Zero current switching for Bidirectional dual boost DC-DC converter

1.A.Vanaja,PG Student,2.C.Balachandra Reddy,Professor&Hod
Department of EEE,CBTVIT,Hyderabad

Abstract - ***This paper presents a new bidirectional DC-DC converter with high conversion ratio for renewable energy systems. The coupled-inductor technique is used to achieve a high conversion ratio with very simple control circuits. In discharging mode, the converter acts as a two-stage boost converters, controlling one power switch to achieve high voltage step-up conversion. In charging mode, the converter acts as two cascaded buck converters that control two power switches simultaneously to achieve high voltage step-down conversion. The operating principles and analysis of the steady-state characteristics are discussed in great detail. Finally, a prototype24 V/200 V circuit with output power of 200 W is implemented to verify the feasibility of the proposed converter. The maximum efficiency levels in discharging and charging modes are about 94.3% and 91.6%, respectively.***

I. Introduction

Electronic power processing technology has evolved around two fundamentally different circuit schemes: duty-cycle modulation, commonly known as pulse width modulation (PWM), and resonance. The PWM technique processes power by interrupting the power flow and controlling the duty cycle, thus, resulting in pulsating current and voltage waveforms.

The bidirectional DC-DC converter is widely used in renewable energy applications. This converter is able to transfer or balance energy between two different DC sources, such as fuel-cell and battery hybrid supplied power systems, island photovoltaic generation systems, and wind power systems. The bidirectional DC-DC converter can be applied in uninterruptible power supplies (UPSs) to transfer the energy between source and battery. The bidirectional DC-DC converter plays an important role in system back-up or in reserving energy for the battery. Figure 1 shows the application of this converter in a hybrid renewable energy supply system.

The resonant technique processes power in a sinusoidal form. Due to circuit simplicity and ease of control, the PWM technique has been used predominantly in today's power electronics industries, particularly, in low-power power supply applications, and is quickly becoming a mature technology. Resonant technology, although well established in high-power SCR motor drives and uninterrupted power supplies, has not been widely used in low-power dc/dc converter applications due to its circuit complexity With available devices and circuit technologies, PWM converters have been designed to operate generally at 30- 50-kHz switching frequency. In this frequency range, the equipment is deemed optimal in weight, size, efficiency, reliability and cost. In certain applications where high power density is of primary concern, the conversion frequency has been chosen as high as several hundred kilohertz.

With the advent of power MOSFET'S, devices switching speed as high as tens of megahertz is possible. Accompanying the high switching frequency, however, are two major difficulties with the semiconductor devices, namely high switching stress and switching loss. For a given switching converter, the presence of leakage inductances in the transformer and junction capacitances in semiconductor devices causes the power devices to operate in inductive turn-off and capacitive turn-on. As the semiconductor device switches off an inductive load, voltage spikes are induced by the sharp di/dt across the leakage inductances, On the other hand, when the switch turns on at high voltage level, the energy stored in the device's output capacitances, 0.5 CV2, is trapped and dissipated inside the device. Furthermore, turn-on high voltage levels induces a severe switching noise known as the Miller effect which is coupled into the drive circuit, leading to significant noise and instability.

II. LITERATURE SURVEY

The concept of Zero Current Switching Technique and Zero Voltage Switching have been introduced. The paper presents the concept of Zero Current Switching Technique and Zero Voltage Switching Technique in detail. For the zero current switching technique, the objective is to use auxiliary LC resonant elements to shape the switching device's current waveform at on-time in order to create a zero-current condition for the device to turn off.

The dual of the above stat ement is to use auxiliary LC resonant elements to shape the switching device's voltage waveform at off-time in order to create a zero-voltage condition for the device to turn on. This latter statement describes the principle of zero voltage switching.

The recognition of the duality relationship between these two techniques leads to the development of the concept of voltage-mode resonant switches and a new family of converters operating under the zero-voltage switching principle.

