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Voltage Controlled Non Isolated Bidirectional DC-DC Converter with High Voltage Gain

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***Abstract*— The renewable systems cannot provide a stable power for user, the renewable energy systems and battery can be utilized for the hybrid power systems. When the renewable energy systems cannot supply enough power for the load, the battery must replenish insufficient power. Whereas the whole power of the renewable energy systems cannot be used completely by the load, the surplus energy can be used to charge the battery. Because the bidirectional DC-DC converters can transfer the power between two DC sources in either direction, these converters are widely used for renewable energy hybrid power systems. Here a voltage controlled non-isolated bidirectional DC-DC converter with high voltage gain is presented. The converter consists of two boost converters to enhance the voltage gain. Four power switches are employed in the converter with their body diodes. Two inductors and a capacitor are also employed as passive components. The input current is divided to the inductor which causes the efficiency to be high and the size of them to become smaller. The voltage gain of the converter is higher than the Conventional Cascaded Bidirectional buck/boost Converter (CCBC) in step up mode. Besides, the voltage gain in step-down mode is lower than CCBC. The converter is implemented in the laboratory with high and low side voltages 25V and 2.5V, respectively. The dsPIC30f2010 microprocessor is used to generate the control pulses. The efficiency of the converter is more than CCBC while the total stresses on active switches are same. Converter is simulated using MATLAB/SIMULINK.**

Keywords—DC-DC converter, High voltage gain converter, Non-isolated bidirectional converter, Voltage Stress

I. INTRODUCTION

Since the usage of the fossil fuel results in environmental pollution, the clean energies become very important in the world. In recent years, the renewable energy systems, including photo-voltaic systems, fuel-cell systems, wind-power generating systems, are developed rapidly. Because the renewable systems cannot provide a stable power for user, the renewable energy systems and battery can be utilized for the hybrid power systems. When the renewable energy systems cannot supply enough power for the load, the battery must replenish insufficient power. Whereas the whole power of the renewable energy systems cannot be used completely by the load, the surplus energy can be used to charge the battery. Because the bidirectional DC-DC converters can transfer the power between two DC sources in either direction, these converters are widely used for renewable energy hybrid power systems, hybrid electric vehicle energy systems and uninterrupted power supplies [3].

The isolated boost bidirectional converter size is large more component is presented in the circuit, core saturation problem, more switching losses, less efficiency as compared to the non-isolated bidirectional DC-DC converter. This project deals with the non-isolated bidirectional DC-DC converter because non-isolated converter does not use a transformer and has one less output rectifier. Without the transformer the overall size of the converter can be reduced, not only by the absence of a bulky component, but wasted heat from switching and copper losses is minimized.

Depending on the application, isolated and non-isolated bidirectional converters are applied. The flyback converters forward-flyback converters, half-bridge converters and full-bridge converters are isolated types of the bidirectional DC-DC converters. These types of converters have large voltage gain in both step-up and step-down operations by adjusting the turn ratio of the transformers. However, the flyback converters have simple structure and easy control, the leakage-inductor energy cannot be recycled, the power switches of these converters suer from high-voltage stresses and the diodes at the secondary side of the converters have reverse recovery problem. The voltage clamp technique in these converters is used to reduce voltage stresses on the switches and recycle the leakage-inductor energy in order to increase efficiency. The non-isolated types of these converters have been researched, which include the conventional boost/buck type, multilevel type, three-level type, sepic/zeta type, switched capacitor type and coupled inductor types. The multilevel types are magnetic less converters, but more switches are used in this converter. If voltage gain is needed to be higher in step-up mode and lower in step-down mode, more switches are required and also the control circuit of this converter would be more complicated. In the three-level type, step-up and step-down voltage gains are low. The converters with coupled inductors have also complicated configuration. This paper proposes a voltage controlled non isolated bidirectional DC-DC converter, which is having a high voltage gain. The closed loop systems are performed over open loop system for maintaining the operating conditions at desired values in presence of normal disturbances.

II. NON-ISOLATED BIDIRECTIONAL DC-DC CONVERTER

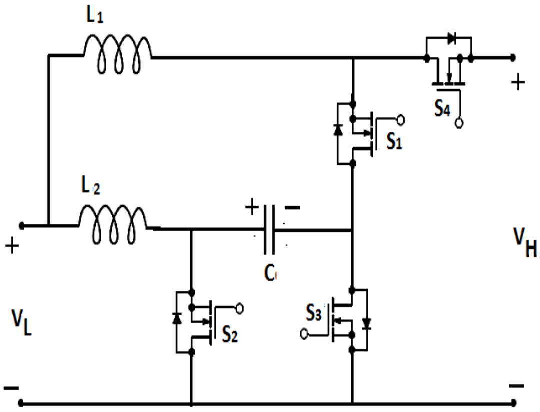

Fig-1: Circuit Diagram

A non-isolated bidirectional DC-DC converter is studied, which has simple structure and large voltage gain. It consists of two conventional boost converters. Four power switches are employed with their body diodes. In each direction, two of the switches are used as power switches and the others are used as the synchronous rectifiers. The input current is divided to the inductors which cause the size of them to become smaller. The operation principle of the converter is also discussed.

