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SOFT SWITCHING NON ISOLATED DC-DC CONVERTER USING ACTIVE RESONANT TANK CELL

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Abstract: *Several new techniques for high frequency DC-DC conversion have been proposed to reduce component stresses and switching losses while achieving high power density and improved performance, among them zero voltage switching (ZVS) techniques are desirable for metal oxide semiconductor field effect transistor (MOSFET) type switches. In this paper a dc-dc converter is designed to achieve a zero voltage switching(ZVS) using an Active Resonant Tank(ART) cell and to eliminate body diode conduction in the dc-dc converter uses synchronous rectifier(SR) instead of conventional diode rectifier. With zero voltage switching techniques the dc –dc converter operate at high frequency, high power density so that to achieve high efficiency of the converter. The proposed technique in this paper eliminates the switching losses, dv/dt noise due to the discharging of MOSFET's junction capacitance and reduces EMI/RFI noise.*

Index Terms: *dc-dc converter, resonant converter, ZVS, synchronous rectifier, active resonant tank .*

1. Introduction

The conventional hard switched pulse width modulated (PWM) dc-dc converter topologies the controllable switches are operated in a switch mode where they are required to turn on and turn off the entire load current during each switching. In this switch mode operation the switches are subjected to high switching power loss that increases linearly with the switching frequency of PWM another drawback of this operation is the
electromagnetic interference (EMI) produces due to large di/dt & dv/vt caused by a switch mode power operation.

Recently some soft switching techniques are introduced to realize high switching frequency converter and to minimize switching losses, EMI noise. In soft switching technique each switch in the converter changes its status (from on to off or vice versa) when the voltage across it &/or the current through it is zero at the switching instant this technique is called Zero Voltage Switching/Zero Current Switching. Most of these topologies required some form of LC resonances these are also called as resonant converters. Zero voltage switching techniques are desirable for metal oxide semiconductor field effect transistor (MOSFET) type switches. To facilitate ZVS while preserving the advantages of the PWM technique hybrid topologies incorporate PWM technique and resonant converters in order to minimize circulating energy and corresponding conduction loss and switching loss. Adding an auxiliary switch across the resonant converter in a ZVS–QRC derives ZVS-PWM converter, which can be considered as hybrid circuits of ZVS–QRCs and PWM converters, wherein ZVS is achieved for the power switch and the converter operates at a constant switching frequency.

In this paper presents a ZVS hybrid topology that consists of an active resonant tank (ART) and buck dc-dc converter with a synchronous rectifier (SR). A synchronous rectifier is an electronic switch that improves power-conversion efficiency by placing a low resistance conduction path across the diode rectifier in a switch-mode regulator. MOSFETs usually serve this purpose. The ART cell is used in dc–dc converter to achieve ZVS for both the power switch and the SRs. The proposed ART cell allows converters to utilize SRs for higher voltage since reverse recovery of body diodes is completely eliminated. However, the reverse recovery problem of MOSFET body diodes is a barrier to SRs' applications with higher voltage ratings, because SR body diodes' reverse recovery is more severe with increased voltage ratings, which significantly increase switches' and body diodes' switching loss. Moreover, the reverse-recovery-related EMI noise may lead to malfunction of converters. In [7], [8], techniques are presented for reducing rectifier reverse-recovery related losses.

2. Zero Voltage Switching Overview

Zero voltage switching can best be defined as conventional square wave power conversion during the switches on-time with "resonant" switching transitions. For the most part, it can be considered as square wave power utilizing a constant off-time control which varies the conversion frequency, or on-time to maintain regulation of the output voltage.

Regulation of the output voltage is accomplished by adjusting the effective duty cycle, performed by varying the conversion frequency, changing the effective on-time in a ZVS design. The foundation of this conversion is sin1ply the volt-second product equating of the input and output. It is virtually identical to that of square wave power conversion. During the ZVS 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 facilitated. Since the output capacitance of the MOSFET switch (Coss) has been discharged by the resonant tank, it does not contribute to power loss or dissipation in the switch. Therefore, the MOSFET transition losses go to zero -regardless of operating frequency and input voltage. This could represent a significant savings in power, and result in a substantial improvement in efficiency. Obviously, this attribute makes zero voltage switching a suitable candidate for high frequency, high voltage converter designs. Additionally, the gate drive requirements are somewhat reduced in a ZVS design due to the lack of the gate to drain (Miller) charge, which is deleted when V_{DS} equals zero.