While not severe in lower switching frequencies, the capacitive tum-on loss due to the discharging of the parasitic junction capacitances of power MOSFET'S becomes the dominating factor when the switching frequency is raised to the megahertz range. For example, a junction capacitance of 100 pF, switching at 300 V, will induce a turn-on loss of 4.5 W at 1 MHz and 22.5 W at 5 MHz. 7

III. PROPOSED METHOD

Bidirectional DC–DC converters are used to transfer the power between two DC sources in either direction. These converters are widely used in applications, such as hybrid electric vehicle energy systems, uninterrupted power supplies , fuel-cell hybrid power systems , PV hybrid power systems, and battery chargers . Many bidirectional DC-DC converters have been researched.

The bidirectional DC-DC fly back converters are more attractive due to simple structure and easy control. However, these converters suffer from high voltage stresses on the power devices due to the leakage-inductor energy of the transformer. In order to recycle the leakage inductor energy and to minimize the voltage stress on the power devices, some literatures present the energy regeneration techniques to clamp the voltage stress on the power devices and to recycle the leakage-inductor energy,. Some literatures research the isolated bidirectional DCDC converters, which include the half-bridge types provide high step-up and step-down voltage gain by adjusting the turns ratio of the transformer. For non-isolated applications, the non-isolated bidirectional DC-DC converters, which include the conventional boost/buck types, multi-level type, three-level type, sepic/zeta type, switched-capacitor type, and coupled-inductor type, are presented.

The multi-level type is a magnetic-less converter, but 12 switches are used in this converter. If higher step-up and step-down voltage gains are required, more switches are needed. This control circuit becomes more complicated. In the three-level type, the voltage stress across the switches on the three-level type is only half of the conventional type. However, the step-up and step-down voltage gains are low. Since the sepic/zeta type is combined of two power stages, the conversion efficiency will be decreased.

The switched capacitor and coupled-inductor types can provide high step-up and step-down voltage gains. However, their circuit configurations are complicated. Fig. 1 shows the conventional bidirectional DC-DC boost/buck converter, which is simple structure and easy control. However, the step-up and step down voltage gains are low. A modified DC-DC boost converter is presented . The voltage gain of this converter is higher than the conventional DC-DC boost converter. Based on this converter, a novel bidirectional DC-DC converter is proposed, as shown in Fig. 2. The proposed converter employs a coupled inductor with same winding turns in the primary and secondary sides. Comparing to the proposed converter and the conventional bidirectional boost/buck converter, the proposed converter has the following advantages: 1) higher step-up and step-down voltage gains; 2) lower average value of the switch-current under same electric specifications. The following sections will describe the operating principles and steady-state analysis for the step-up and step-down modes. In order to analyze the steady-state characteristics of the proposed converter, some conditions are assumed as: 1) The ON-state resistance *RDS(ON)* of the switches and the equivalent series resistances of the coupled inductor and capacitors are ignored. 2) The capacitor is sufficiently large, and the voltages across the capacitor can be treated as

The battery can balance the energy between the power source and the load. The voltage difference between the battery and the DC bus is large, thus, a bidirectional DC-DC converter with high step-up/down voltage conversion ratio is required. The conventional boost/buck bidirectional converter is not suitable in such applications because the conversion ratio will be significantly reduced by parasitic elements.

The bidirectional converter used coupled-inductor technology to achieve a high voltage conversion ratio [16]–[18]. However, the energy stored in the leakage inductor of the coupled inductor causes a high voltage spike on the power switches [19]–[21]. The proposed bidirectional converter is constructed of a dual boost/buck converter to achieve a high voltage conversion ratio by employing a coupled-inductor technique. Fig.1.2 shows the configuration of the proposed bidirectional converter, which has the following features:

1) double-boost structure achieves high voltage conversion ratio at step-up or step-down stage; 2) solitary control with signal in either step-up or step-down operating condition, an effectively simplified control circuit; 3) the leakage -inductance energy of the coupled inductor is recycled, thus reducing the voltage stress on power switches; 4) a low *R*DS-ON switch can be selected to improve system efficiency.