Fig.1 shows the system configuration of the bidirectional converter, which has a capacitor, two inductors and four switch-diodes. Two of the switches work as power switches and the remainders are applied for the synchronous rectifiers. The steady-state analysis of the bidirectional converter in step-up and step-down modes is discussed as follows. In order to analyze the steady-state characteristics of the bidirectional converter, the ON-state resistance R_{DS}(ON) of the switches and the equivalent series resistances of the inductors and capacitors are ignored and the voltages of the capacitors are constant.

III. OPERATING MODES

A. Step-Down Mode Of The Converter

The non-isolated bidirectional DC-DC converter in step-down mode is shown in fig.2. In this operation mode, S_3 and S_4 work as power switches and S_1 and S_2 are the synchronous rectifiers.

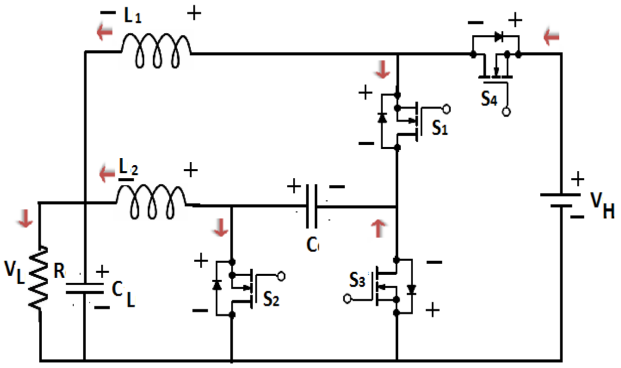

Fig-2: Equivalent circuit in the step-down mode

(a). Mode 1[t_0 −t_1]

During this time interval [t_0, t_1], $S_3$and $S_4$are turned on and S_1 and $S_2$are turned off. The current-flow paths of the proposed converter are shown in fig.3. As seen in this figure, the energy of the DC source V_H is transferred to inductor L_1. Capacitor C is discharged to inductor L_2 and capacitor C_L. The characteristic waveforms of the proposed converter in continuous conduction mode (CCM) are depicted in fig.4. The following equations can be written in this mode:

$$V_{L1} = V_H - V_L \qquad \text{……………...……………(1)}$$

$$V_{L2} = V_C - V_L \qquad \text{………………………...(2)}$$

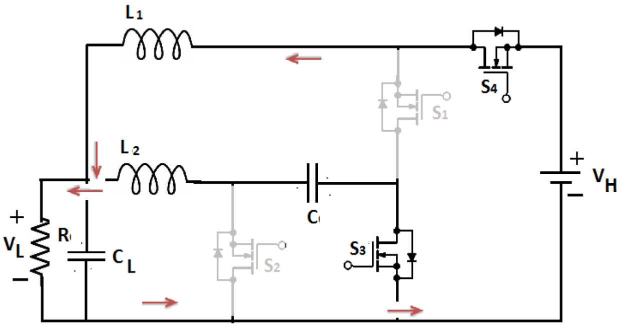

Fig-3: Mode 1 operation in step-down mode

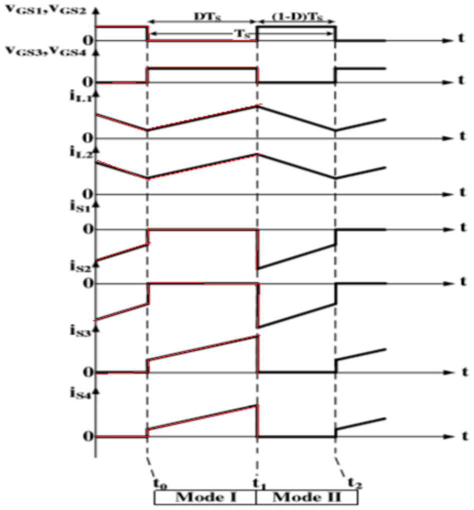

Fig-4: Theoretical waveforms

(b). Mode 2[$t_1 - t_2$]

