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Performance Analysis of DC-DC Converter Zero Current Switching Quasi Resonant Buck Converter Using Fuzzy Controller

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Abstract: Need for DC to DC converter arises on account of the fact that in most situations the source of available power and conditions under which the load demands are incompatible with each other. The quest to develop smaller, lighter and more efficient power converters hassled to design converter circuits capable of operating at higher frequencies and to the development of improved components and innovative packaging. The increasing of frequency is problematic because of direct dependence of switching loss on frequency. However, the use of soft switching technique, ZCS, is an attempt to substantially reduce switching loss and hence attain higher efficiency at increased frequency. DC to DC QUASI RESONANT CONVERTER is a new, high performance power converter and is operated with the technique of soft switching as it is required in many industrial and aerospace applications. It implements zero power consumption operation during switching ON and OFF periods and hence largely reduces the cost and power losses in the converter in order to increase the power density and power transfer efficiency. The resonant tank of this converter consists of only two elements and is operated at the mono resonant frequency in the order of kHz. The converter utilizes only half cycle of the resonant period and is analyzed in steady state. State space averaging technique is then implemented to develop the transfer function and a novel method namely fuzzy logic is used to improve the performance of the system as it has been developed based on the expert knowledge and work on rule base structure.

Key words: GSSA · QRC · ZCS

INTRODUCTION

Power converters are the need of the day, may it be Process control automation, telecommunication, energy conservation or utility related applications and it is highly important to design converter circuits capable of operating at high frequencies owing to ever increasing demand for high reliability and high power density switched mode converters in many industrial and aerospace applications [2]. It is a new soft switching technique, which effectively reduces the power loss and largely increases the power transfer efficiency. Fuzzy logic controller (FLC) has emerged as one of the most active and promising Control methods in the power electronics due to its capability of fast computation with high precision. The fuzzy control systems are based on expert knowledge that converts the human linguistic concepts into an automatic control strategy without any complicated mathematical modeling. Therefore, it naturally provides the ability to deal with the highly nonlinear, time-variant and ill-defined systems where the mathematical models are difficult to be obtained or the control variables are too hard to measure. This makes it well suited in resolving the time-varying nonlinear nature of switches in DC-to-DC converters [3]. In addition, design of fuzzy logic controller is easier than other advanced control methods in that its control function is described by using fuzzy sets and if-then rules rather than cumbersome mathematical equations or large look-up tables. This will greatly reduce the development costs and time.

Generalized State-space Averaging Technique: For the ZCS-QRC buck converter shown in Fig. 1, its four operation modes are shown in Fig. 2,3,4,5, with the following assumptions: 1) L_0 L_r, C_0 C_r 2) switching frequency is much higher than the natural frequency of the low-pass filter L_0-C_0, thus state variables and can be regarded as constant in each switching cycle; and 3) all

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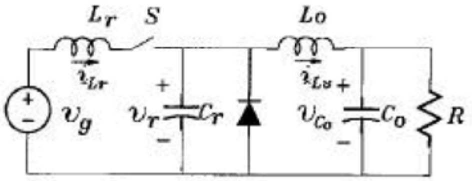

