control for both directions of power flow is implemented using a 32-bit microcontroller, which is placed on the LV side. With availability of high performing microcontrollers with optimized control peripherals, it is possible to use microcontrollers for closing control loops in these systems, in addition to handling the supervisory and communication functions.

II BASIC OPERATION OF BI-DIRECTIONAL CONVERTER

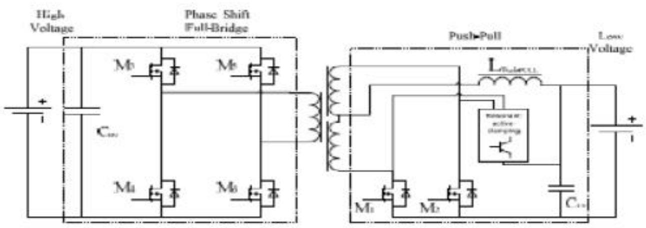

Fig 1. Schematic of system to be implemented

A Buck Mode

A converter consists of four power electronic switches (like MOSFETs or IGBTs) that form a full bridge primary side of the isolation transformer and diode rectifiers or MOSFET switches for synchronous rectification (SR) on the secondary side. Fig 2 shows circuit of a phase-shifted full bridge diode rectifier. In fig 2 MOSFET switches Q1, Q2, Q3, and Q4 form the full bridge on the primary side of the transformer. Q1 and Q4 are

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switched at 50% duty cycle and 180 degrees out of phase with each other. Q2 and Q3 are switched at 50% duty cycle and 180 degrees out of phase with each other. The switching signals for leg Q2–Q3 of the full bridge are phase-shifted with respect to switching signal for leg Q1–Q4. The amount of phase shift decides the amount of overlap between diagonal switches, which in turn decides the amount of energy transferred. Q5 and Q6 provide diode rectification on the secondary, while L and C form the output filter. Inductor LR provides assistance to the transformer leakage inductance for resonance operation with MOSFET capacitance. In this mode the voltage on the input side is stepped down across the transformer to obtain the output voltage. Fig 3 provides the switching waveforms for the system in buck mode of operation.

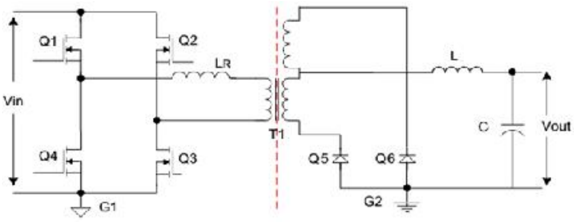

Fig 2. Buck Mode Power Stage operation

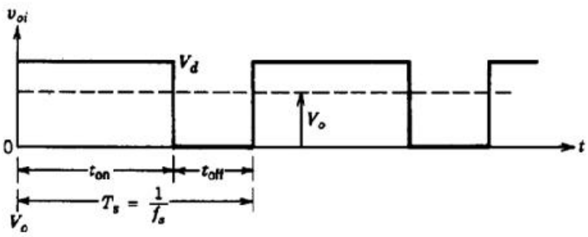

Fig 3. Buck Mode Output Waveforms

B Boost Mode

The synchronous rectifier switches are the push-pull switches in boost mode. The buck mode output inductor acts as a current source in this boost mode letting this topology work as a current-fed push-pull converter. Full-bridge switches on the HV side may be kept off and their body diodes used for rectification. The full-bridge switches are used for active rectification in the boost mode. The push-pull switches are driven with signals greater than 50% duty cycles that are 180 degrees out of phase with each other.

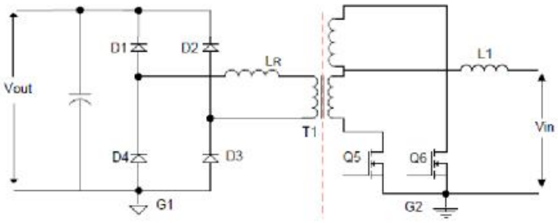

Fig 4. Boost mode power stage operation

During operation, Q5 and Q6 are on simultaneously. The inductive energy in the low-voltage winding of the transformer and that in the boost inductor (L1) increases. Initially for first half cycle Q6 is turned off and the stored inductive energy on the LV side is transferred to the HV side through diodes D1 and D3. During second half cycle Q5 is turned off and diodes D2 and D4 conduct on the HV side. In this mode of operation, the amount of energy transferred to the HV side is decided by the duty cycle of the signals driving switches Q5 and Q6. Unlike the phase-controlled buck mode, this is a duty-controlled operation. In this mode of operation the voltage obtained on the output side is stepped up across the transformer and is more then input voltage. Fig 5. provides the switching waveform of the system in boost mode of operation.