During this time interval [t_1, t_2], S_1 and S_2 are turned on and S_3 and S_4 are turned off. The current-flow paths of the suggested converter are shown in fig.5. Inductor L_1 is demagnetized in this mode to capacitors C and C_L. Inductor L_2 is discharged to capacitor C_L and provides energy to the load. The characteristic waveforms of the proposed converter in continuous conduction mode (CCM) are depicted in fig.4. Therefore, the voltages of inductors L_1 and L_2 can be written as:

$$V_{L1} = -V_L - V_C \quad \text{..................................(3)}$$

$$V_{L2} = -V_L \quad \text{.......................................(4)}$$

By applying volt-second balance principle on the inductor L_1 and L_2, and then simplifying we get the following equations:

$$\frac{V_C}{V_L} = \frac{1}{D} \quad \text{............................(5)}$$

$$\frac{V_H}{V_C} = \frac{1}{D} \quad \text{...........................(6)}$$

Substituting Eqn(5) into Eqn(6), the voltage gain of the proposed converter in step-down mode can be obtained as:

$$G_{VCCM\,stp-down} = D^2 \quad \text{........................(7)}$$

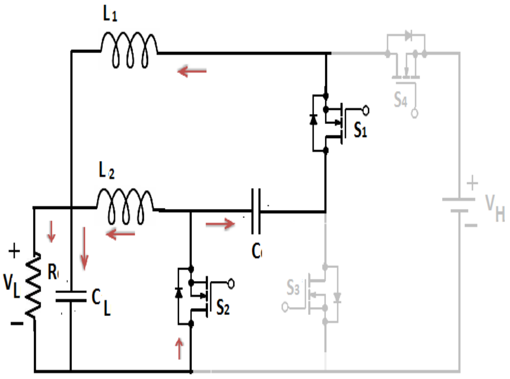

Fig-5: Mode 2 operation in step-down mode

B. Step-Up Mode Of The Converter

The non-isolated bidirectional DC-DC converter in step-up mode is shown in fig.6. In this operation mode, S_1 and S_2 work as power switches and switches S_3 and S_4 are the synchronous rectifiers.

(a). Mode 1[$t_0 - t_1$]

During the interval [t_0, t_1], S_1 and S_2 are turned on and S_3 and S_4 are turned off. As shown in fig.7, in this interval the energy of the DC source V_L is transferred to inductor L_2. Inductor L_1 is magnetized by the DC source V_L and the energy stored in capacitor C. Capacitor C_H is also discharged to the load. The following equations can be obtained in this mode. The characteristic waveforms of the proposed converter in continuous conduction mode (CCM) are depicted in fig.8. The following equations can be written in this mode.

$$V_{L1} = V_L + V_C \quad \text{............................(8)}$$

$$V_{L2} = V_L \quad \text{...(9)}$$

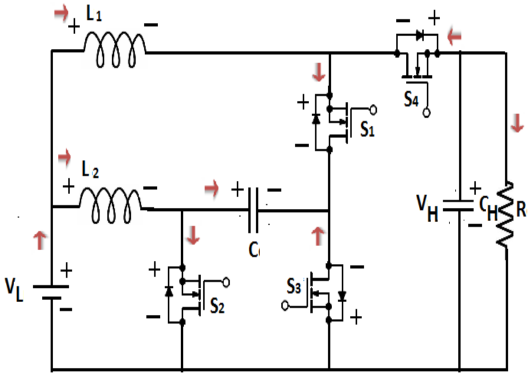

Fig-6: Equivalent circuit in the step-up mode

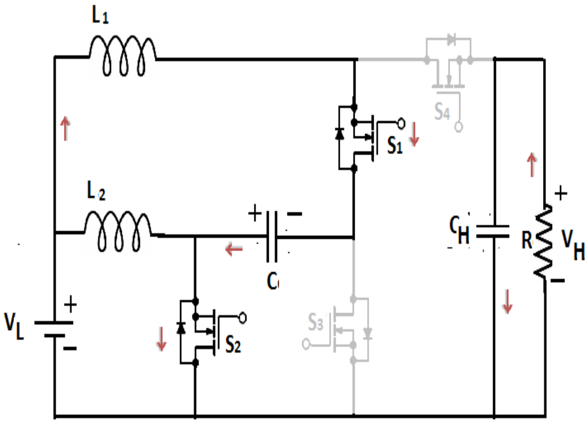

Fig-7: Mode 1 operation in step-up mode

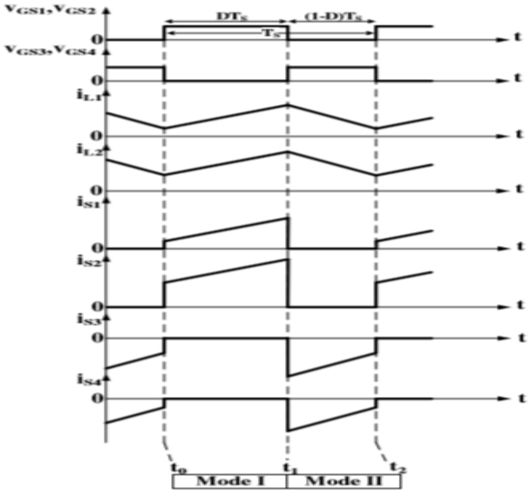

Fig-8: Theoretical waveforms

(b). Mode 2[$t_1 - t_2$]