Fig. 1: ZCS - QRC Buck Converter

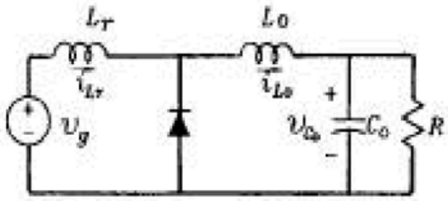

Fig. 2: Inductor Charging Mode

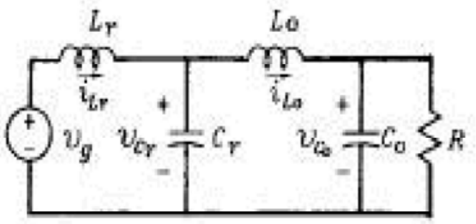

Fig. 3: Resonant Mode

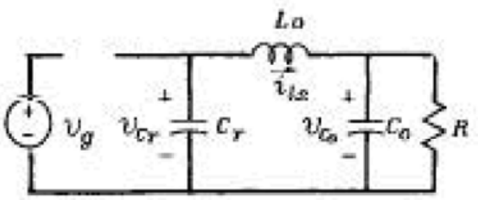

Fig. 4: Capacitor Discharging Mode

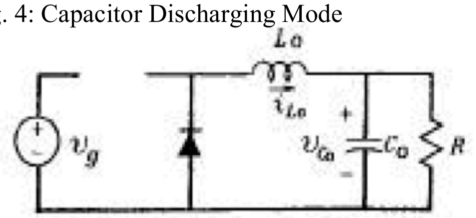

Fig. 5: Free wheeling Mode

the elements including the semiconductor switches are ideal [1]. According to the above discussion, by considering the state variables as those in the low-pass filter, while at the same time considering the state variables in the resonant tank as input variables, we can formulate the corresponding reduced order state equation of the ZCS-QRC buck converter in its four operating modes as follows.

Inductor Charging Stage: The reduced-order state equation of the ZCS-QRC buck converter in this stage is

$$\begin{bmatrix} \frac{dv_{C0}}{dt} \\ \frac{di_{L0}}{dt} \end{bmatrix} = \begin{bmatrix} -\frac{1}{RC_0} & \frac{1}{C_0} \\ -\frac{1}{L_0} & 0 \end{bmatrix} \begin{bmatrix} v_{C0} \\ i_{L0} \end{bmatrix} \qquad \tau_1 = \frac{L_{\Gamma} i_{L0}}{v_g}. \tag{1}$$

where,

Resonant Mode: The reduced-order state equation of the ZCS-QRC buck converter in this stage is

$$\begin{bmatrix} \frac{dv_{C0}}{dt} \\ \frac{di_{L0}}{dt} \end{bmatrix} = \begin{bmatrix} -\frac{1}{RC_0} & \frac{1}{C_0} \\ -\frac{1}{L_0} & 0 \end{bmatrix} \begin{bmatrix} v_{C0} \\ i_{L0} \end{bmatrix} + \begin{bmatrix} 0 \\ \frac{c_{Cr}}{L_0} \end{bmatrix} \tag{2}$$

where,

$$v_{Cr}(t) = v_g(1 - \cos\omega t) \tag{3}$$

$$\tau_2 = \frac{\alpha_i}{\omega} \tag{4}$$

$$\alpha_i = \sin^{-1}\left(-\frac{Z_n i_{L0}}{v_g}\right) \tag{5}$$

$$\omega = 2\pi f_n = \frac{1}{\sqrt{L_r C_r}} \tag{6}$$

$$Z_n = \sqrt{\frac{L_r}{C_r}}. \tag{7}$$

Capacitor Discharging Mode: The reduced-order state equation of the ZCS-QRC buck converter in this stage is equation 8.

$$\begin{bmatrix} \frac{dv_{C0}}{dt} \\ \frac{di_{L0}}{dt} \end{bmatrix} = \begin{bmatrix} -\frac{1}{RC_0} & \frac{1}{C_0} \\ -\frac{1}{L_0} & 0 \end{bmatrix} \begin{bmatrix} v_{C0} \\ i_{L0} \end{bmatrix} + \begin{bmatrix} 0 \\ \frac{v_{Cr}}{L_0} \end{bmatrix} \tag{8}$$

where,

$$v_{Cr}(t) = -\frac{i_{L0}}{C_r}t + V_g(1 - \cos\ \alpha_i) \tag{9}$$

Free wheeling Mode: The reduced-order state equation of the ZCS-QRC buck converter in this stage is equation 10.