3. ZVS Benefits

- Zero power "Lossless "switching transitions.
- Reduced EMI / RFI at transitions.
- No power loss due to discharging Coss .
- No higher peak currents, (ie. ZCS) same as square wave systems
- High efficiency with high voltage inputs at any frequency
- Can incorporate parasitic circuit and component L& C
- Reduced gate drive requirements (no "Miller" effects)
- Short circuit tolerant

4. Proposed ZVS dc-dc buck converter

Buck, boost and buck-boost dc–dc converters are mostcommon non-isolated dc–dc converters. Each converter iscomposed of a three-terminal cell as shown in Fig. 1, whereinFig. 1(a) shows a cell with a diode rectifier for buck and buck-boost converters, where Cj is MOSFET's junction capacitance. Fig. 1(b) shows a cell for boost converter with diode rectifier. Replacing the rectifier diode by a SR in the three basic dc–dc converters, a common cell is derived as shown in Fig. 1(c), for buck and buck-boost converters, MOSFET S1functions as an active switch and MOSFET

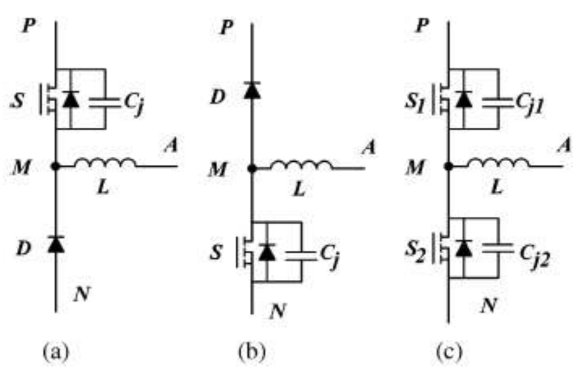

Fig.1.Cells in non-isolated dc–dc converters. (a) Buck and buck-boost's cell. (b) Boost's cell. (c) Common cell with a SR.

S2 functions as a SR; and vice versa for the boost converter.

When we use the conventional PWM hard switching for above shown converter the synchronous rectifier switch SR operates at a ZVS but when it takes transition from SR to active switch S1 the body diode of SR start conducting and reverse recovery problem occurs due to this the switch S1 turn on with extra turn on loss andthe SR's body diode suffers from hard turn-off loss. In short, in the SR buck converter, active switch operates at undesirableconditions of hard turn-on; the SR operates at ZVSturn-on, but the body diode's reverse recovery leads to extra switching loss and EMI problems.

To avoid the above said problem a Current injection concept is used in this concept the current injection cell is placed parallel to the SR switch as shown in fig.2 in which when switch Sa turn on at position 1 the current Io+Ir is injected to the converter.Basically, the cell is utilized to ensure the SR turns off at inductive load and its body diode is not involved during the turn-off interval.. During freewheeling mode while $t<t_1$, SR carries freewheeling current: $i_{SR}(t)=Io$. At $t = t_1$, the cell is

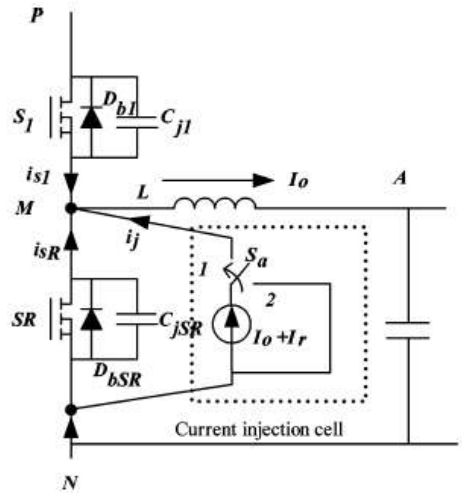

Fig.2Concept of current injection cell in a synchronous buck converter

activated and a current is injected into the node M , where the equation $i_{SR} + i_j = Io$ is satisfied, forcing SR current to reverse with $i_{SR}(t_1) = -Ir$. At $t = t_2$, SR turns off and current I_r charge the junction capacitance C_{jSR} and discharge C_{j1} , and eventually the body diode D_{b1} involves in to carry current I_r . At $t = t_3$, Switch S1 turn on at ZVS. During the interval $t_1 < t < t_3$, SR's body diode never conducts, thus, the body-diode reverse-recovery-related loss is eliminated, moreover, the active switch S_1 achieve ZVS with the help of current injection cell. Therefore, both the SR and the active switch operate at ZVS conditions, and the converter operates at desirable conditions.