During the interval [t_1, t_2], S_1 and S_2 are turned off and S_3 and S_4 are turned on. As shown in fig.9, capacitor C is charged by the input source V_L and the energy stored in inductor L_2. Capacitor C_H is also charged by the input source V_L. and the energy stored in inductor L_1. Therefore, the voltages across the inductors can be written as:

$$V_{L1} = V_L - V_H \quad \text{.....................(10)}$$

$$V_{L2} = V_L - V_C \quad \text{.....................(11)}$$

By applying volt-second balance principle on the inductor $L_1$and L_2, and then simplifying we get the following equations:

$$\frac{V_C}{V_L} = \frac{1}{1-D} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(12)$$

$$\frac{V_H}{V_C} = \frac{1}{1-D} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(13)$$

Substituting Eqn(12) into Eqn(13), the voltage gain of the proposed converter in step-down mode can be obtained as:

$$G_{VCCM\,stp-up} = \frac{1}{1-D^2} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(14)$$

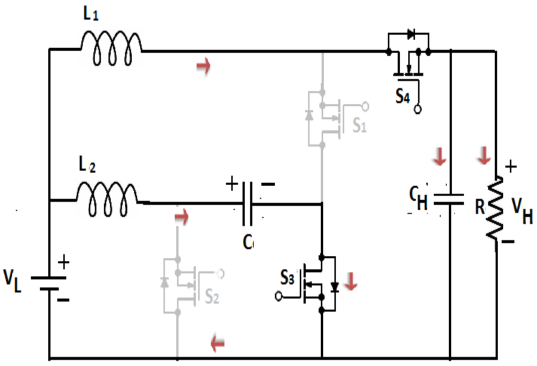

Fig-9: Mode 2 operation in step-up mode

IV. SIMULATION RESULT

In order to justify the validity of the steady-state analysis, the simulation results of both step-up and step-down modes of voltage controlled non isolated bidirectional converter is included in this section. The specifications of the circuit are given in table-1

Table-1: Simulation Parameter

Parameters	Specifications
V_L	25 V
V_H	250 V
Switching Frequency	30 KHz
L_1	1.3 mH
L_2	500 mH
C_L, C_H, C	47μF, 220μF, 220μF
$P_{step-down}, P_{step-up}$	160 W,160 W

A. Simulink Model

The Simulink model of feedback control and gatepulse generation circuit for step-down mode is shown in fig-10. Simulink model of converter is shown in fig-11. Simulink models in step-up mode is shown in fig-12 and fig-13.

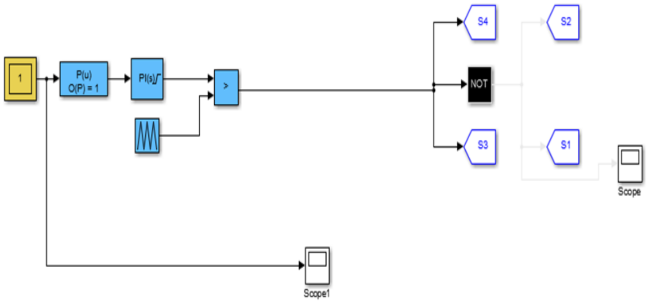

Fig -10: Simulink model of feedback control and gate pulse generation

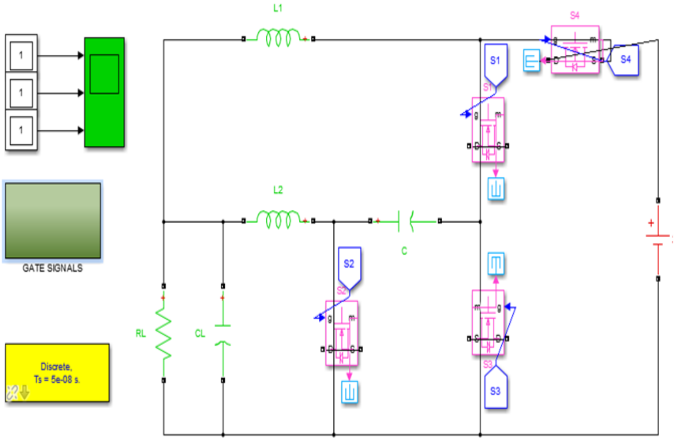

Fig -11: Simulink model of converter in step-down mode

In the step-down mode, the output voltage is fixed at 2.5V and in step-up mode it is 25V. It is obtained by the closed loop control. The output value is compared with reference or set value. This difference is called as an error. This error value is given to PI Controller. This controller is used to regulate the output voltage. The PI Controller output is given to the gate pulse generating circuit.

