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Efficiency Improvement of Feed Forward Controlled Buck Converter by Passive Auxiliary Circuit

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ABSTRACT*:* Generally Buck Converter circuits have snubber circuit where switching losses are dissipated in external passive resistors; this is known as hard switching. Here a new passive auxiliary circuit topology is introduced so that the generation of switching losses are avoided by forcing voltage (ZVS) or current (ZCS) to zero during switching. The efficiency is thus improved due to reduction in switching losses. The operation principles and detailed steady state analysis of the ZVT-PWM synchronous converter with a passive auxiliary circuit are presented. Also, Feedforward control is accomplished by sampling the converter input voltage (instead of the output voltage, as in negative feedback control) and using this signal to control the duty cycle, to regulate the output voltage against line voltage variations (line disturbance).

KEYWORDS: Passive auxiliary circuit, synchronous converter, zero-voltage switching (ZVS), zero-voltage transition (ZVT), feed forward control, PWM buck converters.

I. INTRODUCTION

The field of Power Electronics is very broad and contains components from several disciplines of electrical engineering. Most Power Electronic systems can be simplified into three general components thesource, converter, and load. The source provides the input energy and the load uses that energy to perform the desired task. The converter, being central to the energy flow, can be one of the best places to reduce unwanted losses. The ideal converter does not have any losses and the power in is equal to the power out. In any real converter this is not the case of course and there are losses. Reducing this loss to a minimum is necessary to have a high level of efficiency.

Current trends in consumer electronics demand progressively lower voltage supplies. Portable electronic equipment, such as laptop computers, cellular phones, and future microprocessor and memory chips, require low-power circuitry to maximize the battery run time.However, higher input voltages and lower output voltages have brought about very lowduty cycles, increasing switching losses, and decreasing conversion efficiency. So earlier,asoft-switching active snubber was proposed to reduce the turn-off losses of the switches in abuck converter. The soft-switching snubber provides zero- voltage switching for the switch,thereby reducing its high turn- off losses. The proposed snubber uses an auxiliary switch to discharge the snubber capacitor. But the use of switches in the active snubber circuit againresulted in producing some switching losses during the transition period of the switches. So later on, the efficiency of the synchronous buck converter is optimized by eliminating theswitching losses using a soft switching technique with the help of a passive snubber . The voltage-mode soft-switching method that has attracted the most interest in recent years isthe zero-voltage transition (ZVT). This is because of its low additional conduction lossesand because its operation is closest to the pulse width modulated (PWM) converters. Theauxiliary circuit of the ZVT converters is activated just before the main switch is turned on and ceases after it is accomplished.

Passive snubbers are generally used to reduce other important losses, i.e., switching losses. Moreover, they provide tolerable voltage and current stress across semiconductor switches used in converter-mitigated electromagnetic interference. Much research has already been done using passive snubbers in rectifier and boost topologies emphasizing on the energy recovery and efficiency properties. In addition, it has been reported that the passive circuits are cheaper and more reliable and had a higher performance/cost ratio than the active ones.The proposed circuit not only serves as an energy recovery turn-on snubber, which greatly reduces the reverse-recovery peak current of the power boost diode and the turn-on loss of the boost switch, but also provides a zero-voltage or reduced voltage turn-off condition for the boost switch with an extended operating range. Since it uses fewer circuit components, the circuit layout is simple. The snubbers energy is recuperated to the load.

In dc-dc converters ,the dc output voltage is directly proportional to the dc input voltage. Therefore, it is difficult to achieve good line regulation. Feedforward control is accomplished by sampling the converter input voltage (instead of the output voltage, as in negative feedback control) and using this signal to control the duty cycle[4][5][9][12].

II. ZVT-PWM SYNCHRONOUS BUCK CONVERTER

A. Circuit Description

The ZVT-PWM synchronous buck converter is shown in Fig. 1. It is the combination of the conventional PWM synchronous buck converter and the proposed auxiliary snubber circuit. The auxiliary circuit consists of a resonant inductor L_r, a resonant capacitor C_r, a buffer capacitor C_b, and three auxiliary Schottky diodesD_{S1},D_{S2}, and D_{S3}. The body diodes of the main switch S and synchronous switch S1 are also utilized in this converter.

