Analysis and Development of Fuzzy PI Control for L-type Zero current Quasi Resonant Converter fed DC Drive

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ABSTRACT

An L-type Quasi resonant converter is used for the speed control of a DC motor. DC-DC converters are widely used in applications such as power supplies, car auxiliary power supplies, servo motor drives and medical equipments. The buck quasi resonant converter is an improved form of dcdc converter. In this paper ZCS-QRC fed DC drive is modeled and simulated and is found that the ZCS-QRC fed DC drive with fuzzy logic controller has several advantages than the PI closed loop control. The performance of the Fuzzy L-type ZCSQRC has several advantages than the conventional methods such as Phase controlled converters, DC choppers and PWM converters. The objective of this work is to develop Fuzzy logic control (FLC) for the L-type ZCS-QRC using MATLAB software. The simulation results are presented and evaluated. They validate that the Fuzzy logic control developed yields superior performance than the conventional PI control.

Keywords: *Fuzzy logic controller (FLC), Zero Current Switching (ZCS), Quasi Resonant Converter (QRC), Proportional-integral (PI), Direct Current (DC)*

I. INTRODUCTION

In recent years the Fuzzy control technique has been successfully in control system of power electronic converters and converter fed drives [1,2,3]. Mostly the system without these Fuzzy controllers are strongly nonlinear with variable parameters and structure that makes them difficult by traditional (PI) plant control. Application of fuzzy logic controllers in these condition provides an efficient tool to design robust control systems [4,5]. In this paper a study of FLC application for solution of some control problems of ZCS QRC fed drives is presented. Since the improvement of performance of DC drives is still an important task due to its application in major industrial applications. Fuzzy logic controller has the advantage that it can be designed without the exact model of the system [6-8]. This approach of FLC design [3-5] guarantees the stable operation even if there is a change in the parameters and the motor. It is very essential to design the DC-DC converters capable of operating at higher frequencies but while using PWM techniques they suffer from various difficulties like high switching losses, reduced reliability and Electromagnetic Interference. The above said difficulties can be overcome by employing QRC. Quasi-resonant converters (QRC) [9-11] employ soft switching wherein the devices are switched either at zero current (ZC) or zero voltage (ZV) so that the switching losses are zero, ideally. The reactive components in QRC shape current and voltage into quasi-sinusoidal discontinuous waves. In the ZCS-QRC employed the current produced by LC resonance flows through the switch, thus causing it to turn on and off at zero current.

A closed loop operated dc motor fed by L-type ZCSQRC is modeled and analyzed for speed control by conventional PI controller but the due to nonlinear

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characteristics of the converter an attempt is made to design and simulate a fuzzy speed controller.

II. MODELING OF L-TYPE ZCS-QRC

The QRC with ZCS topology considered comprises of two configuration namely Series(L- type) ZCS QRC and Parallel (M-type) ZCS QRC. To analyze its behavior, the following assumptions are made:

- Armature inductance is much larger than resonant inductance.
- The DC motor is treated as a constant current sink.
- Semiconductor switches are ideal.
- Reactive elements of the tank circuit are ideal.

A switching cycle can be divided into four stages.. Suppose that before MOSFET turns on, diode carries the steady-state output current Ia and capacitor voltage Vcr is

clamped at zero. At time t0, MOSFET turns on, starting a switching cycle.

II. 1. Design of L-type(Series) ZCS QRC fed drive

A switching cycle can be divided into four stages.. Suppose that before MOSFET turns on, diode carries the steady-state output current Ia and capacitor voltage Vcr is clamped at zero. At time t0, MOSFET turns on, starting a switching cycle. The fig.1. shows the half wave series ZCS QRC and fig.2 shows the simulated waveform of series ZCS QRC.

