COMPARISON OF SIMULATION AND EXPERIMENTAL RESULTS OF ZVS BIDIRECTIONAL DC-DC CONVERTER

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Abstrac*t: This paper presents simulation and implementation of soft switched ZVS bidirectional DC-DC converter suitable for aero space application. Operation of the converter in both boost mode and buck mode are verified using Matlab Simulink. The converter system is tested with C filter and two stage cascaded LC filter. The results obtained with the two filters are compared. A hardware model is developed. Simulation and implementation results of both the modes are presented. The experimental results are compared with the simulation results.*

Keywords*: boost mode, buck mode, Simulink, Soft Switching.*

1.0 Introduction

Bidirectional DC to DC Converters are extensively used in aero space applications to provide a means of coupling batteries and the high voltage side DC bus which provides power to the various flight control systems. When in a "step up mode" the converter functions to boost the battery voltage to the required high voltage bus voltage and in "step down" mode the converter reduces the high voltage available at the DC Bus to the voltage suitable for the battery charging. As with most components intended for aero space applications the minimization of the size and weight of bidirectional DC to DC converters is of great concern. Also in concern of the aerospace system is the electromagnetic Interference (EMI) generated by any component.

Circuit topologies of the DC to DC converter with bi-directional power flow control, conversion capability and electrical isolation between the two sides through a single transformer for fuel cell applications was evaluated [1]. A DC to DC Converter Structure which fulfills the requirements for very low input and high output voltage ratings was presented [2]. An isolated full bridge converter in which ZVS and ZCS are achieved by adding active clamping circuits to improve the performance of the bidirectional PWM converter was proposed [3]. A new converter topology was proposed [4] which achieved bidirectional power flow between individual inputs and output. Soft switching implementation without additional devices, high efficiency, high reliability and simple control were the special features of the proposed converter. A hard switched bidirectional flyback converter was modified into a soft switched one by adding an additional circuit in [5]. Two multiphase 1000-WS DC–DC Converters made of many interleaved buck phases (16 and 36) was proposed [6]. A half bridge topology with advantages such as reduction in physical size, increase in power density and lower wiring costs was proposed [7].

The operation principles and various switching modes of the dual H-bridge-based DC–DC converter was analyzed and derived the expressions for voltage ripple [8]. A non isolated Bidirectional DC to DC converter with features such as operating with continuous inductor current, fixed switching frequency, and the switch stresses of a conventional PWM converter regardless of the direction of power flow was proposed [9]. A novel class E buck/boost resonant bidirectional DC-DC converter for renewable energy system was proposed [10].

The converter considered for aero space application uses dual half bridge topology and Zero Voltage Switching (ZVS) is possible in either direction of power flow without using voltage clamping circuit or extra switching components and resonant components. Soft-switching converters provide an effective solution to suppress EMI and also improves the efficiency.

The above literature does not deal with simulation and Implementation of dual half bridge bidirectional DC to DC converter for both "boost" and "buck" mode. In this paper an attempt is made to simulate and implement the bidirectional DC to DC Converter with dual half bridge topology with reduced components and EMI protection by soft switching concept.

2.0   System Architecture and Circuit Description

Fig.1 shows the block diagram representation of dual half bridge ZVS bidirectional DC to DC converter. A bidirectional DC-DC converter is one in which the power can flow from DC source to battery while charging and from battery to DC source while discharging. This can be achieved by using rectifier, inverter and transformer. While the DC mains is "on", Converter I in block diagram works as inverter and Converter II act as uncontrolled converter and the converter works in boost mode (forward charging mode) to charge the battery. When the DC mains "fail", converter II in Fig.2 works as inverter and converter I works as uncontrolled converter and the circuit works in buck mode
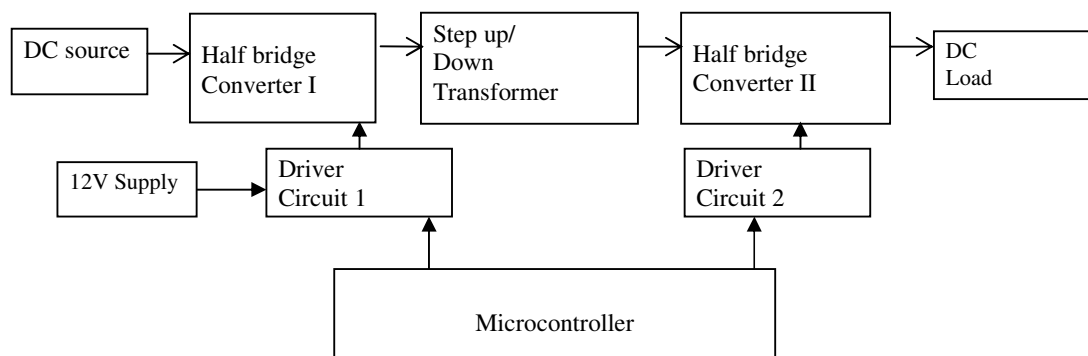
Fig.1 Block Diagram of ZVS Bidirectional DC to DC Converter