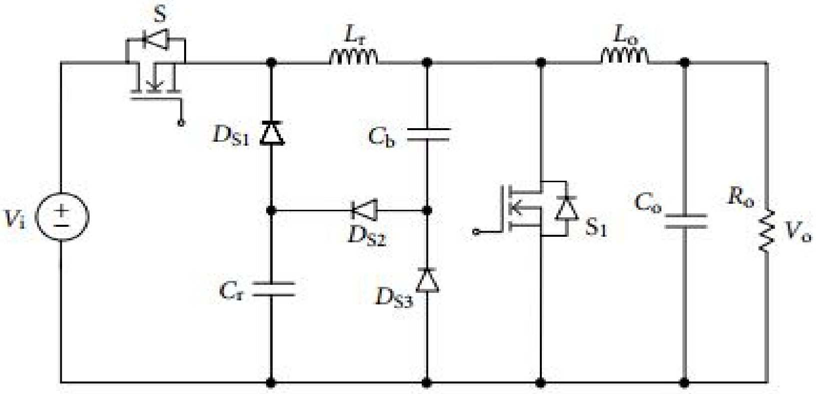


Figure 1: ZVT Buck Converter

B. Design of Auxillary Circuit

The resonant inductor and the resonant capacitor are the most important components when designing the auxiliary circuit. The proposed auxiliary resonant circuit provides soft switching conditions for the main transistor.

1. Snubber inductor L_r is selected to permit its current to rise up to, at most, the maximum output current within $t_r$time periods during the turn-on of the main transistor or the turn off of the synchronous switch. Here $t_r$is the rise time of the main transistor.

$$\frac{Vi}{Lr} \leq Iomax$$

2. Snubber capacitor $C_r$is selected to discharge from $V_i$to zero with the maximum output current over at least the time period $t_f$during the turn off of the main transistor. Here, t_f is the fall time of the main transistor.

$$Z = \sqrt{\frac{Lr}{Cr}}$$

and,

$$\frac{1}{Iomax} Vi \geq tf$$

The value of $C_b$is normally larger than the value of $C_r$to provide the condition for the energy transfer from inductor $L_r$to C_b.

III. FEEDFORWARD CONTROL OF BUCKCONVERTER

In PWM dc-dc buck-derived converters operated in Continuous Conduction Mode (CCM) and without any control, the dc output voltage is almost independent of the output current, but it is directly proportional to the dc input voltage. Therefore, it is not easy to achieve a good line regulation in these converters.

