SOFT SWITCHED NON - ISOLATED BIDIRECTIONAL ZVS - PWM ACTIVE CLAMPED DC - DC CONVERTER

Samuel Rajesh Babu R.[1], Joseph Henry[2]

[1]Research scholar, Sathyabama University, Chennai.
[2]Vel Tech University, Chennai.

ABSTRACT

This paper presents a new soft-switched Non isolated bi-directional ZVS - PWM active clamped DC-DC converter. In addition, unified ZVS is achieved in either direction of power flow with neither a voltage-clamping circuit nor extra switching devices and resonant components. Bi-directional power flow is obtained by the same power components and provides a simple efficient and galvanically isolated converter. The proposed converter can operate with soft switching, a continuous inductor current, fixed switching frequency, and the switch stresses of a conventional pulse width modulation converter regardless of the direction of power flow. These features are due to a very simple and inexpensive auxiliary active clamp technique is used for Zero-voltage-switching of the main and auxiliary switches. The active clamp auxiliary circuit significantly improves converter efficiency regardless of the direction of power flow as it reduces the losses due to switching transitions.The proposed converter has distinct advantages like high power density, high efficiency and low cost application. The detailed design and operating principles are analyzed and described. The simulation results are verified with the experimental results.

Keywords: Bidirectional DC – DC converters, non-isolation, energy conversion, ZVS operation, auxiliary switch, active clamp technique, soft switching.

I. INTRODUCTION

High power non isolated bidirectional DC-DC converters have become key components in alternative energy systems. Depending upon the operation, the converter controls direct current (DC) electric power between a voltage bus that connects an energy generating device such as a fuel cell stack, a photovoltaic array, and a voltage bus that connects an energy storage device such as a battery or a super capacitor, to provide clean and stable power to a dc load. Galvanic isolation is often required for flexibility of system reconfiguration and meeting safety standards. This requirement challenges power electronic researchers and engineers to implement non isolated bidirectional DC-DC converters.

This paper presents a new non isolated bidirectional dc-dc converter with reduced power component counts. Non-isolated bidirectional DC-DC converters, which will be the main focus in this paper , are typically based on the boost/buck converter structure shown in fig1a. S1 operates like a boost switch and S2 is kept open, then energy is transferred from the low-side source V_{lo} to the high-side source V_{hi}.. Similarly when S1 is kept open and S2 operates like a buck switch and the energy is transferred from V_{hi} to V_{lo}.

It is not difficult to implement soft switching in isolated bidirectional dc–dc converters as they tend to be based on conventional half-bridge and full-bridge structures that can use inductive energy stored in the main power transformer to discharge the capacitance across the converter switches. It is more challenging to do non-isolated converters as there is no such transformer.

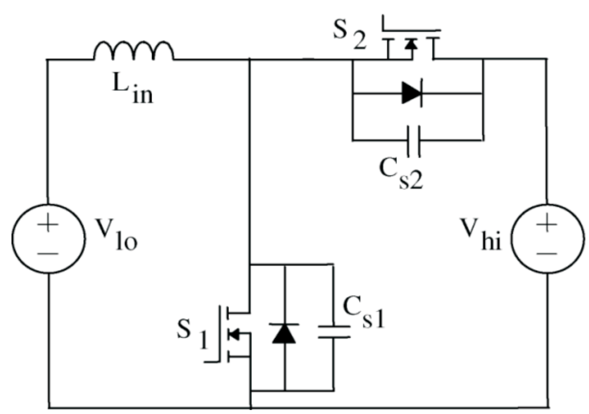

Fig. 1a: Standard Boost/Buck Converter Structure for Bidirectional DC-DC power conversion

Previously Proposed Technology

Previously proposed techniques to implement soft switching in non-isolated bidirectional dc–dc converter can be categorized below:

1. Converters[1] such as the ones proposed in fig 1b, that are made to operate with an inductor (Lin) current that flows in both directions during each switching cycle. Both converter switches are on (never simultaneously) sometime during each cycle so that the energy stored in the inductor when one switch is turned on, the other switch with zero voltage switching (ZVS) after the switch is turned off.

Drawback

The main drawback of this technique is that the inductor current has a lot of ripple with a very high peak as it must flow in both directions during each switching cycle[2]. This results in very high turn-off losses that take away from the improvement in efficiency due to the ZVS turn on and additional filtering is needed to reduce voltage ripple.

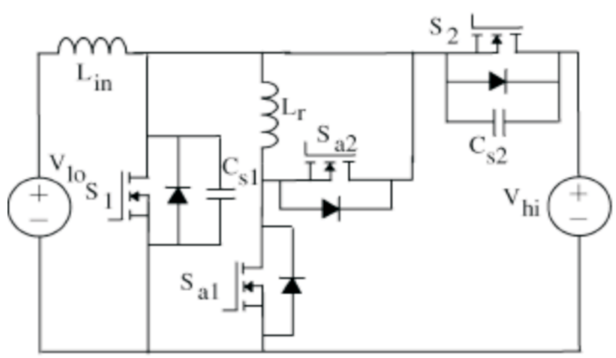

Fig. 1b: Previously Proposed Bidirectional Converters with 4 Switches

2. Another approach in implementing soft switching[3] in a non-isolated bidirectional DC–DC converter in fig 1c, is to use quasi-resonant or multi-resonant techniques. Doing so, however, results in the converter having high peak voltage and/or current stresses, and forces the converter to be operated with variable switching frequency control, which complicates the design of the converter especially the design of the magnetic and filtering elements as the converter must be able to operate under a wide range of switching frequencies.

Drawback

In the case of a converter such as the one proposed, the converter can be made to operate with constant switching frequency, but the switch stresses remain constant[4]. A fixed-frequency resonant-type bidirectional converter was proposed, but this converter was very costly and sophisticated as it required two half-bridge converters in series.

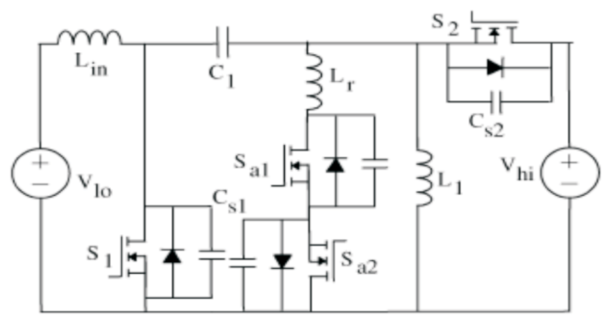

Fig.1c: Previously Proposed Bidirectional Converters with 5 Switches

II. PROPOSED CONVERTER OPERATION

Proposed Circuit

A third approach has been to use auxiliary circuits to assist the switches to operate with soft switching as it is done in zero-voltage transition (ZVT) converters[8]. This has been done with converters such as the ones proposed. Although this approach is an improvement over the other two approaches, it can be costly and complex. This is because a separate independent auxiliary circuit is needed for each main power switch so that the converter must be implemented with four active switches. Converters such as the proposed one to have a single auxiliary circuit, but require two auxiliary switches to make the circuit bidirectional[12].

