Design and Simulation of Soft Switched Converter Fed DC Servo Drive

Bal Mukund Sharma, A. N. Tiwari, K. P. Singh

Abstract— Resonant switching is preferred over hard switching to minimize the switching losses. Resonant switching DC-DC converters are attractive for power supply in many applications due to their distinct advantages such as high efficiency, high frequency operation, compact structure, low EMI, etc.as compared to hard-switched converters. The paper deals with design and simulation of ZCS-Quasi resonant converter fed DC servo drive using Matlab Simulink. The salient feature of QRC is that the switching devices can be either switched on at zero current or switched off at zero current, so that switching losses may be zero, with low switching stresses, low volumes and high power density. The output of QRC is regulated by varying the switching frequency of the converter.

Index Terms— Quasi resonant converter (QRC), Zero current switching (ZCS), Pulse width modulation (PWM), Low power factor load, and Power supply.

I. INTRODUCTION

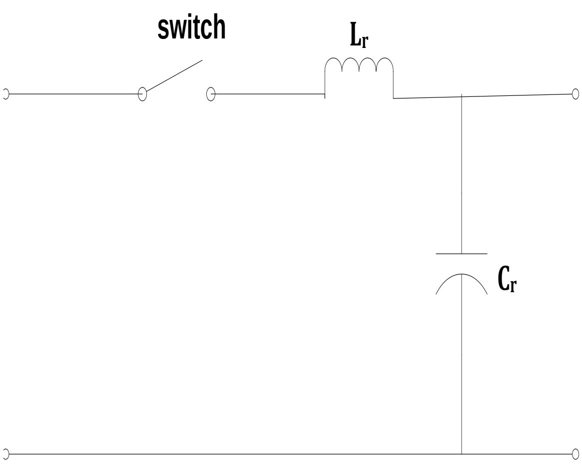
Various soft-switched converters using either zero-voltage switching (ZVS) or zero-current switching (ZCS) have been proposed in the literature, and the basic issue is to achieve high frequency operation with reduced switching losses and EMI. When the switching frequency becomes higher, the harmonics filtering is easier and the audible noise (below 18 kHz) can be reduced. This is a very desirable enhancement in motor drive systems, for example. However, these features are sometimes accomplished at the expense of producing higher voltage or current stresses and circuit complexities which prevent implementation of the well-known PWM techniques. However, more recently, some modified topologies have been presented in order to solve these problems.

Resonant switching is preferred over hard switching to minimize the switching losses. Resonant switching DC-DC converters are attractive for power supply in many applications due to their distinct advantages as compared to hard-switched converters. Quasi Resonant Converter (QRC) is fast replacing conventional PWM converters in high frequency operation. 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 ideally zero. 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. The zero current switching-quasi resonant converters operating in full wave mode has been simulated successfully.

II. 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, IGBT) 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.

The two types of ZCS-Quasi resonant converters are: (a) half wave, and (b) full wave as shown in Figure: 1- (a) and (b).



(a)

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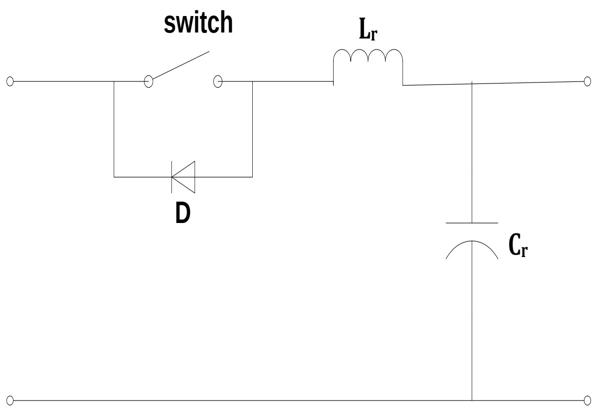
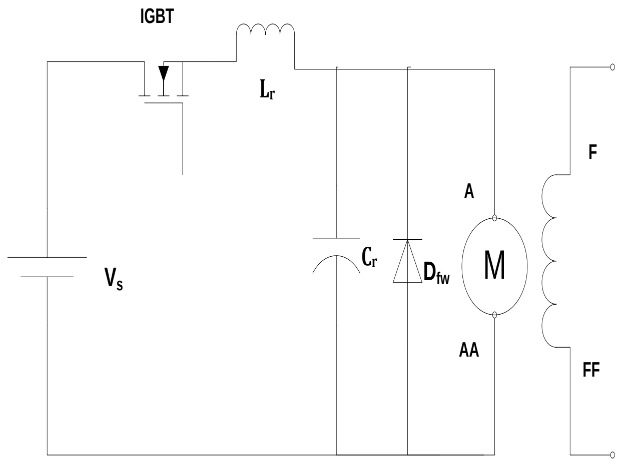


(b)

Figure 1–(a) Half wave ZCS-Quasi resonant converter, (b) Full wave ZCS-Quasi resonant converter.