2.1. Boost mode of operation

In the forward charging mode the energy from the DC mains charges the battery over a specified input voltage range while powering the down stream load converter. In this mode of operation only the switches M_1 and M_2 are gated and the body diodes of switches M_3 and M_4 provides battery side rectification. In this mode supply is given to the load as well as it charges the battery. Hence it is called as forward charging mode.

In the steady state the output voltage of the half bridge converter can be calculated using the formula

$$V_{out} = (N_s/N_p) V_{in} D \qquad (1)$$
$$\text{where D (Duty Cycle)} = T_{on}/T \qquad (2)$$

N_p Number of primary turns
Ns   Number of secondary turns.

T   Time period of the trigger pulse to the switch.

T_{on-} On time of the trigger pulse to the Switch

Number of turns in the primary and secondary can be calculated using the following formulae

$$N_p = V_{in\ min}\ D_{max}/2F_{pwm}A_{core}\ \triangle B \qquad (3)$$

$$Ns = V_{out}/2F_{pwm}A_{core}\ \triangle B \qquad (4)$$

The rms secondary current $(I_s)_{rms}$ is given by the equation

$$(I_s)_{rms} = Io_{av}\ (D)^{½} \qquad (5)$$

The circuit shown in Fig.2 for boost mode model is simulated with a switching frequency of 55 KHz and Amplitude of 1V. The following waveforms are obtained.
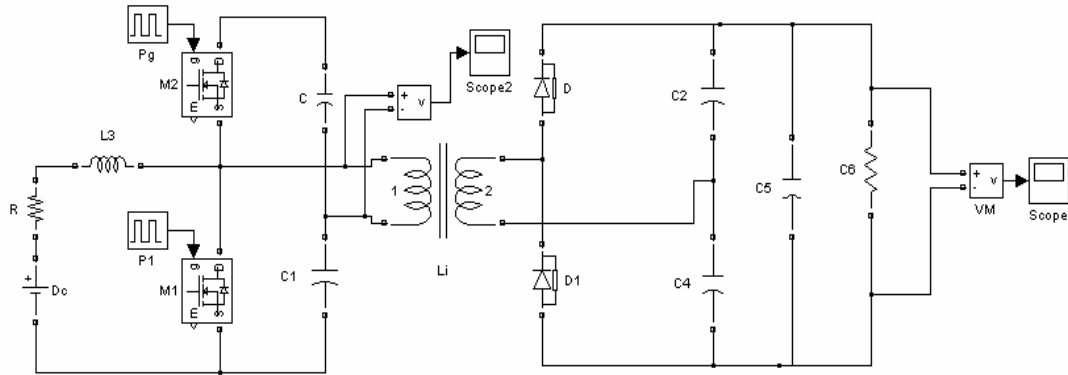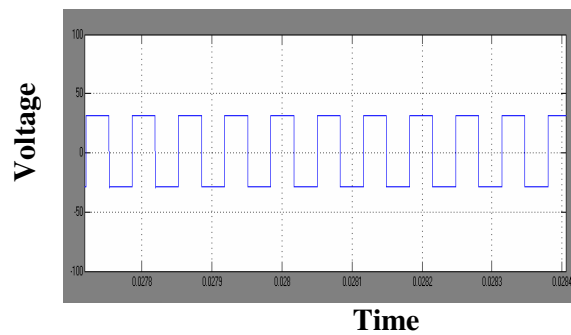

