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A Resonant Converter Topology for Bidirectional DC DC Converter

Ancy A.M
M.Tech Scholar, EEE Department
ASIET Kalady, Mahatma Gandhi University Kottayam
India

Siby C Arjun
Asst.Professor, EEE Department
ASIET Kalady, Mahatma Gandhi University KottayamKerala,
Kerala, India

Abstract—**A new bidirectional dc–dc converter composed of two class-E resonant converters is presented in this paper. Bidirectional converters are main types of DC-DC converter currently used in the industry today .Bidirectional DC-DC converter may be isolated or non isolated depending on its application. Bidirectional DC-DC converters are being increasingly used to achieve power transfer between two dc power sources in either direction without changing polarity. It reduces the cost and improves the system efficiency, and also improves the performance of the system. They are used in many application such as dc un interrupted power supplies, aerospace power systems, electric vehicles and battery chargers. The aim of this project is to use class E resonant technique in bidirectional dc dc converter. Bidirectional power flow is controlled by transistor control pulse frequency changes, with a constant break between the succeeding pulses as in quasi-resonant converters. The boost or buck mode converter operation depends on the mutual relation between the control pulses of the transistor pairs which are located diagonally in the converter bridge. Due to the zero voltage switching of the transistor with high frequency ,this converter topology have important features like low size, low weigh..Simulation of existing converter with full bridge circuit and modified half bridge circuit is done using MATLAB/SIMULINK.**

***Keywords*—Bidirectional dc dc converter, Class E resonant converter**

I. INTRODUCTION

DC-DC power converters are employed in a variety of applications, including power supplies for personal computers, office equipments, spacecraft power systems, laptop computers, telecommunication equipments , fuel cell vehicles, renewable energy systems etc. In electric vehicle applications, an auxiliary energy storage battery absorbs the regenerated energy fed back by the electric machine. Bidirectional dc-dc converter is required to draw power from the auxiliary battery to boost the high-voltage bus during vehicle starting, acceleration and hill climbing. With its ability to reverse the direction of the current flow, and thereby power, the bidirectional dc-dc converters are being increasingly used to achieve power transfer between two dc power sources in either direction. Most of the existing bidirectional dc-dc converters fall into the generic circuit structure illustrated in figure 11.Based on the placement of the auxiliary energy storage, the bidirectional dc-dc converter can be categorized into buck and boost type. To realize the double sided power flow in bidirectional dc-dc converters, the switch cell should carry the current on both directions. It is usually implemented with a unidirectional semiconductor power switch such as power MOSFET (Metal-Oxide-Semiconductor-Field-Effect-Transistor) or IGBT (Insulated Gate Bipolar Transistor) in parallel with a diode; because the double sided current flow power switch is not available.

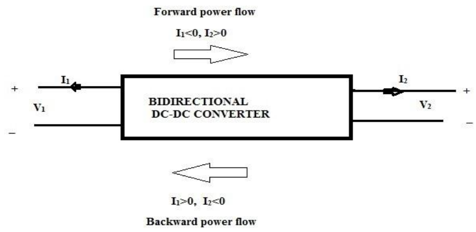

Figure 1. Illustration of Bidirectional Power Flow

Literature provides many solutions in this area, the main of which can be classified into several characteristic types. The first type is, named as, a dual active-bridge (DAB) converter [6]. The main drawback of this solution is that the converter cannot achieve zero-voltage switching (ZVS) in a wide range of load variations while input or output voltage rises. In order to eliminate this problem in control system, the phase shift was additionally enhanced with a pulse width modulation [7], [8]. A three-port active bridge (TAB) was introduced. as an extension of the DAB topology [9]. Another type of BDC is characterized by a current-fed inverter/ rectifier on the low-voltage (LV) side of the transformer and a voltage-fed inverter/rectifier on the high-voltage (HV) side. The drawback of this system is the high voltage spikes provoked by the transformer leakage inductance when the boost converter is switched transformer leakage inductance can be used as a useful element in the resonant converters.