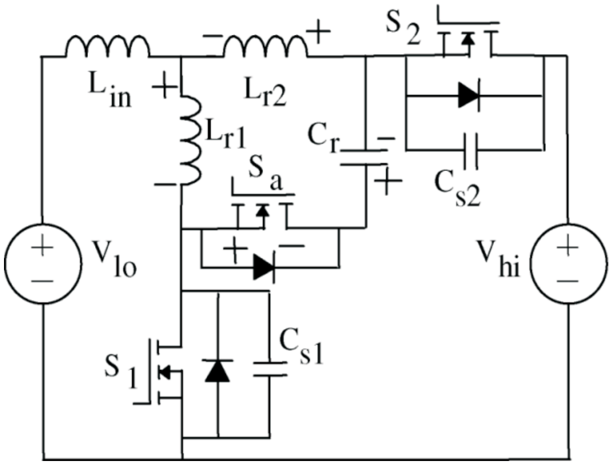

Fig.2a. Proposed soft-switched non-isolated DC-DC PWM converter

Due to the problems associated with each of these approaches - High stresses, variable-frequency control, cost, and complexity - non isolated ZVS bidirectional dc-dc converters are not as widely used. In this paper, a new soft-switched bidirectional dc-dc converter with a simple active auxiliary circuit is proposed. The proposed converter, shown in Fig2a, is very similar to the conventional converter in Fig1a except that auxiliary switch Sa, capacitor Cr, and inductors Lr1 and Lr2 have been added. These four components make up a simple circuit that is based on well-established active clamp technology[1] and that can be used to ensure that the main power switches S1 and S2 operate with ZVS regardless of whether the converter is operating in a boost or buck mode.

The proposed converter can operate with a continuous inductor current, fixed switching frequency, and the switch stresses of a conventional PWM converter regardless of the direction of power flow[12].

To produce a regulated output voltage without input-output isolation, most have a fundamental drawback. Their efficiency is no better when the input is equal to the output. In looking at the popular approach such as buck-boost converter, when properly controlled will be more efficient even the input is near or equal o the output voltage. This appears to be the valuable technique has been largely overlooked.

The use of bi-directional dc-dc converter[15] allows use of multiple energy storage, and the flexible dc-link voltages can enhance the system efficiency and reduce component sizing.A pulse-width modulated, bi-directional dc - dc voltage converter having a regulated output, and capable of converting between a high-potential direct current voltage and a low-potential direct current voltage.

The converter's magnetic components, as well as several of its semiconductor rectifiers, perform dual functions (one in the step-up mode, and another in the step-down mode), which serves to minimize the total component count, and allows the converter to be both compact and lightweight. Additionally, as the converter maintains a continuous input current during voltage step-up conversion, the generation of signals which might cause electromagnetic interference is reduced.

The converter proposed in [1] uses Non isolated bi-directional ZVS - PWM active clamped DC-DC converter. In addition, unified ZVS is achieved in either direction of power flow with neither a voltage-clamping circuit nor extra switching devices and resonant components. Bi-directional power flow is obtained by the same power components and provides a simple efficient and galvanically isolated converter[4]. The proposed converter [5] can operate with soft switching, a continuous inductor current, fixed switching frequency, and the switch stresses of a conventional pulse width modulation converter regardless of the direction of power flow [3]-[10]. These features are due to a very simple and inexpensive auxiliary active clamp technique is used for Zero-voltage-switching of the main and auxiliary switches[8]. The active clamp auxiliary circuit significantly improves converter efficiency regardless of the direction of power flow as it reduces the losses due to switching transitions[14].The proposed converter has distinct advantages like high power density, high efficiency and low cost application.

APPLICATIONS

Non Isolated Bidirectional DC-DC converters will be widely used in various applications such as

1. Energy storage system with galvanic isolation
2. Traction drive of hybrid fuel cell system
3. Residential fuel cell generation
4. DC UPS and industrial applications
5. Aerospace power systems
6. Electric vehicles and battery chargers
7. Electrolyser system
8. High step-up applications

MODES OF OPERATION

The modes of converter operation of the proposed converter can be operated in boost and buck mode. The equivalent circuit diagrams of boost and buck mode is shown in Fig. 2b and 2c.

(A) Boost Mode of Operation

Mode 0 (t < t0): Before time t = t0, the converter operates as a standard PWM boost converter with switch S1 ON and the current through Lin, I_{Lin} rising.

Mode 1 (t0 < t < t1): At t = t0, switch S1 is turned off and the rise in voltage is limited by Cs1. The current through Lr1 charges up Cs1 and begins to flow through Cr. Also, during this mode, input current begins to be diverted to Lr2 and the capacitance across S2 - Cs2 begins to be discharged.

Mode 2 (t1<t < t2): This mode is a continuation of Mode 1 except that Cs2 is completely discharged at t = t1 and current flows through the anti parallel diode across S2.

Mode 3 (t2 < t < t3): At t = t2, current stops flowing through the auxiliary active clamp circuit and the converter operates as a standard PWM boost converter. The current through Lin decreases during this mode as a negative voltage is impressed across Lin.

Mode 4 (t3 < t < t4): Some time before switch S1 is to be turned ON, at t = t3, switch Sa is turned on with zero-current switching (ZCS). Capacitor Cr begins to discharge through Lr1 and Lr2, as ILin continues to decrease. will continue until current has been completely transferred to S1 and the converter enters Mode 0 at t = t7.

Mode 5 (t4 < t < t5): At the beginning of this mode, switch Sa is opened so that the current in the inductor Lr1 starts flowing through the output capacitor of switch S1. The current through S1 discharges the switch capacitor Cs1 so that the voltage across the switch drops to zero by the end of the mode.

Mode 6 (t5 < t < t6): At t = t5, capacitor Cs1 has been completely discharged and the anti parallel diode across S1 begins to conduct. S1 can be turned on while this diode is conducting.

Mode 7 (t6 < t < t7): Some time after S1 has been turned on, at t = t6, the current through Lr1 will begin to reverse direction and the transfer of current from Lr2 to S1 will begin. This mode of operation will continue until current has been completely transferred to S1 and the converter enters Mode 0 at t = t7.

(B) Buck Mode of Operation

Mode 0 (t < t0): Before time t = t0, the converter operates as a standard PWM buck through Lin - ILin, rising.

Mode 1 (t0 < t < t1): At t = t0, switch S2 is turned off and the rise in voltage across it is limited by Cs2. The current through Lr2 charges up Cs1 and begins to flow through Cr. Also, during this mode, input current begins to be diverted to Lr1 and the capacitance across S1, Cs1, begins to be discharged.

Mode 2 (t1<t < t2): This mode is a continuation of mode 1 except that Cs2 is completely charged at t = t1. Some time during this mode, Cs1 may be completely discharged and/or current may stop flowing through Cr.

Mode 3 (t2 < t < t3): At t = t2, current stops flowing through the auxiliary active clamp circuit and the converter operates as a standard PWM buck converter. The current through *L*in. decreases during this mode as the converter is in a freewheeling mode of operation.

Mode 4 (t3 < t < t4): Some time before switch *S*1 is to be turned on, at *t* = *t*3, switch *S*a is turned on with ZCS. Capacitor *Cr* begins to discharge through *Lr*1 and *Lr*2, as *I*Lin continues to decrease.

