Comparative Analysis of Buck, Synchronous-Buck and Modified Synchronous-Buck Converters for Portable Applications

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Abstract

Power electronic converters play an important role in many electronic circuits used in portable applications. In this work three step down converters namely buck converter, synchronous buck converter and modified synchronous buck converters are proposed. These are designed especially for portable applications. The operating principles, design parameters and efficiency of these converters presented. These converters are simulated in the MATLAB/SIMULINK environment.
Keywords: Buck Converter, Synchronous Buck Converter, Modified Synchronous Buck Converter, Efficiency, Matlab/Simulink

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, defense, 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 designed to match the nature of the load . Recent advances in power converter endorses high efficiency, high power density[1]. 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[2]. 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.

The paper is organized as follows: Section II gives the basic operations of buck converter, synchronous buck converter and modified synchronous buck converter. Section III Presents Design Parameters of Buck, Synchronous Buck and Modified Synchronous Buck Converters. Section IV Presents Simulation Results and Efficiency Comparison of Converters. V Conclusion

II. BASIC OPERATION OF CONVERTERS

A. Buck-Converter

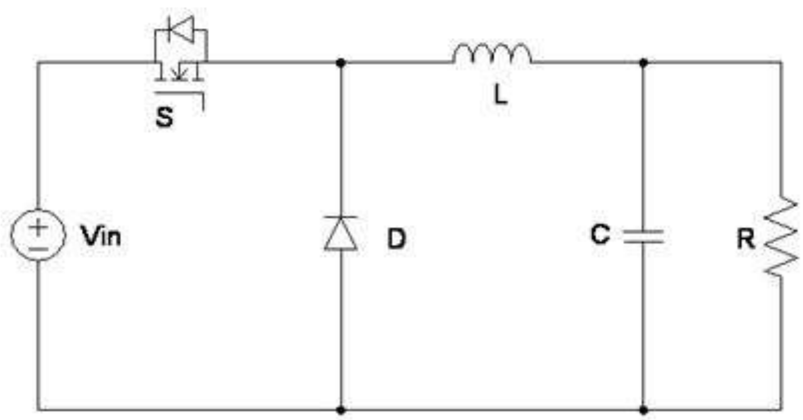

Fig. 1: Buck Converter

Buck Converter is also known as Step-down Converter. When the MOSFET switch is ON, the voltage across the load is Vin. The current flowing through the load is same as shown in the Fig.1. When the MOSFET switch is turned off, the current through the load is in the same direction as mentioned but the voltage across the load is zero. The power is flowing from source to load. Therefore, the average voltage across the load is less than the source voltage, which is determined by the duty cycle of the pulse provided to the MOSFET switch[3]. The inductor is used to smoothen the load current and make it a DC current and, the capacitor is used to reduce the ripples of the output voltage and supply a steady voltage.

B. Synchronous Buck Converter

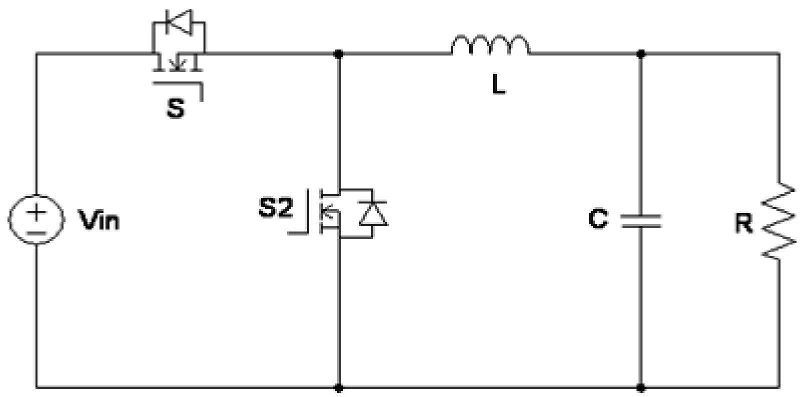

Fig. 2: Synchronous Buck Converter

In this converter two MOSFETS are used which are synchronized. The second MOSFET is used in place of diode so that conduction loss is minimized. But in this converter, no auxiliary circuit is present for reducing the switching losses[3]. Thus this converter can be used only for low switching frequency applications[5].