III. DESIGN OF COMPONENTS SPECIFICATIONS

The Power circuit of Half wave ZCS-Quasi resonant converter fed DC servo drive has been shown in figure: 2 (a). The sinusoidal current waveform in the case of zero current resonant switches is generated by the waveform shaping LC resonating elements as shown in figure: 2(b). A switching cycle can be divided into four stages. The constant gate pulses are applied at the gate of the switch *S*. When the switch is turned on and diode (D_{fw}) conducts resonant inductor current rises. When diode is off and the switch is remains on, resonant capacitor voltage rises. The switch will be naturally commutated at time when resonant inductor current reduces to zero. When the switch and diode are off, the capacitor is discharged across the load and capacitor voltage is zero.



(a)

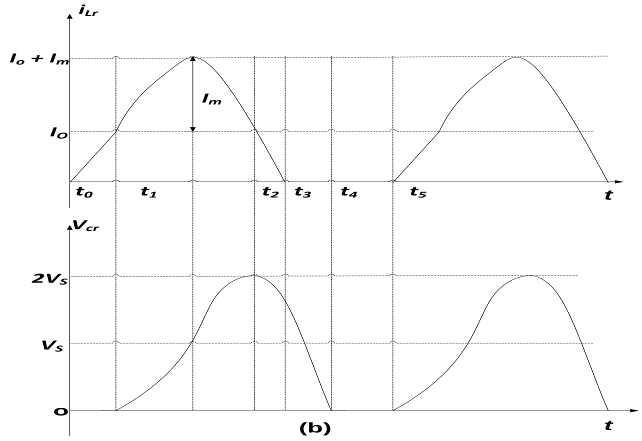


Figure 2 –(a) Power circuit of Half wave ZCS-Quasi resonant converter fed DC servo drive; (b) Waveforms of Half wave ZCS-Quasi resonant converter fed DC servo drive.

In this proposed topology, the resonant inductor(L_r), DC link resonant capacitor (C_r) have been designed. For this, the following equations are required:

Assume that the intervals t_{d1} and t_{d3} are very small The maximum frequency will occur when $t_{d5} = 0$. since$t_{d1} = t_{d3} = t_{d5} = 0$,

$$t_{d2} + t_{d4} = T. \qquad (1)$$

Resonant capacitor

Substituting $t_{d4} = \frac{2\,V_S\,C_r}{I_O}$ and $t_{d2} = \pi\sqrt{L_r C_r}$,

using $x = \frac{I_m}{I_O} = \left(\frac{V_S}{I_O}\right)\sqrt{\frac{C_r}{L_r}}$ in equation(1).

Resonant capacitor of zero current switching-quasi resonant converters is calculated by the following equation:

$$\left(\pi\sqrt{L_r\,C_r} + \frac{2\,V_S\,C_r}{I_O}\right) = T \text{ or}$$

$$\left(\frac{\pi\,V_S\,C_r}{x\,I_O} + \frac{2\,V_S\,C_r}{I_O}\right) = T$$

$$C_r = \frac{T}{\frac{V_S}{I_O}\left(\frac{\pi}{x}+2\right)} \qquad (2)$$

Resonant inductor

Resonant inductor of zero current switching-quasi resonant converter is calculated by the following equation :

$$L_r = \left(\frac{V_S}{X\,I_O}\right)^2 C_r \qquad (3)$$

Duty cycle:

Duty cycle of zero current switching-quasi resonant converter is calculated by the following equation:

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Total time period $T = t_{d2} + t_{d4}$

$$T = C_r\left(\frac{V_S}{I_O}\right)\left(\frac{\pi}{x} + 2\right)$$

$$Duty\ cycle = \frac{t_{on}}{T} \qquad (4)$$

IV. MODES OF OPERATION

1. MODE. I : When S is turned on at $t = t_O$, the input current (i_{Lr}) rises linearly and is governed by the state equation $V_S = L_r\left(\frac{di_{Lr}}{dt}\right)$ The duration of the mode, $t_{d1} = (t_1 - t_o)$ can be solved with boundary conditions which can be expressed by equations (6) **:**

$$i_{Lr}(t_o) = 0 \quad and \quad i_{Lr}(t_1) = I_O$$

$$t_{d1} = (t_1 - t_0) \qquad (5)$$

$$t_{d1} = \frac{L_r I_O}{V_S}. \qquad (6)$$

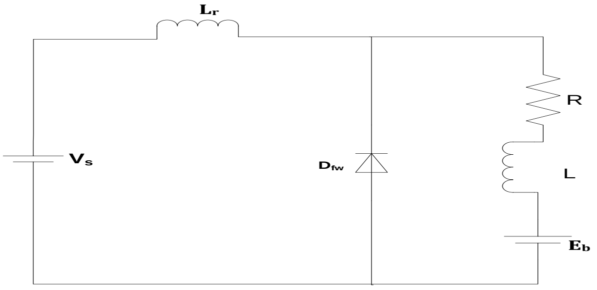

Figure (a) Equivalent circuit for mode 1 operation.

2. Mode. II : At time $t = t_1$, when the input current rises to the level of I_O, D_{fw} turned off and the amount of current $(i_{Lr}(t) - I_O)$ is now charging C_r , which can be given by the state equations (7) to (21)

$$C_r\frac{dV_{Cr}}{dt} = i_{Lr} - I_{O,} \qquad (7)$$

$$L_r\frac{di_{Lr}}{dt} = V_s - V_{Cr}(t), \qquad (8)$$

$$i_{Lr}(t) = I_O + \frac{V_s}{Z_O}\sin\omega_r t, \qquad (9)$$

with the initial conditions $V_{Cr}(t_1) = O$ and $i_{Lr}(t_1) = I_O$.

For duration $t_{d2} = (t_2 - t_1)$

(10)

The inductor current i_{Lr} is given by

$$i_{Lr} = I_O + I_m \sin\omega_r t \qquad (11)$$

where $I_m = V_S\sqrt{\frac{C_r}{L_r}}$ and $\omega_r = \frac{1}{\sqrt{L_r C_r}}$ (12)

The capacitor voltage V_{cr} is given by

$$V_{Cr} = V_S(1 - \cos\omega_r t) \qquad (13)$$

The peak switch current, which occur at $t = \left(\frac{\pi}{2}\right)\sqrt{L_r C_r}$ is

$$I_p = I_m + I_O$$

(14)

$$V_{C(Peak)} = 2V_S$$

(15)

with the initial conditions $V_{Cr}(t_2) = 2V_S$ and $i_{Lr}(t_2) = I_O$

Therefore $t_{d2} = \pi\sqrt{L_r C_r}$. (16)

If a half wave resonant switch is used, switch S will be naturally commutated at time when the resonating input current $i_{Lr}(t)$ 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, voltage V through freewheeling diode D_{fw}. Current through D_{fw} again oscillate to zero. The duration of this stage $t_{d3} = (t_3 - t_2)$ can be solved by setting $i_{Lr}(t_3) = O$.

For duration $t_{d3} = (t_3 - t_2)$ (17)

The inductor current that falls from I_O to zero is given by

$$i_{Lr} = I_O - I_m \sin\omega_r t \qquad (18)$$

The capacitor voltage is given by $V_{Cr} = 2V_s\cos\omega_r t$

(19)

This mode ends at time $t = t_3$, with the initial conditions $V_{Cr}(t_3) = V_{Cr3}$ and $i_{Lr}(t_3) = 0$

Therefor $t_{d3} = \sqrt{L_r C_r}\ \sin^{-1}\left(\frac{1}{x}\right)$ (20)

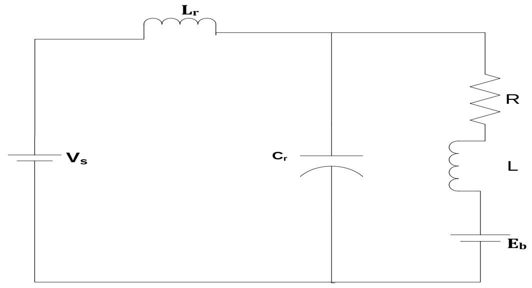

Figure (b) Equivalent circuit for Mode 2 operation.