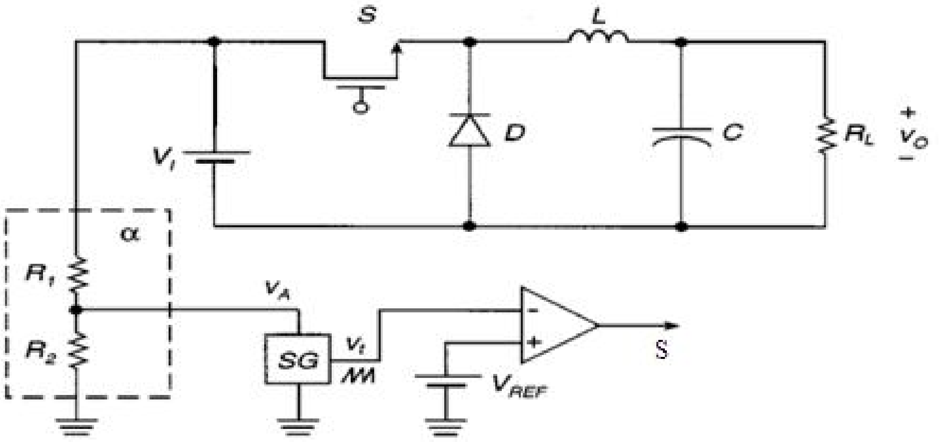


Figure 2: Open loop buck converter with input-voltage Feedforward control

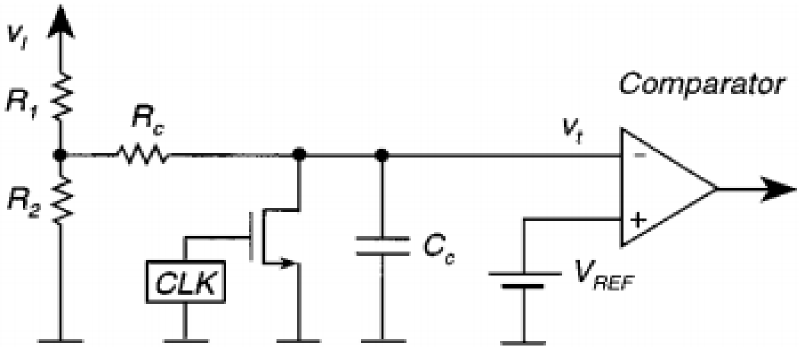


Figure 3: Sawtooth Generator

Fig 2 shows a buckcircuit with a peak-voltage-modulation feedforward control circuit. The feedforward control circuit consists of a sawto oth generator, a reference voltage V_{REF}, and a comparator. The sawtooth generator in Fig 3 consists of a voltage divider, a resistor R_c, a solid-state switching device, a capacitor C, and a clock oscillator. When the MOSFET is off, the capacitor C, is charged through the combination of resistors R_1, R_2, and $R_{c..}$When the MOSFET is ON, the capacitor $C_c$is discharged rapidly through the MOSFET on-resistance. The output voltage of the sawtooth generator for the charging time interval is given by

$$Vt = \alpha Vi\left(1 - e^{\frac{t}{\tau c}}\right) \approx \frac{\propto Vi}{\tau c}t$$

and it’s magnitude is,

$$VTm = vt(T) \approx \frac{\propto Vi}{\tau c} = \propto Vi$$

where,

$$\propto = \frac{R2}{R1+R2}$$

and

$$\mu = \propto \frac{T}{\tau c}$$

The sawtoothvoltage V_t is applied to the inverting input of the comparator and the reference voltageV_{REF} is applied to the non inverting input. When the sawtooth voltage V_t is lower thanthe reference voltage V_{REF}, the comparator output voltage goes high and, therefore, thegate-to-source voltage V_{GS} of the power MOSFET in the buck converter also goes high.The crossing time of the two voltages determines the duty cycle D.

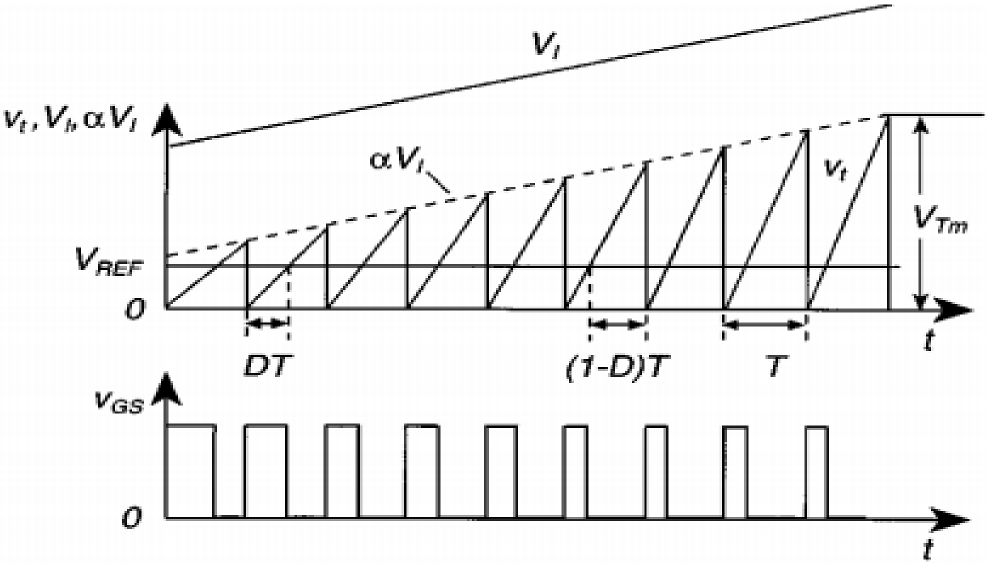


Figure 4: Waveforms for the buck converter with peak voltage feedforward control

Fig 4 shows the waveforms for the buck converter with peak voltage feedforward control. From the figure and geometry, duty cycle

$$D = \frac{VREF}{\mu Vi}$$

Thus, the duty cycle D decreases when the input voltage Vi increases.

IV. FEEDFORWARD ZVT BUCK CONVERTER

The proposed Feedforward ZVT Buck converter is shown in Fig 5. In this technique, the main switch S of the

ZVT Buck converter is been driven by the pulses generated by the Feedforward control technique. For varying inputs, the Duty cycle gets automatically adjusted in order to maintain a constant output voltage.