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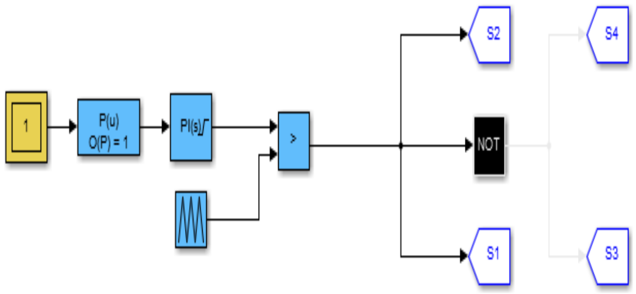

Fig -12: Simulink model of feedback control and gate pulse generation

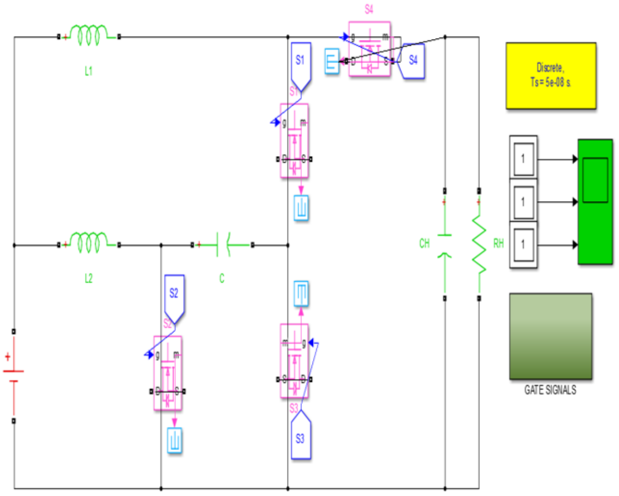

Fig -13: Simulink model of converter in step-up mode

B. Simulation Results

The voltage and current waveforms of electrical components of the converter in stepdown operation mode is shown below. Here the output voltage is fixed at 2.5V, that is even if we vary the input voltage the output voltage does not changes.

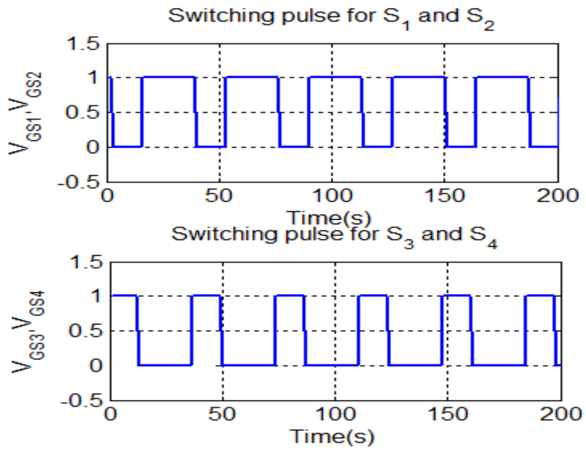

Fig -14: Switching pulse

Fig-14 shows the switching pulses for the four switches. Fig-15 shows the input voltage in step-down mode and it is 25V. Output voltage is shown in fig-16. For an input voltage of 25V, output voltage is obtained as 2.5V. Fig-17 shows the current through the inductors $L_1$and L_2 in step-down mode. The voltage waveforms of switches in step-down mode are shown in fig-18.

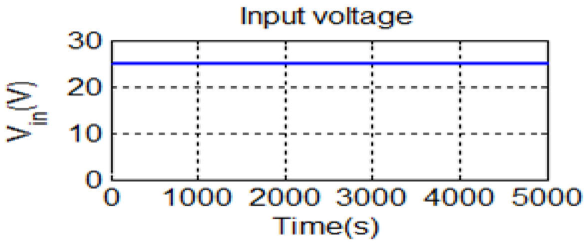

Fig -15: Input voltage

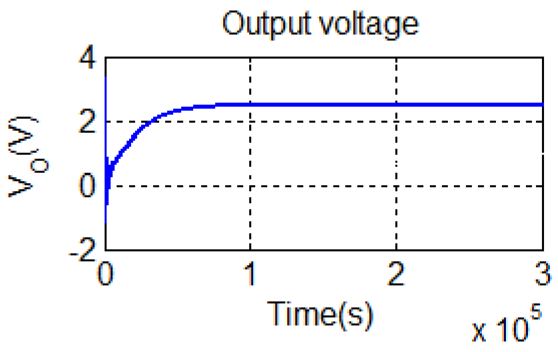

Fig -16: Output voltage

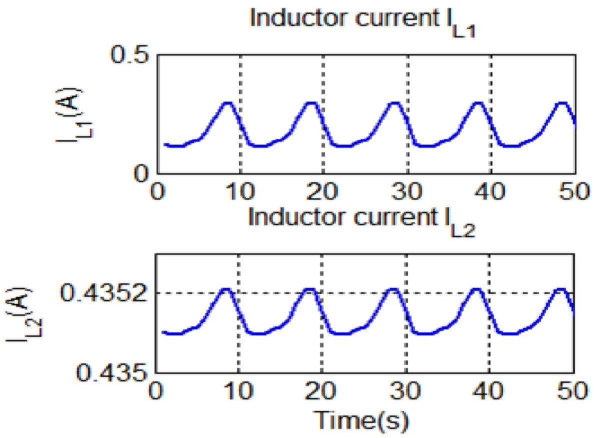

Fig -17: Inductor current

As shown in the fig-17, the current of inductors $L_1$and L_2 are about 0.2A and 0.45A, respectively, in step-dwn mode. From the waveform of voltage stress V_{S1}=V_H= 25V, V_{S2}= V_{S3} equal to square root of V_L and V_H which is equal to 7.9V and V_{S4} is sum of V_{S2} and V_H is equal to 32.9V are obtained.

