A FB Hybrid Resonant Boost DC-DC Converter with ZVC Switching

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Abstract: A novel soft-switching converter combining resonant half- bridge and phase-shifted pulsewidth modulation (PWM) full bridge configuration is proposed to ensure the switches in the leading-leg operating at zero-voltgae switching from true zero load to full-load, and the switches in the lagging leg working at zero-current switching with minimum duty cycle loss and circulating conduction loss by significantly reducing leakage or series inductance. The hybrid resonant and PWM converter is attractive for electrical vehicle battery charger application.

Index Terms: Battery charger, full-bridge converter, high efficiency, Simulink model of proposed hybrid converter hybrid resonant and pulse width modulation (PWM) converter, LLC half- bridge converter, phase-shifted control.

I. INTRODUCTION

The terms buck and boost come from electrical transformer jargon. A bucking, or buck, transformer is a step-down transformer that outputs a lower secondary voltage than the primary source. The rated secondary current is greater than the primary current by a factor of the ratio of the primary to secondary voltages. A boost transformer steps the source voltage up to a higher voltage but requires a primary current that is greater than the secondary current by a factor of the ratio of the secondary to primary voltages. These voltage and current relationships are also true for the buck and boost converters, except that the voltages and currents are DC rather than AC. Indeed, DC-DC converters are often called "DC transformers." As the name implies, the buck/boost converter can output voltage magnitudes that are   greater or less than the source. Drawbacks of switching converters include complexity, electronic noise and to some extent cost, although this has come down with advances in chip design. Although MOSFET switches can tolerate simultaneous full current and voltage (although thermal stress and shorten the MTBF), bipolar switches .

The Insulated Gate Bipolar Transistor (IGBT) is a minority-   carrier device with high input impedance and large bipolar current-carrying capability.

Many designers view   IGBT as a device with MOS input characteristics and bipolar output characteristic that is   a voltage-controlled bipolar device. To make use of the advantages of both Power MOSFET and BJT, the IGBT has been introduced. It's a functional integration of Power MOSFET and BJT devices in monolithic form. It combines the best attributes of both to achieve optimal device characteristics.

The IGBT is suitable for many applications in power electronics, especially in Pulse Width Modulated (PWM) servo and three-phase drives requiring high dynamic range control and low noise. It also can be used in Uninterruptible Power Supplies (UPS),   Switched-Mode Power Supplies (SMPS), and other power circuits requiring high switch repetition rates. IGBT improves dynamic performance and efficiency and reduced the level of audible noise. It is equally suitable in resonant-mode converter circuits.

Optimized IGBT is available for both low conduction loss and low switching loss. The main advantages of IGBT over a Power MOSFET and a BJT are:
1. It has a very low on-state voltage drop due to conductivity modulation and has superior on-state current density. So smaller chip size is possible and the cost can be reduced.
2. Low driving power and a simple drive circuit due to the input MOS gate structure. It can be easily controlled as compared to current controlled devices (thyristor, BJT) in high voltage and high current applications.
3. Wide SOA. It has superior current conduction capability compared with the bipolar transistor. It also has excellent forward and reverse blocking capabilities.
The main drawbacks are:
1. Switching speed is inferior to that of a Power MOSFET and superior to that of a BJT. The collector current tailing due to the minority carrier causes the turnoff speed to be slow.
2. There is a possibility of latch up due to the internal PNPN thyristor structure. The IGBT is suitable for scaling up the blocking voltage capability. In case of Power MOSFET, the on-resistance increases sharply with the breakdown voltage due to an increase in the resistively and thickness of the drift region required to support the high operating voltage.

Because of their unipolar nature, the power MOSFET can switch at very high speed. Indeed, there is no need to remove minority carriers as with bipolar devices. The only intrinsic limitation in commutation speed is due to the internal capacitances of the MOSFET. These capacitances must be charged or discharged when the transistor switches. This can be a relatively slow process because the current that flows through the gate capacitances is limited by the external driver circuit. This circuit will actually dictate the commutation speed of the transistor (assuming the power circuit has sufficiently low inductance

II.   SOFT SWITCHING

Soft switching can mitigate some of the mechanisms of switching loss and possibly reduce the generation of EMI Semiconductor devices are switched on or off at the zero crossing their voltage or current waveforms. The soft-switching techniques applied to the soft-switching techniques applied to the   power converters have attracted attention for its peculiar advantages over the hard-switching techniques such as low switching loss, high-power density, EMI/RFI noise reduction and so on [5], [6], [7], [8].

