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Digital Simulation of Push-Pull Multi-Output Resonant Converter

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ABSTRACT

Digital components requiring different voltages are present, which has increased the demand for multiple output power distribution systems with tight load regulation. In aerospace applications allowable size and weight are highly restricted. Therefore high switching frequency is required to reduce the converter size. In this paper, a detailed analysis and design of push-pull multi-output resonant converter has been carried out. The proposed converter is suitable for aerospace applications.

Keywords: push-pull converter, resonant converter, Zero voltage switching.

1. INTRODUCTION

In aerospace applications the allowable size and weight are highly restricted to accommodate greater payload. For minimization of size and weight, high frequency operation of traditional pulse width modulated converters requires a substantial reduction in switching losses. In recent years, number of soft switching technologies has been proposed. Soft switching results in practically zero switching losses and extends the switching frequency to 100s of KHz[3].

Unfortunately switching losses in new circuits can be reduced only at an expense of much increased voltage/current stresses of the switches, which leads to substantial increase in conduction loss [1].Switched-mode power supply being efficient and compact are extensively used in power conversion processes. The analysis, design and modeling processes have all matured in the past three decades. Most of these developments centered around hard switching converters, where the switching frequency was limited to a few 10s of KHz. The present direction of evolution in SMPS is towards higher power density.

In the effort to increase the power density of power supplies, the switching frequency is pushed to high values which, in PWM converter realizations, normally lead to considerable power loss, high switching stresses, reduced reliability, and acoustic noise. Another significant draw- back of the switch-mode operation is the EMI produced due to large di/dt and dv/dt [2].This paper presents the design of multi output push pull ZVS resonant converter. The proposed method reduces the switching losses and size of the converter. Therefore it can be used as high density power supply for aerospace applications.

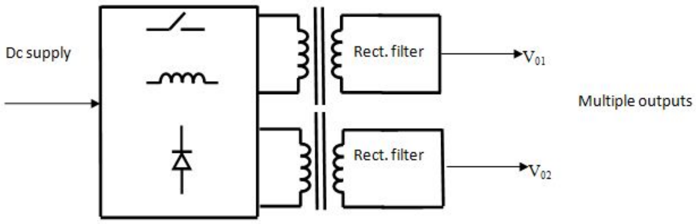

Fig.1.Multipleoutputs by using single power- converter.

2. ANALYSIS OF MULTI-OUTPUT PUSH-PULL ZVS RESONANT CONVERTER

The proposed push-pull topology is basically two forward converters that are connected in anti-phase. It contains two additional resonant tanks that are added in this topology compared to PWM push-pull converter. These resonant tanks shapes the switch voltage, so that the active switches (S1 and S2) are turned on at ZVS. Hence the turn-on losses of the switch will be reduced considerably compared to PWM converters. The circuit has two linear transformers whose primary and secondary windings are arranged in a center-tapped configuration. The push-pull converter operates in two quadrants (I and III) of the B-H curve, see-sawing back and forth as the each primary is activated. This allows the push-pull converter to deliver twice the maximum power than that of a forward converter. This makes the proposed converter effective for medium and high power applications. The different modes of operation are:

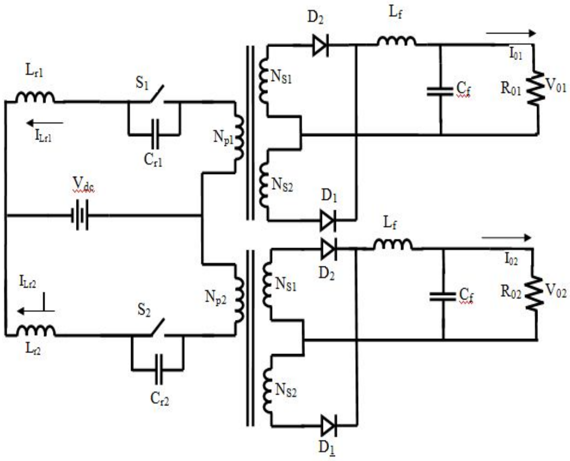

Fig.2 Circuit diagram of multi-output push-pull ZVS-RC.

Following assumptions are made to analyze the steady state behavior

1. Magnetizing inductance is larger than resonating inductance.
2. Reactive current in the elements are ideal.

3. All the semiconductor devices are ideal
4. The output filter C_f and the load R_{01}, R_{02} are a constant sink of current I_{01} and I_{02} respectively.

The following parameters are defined as

1. Characteristic impedance $Z_0 = \sqrt{\frac{Lr}{c_r}}$

2. Resonant angular frequency $W_0 = 1/\sqrt{L_r C_r}$

3. Resonant frequency $f_0=W_0/2п$

4. Normalized load resistance $R = R_L / Z_0$

5. The primary current through primary of transformer (L_m) is $I_{Lr}=I_m$

2.1 *Modes of Operation*

The switch S_1 and S_2 alternatively power their respective windings. The resonating capacitors $C_{r1}$and C_{r2} and resonating inductors $L_{r1}$and $L_{r2}$are used to form the resonant tank. The secondary voltage of the transformer is rectified by fast recovery diodes D_1 and D_2 and filtered to produce a steady ripple free output voltage V_0.