Fig. 2 Simulink model for Boost Mode operation

Fig.3 Inverter output
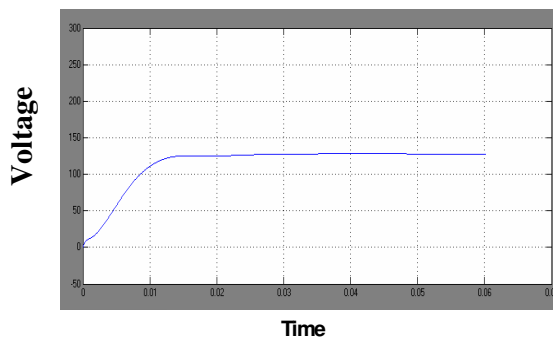**Scale x axis 1unit = 100μec**
y axis 1 unit = 5V

Fig.4 Boost Mode DC Output voltage
Scale x axis 1unit   = 1msec
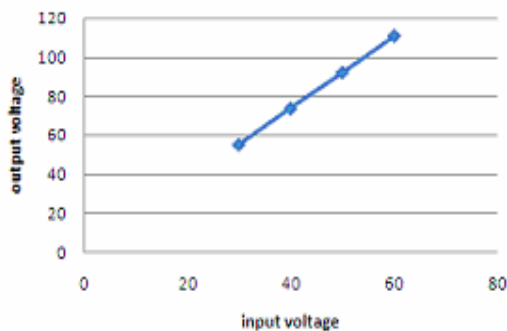**y axis 1 unit = 50V**

Fig.5 Variation of Output voltage
With Input in Boost mode
Scale x axis 1 unit = 20 V
y axis 1 unit = 20V

Fig. 3 shows the output of the inverter. Fig.4 shows the output voltage waveform in boost mode.   Fig.5 is a graph which shows the relationship between input and output voltage.   It is observed that the output voltage increases with the increase in input voltage. The graph in Fig.6 shows the comparison of proposed converter with conventional converter.   Initially, the converter system is constructed with C filter.   Then the C Filter is replaced with two stage cascaded LC Filter. The graph in Fig.7 shows the input vs efficiency curve of the system in boost mode with C and LC filter.   It can be seen that the efficiency is higher with LCLC filter.
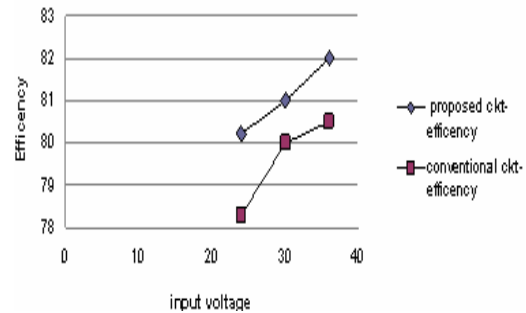

Fig.6 Efficiency vs. Input voltage
With and without soft switching
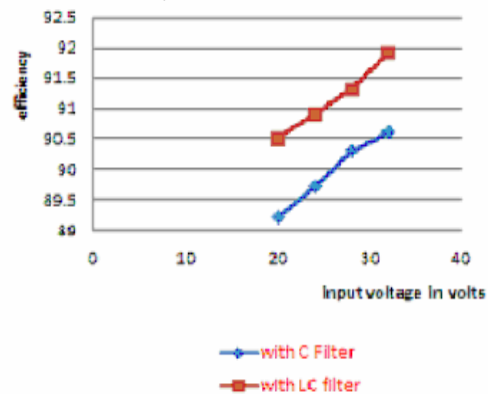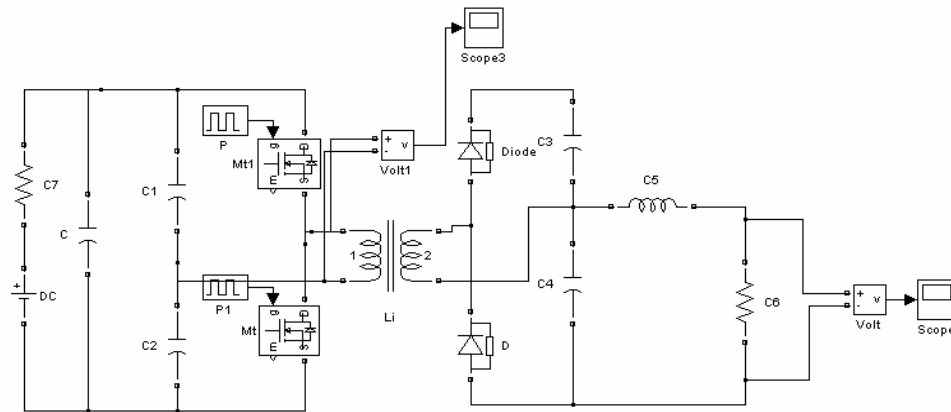**Scale x axis 1unit = 10V**
y axis 1 unit = 1 V