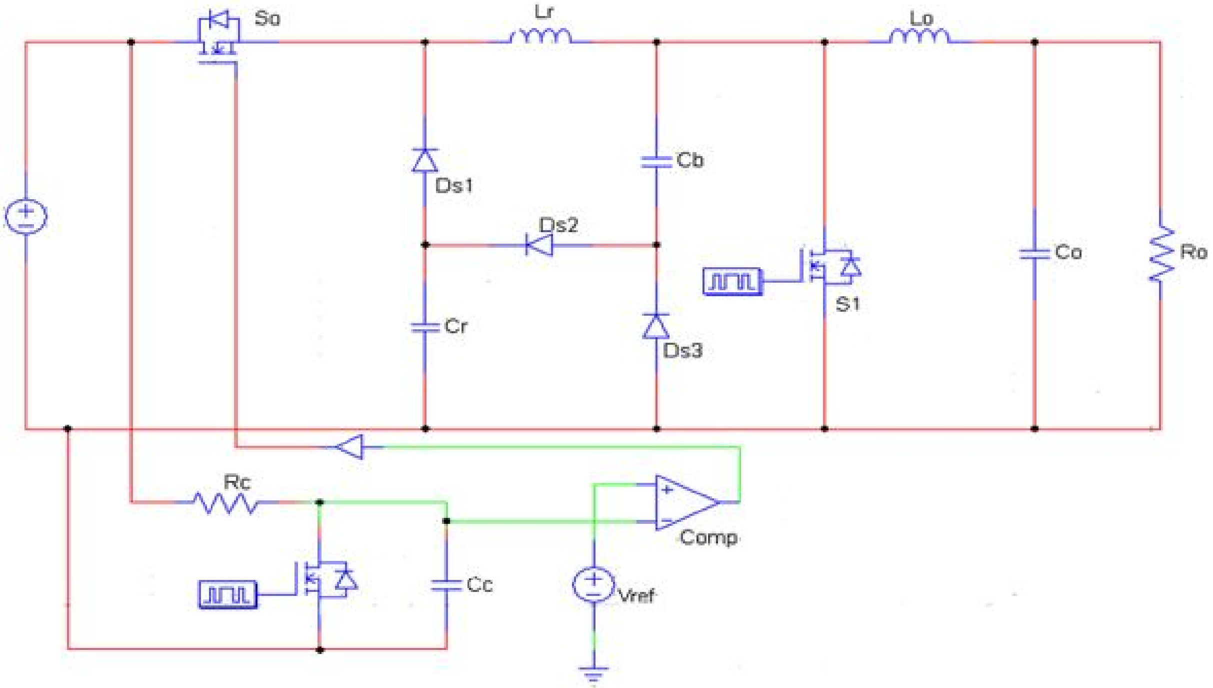


Figure 5: Feedforward ZVT Buck converter

V. SIMULATION RESULTS AND EXPERIMENTAL RESULTS

An ZVT Buck converter operating with an input voltage = 20.4V, output voltage = 8.38V with a switching frequency of 23 KHz is proposed, and is shown in Fig.11. Fig 12 gives the ZVS switching achieved across the switches. The converter is simulated using simulation software PSIM and MATLAB. The major parameters and components are given in Table I. Fig 6 shows the voltage across and the current through the switch of a conventional converter. An overlapping between current and voltage waveforms occurs because of the switching losses.