2.1.1 Mode 1: (T_0, T_1)

The switch S_1 is opened for the beginning of a new cycle at t equal to t_o. The current flows through the resonant capacitor (C_{r1}) and resonant inductor (L_{r1}) The capacitor voltage rises linearly from 0 to $2V_{dc}$. The capacitor voltage is given by the equation,

$$V_{cr1}(t) = \frac{I_m t}{2C_r} \tag{1}$$

The switch S_2 opened in the previous cycle is still continued. The capacitor voltage v_{cr2} in the lower part decreases linearly from $2V_{dc}$ to zero $V_{cr2}(t) = 2V_{dc} - \left(\frac{I_m}{2}\right) Z_0 Sin\omega_0 t$

$$i_{Lr2} = -I_m Cos\omega_0 t \tag{2}$$

2.1.2. Mode 2: (t_1, t_2)

The switch S_1 is opened for the beginning of a new cycle is continued. The current flows through the resonant capacitor C_{r1} and resonant inductor L_{r1}The state equations are

$$\frac{dv_{cr1}}{dt}=\frac{i_{Lr1}(t)}{C_{r1}} \tag{3}$$

$$\frac{di_{Lr1}}{dt}=\frac{(2V_{dc}-V_{cr1}(t))}{L_{r1}} \tag{4}$$

The initial conditions are

$$V_{cr1}(0)=2V_{dc} \tag{5}$$

$$i_{Lr1}(0)=\frac{I_m}{2} \tag{6}$$

The solution for the above equations are given by

$$V_{cr1}(t)=2V_{dc}+\left(\frac{I_m}{2}\right)Z_0 Sin\,\omega_0 t \tag{7}$$

$$i_{Lr1}(t)=\left(\frac{I_m}{2}\right)Cos\,\omega_0 t \tag{8}$$

At t equal to t_2, i_{Lr1} reaches zero value and v_{cr1} reaches its peak value. They are given by

$$V_{cr1}(t_2)=2V_{dc}+\left(\frac{I_m}{2}\right)Z_0 \tag{9}$$

The switch S_2 is turned on when V_{cr2} become zero at t = t_1, to achieve zero voltage condition. During this stage current i_{Lr2} linearly and reaches the value $I_m/2$ at t = t_2.Thecorresponding stateequation for i_{Lr2} is given by

$$\frac{di_{Lr2}}{dt}=\frac{2V_{dc}}{L_{r2}} \tag{10}$$

The solution of above equation is given by

$$i_{Lr2}=\left(\frac{I_m}{2}\right)Cos\,\omega_0 t \tag{11}$$

2.1.3. Mode 3: (t_2, t_3)

The switch S_1 is opened for the beginning of the new cycle and it is still continued. The current flows through the resonant capacitor $C_{r1}$and the resonant inductor L_{r1} .The state equations are

$$\frac{di_{Lr1}}{dt}=\frac{(2V_{dc}-V_{cr1}(t))}{L_{r1}} \tag{12}$$

$$\frac{dv_{cr2}}{dt}=\frac{i_{Lr1}(t)}{C_{r1}} \tag{13}$$

The initial conditions are

$$V_{cr1}(0)=2V_{dc} \tag{14}$$

$$i_{Lr1}(0)=-\frac{I_m}{2} \tag{15}$$

The inductor current is

$$i_{Lr1}=\left(\frac{I_m}{2}\right)Cos\alpha \tag{16}$$

In this stage the switch in the lower circuit is on

$$\frac{di_{Lr2}}{dt}=\frac{(2V_{dc}-V_{cr2}(t))}{L_{r2}} \tag{17}$$

The initial conditions

$$i_{Lr2}(0)=\frac{I_m}{2} \tag{18}$$

The solution of above equation is given by

$$i_{Lr2}(t)=\left(\frac{I_m}{2}\right)Cos(\omega_0 t) \tag{19}$$

2.1.4. Mode 4: (t_3, t_4)

The switch S_1 is turned on when v_{cr1} become zero to achieve zero voltage condition. During this mode the current i_{Lr1} increases linearly and reaches the value $I_m/2$ at t equal to t_4. The corresponding state equation is

$$\frac{di_{Lr1}}{dt}=\frac{2V_{dc}}{L_{r1}} \tag{20}$$

With initial conditions

$$i_{Lr1}(0)=\left(\frac{I_m}{2}\right)Cos\alpha \tag{21}$$

The inductor current i_{Lr1} (t) is given by the equation

$$i_{Lr1}(t)=\left(\left(\frac{2V_{dc}*t}{L_r}\right)+\left(\frac{I_m}{2}\right)Cos\alpha\right) \tag{22}$$

The switch S_2 is opened at t = t_4. The current flows through resonant capacitor C_{r2}

and the resonant inductor L$_{r2}$.The capacitor voltage rises linearly from zero to $2V_{dc}$ and it is governed by equation

$$V_{cr2}(t) = \frac{(I_m t)}{2C_{r1}} \tag{23}$$

At the end of this mode, a new mode cycle starts.

