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A Novel Zero-Voltage-Switching PWM Full Bridge Dc-Dc Buck Converter

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Abstract

Introducing resonant inductance and clamping diodes into the full-bridge converter can eliminate the voltage oscillation across the rectifier diodes and increase the load range for zero-voltage-switching (ZVS) achievement. The resonant inductance is shorted and its current keeps constant when the clamping diode is conducting, and the clamping diode is hard turned-off, causing significant reverse recovery loss if the output filter inductance is relatively larger. This paper improves the full-bridge converter by introducing a reset winding in series with the resonant inductance to make the clamping diode current decay rapidly when it conducts. The reset winding not only reduces the conduction losses, but also makes the clamping diodes naturally turn-off and avoids the reverse recovery. As the diodes are turned off naturally and reverse recovery voltage is avoided the distortions caused in the output voltage is removed to a maximum extend by varying the turns ratio of the transformer. The energy stored in the reset winding is also increased by which the inductor value of the snubber circuit to turn off the clamping diodes also increases, which results in reductions in the distortions of the output voltage.

Keywords: Clamping diode, full bridge converter, reset winding, Zero-voltage-switching (ZVS)**.**

Introduction

Power electronics is the field of electrical engineering related to the use of semiconductor devices to convert power from the form available from a source to that required by a load. The load may be AC or DC, single-phase or three-phase, and may or may not need isolation from the power source. The power source can be a DC source or an AC source (single-phase or three-phase with line frequency of 50 or 60 Hz), an electric battery, a solar panel, an electric generator or a commercial power supply. A power converter takes the power provided by the source and converts it to the form required by the load. The power converter can be an AC-DC converter, a DC-DC converter, a DC-AC inverter or an AC-AC converter depending on the application.

Power converters typically consist of semiconductor devices such as transistors and diodes, energy storage elements such as inductors and capacitors, and some sort of controller to regulate the output voltage. Transistor type devices like BJTs (Bipolar Junctions Transistors), MOSFETs (Metal Oxide Silicon Field Effect Transistors) and IGBTs (Insulated Gate Bipolar Transistors) are used as switches in power electronic converters and are made to operate as switches that are either fully on or fully off at any given moment in time. These devices can be operated at higher switching frequencies than thyristor based devices, which helps reduce converter size. While BJTs and MOSFETs are basic devices, IGBTs are hybrid devices that have an insulated gate like a MOSFET but a conduction region that is the same as a BJT.

The size of the energy storage components of a power electronic converter, such as inductors (L) and capacitors (C), accounts for much of the overall size of the converter. These components are needed to store and transfer energy from the input power supply to the output load in the converter. Their values depend on the frequency that the converter switch is turned on and off. As the switching frequency is increased, the values of the inductors and capacitors decrease and so do their physical size and weight; therefore the higher the converter switching frequency, the smaller is the converter size. Higher switching frequency operation, however,

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results in increased switching losses and EMI noise emissions.

Switching Methods

There are different types of switching methods, they are

1. Soft switching, and
2. Hard switching

Soft Switching Method

Conventional PWM power converters were operated in a switched mode operation. Power switches have to cut off the load current within the turn-on and turnoff times under the hard switching conditions. Hard switching refers to the stressful switching behavior of the power electronic devices. The switching trajectory of a hard switched power device is shown in Fig.1.

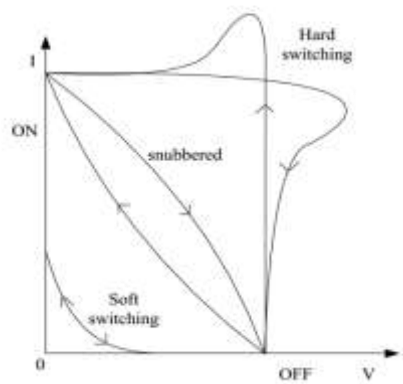

Figure-1: Switching trajectory for different switching techniques

During the turn-on and turn-off processes, the power device has to withstand high voltage and current simultaneously, resulting in high switching losses and stress. Dissipative passive snubber circuits are usually added to the power circuits so that the dv/dt and di/dt of the power devices could be reduced, and the switching loss and stress could be diverted to the passive snubber circuits.