C. Modified Synchronous Buck Converter

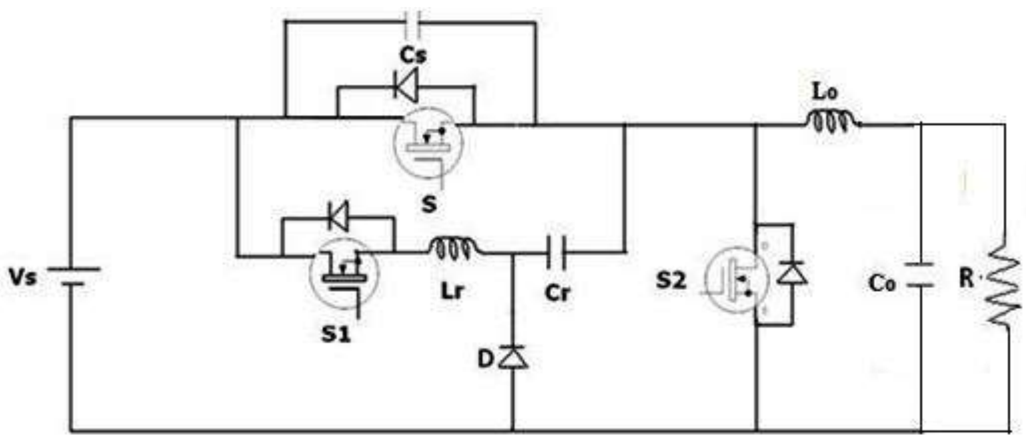

Fig. 3: Modified Synchronous Buck Converter

In this converter, not only the conduction losses are reduced by replacing the diode with MOSFET, but also switching losses are reduced by providing an auxiliary circuit The Lr and Cr are in resonance with each other and help in providing the time delay to minimize the switching losses[3]. So this converter can be used for high as well as low switching frequencies [2].

III. DESIGN PARAMETERS OF BUCK, SYNCHRONOUS BUCK AND MODIFIED SYNCHRONOUS BUCK CONVERTERS

The values chosen for designing buck converter are as follows. Vs= 5volts, Switching frequency = 40kHz, Output voltage (Vout) = 1.5 volts, output inductor (L0) = 83.3 μH, output capacitor (C0) = 497 μF, load current 1A, Resistance 8Ω and current ripple is 30% of maximum load current.

A. Buck Converter

The duty ratio is calculated using equation
D= (Vo/Vi)

Inductance is calculated by equation
L= (Vin/Vo) (D/ (Fsw * Iripple)
Capacitance is calculated by equation
C= (ΔI*ΔT) / (ΔV-(ΔI*ESR)
Inductor loss is calculated by equation
$P_{IND\_LOSS} = I_{load}{}^2 * ESR$
Capacitor loss is calculated by equation
$P_{CAP\_LOSS} = I_{ripple}{}^2 * ESR$
Diode current is calculated by equation
$I_D = (1 - D * I_{load})$
Power dissipation in diode is given by
$P_{DIODE\_LOSS} = V_F * I_D$
A N-channel MOSFET with input voltage 5 V, 1A.load current, $T_{rise} = T_{fall} = 55$ ns, $R_{DS(on)} = 0.02\Omega$, C_{oss}=890pf,
$P_{MOSFET\_conduction\_loss} = (I_D)^2 * R_{ds(hot)} * D$

$$P_{MOSFET\_switching\_loss} = (V * I_D / 2) * (T_{on} + T_{off}) * Fsw + (C_{oss} * V^2 * F_{sw})$$

$$\eta_{converter} = \frac{P_{output}}{P_{output} + P_{total\ loss}}$$

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B. Synchronous Buck Converter

In this converter two MOSFETS are used. The second MOSFET is used in place of diode so that conduction loss is minimized.
Select N-channel MOSFET with $R_{DS(on)}$ = 0.0044 ohm
$P_{MOSFET\text{-}2\_conduction\_loss} = (I_D)^2 * R_{ds(hot)} * (1 - D)$

C. Modified Synchronous Buck Converter

The Lr and Cr are in resonance with each other and help in providing the time delay to minimize the switching losses.

$$C_r = \frac{I_{inmax} T_D (a-1)^2}{V_0 [1 + \frac{\pi(a-1)}{2}]}$$

Current stress factor (a) is between 1 and 1.5

$$L_r = \frac{V_0 T_D}{I_{inmax} [1 + \frac{\pi(a-1)}{2}]}$$

Time Delay T_D=0.1 sec.