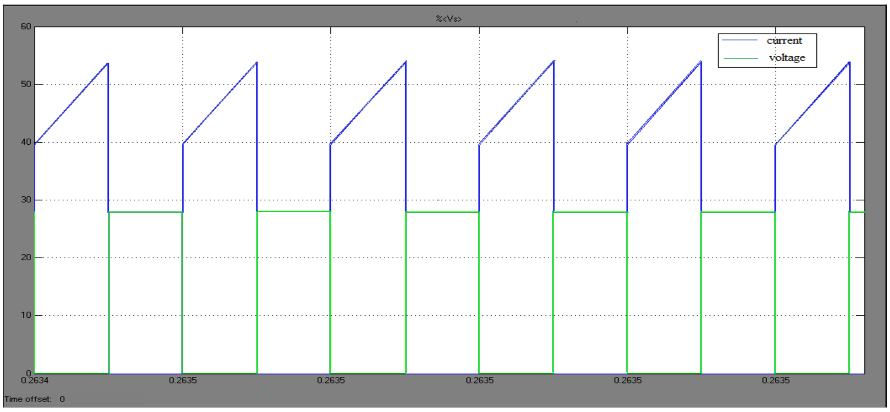


Figure 6: Current and Voltage waveforms of the main switch

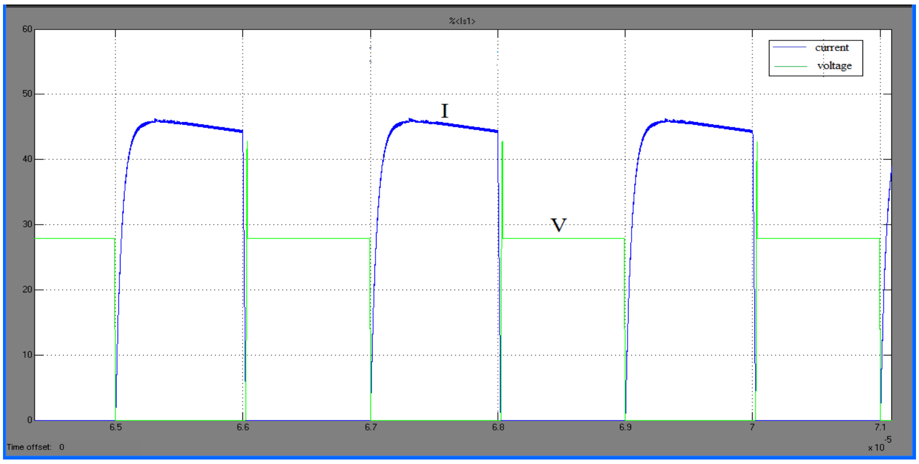


Figure 7: Current and Voltage waveforms of the main switch and Synchronous switch with Auxillary resonant circuit

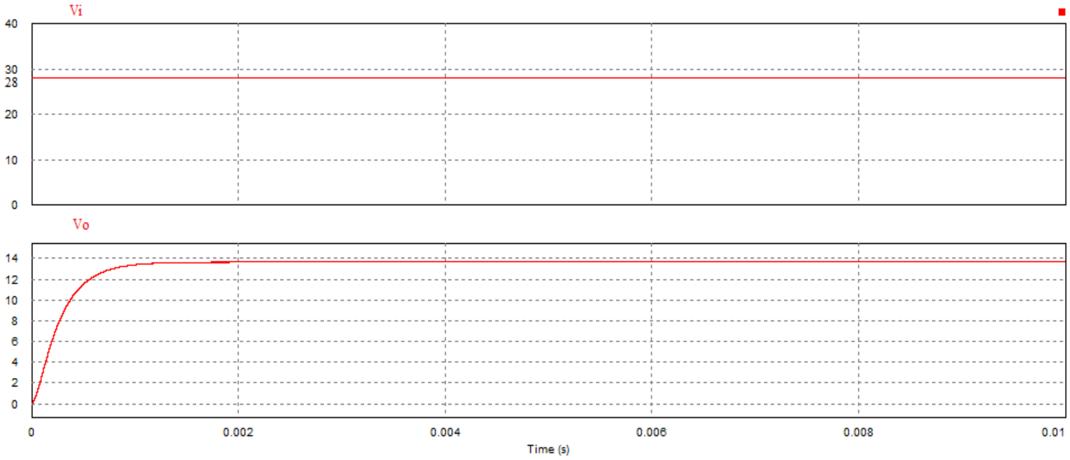


Figure 8: Buck converter without Passive snubber circuit

Fig.7 shows the voltage across and the current through the switch of a conventional converter provided with an auxiliary resonant circuit. Fig 8 is a Buck converter without Passive snubber circuit with Vi=28V and Vo=13.76V. Fig 9 and Fig 10 gives the output waveforms for FeedforwardBuck converter with Passive snubber circuit with different input voltages. A constant output voltage was obtained in both the cases with almost zero switching losses. For Vi= 28V, the value of duty cycle ,D = 0.51,and for Vi = 35V, the value of D changed to 0.41. Thus the duty cycle got automatically adjusted inorder to get a constant output.