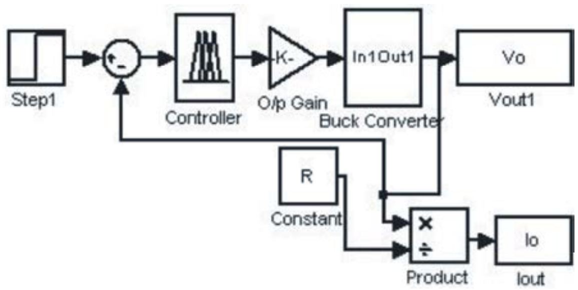

Fig. 6: Proposed fuzzy controller for QRC Buck converter

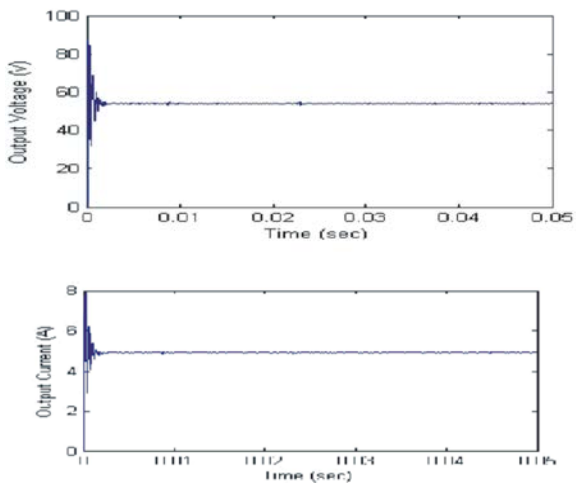

Fig. 7: Case: 1 Minimum Line and Maximum load condition

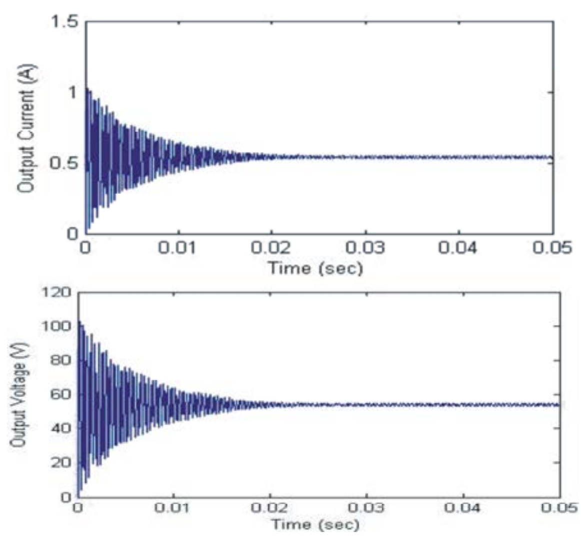

Fig. 8: Case: 2 Minimum Line and Light load condition

$$\begin{bmatrix} \frac{dv_{C0}}{dt} \\ \frac{di_{L0}}{dt} \end{bmatrix} = \begin{bmatrix} -\frac{1}{RC_0} & \frac{1}{C_0} \\ -\frac{1}{L_0} & 0 \end{bmatrix} \begin{bmatrix} v_{C0} \\ i_{L0} \end{bmatrix} \tag{10}$$

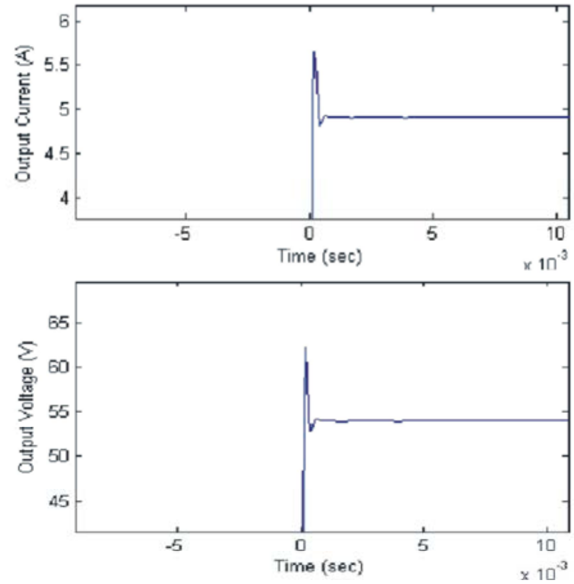

Fig. 9: Case: 1 Minimum Line and Maximum load condition

We can get the input-to-output transfer function of the ZCS-QRC buck converter as,

