A ZERO CURRENT SWITCHING RESONANT BUCK CONVERTER

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Abstract - In this paper a zero current switching auxiliary circuit used for soft switching of DC-DC buck converter is presented. Buck converters are high frequency dc-dc converters operating on PWM principle. The switching devices are made to turn on and turn off the entire load current at high di/dt and withstands high voltage stress across them. This propels the need for soft switching techniques which provides an effective solution and eliminates electromagnetic interference. The proposed model of zero current switching (ZCS) resonant buck converter is simulated in matlab/Simulink. The performance of the converter is improved by introducing PID controller and fuzzy logic controller. The ZCS buck converter obtained has achieved improved efficiency along with reduced ripple output. The feasibility of circuit is confirmed by waveforms that were found to be in precise proximity of the theoretical waveforms.

Keywords - Buck converter, Soft switching, Zero current switching.

I. INTRODUCTION

Buck converter is a step down DC-DC converter that is widely being used in different electronic devices like laptop, PDAs, cell phones and also in electric vehicles to obtain different levels of voltages. A few applications of DC-DC converters are where 5V DC on a personal computer motherboard must be stepped down to 3V or less. In all of these applications, power conversion is required retaining high efficiency as much as possible. The main advantage of switching regulators is that the energy stored by inductor and capacitor can be transformed to output voltage that can be less than the input, can be greater than the input. These converters essentially just change the input energy into a different impedance level. However, the higher input voltages and lower output voltages have brought about very low duty cycles, increasing switching losses and decreasing conversion efficiency. Power switches have to cut off the load current within the turn-on and turn-off times under the hard switching conditions.

Hard switching techniques refer to the stressful switching behaviour of the power electronic devices. So, the efficiency of buck converter is improved by adopting soft switching techniques and thus minimizing the switching losses. Soft switching is achieved by reducing the switch current or voltage to zero just before the switching instants and thus the switching losses would be reduced to zero. If the switch voltage is reduced to zero at switching instants, it is commonly called zero-voltage switching (ZVS) and if the switch current is reduced to zero it is called zero-current switching (ZCS). The major limitation in ZVS technique is that a large external resonating capacitor is needed to lower the turn off switching loss. Conversely zcs eliminates the voltage and current overlap by forcing the switch current to zero before the switch voltage rises, making it more effective than zvs in reducing losses.

This paper introduces a new auxiliary circuit for buck converter to provide ZCS condition. Soft switching is achieved by reducing the switch current to zero just before switching instants and thus the switching losses would be reduced to zero. The gate driver circuit for the switch is controlled by PID controller and Fuzzy logic controller.

II. PROPOSED ZERO CURRENT SWITCHING BUCK CONVERTER

In this section the proposed converter is introduced and analyzed. Consider the buck converter circuit shown in fig 1.

![Circuit diagram of proposed converter](image)

Mode 1(t1-t2): Initially, \( S_m \) is turned on and \( C_r \) charges through a resonance with \( L_m \). Also, during this mode, power is transferred from input to output.

Mode 2(t2-t3): At \( t_2 \), \( I_{L_m} \) has reached zero and \( S_m \) can be turned off under ZCS. In this mode, the resonance voltage stays constant equal to \( 2V_s-V_{out} \). Because of the topology structure this interval can be eliminated.
Mode 3\((t_3-t_4)\): At \(t_3\), \(S_a\) is turned on and a resonance between \(C_r\) and \(L_a\) until its voltage reaches the output voltage.

Mode 4\((t_4-t_5)\): At \(t_4\), diode D is turned on and \(L_a\) energy is transferred to the load and its current linearly decreases to zero. The voltage across \(C_r\) remains constant and equal to \(V_{out}\).

Mode 5\((t_5-t_6)\): At \(t_5\), \(S_a\) can be turned off under ZCS. In this interval the load is supplied by output capacitor. All the equivalent circuits corresponding different modes are shown in fig 2.

At steady state condition, the converter voltage gain can be calculated by considering the converter efficiency equal to 100%. In this converter, energy is absorbed from the input source only in the first interval. Thus, the voltage gain can be calculated using this fact. For the first interval the following relations can be derived.

\[
E_{in} = \int_{t_1}^{t_6} V_s I_{Lm} \, dt = 2C_r V_s^2
\]

\[
E_{out} = \frac{V^2_{out} T}{R}
\]

\[
E_{in} = E_{out}
\]

\[
A = \frac{E_{out}}{E_{in}} = \sqrt{\frac{2R}{C_r}}
\]

From buck converter design rules,

\[
\frac{\Delta V}{\Delta t} = \frac{V_s (1 - D)}{t_{on} - D_{on} - t_{off}}
\]

\[
C_m = \frac{\Delta I}{\Delta V}
\]

By increasing the frequency, the power transferred ascends, but the frequency is limited to the two resonant periods.
\[ T_{\text{min}} = a_{\text{min}} + a_{\text{max}} = \pi \sqrt{L \frac{C_{\text{r}}}{r}} + \pi \sqrt{L_{\text{aux}} \frac{C_{\text{r}}}{r}} = \frac{1}{f_{\text{max}}} \] (7)

The input and output voltages of the proposed converter are 100V and 50V respectively. The output current is about 1.2A. The switching frequency is about 25KHZ. The main and auxiliary inductors are about 2.77mH and 0.28mH. The resonant capacitor is 0.12µF. The output filter capacitor is chosen as 50µF for 1% ripple in output voltage.

