International Journal of Applied Engineering Research ISSN 0973-4562 Volume 10, Number 17 (2015) pp 37857-37865

Inductor-Coupled Bidirectional Dc-Dc Converter With Loss Reduction For Hybrid Electric Vehicles

S.Meenakshi, D.Manimegalai, R.Santhosh Kumar

Assistant Professors, Department of Electrical and Electronics Engineering, Veltech, Chennai.

Abstract

This paper presents an interfacing circuit which acts as a bidirectional dc dc converter between battery or ultra capacitor and DC bus with zero voltage transition (ZVT) auxiliary circuit in electric vehicle (EV), fuel cell electric vehicle (FCEV) and hybrid electric vehicle (HEV). The auxiliary circuit provides soft switching to the switching element and the circuit uses a simple PWM control. So, the energy conversion through the converter is highly efficient. The converter operates in ZVT Buck to charge ultracapacitor or battery and in ZVT Boost to discharge ultracapacitor or battery. The performance of the proposed converter was simulated using PSPICE software. The dynamic response of the converter with respect to abrupt load changes and operating mode change is shown through PSim simulation result. The results confirm aforementioned advantages and features of the proposed converter.

Keywords: Battery, DC-DC Converter, Soft Switching, coupled inductor, HEV, Ultracapacitor (UC)

Introduction

BIDIRECTIONAL DC-DC CONVERTERS have been widely used in various industrial applications such as renewable energy systems, hybrid electric vehicle, fuel cell vehicle, uninterruptible power supplies and satellite. In those applications, bidirectional DC-DC converters control the power flow between the dc bus and the low voltage sources such back-up batteries, fuel cell batteries, and super capacitors.

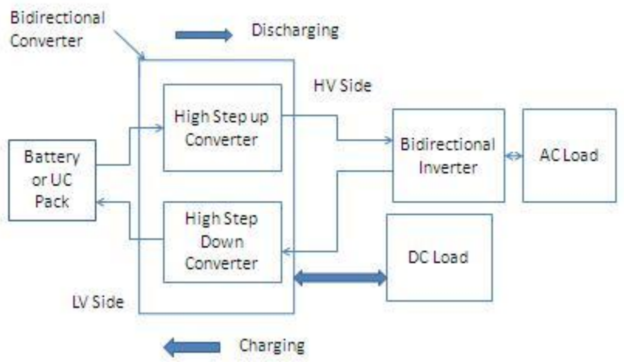


Fig-1:A bidirectional converter in a power electronic converter system

An example of power electronic converter system that requires a bidirectional dc–dc converter is shown in Fig. 1. In this system, a bidirectional converter is used to interface a low-voltage fuel cell stack (Vlo) to dc voltage bus (Vhi). The high-voltage bus is used to supply energy to various loads such as the inverter shown in Fig.1.The block-labeled “bidirectional converter” represents the bidirectional dc–dc interface converter and shows that a single converter must be able to perform the functions of step-up and step-down converters. The bidirectional converter may be transformer-isolated or non-isolated, depending on the application. The non-isolated converters are less expensive than the isolated ones, as they need fewer active switches and passive components. Non–isolated bidirectional converter incorporating coupled inductor and ZVS has attracted due to high conversion ratio, reduced switching losses and simplicity in design.

Energy storage devices (battery and UC) are combined easily to meet the storage and peak current characteristics of EV [2-4] and also to save more energy during regenerative braking phases [5-6]. Ultracapacitors are new family of energy storage systems which have 20 times more energy storage capacity than a conventional capacitor.

In electric vehicle, the energy storage system usually requires fuel cell, battery and UC. The voltage level of energy storage system in EV is much lower than DC bus. Therefore an interface circuit is required between UCs and batteries with DC bus. This interface circuit should be able to handle power flow from low voltage (LV) to high voltage (HV) and vice versa. Several bidirectional non-isolated, DC-DC converter topologies that can be used as an interface circuit in hybrid electric vehicle (HEV) are analyzed in [7].

A suitable topology for power flow from LV to HV is Boost type converter while power flow from HV to LV requires a Buck type converter. To achieve bidirectional capability, the Buck and Boost converter were combined [8-9] as shown in Fig. 2 S1 operates like a boost switch and S2 operates as a boost diode when energy is transferred from the low-side source Vlo to the high side source Vhi and S1 operates like a buck diode and S2 like a boost diode when energy is transferred from Vhi to Vlo. 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 so for non-isolated converters as there is no such transformer.

Several converters for interfacing circuit have been proposed but they are hard switching and their efficiency is low. In (10)soft switched isolated interface circuit, its efficiency is low because of transformer losses. The transformer in this converter is used for isolation and providing soft switching. Since HEV no need of isolation, this converter is not a proper solution.

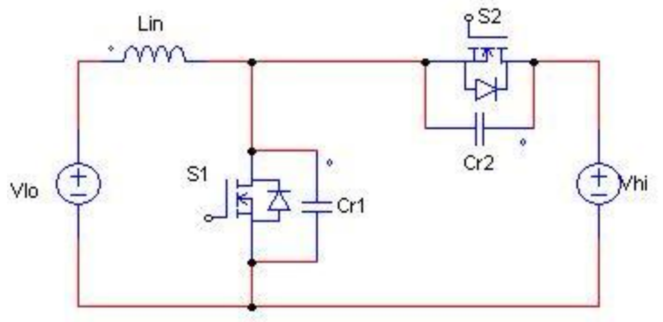


Fig -2: Conventional half bridge bidirectional converter

The major challenge in designing EV converter is converting the electrical output from the storage system to DC bus and vice versa. The important characteristics of DC DC converter for EVs are

[1] High efficiency
[2] High reliability
[3] High power density.

