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Buck Converter using Soft Switching PWM Converter with Current Sharing in Switches

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***Abstract* — Buck converter using a soft switching PWM converter is analyzed and simulated here in this paper. The buck converter consists of two switches which shares the output current and provide soft switching condition for each other. These switches operate out of phase with each other. A conventional PWM circuit is used to provide control for the soft switching converter circuit.**

***Keywords*-soft switching, hard switching, Zero voltage switching, zero current switching, DC converters, buck converter.**

I. INTRODUCTION

Power switches have to cut off the load current with in the turn off and turn on times under the hard switching conditions. Hard switching refers to stressful switching behavior of the power electronic devices. However, stresses on devices are heavily influenced by the switching frequencies accompanied by their switching losses. The switching loss is proportional to the switching frequency, thus limiting the maximum switching frequency of the power converters. It is obvious that switching-aid-networks do not mitigate the dissipation issues to a great extent. Soft switching techniques use resonant techniques to switch ON at zero voltage and to switch OFF at zero current. The reduction of switching loss and the continual improvement of power switches allow the switching frequency of the resonant converters to reach hundreds of kilo-Hertz (typically 100kHz to 500kHz). Unlike the resonant converters, new soft-switched converters usually utilize the resonance in a controlled manner. Resonance is allowed to occur just before and during the turn-on and turn-off processes so as to create ZVS and ZCS conditions. The two basic configurations such as Zero current switching and Zero voltage Switching. In a ZC resonant switch, an inductor L_r is connected in series with a power switch S in order to achieve zero-current-switching (ZCS). The resonant switch is said to operate in *half-wave* mode. If a diode is connected in anti-parallel with the unidirectional switch, the switch current can flow in both directions. In this case, the resonant switch can operate in *full-wave* mode. At turn-on, the switch current will rise slowly from zero. It will then oscillate, because of the resonance between L_r and C_r. Finally, the switch can be commutated at the next zero current duration. The objective of this type of switch is to shape the switch current waveform during conduction time in order to create a zero-current condition for the switch to turn off. In a ZV resonant switch, a capacitor C_r is connected in parallel with the switch S for achieving zero-voltage-switching (ZVS). If the switch S is a unidirectional switch, the voltage across the capacitor C_r can oscillate freely in both positive and negative half-cycle. Thus, the resonant switch can operate in *full-wave* mode. If a diode is connected in anti-parallel with the unidirectional switch, the resonant capacitor voltage is clamped by the diode to zero during the negative half-cycle. The resonant switch will then operate in *half-wave* mode. The objective of a ZV switch is to use the resonant circuit to shape the switch voltage waveform during the off time in order to create a zero-voltage condition for the switch to turn on. Buck converter with a soft switching PWM converter is analyzed and simulated in this paper. The buck converter circuit diagram and operation is explained in the second session. In the third session Control circuit for the soft switching cell in explained. Simulation diagram and simulation design are explained in the fourth and fifth session.

II. CIRCUIT DIAGRAM AND OPERATION

The buck converter is the most widely used dc-dc converter topology in power management and microprocessor voltage-regulator (VRM) applications. Those applications require fast load and line transient responses and high efficiency over a wide load current range. They can convert a voltage source into a lower regulated voltage. For example, within a computer system, voltage needs to be stepped down and a lower voltage needs to be maintained. For this purpose the Buck Converter can be used . Furthermore buck converters provide longer battery life for mobile systems that spend most of their time in “stand-by”. Buck regulators are often used as switch-mode power supplies for baseband digital core and the RF power amplifier (PA). Fig 1 shows the buck converter consisting of soft switching cell which consists of two switches S_1 and S_2 which shares the output current and provide soft switching condition for each other. There are two coupled inductors L_1 and L_2 and two diodes D_1 and D_2.The turns ratio for inductor is 1:n. The circuit also consists of Buck inductor L and filter capacitor C. The snubber capacitor for S_2 is Cs.

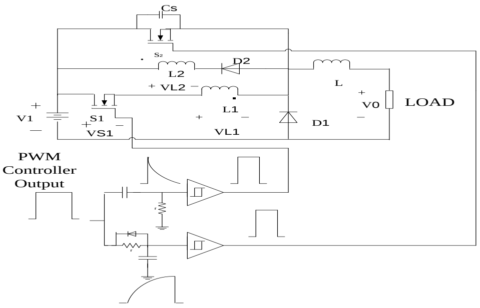

Fig.1 Soft-Switching buck converter

The theoretical waveforms of soft switched buck converter are shown in Fig. 2. Assumptions are Cs is charged to input voltage V_1, D_1 Diode is conducting and all other semiconductor devices remains turned off before starting. The input voltage V_1 is assumed constant and buck converter has seven different operating intervals. Interval { t_0-t_1} : In this interval switch S1 is turned on. When switch S1 is on input voltage is placed across the inductor L_1. Inductor L_1 current starts increasing Inductor L_1 current during this interval is given by

$$I_{L1}(t)=\frac{V_1(t-t_0)}{L_1} \qquad (1)$$

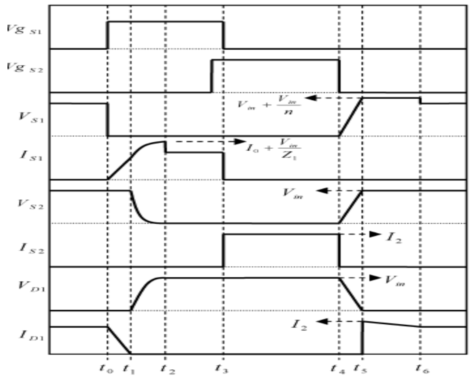

Fig. 2. Theoretical waveform of Buck Converter [1]