Mode 5 (t4 < t < t5): Switch Sa is turned off at t = t4.The current in Lr2 is used to discharge Cs2.

Mode 6 (t5 < t < t6): At t = t5, capacitorCs2 has been completely discharged and the anti parallel diode across S2 begins to conduct. S2 can be turned on while this diode is conducting.

Mode 7 (t6 < t < t7): Some time after S2 has been turned on, at t = t6, the current through Lr2 will begin to reverse direction and the transfer of current from Lr1 to S2 will begin. This mode of operation will continue until current has been completely transferred to S2 and the converter enters Mode 0 at t = t7.

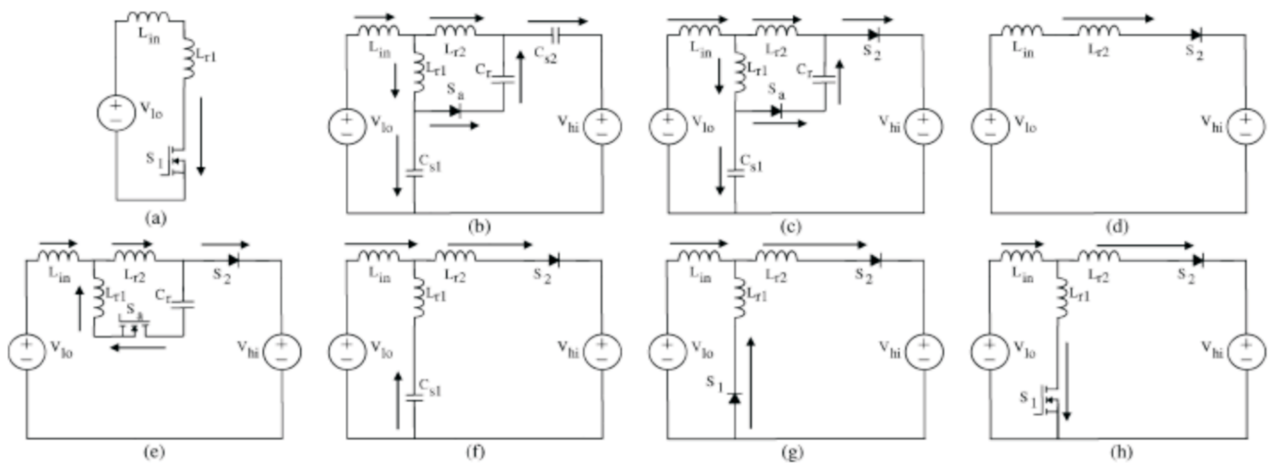

Fig.2b. Equivalent circuit diagrams for boost mode of operation. (a) Mode 0 (t < t0). (b) Mode1 (t0<1< t1). (c) Mode 2 (t1 < t < t2). (d) Mode 3 (t2 < t < t3). (e) Mode 4 (t3 < t < t4). (f) Mode 5 (t4 < t < t5). (g) Mode 6 (t5 < t < t6). (h) Mode 7 (t6 < t < t7).

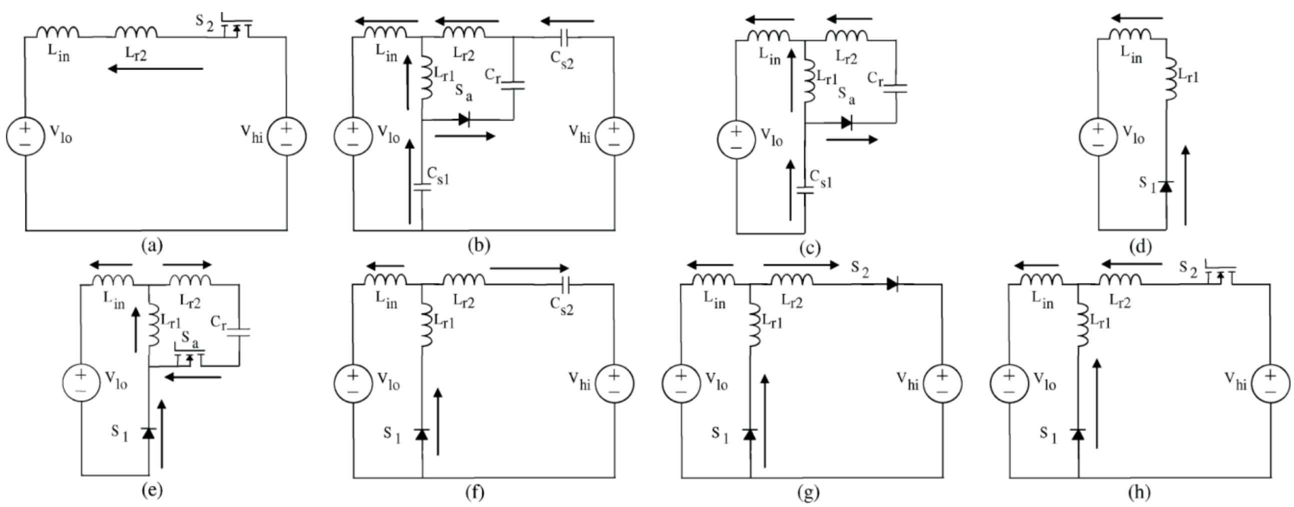

Fig.2c. Equivalent circuit diagrams for boost mode of operation. (a) Mode 0 (*t* < *t*0). (b) Mode1 (*t*0<1< *t*1). (c) Mode2 (*t*1< *t* < *t*2). (d) Mode 3(*t*2 < *t* < *t*3). (e) Mode 4 (*t*3 < *t* < *t*4). (f) Mode 5 (*t*4 < *t* < *t*5). (g) Mode 6 (*t*5 < *t* < *t*6). (h) Mode 7 (*t*6 < *t* < *t*7).

CONVERTER WAVEFORMS

Typical converter waveforms for the boost mode of operation are shown in Fig.2d. The current flowing through S2 is shown as a negative current waveform. It should be noted that the waveforms in Fig.2d also describe the buck mode of operation as the waveforms for both modes are identical-the waveforms for S1 in the boost mode are the waveforms of S2 in the buck mode and vice versa. Referring to Fig.2a, the inductor current ILr1 is positive if it enters the inductor through its positive terminal, the currents through switches S1 and S2 are considered positive if they flow into a switch through its drain, and the current through Sa is considered positive if it flows through the switch source. Any current flowing into the positive terminal of the capacitor Cr is considered to be positive.

III. SIMULATION RESULTS AND DISCUSSIONS

The converter is simulated in a manner similar to the proposed converter, which is also an active clamp converter but one that can operate in one direction only. The converter is operated with a low-side voltage of Vlo = 100 V, a high-side voltage of Vhi = 200 V and a switching frequency of 100 KHz. The analytical and operating principle of the proposed

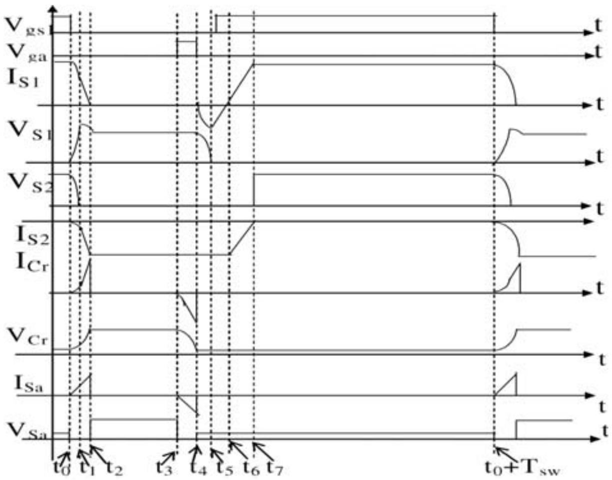

Fig.2d. Waveforms of the proposed Converter.