In order to achieve the high efficiency soft switching techniques are gaining more popular than the hard switching.
Zero-voltage transition (ZVT) and zero-current transition (ZCT) converters are new family of soft switched converter. In these converters, an auxiliary circuit containing resonant elements and a switch is used to provide soft switching at switching instants and is usually incapable of transferring energy from input to output [11–12].
The soft switching circuit introduced in [10,13] is for bidirectional isolated topologies can cause many problems when used for EV application like:

1. The transformer leakage inductance cause high voltage stresses and ringing across the converter switches and diodes
2. Increase converter size and cost
3. Increases EMI [15].

No such transformers and problems in non-isolated, so they are much preferred.
In this paper, a high efficiency bidirectional soft switching converter is developed that can be used as an interface circuit between UC or battery and DC bus in EV. The presented converter acts as a ZVT Buck to charge UC or battery. On the other hand, it acts as a ZVT Boost to discharge UC or battery. The control circuit is simple and remains PWM and it has a fast dynamic response.
The auxiliary circuit consists of two switches, two diodes, two coupled inductors and two resonant capacitors. This paper is organized as follows. Section II presents the description and operation of the proposed converter in buck and boost mode with its equivalent circuits. Section III presents the design guidelines for the proposed converter. Design parameter values and the simulation results of buck and boost mode of bidirectional converter are presented in section IV. Section V gives the conclusion and references.

Description and Operating Principle of the Circuit
The bidirectional converter interface circuit is shown in fig3. This converter operates in two modes.

1. Buck mode of operation (to charge a battery or UC)

Boost mode of operation (to discharge a battery or UC) In Buck mode of operation main switch S1 and Diode D2 are ON while, during in Boost mode main switch S2 and Diode D1 are ON. The soft switching conditions for S1 and S2 is achieved by using auxiliary circuit consist of two switches (Sa1, Sa2), two diodes (Da1,Da2), two coupled inductors (Ls1/Lr1, Ls2/Lr2), two resonant capacitors (Cr1,Cr2).

To simplify the analysis, it is considered that, the converter is operating in steady state and the assumptions are made as follows:

1. All components and devices are ideal.
2. Inductor Lf is large enough to assume its current is constant in a switching cycle.
3. The leakage inductance of coupled inductors is very small and can be ignored.

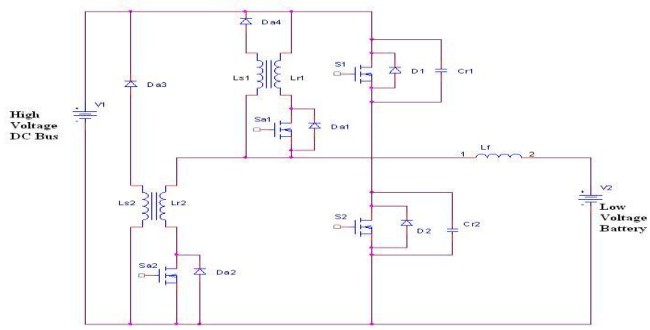


Fig-3: Circuit Diagram of Bidirectional Converter

A. Principle of Operation in Buck Mode

The proposed converter in buck mode is shown in fig 2. The theoretical waveforms are shown in fig 3. The Vgs and Vgsa are gate pulses for main and auxiliary switches S1 and Sa1 There are seven modes of operation in one switching cycle. They are as follow with their equivalent circuits.

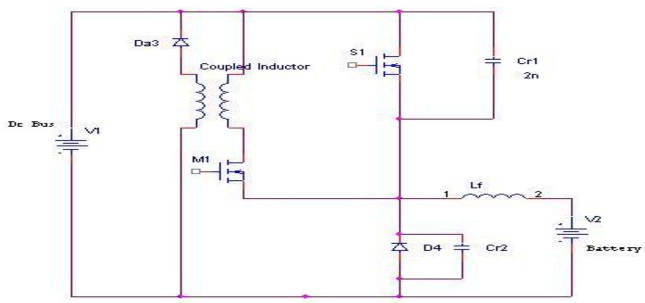


Fig-4: Bidirectional Converter in Buck Operating Mode

International Journal of Applied Engineering Research ISSN 0973-4562 Volume 10, Number 17 (2015) pp 37857-37865

Mode 1(t0-t1):
Before t0, the diode D2 is ON, the capacitor Cr1 is charged fully and the output current flows through it. At t0, the Sa1 is softly turned on under ZCS due to series resonant inductor Lr1. The input voltage V1 is kept across Lr1 and its current starts to increase linearly. At t1 the inductor Lr1 current reaches I0 and D2 turns OFF under ZCS condition. Based on the equivalent circuit shown in fig 3(a), the duration of the interval is

$$t1 - t0 = \frac{Lr1 * Io}{V1} \qquad (1)$$

The current ILr1 in the inductor Lr1 is given by

$$ILr1 = \frac{V1}{Lr1} t \qquad (2)$$

Mode 2(t1-t2):
At t1 resonance starts between Lr1 and Cr1. Thus Cr1 starts discharging and the current in Lr1 increases in resonance manner. At t2 the capacitor Cr1 discharges fully and the current in inductor Lr1 reaches its maximum. Based on the equivalent circuit shown in fig 3(b), the inductor current Lr1 and the capacitor Cr1 voltage is given by

$$A.\ \ ILr1 = Io + \frac{V1}{Zo} \sin\left(\omega o (t - t1)\right) \qquad (3)$$

$$VCr1(t) = V1 \cos\left(\omega o (t - t1)\right) \qquad (4)$$

$$where\ Zo = \sqrt{\frac{Lr1}{Cr1}} \qquad (5)$$

$$\omega o = \frac{1}{\sqrt{Lr1Cr1}} \qquad (6)$$

Mode 3(t_2-t_3):
At t_2, D1 prevents Cr1 from going negative.Thus D1 conducts under ZCS and clamps S1 voltage to zero and S1 turns ON under ZVS condition. Since the voltage across Lr1 is zero its current remains constant till t_3. Using the equivalent ciruit in fig 3(c), the current in Lr1 and S1 is given by

$$ILr1 = Io + \frac{V1}{Zo} \qquad (7)$$

$IS1 = I_0 - ILr1 = -V_1 / Z_0$ (8)