MODE 1: Linear Stage [t_0 , t_1]

Input current i_{Lr} rises linearly and its waveform is governed by the state equation:

$$L_r (di_{Lr} / dt) = E \qquad (1)$$

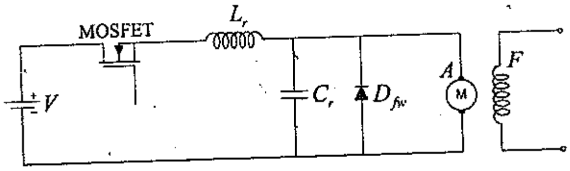

Figure 1 ZCS-Half-wave series quasi-resonant Converter

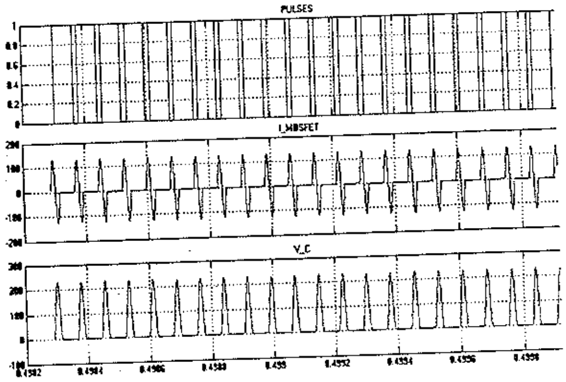

Figure 2 Waveforms for Halfwave series ZCS-QRC

the duration of this stage td1 (= t1 – t0) can be solved with boundary conditions of ILr (0) = 0 and ILr (td1)= Ia , thus

$$t_{d1} = (L_r I_a) / E \qquad (2)$$

MODE 2 : Resonant Stage [t1 , t2]

At time t1, the input current rises to the level of Ia , freewheeling diode is commutation off, and the difference between the input current and the output current iLr(t) - Ia flows into Cr, as can be seen from Fig.1(b).Voltage Vcr rises in a sinusoidal fashion.The state equations are

$$C_r (dV_{cr} / dt) = i_{Lr} (t) - I_a \qquad (3)$$

$$L_r (di_{Lr} / dt) = E - V_{cr} (t) \qquad (4)$$

with initial conditions $V_{cr}(0) = 0$, $i_{Lr}(0) = I_a$ therefore,

$$i_{Lr} (t) = I_a + (E / Z_0) \sin \omega t \qquad (5)$$

$$V_{cr} (t) = E (1 - \cos \omega t) \qquad (6)$$

MODE 3 : Recovering Stage [t_2, t_3]

Since MOSFET is off at time t2, capacitor begins to discharge through the output loop and Vcr drops linearly to zero at time t3 as shown in the Fig 2. The state equation during this interval is

$$C_r (dV_{cr} / dt) = - I_a \qquad (7)$$

The duration of this stage t_{d3} ($= t_3 - t_2$) can be solved with the initial condition Vcr (0) = V_{cr}

$$t_{d3} = C_r V_{cr} / I_a \qquad (8)$$

$$t_{d3} = C_r E (1 - \cos\alpha) / Ia \qquad (9)$$

MODE 4: Freewheeling Stage [t_3, t_4]

After t_3, output current flows through diode. The duration of this stage is t_{d4} ($= t_4 - t_3$), and

$$t_{d4} = T_s - t_{d1} - t_{d2} - t_{d3} \qquad (10)$$

where Ts is the period of the switching cycle.

After an interval of Toff, during which It is zero and Vcr = 0, the gate drive to the MOSFET is again applied at T4 to turn it on, and the operation during the next cycle is similar to that of the preceding cycle. By controlling the dead time (T4- T3), the average value of the armature voltage and hence the speed of the dc motor can be controlled.

- characteristic impedance
  $Z_n = \sqrt{(L_1 / C_1)}$
- resonant angular frequency
  $\omega = 1 / \sqrt{(L_1 C_1)}$
- resonant frequency
  $f_n = \omega / 2 \Pi$.

III. PI CONTROLLER

In the industry, PI controllers are the most common control methodology to use in real applications. Fundamentally they are simple to implement and they provide good performance.The closed-loop speed control employs an inner current control loop within an outer speed loop. The speed controller consists of PI controller which processes the speed error (i.e.) it compares the actual speed of motor (wm) with the reference speed (wref) and the output of the sped controller ec is applied to a current limiter which sets the current reference (Iref) for the inner current control loop. The armature current Ia is sensed by a current sensor, filtered preferably by an active filter to remove ripple, and compared with the current reference (Iref). The current controller compares the actual current with the reference current and produces pulses as a result. These pulses are fed to MOSFET and hence this results in variation of armature voltage to obtain the required (reference) speed of motor. Any positive speed error, caused by either an increase in the speed command or an increase in the load torque, produces a higher current reference (Iref). The motor accelerates due to an increase in Ia , to correct the speed error and finally settles at a new Iref which makes the motor torque equal to the load torque and the speed error close to zero. For any large positive speed error, the current controller saturates and the current reference Iref is limited to a value and the drive current is not allowed to exceed the maximum permissible value. The speed error is corrected at the maximum permissible armature current until the speed error becomes small and the current limiter comes out of saturation. Now the speed error is corrected with Ia less than the permissible value. Since the speed control loop and the current control loop are in cascade, the inner current loop is also known as cascade control. It is also called as current guided control.