Fig.7 Efficiency vs. Input voltage
With C and LCLC filter
Scale x axis 1unit = 10
y axis 1unit   = 0.5

2.2 Buck Mode Of Operation

In this mode the DC supply is not present and the load takes the power from the battery. During this mode switches M_3 and M_4 are turned on in the secondary side. But switches M_1 and M_2 are not switched on at all. The simulation results of this mode of operation are obtained with the Simulink model shown in Fig.8.

The results obtained for buck mode are similar to the boost mode.

The inverter output voltage waveform for buck mode is shown in Fig.9. The simulated output voltage of the converter system in buck mode is shown in Fig.10. The relationship between output voltage and input voltage is shown in Fig.11. In both modes of operation, the duty cycle considered is 50% for simulation. Fig.12 shows the input vs efficiency graph with C and LCLC filter in buck mode. The efficiency increases by 1.5% by using LCLC filter
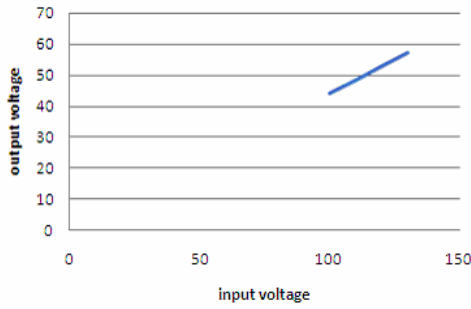

Fig.8 Simulink model for Buck Mode operation

Time

**Fig.9 Inverter output voltage
Scale x axis 1 unit = 0.05sec
y axis 1unit = 20V**

Time

**Fig.10 DC Output Voltage
Scale x axis 1 unit = 0.05sec
y axis 1unit = 10V**

**Fig.11 Variation of Output voltage
with Input in Buck mode
Scale x axis 1unit = 50V
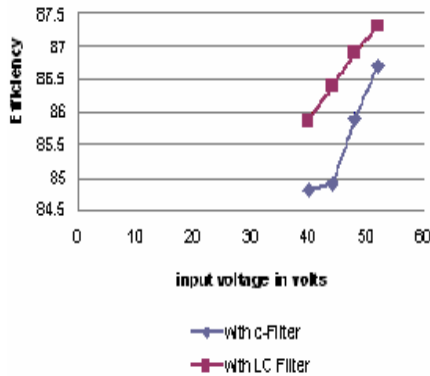y axis 1unit = 10V**

**Fig.12 Efficiency vs. Input voltage
With C and LCLC filter
Scale x axis 1unit = 10V
y axis 1 unit = 0.5**

3.0   Hardware results
        The hardware model is developed
with the following specifications:

Devices	Rating
MOSFET IRF 840	500V, 8A
Drivers IR 2110	20V
Transformation Ratio	1:2

The hardware kit consists of power circuit section, control section and power supply section.   The hardware setup is shown in Fig.16. The results are obtained for both the modes and the oscillograms taken are presented.
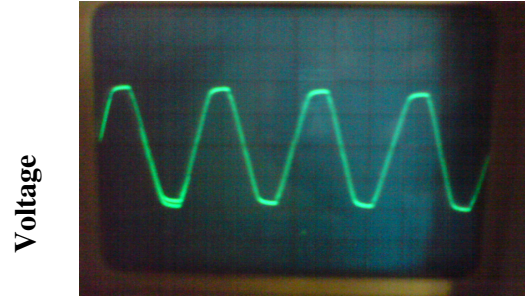

