ZCS QUASI RESONANT CONVERTER FED RESISTIVE LOAD EXPERIMENTAL INVESTIGATION

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*Abstract— **This paper deals with the comparison of experimental results with the simulation results ZCS- QRC fed resistive load. Zero current switching quasi resonant converter circuit is designed and then simulated on MATLAB. The hardware implementation of the same circuit is also shown. The voltage and current waveforms are traced and thereafter the experimental results are compared with those of the simulated results. Effects of variation of switching frequency of the MOSFET and input voltage on output voltage of converter are discussed in this paper.***

Keywords— Quasi Resonant Converter, Zero Current Switching, Pulse Width Modulation.

I. INTRODUCTION

Absence of any moving parts in power electronics converters have made them widely used in the industries. They behave as static devices which provide greater efficiency and performance results and their working is easily controllable. Such converters find various applications in AC drives and DC drives such as traction vehicles, cranes, paper mills, textile mills, UPS for critical loads, transformer tap changers, special power supplies for aircraft and space application etc.

In designing switch mode dc-dc converters, the efforts made to increase operating frequency to reduce size, cost, and weight of magnetic and filter elements are constantly hampered by higher switching stresses and switching losses. By incorporating additional inductor and capacitor elements to shape the semiconductor switch's current waveform, a "zero current switching "property can be realized.

II. QUASI RESONANT CONVERTER

Technique called zero current switching was proposed by F C Y Lee et al in the year 1987[1, 4], according to which switch can be turned off at zero current by simply connecting an inductor of appropriate value in series with the switch. If the power switches incorporated in the PWM converters are replaced by resonant switches, this gives rise to a new family of converters known as "Quasi Resonant Converters" (QRC). This new family of converters enjoys advantages of both the techniques PWM as well as resonant converters. Therefore these converters can be viewed as hybrid between PWM converters and resonant converters. They work on the same principle of inductive and capacitive energy storage and power transfer like PWM converters.

The LC resonant tank circuit is present near the power switch, which not only shapes the current waveforms through the power switch and voltage waveform across the device, but it can also store and transfer energy from input to output. The asymmetric half bridge converter has an advantage of high efficiency with fixed input voltage PWM switching [1] – [4]. A new group of quasi resonant converter is given by [5].

Two types zero current switching quasi resonant converters are (a) half wave and (b) full wave as shown in Fig. 1 and Fig. 2. [6, 7, 8].

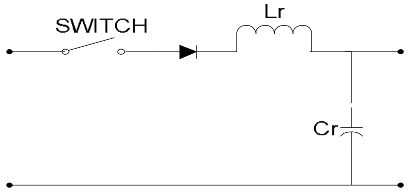

Fig 1 : Half wave ZCS-QRC

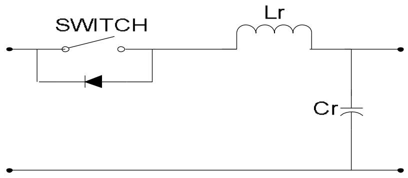

Fig 2 : Full wave ZCS-QRC

The voltage gain of the QRC is dependent on switching frequency of the converter i.e. the output voltage can be simply be varied by varying the switching frequency of the switch. Therefore converter is known as frequency modulated converter. The FM-ZCS-QRC circuit and its operating waveforms are shown in Fig. 2(a) and Fig. 2(b). The sinusoidal voltage waveform in case of Zero voltage resonant switch and sinusoidal voltage waveform in case of Zero current resonant switch, generated by the waveform shaping LC resonant tank circuit creates a zero current condition for the switch to turn off without switching stresses and losses ideally.

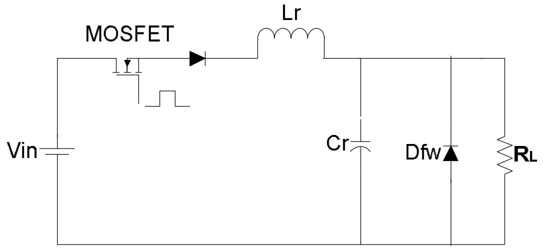

Fig 2 (a) : Power circuit of half wave FM-ZCS-QRC fed resistive and motor load.

