IMPLEMENTATION OF FM-ZCS-QUASI RESONANT CONVERTER FED DC SERVO DRIVE

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ABSTRACT

This paper deals with the implementation of FM-ZCS-QRC fed DC servo drive using micro controller. The salient feature of QRC is that the switching devices can be either switched on at zero voltage or switched off at zero current, so that switching losses are zero ideally, switching stresses are low, volumes are low and power density is high. This property imparts high efficiency and high power density to the converters. The output of QRC is regulated by varying the switching frequency of the converter. Hence it is called Frequency modulated Zero current/zero voltage switching quasi resonant converter. The present work deals with simulation and implementation of DC Servo motor fed from ZCS-QRC. Simulation results show that the ZCS-QRC's have low total harmonic distortion. The ZCS-QRC operating in half wave and full wave modes are simulated and implemented successfully. The experimental results are compared with the simulation results.

Keywords : *Zero Current switching (ZCS), Quadrature Resonant Converter (QRC), Frequency modulated (FM).*

1. INTRODUCTION

Thyristorised power controllers are now widely used in the industry. Conventional controllers involving magnetic amplifiers, rotating amplifiers, mercury arc amplifiers, resistance controllers etc., have been replaced by thyristorised power controllers.

Controllers of DC drives and AC drives widely use thyristorised power controllers in rolling mills, textile mills, paper mills, cranes, traction vehicles and mine winders etc., Some other areas where thyristorised power controllers employed are uninterruptible and standby power supplies for critical loads, static power compensation, special power supplies for air craft and space applications, transformer tap changers and static connector for industrial power systems, power conversion at the terminals of HVDC transmission system, HV supplies for electronic precipitators and X-ray generators.

2. QUASI RESONANT CONVERTER

The fundamental departure from the conventional "forced turn off "approach is the "zero current switching" (ZCS) technique, proposed by F C Y Lee et al (1987). Replacing the switches as power switches (MOSFET, GTO) in the PWM converters by resonant switches gives rise to a new family of converters, namely "Quasi Resonant Converters "(QRC). This new family of converters can be viewed as a hybrid between PWM converters and resonant converters. They utilize the principle of inductive or capacitive energy storage and power transfer in a similar fashion as PWM converters. The circuit topologies also resemble those of PWM converters. However an LC tank circuit is always present near the power switch and is used not only to shape the current waveforms through the power switch and the voltage waveform across the device. It can also store and transfer energy from input to output in a manner similar to the conventional resonant converters.

Performance of the DC motor fed from series QRC is given in [1]. Large signal non linear model for simulation of ZCS – QRC is given in [3]. Cyclic quasi resonant converter for high performance DC to DC conversion is given in [4]. A new group of quasi resonant converters is given by [5]. The above literature does not deal with implementation of ZCS – QRC fed servo drive.

The two types of ZCS-QRC converters are (a) half wave (b) full wave as shown in Figures 1 and 2.

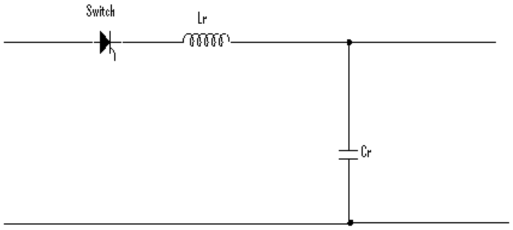

Figure 1. Half wave ZCS-QRC

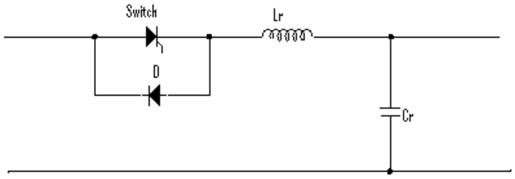

Figure 2. Full wave ZCS-QRC

A conventional Frequency modulated-zero current switching-Quasi resonant converter circuit and its operating waveforms are shown in figures 3 and 4 respectively. The sinusoidal current waveform in the case of zero current resonant switch/ the sinusoidal voltage waveform in the case of Zero voltage resonant switch, generated by the waveform shaping LC resonant elements creates a zero current / voltage condition for the switch to turn-off / turn-on without switching stresses and losses.