**Fig.13 AC input
Scale x axis 1 unit   = 20μsec
        y axis 1unit   = 5V**

The AC voltage from the mains is step down to 24V. The AC input is shown in Fig.13. The rectified input voltage to the converter is 24.2V which is shown in Fig.18. The duration of the pulse to the switches is 50μsec. For the boost mode, t_{on} is15μsec and the output voltage obtained is 49V. For the buck mode, t_{on} is   5μsec and the output voltage is 12V. The gate pulses applied to the switches 1&2 and 3&4 are shown in the Figs.14 and15 respectively. The boost and buck mode outputs are shown in Figs.18 and 19 respectively.
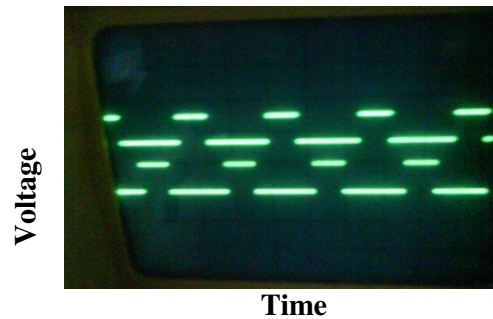

**Fig.14 gate pulses to Switches 1&2
Scale x axis 1 unit   = 20μsec
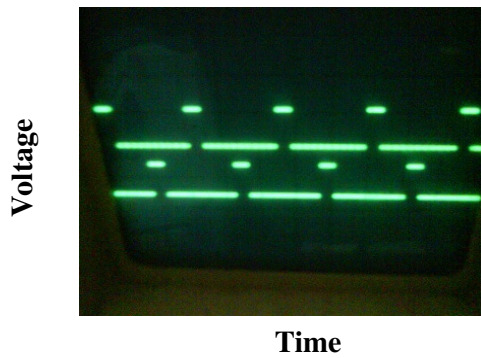   y axis 1unit   = 5V**

Voltage

Time

Fig.15 gate pulses to Switches 3 & 4
Scale x axis 1 unit = 20μsec
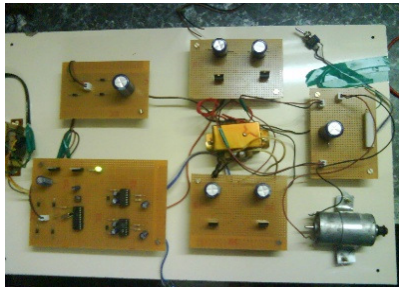**y axis 1unit = 5V**
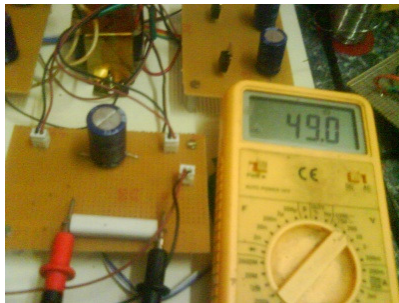

Fig.16 Hardware Setup

Fig. 17 Output Voltage for boost mode

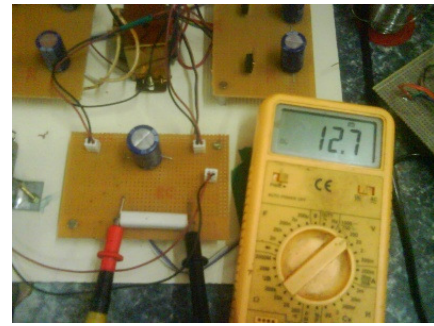**Fig.18 Input DC Voltage**

Fig.19 Output Voltage for buck Mode

4.0   Conclusion

This paper has presented a dual half bridge ZVS Bidirectional DC to DC Converter. This Converter has minimum number of devices compared to full bridge topology. The hardware and simulation results are presented for boost and buck modes. The converter system is tested with C and two stage LC filter. The input voltage vs efficiency graph is obtained for boost and buck modes. The efficiency obtained for boost mode with LCLC filter is 91.7and for buck mode is 87.4. There is a good agreement between simulation and experimental results. This work deals with simulation and implementation of open loop converter. The closed loop control is beyond the scope of this work.

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