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HIGH FREQUENCY DC-DC CONVERTER DESIGN USING ZERO VOLTAGE SWITCHING

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Abstract: Resonant mode conversion techniques are used nowadays to improve pulse width modulated dc- dc converters.

Moreover the quest for ever smaller 50 to 500 watts dc-dc switching supplies has led to the development of circuits that operates in 500 KHz -1 MHz range and above. Since the parasitic elements that normally present in a power circuit can be very significant at this frequency, most of the work is focused on resonant topologies. The topology enables to advantageously employ transformer leakage inductance, MOSFET output capacitance and the MOSFET body diode, to easily move their designs upwards in frequency. The topology offers additional advantages like zero voltage switching at a constant switching frequency, which substantially reduces switching losses. The ability to move upwards in frequency will ultimately reduce the overall size of the power supply.

A resonant transition converter is selected for developing a compact 30W power supply for power requirements of an advanced electronic power conditioner. The switching frequency considered is 500kHz for achieving the required power conversion density. At this switching frequency it is possible to take advantage of lead inductances and parasitic capacitance of switching MOSFETs to either eliminate or substantially reduce the resonant tank elements required for achieving a resonant transition conversion to improve efficiency.

Keywords: Resonant converters, Resonant transition converter, ZVS.

I. INTRODUCTION

The demand for higher switching frequencies (500 KHz -1 MHz range) in order to achieve higher power conversion densities and efficiency better than 90% has rekindled interest in resonant mode topologies. The pulse width modulated half bridge converter developed belongs to the class of Resonant Transition Converter and offers ZVS characteristics. Except for the resonant transitions, it is identical to the square wave PWM converter topology. ZVS in Resonant Transition Converter is obtained relying mainly on the parasitic components of power transformers and output capacitance of the MOSFET Switches, which form the resonating LC tank circuit that substantially reduces switching losses during each transition, giving us low conduction losses and constant frequency operation.

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However, with conventional PWM technologies, the switching losses also increase proportionately with the frequency of operation. In order to realize the high power densities possible with high switching frequencies, it is therefore essential to reduce the switching losses by employing resonant switching techniques. Therefore, focusing on the overall system performance, its size, weight, efficiency and power conversion density, Resonant Transition Converter topology was found to be suitable to operate at high frequencies. Therefore the topology is employed to develop a 30W, 500 KHz, DC-DC Converter with multiple outputs for power requirements of an advanced electronic power conditioner.

II. Need for Resonant Converter

In all the pulse-width modulated DC-DC and DC-AC converter topologies discussed earlier, 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 these switch-mode operation the switches are subjected to high switching stresses and the finite duration of the switching transitions will cause the high peak pulse power dissipation in the device that will cause the degradation in converters efficiency and worst of all will lead to the destruction of the device. These converters are therefore termed as 'Hard Switching' converter topologies where the switching losses contribute to the major percentage of overall losses, as high switching power loss increases linearly with the switching frequency of the pulse-width modulation. Another significant drawback of the switch-made operation is the electromagnetic interference (EMI) produced due to large di/dt and dv/dt caused by a switched-mode operation. These shortcomings of switch-mode converters are exacerbated if the switching frequency is increased in order to reduce the converter size and weight, and hence to increase the power density. . Fig1 shows the switching losses for a hard switching PWM converter and soft switching resonant converter.

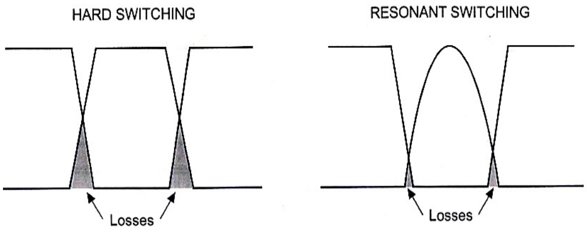

Fig.1 Switching Transition Losses in PWM and Resonant Converters

Therefore to realize high switching frequencies in converters, with the miniaturization trends in electronics, the aforementioned shortcoming are minimized if each switch in the converter changes its status (from On to OFF or vice versa) when the voltage across it and/or the current through it is zero at the switching instant. The converter topologies and the switching strategies, which result in zero-voltage and/or in zero-current switching, are called “Resonant Converter”. Since most of these topologies (but not all) require some form of L-C resonance, these are broadly classified as “Resonant Converters”.