IV. SIMULATION RESULTS AND EFFICIENCY COMPARISON

The values chosen for designing buck converter are as follows. Vs= 5volts, Switching frequency = 40kHz, Output voltage (V_{out}) = 1.5 volts, output inductor (L0) = 83.3 µH, output capacitor (C0) = 497 µF, load current 1A, Resistance 8Ω and current ripple is 30% of maximum load current.

A. Buck Converter

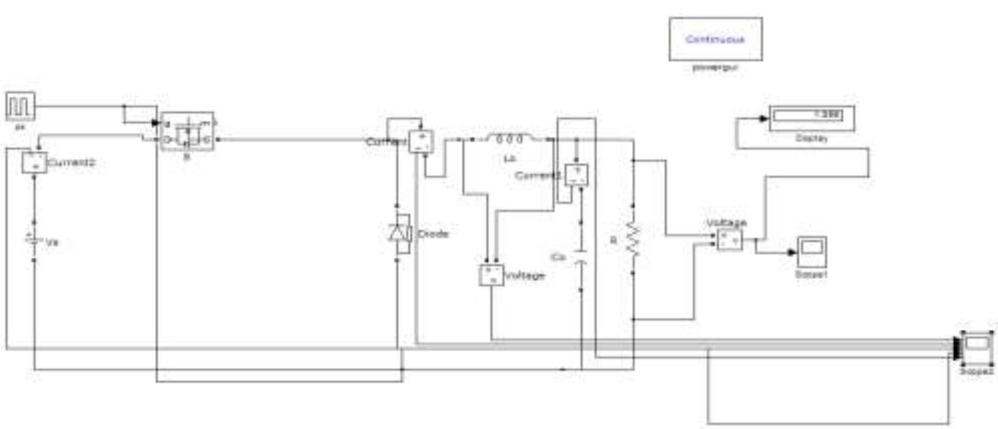

Fig. 4: Buck Converter Simulink Model

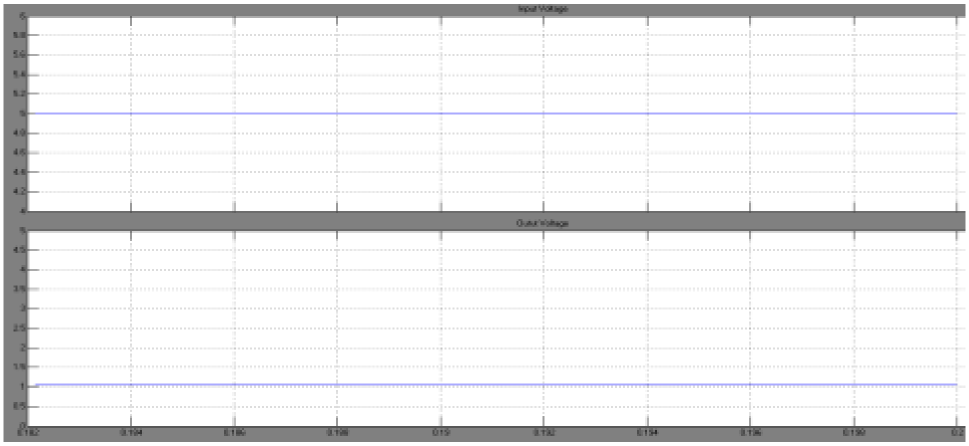

Fig. 5: Waveforms of Input and Output Voltages

As explained in section II the buck converter is a step down converter, the output voltage Vo is less than the input voltage Vs. Simulation of buck converter is carried out for input voltage of 5v, which is shown in fig.4, and the other design parameters are described above[4]. The obtained output voltage in simulation is 1.05v which is shown in fig 5.

B. Synchronous Buck Converter

With the Buck converter for the design parameters described above the output voltage obtained is 1.05V which is lesser than the expected level. To obtain the expected output voltage 1.5V, Synchronous Buck Converter is simulated [6]. Simulation of Synchronous Buck converter is carried out for input voltage of 5v. The obtained output voltage in simulation is 1.49V which is shown in fig 7. In Synchronous Buck Converter the switches S and S1 work in complementary mode which is shown in fig 6.