DC-DC converter is first verified with the simulation. The simulation parameters are as follows:

Design Parameter	Rating
Input voltage(Boost mode)	100 V
Input voltage(Buck mode)	200 V
Lr1	5mH
Lr2	8mH
Lin	8Mh
Cs1	9%F
Cs2	1000%F
R	2.5Ω
Ton	50%
Toff	50%
T	100%
Switching Frequency	100KHz
Duty cycle (Boost mode)	0.7
Duty cycle (Buck mode)	0.5
Output voltage(Boost mode)	200 V
Output voltage(Buck mode)	100 V
MOSFET	IRF840
DIODE	IN4007
LOAD	R- Load & Motor Load.

Non-isolated bi-directional dc-dc converter is simulated using Mat lab Simulation. It has two modes of operation such as,

(i) Boost mode or Forward mode & ii) Buck mode or Reverse mode. The Proposed circuit is simulated with Resistive & Motor load.

(i) Boost mode with R-load: The circuit diagram for boost mode is shown in fig 3.1(a). The input voltage is given as Vdc = 100 V, which is boosted to 200V at duty cycle, D = 0.7 as shown in fig.3.1 (b).Fig 3.1(c) shows the triggering pulses for Mosfet M1 & M2.Fig 3.1(d) shows the pulse Vgs& Vds across boost switch M1. The output DC voltage is shown in fig 3.1(e).

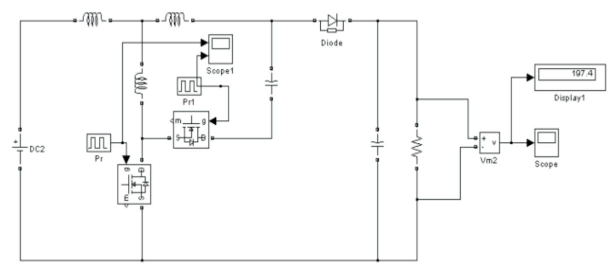

Fig 3.1(a): Circuit Diagram

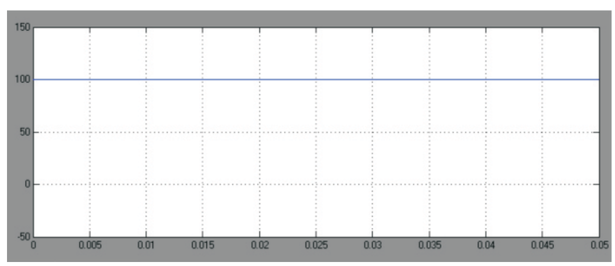

Fig 3.1(b): Input DC Voltage

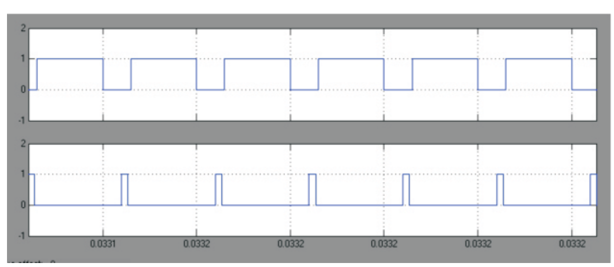

Fig 3.1(c): Driving Pulses for Switches

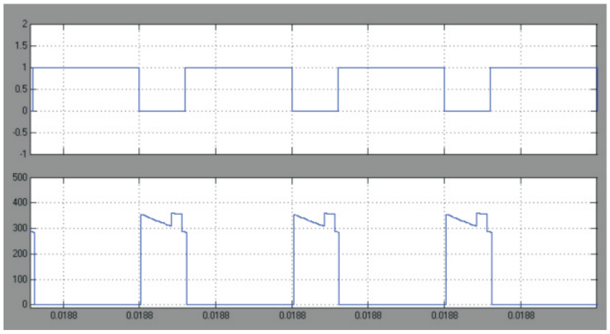

Fig 3.1(d): Pulse And Voltage Across Boost Switch M_1

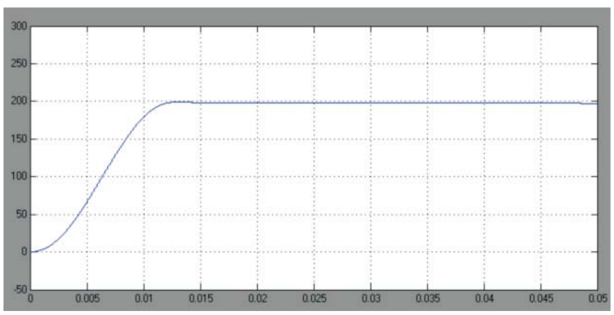

Fig 3.1(e): Output Voltage

(ii) Buck mode with R-load: Fig 3.2(a) shows the reverse or buck mode of operation. In this case, the high voltage Vin = 200 V is step down to low voltage Vo = 100 V, at duty cycle, D = 0.5 as shown in fig.3.2 (b).Fig 3.2(c) shows the triggering pulses for Mosfet M3 & M2. Fig 3.2(d) shows the pulse Vgs & Vds across boost switch M3. The output DC voltage is shown in fig 3.2(e).