III. RESONANT TRANSITION CONVERTERS

The resonant transition converters are more recent family of soft switching converters. They combine the low switching loss characteristics of the resonant converters and the constant frequency and low conduction loss characteristics of the PWM converters. They are essentially square wave converters for most of the part, except during the resonant transitions. The resonant transition is achieved relying mainly on the parasitic components like the magnetizing and the leakage inductance of the transformer and the output capacitance of the MOSFET, and by adopting suitable switching strategies. Fig 2. shows the circuit configuration for resonant transition converter in half-bridge.

The pulse width modulated half-bridge converter, which has been chosen for the study and implementation for the work. Belongs to the class of resonant transition converters. Some of the salient features of resonant transition converter are as follows

- Zero Voltage switching for all the switches in half-bridge and full-bridge.
- Constant Frequency Operation.
- Peak Voltage/Current stresses of the device are limited as the voltage and currents are almost a square wave except for resonant transition period.
- Parasitic inductance of the transformer and the parasitic capacitance of the MOSFET in the circuit may be used as the resonant elements.
- 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.

IV. DESIGN AND DEVELOPMENT

Resonant transition converter relies mainly on the parasitic elements of the transformer and the MOSFETs to achieve loss less transition. Hence these elements have to be considered in the analysis and design of the converter. Fig2 shows the schematic of pulse width modulated converter used for analysis and simulation. As may be seen, the circuit includes the parasitic elements like the output capacitance (C1 and C2) of the MOSFETs and the magnetizing (Lm) and leakage inductance (Llk) of the transformer.

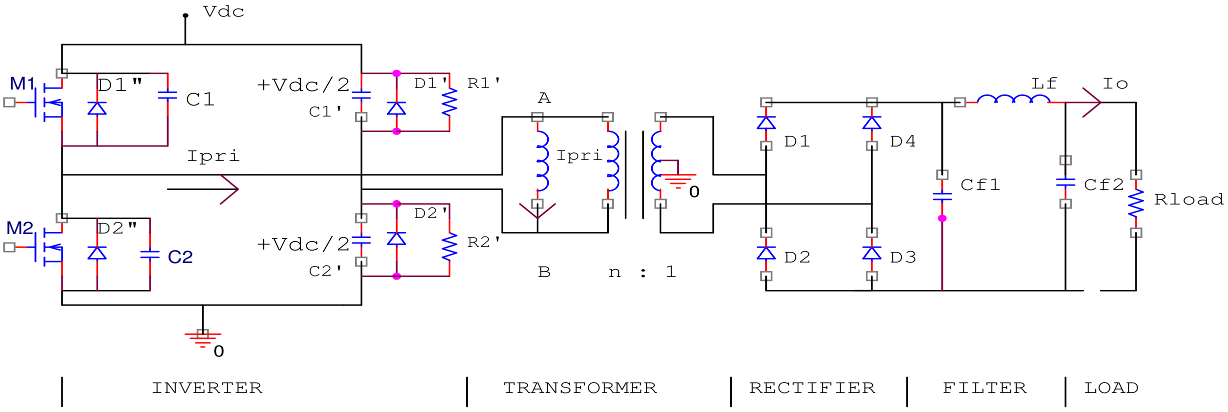

Fig 2 Resonant transition converter in half-bridge

Zero voltage switching demands that, before a MOSFET is switched ON, its output capacitance will be completely discharged. This discharge is accomplished by the energy stored in the magnetizing and the leakage inductances. Therefore these parameters are crucial for the ZVS view point and have to be considered in the analysis.

Design specifications include:30W, multiple outputs of 18V and ±15V, volume of less then 1.5’’(W)*2.5’’(L)*1.2’’(H), switching frequency of 500kHz, operable temperature limits -40° to +80° and an input voltage of 220V DC. Transformer ratings 135V/18V,15V, transformer leakage inductance of 10µH and additional inductance of 30µH. During simulation it is seen that the primary current of 332mA (and 300mA calculated) for the given full load was insufficient to discharge the parasitic capacitance across the MOSFET, and hence suddenly discharging through the MOSFET to be turned on next. Thus achieving hard switching. This is shown in fig.3.

Hence the minimum current required to obtain ZVS or to charge/discharge the capacitance is the important factor to be considered. Moreover the leakage inductance of the transformer around 10µH was too low to provide the desired current to charge/discharge the MOSFET capacitance to achieve zero voltage transition.