Using high switching frequencies leads to a significant reduction of size of passive components. Semiconductor devices are exposed to very high di/dt during commutations because of the energy stored in their parasitic which increase switching losses and electromagnetic interference and may cause breakdown of the device. Parasitic inductances and capacitances cause significant problems as the frequency of the circuit is increased. To address these problems in the design of high-frequency operating dc-dc converters topologies that incorporates these parasitics into circuit elements are to be used. The class-E resonant inverter topology, addresses these problems which allow its operation in the order of megahertz frequencies with zero-voltage switching and zero-voltage slope at turn-on if the switching conditions are met. The class-E topology also absorbs the power MOSFETs parasitic capacitors into the circuit elements and can be implemented with few components. These characteristics of class E converter allow achieving high power densities, high efficiency and it will cause reduction in the size and weight of the converter. Since class-E inverter can operate at very high frequencies, it can be used in designing resonant dc-dc converters.

II. CLASS E INVERTER [17]

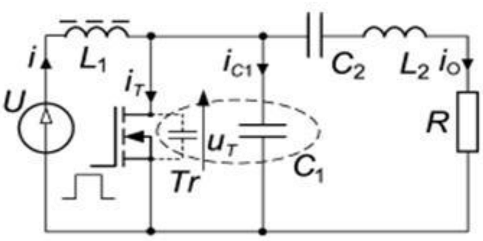

Figure 2. Class E inverter

A Class E inverter is a well-known resonant converter that can operate at frequencies from hundreds of kHz to tens of MHz and power levels from watts to kilowatts with high efficiency. Its basic circuit is shown in Fig. 2. It consists of a choke inductor L_1, a shunt capacitor C_1, a series resonant circuit C_1,L_1, a load resistor R, and a transistor Tr. The shunt capacitance C_1 includes the output transistor capacitance. The transistor Tr is usually switched periodically at a duty cycle of 0.5. The proper choice of circuit parameters guarantees the transistor T r is switched on for ZVS (zero-voltage switching) and ZdVS (zero-voltage slope switching) conditions that determine the optimum operation of Class E inverter.

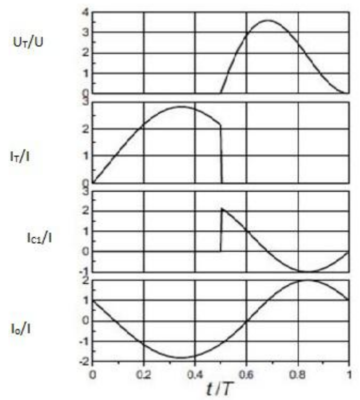

Figure 3. Class E inverter waveform

The voltage and current waveforms of figure.3.are normalized to the dc supply voltage U and the average value I of the supply current i, respectively, and the time axis is normalized to the switching period T . During the off interval of the transistor, the current i_T remains at zero while the voltage u_T increases to a maximum of 3.6 times the dc voltage U. At the end of the off interval, when the voltage u_T has decreased to zero, the transistor is switched on and the current i_T increases toward a maximum of 2.9 times the dc current I. At the end of the on-interval, the transistor is switched off and the current i_T drops to zero before the voltage u_T begins to rise. During switching transitions, both transistor voltage and current have zero crossover values and,as a result, the only power losses remaining are the conduction losses. Efficiencies of Class E inverters can significantly exceed 90 percentage. Increased efficiency not only means lower input power, but also less heat dissipation in the transistor.

III.CLASS-E RESONANT BRIDGE BIDIRECTIONAL CONVERTER[1]