Zero-current switching:

Transistor turn-off transition occurs at zero   current. Zero-current switching eliminates the switching loss   caused by IGBT current tailing and by stray inductances. It can   also be used to commutate SCR's.

Zero-voltage switching:

Transistor turn-on transition occurs at zero voltage. Diodes may also operate with zero-voltage switching. Zero-voltage switching eliminates the switching   loss   induced by diode stored charge and device output capacitances.   Zero-voltage switching is usually preferred in modern converters .Zero-voltage transition converters are   modified PWM converters, in   which an inductor charges and discharges the device capacitances Zero-voltage switching is then obtained.

III.   FEATURES OF ZVS AND ZCS SWITCHING

1. The sinusoidal approximation allows a great deal of insight to be gained into the operation of resonant inverters and dc–dc converters. The voltage conversion ratio of dc–dc resonant converters can be   directly related to the tank network transfer function. Other important converter properties, such as the output characteristics, dependence (or lack thereof) of transistor current on load current, and zero-voltage and zero-current-

switching transitions, can also be understood using this approximation. The approximation is accurate provided that the effective Q–factor is sufficiently large, and provided that the switching frequency is sufficiently close to resonance.

2. Simple equivalent circuits are derived, which represent the fundamental components of the tank network waveforms, and the dc components of the dc terminal waveforms.

3. Exact solutions of the ideal dc–dc series and parallel resonant converters are listed here as well. These solutions correctly predict the   conversion ratios, for operation not only in the fundamental continuous conduction mode, but in discontinuous and sub harmonic modes as well.

4. Zero-voltage switching mitigates the switching loss caused by diode   recovered charge and semiconductor device output capacitances. When the objective is to minimize switching loss and EMI, it is   preferable to operate each MOSFET and diode with zero-voltage switching.

5. Zero-current switching leads to natural commutation of SCRs, and can also mitigate the switching loss due to current tailing in IGBTs. This paper proposes an improved zero-voltage and zero-current-switching (ZVZCS) full bridge PWM converter to improve the disadvantages of the previously presented ZVZCS-FB-PWM converters [1]–[4].

Various hybrid half- and full-bridge converters, as shown in Fig. 1-3 , have been proposed [9], [10], [11] for efficiency improvement. The common characteristic is that the input energy can be transferred to the output even in the freewheeling interval of the output inductor by observing the three-level voltage waveforms of the secondary-side rectifier. Therefore, those soft-switching dc–dc topologies can achieve high efficiency and significantly reduce the   output inductance requirement because of their parallel power processing feature [12].

IV.   HYBRID HALF AND FULL-BRIDGE CONVERTERS ZVS WITH SINGLE TRANSFORMER

In Fig switches $S1$–$S4$ are controlled by the phase shifted constant frequency pulse width modulation (PWM) technique to   provide   zero-voltage-switching (ZVS) condition for all MOSFET switches like the ZVS full-bridge converters   would do. Moreover, the circuit configuration through the additional two active switches ($S5$ and $S6$) is changed to half-bridge from full-bridge during the freewheeling interval of the output inductor, which can significantly reduce the output filter and effectively improve efficiency because the active power is transferred to the output in the freewheeling interval.
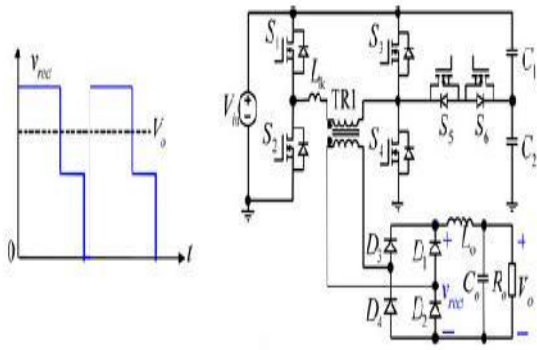
Fig. 1. Hybrid half- and full-bridge converters & ZVS with single transformer