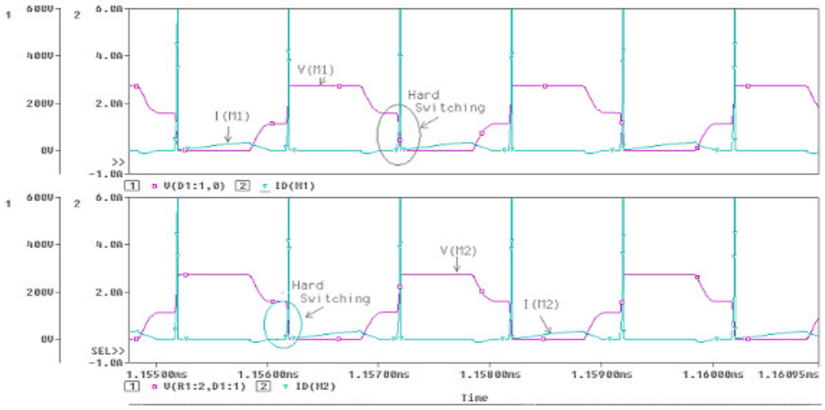

Fig 3. Shows the primary current in sufficient to discharge the parasitic capacitance and hence discharging through the MOSFET achieving hard switching.

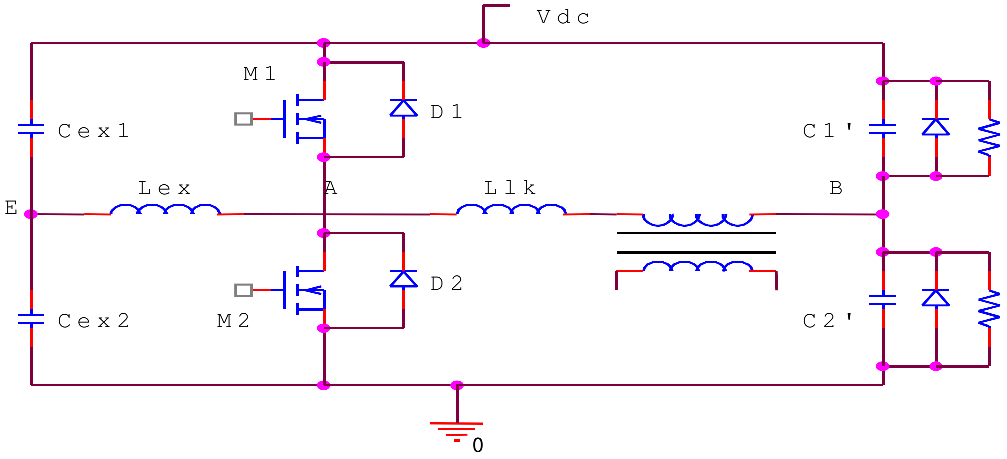

Fig 4. Schematic of the modified circuit to aid ZVS

In Fig 4,Lex is the external inductor added to aid ZVS. The ideal design to restore ZVS is: Iex $_{(peak)}$ = maximum current during turn off plus the minimum current needed to discharge the capacitor across the switch coming into the conduction and the charge the one across the switch tuning off.

V. SIMULATION AND EXPERIMENTAL RESULTS

The designed is simulated using ORCAD 10.0. Simulation results and experimental results are presented for the following operating point

Input Voltage, V_{DC} = 220V

Output Voltage, V_o = 18V, ±15V

Output Power, P_o = 30W

It is seen that both the results match to large extent. The comparison is given in the following table. The experimental and simulation results are tabulated as below.

Table1. Shows the voltages, currents and losses for M1& M2

Parameters	Simulated	Experimental
V_{M1}	270V	268V
I_{M1}	1.3A	1.32A
P_{M1}	1.01W	2.13W
V_{M2}	270V	268V
I_{M2}	1.76A	1.41A
P_{M2}	2.3W	3.6W

Table 2. Shows the input and output voltages and currents for the converter

Parameters	Simulated	Experimental
V_{bdg}	135V	140V
I_{bdg}	400mA	500mA
P_{bdg}	38.18W	49W
V_o	16V	18.2V
I_o	1.4A	1.5A
P_o	22.4W	28W

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The efficiency of the converter is found to be 82%. The estimated power density value was $6W/cm^3$ and the experimental value is $5W/cm^3$.

