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Implementation of modified synchronous buck converter for portable application

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***Abstract*: Power electronic converters play an important role in many electronic circuits used in portable application. In this work two zero-voltage-transition (ZVT) pulse width modulated (PWM) synchronous buck converters are proposed, one with passive component and the other with active component. These are designed especially for low power device applications such as charging mobile phone batteries and laptop batteries. The operation principles, switching and conduction losses of the ZVT-PWM synchronous converters are presented. In addition, the proposed converter circuits are cheaper, more reliable and have a higher performance / cost ratio. The proposed system is simulated in the MATLAB-Simulink environment.**

Key words: ZVT, Synchronous buck converter, soft switching, Losses, Efficiency.

I. INTRODUCTION

The role played by power converting circuits is extremely important to almost any electronic system built today. The growing demand of computers in medical instruments, aircraft, defiance, space market, industrial automation and commercial applications impede the general power quality solutions, but sparked the need of precise solutions. With the increasing demand of uninterrupted and high quality power for critical loads, power converter should be properly design to match the nature of the load, the type of power distribution, the quality of local power and the required reliability. Recent advances in power converter endorses high efficiency, high power density. Lower operating voltages, increased current requirements and the dynamic characteristics of microprocessor based or microcontroller based system create new demands on power distribution and management [2]. The issues such as achieving high efficiency, high power density, and proper voltage regulation etc., [22] become critical if buck converters are considered for low operating voltage [3]. Circuits that use converters of any type depend on power that is consistent in form and reliable in order to properly function. In addition, today's demands require more efficient use of energy, from large stationary systems such as power plants all the way down to small mobile devices such as laptops and cell phones. This places a need to reduce any losses to a minimum. The power conversion circuitry in a system is a very good place to reduce a large amount of unnecessary loss. This can be done using circuit topologies that are low loss in nature. For low loss and high performance, soft switching topologies have offered solutions in some cases. Attaining high performance and low power consumption in MP3 players, personal media players, digital cameras and other portable consumer applications has long been a challenge for designers. Naturally, battery life is of prime importance in handheld battery-powered products, making their success directly related to the efficiency of the power system. A key component of such systems is the step down dc-dc switching regulator, which is also commonly referred to as a step down dc-dc converter or buck converter with low efficiency of switching converters [3]. However small size requirements encountered in computer systems and portable devices call for increased switching frequencies. As the switching frequency is increased, the benefit of the low MOSFET on resistance (Rdson,) is diminished by the increase in the switching losses, the gate drive loss, and the body diode loss [3] [4]. Supply voltage scaling is an essential step in the technology scaling process. Two primary reasons for scaling the supply voltage are to maintain the power density of an integrated circuit below a limit dictated by available cost effective cooling techniques and to guarantee the long term reliability of manufactured devices. Microprocessors, with increased power consumption and reduced supply voltages, demand greater amounts of current from external power supplies, creating an increasingly significant power generation and distribution problem (both on chip and off-chip) with each new technology generation [2-4]. Energy efficient, low noise power delivery has become increasingly challenging with the advancement of integrated circuit technologies [5].

The paper is organized as follows: Section II gives the basic operation of synchronous buck converter. Section III presents different losses in converters. Section IV and V briefs the basic features of ZVT techniques. Section VI gives simulation results. Section VII includes efficiency comparison.

II. SYNCHRONOUS BUCK CONVERTER

In the synchronous buck converter topology, a power MOSFET replaces the traditional buck converter output-stage commutating diode. This improvement reduces the typical 0.5-V-to-1-V diode drop to about 0.3 V or less, resulting in typical circuit efficiency improvements of around 5% and higher. The basic synchronous buck converter circuit includes a pair of MOSFETs, an output filter, and a controller that provides the synchronous switching function [6] [7]. Figure 1 shows the simplified schematic diagram of a typical synchronous buck converter.

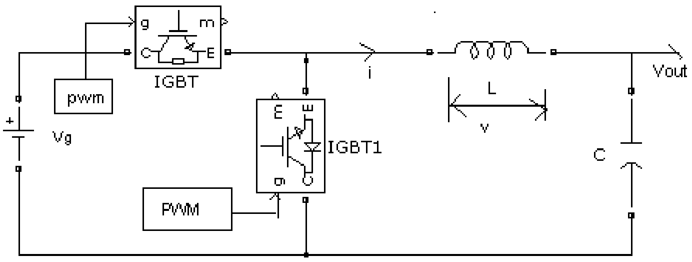

Fig. 1: Basic Synchronous buck converter

III LOSSES IN CONVERTER

MOSFETs are very popularly used in most converters so it makes the most since to use them in the description of switching element loss. The switch losses can be divided into to general forms of loss, conduction losses and switching losses. These losses are described in detail below [8]. The calculations used are approximations since the internal losses of every device cannot be measured during operation. This is a numerical method based on certain device characteristics with the synchronous buck converter in mind.