V. ZERO-VOLTAGE ZERO-CURRENTSWITCHING (ZVZCS) HYBRID HALF- AND FULL-BRIDGE CONVERTER

To overcome this problem, a zero-voltage zero- current switching (ZVZCS) hybrid half- and full-bridge converter was developed . As shown in Fig.4, the leading leg using MOSFETs is a three-level leg, where the switches realize ZVS in a wide load rang, and their voltage stress is half of the input voltage. The lagging leg adopting insulated gate bipolar transistor (IGBT) operates at ZCS in the full-load and full-line range . This circuit also maintains the basic feature that the active power is transferred to the output in the free wheeling interval of the output inductor. Hence, it is very suitable for high-voltage and high-power applications. However, the conduction loss in the lagging leg increases and the magnetizing energy of the transformer cannot be recycled due to the series diodes. In addition, the input voltage utilization is low because of the voltage drop across the blocking capacitor.
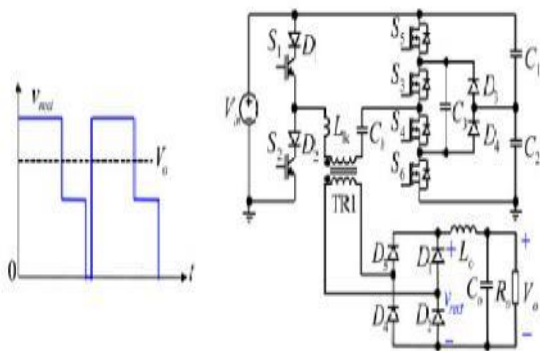

Fig. 2. Hybrid half- and full-bridge converters & ZVZCS with single transformer

VI. ZERO-VOLTAGE SWITCHING (ZVS) WITH TWO TRANSFORMERS HYBRID HALF- AND FULL-BRIDGE CONVERTER

The topology in Fig. 3 removes two active switches and their associated drivers in Fig. 3 and 4 by adopting additional transformer. One of the distinctive features of this topology is the full ZVS range of the active switches (S3 and S4) in the lagging leg because the desired magnetizing current peak value of the transformer TR2 is independent of the shifted phase angle and the output current. Thus, the duty   cycle loss is significantly reduced by using a small leakage inductance to obtain a reasonable ZVS range of the leading leg. It also can significantly reduce the output filter and effectively improve efficiency because of hybrid half- and full-bridge configuration. However, when the transformer TR1 primary side is shorted with S1 and S3 or S2 and S4 ON, a circulating current will be created through the switches and the windings of transformer TR1 due to series connection of the secondary sides of the transformers TR1 and TR2 , resulting in excessive conduction loss. In addition, the ZVS condition of the switches (S1 and S2) in the leading leg will be lost when the output current is zero and the phase-shift angle is nearly 180◦.
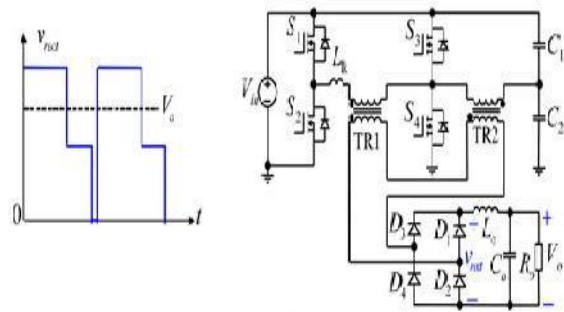

Fig. 3. Hybrid half- and full-bridge converters. & ZVS with two transformers

VII. BASIC OPERATION OF PROPOSED CONVERTER

Fig.4   shows the circuit diagram of the proposed converter   which composed of two parts: 1)   the resonant half-bridge circuit including two MOSFETs S1 and S2 , loosely coupled transformer TR2 , resonant capacitor C3 , and the secondary rectifier D5 , D6 , and C1 , C2 ; and 2) the phase-shifted full-bridge circuit including two MOSFETs S1 and S2 as leading-lag, two IGBTs as lagging leg, tightly coupled transformer TR1 , the secondary rectifier D1−4 , and D7 , and the LC output filter. The topology operating principle can be explained by the gating sequence and associated key voltage and current waveforms shown in Fig. 3, where Cs 1 and Cs 2 are

the equivalent capacitance of the MOSFETs $S1$ and $S2$, respectively, Vrect is voltage of the output inductor left-side point referred to the output ground, Vo is the output voltage, $i$pri1 and $i$pri2 are the primary current of the transformer TR1 and TR2 respectively, $iLm2$ is the magnetizing current of the transformer TR2 , and the $v$ds1 is the drain-to-source voltage of device $S1$. The proposed circuit combines the behavior of two different converter topologies: *LLC* half-bridge converter operating at the load-independent resonant frequency and the constant frequency phase-shifted full-bridge converter.