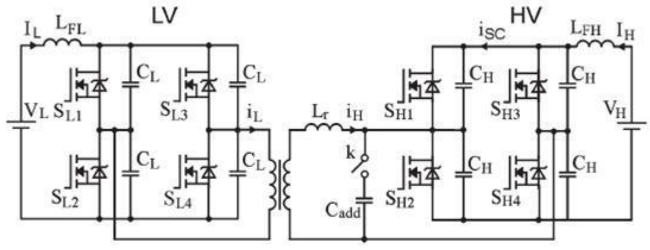

Figure 4. Class-E resonant bridge Bidirectional converter

The class-E resonant bridge BDC is shown in Fig. 4. It consists of two bridge inverters fed by current sources due to the input inductances L_{FL} and. L_{FH}. Inverter outputs are connected by a transformer, which is characterized by secondary-to-primary turns ratio k_T . During the power transfer from the LV source VL to the HV source VH, an additional capacitor C_{add} is introduced by closing the key k. The LV converter transistors are controlled and the converter operates as a class-E boost converter while the HV converter transistors are not controlled and the converter operates as a class-E rectifier composed of transistor body diodes. The resonant circuit [(Cadd + 2CH)Lr] is formed by the inductance L_r, capacitance C_{add} (switch k is closed), and capacitances C_H which are placed parallel to the diode. During power flow in the opposite direction, from the (VH) source to the (VL) source, the HV converter transistors are controlled and the converter operates as a class-E buck converter , while the LV converter transistors are not controlled and the converter operates as a class-E rectifier composed of transistor body diodes. The switch k is opened, and the resonant circuit is formed by the capacitances C_L and the inductance L_r .To ensure ZVS in a class-E resonant converter, it has to be controlled by frequency change, keeping a constant break between the succeeding control pulses of the transistor, as it is the case with quasi-resonant converters. The LV-boost and HV buck mode operation is characterized by an overlap or a break of the control pulse of the transistor pairs which are located diagonally in the bridge.

A. Boost and Buck operation[2]

This converter system is devoid of parasitic oscillations as all the parasitic capacitances and inductances are included in the resonant tank circuit. The characteristic feature of resonant converters is that the transformer parasites do not disturb the circuit, because they are used as resonant circuit elements.

In a current fed full bridge boost converter type the overlapping conduction time of the four converter switches is kept constant and the output voltage is regulated by varying the switching frequency. The conduction time is particularly calculated to ensure ZVS operation under a wide load range. MOSFETs and body diodes are used as the converter switches without the need for any additional diodes in series. The converter transistor turn-off time is constant and is equal to the time of the parallel connected capacitor overcharge. During the ZCS switch off time, the L-C tank circuit resonates.

This traverses the voltage across the switch from zero to its peak, and back down again to zero. At this point the switch can be reactivated, and lossless zero voltage switching is facilitated. Therefore the switch transition losses go to zero regardless of operating frequency and input voltage. This could result in significant savings in power and improvement in efficiency. This feature of the converter makes it suitable for high frequency and high voltage converter design.

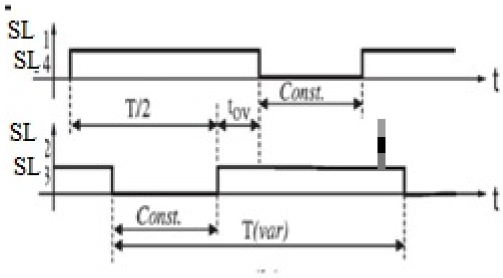

Figure 5. Control pulses for the boost converter

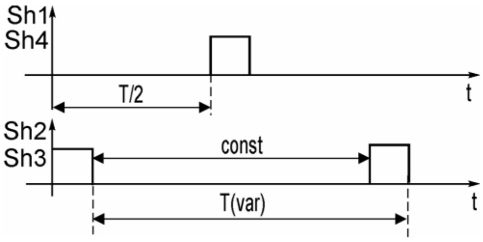

Figure 6.Control pulse for the buck converter

The inductance L_r represents the transformer leakage inductance, the capacitance C includes the transformer parasitic capacitance, and the capacitances C_T include the transistor parasitic capacitances. The transistor control pulse waveforms are shown in the figure.
The converter is controlled by varying the switching frequency f=1/T, while simultaneously keeping a constant break between the pulses. Thus, the transistor pulse overlap tov gradually decreases while the switching frequency increases. The maximal output voltage (power) is achieved with the minimal switching frequency, which is marked as nominal, i.e., fn. For this frequency, the converter operates in the optimal operation point while its transistors are switched at zero-current conditions. During the constant break between the control pulses, two transistors and two capacitors alternatively conduct $S_{L1}S_{L4}$ $C_{L3}C_{L2}$. or S_{L2} $S_{L3}C_{L1}C_{L4}$ Because of the system symmetry, each transistor and each capacitor conducts, as in the previous subinterval, half values of the input and output current.