The soft switching phenomenon known as zero- current switching (ZCS) & zero-voltage switching (ZVS) can lead to reduce switching loss. When the turn-on & turn-off transitions of a semiconductor switching device coincides with the zero crossing of applied waveforms. In converters containing MOSFETs &diodes, zero-voltage switching mitigates the switching loss otherwise caused by diode recovered charge & semiconductor output capacitance. Zero current switching can mitigates the switching loss caused by current tailing in IGBTs & by stray inductances. Zero-current switching can also be used for communication of SCRs. In the majority of applications, where diode recovered charge & semiconductor output capacitances are the dominant sources of PWM switching loss, zero voltage switching is preferred.

Zero Voltage Switching

ZVS techniques are techniques that force the voltage across a switch to be zero just before it is turned on or off and to keep this voltage zero while a switching transition occurs. All MOSFETs and most IGBTs have anti-parallel diodes that are built into the body of each device that allows current to flow from source to drain in a MOSFET and from emitter to collector in an IGBT. A ZVS turn-on in MOSFETs and IGBTs is therefore done by forcing current through the body-diode of the devices just before they are turned on. This clamps the voltage across the device to a single diode drop (which is an eligible voltage) during a switching transition so that turn-on switching losses are greatly reduced. A ZVS turn-off is achieved by slowing down the rate of voltage rise across a switch when it is turned off by adding some capacitance across the switch; this limits the overlap between voltage and current during the switching transition. And full wave zero voltage topology and waveforms are shown in fig.2 and fig.3 respectively.

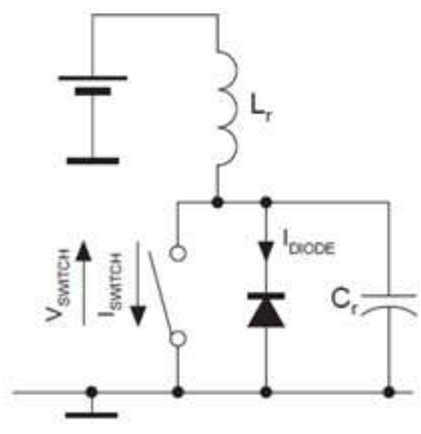

Figure-2: Full wave zero voltage switch- topology

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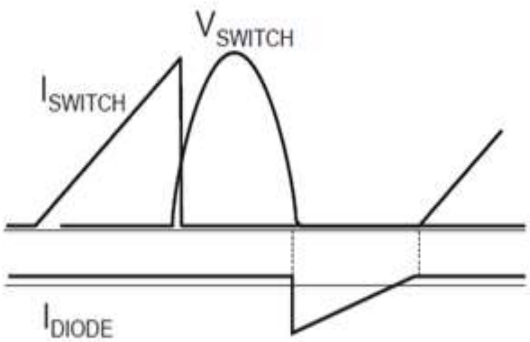

Figure-3: Full wave zero voltage switch waveforms.

Zero Current Switching

ZCS techniques are techniques that force the current through a switch to be zero when the switch is about to turn on or off and keep this current zero while a switching transition occurs. A ZCS turn-off is achieved by diverting current away from the switch into the rest of the power converter just before the switch is turned off. This is typically done by providing a path of negative voltage potential to the switch or by imposing a negative voltage somewhere in the current path. A ZCS turn-on can be done by adding an inductor in series with the switch that slows down the rate of current rise when the switch is turned on; this limits the overlap in voltage and current during the switching transition. And full wave zero current topology and waveforms are shown in fig.4 and fig.5 respectively.