FB ZVCS DC-DC converter is modelled using the blocks of Simulink and the result of ZVCS DC-DC converter is shown in fig 5. Input voltage is shown in Fig 6.Driving pulse of Q1-Q4 switch are shown in Fig 7. DC Output voltage is shown in Fig 8 & Fig 9. DC output Current is shown in Fig 10. Experimental waveforms of the primary voltage (V) and primary current (I), and secondary rectifier voltage is shown in Fig 10. ZVS of leading leg switches (a)Turn on & (b)Turn off is shown in Fig.11 The specification are listed below in the table I
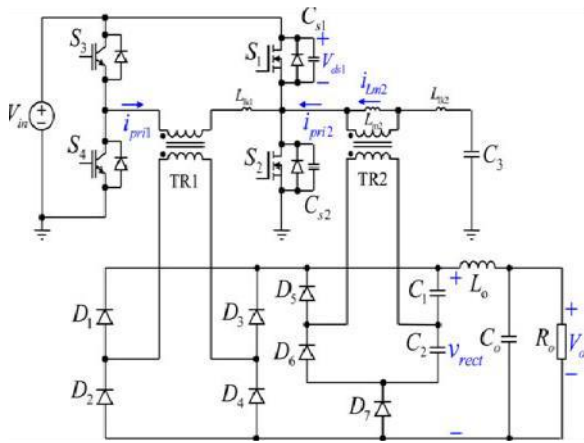

Fig.4.Circuit configuration for the proposed converter
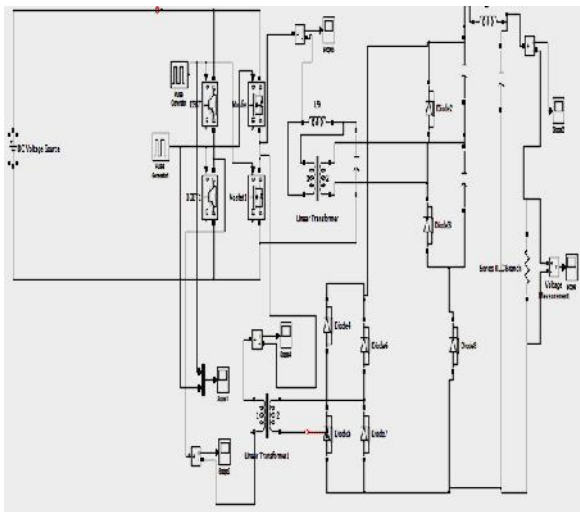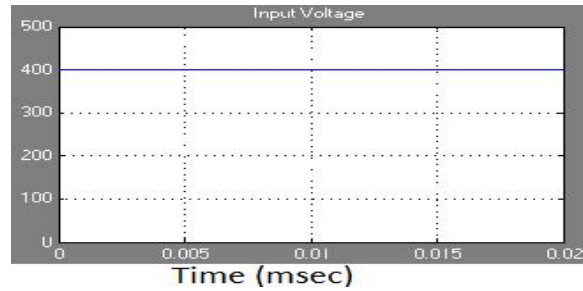

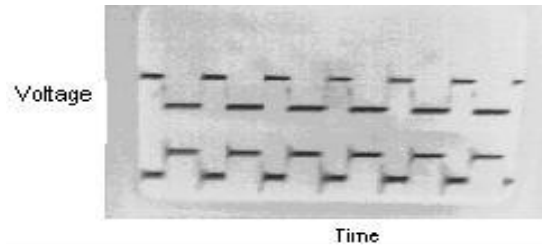Fig.5. Simulink model of proposed converter

Fig.6. Intput Voltge

Fig 7. Driving Pulses for switches
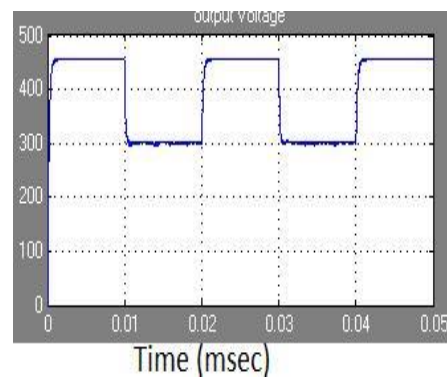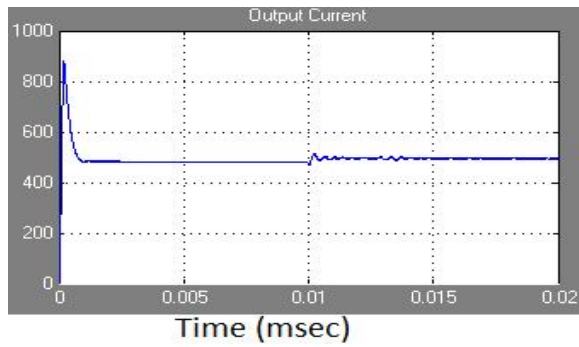