V.MATLAB SIMULATIONS

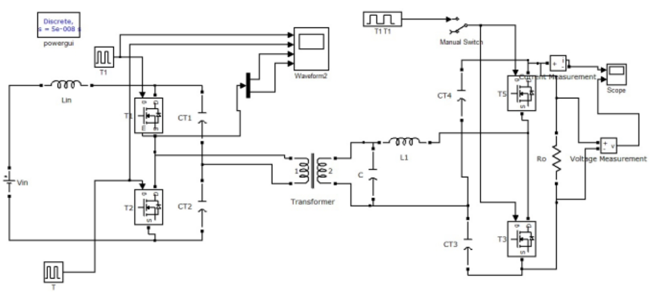

Figure 7. Model of half bridge boost converter circuit

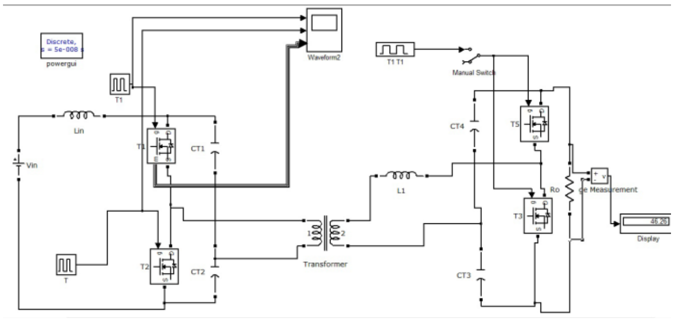

Figure 8. Model of half bridge buck converter circuit

A).Simulation results for full bridge boost converter

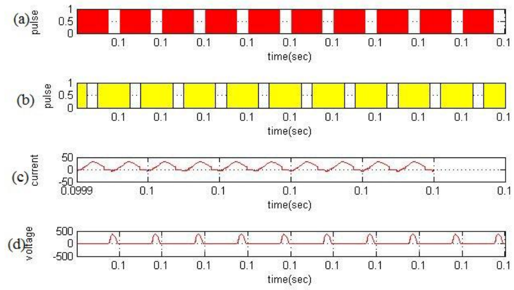

Figure 9. Waveform of(a)pulses(b)switch 1 current(c)voltage across switch1

Control pulses for the switch 1 and switch 4 are shown waveform (a).The current through the switch 1 is shown in waveform(c) and voltage across the switch 1 is shown in waveform(d).When the switch is ON, current is owing through the switches 1 and 4 .But the voltage across the switch is zero. Hence power dissipation across the switch is zero.

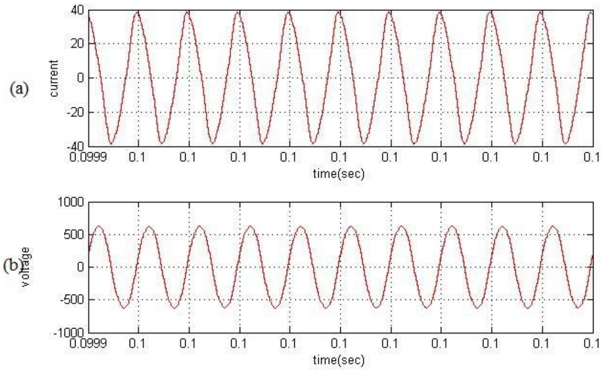

Figure 10. Waveform of(a)inductor(L) current(b)capacitor(C) voltage.

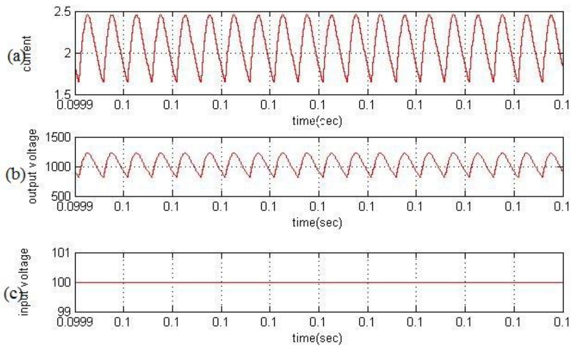

Figure 11. Output waveforms of boost converter

The boost converter consists of an inverter section and rectifier section. Control pulses are given to the inverter section . The inverter converts the input dc voltage(100 V)to the ac. This ac is rectified to dc voltage around 1200 V .The frequency of operation 200 kHz. For the boost operation pulse delay is 75 percentage of the total time period. When the switch is on current is owing through the switch .At that time the voltage across the switch is zero. During the switching operation ,voltage and current across the switch is zero. Hence the switching losses are zero. The input voltage is boosted, due to parasitic capacitance. But the rectifier section does not satisfies the condition of switching losses. During the resonance condition, the current owing through the switch is very large .It will cause stress on to the switch.