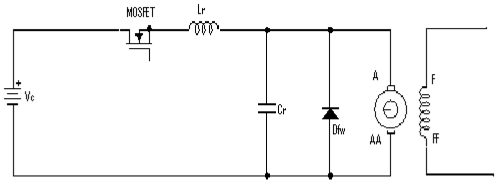

Figure 3. Power circuit of half wave FM-ZCS-QRC fed servo drive

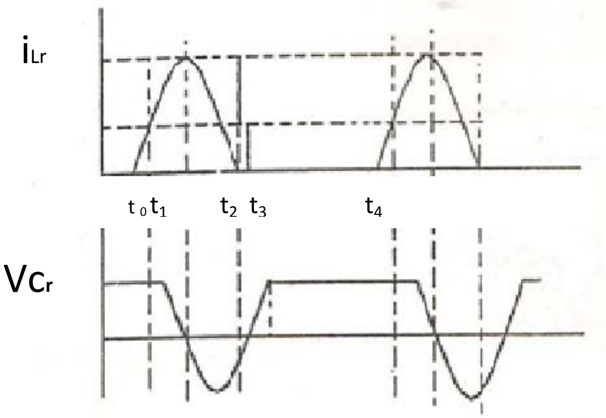

Figure 4. Waveforms of Half wave FM-ZCS-QRC

A switching cycle can be divided into four stages. The associated equivalent circuits for these four stages are shown in modes of operation for half wave and full wave circuits respectively. Assume initially free wheel diode (D_{fw}) carries the output current (I_o) and resonant capacitor voltage (V_{Cr}) is clamped at zero and switch S is off. At the beginning of the switching cycle $t = t_o$, S is switched on.

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

$i_{Lr}(0) = 0$ and $i_{Lr}(t_{d1}) = I_o$

Thus $t_{d1} = (L_r I_o/V)$

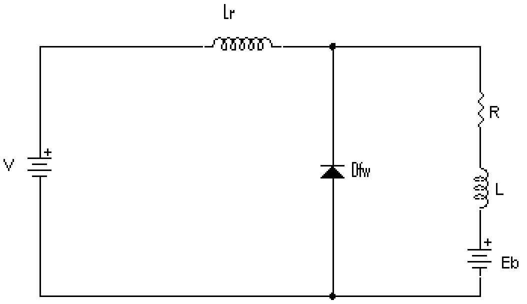

Figure 5 Equivalent circuit for mode 1

II. mode 2 : At time $t = t_1$, when the input current rises to the level of I_o , D_{fw} is turned off and the amount of current ($i_{Lr}(t) - I_o$) is now charging C_r , the state equations are :

$C_r (dV_{Cr}/dt) = i_{Lr}(t) - I_o$;

$L_r (di_{Lr}/dt) = V - V_{Cr}(t)$

With the initial condition $VCr(0) = 0$

And $i_{Lr}(0) = I_o$. Therefore

$i_{Lr}(t) = I_o + (V / Z_o) \text{Sin } \omega t$

If a half wave resonant switch is used, switch S will be naturally commutated at time when the resonating input current iLr (t) reduces to zero. On the other hand, if a full wave resonant switch is used, current $I_{Lr}(t)$ will continue to oscillate and energy is fed back to source, V through D_{fw}. Current through D_{fw} again oscillate to zero . The duration of this stage td2 = $(t_2 - t_1)$ can be solved by setting $i_{Lr}(t_{d2}) = 0$.

Thus, $t_{d2} = \alpha / \omega$

Where $\alpha = \arcsin (Z_o I_o / V)$

$\Pi \le \alpha \le 3\pi / 2$ for half wave mode

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

At time t_2, V_{Cr} can be solved using

$V_{Cr} (t_{d2}) = V (1 — \text{Cos}\ \alpha)$

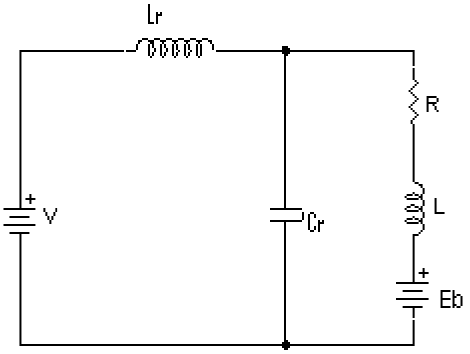

Figure 6. Equivalent circuit for mode 2

III. mode 3: This stage begins at t_2, when the current through 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_3. The state equation during this interval is $C_r(dV_{Cr}/dt) = I_o$. The duration of this stage $t_{d3} = (t_2 - t_1)$ can be solved with the initial condition.