PV Module Battery AC Load DC-DC Converter with MPPT DC-DC Bidirectional Converter DC-AC Inverter PV Module Charger

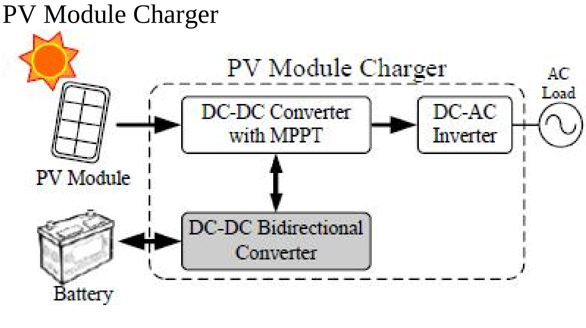


Fig.1.1Renewable energy hybrid supply system

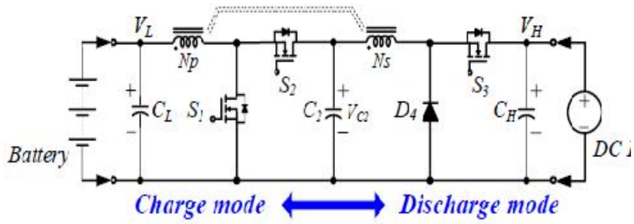


Fig.1.2 Proposed converter circuit with leakage inductances.

The following conditions were assume din analyzing the steady-state characteristics of the proposed converter:

1. All the circuit components are ideal.

2. The capacitors *C*L, *C*2,and *C*H are large enough, and the voltages can be treated as constant.

3. The magnetizing inductance *L*mof the coupled inductor is large enough, andthe converter is operated in continuous conduct mode (CCM).

A .Discharging Mode:

The power switch *S*1is the main power switch. The switches *S*2and *S*3are off during the entire period. Fig.1.4 shows the typical waveforms of the proposed converter during discharging mode. The operating principles during aswitching cycle are described as follows.

Mode I: [to–t1]

In this mode, switch *S*1and diode *D*S3 are turned on. Fig. 5(a) shows the equivalent circuit. The energy stored in the leakage inductor *L*K2is released to capacitor *C*2, and*i*Lk2, (*i*S3) are decreased gradually. The battery voltage *V*L releases energy into the leakage inductor *L*K1.Thus, the leakage inductor current *i*Lk1rapidlyincreases. Moreover, the magnetizing inductance current *i*Lmis equal to*i*Lk1+*ni*Lk2, where *n*=*N*S/*N*P. This mode ends when the current *i*S3is reduced to zero and the diode *D*S3is turned off.

$$v_p = V_L - v_{LK1} \tag{1}$$

$$V_{C2} = V_{LK2} + V_H + V_S \tag{2}$$

Mode II: [t1–t2]

In this mode, *S*1and *D*4are turned on.Fig. shows that the equivalent circuit. *V*L charges the magnetizing inductor Lmand the leakage inductor*L*K1. The magnetizing-inductor current *i*Lmand the leakage-inductor current *i*Lk1are increased linearly. In addition, *V*L transfers its energy into *C*2viathe secondary winding *N*S and *D*4. Thus, the voltage across *C*2is charged to *nV*L. This mode ends when *S*1is turned off.

$$v_p = V_L - v_{lk1} \tag{3}$$

$$v_s = V_{C2} - v_{LK2} \tag{4}$$

Mode III: [t2–t3]

In this mode, *S*1and *D*S3areturned offand*D*S2is turned on. Fig. 5 (c) shows the equivalent circuit. The energyof the leakage inductors*L*K1and *L*K2are released into *C*2through *D*S2and *D*4,respectively. This mode ends when the current *i*Lk2, namely *i*D4, is equal to zero and *D*4is turned off.