IV. DESIGN OF FUZZY LOGIC CONTROL

PI controller is a standard control structure for classical control theory. But the performance is greatly distorted and the efficiency is reduced due to non linearity in the process plant. The fuzzy PI controllers are the natural extension of their conventional version, which preserve their linear structure of PI controller. The principle in order to obtain a new controller that possesses analytical formulas very similar to digital PI controllers. Fuzzy PI controllers have variable control gains in their linear structure. These variable gains are non liner function of the errors and changing rate of error signals. The main contribution of these variable gains in improving the control performance is that they are self-tuned and they can adapt to rapid changes of the error caused by time delay effects, nonlinearities and uncertainties of the underlying process. The Fuzzy logic controller employed to control the speed of ZCS-QRC fed DC drive is as shown in Fig.3. The FLC is an attractive choice when precise mathematical formulations are not possible.

In order to obtain the control surface for a nonlinear, time –varying and complex dynamic system , there are a number of simplifying stes to be followed . For the design of fuzzy logic controller, the following steps have been used:

- Identifying the variables (inputs and outputs) of the plant.
- Partitioning the universe of discourse of the interval spanned by each variable into a number of fuzzy subsets, assigning each a linguistic label (subsets include all the element in the universe).
- Assigning or determining membership function for each fuzzy subset.
- Assigning the fuzzy relationship between the input fuzzy subsets on the one hand and the output fuzzy subsets on the other hand, thus forming the rule base.
- Choosing appropriate scaling factors for the input and the output variables in order to normalize the variables to [0,1] or [-1,1] interval.
- Fuzzifying the inputs to the controller.
- Using fuzzy approximate reasoning to infer the output contributed for each rule.
- Aggregating the fuzzy outputs recommended by each rule.
- Applying defuzzification technique to form a crisp output.
- Sending the change of control action to control the plant.

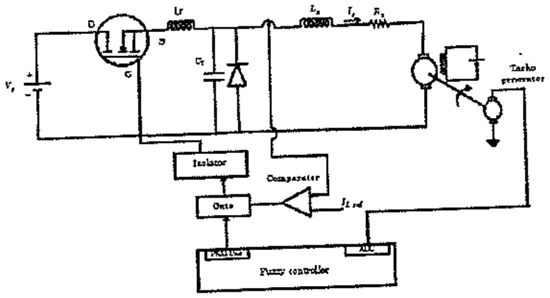

Figure 3 Fuzzy controlled ZCS QRC fed DC drive

The derivation of fuzzy control rules is heuristic in nature and based on the following criteria:

- When the output of the converter is far from the set point, the change of duty cycle must be large so far as to bring the output to the set point quickly.
- When the output of the converter is approaching the set point, a small change of duty cycle is necessary.
- When the output of the converter is near the set point and is approaching it rapidly, the duty cycle must be kept constant so as to prevent overshoot.
- When the set point is reached and the output is still changing, the duty cycle must be changed a littlr bit to prevent the output from moving away.
- When the set point is reached and output is steady, the duty cycle remains unchanged,
- When the output is above the set point, the sign of the change of the duty cycle must be negative and vice-versa.

A. Design of membership function

Error and change in error are the two inputs of the FLC and the change in duty cycle is the resulting output of FLC. Five triangular membership functions are chosen for simplicity in modeling and simulation of fuzzy controller. The membership functions for error, change in error and pulses are shown in fig.4,5&6 respectively.