2.1 DESIGN OF CONTROL CIRCUIT USING PID CONTROLLER:
The reference voltage is the desired output voltage that is 50V. Vout is the output voltage of the converter which is less than 50V. The output is fed back to the summing point and an error signal is generated. The PID controller modifies the error and generates a steady output signal. This signal is compared with the repeating sequence which is a saw tooth wave. During one switching cycle the amplitude of output signal of PID controller is less than that of amplitude of repeating sequence the outcome would be a high state pulse. During next switching cycle the amplitude of output signal of PID controller is greater than that of amplitude of repeating sequence the outcome would be low state pulse. Thus an on-going pulse and off-going pulse is formed. This signal fed to gate terminal of the IGBT and this drives main circuit. The switch of the auxiliary circuit is driven by applying NOT gate to the signal at gate terminal of IGBT in the main circuit.

2.2 DESIGN OF CONTROL CIRCUIT USING FUZZY LOGIC CONTROLLER:
The derivation of the fuzzy control rules is heuristic in nature and based on the following criteria [15]:
(1) When the output of the converter is far from the set point, the change of duty cycle must be large so as to bring the output to the set point quickly.
(2) When the output of the converter is approaching the set point, a small change of duty cycle is necessary.
(3) When the output of the converter is near the set point and is approaching it rapidly, the duty cycle must be kept constant so as to prevent overshoot.

2.2.1 MEMBERSHIP FUNCTIONS:
The membership function is a graphical representation of the magnitude of participation of each input. It associates a weighting with each of the inputs that are processed, define functional overlap between inputs and ultimately determines an output response. The rules use the input membership values as weighting factors to determine their influence on the fuzzy output sets of the final output conclusion. Once the functions are scaled and combined, they are defuzzified into a crisp outputs which drives the system.

Three continuous membership functions are chosen to model, analyze and simulate the fuzzy controller. It has been defined taking into account the conditions of normality and convexity of fuzzy sets. It embodies the mathematical representation of membership in a set and is required to have uniform shapes, parameters and functions for the sake of computational efficiency [16]. The membership functions for the input and output are shown in figure (5).

2.2.2 DEVELOPMENT OF RULE BASE:
The collection of rules is called a rule base and it expresses input output relationship in linguistic terms. They are typically written as antecedent – consequent pairs of IF THEN structure and the inputs are combined by AND operator. The antecedent (condition part) and consequent (operation part) are the description of process state and control output respectively in terms of logic combination of a fuzzy propositions. The generic linguistic control rule has the form as IF x is A AND y is B THEN z is C where x, y are the input linguistic variables and z is output linguistic variables. 49 rules as shown in table are formed depending on the number of membership functions to play a key role in the improvement of system performance [15]. NB (Negative Big), NM (Negative Medium), NS (Negative Small), ZE (Zero), PS (Positive Small), PM (Positive Medium), and PB (Positive Big) [15].

**III. SIMULINK MODELS AND RESULTS:**

![Fig. 7: Open loop model for ZCS buck converter](image1)

![Fig. 8: Input voltage, output current and output voltage of open loop ZCS buck converter](image2)

![Fig. 9: Voltage and current of the main switch](image3)

![Fig. 10: Voltage and current of the auxiliary switch](image4)
A Zero Current Switching Resonant Buck Converter
COMPARISON OF PERFORMANCE OF BUCK CONVERTER WITH PID AND FUZZY LOGIC CONTROLLER

It is clear that the settling time with fuzzy logic controller is less than the settling time with PID controller. The ripple content gets reduced with fuzzy logic controller. The main switch Sm and auxiliary switch Sa achieved the ZCS condition.

CONCLUSION:

Summing up in simple terms, soft switching techniques not only reduces the switching losses but also allows the switching frequency be typically 100-500 KHz. In these soft switched converters resonance is allowed to occur just before and during the turn-on and turn-off processes so as to ensure ZVS and ZCS conditions. For high efficiency power conversion, the ZCS topologies are most frequently adopted. The performance of the proposed converter is improved by PID controller and fuzzy logic controller.

REFERENCES:


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