Where $Z_0 = \sqrt{(Lr1 / Cr1)}$ (9)

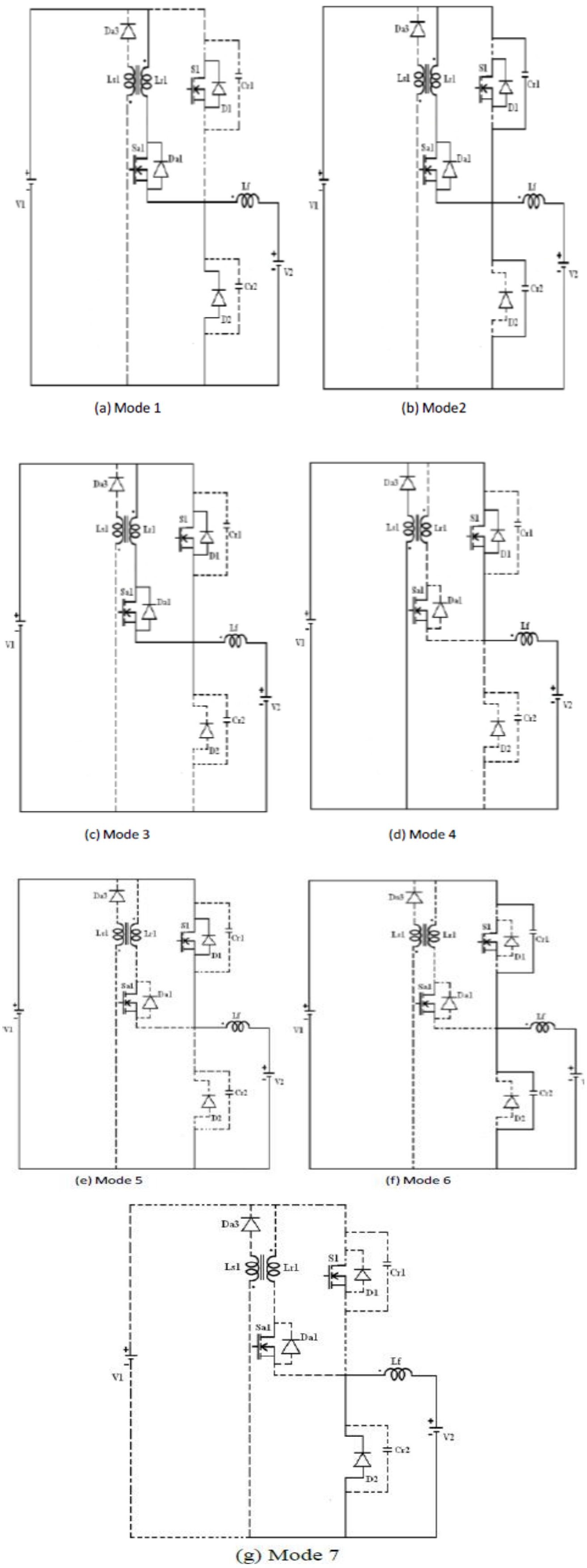


Fig-5: Equivalent Circuits for Each Operating Mode in Buck Mode

Mode 4(t_3-t_4):

At t_3, At t_3, Sa1 almost turns off ZVS. In this condition, Lr1 current drops gradually to zero and current flows through Ls1 and Da4. Then, the secondary voltage of the Flyback transformer is clamped to V1. The secondary voltage is reflected to the primary and the primary voltage equals V1/n, where V1 is the input voltage and n is the turn ratio of the Flyback transformer. When Sa1 turns off, the voltage across this switch is V1/n. By selecting large values for n (i.e., n>5), the voltage across Sa1 is very small and the switch turns off almost ZVS. At t_3, the energy entirely transfers from Lr1 to Ls1 and Ls1 current rises to maximum. Based on the equivalent circuit shown in fig 3(d), the current through Ls1 is given by

$$ILS1 = \frac{Io}{n} + \frac{V1}{nZo} - \frac{V1}{LS1}(t - t3) \qquad (10)$$

This interval ends when the current through Ls1 becomes zero. Also in this interval energy is transferred from energy device to DC bus.

Mode 5(t_4-t_5):

In this mode, the circuit operates purely as a regular buck converter and energy is transferred from battery or UC to DC bus through the main switch S1 and all other semiconductor devices are OFF. The equivalent circuit is shown in fig 3(e).