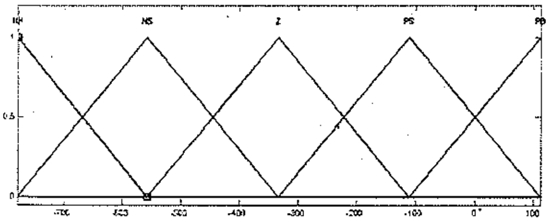

Figure 4 Triangular membership function for error

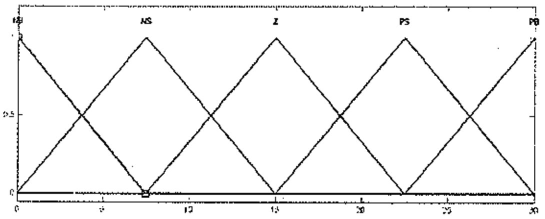

Figure 5 Triangular membership function for change in error

Figure 6 Triangular membership function for pulses

Table 1. Rule table with 25 rules

u(t)		e(t)				
		NB	NS	Z	PS	PB
de(t)	NB	NB	NB	NS	NS	Z
	NS	NB	NS	NS	Z	PS
	Z	NS	NS	Z	PS	PS
	PS	NS	Z	PS	PS	PB
	PB	Z	PS	PS	PB	PB

B. Development of rule base :

The rules connecting the inputs and outputs are based on the understanding of the system. Normally the fuzzyrules have if ….then ….structure. The inputs are combined by AND operator. Table 1 shows the fuzzy rule base created in the present work based on intuitive reasoning and experience.

C. Defuzzification:

Mamdani type fuzzy inference system is used in the present work. With the fired rules, the defuzzication is done to get a final 'crisp' value of the incremental control. Several defuzzification methods are available. The centre of gravity method is the most commonly used method which gives the defuzzified 'crisp' value as

$$Z = \delta d_K = (\mu_i C_i / \mu_i) \qquad (11)$$

Where,

μ_i - membership value of the output set 'i'
C_i - corresponding output fuzzy value
δd_K - Change of duty cycle inferred by the fuzzy controller at the K^{th} instant
d_K - updated duty cycle
η - gain factr of the fuzzy controller

$$d_K = d_{K-1} + \eta\, \delta d_K \qquad (12)$$

The defuzzified value 'z' is multiplied by suitable gain to get the incremental duty ratio. A lower gain helps in reducing the oscillations of the fuzzy controller but gives a slower response. A higher gain makes the controller oscillatory. The rule viewer and surface viewer of fuzzy logic controller employed are shown in Fig.7 & 8 respectively.

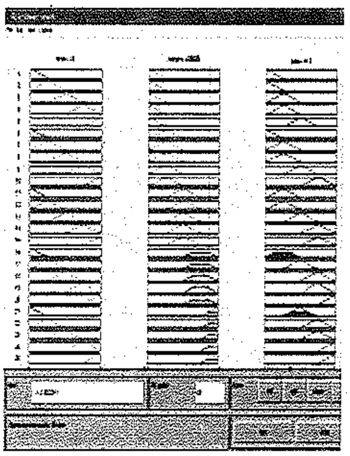

Figure 7 Simulink window with Rule viewer

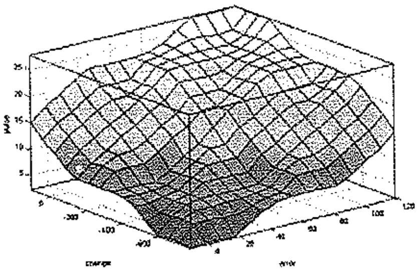

Figure 6 Surface viewer of Fuzzy logic controller

V. RESULTS AND DISCUSSIONS

The behaviour of the PI controlled QRC fed DC drive and Fuzzy logic controlled L-type ZCS QRC fed DC drives are studied using MATLAB. It can been observed from the waveforms that for the speed control the switching period TOFF is varied but the TON is kept constant. Also it can be observed that by varying the switching frequency from 9 KHz to 13 KHz the speed of the DC motor can be varied from 30 rad / s to 42 rad / s .The circuit elements of QRC are represented using standard models available in MATLAB. The pulse to the MOSFET is fed by means of pulse generator. In closed loop configuration the pulses to turn on and turn off the device is designed by using the equations obtained while analyzing the stages of operation. The simulated waveforms of the converter comprises of pulses, MOSFET current, capacitor voltage and diode current. The simulated waveform of the converter side load torque value 7 Nm for PI controller and FLC QRC are shown in Fig. 9 & Fig.10 respectively.