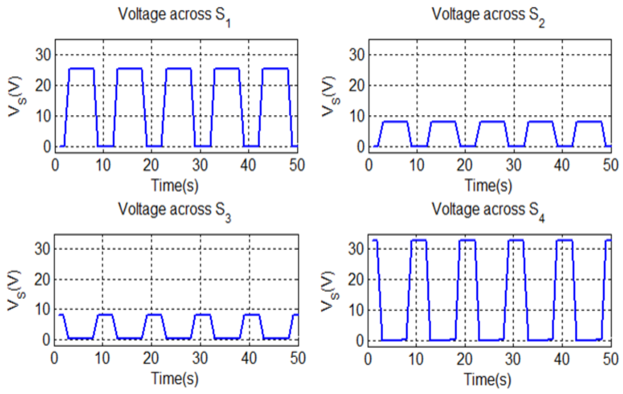

Fig -18: Voltage stress

Fig-19 shows the input voltage in step-up mode and it is 2.5V. Output voltage is shown in fig-20. For an input voltage of 2.5V, output voltage is obtained as 25V. Fig-21 shows the current through the inductors $L_1$and L_2 in step-down mode.

The voltage waveforms of switches in step-down mode are shown in fig-22.

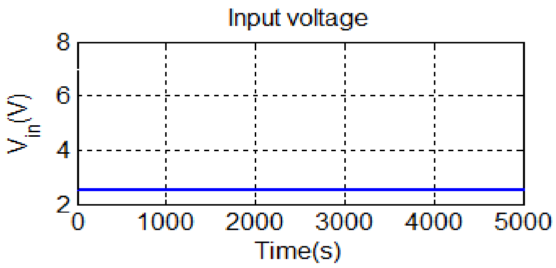

Fig -19:Input voltage

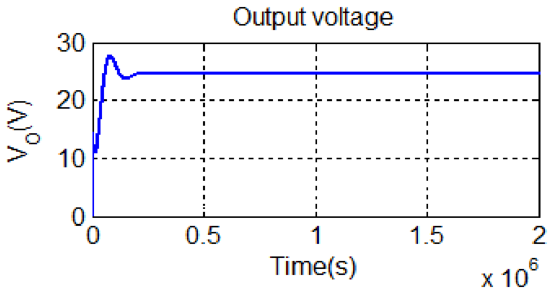

Fig -20:Output voltage

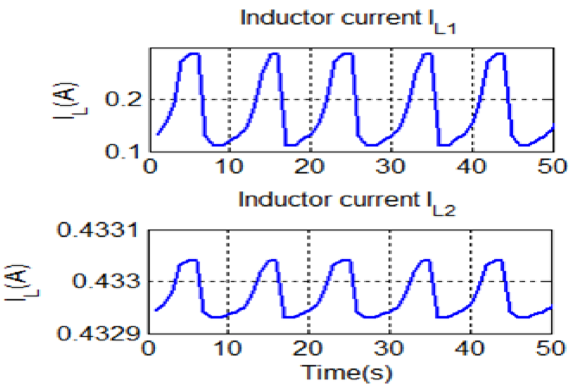

Fig -21: Inductor current

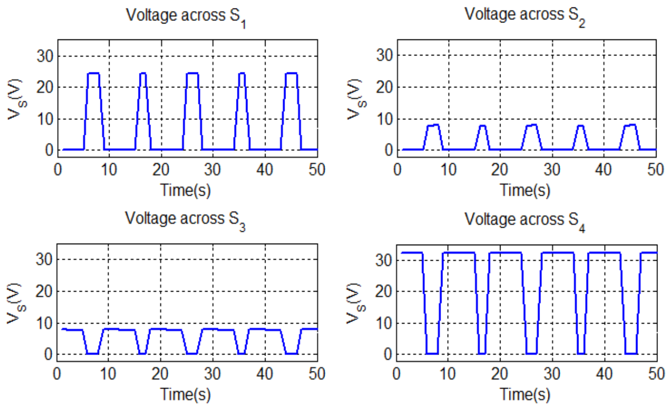

Fig -22: Voltage stress

V. EXPERIMENT SETUP AND RESULTS

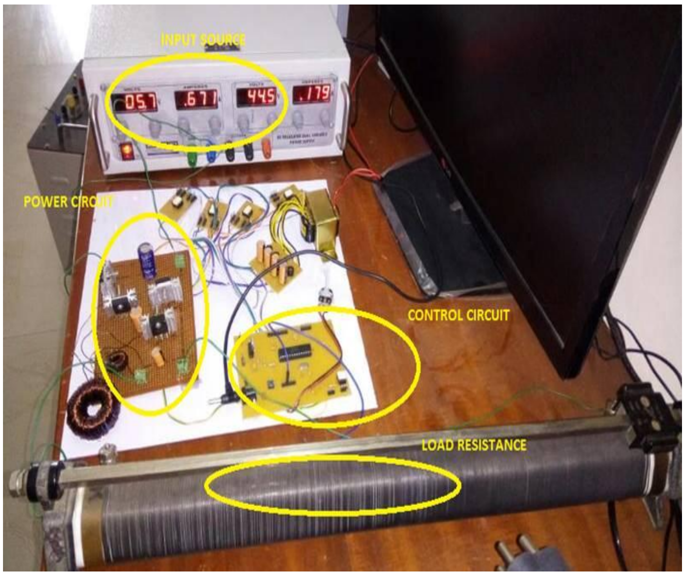

Fig -23: Experiment setup

The experiment setup is shown in fig-22, IRFP260 and IRFP460 are used as switches. The controller used in the prototype is dsPIC30F2010. The hardware results are shown below, Output pulse from driver IC which is of 12V is shown in fig-24. Fig-25 shows the input and