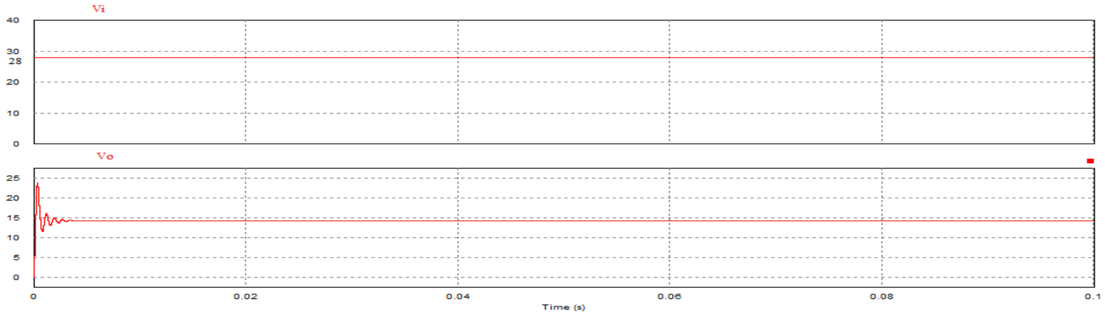


Figure 9: Buck converter with Passive snubber circuit for Vi=28V

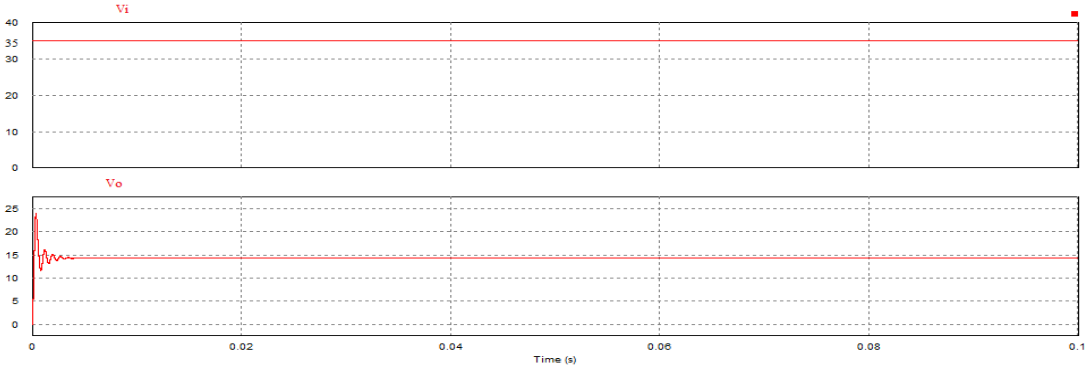


Figure 10: Buck converter with Passive snubber circuit for Vi=35V

The ZVT buck converter is provide a 20.4 V DC supply and obtained a 8.38 V output. The switching frequency is 23 KHz. It can be observed that the voltage across the switches rises only after the switching pulse fully ends. ZVS across the switches is shown in the Fig 12.