A. CONDUCTION LOSSES

Conduction losses are defined as losses that are sustained due to the equivalent resistance of the MOSFET channel after the channel is completely enhanced. This resistance is the Eds (on) value for the transistor [9]. Estimation of this loss can be made using the following equations for the high and low side devices.

$$P_{CONDHS} = I_{OUT}^2 R_{DS(ON)}\ D \qquad (1)$$

$$P_{CONDHS} = I_{OUT}^2 R_{DS(ON)}\ (1-D) \qquad (2)$$

B. SWITCHING LOSS

Switching Losses occur during switching transitions as spikes in power are created due to rising voltage and falling current overlaps and vice versa depending on the transition occurring. In general these losses occur due to device parasitic capacitances. A good part of the switching losses sustained are due to the charging and discharging of these capacitances through larger resistance then are seen during device conduction. The equations used for estimation of these losses the below.

$$P_{SW(HS)}\left(\frac{Vi_{n.}I_{out}}{2}\right).F_{SW}.\left(t_{s(L-H)}+t_{s(H-L)}\right) \qquad (3)$$

$$t_{s(L-H)} = \frac{Q_{G(SW)}}{I_{PRIVER\,(L-H)}} \qquad (4)$$

$$t_{s(H-L)} = \frac{Q_{G(SW)}}{I_{PRIVER\,(H-L)}} \qquad (5)$$

$$PSW(LS) = \left(t_2.V_F + t_3.\frac{VF + I_{OUT}.1.1.RPS_{(IN)}}{2}\right).I_{OUT}.F_{SW} \qquad (6)$$

$$t_{2R} = K_{2R}.\left(R_{DRIVER} + R_{GATE}\right).C_{ISS} \qquad (7)$$

Note for the low side that equation 6 is used twice to calculate the rising and falling edge losses. Diode losses during dead space are included as switching losses as well with equation1, these losses are often lumped with the low side switching losses since it typically is the low side MOSFET's body diode conducting. These are additional losses, due to the gate drive that are typically insignificant unless the switching frequency becomes extremely high, that not stated here [8].

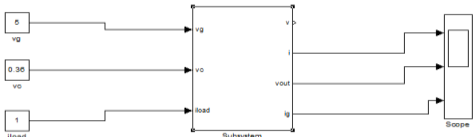

Fig. 2: Simulation of Synchronous Buck Converter

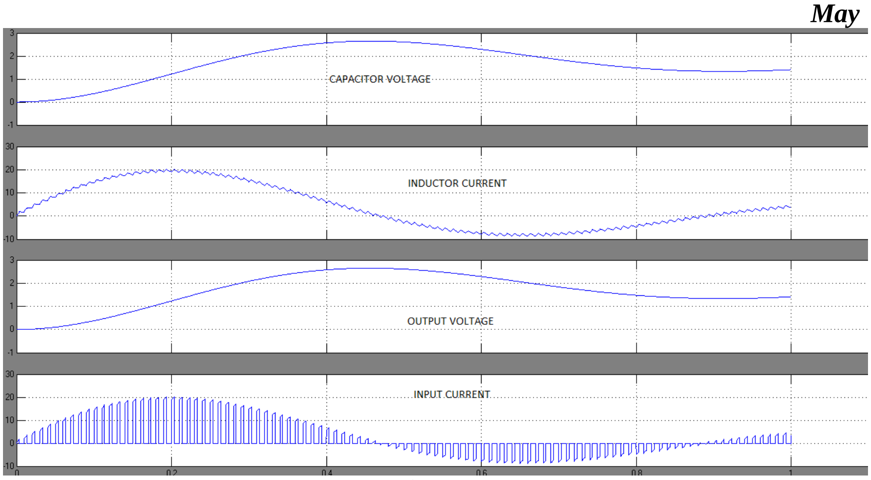

Fig. 3: simulated output of Synchronous Buck Converter

IV. ZVS, ZCS, & ZVT

Understanding how soft switching is accomplished is important in understanding how to use the topologies that achieve this goal. Soft switching topologies make use of additional circuit elements passive or active in order to limit di/dt or dv/dt during switching and minimize current and voltage overlap to reduce switching losses [9-12]. Essentially, in the switching device at the switching interval, either the current or the voltage must be driven to zero to bring the product of the two as close to zero as possible. This leads to the concepts of zero voltage switching (ZVS) and zero current switching (ZCS)[24-27]. Just as in the name either the voltage or current is driven to zero during switching.