Mode 6(t_5-t_6):

In this mode, the S1 is turned OFF under ZVS due to the charge of the capacitor Cr1 linearly from zero to V1 by the current through inductor Lf. Based on the equivalent circuit is shown in fig 3(f), the duration of the interval is given by

$$t6 - t5 = \frac{Cr1 * V1}{Io} \qquad (11)$$

$$VCr1 = \frac{Io}{Cr1}(t - t6) \qquad (12)$$

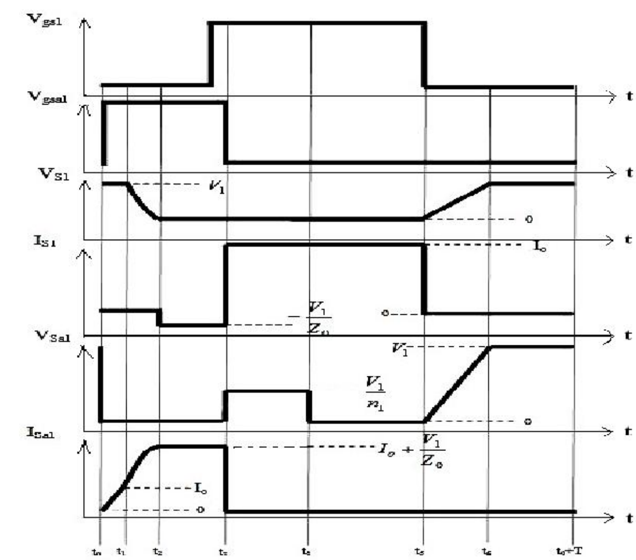


Fig 6. Waveform of Buck Operation Mode

Mode 7(t_6-t_7):

When the voltage across the capacitor Cr1 reaches V1, D2 tarts to conduct and the energy flows from Lf to DC bus as shown in the equivalent circuit in fig 3(g).

B. Principle of Operation in Boost Mode

The boost mode operation is also able to be classified into 7 modes like as buck mode operation. The circuit diagram and equivalent circuit for 7 modes of operations are shown in fig 5. In order to compare boost mode with buck mode, the difference in operation is that, in fifth mode, it purely operates as boost converter and voltage and current polarity direction are similar to that of buck mode as shown in the theoretical waveform in fig 4. So, main inductor current flows continuously even its level is below zero. On the basis of zero current level, the current flows to the opposite direction compared with that of boost mode. Particularly, when the boost mode is analyzed, the operation of switches is changed, but analysis method is similar to that of buck mode. In boost mode, switch S2 is operated as a main switch and Sa2 as auxiliary switch. The resonance is carried over by the inductor Lr2 and capacitor Cr2 respectively. The soft switching is achieved similar to that of buck mode; the detailed description of boost modes of operations is omitted.

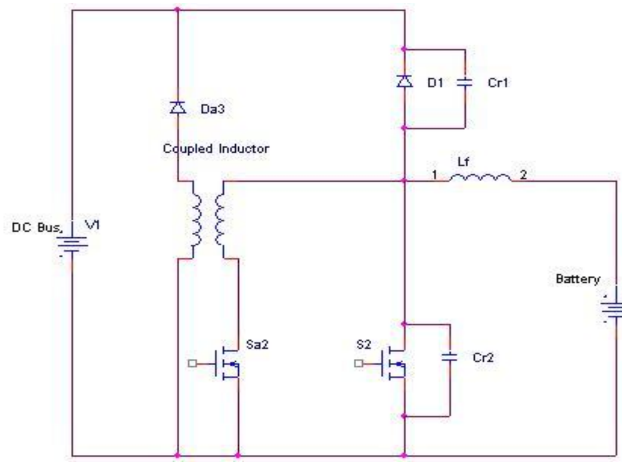
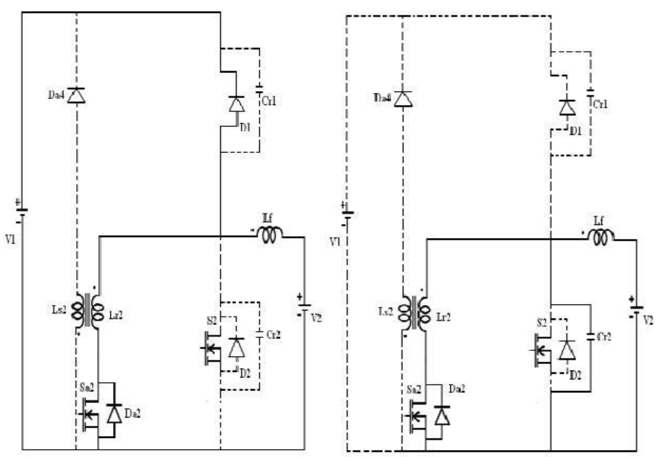
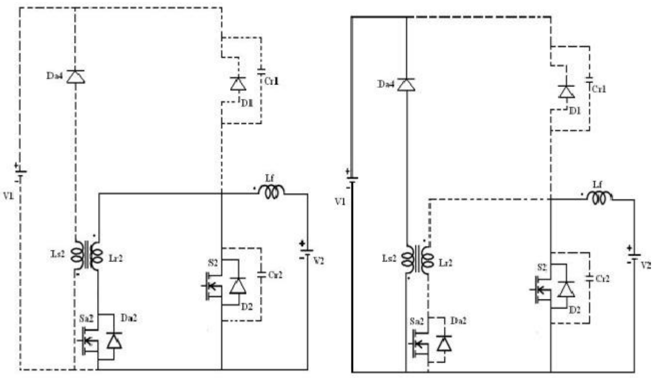


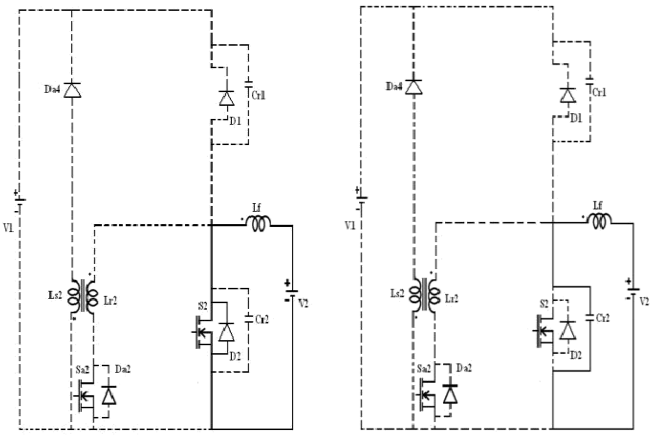
Fig-7: Bidirectional Converter in Boost Operating Mode