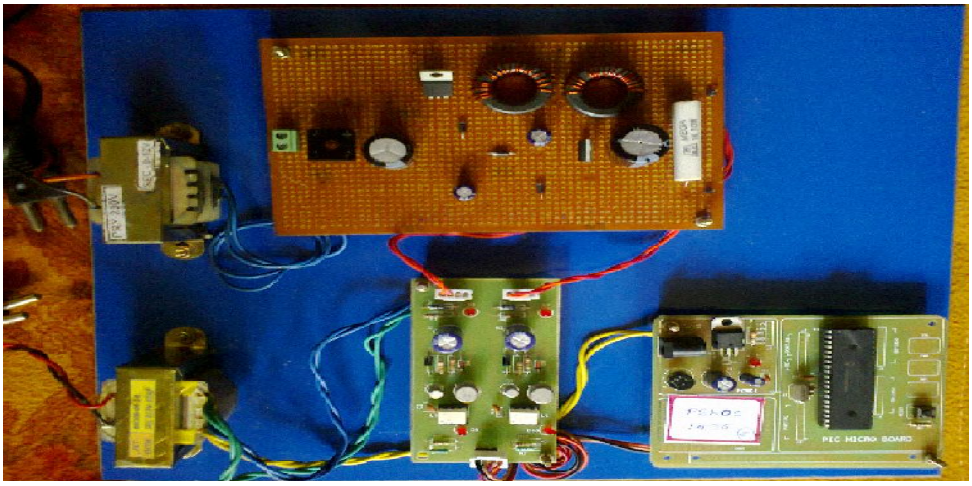
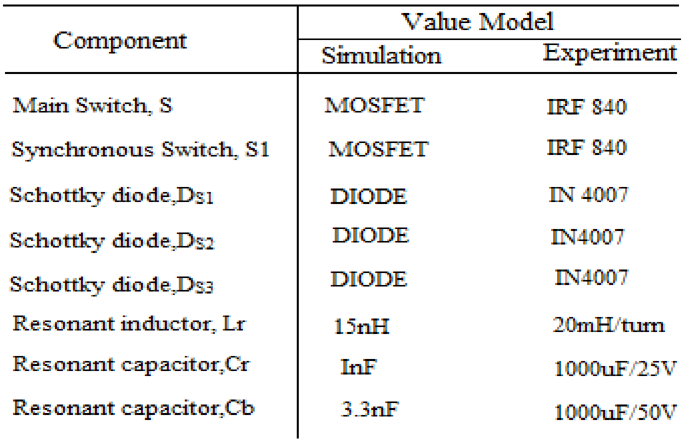
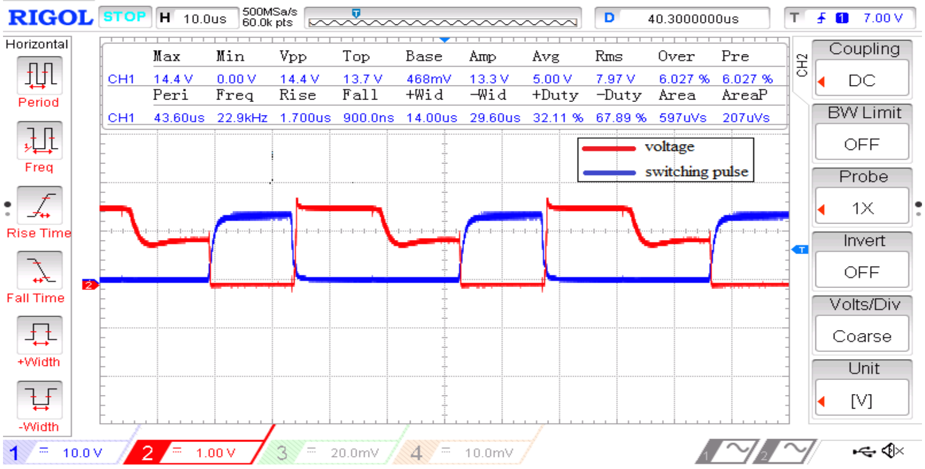


Figure 11: Buck converter with Passive auxiliary circuit

TABLE I
COMPONENTS USED



Component	Value Model	
	Simulation	Experiment
Main Switch, S	MOSFET	IRF 840
Synchronous Switch, S1	MOSFET	IRF 840
Schottky diode,Ds1	DIODE	IN 4007
Schottky diode,Ds2	DIODE	IN4007
Schottky diode,Ds3	DIODE	IN4007
Resonant inductor, Lr	15nH	20mH/turn
Resonant capacitor,Cr	InF	1000uF/25V
Resonant capacitor,Cb	3.3nF	1000uF/50V



	Max	Min	Vpp	Top	Base	Amp	Avg	Rms	Over	Pre
CH1	14.4 V	0.00 V	14.4 V	13.7 V	468mV	13.3 V	5.00 V	7.97 V	6.027 %	6.027 %
	Peri	Freq	Rise	Fall	+Wid	-Wid	+Duty	-Duty	Area	AreaP
CH1	43.60us	22.9kHz	1.700us	900.0ns	14.00us	29.60us	32.11 %	67.89 %	597uVs	207uVs

Figure 12: ZVS across the switches

VI. CONCLUSION

The concepts of the ZVT used in medium and high power were implemented in a synchronous buck converter, and it was shown that the switching losses in the synchronous buck were eliminated. Aside from the main switch being turned on under ZCT and turned off under ZVT, the synchronous switch is also turned on under ZCT and turned off under ZVT. Hence, the switching losses are reduced, and the newly proposed ZVT synchronous buck is highly efficient than the conventional converter. The additional voltage and current tresses on the main devices do not take place, and the auxiliary devices are subjected to allowable voltage and current values. Moreover, the converter has simple structure, low cost, and ease of control. Feedforward control with peak voltage modulation provides a good dc voltage regulation against input voltage variations in PWM buck converters. However, it cannot regulate against load current variations. Small output voltage deviations are also caused by the converter parasitic components. A combination of feedforward and negative feedback is recommended for future research.

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