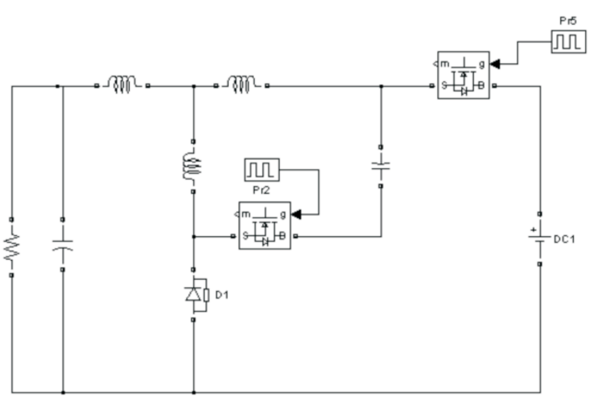

Fig 3.2(a): Circuit Diagram

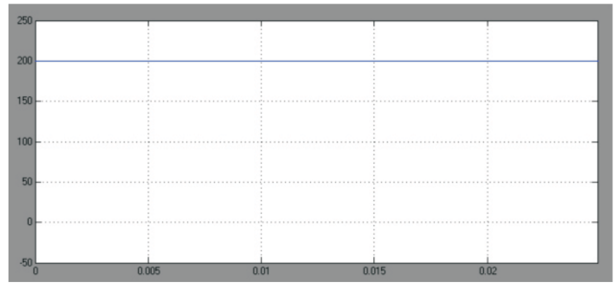

Fig 3.2(b): Input DC Voltage

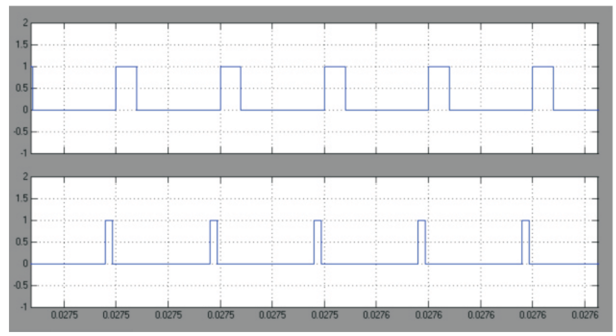

Fig 3.2(c): Driving Pulses for Switches

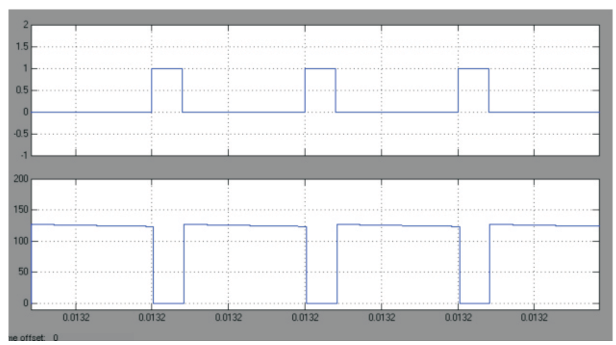

Fig 3.2(d): Pulse And Voltage Across Buck Switch M_2, M_3

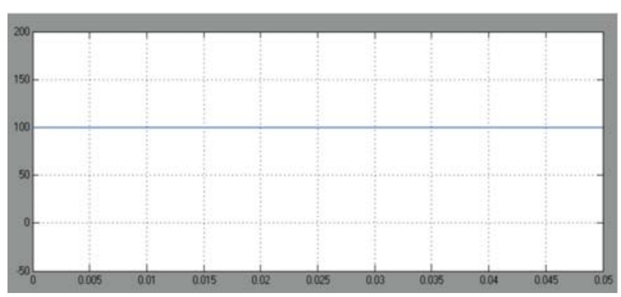

Fig 3.2(e): Output Voltage

(iii) Boost mode with Motor load: Fig 3.3(a) represents boost converter fed dc drive. Boost converter is used to control the speed of the dc motor. Fig 3.3(b) shows the dc input voltage. Fig 3.3(c) shows the triggering pulses for Mosfet M1& M2.

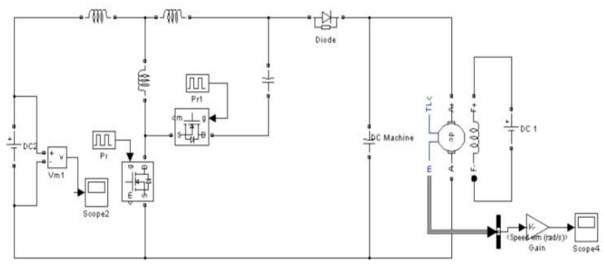

Fig 3.3(a): Circuit Diagram

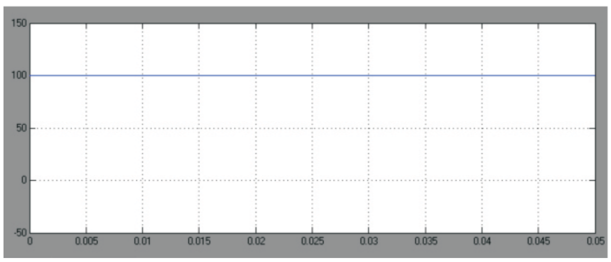

Fig 3 .3(b): Input DC Voltage

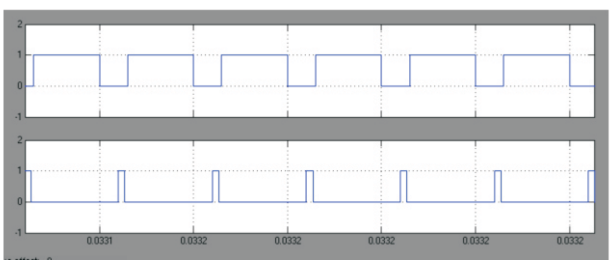

Fig 3.3(c): Driving Pulses for Switches M_1,M_2

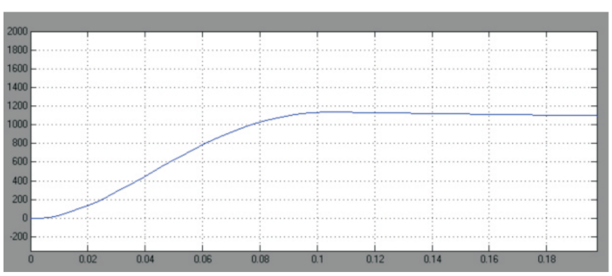

Fig 3.3 (d): Armature Speed in RPM

Open loop System: Fig 3.4 (a) shows the open loop circuit diagram or input disturbance circuit diagram. In this circuit, the input supply is varied from 100V to 110V at t = 1 sec, the corresponding variations in the output side is noted in fig 3.4(b).The input disturbance is given through switch combination. In this case, the output voltage gets increased due to the disturbance.

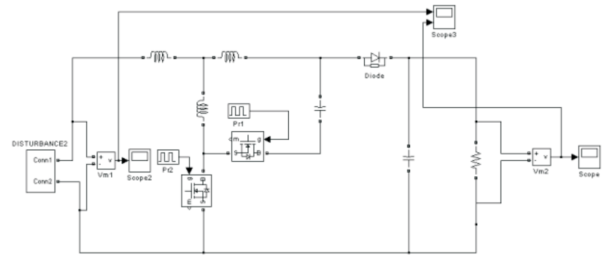

Fig 3.4(a): Open loop diagram

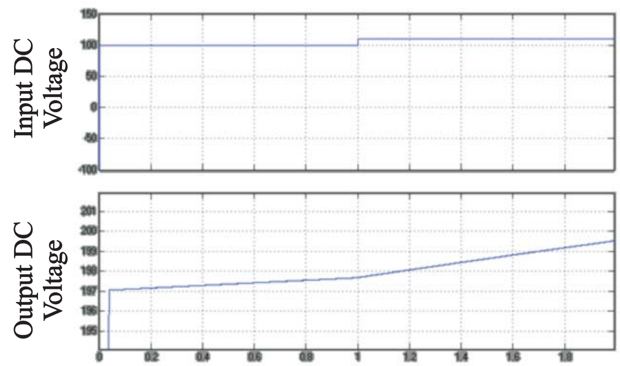

Fig 3.4(b): Input and Output Voltage with disturbance

Closed loop System: Fig 3.5(a) shows the closed loop circuit diagram. 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. This adjusts the Ki, Kp value which depends upon the error. The PI Controller output is given to the controlled voltage source. This CVS is used to regulate the input voltage with the help of feedback system. Thus, the output voltage is regulated with the help of feedback system. Fig 3.5(b) shows the input and output voltage with input disturbance. Thus regulated output voltage is obtained.