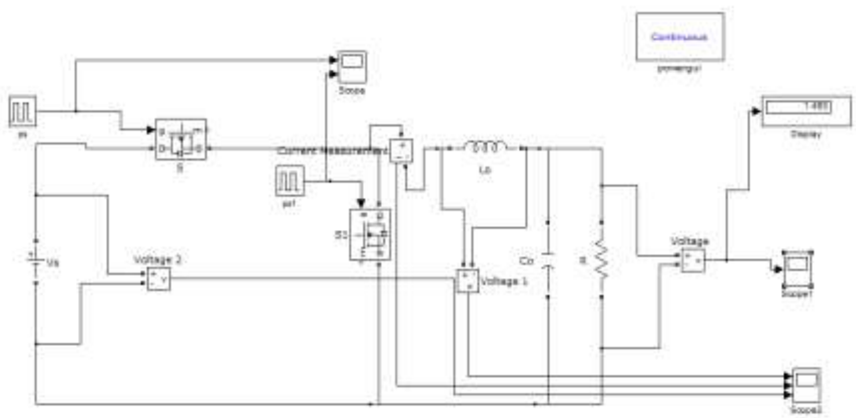

Fig. 6: Synchronous Buck Converter Simulink Model

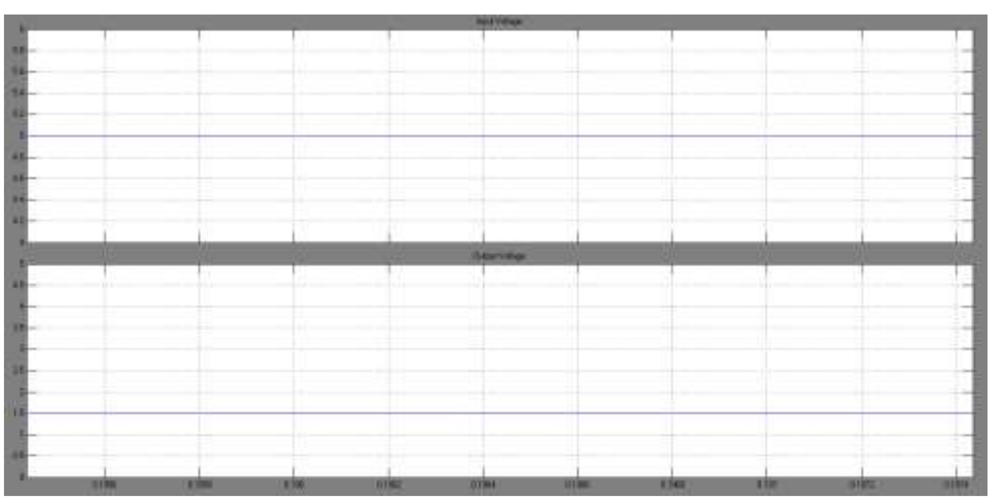

Fig. 7: Waveforms of Input and Output Voltages

C. Modified Synchronous Buck Converter

The values chosen for the simulation of modified synchronous buck converter are as follows. Vs= 5volts, switching frequency = 40kHz, Output voltage (V_{out}) = 1.5 volts, resonant capacitor (Cr) =0.1µF, resonant inductor (Lr) = 0.3 µH, capacitor in parallel to main switch S (Cs) = 0.05nF, output inductor (L0) = 83.3 µH, output capacitor (C0) = 497 µF, load current 1A and current ripple is 30% of maximum load current[6]. The simulation is done in MATLAB-Simulink environment. Fig 8 shows the simulink model of modified synchronous buck converter[2].