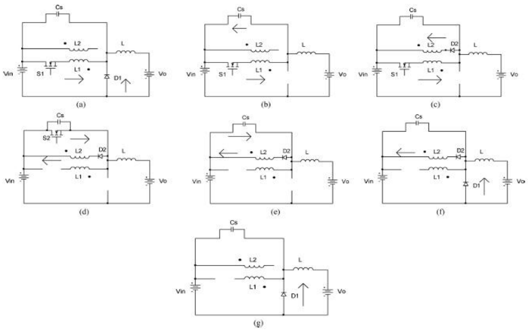

Fig.3 Equivalent circuit of each operating interval [1]

Voltage stress across diode D_2 during this interval is

$$V_{D2}=(n+1)V_1 \qquad (2)$$

From eqn. (1) it is clear that S_1 is turned on at zero current switching condition. At the end of first interval current across inductor L_1 reaches Io and diode D_1 is turned off under *zero current condition*

Interval { t_1-t_2} : During this interval resonance starts between inductor L_1 and snubber capacitor Cs. The capacitor Cs begins to discharges to zero voltage Capacitor Cs voltage and inductor L_1 currents are

$$I_{L1}(t)=I_0+\frac{V_1}{Z}\sin(\omega_1(t-t_1)) \qquad (3)$$

$$V_{Cs}(t)=V_1\cos(\omega_1(t-t_1)) \qquad (4)$$

where

$$Z=\sqrt{\frac{L_1}{C_s}} \qquad (5)$$

$$\omega_1=\frac{1}{\sqrt{L_1C_s}} \qquad (6)$$

Interval { t_2-t_3} : During this interval Diode D_2 conducts. The voltage across L_2 is n(V_{Ds1}+V_{BD2}) and voltage across D_2 is nV_{Ds1}+ (n+1)V_{BD2}thus D_2 is forward biased and conducting. In this interval S_1 is ON. The switch S_2 can be turned off at ZV-ZC conditions because current across L_1 remains constant and no current flows through the switch S_2.Equqtion for Inductor currents I_{L1} and I_{L2} during this interval is given by

$$I_{L1}=I_0+\frac{V_1}{(n+1)Z} \qquad (7)$$

$$I_{L2}=\frac{V_1}{(n+1)Z} \qquad (8)$$

Interval { t_3-t_4} : During this interval switch S_1 is turned off under zero voltage condition Inductors L_1 and L_2 has small leakage inductor. So when switch S1 is off this energy is absorbed by S_1 output capacitor therefore a small voltage appears across S_1 and it turns off at almost zero voltage condition. Current across switch S_2 and inductor L_2 is given by.

$$I_{L2}=\frac{I_0}{n}+\frac{V_1}{nZ}$$

(9)

$$I_{S2}=I_0+I_1$$

(10)

Interval { t_4-t_5} : During this interval switch S_2 is turned off. Capacitor Cs starts charging to input voltage V_1 with current I_{s2}. Current across inductor L_2 is almost constant.

$$t_5-t_4=\frac{V_1C_S}{I_{S2}}$$

(11)

Interval { t_5-t_6} : During this interval Diode D_1 begins to conduct. When D_1 conducts supply voltage V_1 is placed across Inductor L_2 until its current reduces to zero.

$$t_6-t_5=\frac{L_2I_{L2}}{V_1}$$

(12)

Interval { t_6-t_0+T} : During this interval Diode D_1 starts conducting and circuit operates as a regular buck converter.

III. CONTROLLER CIRCUIT

Conventional PWM circuit is adopted for controlling the converter. Schematic diagram of controller is shown in Fig 1 along with soft switching buck converter. Circuit consist of a derivative circuit, integrator circuit and Schmitt trigger buffer circuit. Output of the conventional PWM controller is applied to the derivative circuit. Output of derivative circuit is then applied to Schmitt trigger buffer. By tuning derivative elements Schmitt trigger produces a pulse with maximum duration (DmaxT/2) where Dmax is converter maximum operating duty cycle. This pulse is applied to the switch S_1. For controlling the switch S2 output of conventional PWM converter is applied to integrator circuit and then to Schmitt trigger buffer . By tuning the integrator elements the output of this buffer is a pulse with maximum duration of (DmaxT/2) and delay of (DmaxT/2). This pulse is a proper pulse for S2 . With this circuit, at converter nominal duty cycle, two pulses with equal duration are applied to the switches and output current is equally shared between the switches. At lower operating duty cycles, the duration of S2pulse is decreased while duration of pulse remains equal to (DmaxT/2). With this circuit, the conventional PWM controllers can be simply adopted for controlling the proposed converter