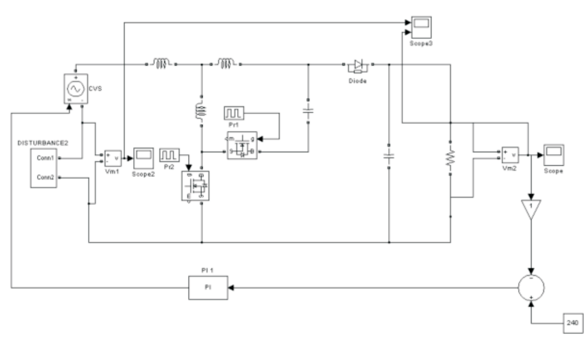

Fig 3.5(a): Closed loop System

The input disturbance is given through switch combination. From the above closed loop curve, it is noted that the output remains constant even though the input disturbance has occurred. Thus, the regulated output voltage is obtained from the closed loop system with respect to the set value, $V = 240$ V.

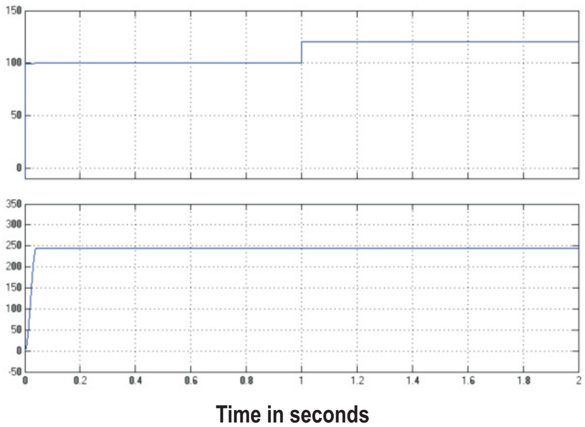

Fig 3.5(b): Input and Output Voltage with disturbance

Thus the proposed converter operates with continuous inductor current and provides soft switching regardless of the direction of power flow. Therefore, ZVS-PWM converters are especially suited for constant load applications.

Comparison between Conventional Circuit & Proposed Circuit: The comparison simulation results between Conventional DC-DC converter and proposed non-isolated bidirectional ZVS-PWM active clamped DC-DC converter have been discussed. Fig.3.6 shows the performance of the converters. From the curve, it is noted that the non-isolated bidirectional DC-DC converter has better performance than conventional DC-DC converter.

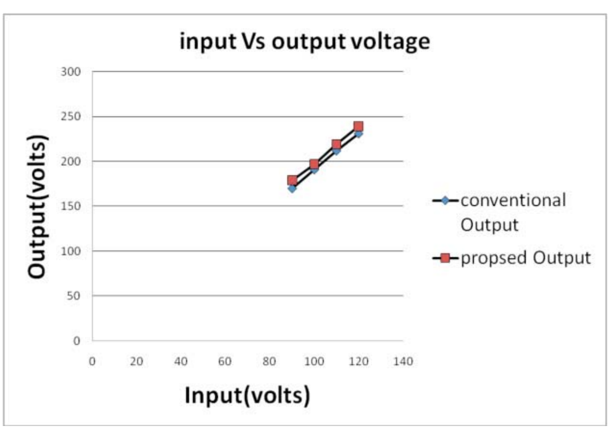

Fig 3.6: Converter Performance

The simulation results are consistent with the theoretical analysis, which verifies the previous analysis and the operating modes concept.

DESIGN CALCULATIONS

To Find Converter Losses: The losses in the converter can be divided into two components: Switching & Conduction loss.

Total Converter Losses $= 0.12048$ W.

To Find Efficiency: $$\%\eta = \frac{\text{Output}}{\text{Input} + \text{Losses}} \times 100$$

$$= \frac{200 \times 0.04 \times 100}{((200 \times 0.04) + 0.12048)}$$

$$\%\eta = 98.51\%$$

Thus, the feasibility of the proposed converter was confirmed with experimental results that showed the effectiveness of the auxiliary circuit in improving efficiency.

IV. EXPERIMENTAL RESULTS

The hardware for Non isolated bi-directional ZVS - PWM active clamped DC-DC converter is fabricated in the laboratory with resistive and motor load. Converter uses two MOSFET switches using IR840. Pulses required by the MOSFET's are generated by using a PIC microcontroller 16F84A. These pulses are amplified by using a driver amplifier IC IR2110. Voltage Regulators 7812,7805 are used for supplying desired voltages to PIC controller and driver IC's. Output Diodes are used to get rectified dc output.

The converter was built to operate with a low-side voltage of $Vlo = 15$ V, a high-side voltage of $Vhi = 43.7$ V, and a switching frequency of 10 to 50 kHz.

The selection of the main power circuit inductor Lin and the main power switches S1; S2 was done as if the converter was a regular PWM converter. The selection of the active clamp components was done by considering the high and low-side voltages and the load range (which affects the current flowing in the converter). It was determined that the ZVS operation range is not dependent on whether the converter operates in the boost or buck mode of operation as the voltages and the currents to be considered in the design of this range are the same.

The hardware layout with resistive load is shown in Fig. 4.1 The hardware consists of power circuit and microcontroller based control circuit. The pulses are generated by using the PIC microcontroller 16F84A. These pulses are amplified using the driver IC IR2110. Control circuit for generating the driving pulses is shown in Fig. 4.2. The driving pulses are generated by the microcontroller. Boost mode output pulse is shown in Fig 4.3 . Boost mode DC output voltage is shown in Fig 4.4. Buck mode output pulse is shown in Fig 4.5 . Buck mode output voltage is shown in Fig 4.6 . The hardware layout with motor load is shown in Fig. 4.7 Fig 4.8 shows DC output voltage of boost mode with motor load. The specifications are as follows:

DESIGN PARAMETER	RATING
LOW SIDE VOLTAGE	15 V
HIGH SIDE VOLTAGE	43.7V
Lin	10 μH
Cs1 = Cs2	2200 micro F
R	3Ω
Transformer	500 milli Amp
MOSFET	IRF840
DIODE	1N4007
Duty cycle	50%
Switching Frequency	10 to 50Khz