$$v_p = V_L - v_{lk1} - V_{C2} \tag{5}$$

$$v_s = V_{C2} - v_{LK2} \tag{6}$$

Mode IV: [t3–t4]

In this mode, *S*1is turned offand*D*S2and *D*S3are turned on. Fig. 5 (d) shows the equivalent circuit. The energies of *V*L, *L*m, and *L*K1are released into *C*2through *D*S2. Moreover, part of the *L*m energy is transferred to *C*H and load *R*H via the secondary side of the coupled inductor. This mode ends when the voltage across *C*2is equal to *nV*in

$$V_{c2} = V_L - v_p - v_{lk1} \tag{7}$$

$$v_s = V_L - v_p - v_{LK1} - v_{LK2} - V_H \tag{8}$$

$$v_s = n v_p \tag{9}$$

$$v_{LK2} = n v_{Lk1} \tag{10}$$

Substituting(9) and(10) into(8)yields

$$v_p = \frac{V_L - V_H}{1+n} - v_{LK1} \tag{11}$$

$$v_s = \frac{n(V_L - V_H)}{1+n} - v_{LK2} \tag{12}$$

Mode V: [t4–t5]

In this mode, *S*1 is turned offand*D*S2and *D*S3are turned on. Fig. 5(e) shows the equivalent circuit. The energy of *L*mis released into *C*H via the coupled-inductor and *D*S3. The *i*Lm decreases linearly, and the energy stored in *C*2is transferred to *C*H and *R*H. This mode ends when *i*Lk1is equal to zero.

$$v_p = \frac{V_L - V_H - v_{LK1} - v_{LK2}}{1+n} \tag{13}$$

$$v_s = \frac{n(V_L - V_H - v_{LK1} - v_{LK2})}{1+n} \quad (14)$$

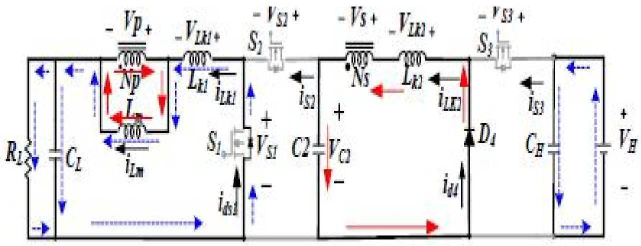
$$V_{C2} = V_H + v_{LK2} + v_S \quad (15)$$

Mode VI: [t5–t6]

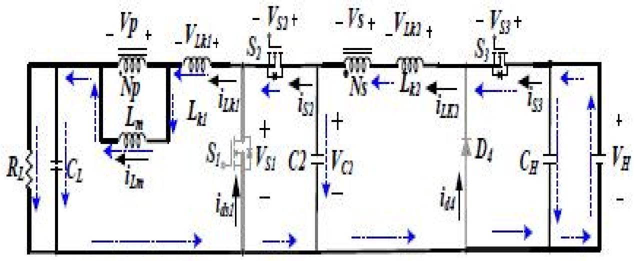
In this mode, *S*1and*D*S2are turned off and *D*S3 is turned on. Fig. 5(f) shows the equivalent circuit. The energy of *L*mis released to *C*H and *R*Hvia the secondary side of the coupled-inductor and *D*S3. The energy stored in *C*2is also transferred to *C*H and *R*H. This mode ends when *S*1is turned on.

$$v_s = V_{C2} - v_{LK2} - V_H \quad (16)$$

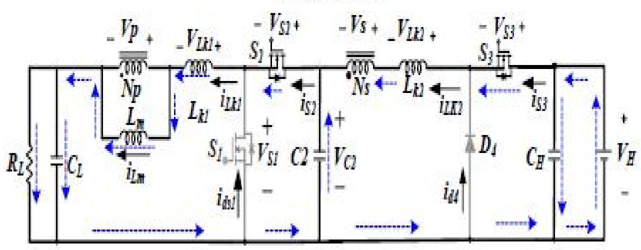
$$v_p = \frac{V_{C2} - v_{LK2} - V_H}{n} \quad (17)$$