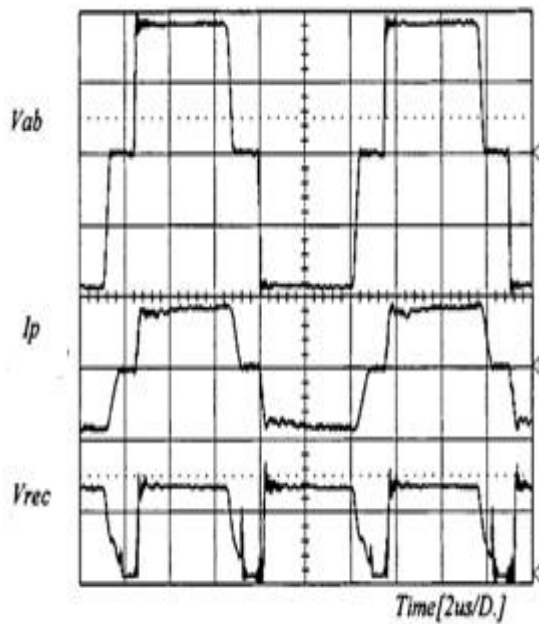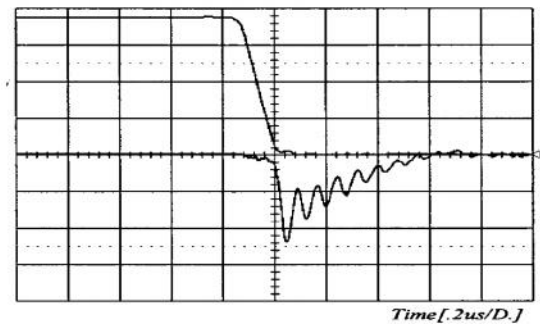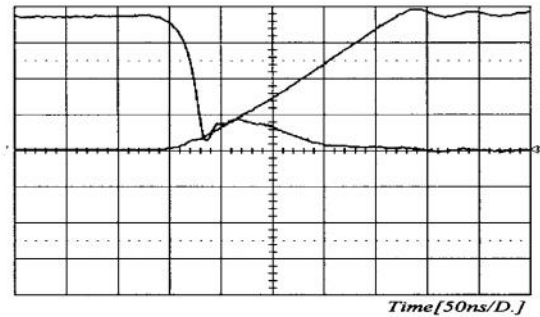Fig.8.output Voltge

Fig.9. output Voltage

Fig.10. Output current

Fig.11.ZVS of leading leg switches
(a)turn on & (b)Turn off

Table 1: Design parameter of hybrid inverter

DESIGN PARAMETER	RATING
Input Voltage	400V
Switching Frequency	50 KHz
Output Voltage	495.6V
Output Current	16.52 A
POWER	15.7 W
TON	50 %
TOFF	50 %
Duty cycle	50 %
T	100 %
Switching Frequency	50 KHz
L_o	0.2 mH
C_o	20 microfarad
R_o	30Ω

Fig. 10. Experimental waveforms of the primary voltage (V)
and primary current (I), and secondary rectifier voltage.

VIII. CONCLUSION

A novel hybrid resonant and PWM converter combining resonant half-bridge and phase-shifted full-bridge topology has been proposed to achieve high efficiency and true full soft-switching range and

design considerations are illustrated. Experimental results from the 2.5 kW IGBT/MOSFET based prototype is shown to verify the operation principle.

The distinctive features of the proposed circuit are summarized as follows.

1) With the parallel *LLC* resonant half-bridge configuration, ZVS of MOSFETs in the leading leg can be ensured from true zero-load to full-load, and thus, the super junction MOSFET with slow reverse recovery body diode can be reliably used.

2) IGBTs in the lagging leg work at zero-current switching with

minimum circulating conduction loss because the paralleled secondary-side dc voltage source effectively reset the circulating current; therefore, the turn-off loss and the conduction loss of the IGBTs are significantly reduced.

3) Duty cycle loss is negligible since the leakage inductance of the main transformer can be minimized without losing ZVS operation; thus, the current stresses through the primary-side semiconductors are minimized by the optimized turns ratio of the main transformer.

4) The topology is suitable for wide-range output voltage or current source applications because of the buck-type configuration with the simple phase-shift PWM, and thus, it is a good candidate for the electrical vehicle battery charger. The hybrid resonant and PWM converter has been designed, implemented, and tested for a 3.4-kW hardware prototype. Experimental results show that 98% maximum efficiency and full range soft switching are achieved.

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