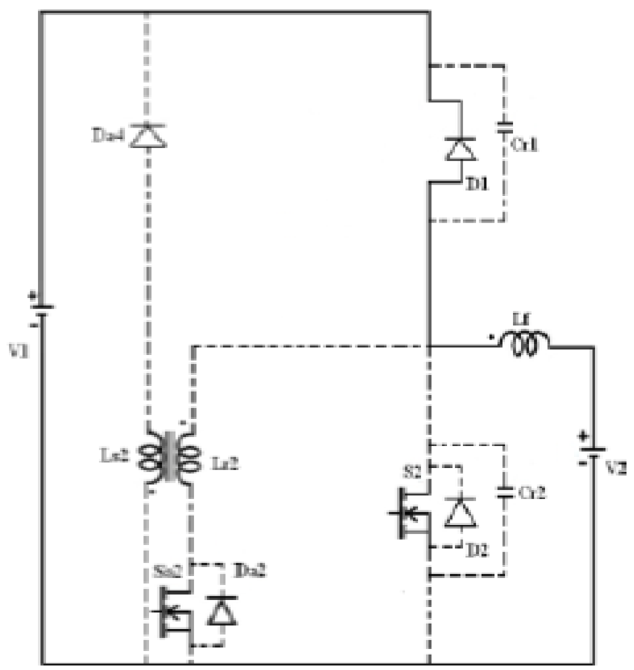
(a) Mode 1 (b) Mode 2



(c) Mode 3 (d) Mode 4



(e) Mode 5 (f) Mode 6



(g) Mode 7

Fig-8: Equivalent circuits for each operating mode in boost mode

C. Salient Features of the Proposed Circuit

1. The semiconductor devices used in the circuits are almost turns ON and OFF under ZVS or ZCS.
2. The switching frequency remains constant for main and auxiliary switches.
3. The voltage and current ratings of the main switches remains same as that of the hard switching converter

Design Guidelines

In this section, a guideline for the selection for the design of the proposed bidirectional buck–boost converter is presented.

A. Selection of Buck and Boost Converter Components

- The process of selecting converter components like inductor, main switches, main diode, output capacitor etc., is same as that for a conventional PWM converter.
- In the proposed circuit, the design and ratings of these components are the same as that of the hard switched boost converter.

B. Selection of Turns Ratio (n) of Flyback Transformer/Coupled Inductor

To transfer the energy in the auxiliary circuit can be fed entirely back to the input in buck mode and similarly to the output in boost mode, the turns ratio of the flyback transformer should be selected as large as possible.

- Advantages of large value of n is
  - ➢ the current flows in Ls which is reflected by the current in Lr is low, so the current through the auxiliary diode is also quite small. Hence the conduction loss in the auxiliary circuit is reduced and the EMI problem caused by the reverse recovery current of the auxiliary diode is eliminated.
  - ➢ the voltage across the auxiliary switch at turn-off instant is quite low and the switch turns off almost at ZVS.

The main consideration in the design is the turns ratio, the selection of too large value will result in large value of Ls and the current flows in Ls cannot reaches zero at fourth interval.

$$Lsx = n^2 Lrx \qquad (13)$$

Where x=1and 2

Fig 9 shows the values of Ls and its current for various values of turns ratio (n). The graph gives that larger the n value smaller the current flows through the inductor but the selection of n should satisfy the equation (14) that it should be zero at the fourth interval.

$$VLs = -V1 = Ls\frac{dI}{dt} = Ls\frac{\Delta I}{\Delta t} = Ls\frac{It4 - It3}{t4 - t3} = Ls\frac{(0 - \frac{Io}{n} - \frac{V1}{nZo})}{(1 - Dmax)T} \qquad (14)$$

Where Dmax is the maximum duty ratio

So, by selecting large values for n (i.e., n > 5), the voltage across Sa1 is very small and the switch can be turned off under almost ZVS condition.

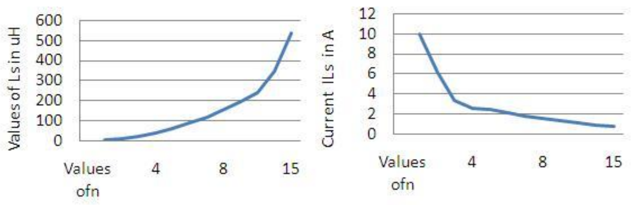


Fig-9: Values of inductor Ls and current flows through it (ILs) for various values of turns ratio (n)

C. Selection of Resonant Inductor Lr and Resonant Capacitor Cr

The rate of rise of current in the auxiliary circuit in the interval t_1 depends on Lr. Larger value of Lr increases the length of the resonant interval t_2. This in turn increases auxiliary circuit RMS current leading to conduction losses.

The value of Lr and Cr together decides the resonant interval t_2. The resonance interval should be as small as possible. This in turn minimizes the conduction losses in the auxiliary switch.

- The length of the resonant interval is approximately a quarter of the resonant period π/ 2√(Lr*Cr). The selection of the values of Lr and Cr is based on

$$\frac{\pi}{2\sqrt{Lr * Cr}} \text{ (5 to 10 \%) of Ton (Max)} \quad (15)$$

- Larger value of Cr increases the peak of auxiliary circuit current. Lower values Cr of increases rise of voltage across main switch. Value of Cr is so selected that voltage across the main switch does not exceed the specified limit. The selection of Cr is based on equation 16.

$$Cr = \frac{I * t_f}{2V_f} \quad (16)$$

Where I is the on-state current and t_f is the fall time of main switch and V_f is the off-state voltage

- The resonant inductor Lr is obtained so that it minimizes the reverse recovery loss of the diode D by limiting its di/dt.

$$Lr = \frac{Vo - Vin}{\frac{dIDmax}{dt}} \quad (17)$$

Where IDmax is maximum current of diode at reverse recovery time(trr), dt is time duration for reverse recovery of diode, Vo is output voltage and Vi is input voltage.