Similarly the simulated waveforms of the motor side comprises of the armature voltage, armature current and speed. The simulated waveforms of the motor side for the load torque value 7 Nm for PI controller and FLC QRC are shown in Fig.11 & Fig.12 respectively.

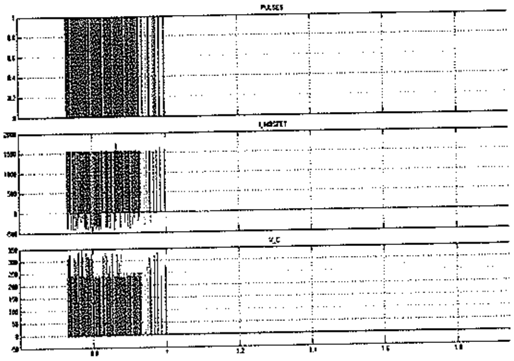

Figure 9 Waveform of converter side PI QRC at load torque of 7 Nm

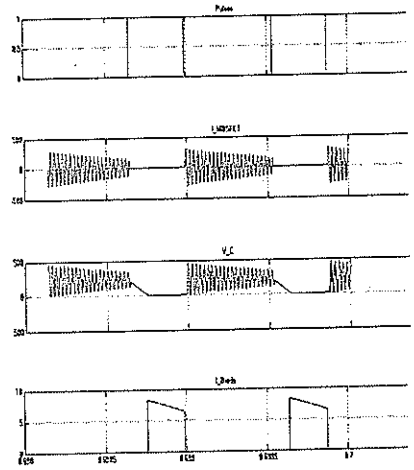

Figure 10 Waveform of converter side FLC QRC at load torque of 7 Nm

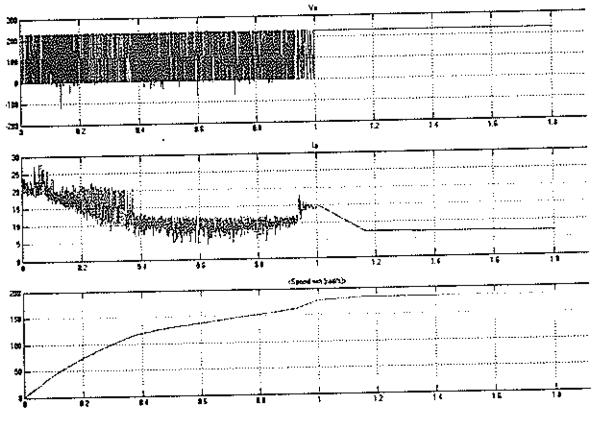

Figure 11 Waveform of motor side PI QRC at load torque of 7 Nm

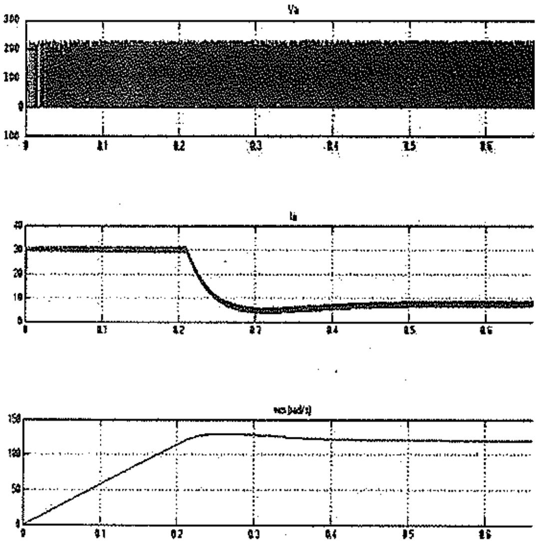

Figure 12 Waveform of motor side FLC QRC at load torque of 7 Nm

VI. CONCLUSION

The simulation results prove that the developed fuzzy control has good response than compared to the conventional PI controller. The FLC QRC-fed DC drive has been found to operate with improved efficiency which is a consequence of the soft switching employed than the conventional PI controller. The drive also has other desirable features like reduction in armature current ripple and EMI levels, high power density and high reliability. The work of this paper has indicated that the application of resonant converters to DC drives has a promising future due to the reduction in switching losses and switching stresses. The implementation of fuzzy logic controller has enhanced speed control of DC drive than PI controller. It improves the Drive robustness (minimal rising time, steady state error to zero). Thus these results validate the effectiveness of the developed fuzzy controller.

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