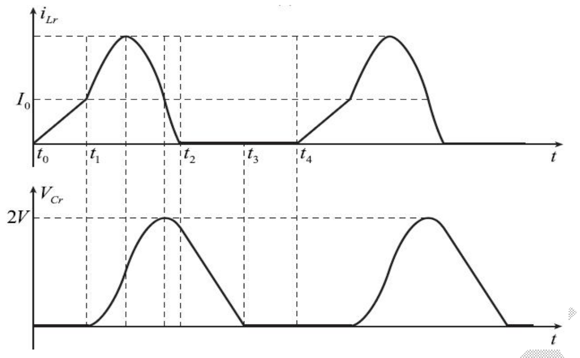

Fig 2 (b). Waveforms of Half wave FM-ZCS-QRC

As shown in the waveforms the switching cycle of the converter can be divided into four stages. Assuming that the circuit is under steady state and the inductor current i_{Lr} is nearly constant at I_0, initially free wheel diode (D_{fw}) carries the output current, resonant capacitor is uncharged and switch S is turned off. The switching cycle begins at $t=t_0$.

Four modes of operation of converter is explained as follows with associated equivalent circuits.

MODE 1: When switch is turned on at $t=t_0$, the input current (i_{Lr}) rises linearly and is governed by the equation $Vin = L_r\left(di_{Lr}/dt\right)$. The duration of the mode is $t_{d1} = \left(t_1 - t_0\right)$ can be solved with boundary conditions

$$i_{Lr}\left(0\right) = 0 \text{ and } i_{Lr}\left(t_{d1}\right) = I_0 \quad \text{........... (1)}$$

$$\text{Thus} \quad t_{d1} = \frac{L_r I_0}{V_{in}} \quad \text{........... (2)}$$

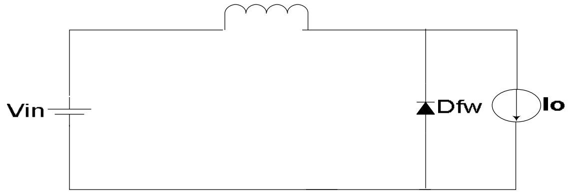

Fig 3 : Equivalent circuit for mode 1.

MODE 2: At time $t=t_1$, when the input current rises to the level of I_0, switch S remains on but diode D_{fw} is turned off and amount of current $\left(i_{Lr}\left(t\right) - I_0\right)$ is now charging the capacitor C, the equations are as follows

$$C_r\left(\frac{dV_{Cr}}{dt}\right) = i_{Lr}\left(t\right) - I_0 \quad \text{........... (3)}$$

$$L_r\left(\frac{dI_{Lr}}{dt}\right) = V_{in} - V_{Cr}\left(t\right) \quad \text{……… (4)}$$

With initial condition $V_{Cr}(0) = 0$ and $i_{Lr}(0) = I_0$.

$$i_{Lr} = I_0 + \left(\frac{V_{in}}{Z_0}\right)\sin\omega_0 t \quad \text{........... (5)}$$

where $\omega_0 = \frac{1}{\sqrt{LC}}$, $Z_0 = \sqrt{\frac{C}{L}}$ and $\omega_0 = \frac{1}{\sqrt{LC}}$,

The duration of this mode is $t_{d2} = \left(t_2 - t_1\right)$ can be solved by setting $i_{Lr}\left(t_{d2}\right) = 0$.

thus, $t_{d2} = \frac{\alpha}{\omega}$ .... (6)

where $\alpha = \sin^{-1}\left(\frac{Z_0}{V_{in}}\right)$

$\pi < \alpha < 3\pi/2$ for half wave mode

$3\pi/2 < \alpha < 2\pi$ for full wave mode

$$V_{Cr}(t_{d2}) = V_{in}(1 - \cos\alpha) \quad \text{........... (7)}$$

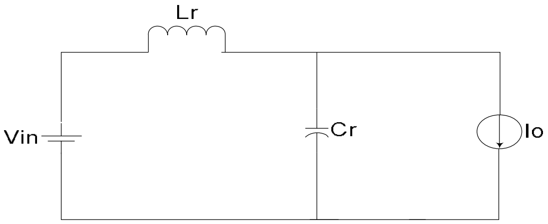

Fig 4 : Equivalent circuit for mode 2 operation.