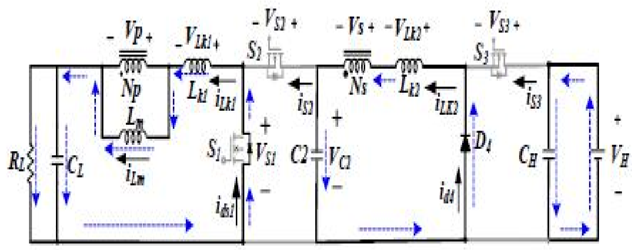
(a) Mode I



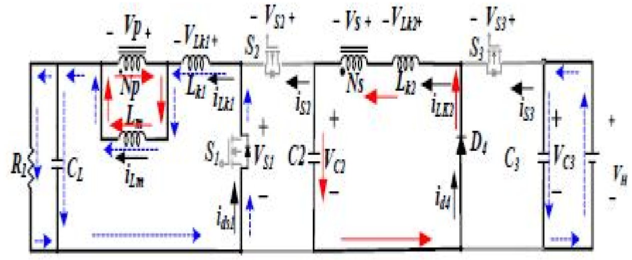
(b) Mode II



(c) Mode III



(d) Mode IV



(e) Mode V

Fig.Equivalent circuit in charging mode. (a) Mode I,(b) Mode II,(c) Mode III,(d) Mode IV,and (e) Mode V.

IV.Simulation results for extension circuit:

By using Zero current switching for bidirectional dual boost DC-DC converter to improve the life of switching divices. Battery back-up is employed along with pv module to improve the system reliability. Soft switching technique enhances the durability of semi conductor conversion system.