Where $$x = \frac{I_m}{I_O} = \left(\frac{V_S}{I_O}\right)\sqrt{\frac{C_r}{L_r}}$$

(21)

3. Mode. III : This stage begins at t_3, when the current through inductor L_r is zero. At $t = t_3$, 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_4. The state equation for this mode is given by the equations (22) to (25)

$$C_r \frac{dV_{Cr}}{dt} = I_O \qquad (22)$$

The duration of this stage $$t_{d4} = (t_4 - t_3)$$

(23)

The capacitor supplies the load current I_O, its voltage is given by $$V_{Cr} = V_{Cr3} - \frac{I_O}{C_r} t_4$$

(24)

This mode ends at time $t = t_4$, with the initial conditions $V_{Cr}(t_4) = 0$

therefore $$t_{d4} = \frac{V_{Cr3}\, C_r}{I_O} \qquad (25)$$

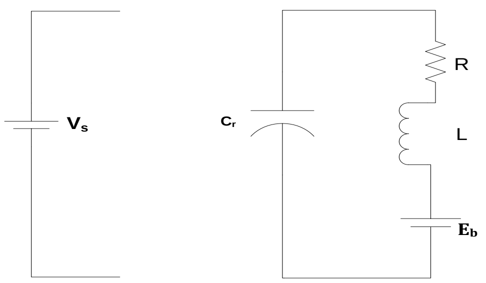

Figure (c) Equivalent circuit for Mode 3 operation.

4. Mode. IV : This stage starts with the conduction of freewheeling diode and the armature current freewheels through D_{fw} for a period t_{d5} until S is turned on again. The duration of this stage is

$$t_{d5} = T - t_{d1} - t_{d2} - t_{d3} - t_{d4}, \qquad (26)$$

where T is the period of a switching cycle.

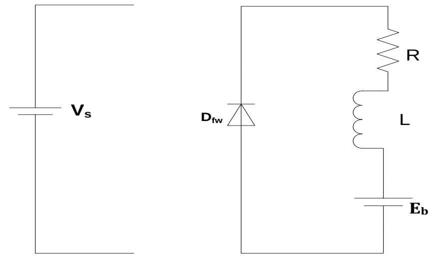

Figure (d) Equivalent circuit for Mode 4 operation.

Table-1: Parameters used for simulation

DC supply voltage V_S	280V
Resonant inductor L_r	168 µH
Resonant capacitor C_r	2.2 µF
Armature Resistance R_a	0.5Ω
Inductance L_f	120H
Field armature mutual inductance L_{af}	1.23 H
Total inertia J	0.05 Kg.m^2
Viscous friction coefficient B_m	0.02 N.m.s
Coulomb friction torque T_f	0 N.m
Load torque T_L	5 N-m
Field voltage V_f	240V

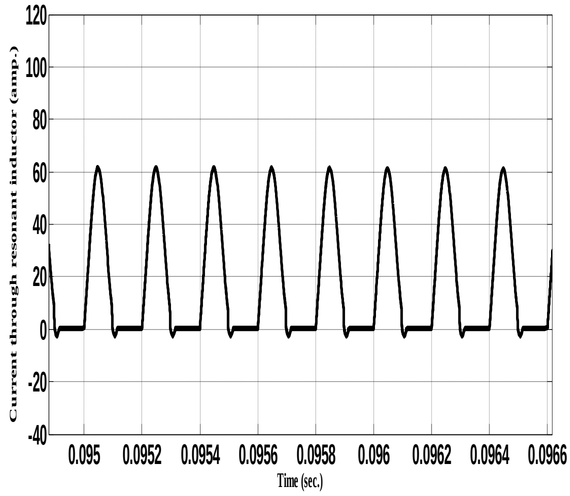

Figure: (a) Current through resonant inductor (L_r).

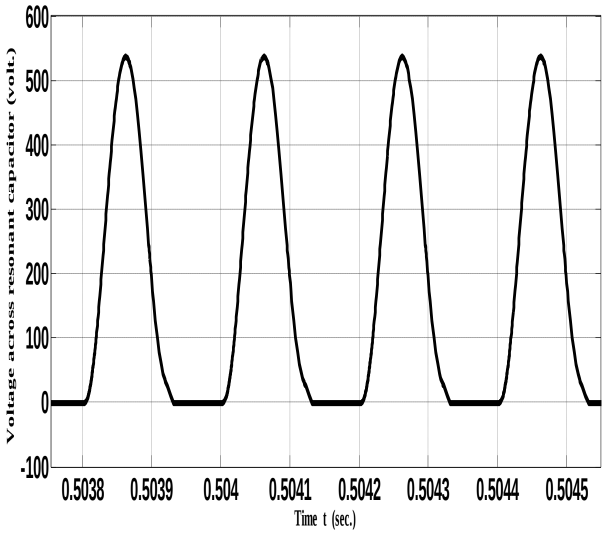

Figure: (b) Voltage across resonant capacitor (Cr).