output voltage in the step-down mode. In the step-down mode a gain of 0.1 is obtained. Fig-26 shows the input and output voltage in the step-up mode and in this mode a gain of 5 is obtained.

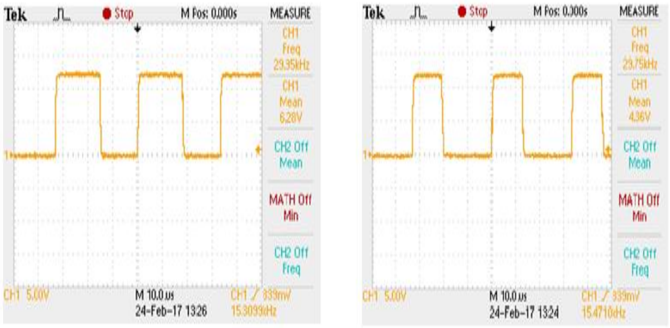

Fig-24: Output of TLP250

Fig-27 shows the input and output voltage pairs for the voltage controlled converter in step-down mode. Here for different input voltages output voltage is constant. Fig-28 shows the voltage across the four switches in the order S1 to S4. Here voltage stress of Switches S2 and S3 are equal and it is less compared to voltage stress of S1 and S4. Due to this two types of switches are used in the hardware setup..

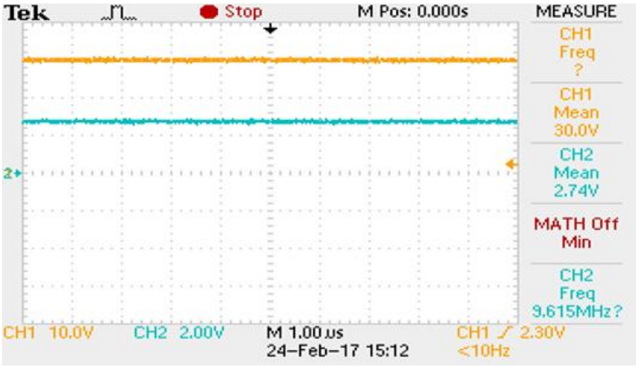

Fig-25: Input and output voltage of step-down mode

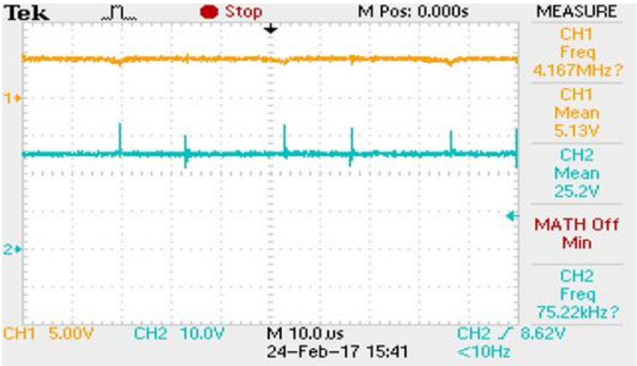

Fig-26: Input and output voltage of step-up mode

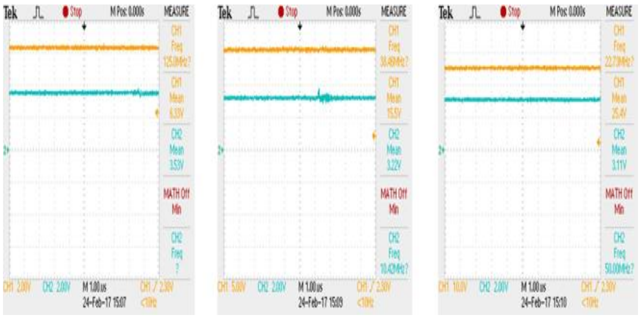

Fig-27: Input and output voltage of voltage controlled converter in step-down mode with different input voltages