There are many topologies that use ZVS, ZCS, or both to reduce overall switching losses. Converters such as the ones termed as quasi-resonant can be used to achieve ZVS or ZCS [28]. However, converters such as these can cause additional problems that offset soft switching benefits, such as additional voltage or current stress on the main switch [30]. Converters that have soft switching but reduce or eliminate this stress are more highly desirable. For this reason, what are known as zero voltage transition (ZVT) converters have become very popular and as stated previously, the number of ZVT topologies that have been introduced is large [16-18]. ZVT converters accomplish soft switching while

$$K_{2R} = \ell_n\left(\frac{V_{DRIVE}}{V_{DRIVE} - V_{SP}}\right) - \ell_n\left(\frac{V_{DRIVE}}{V_{DRIVE} - V_{TH}}\right) \quad (8)$$

$$t_{2R} = K_{3R}.(R_{DRIVER} + R_{GATE}).C_{ISS} \quad (9)$$

Minimizing additional stresses associated with other previous topologies [28-29].

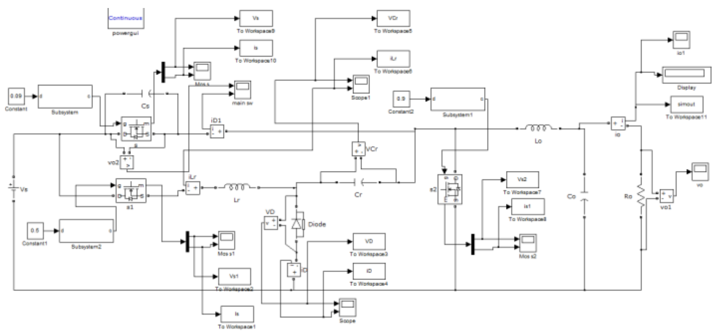

Fig. 4: Soft switching converter with Active component

V. SOFT SWITCHING

There are may types of ZVT converters. This class of converters has been categorized more thoroughly into various types in [30]. However, in general there are two types of ZVT converters, ones that use passive auxiliary circuit elements only such as in [15] and ones that use active elements in the auxiliary circuit [19]21][23]. Active types will be the only ones discussed to follow. Although there are many different topologies that use ZVT the basic concept can explained by using the buck topology from [21]. This family of topologies is typically considered to be the conventional ZVT topologies. In this section ZVT will be explained using an example with this conventional ZVT buck converter. Below is simulation of this topology in MATLAB and its corresponding waveforms.

$$K_{3R} = \ell_n\left(\frac{V_{DRIVE}}{V_{DRIVE} - 0.9V_{SPEC}}\right) - \ell_n\left(\frac{V_{DRIVE}}{V_{DRIVE} - V_{SP}}\right) \quad (10)$$

$$P_{DIODE} = t_{DEADTIME}.F_{SW}.V_F.I_{OUT} \quad (11)$$

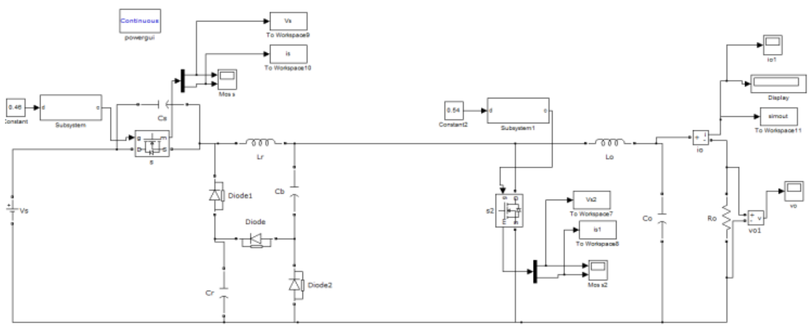

Fig. 5: Soft switching converter with Passive component

VI.SIMULATION RESULTS

It is noted from that the main switch S is turned on under ZVS, when voltage across Cs is zero. The converter has not exceeded the voltage limits; however the current stress is slightly higher for a very short period of time. The main switch also switches off under ZVS. The current and voltage waveforms obtained through simulation and experimental investigations are in close agreement with the theoretical analysis. It is noted that auxiliary switch S_1 also operates with soft switching. The switch S_1 is turned on under ZCS because of the inductor L_r and turns off under ZCS when resonant current through L_r and C_r falls to zero. Its body diode also turns on as soon as S_1 is off at zero current and turns off when the resonant current is zero. The auxiliary switch is active only for a short period of time, which is verified by its conduction period and it is too small. Also, the current and voltage stresses are well within the operating limits.