Mode 3: This stage begins at t_2, when the current through the inductor L_r is zero. At $t= t_2$, S is turned off. The capacitor C_r discharges through the load to supply constant load current. Hence V_{Cr} decreases linearly and reduces to zero at $t= t_3$.

$$C_r(\frac{dV_{Cr}}{dt}) = I_0$$

$$t_{d3} = (t_3 - t_2)$$

$$V_{Cr}(0) = V_{in}(1 - Cos\alpha)I_0 \quad .... (8)$$

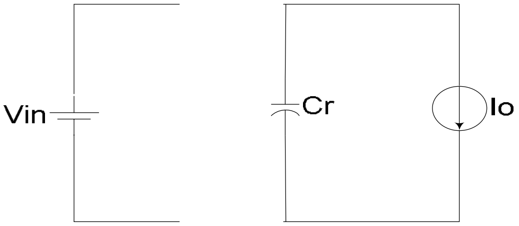

Fig 5 : Equivalent circuit for mode 3operation

MODE 4: This stage starts with the conduction of freewheeling diode and the armature current freewheels through D_{fw} for a period t_{d4}.

$$t_{d4} = T_s - t_{d1} - t_{d2} - t_{d3}$$

where T_s is the period of switching cycle.

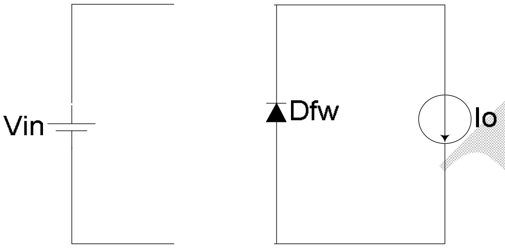

Fig 6 : Equivalent circuit for mode 4.

III. SIMULATION RESULTS

The full wave ZCS-QRC has been simulated using MATLAB simulink software. For simulation purpose values chosen are L_r = 132 µH, C_r = 0.31 µF, Vin =14 V, R_L = 125Ω.

The current through the inductor is shown in Fig.7.1. Voltage across the capacitor is shown in Fig.7.2.current waveform with gate pulses showing zero current switching is shown in Fig.7.3.

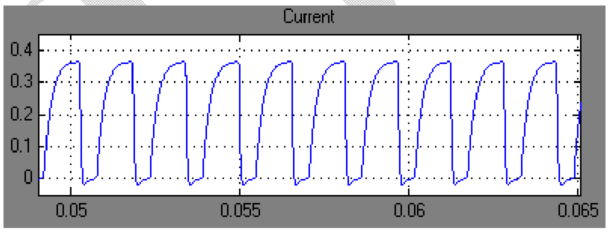

Fig.7.1 : Current waveform.

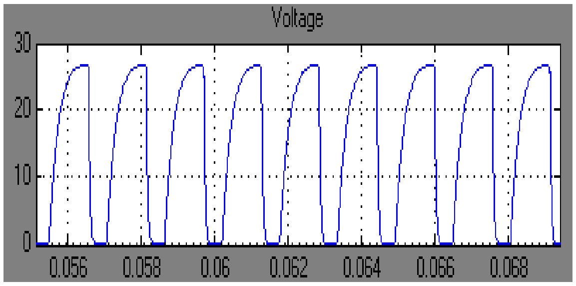

Fig.7.2 : Voltage waveform.

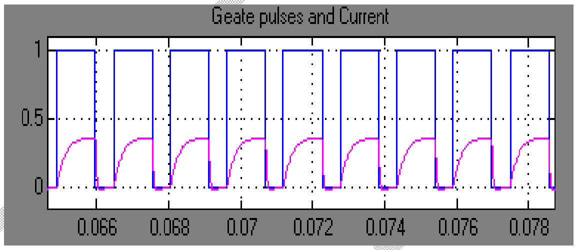

Fig.7.3 : Gate pulses and current waveform.

IV. EXPERIMENTAL SETUP AND RESULTS

The experimental set up of full wave ZCS-QRC fed resistive load is shown in Fig. 8.1. The gating pulses for MOSFET switching are generated by PWM generator IC (PIC 2010). These pulses are applied to the gate terminal of the MOSFET through optoisolator (6n137) and driver IC (IR2110).L_r = 132µH, C_r = 0.31 µF, Vin=14 V.