D. Gating Signals of the Auxiliary Switch and the Main Switch

The gating signals to main and auxiliary switches are as shown in fig.8, to ensure ZVS and ZCS transitions of the main and the auxiliary switches, respectively.

The turn on of auxiliary switch is at zero current. The minimum on time of the auxiliary switch is t=t1+t2+t3. This ensures that the turnoff transition of the auxiliary switch is at zero current.

The minimum delay for the turn on of the main switch is td=t1+t2. The delay is a function of load and other operating conditions. Since the capacitors are ground referenced or power supply referenced, it is possible to program the delay between the auxiliary switch and the main switch dependent on the capacitor voltage to sense the completion of the resonant process. This helps the control circuit to reduce the switching loss close to zero and not getting the body diode of the main switch to conduct.

E. Design Procedure and Example

The procedure is based on the guidelines that were presented in the previous section. Design procedure is shown for the auxiliary switch commutated boost converter. The same has been simulated, fabricated and tested. Simulated waveforms are shown in preceding sections. The converter is designed for specifications shown in Table 1 for buck and boost mode of operations.

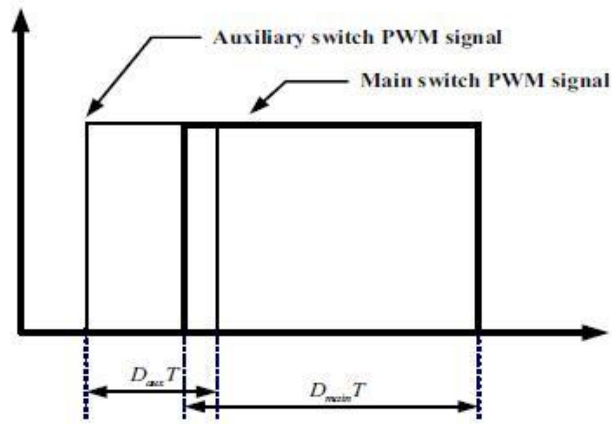


Fig-10: PWM Gating Signal for Main and Auxiliary Switches

The steps for design procedure as follows:

1. Calculation of input filter inductor and output filter capacitor is same as that of conventional hard switched buck and boost converter.
2. According to equation (16) and (17), the design of resonant inductor and capacitor is given by Lr ≅2.44 µH and Cr ≅2nF.
3. The turns ratio of flyback transformer or coupled inductor is chosen as n=7 as per design consideration

And the value of Ls is calculated by the equation (13) Ls ≅117.6µH.

Simulation Results

A. Open Loop Simulation

To verify the above analysis and design procedures the proposed converter is simulated using PSPICE software and the results are shown in fig 9-14.

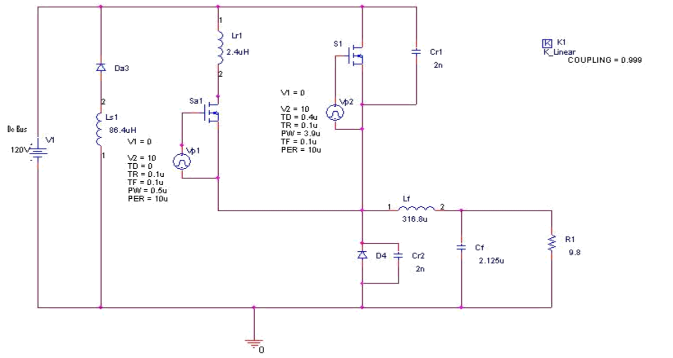


Fig-11: Simulation Model of Buck Converter

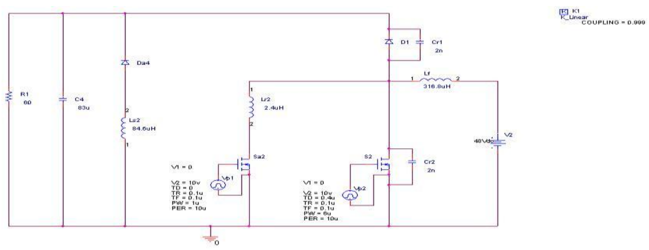


Fig-12: Simulation Model of Boost Converter

TABLE 1 DESIGN SPECIFICATIONS FOR BUCK AND BOOST MODE

COMPONENT	PARAMETER FOR BUCK	PARAMETER FOR BOOST
Input Voltage (Vi)	150V	60V
Output Voltage (Vo)	60V	150V
Switching Frequency (fs)	100KHz	100KHz
Filter Inductor (Lf)	1mH	1mH
Filter Capacitor (Cf)	2.125 F	83uF
MOSFET Switches	IRF840	IRF840
Diodes	MUR480	MUR480
Resonant Inductors and coupling Coefficient (Lr/Ls/k)	2.4H/117.4 H/1	2.4H/117.4 H/1
Resonant Capacitor (Cr)	2nF	2nF