3. DESIGN

The design parameters are given for a multi-output push-pull ZVS-RC with following specifications:

1. Input voltage -100V dc
2. Outut voltage of secondary-24V
3. Outut voltage of secondary-24V
4. Resonant frequency-31.62KHz
5. Switchingfrequency -1KHz
6. Turns ratio between primary and secondary n1=1,n2=1
7. Characteristics impedance=32Ω
8. The resonant capacitors are assumed to be equal Cr1=Cr2=1μF

4. SIMULATION RESULTS

The circuit shown in Fig.2 is simulated using MATLAB. Fig.3. shows input voltage of 100V dc and current of 15A. Fig .4.Showsthe pulses given to switch1 and switch 2. Fig .5. gives Simulated open loop output waveforms of the voltage 24V and current 30A for secondary1. Fig .6. gives the simulated open loop output waveforms of the voltage 24V and current 30A for secondary2

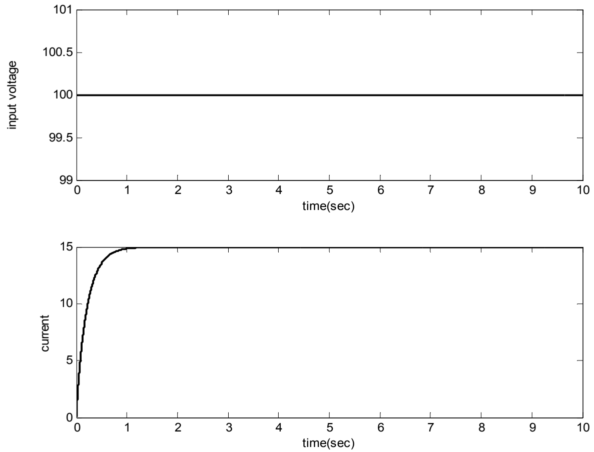

Fig.3. Input voltage and current.

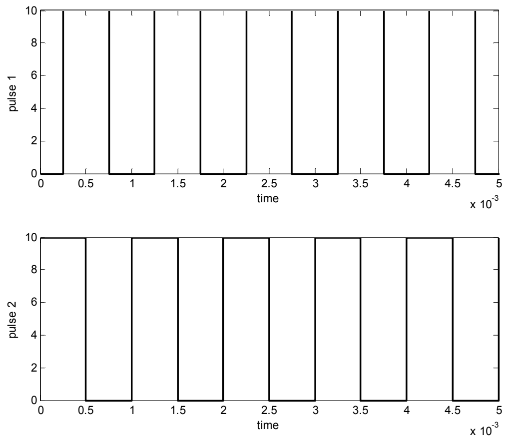

Fig.4.pulses for switch1 and switch2

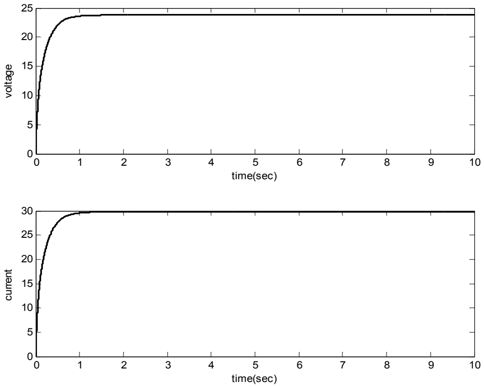

Fig.5.Simulated open loop output wave- forms of the voltage and current for secondary1

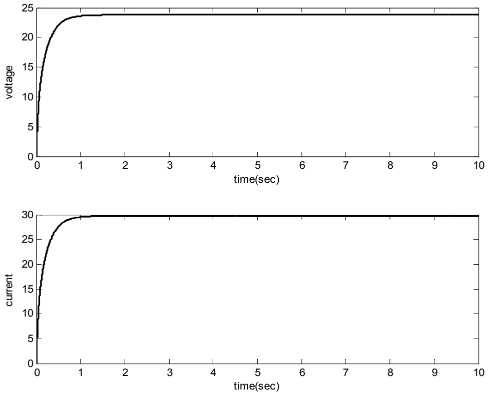

Fig.6.Simulated open loop output wave- forms of the voltage and current for secondary2

5. CONCLUSION

Digital simulation of push pull multi output resonant converter has been presented. The converter rated at 720W, operating at switching frequency of 1kHz has been designed and simulated.With the obtained results it can be proposed that the converter is suitable for high-density and medium power requirement, for example in aerospace

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