B).Simulation results for full bridge buck converter

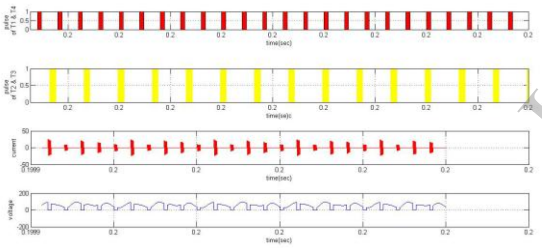

Figure 4.5: Waveform of(a)pulses(b)voltage across switch 1(c)switch 1 current

For the buck operation change the pulse delay as 25 percentage of the total time period. Now rectifier section operates as an inverter and vice versa.

C).Simulation results for half bridge boost converter

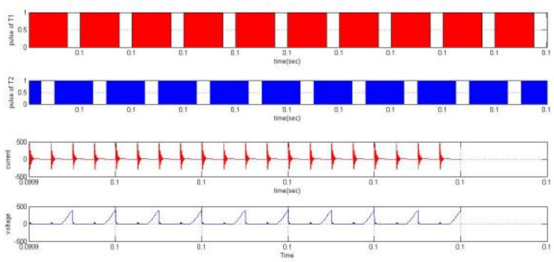

Figure 4.6: Waveform of(a)pulses(b)voltage across switch 1(c)switch 1 current

The boost converter consists of an inverter section and rectifier section. Control pulses are given to the inverter section . The inverter converts the input dc voltage(50 V)to the ac. This ac is rectified to dc voltage around 200 V .The frequency of operation 200 kHz. For the boost operation pulse delay is 75 percentage of the total time period. When the switch is on current is owing through the switch .At that time the voltage across the switch is zero. During the switching operation ,voltage and current across the switch is zero. Hence the switching losses are zero. The input voltage is boosted, due to parasitic capacitance. But the rectifier section does not satisfies the condition .

D).Simulation results for half bridge buck converter

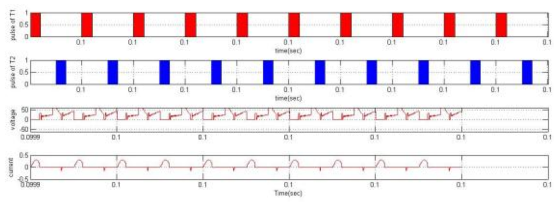

Figure 4.7: Waveform of(a)pulses(b)voltage across switch 1(c)switch 1 current

The buck converter control frequency is 200 kHz. A constant off time is kept. The control pulses do not overlap. Pulse delay is25 percentage of the total time period .

In half bridge converter consists of only four switches. So no. of switches are deceased. But same results are obtained with the existing full bridge converter.

CONCLUSION

In this project work class E resonant converter technique is used in bidirectional dc dc converter .This resonant technique is used in full bridge as well as half bridge converter.

The ZVS transistor switching process is evident because the transistor's current and voltage waveforms do not overlap.The transistor current wave form has positive and negative value so the internal transistor body diodes participate in the current flow. Because the transistor current and voltage waveforms do not overlap, the ZVS conditions are fulfilled. So the class E resonant bidirectional DC-DC converter is devoid of the transistors switching power dissipation within the whole operation range, therefore it is marked by high efficiency. The important features of this converter topology are, low size, low weight and high dynamics because of the transistors ZVS switching process with high frequency. The converters employed in the system are current sourced. Therefore, the connection parasitic inductance are of no importance and system is eco friendly.

By using class E resonant Technology in full bridge converter circuit andhalf bridge converter circuit with same frequency operation, same results are obtained. The half bridge converter require only four switches but full bridge converter require eight switches.

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