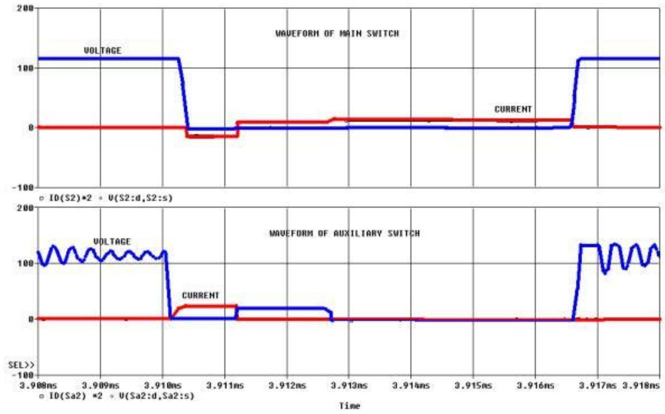


Fig-13: Voltage and Current Waveform of Main S1 and Auxiliary Sa1 Switches of Proposed Converter in Buck Mode

From the voltage and current waveform across the main and auxiliary switch shown in fig 13 and 14, confirms that the switches are operated under ZVS and ZCS conditions.

B. Closed Loop Simulation

To analyze the dynamic response, proposed converter with current feedback is designed and simulated in Psim software. As shown in fig 15, at first the converter is operated in boost mode, the current in the filter inductor is around -10A. Then the converter is switched to buck mode, the transition time for Lf current changed from -10A to +10A is shown in fig 16.

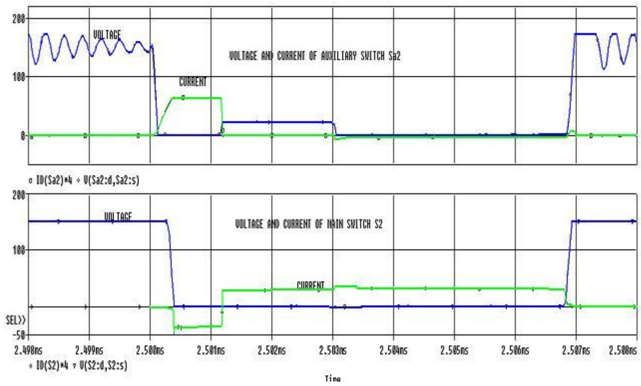


Fig-14: Voltage and Current Waveform of Main S2 and Auxiliary Sa2 Switches of Proposed Converter in Boost Mode

After reaching the steady state (at t=0.5ms), the load is changed from +10A to +5A in order to show that the converter has fully adequate to dynamic response in load change as well as change in operating mode. Fig. 16(b) clearly shows that at the first, the ultracapacitor is in discharging mode but after the converter switches from boost mode to buck mode the ultracapacitor voltage increases slowly. Similarly, for mode change from buck to boost as shown in fig 17 and fig 18.

The transition time of Lf current from +10A to -10A is around t=0.5ms and the capacitor voltage decreases due to mode change from buck to boost operation.