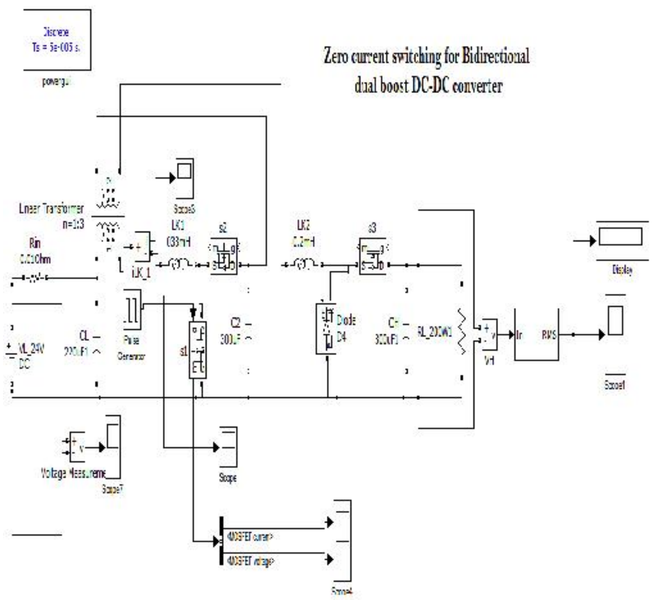


Fig: Extension circuit

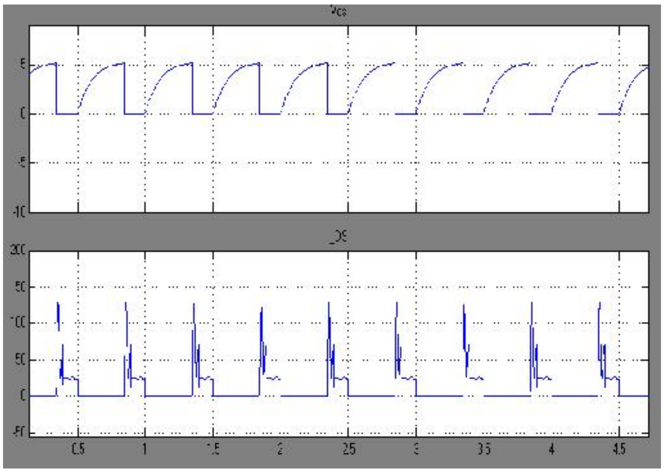


Fig: Switching voltages and currents

CONCLUSIONS

This paper has presented a novel bidirectional DC to DC converter for renewable energy systems. The proposed converter can achieve high conversion ratio using the coupled inductor technique A clamping circuit is used to reduce the voltage stress on the power devices, and the leakage-inductor energy can be recycled. The experimental waveforms agree with the theoretical analysis. The efficiency in discharging and charging mode is over 90%in full load condition. The highest efficiency levels in discharging mode and charging mode are94.3% and 91.6%, respectively.

REFERENCES

[1] T. Bhattacharya, V. S. Giri, K. Mathew, and L. Umanand, "Multiphase bidirectional flyback converter topology for hybrid electric vehicles," *IEEE Trans. Ind. Electron.*, vol. 56, no. 1, pp. 78–84, Jan. 2009.

[2] Z. Amjadi and S. S. Williamson, "A novel control technique for a switched-capacitor-converter-based hybrid electric vehicle energy storage system," *IEEE Trans. Ind. Electron.*, vol. 57, no. 3, pp. 926–934, March. 2010.

[3] F. Z. Peng, F. Zhang, and Z. Qian, "A magnetic-less DC–DC converter fordual-voltage automotive systems," *IEEE Trans. Ind. Appl.*, vol. 39,no. 2, pp. 511–518, Mar. 2003.

[4] L. A. Flores, O. Garcia, J. A. Oliver, and J. A. Cobos, "High-frequency bi-directional DC/DC converter using two inductor rectifier," in *Proc. IEEE IECONConf.*, pp. 2793–2798, Nov. 2006.

[5] M. A. Abusara, J. M. Guerrero, and S. M. Sharkh, "Line-Interactive UPS for Microgrids," *IEEE Trans. Ind. Electron.*, vol.61, no. 3, pp. 1292–1300, March. 2014.

[6] N. Mohan, T. M. Undeland, and W. P. Robbins, *Power Electronics: Converters, Applications and Design*,Third Edition, John Wiley & Sons, Inc., 2003.

[7] K. Yamamoto, E. Hiraki, T. Tanaka, M. Nakaoka, and T. Mishima, "Bidirectional DC-DC converter with full-bridge / push-pull circuit for automobile electric power systems," in *Proc. IEEE PESCConf.*, pp. 1–5, June. 2006.

[8] G. Chen, Y. S. Lee, S. Y. Hui, D. Xu, and Y. Wang, "Actively clamped bidirectional flyback converter," *IEEETrans. Ind. Electron.*, vol. 47, no. 4, pp. 770–779, Aug. 2000.

[9] F. Z. Peng, H. Li, G. J. Su, and J. S. Lawler, "A new ZVS bidirectional DC-DC converter for fuel cell and battery application," *IEEE Trans. Power Electron.*, vol. 19, no. 1, pp. 54–65, Jan. 2004.

[10] B. R. Lin, J. J. Chen, and F. Y. Hsieh, "Analysis and implementation of a bidirectional converter with high conversion ratio," *in Proc. IEEE ICIT Conf.*, pp. 1–6, April. 2008.

[11] L. S. Yang, T. J. Liang, H. C. Lee, and J. F. Chen, "Novel High Step-Up DC–DC Converter with Coupled-Inductor and Voltage-Doubler Circuits," *IEEE Trans. Ind. Electron.*, vol. 58, no.9, pp. 4196–4206, Sept. 2011.

[12] K. I. Hwu and Y.T. Yau, "A Buck Resonant Voltage Divider with Bidirectional Operation Considered," *IEEE Trans. Ind. Appl.*, vol. 49, no. 4, pp.1566–1576, July-Aug. 2013.