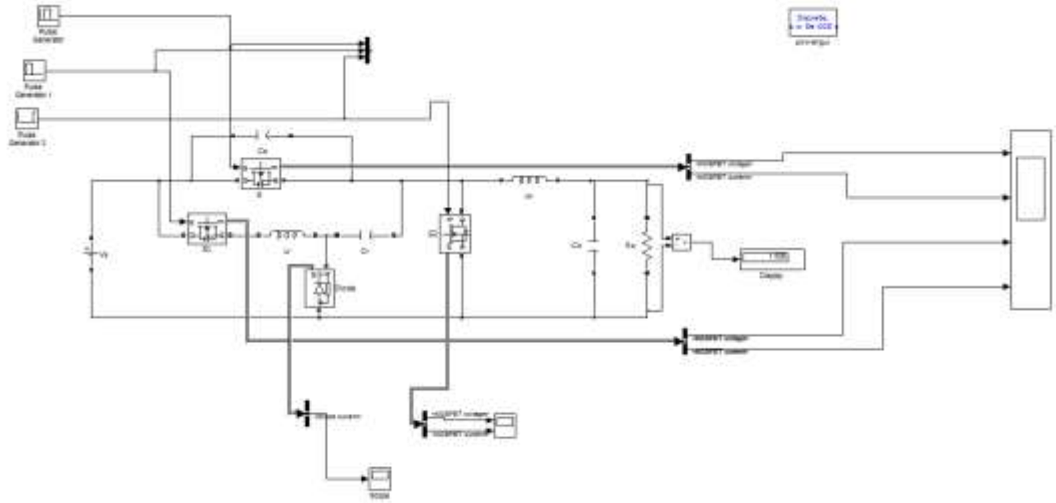

Fig. 8: Modified Synchronous Buck Converter Simulink Model

Simulation of Modified Synchronous Buck converter is carried out for input voltage of 5v. The obtained output voltage in simulation is 1.5V which is shown in fig 9.

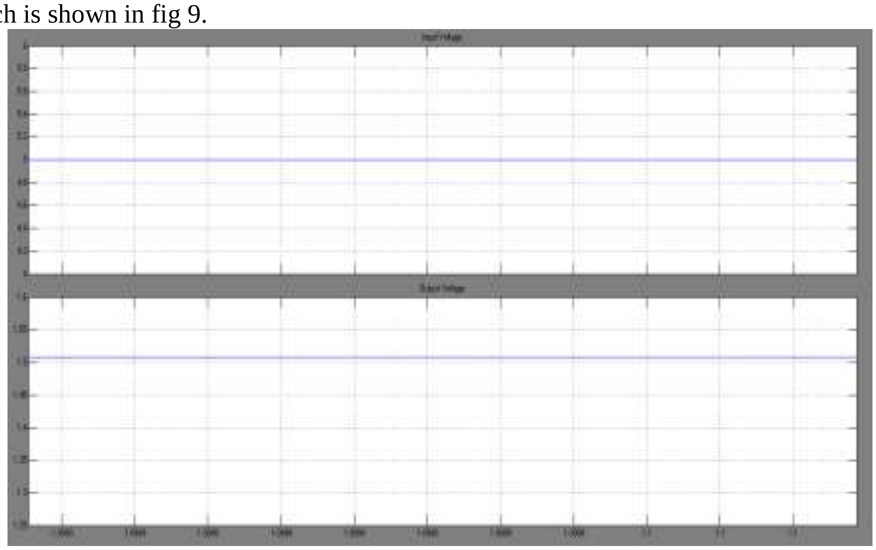

Fig. 9: Wave forms of Input and Output Voltages

Table - 1
Efficiency Comparison of Buck, Synchronous Buck and Modified Synchronous Buck Converter

Type of Converter	*Input Voltage*	*Output Voltage*	*Efficiency*
Buck Converter	*5V*	*1.05V*	*77%*
Synchronous Buck Converter	*5V*	*1.49V*	*89%*
Modified Synchronous Buck Converter	*5V*	*1.5V*	*91%*

V. CONCLUSION

The operation and the design of Buck Converter, Synchronous buck converter and Modified synchronous buck converter are studied [7]. The above three converters are simulated in MATLAB-Simulink environment with the Switching Frequency of 40 KHz. As we know all the three converters are step down converters. In the case of step down converters the output voltage should be less than input voltage [3]. Simulation results of all the three converters prove the condition of step down converter. Finally, Comparison in terms of efficiency improvement of the Buck Converter, Synchronous Buck Converter and Modified Synchronous Buck Converter is done with the help of MATLAB-Simulink software which shows that Synchronous Buck Converter and Modified Synchronous Buck Converter is highly efficient than Buck Converter.

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