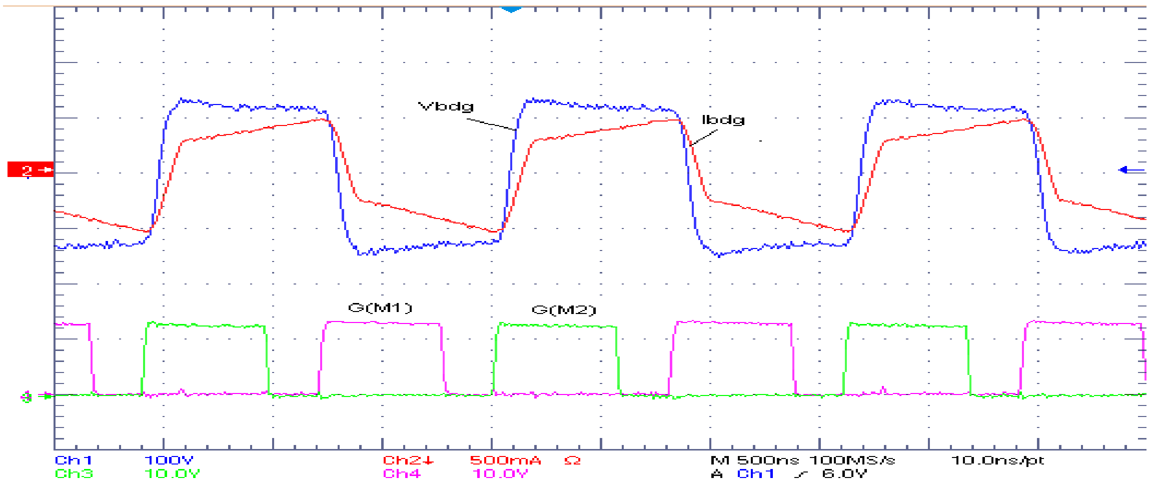

Fig 5: Shows the gate voltage's V_g (M1) & V_g (M2) for the M1&M2. The bridge voltage and current V_{bdg} and I_{bdg} for V_{dc} =270V

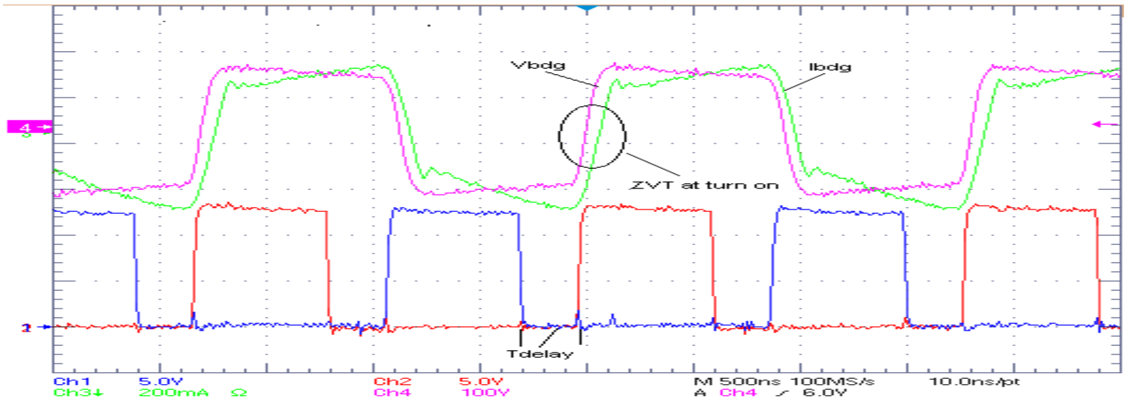

Fig 6: Shows the zero voltage switching at transition from ON to OFF within the given T_{delay}

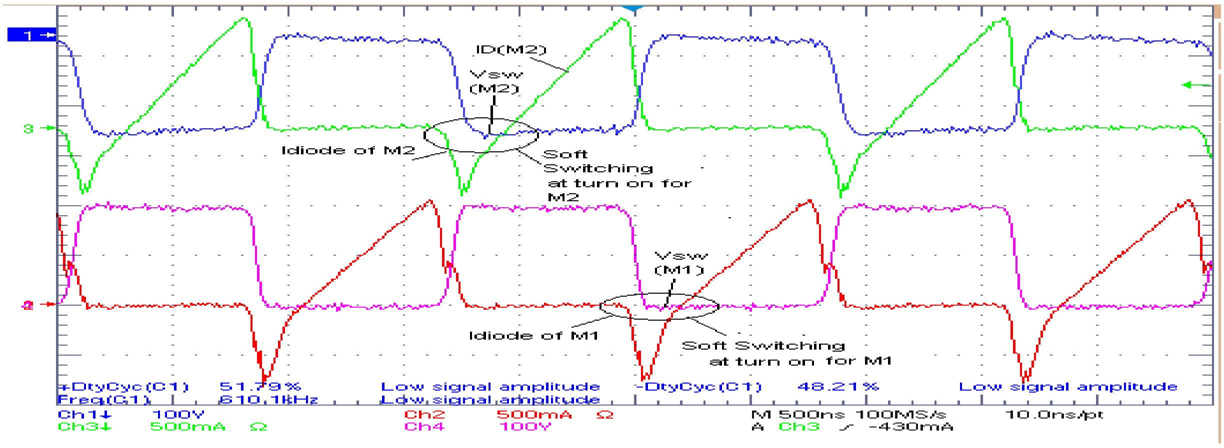

Fig 7: Shows the switch voltage V_{DS} and drain current I_D for M1&M2. It also shows the current through the diode I_{diode} achieving zero voltage turn on.