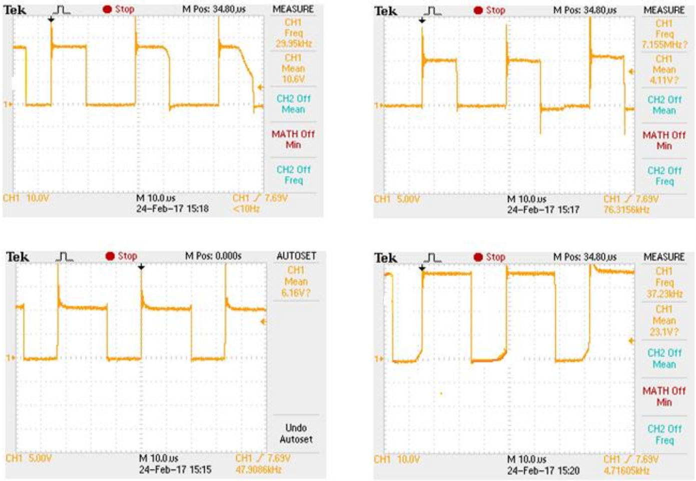

Fig-28: Voltage stress of switches

VI. CONCLUSION

In this paper, a voltage controlled non isolated bidirectional DC-DC converter with high voltage gain is presented. Bidirectional converter is used for the battery charging purposes. The output of the converter is made fixed by the method of feedback. The complete system is simulated in MATLAB/SIMULINK R2016 and hardware section of complete system is done with high and low side voltages 25V and 2.5V respectively. From the analysis, it is found that the proposed converter has higher efficiency because input current is divided to the inductors. Voltage gain of the proposed converter in both step-down and step-up mode is more proper than the conventional bidirectional buck boost converter. But the stresses on the active switches are same. So this converter can be implemented in systems where a storage element is required. In order to charge and discharge the battery bidirectional converter is needed.

REFERENCE

[1]. H. Ardi, R. Reza Ahrabi and S. Najafi, `Non Isolated Bidirectional DC-DC Converter Analysis And Implementation", IET Power Electronics, vol.5 no.12,pp.3033-3044, Dec.2014

[2]. Z. Zhang, O.C. Thomson, M.A.E. Andersen and H.R. Nielsen, “Dual-Input Isolated Full Bridge Boost DC-DC Converter Based On The Distributed Transformers”, *IET Power Electron*, vol. 5, no. 7, pp. 10741083, Aug. 2012.

[3]. C.C Lin and L.S. Yang, “Study Of Non Isolated Bidirectional DC-DC Converter”, IET Power Electron, vol. 6, no. 1, pp. 3037, Jan. 2013.

[4]. Y.P. Hsieh, J.F Chen,T.J. Liang and L.S. Yang, “Analysis And Implementation Of A Novel Single Switch High Step-Updc-DC Converter”, IET Power Electron, vol. 5, no. 1, pp. 1121, Jan. 2012.

[5]. R.Y. Duan and J.D. Lee, “High-Efficiency Bidirectional DC-DC Converter With Coupled Inductor”, IET Power Electron, vol. 5, no. 1, pp. 115123, Jan. 2012.

[6]. W. Li and X. He, “Review Of Non Isolated High Step-Up DC-DC Converter In Photovoltaic Grid-Connected Applications”, IEEE Trans. Ind Electron, vol. 58, no. 4, pp. 12391250, April. 2011

[7]. Pratapsinh G. Parmar, Urvashi D. Patel and Manish S. Patel, “Closed Loop Control of Bi-Directional DC-DC Converter”, IJIREEICE, vol. 4, Issue 2, Feb. 2016.

[8]. L.H. Huber and M.M. Jovanoiv, “Forward Flyback Converter With Current doubler Rectifier: Analysis Design And Evaluation Results,” IEEE Trans. Power Electron., vol. 14, no. 1, pp. 184–192, Jan. 1999

[9]. F. Zhang and Y. Yan, “Novel Forward-Fly Back Hybrid Bidirectional DC-DC Converter,” IEEE Trans.Ind. Electron., vol. 56, no. 5, pp. 1578–1584, May. 2009

[10]. L.S Yang and T. J. Liang, “Analysis And Implementation Of A Novel Bidirectional DC-DC Converter,” IEEE Trans. Ind. Electron., vol. 59, no. 1, pp. 422–434,Jan. 2012.