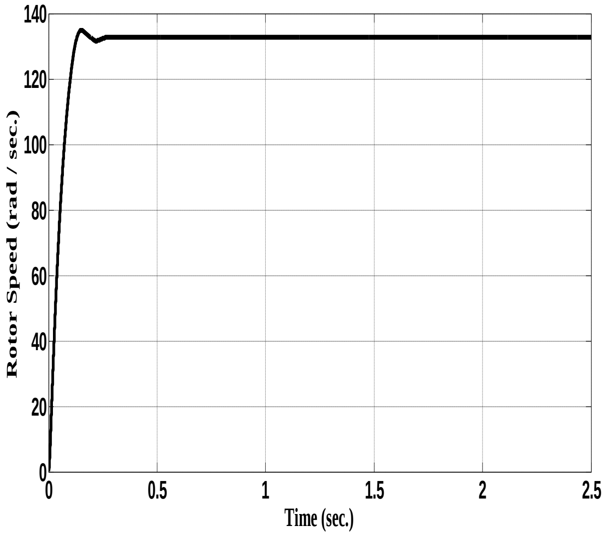

Figure: (c) Rotor speed ω_n (rad / sec.)

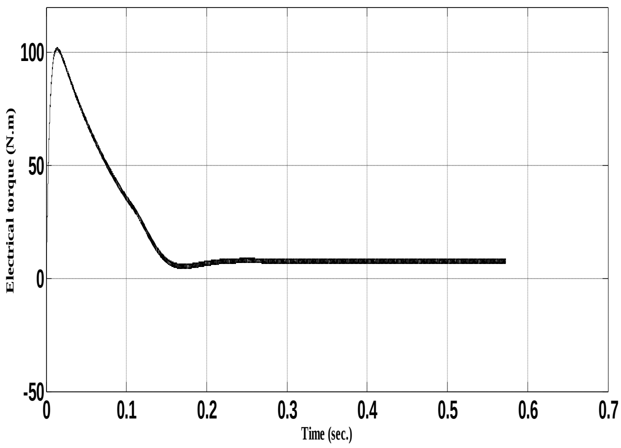

Figure: (d) Electrical torque T_e (N.m).

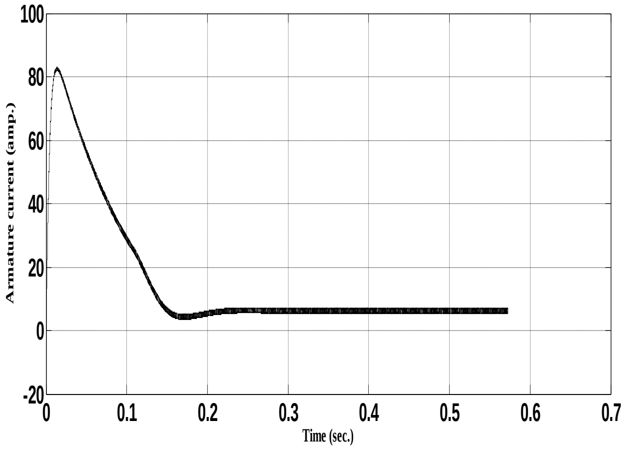

Figure: (e) Armature current I_a (Amp.).

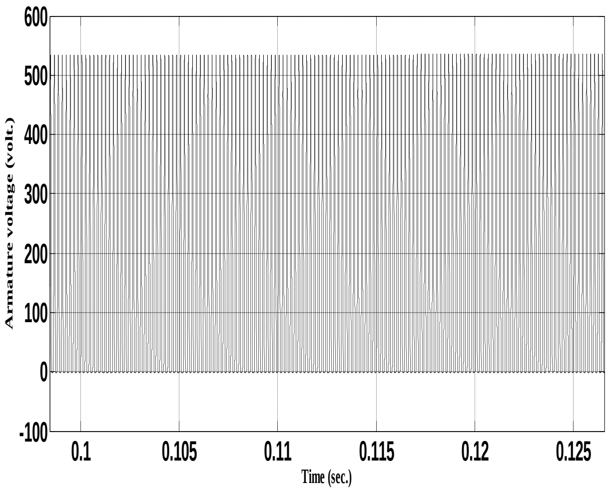

Figure: (f) Armature voltage V_a (volt.).