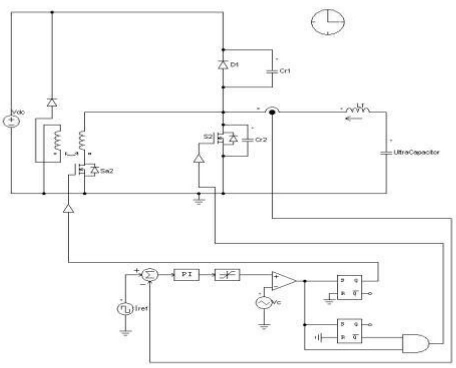


Fig-15: Simulation Model of Closed Loop Buck Mode in Psim

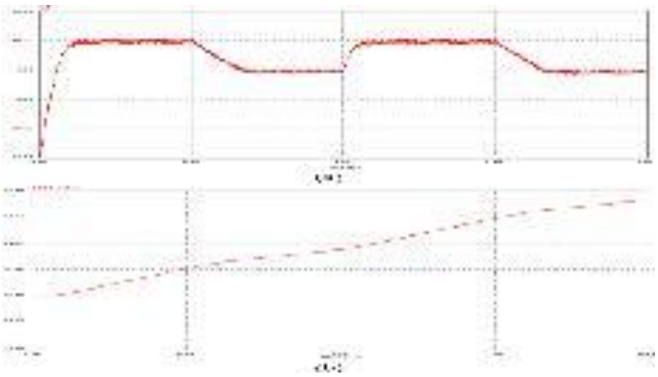


Fig-16: (a) The Filter Inductor (Lf) Current and (b) the UC Voltage

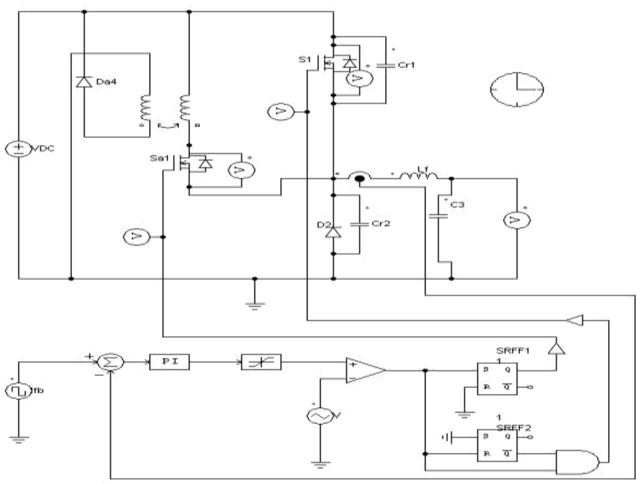


Fig-17: Simulation Model of Closed Loop Boost Mode in Psim

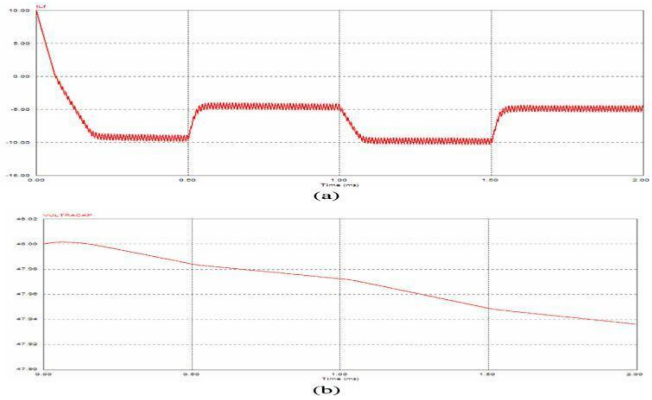


Fig-18: (a) The Filter Inductor (Lf) Current and (b) the UC voltage

Conclusion

The presented non-isolated soft switched bidirectional converter can be employed as an interface circuit between batteries and DC bus. The converter acts as a ZVT buck to charge battery and a ZVT boost to discharge battery. The converter is analyzed and its different operating modes are presented. Design considerations are discussed and the circuit follows the soft switching techniques. The converter response to abrupt load change and also change in operating modes is discussed and the simulation results demonstrate the fast dynamic response of the proposed converter. The idea employed to provide the ZVS condition for the proposed buck–boost converter is extended to other bidirectional non-isolated DC–DC converters that can be used for similar application such as cascade buck–boost, Cuk and Sepic/Luo converters.

References

[1] A. Mirzaei*, A. Jusoh, Z. Salam, E. Adib, H. Farzanehfard "Analysis and Design of a High EfficiencyBidirectional DC-DC Converter for Battery andUltracapacitor Applications" IEEE International Conference on Power and Energy (PECon2010), Malaysia Dec-2010.

[2] M.Y. Ayad, S. Rael, Hybrid Power Source Using Supercapacitors and Battery, EPE-Toulouse, 2003.

[3] X. Yan, D. Patterson, Improvement of driving range, acceleration and deceleration performances in an electric vehicle propulsion system, in: Proc. IEEE Power Electronics Specialists Conf., June, 1999, pp. 638– 643.

[4] L. Lianbing, L. Sun, Z. Liu, H. Sun, Ultra-capacitor control strategy of EV with energy hybridization, in: Proc. IEEE Vehicle Power and Propulsion Conf., September, 2008, pp. 1–4.

[5] P. M. Hunter and A. H. Anbuky, "VRLA battery rapid charging under stress management," IEEE Trans. Ind. Electron., vol. 50, no. 6, pp. 1229–1237, Dec. 2003.

[6] I. Buchmann, "Learning the basics about batteries,"

Battery University. com, 2003 [Online]. Available: www.batteryuniversity.com
[7] R M. Schupbachj, J. C. Balda, "Comparing DC-DC Converters for Power Management in Hybrid Electric Vehicles," Phil. Electric Machine and Drives Conference, IEMDC03, IEEE International London, vol. 3, pp. 1369–1374, June 2003.
[8] J.W. Dixon, M. E. Ortlizar, "Ultracapacitors + DC–DC converters in regenerative braking system," IEEE AESS Syst Mag, pp 16–21, 2002.
[9] A. E. Rufer, P. E. Barrade and D. Hotellier, "Power–electronic interface for a supercapacitor-based energy-storage substation in DCtransportation networks," JEPE, vol, 14, pp. 43–49, 2004.
[10] K. Yamamoto, E. Hiraki, T. Tanaka, M. Nakaoka, T. Mishima, Bidirectional DC–DC Converter with Full-bridge/Push–pull circuit for Automobile Electric Power Systems, In: Presented at 37th IEEE PESC Conference, Jeju, Korea, 2006, June, p.
[11] N. Lakshminarasamma, V. Ramanarayanan, A family of auxiliary switches ZVS–PWM DC–DC converters with coupled inductor, IEEE Trans. Power Electron. 22 (5) (2008) 2008–2017.
[12] SP. Yang, JL. Lin, SJ. Chen, A novel ZCZVT forward converter with synchronous rectification, IEEE Trans. Power Electron. 21 (4) (2006) 912–922
[13] H. Tao, J.L. Duarte, M.A.M. Hendrix, Three-port triple-half- bridge bidirectional converter with zero-voltage switching, IEEE Trans. Power Electron. (2008) 782–792.
[14] D.M. Bellur, M.K. Kazimierczuk, DC–DC converters for electric vehicle applications, Elect. Insul. Conf. Elect. Manuf. Expo. (2007) 286–293.
[15] Mohammad H. Rashid, Power Electronics Handbook published by Academic Press,2001.

BIBLIOGRAPHY OF AUTHORS

Meenakshi.S, received BE in Electronics and Instrumentation Engineering from Madras University, Chennai, India in 2000 and received MBA in Business Administration from Bharathidasan University, Trichy, India, in 2009. Also completed ME (Power Electronics and Drives) Anna University, Chennai, India. Currently working as Assistant Professor in VelTech Engineering College, Avadi, Chennai-600062.

Manimegalai.D, received BE in Electrical and Electronics Engineering from Madras University, Chennai, India in 2003 and received M.E in Applied Electronics from Anna University, Coimbatore, India, in 2009. Currently working as Assistant Professor in VelTech Engineering College, Avadi, Chennai-600062.

R.Santhosh Kumar, received B.E in Electrical and Electronics Engineering from Anna University, Chennai, India in 2008 and also received M.E in Embedded System Technologies from Anna University, Chennai, India in 2011. Now, pursuing Ph.D in Faculty of Electrical Engineering, Anna University, Chennai. Currently working as Assistant Professor in VelTech Engineering College, Avadi, Chennai, Chennai – 600 062.