$$\frac{\vartheta_0}{\vartheta_g} = \frac{M\left(1-\frac{J_i}{H_i}\right)}{s^2 L_0 C_0 + s\left(\frac{L_0}{R} - RC_0\frac{J_i}{H_i}\right) + 1 - \frac{J_i}{H_i}}. \tag{11}$$

Configuration of Fuzzy Controller with ZCS – QRC Buck Converter: A block diagram of fuzzy controller is shown in Figure 5. The dc-dc converters often contain a switched-inductor- function in all modes. The converter modes are referred to as the discontinuous conduction mode (DCM) and the continuous conduction mode whether the inductor current goes to zero or not respectively. The average-value modeling of dc-dc Converters has been a subject of interest in the literature and is often performed by averaging the switching-cell/network (known as the circuit averaging/averaged-switch modeling) or by averaging the state-space equations of the converter system (known as the state-space averaging).

Simulation Results of ZCS-QRC Buck Converter: A fuzzy controller can control system input and output through fuzzy rules. A fuzzy system receives two inputs error and derivative of error based on output voltage of the ZCS – QRC Buck converter. The error input is computed by subtracting the actual output voltage from

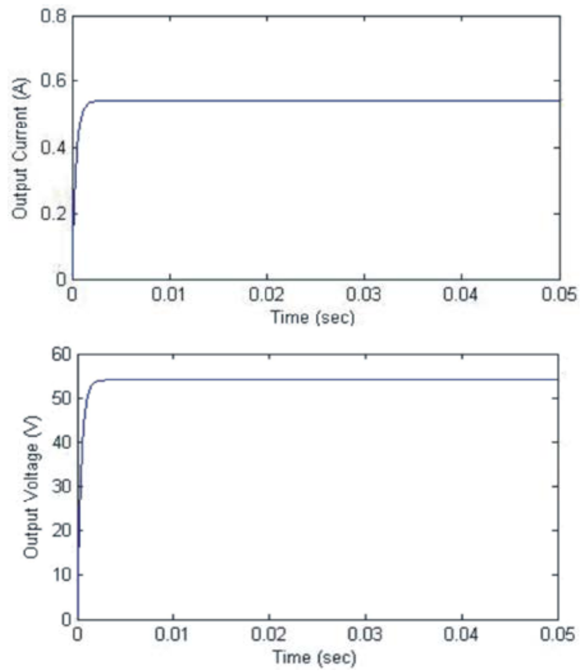

Fig. 10: Case: 2 Minimum Line and Light load condition

the desired voltage and the derivative input, which reflects the rate at which the error changing is computed by previous error from the current error. After pre – processing step, fuzzy processing begins by plugging input values into pre – defined input membership functions to produce fuzzy inputs. This process is called fuzzzification. The simulation results for various load conditions without resonant switching are analyzed with fuzzy controller.

The simulation results for various load conditions with resonant switching are analyzed with fuzzy controller.

CONCLUSION

The GSSA technique with fuzzy controller for the analysis of a class of periodically switched networks with is proposed in the present paper. For the application of GSSA, the ZCS-QRC buck converter has been analyzed. The transient time-domain characteristic analysis results of the ZCS-QRC buck converter simulation approach of QRC's can be analyzed using GSSA. It should also be noted here that due to QRC there is a drastic change in maximum peak overshoot and settling time. In principle, the GSSA technique can be applied to any type of converters and the fundamental GSSA equation can be derived with the same procedure as for QRC's regardless of the type of converters.

DESIGN PARAMETETERS: **Lr=1.6micro H, Cr=0.064micro F,L0=0.2mH,C0=0.02mF**

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