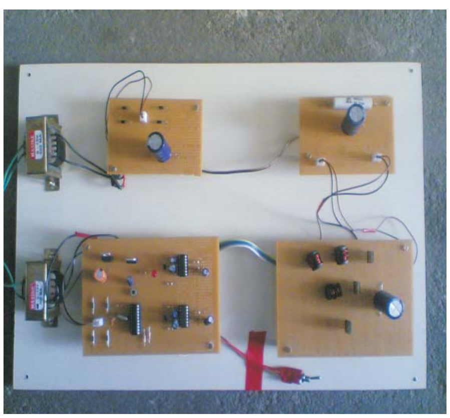

Fig 4.1 Hardware Layout with Resistive load

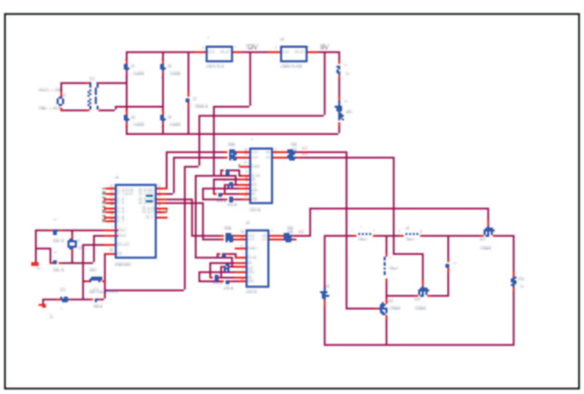

Fig 4.2 Control circuit for generating the driving pulses

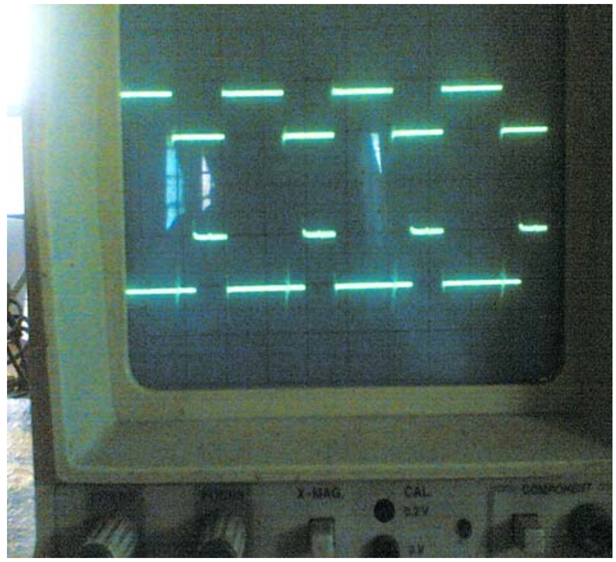

Fig 4.3 Boost mode output pulse

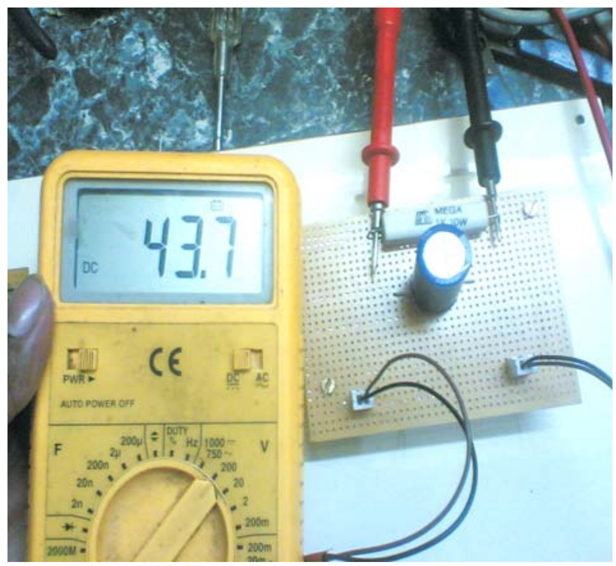

Fig 4.4 Boost mode DC output voltage

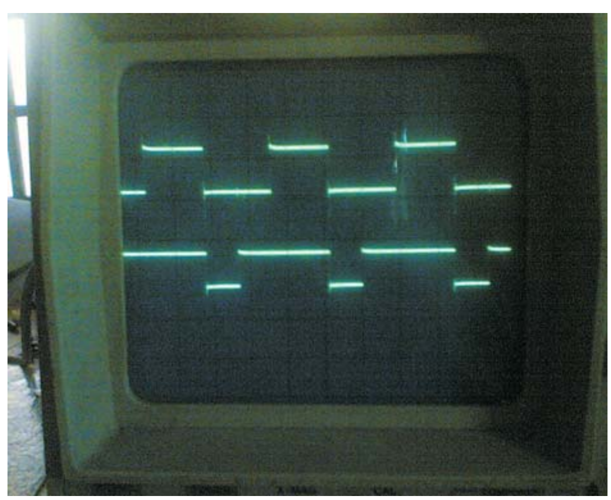

Fig 4.5 Buck mode output pulse

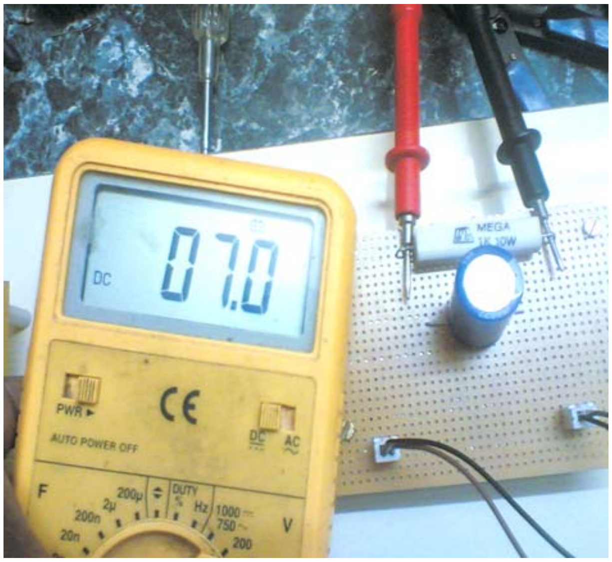

Fig 4.6. Buck mode DC output voltage

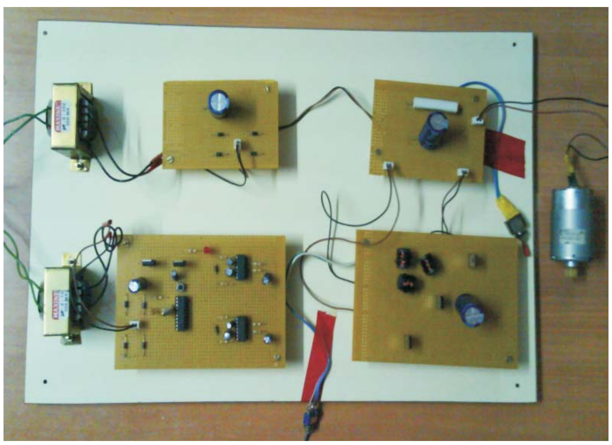

Fig 4.7 Hardware Layout of Boost mode with Motor load

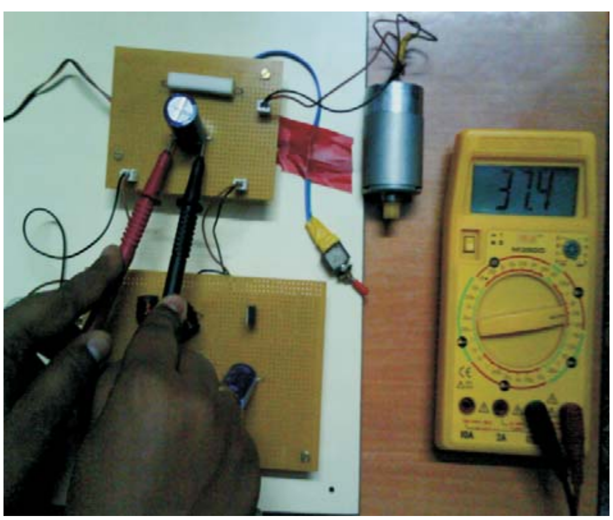

Fig 4.8 DC output voltage of boost mode with motor load

EXPERIMENTAL EFFICIENCY GRAPHS

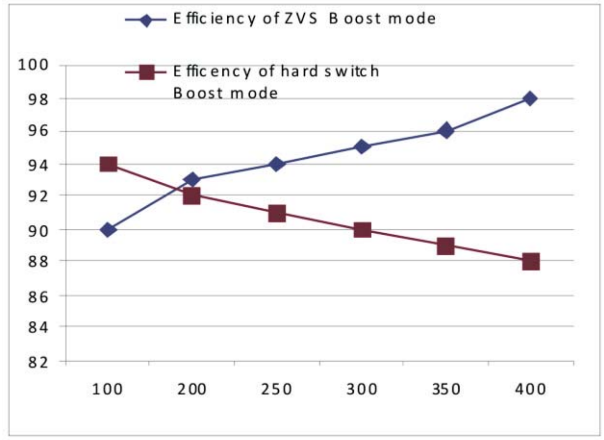

Fig 4.9 Efficiency of ZVS and hard-switched converter operating in boost mode

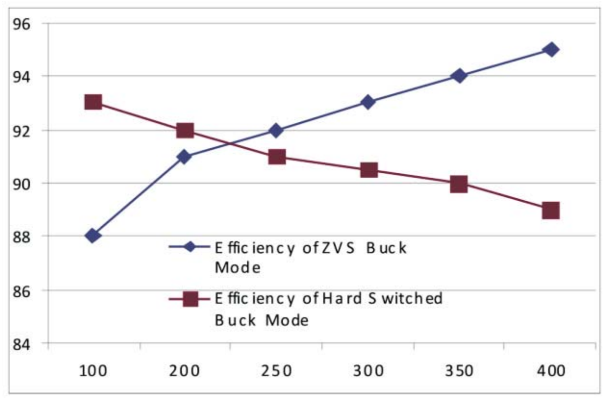

Fig 4.10 Efficiency of ZVS and hard-switched converter operating in buck mode

Graphs of Converter efficiency are shown in Fig 4.9 and 4.10 when the converter is operating in boost and buck modes. It can be seen that the efficiency curves of the ZVS and the hard switched converter diverge at heavier loads. This is because the active clamp auxiliary circuit significantly improves converter efficiency regardless of the direction of power flow as it reduces the losses due to switching transitions, which still exist in the hard-switched converter and become more dominant at heavier loads.

V. CONCLUSION

A new Non-isolated bidirectional ZVS PWM active clamped DC-DC converter is simulated and tested in the laboratory. The outstanding features of the proposed converter are it can operate with continuous inductor current, fixed switching frequency, and the switching stresses of a conventional PWM converter regardless of the direction of power flow. These features are due to a simple and inexpensive auxiliary circuit that is based on well-established active clamp technology. The proposed converter has advantages like reduced Switching losses, reduced switching stresses, reduced EMI, increased power density and high efficiency. Power density is increased by reducing the volume. The volume is reduced due to the increased frequency. This converter can be used for battery charging,,control of DC drives. The simulation results closely agree with hardware results.

REFERENCES

[1] Pritam Das, Brian Laan, Seyed Ahmad Mousavi, and Gerry Moschopoulos, Member, IEEE, “A Nonisolated Bidirectional ZVS-PWM Active Clamped DC–DC Converter”

[2] M. Jain, M. Daniele, and P. K. Jain, “A bidirectional DC–DC converter topology for low power application,” IEEE Trans. Power Electron., vol. 15, no. 4, pp. 595–606, Jul. 2000.

[3] H. M. Suryawanshi, M. R. Ramteke, K. L. Thakre, and V. B. Borghate, “Unity-power-factor operation of three-phase AC–DC soft-switched converter based on boost active clamp topology in modular approach,” IEEE Trans. Power Electron., vol. 23, no. 1, pp. 229–236, Jan. 2008.