V. RESULTS AND CONCLUSION

The proposed full wave Zero Current Switching, Quasi Resonant Converter is modeled and simulated using MATLAB with DC servo drive load with parameters given in Table-1. In this paper a new soft switching topology to achieve DC Servo Drive fed from zero current switching-quasi resonant converter using MATLAB is proposed. The topology is simple to implement and can be used for high frequency operation. The zero current switching-quasi resonant converter has been simulated and different performance results have been plotted which have been shown in figure 3(a), 3(b), 3(c), 3(d), 3(e) and 3(f) respectively. 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, ie. Whenever current is zero, converter switch is turned -on and turned-off. Quasi resonant converter fed Servo drive is a viable alternative to the DC drive since it has less losses and high power density.

REFERENCES

1. K.H. Liu, Ramesh Oruganti, and F.C.Y. Lee: "Quasi-resonant Converters Topology and Characteristics", IEEE Transactions on Power electronics, Vol. PE-2, No. 1, pp. 62 – 71, Jan. 1987.
2. D. M. Divan, "The resonant DC link converter—A new concept in static power conversion," IEEE
3. Trans. Ind. Applicat., vol. 25, pp. 317–325, Mar./Apr. 1989.
4. J. He and N. Mohan, "Parallel resonant dc link circuit—A novel zero switching loss topology with minimum voltage stresses," in Conf. Rec. IEEE PESC'89, pp. 1006–1012, 1989.
5. G.H. Cho, and J.G. Cho: "Cyclic Quasi-resonant Converter: a New Group of Resonant Converters Suitable for Higher Performance DC/DC and AC/AC Conversion Applications", proc IEEE IECON, pp. 956 – 963, 1990.
6. R.B. Ridely, W.A. Tabisz, F.C.Y. Lee, and V. Vorperian: "Multi Loop Control of Quasi-resonant Converters", IEEE Transactions on Power Electronics, Vol. 6, No. 1, pp. 28 – 38, Jan. 1991.
7. J. S. Lai and B. K. Bose, "An inductionmotor drive using an improved high frequency resonant link inverter," IEEE Trans. Power Electron., vol. 6, pp. 504–513, July 1991.
8. G. Venkataramanan and D. M. Divan,"Pulse width modulation with resonant dc link converters," IEEE Trans. Ind. Applicat., vol. 29, pp. 113–120, Jan./Feb. 1993.
9. S.R. Reddy, and C. Chellamuthu: "Performance of a DC Motor Fed from Series and Parallel Quasi resonant Converters, International Journal of Power and Energy Systems", Vol. 17, No. 3, pp. 161 – 168, 1997.
10. L.K. Wong, F.H. Leung, and P.K.S. Tam: "A Simple Large Signal non Linear Modeling Approach for Fast Simulation of Zero Current Switching Quasi-resonant Converters", IEEE Transactions on Power Electronics, Vol. 12, No. 3, pp. 437 – 442, May 1997.
11. L. Bo-Tao, L. and Yim-Shu: "Novel Actively-clamped Zero Current Switching Quasi-resonant Converters, IEEE International Symposium on Circuits and Systems", Hong Kong, 9-12, Vol. 2, pp. 869 – 872, June 1997.
12. 11. S. Arulselvi, C. Subhashini, and G. Ume: "A New Push-pull Zero Voltage Switching Quasiresonant Converter: Topology, Analysis and Experimentation", IEEE INDICON 2005, 11-12 pp. 482 – 486, Dec. 2005.
13. S. Arulselvi, G. Ume, and B. Kalaranjani: "Design and Simulation of Model based Controllers for Quasi Resonant Converters using Neural Networks", India International Conference on Power Electronics 2006, IICPE 2006, Chennai, India, 19-21 pp. 197 – 202, Dec. 2006.
14. K.N. Rao, and V.C.V. Reddy: "Implementation of FM-ZCS-Quasi Resonant Converter fed DC servo drive", Journal of Theoretical and Applied Information Technology, Vol. 5, No. 4, pp. 432 – 436, April 2009.
15. K.N. Rao, and V.C.V. Reddy: "Digital Simulation of FM-ZCS-Quasi Resonant Converter Fed DC Servo Drive using Matlab Simulink", IESPEEE09 , SRM University, Chennai, India.