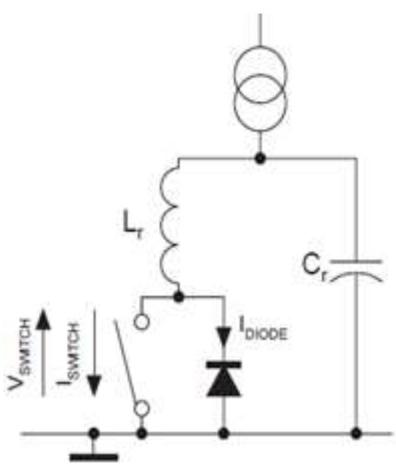

Figure-4: Full wave zero current switch- topology

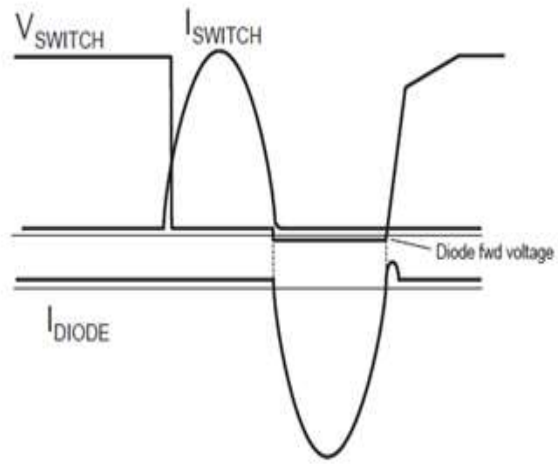

Figure-5: Full wave zero current switch waveforms

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Proposed Topology of ZVS PWM Full Bridge Converter

The leakage inductance of the transformer and the intrinsic capacitors of the switches are used to achieve ZVS for the switches. The ZVS characteristics are load dependent and will be lost at light load. In ZVZCS PWM full-bridge converters, one leg achieves ZVS, and the other leg achieves ZCS. However, there is serious voltage oscillation across the rectifier diodes caused by the reverse recovery no matter ZVS or ZVZCS is realized for the switches. In order to overcome this problem, a resonant inductance and two clamping diodes introduced into the primary side of transformer. The solution eliminates the voltage ringing and overshoot, thus the voltage stress of the rectifier diodes is reduced, and without introducing losses or an additional controlled power device. The difference between them two locations of the resonant inductance and the transformer was analyzed and an optimal position was presented. No matter what the positions of the transformer and the resonant inductance are, the resonant inductance is clamped and its current keeps constant when the clamping diodes conduct. The output filter inductance must had enough current ripple so that the clamping diodes turn off naturally, otherwise the clamping diodes will be forced to be turned off, resulting in serious reverse recovery. In this, an auxiliary transformer winding is introduced to the ZVS PWM full-bridge converter to be in series with the resonant inductance.

The introduced winding not only makes the clamping diode current decay rapidly and reduces the primary side conduction losses, but also can makes

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the current ripple of the output filter be smaller; hence the output filter capacitor can be reduced. The winding plays the role of forcing the clamping diode current to decay to zero, so it is called reset winding. The proposed diagram of ZVS PWM full bridge converter is as shown in fig 6.

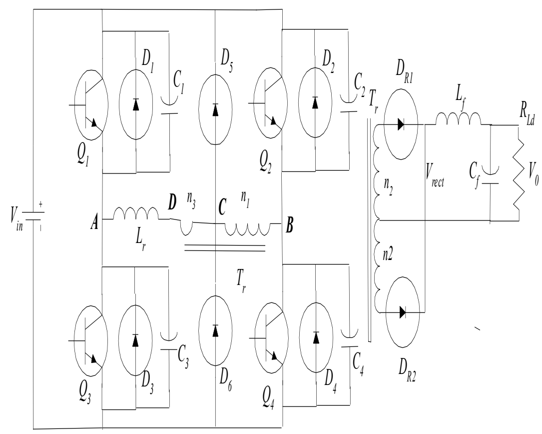

Figure-6: Proposed novel zero voltage switching PWM full bridge converter

Salient Features of Proposed topology

Features of Proposed topology are:

- Leakage inductance of the transformer and the intrinsic capacitance of the IGBT in the circuit may be used as the resonant elements.
- Zero Voltage switching for all the switches full-bridge so the switching losses are minimises.
- High Switching frequency of presented topoloy reduces the size of component.
- The size of converter is compact due tolesser number of component.
- Peak Voltage/Current stresses of the device are limited as the voltage and currents are almost a square wave except for resonant transition period.
- Constant Frequency Operation
- There is higher overall efficiency at given power level, mainly due to the absence of switching losses at the power switches and rectifiers. Lower loss in turn means smaller heat sinks, hence reduction in size and weight of overall package.
- Conduction losses reduces due to use of insulated gate bipolar transistor (IGBT).

Design of Components

In the proposed converter the design of various components are needed for generating a low level dc voltage. The design formulae for different components are shown.

Design of filter Inductor

The value of filter inductor can be calculated using following formula

$$L_f \le \frac{V_{in} - KV_O}{k^2\left[\frac{2v_{in.\Delta I}}{V_o T_s K} - \frac{I_o R_{DS(on)} + KV_f}{KL_r}\right]} \qquad (1)$$

Where,

L_f =Filter inductor
V_{in}=Dc input voltage
V_O =Dc output voltage
L_r =Resonant inductance
I_o =Output current
V_f =Forward voltage
K =Turns ratio

Another formula which is used for actual value of filter inductor is,

$$L_f = \frac{(V_{in} - V_o).V_o}{V_{in}.f_{sw}.\Delta I_l} \qquad (2)$$

Where,

f_{sw} =Converter switching frequency
ΔI_l =Peak to peak inductor current ripple
ΔI_l To be between 20% to 40% of I_o

The maximum current flowing in inductor is

$$I_{lmax} = I_{omax} + \frac{\Delta I_{lmax}}{2} \qquad (3)$$

Design of Filter Capacitor

The value of filter inductor can be calculated using following formula

$$C_f = \frac{L_f(I_{lmax})^2}{\left(V_o + \Delta V_{o,overshoot}\right)^2 - V_o^2} \qquad (4)$$

Where,

$\Delta V_{o,overshoot}$ =4% of V_o

.

This can be split into two equal parts for the contribution of ESR and capacitance.

$$ESR = \frac{\Delta V_{o,overshoot}}{I_{lmax}} \qquad (5)$$

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Results and discussion

Table.1. System Parameters

Components	Value
Input dc voltage(V_{in})	270 V
Output dc voltage(Vo)	150 V
Filter capacitor(C_f)	9 μF
Filter inductor(L_f)	250 μH
Resonant inductor(L_r)	8.5 μH
Output current(I_o)	6 A
Switching frequency(f_{sw})	100 KHz
Forward voltage(V_f)	1.4 V

The presented system shown in fig.7.It includes the full bridge converter with transformer having three windings. The ac output of transformer is fed to the rectifier which converts ac into dc. LC filter is used for removing ac component from dc component to getting pure dc output. Low level output is getting from this converter. The Simulation diagram for the proposed system is shown below:

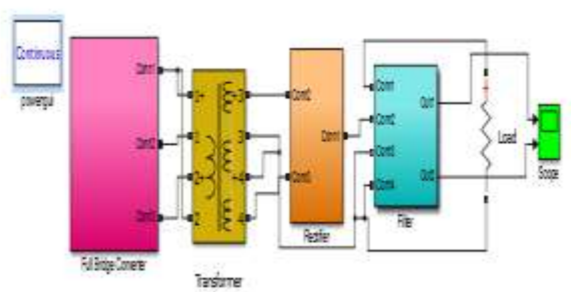
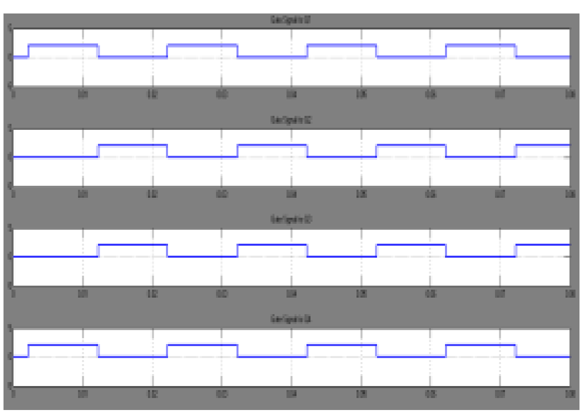
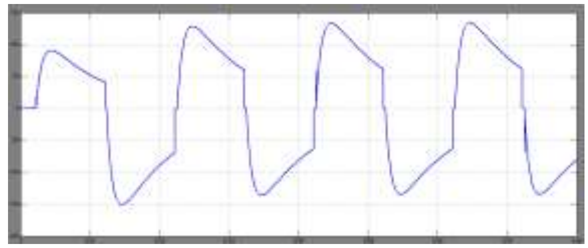


Figure-7: Simulation for novel zero voltage switching PWM full bridge converter

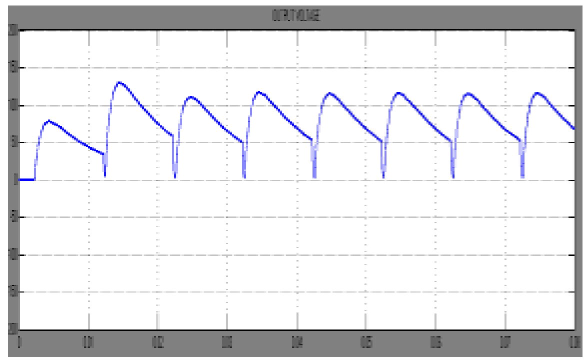
Different results have been observed



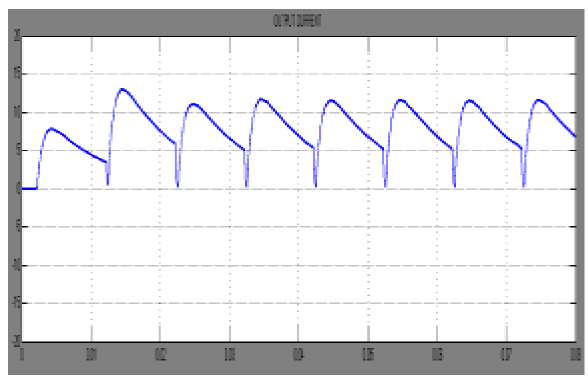
(a) Gate signal for Q1, Q2, Q3, Q4



(b) Ac converter output Voltage



(c) Output Voltage



(d) Output Current

Figure-8: (a) ,(b),(c),(d) Simulation results for novel zero voltage switching PWM full bridge converter

Conclusion

In step down, step up, buck-boost and cuk converters in their basic forms are capable of transforming energy only in one direction, whereas a full bridge converter is capable of a bidirectional power flow. A new ZVS PWM full-bridge converter is proposed in this paper, it employs an additional reset winding to make the clamping diode current decay rapidly when the clamping diode conducts, thus the conduction losses of the clamping diodes, the

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leading switches and the resonant inductance are reduced and the conversion efficiency can be increased. In the meanwhile, the clamping diodes can be turned off naturally without reverse recovery over the whole input voltage range, and the output filter inductance can be designed to be large to obtain small current ripple, leading to reduced filter capacitance. Compared with the traditional full bridge converter the proposed circuit provides another simple and effective approach to avoid the reverse recovery of the clamping diodes.

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