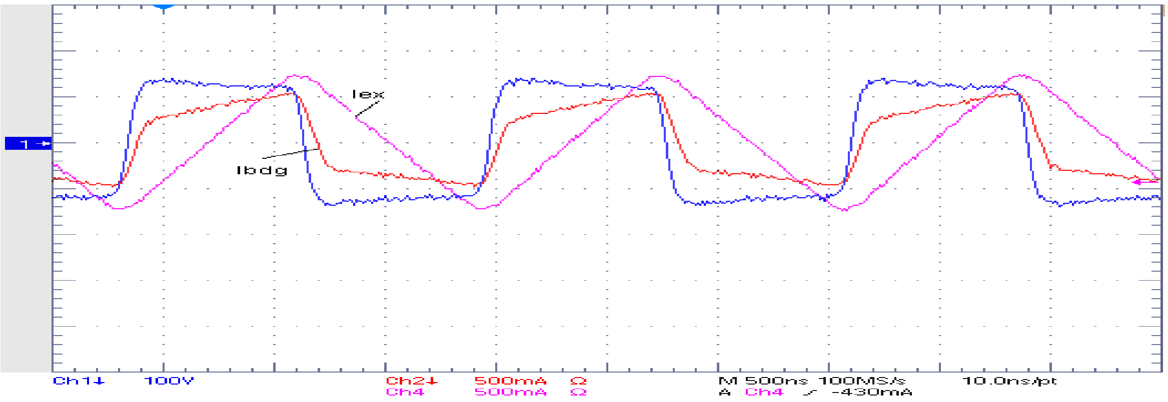

Fig 8: Shows current due to external inductor I_{ex} and the bridge voltage and current V_{bdg} , I_{bdg}

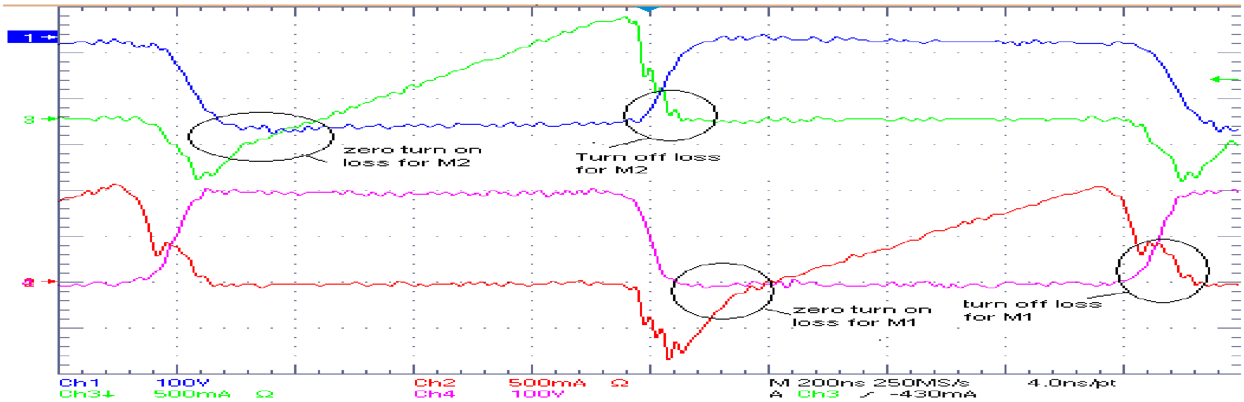

Fig 9: Shows the turn on and turn off losses for MOSFETs M1 and M2. Zero turn on losses and some finite turn off losses.

VI. CONCLUTION

Soft switching would become necessary if higher power conversion density is demanded by the application. This is more important when the power device have to switch large currents at high voltage levels. Soft switching is only the option in future for operating at higher frequency and minimum losses for the converter. The Zero Voltage Transition Converter taken up for development has potential advantages catering to many applications. The methodology gives zero voltage switching, without compromising on the device stresses or the conduction losses. Provides constant frequency operation and possibility of achieving ZVS using the parasitic elements alone. The developed converter in ZVT topology exhibited the low loss switching characteristics of the resonant converter.

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