In the proposed dc-dc buck converter the same concept is achieved with help of active resonant tank (ART) cell which is placed in parallel with a SR as shown in fig.3.Provides a solution to high-voltage synchronous rectification since the power switch operates at ZVS and the SR's body diode in a converter have no chance to carry any current during switching transition from a SR to an active switch, such that reverse-recovery related loss and noise can be removed

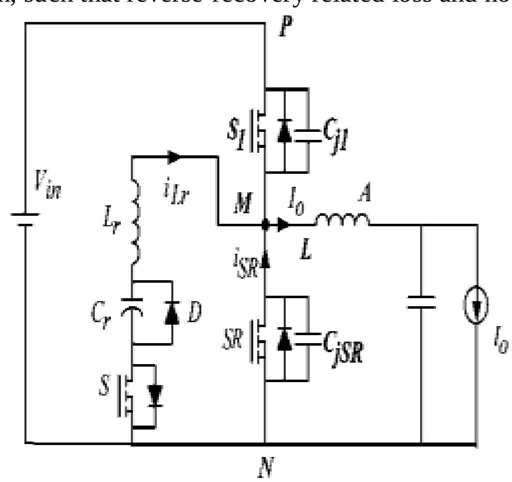

Fig.3. ZVS Buck Converter

when an active switch turns on. Basically, a proposed resonant tank is charged when an active switch turns on. During the SR-to-Switch switching transition, the ART cell is activated,and energy stored in the capacitor is transferred to the resonant inductor in the cell. In the meanwhile, inductor freewheeling current is shifted to the ART cell and the current in the SR is reversed. With SR's turning off, the resonant inductor current is released to discharge the active switch's junction capacitance, and thus ZVS can be achieved.Since the ART is activated only during the switching transition interval, the converter operates with minimum current stress and the conduction loss in the ART is limited.

5. EXPERIMENTAL RESULTS

A prototype shown in fig. 3 is built to verify with thespecification of Vin = 10 to 20V, Vout =5V, Iout=0-1A,switching frequency: 100kHz. N-channel MOSFET IRF540 are selected for S1 and SR switches, P-channel MOSFET IRF9530 is selected as the auxiliary switch S. Output filterinductance 88 H, and the ART cell's resonant inductance1.5μH; resonant capacitance 1nF.
Fig.4 shows the experimental results for Vin = 10V, R_L= 22Ω.at switching frequency of 100KHz. The performance result is shown in Table I for different duty cycle D.

(a) Gate pulse of S1

(a) Gate pulse of SR

(b) Gate pulse of S

Fig. 4Experimental gate pulses

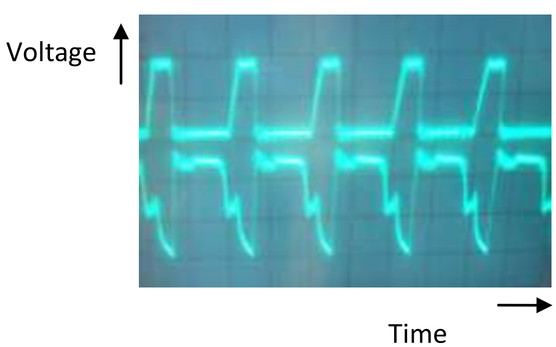

Fig.5 Gate pulse and voltage across the MOSFET S1 for D = 30% at vin =10

Table I

Converter efficiency performance result set for V_{in} = 10V, fs = 100 kHz, RL = 22Ω

Duty Cycle D in %	Input current I_{in} in Amp	Input power P_{in} in Watt	Output Voltage V_o In Volt	Output Current I_o in Amp	Output Power P_o in Watt	Efficiency η in %
25	0.026	0.26	1.7	0.074	0.125	48
30	0.038	0.38	2.3	0.102	0.234	61
35	0.057	0.57	3.1	0.137	0.424	74
40	0.063	0.63	3.3	0.147	0.485	77
45	0.083	0.83	4	0.177	0.708	85
50	0.11	1.1	4.8	0.214	1.02	93