IV. SIMULATION CIRCUIT

Simulation circuit for a buck converter with input voltage 100V and output voltage of 40V is shown in Fig 4. The value of this inductor is calculated as 100 µH according to [7] considering 2A ripple current. The value of output ripple capacitor is taken as 50 µF to maintain ripple voltage less than 0.2V. The filter inductor and filter capacitor are designed like a regular PWM buck converter. . Therefore, it is important to select L_1,C_S ,n , and semiconductor devices. C_S is the snubber capacitor of S_2 and its value can be calculated like any turn-off snubber [7]. L_1 is the turn-on snubber of S_1 and its value can be calculated like any turn-on snubber [7].

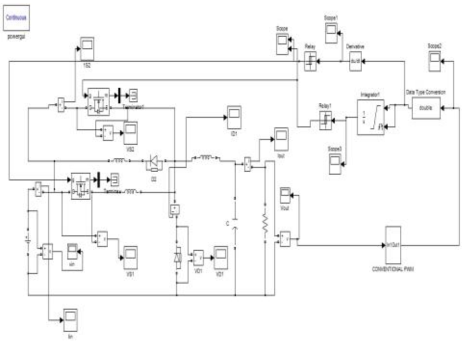

Fig.4 Simulation of soft switching buck converter

Minimum value of L1 and Cs are calculated as 0.8 µH and 1.8 nF. However, in order to clearly verify the achieved soft-switching condition, a 10-nF capacitor is used for C_s and a 10 µH inductor is used for L_1. In an ideal buck converter with aforementioned input and output voltage levels and switching frequency, the switch is ON for 4 µs and is OFF for 6 µs. Since 0.5 µs of the duty cycle is lost due to in the first interval, so the switch-on time should be 4.5 µs. Also, considering 90% efficiency for the converter at the worst case condition and input voltage ripple, the maximum switch-on time is approximately 5 µs. Therefore, according to (14) , with the selected value of n, is limited to 7. In theoretical analysis, it was predicted that S_2 current remains zero until S_1 is turned off. However, in practice due to conducting voltage,S_2 current has increased before S_1 is turned off and S_1 current does not remain constant as specified in the third interval. This is a desirable effect since it decreases the converter circulating current and also reduces the L_1 leakage inductance energy. The simulation wave forms are as shown in fig. 5.

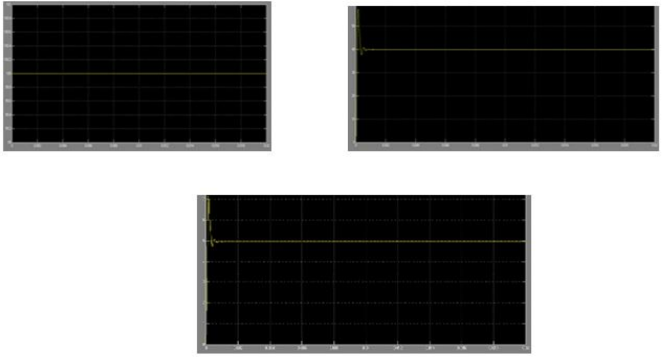

Fig 5. Input Output and Inductor current

V. SIMULATION DESIGN

The main purpose of designing is to find value of the components used. The main components of the circuits are buck inductor, capacitor, load and switch in this case it is the proposed converter.

Specifications
Input Voltage =100V
Output Voltage=40V
Switching Frequency=100kHz
Load = Resistive Load=50Ω
Vr=output voltage ripple
Iripple=Output current ripple

$$D = \frac{V_0}{V_1} \quad (13)$$

Where D= duty ratio

$$L = \frac{(V_1 - V_0)}{I_{ripple} \times f_S} \quad (14)$$

$$C = \frac{(1-D) \times V_0}{8 \times V_r \times f^2 \times L} \quad (15)$$

$$I_P = \frac{3.13 \times P_0}{V_1} \quad (16)$$

Where P_0= Maximum output power

$$C_S = \frac{I_P \times t_f}{2 \times V_1} \quad (17)$$

Where
I_P=Peak switching current
C_S=Snubber Capacitor
t_f= Fall time

$$\Delta V_1 = \frac{L_1 \times I_0}{t_{ri}} \quad (18)$$

where,
ΔV_1= Fall in input voltage during turn on

t_r = Rise time of S_1

$$L_1 = \frac{\Delta V_1 \times t_{ri}}{I_0} \qquad (19)$$

VI. CONCLUSION

In this paper, a soft-switching PWM buck converter was analyzed and simulated. It is consists a soft switching switch cell that can be applied in dc–dc converters instead of their switch. This switch cell is composed of two switches that provide soft- switching condition for each other. Furthermore, the converter output current can be shared between the switches. The operation of the proposed converter was explained in detail in the paper and general guidelines for the design of the converter were given. The efficiency of soft switched buck converter is more than that of a regular buck converter because of soft switching feasibility of the new buck converter is thus confirmed.

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AUHTOR’S PROFILE

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