$V_{Cr}(o) = V (1—\text{Cos}\ \alpha)\ I_o$

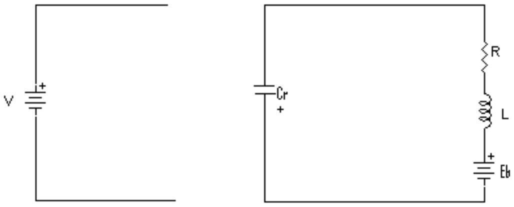

Figure 7. Equivalent circuit for mode 3 operation

IV. mode 4: This stage starts with the conduction of freewheeling diode and the armature current freewheels through D_{fw} for a period t_{d4} until S is turned on again. The duration of this stage is $t_{d4} = T_S - t_{d2} - t_{d3}$. Where T_S is the period of a switching cycle.

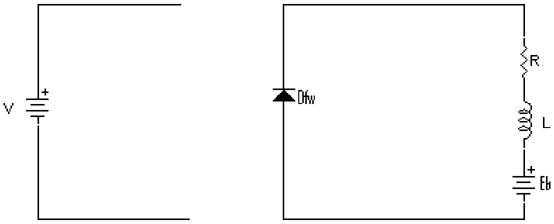

Figure 8. Equivalent circuit for mode 4 operation

3. SIMULATION RESULTS

The understanding of the operation of a power electronic circuit requires a clear knowledge of the transient behavior of current and voltage waveform for each and every circuit element at every instant of time. For the easy understanding of the transient response computer aided simulation software's were used. The FM-ZCS-QRC has been simulated using MATLAB simulink software. For simulation purpose the values chosen are L_r = 168 µH, C_r = 2.2µF , V = 75V, R_a = 5 Ω, L_a =30 mH, and E_b = 35 V.

Full wave ZCS QRC with motor load is shown in the Figure 4a. The current through the inductor is shown in the Figure 4b. Voltage across the capacitor is shown in the Figure 4c. Speed response curve is shown in Figure 4d. The speed increases and settles at 100 rad /sec.

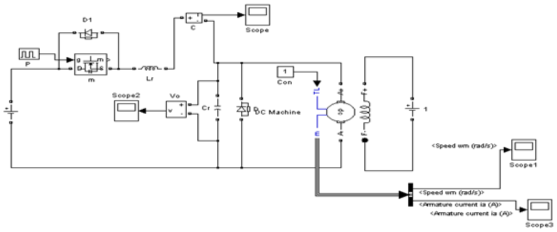

Figure 9. Full wave QRC with motor load

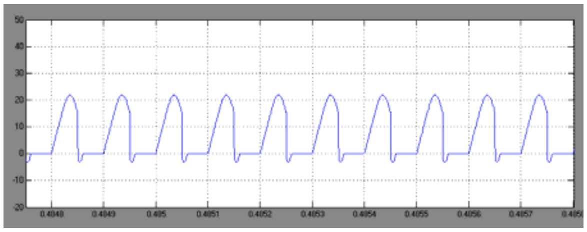

Figure 10. Current through inductor L_r

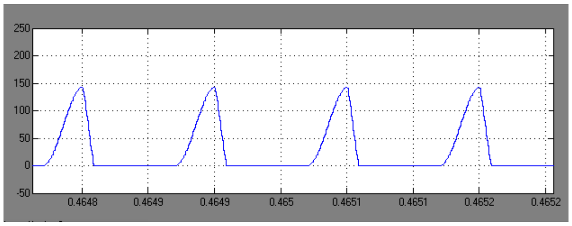

Figure 11. Voltage across capacitor C_r

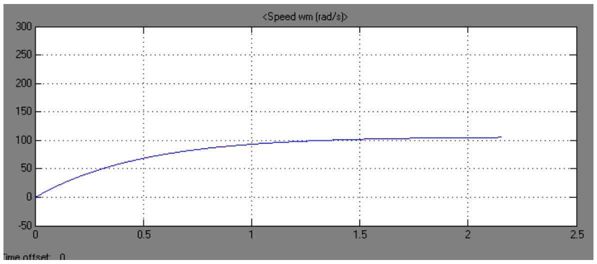

Figure 12. Rotor speed in rad/sec

4. EXPERIMENTAL RESULTS

The hardware for the QRC fed DC servo drive is fabricated and tested in the laboratory. The pulses required for the MOSFET are obtained using a low cost microcontroller 89C2051. The pulses obtained from the micro controller are amplified by using a driver amplifier IR 2110. Resonant period is calculated and pulses are generated by using the calculated values. Experimental set up is shown in Figure 13. AC input voltage is shown in Figure 14. DC output of the rectifier is shown in the Figure 15. Driving pulses given to the MOSFET are shown in Figure 16. Voltage across the MOSFET is shown in Figure 17. Voltage across the capacitor is shown in Figure 18. From the Figures 11 and 18, it can be seen that the experimental results coincide with the simulation results.