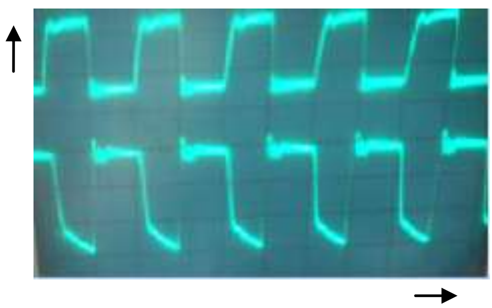

Fig.6 Gate pulse and voltage across the MOSFET S1 for D = 50% at vin = 10V

Fig. 7Experimental input and output voltage

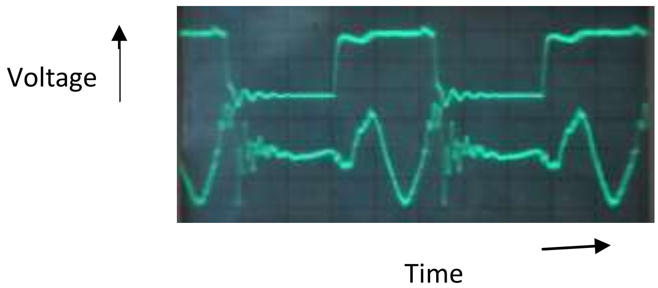

Fig. 8 Gate pulse of S and resonant current through Lr, iLr

Fig.(4) shows the g\experimental gate pulse fig.4.(a) is for gate pulse for switch S1,fig.4(b) for switch SR it shows that when switch S1 is on the switch SR is off state and fig.4(c) is the gate pulse for auxiliary switch S which is activated only at the transition period from SR to S1 or vice versa.

Fig.5. and fig.6 shows that ZVS condition for the duty cycle 30% and 50% of the switch S1 when the Switch SR turns off. Here it shows that as the gate pulse is applied the voltage across the switch i.e Vds comes to zero because of this condition the switching loss of the converter is reduces and operate at higher switching frequency so that to get higher efficiency of the converter.

Fig.7 shows the experimental result of output voltage at Vin =10V and D=30% i.e. Vout =2.3Vit showing.

Fig.8 shows that resonant inductor current i_{LR}Which is in sinusoidal form occurring when the switch S is activated.

Fig.9 shows the efficiency curve of prototype. Here the converter is operated at fs=100 KHz and Vin = 10V the performance is calculated for different duty cycle of switch S1 keeping as shown in Table I. It seen that the efficiency of the converter improves upto 93% under the ZVS technique. Thus the Zero Voltage Switching (ZVS) was found to be efficient in reducing the switching losses and hence converter are operates at higher switching frequency with increase efficiency

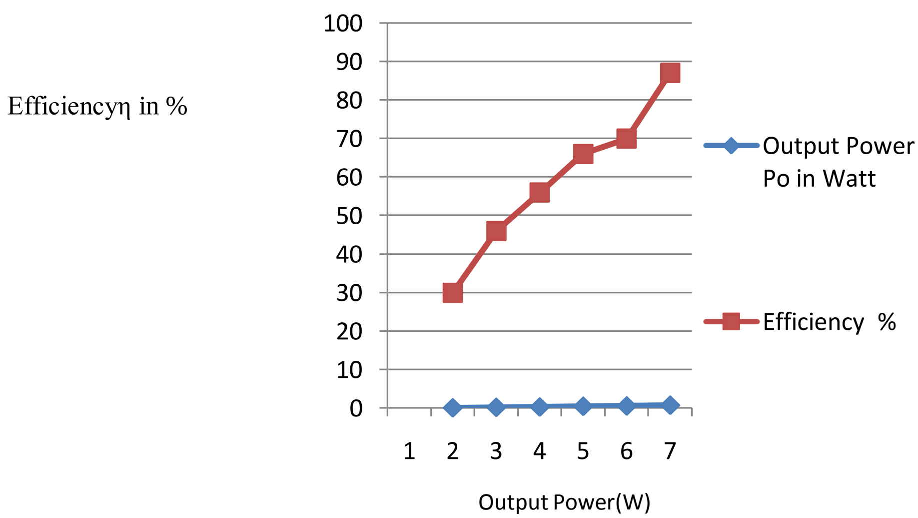

Fig. 9 Efficiency curve for 100KHz

Fig. 10 Experimental Setup

CONCLUSION

In this paper Experimental result of ZVS dc-dc buck converter is implemented. In the conventional hard switched Pulse Width Modulation (PWM) the switches are subjected to high switching stresses and switching loss increases linearly with the switching frequency of the PWM, and also the Electromagnetic interference (EMI) produced due to large di/dt and dv/dt caused by a switch mode operation. To minimize or eliminate the losses occurrence in conventional method Zero Voltage Switching technique is used. WhereART cell is used to achieve zero voltage switching which is connected in parallel with the SR to achieve ZVS for the active switch and to eliminate reverse recovery of the body diode. Because of ZVS technique the dc–dc converter operates at higher switching frequency of 100 kHz, and achieved efficiency of 93%. The ZVS technique in this paper eliminates the switching losses, dv/dt noise due to the discharging of MOSFET's junction capacitance and reduces EMI/RFI noise.

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