[4] K.Zhiguo, Z.Chunbo, Y.Shiyan, and C.Shukang, “Study of bidirectional DC–DC converter for power management in electric bus with super capacitors,” in Proc. IEEE VPPC Conf. Rec., 2006, pp. 1–6.

[5] C. P. Henze, H. C. Martin, and D. W. Parsley, “Zero voltage switching in high frequency power converters using pulse width modulation,” in Proc. EEE APEC Conf. Rec., 1988, pp. 33–40

[6] K. T. Chau, T. W. Ching, and C. C. Chan, “Bidirectional soft-switching converter-fed DC motor drives,” in Proc. IEEE PESC Conf. Rec., 1998,pp. 416–422.

[7] E Sanchis-Kilders, A. Ferreres, E. Maset, J. B. Ejea, V. Esteve, J. Jordan,A. Garrigos,and J Calvente, “Soft switching bidirectional converter for battery discharging–charging,” in Proc. IEEE APEC Conf. Rec., 2006,pp. 603–609.

[8] H. Li, F.-Z. Peng, and J. S. Lawler, “A natural ZVS medium-power bidirectional DC–DC converter with minimum number of devices,” IEEE Trans. Ind. Appl., vol. 39, no. 2, pp. 525–535, Mar. 2003.

[9] P. Jose and N. Mohan, “A novel ZVS bidirectional cuk converter for dual voltage systems in automobiles,” in Proc. IEEE IECON Conf. Rec., 2003,pp. 117–122.

[10] R. Li, A. Pottharst, N. Frohleke, and J. Bocker, “Analysis and design of improved isolated full-bridge bidirectional DC–DC converter,” in Proc. IEEE PESC Conf. Rec., 2004, pp. 521–526.

[11] L. Zhu, “A novel soft-commutating isolated boost full-bridge ZVS -PWM DC–DC converter for bidirectional high power applications,” in Proc. IEEE PESC Conf. Rec., 2004, pp. 2141–2146.

[12] S. Inoue and H. Akagi, “A bidirectional isolated DC – DC converter asa core circuit of the next - generation medium - voltage powerconversion system,” IEEE Trans. Power Electron., vol. 22, no. 2, pp. 535–542, Mar.2007.

[13] D.M. Sable and F. C. Lee, “A zero - voltage - switching bidirectional battery charger/discharger for NASA EOS satellite,” in Proc. IEEE APEC Conf. Rec., 1992, pp. 614–621.

[14] H. Shiji, K. Harada, Y. Ishihara, T. Todaka, and G. Alzamora, “A zerovoltage-switching bidirectional converter for PV systems,” in Proc. IEEEINTELEC Conf. Rec., 2003, pp. 14–19.

[15] I.-D. Kim, S.-H. Paeng, J.-W. Ahn, E.-C. Nho, and J.-S. Ko, “New bidirectional ZVS PWM Sepic/Zeta DC–DC converter,” in Proc. IEEE ISIE Conf. Rec., 2007, pp. 555–560.

R. Samuel Rajesh Babu has obtained his B.E degree from Madras University in 2003. He has obtained his M.E degree from Anna University in 2005. Presently he is doing his research at Sathyabama University. His area of interests is DC - DC converters.

Dr. Joseph Henry has obtained his B.E Degree from Madras University in 1960.He obtained his M.E degree from IIT-Bombay in 1964. He obtained his Ph.D degree from IIT Delhi in 1978. Presently he is a professor in Vel Tech University. His areas of interest are Power Electronics and Digital Protection