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 provides 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 Lr 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 Lr and Cr. 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 Cr 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 Cr 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” mode. Buck regulators are often used as switch-mode power supplies for device digital core and the RF power amplifier (PA). Fig 1 shows the buck converter consisting of soft switching cell which consists of two switches S1 and S2 which shares the output current and provide soft switching condition for each other. There are two coupled inductors L1 and L2 and two diodes D1 and D2. The turns ratio for inductor is 1:n. The circuit also consists of Buck inductor L and filter capacitor C. The snubber capacitor for S2 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 \( V_1 \), D1 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

\[
I_{L1}(t) = \frac{V_1(t - t_0)}{L_1} \quad (1)
\]

Interval \( \{ t_1-t_2 \} \) : During this interval resonance starts between inductor \( L_1 \) and snubber capacitor \( C_s \). The capacitor \( C_s \) starts discharging to zero voltage Capacitor \( C_s \) voltage and inductor \( L_1 \) currents are

\[
I_{L1}(t) = I_0 + \frac{V_1}{Z} \sin(\omega_2 (t - t_1)) \quad (3)
\]

\[
V_{C_s}(t) = V_1 \cos (\omega_2 (t - t_1)) \quad (4)
\]

where

\[
Z = \sqrt{\frac{L_1}{C_s}} \quad (5)
\]

\[
\omega_2 = \frac{1}{\sqrt{L_1C_s}} \quad (6)
\]

Interval \( \{ t_2-t_3 \} \) : During this interval Diode \( D_2 \) conducts. The voltage across \( L_2 \) is \( n(V_{in1}+V_{in2}) \) and voltage across \( D_2 \) is \( nV_{in1}+(n+1)V_{in2} \) 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 \( S_2 \). Equation for Inductor currents \( I_{L1} \) and \( I_{L2} \) during this interval is given by

\[
I_{L1} = I_0 + \frac{V_1}{(n+1)Z} \quad (7)
\]

\[
I_{L2} = \frac{V_1}{(n+1)Z} \quad (8)
\]

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 \( S_1 \) 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

\[
I_{L2} = \frac{I_0}{n} + \frac{V_1}{nZ} \quad (9)
\]

\[
I_{S2} = I_0 + I_1 \quad (10)
\]

Interval \( \{ t_4-t_5 \} \) : During this interval switch \( S_2 \) is turned off. Capacitor \( C_s \) starts charging to input voltage \( V_1 \) with current \( I_{L2} \). Current across inductor \( L_2 \) is almost constant.

\[
t_5 - t_4 = \frac{V_1 C_s}{I_{S2}} \quad (11)
\]

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.

\[
t_6 - t_5 = \frac{L_2 I_{L2}}{V_1} \quad (12)
\]

Interval \( \{ t_6-t_7+T \} \) : 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 S1. 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 S2 pulse 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 L1, Cn, and semiconductor devices. Cn is the snubber capacitor of S2 and its value can be calculated like any turn-off snubber [7]. L1 is the turn-on snubber of S1 and its value can be calculated like any turn-on snubber [7].

![Fig 4 Simulation of soft switching buck converter](image)

**Specifications**

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

**Formulas**

1. \[ D = \frac{V_o}{V_i} \] (13)

   - Where D= duty ratio

2. \[ L = \frac{(V_i - V_o)}{I_{ripple} \times f_S} \] (14)

3. \[ C = \frac{(1 - D) \times V_o}{8 \times V_i \times f^2 \times L} \] (15)

4. \[ I_p = \frac{3.13 \times P_o}{V_i} \] (16)

   - Where \( P_o \) = Maximum output power

5. \[ C_s = \frac{I_p \times t_f}{2 \times V_i} \] (17)

   - Where

   - \( I_p \) = Peak switching current

   - \( C_s \) = Snubber Capacitor

   - \( t_f \) = Fall time

6. \[ \Delta V_i = \frac{L_i \times I_o}{I_{ri}} \] (18)

   - Where

   - \( \Delta V_i \) = Fall in input voltage during turn on
\[ t_r = \text{Rise time of } S_1 \]

\[ L_s = \frac{\Delta V_s \times I_{s0}}{I_0} \quad (19) \]

**VI. CONCLUSION**

In this paper, a soft-switching PWM buck converter was analyzed and simulated. It consists of 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.

**REFERENCES**


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