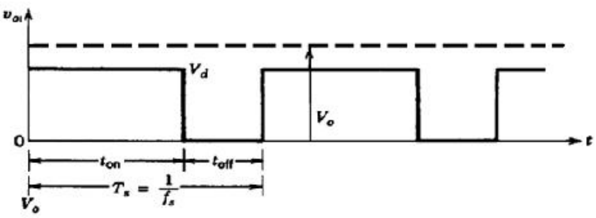

Fig 5. Boost Mode Output Waveforms

III SIMULATION AND RESULTS

The below block shows the simulink model of the DC-DC bi-directional converter in buck and boost mode for RLE load.

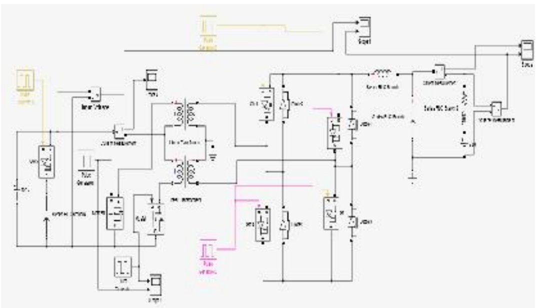

Fig 6. Simulink of block diag of Bi directional converter in buck-boost mode.

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The below graph shows the output waveform of the simulink model with 6V as input voltage.The output obtained for the 6V in of the system is 12V in boost mode for RLE load

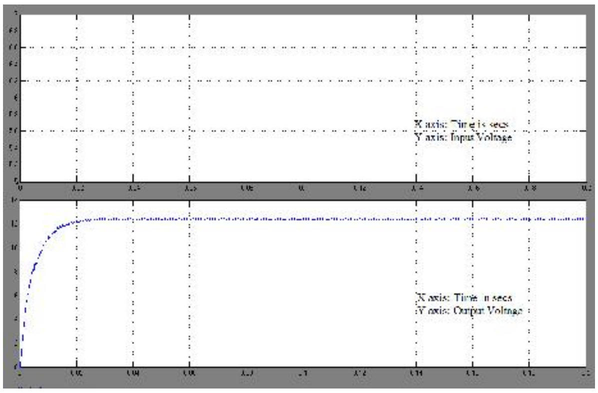

Fig 7. Output of the simulink model in boost mode of operation for motor load

The below graph in Fig 8 shows the output waveform of the simulink model with 12V as input voltage with RLE load. The output obtained to charge the battery on LV side is 6V in buck mode of operation. Which is maintained constant with the help of clamping circuit on LV side.

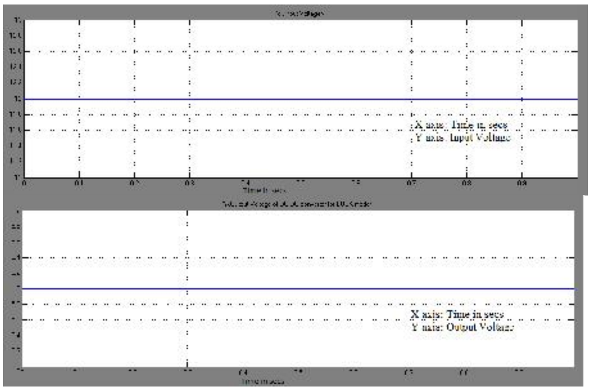

Fig 8. Output of simulink model in buck mode of operation for motor load

Simulation results

Input Voltage	Output Voltage
Buck Mode	
12V	6V
Boost Mode	
6V	12V

Table 1. Results of Simulation

IV. CONCLUSION

We have efficiently analysed DC-DC bi-directional converter performance with RLE load in MATLAB Simulink. We have effectively obtained the results of the converter model for buck mode and boost mode operation on software basis. The software results shows that it is possible to achieve stable results with PCMC control technique for PSFB rectifier scheme. Also the active clamp technique helps to reduce the transients in buck mode while charging the battery. This system can be further implemented on hardware.

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