Figure 13. Experimental set up

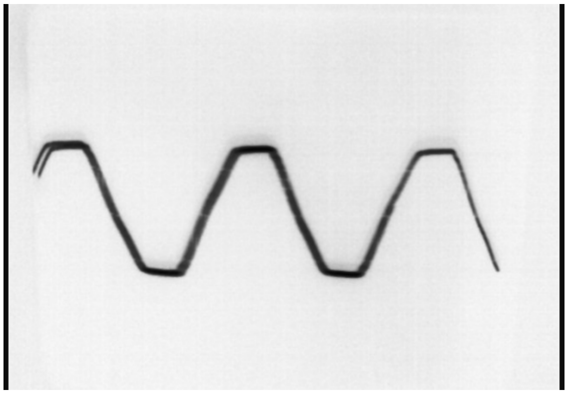

Figure 14. Ac input voltage

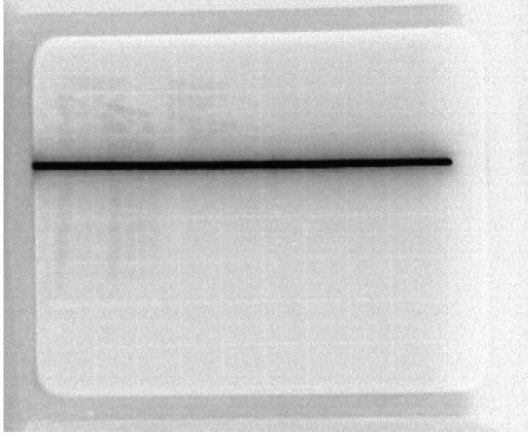

Figure 15. Rectifier output voltage

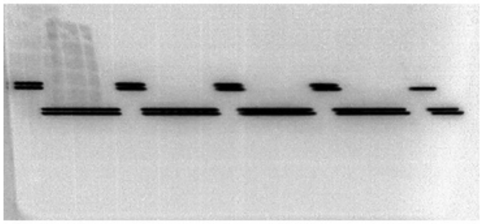

Figure 16. Driving pulses

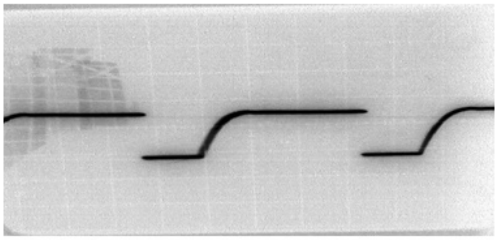

Figure 17. Voltage across switch

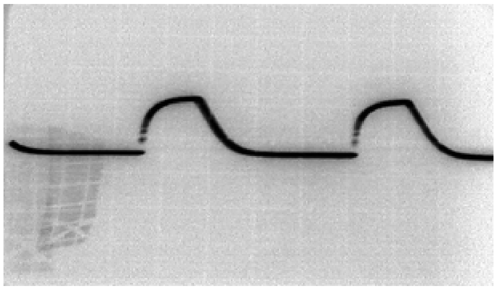

Figure 18. Voltage across capacitor

5. CONCLUSION

FM-ZCS-QRC fed DC servo drive was simulated using mat lab simulink software. By virtue of this modeling approach , design of quasi resonant converters can be realized efficiently and effectively by using soft switching techniques. Switching stresses get reduced since voltage and current waveforms have lesser slope. Power density is increased since the volume is reduced. The approach of maintaining zero current switching condition is also identified from the simulated waveforms i.e., whenever current is zero, switch S turns on and off.. QRC fed Servo drive is a viable alternative to the conventional DC drive since it has less losses and high power density. The speed of the servo motor can be varied by varying the off time of the QRC. The experimental results coincide with the simulation results.

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BIOGRAPHY :

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