Fig 8.1 : Experimental setup

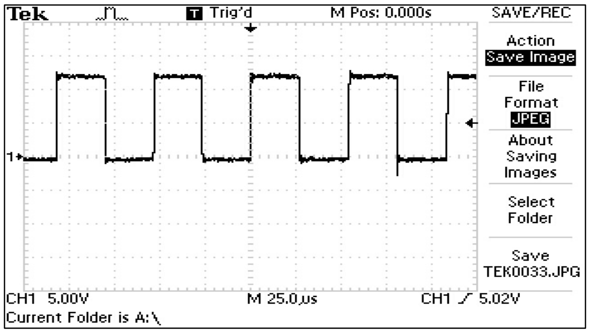

Fig 8.2: MOSFET gate pulses

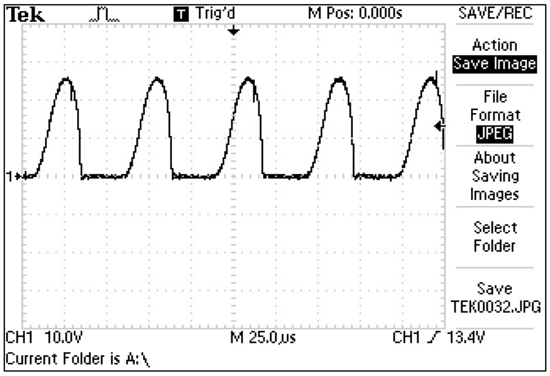

Fig 8.3 : Voltage waveform across capacitor

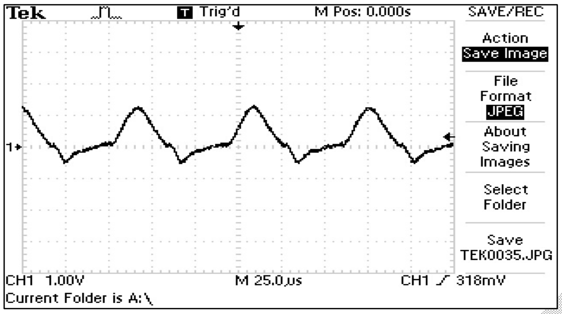

Fig 8.4 : Current waveform through inductor

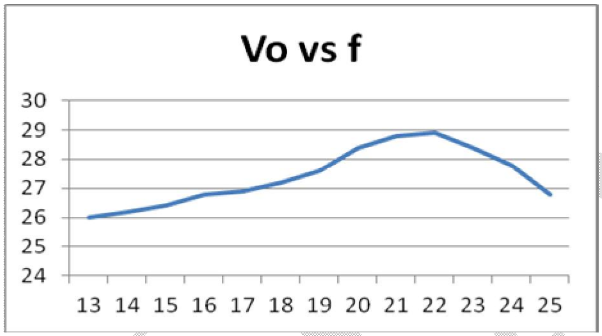

Fig 8.5 : Variation of output voltage with input voltage at constant switching frequency.

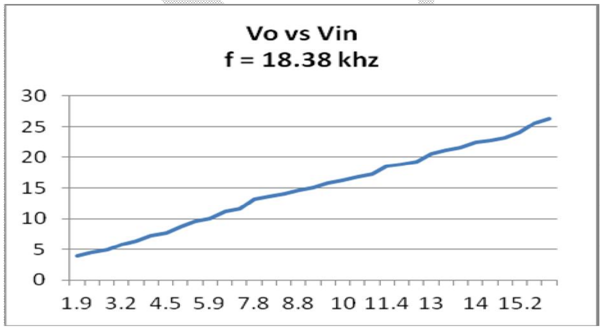

Fig 8.6 : Variation of output voltage with switching frequency at constant input voltage.

The gate pulses waveform is shown in Fig.8.2. Voltage waveform across capacitor and current waveform through inductor is shown in Fig. 8.3 and Fig. 8.4. The variation of V_0 (p-p) with input voltage is shown in fig. 8.5 and variation of V_O (p-p) with switching frequency is shown in fig. 8.6. By analysing the waveforms we get to know that zero current switching phenomena is taking place. Also we are getting quasi sinusoidal waveforms of both current as well as voltage. From the Fig. 8.5, we can observe that at constant switching frequency output voltage V_O (p-p) varies linearly with the change in input voltage. In the fig. 8.6 we are getting a peak at around 22 khz switching frequency. This graph shows the dependency of output voltage on the switching frequency. Conceptually this peak should come around the resonant frequency. The resonant frequency for the given circuit is 22.74 kHz.

V. CONCLUSIONS

ZCS-QRC fed resistive load was simulated using MATLAB (2011) simulink software. By virtue of this modeling approach, design of quasi resonant converters can be realized efficiently and effectively by using soft switching techniques. The approach of maintaining zero current switching condition is also identified from the simulated waveforms i.e. switching of switch S takes place only when the current is zero. The variation of output voltage with switching frequency is shown which implies that the output of the converter can be controlled or regulated by changing the switching frequency. Thereby it can be concluded by the above discussion that any measurable and controllable quantity in any system which varies with the supply voltage can be controlled by the above converter the only need is to convert that quantity into appropriate value of switching frequency of MOSFET resulting in frequency modulation.

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