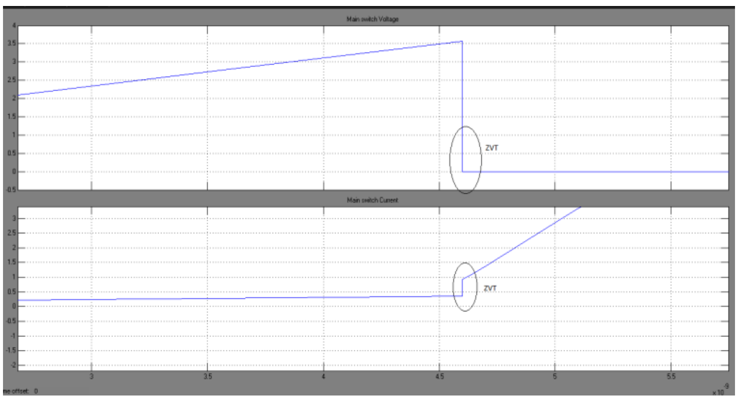

Fig. 6: Main switch Current and voltage

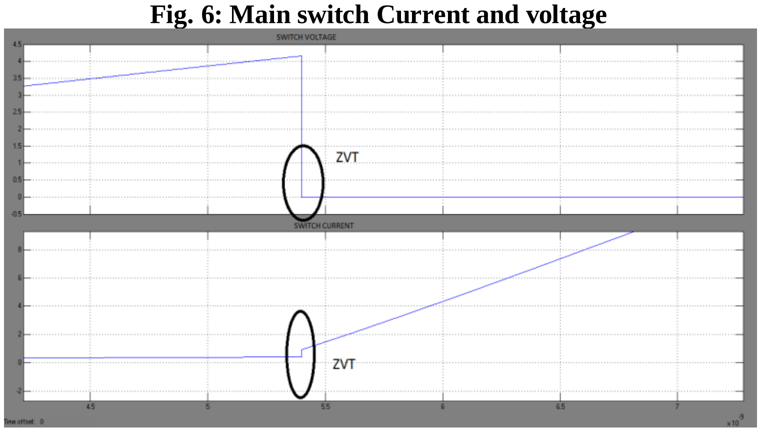

Fig. 7: Synchronous switch current and voltage

VII.COMPARISON CURVE

The efficiency of conventional synchronous buck converter is compared with the Zero Voltage Transition Synchronous converter It can be observed that the efficiency values of the soft switching converter are relatively high with respect to those of the hard switching converter. The efficiency values towards the minimum output power decrease naturally because the converter is designed for the maximum output current. At 50% output power, the overall efficiency of the proposed converter increases to about 95% from the value of 85% in its counterpart hard switching converter. The high efficiency concludes the correctness of the design values.

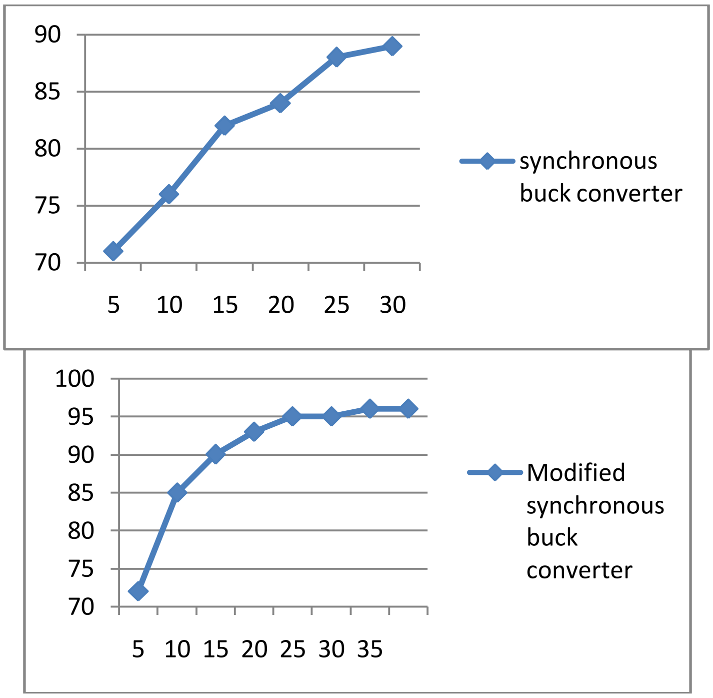

Fig. 8: Comparison of efficiency
(Sync Buck Vs ZVT Sync Buck)

VIII CONCLUSION

Soft switching can be used to improve converter performance. However several factors come into play that can influence the benefits of soft switching. Examples of these factors are power semiconductor technology, switching frequency, and power range. Based on the data obtained it seems that for the given components, switching frequency, load range, and other operating characteristics that the benefits of ZVT are outweighed by the additional losses induced. By operating at a fairly low switching frequency and using switching components that have inherently low switching losses, ZVT's benefits might be overshadowed at this load range. Another factor that could be contributing to the discrepancy in the efficiency data could be the length of the resonance period used in this design. The resonance period length could be reduced leading to smaller conduction losses and perhaps higher efficiencies.

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