INT J COMPUT COMMUN, ISSN 1841-9836
9(1):48-55, February, 2014.

Modeling and Simulation of Genetic Fuzzy Controller for L-type ZCS Quasi-Resonant Converter

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Abstract: A new method of speed control of DC drives using series Quasi-Resonant (QR) Zero current switching (ZCS) DC to DC converters is proposed. It employs a Fuzzy logic controller (FLC) in feedback loop conventionally but due to the advent of new intelligent techniques the FLC are optimized by Genetic algorithm (GA). In this paper the GA optimization technique is applied for speed control of series ZCS-QRC fed drive. The main objective of this work is to obtain reduced transient response, reduced switching stresses and switching losses which in turn enhances the efficiency and commutation capability of motor.
Keywords: Fuzzy logic controller (FLC), Zero Current Switching Quasi-Resonant Converter (ZCS-QRC), Genetic Algorithm (GA), Integral Absolute Error (IAE), Direct Current (DC)

1 Introduction

The dc motor drives have the advantage of high controllability and are used in many applications such as robotic manipulators, position control, steel mining, and paper and textile industries. In some industrial applications, the dynamic response of drives is bounded by certain limitations such as transient time and steady state error. In addition when they are fed from PWM converter [1], they suffer from high switching losses, reduced reliability, electromagnetic inference and acoustic noise. To overcome the above difficulties quasi-resonant converters [2]- [3] are used which can be either zero current (ZC) or zero voltage switching (ZV) .In order to improve the speed response and regulation of the converter fed drives it is necessary to have closed loop control. Conventionally closed loop response employs PI controller but the performance of the drive is sensitive to load disturbances and parameter variations. The advent of FLC has been suggested as an alternative approach to conventional control techniques for complex control system like non linear system. The design of FLC does not require the exact mathematical model of the system and can compensate the parameter variation due to load disturbances ([4]- [5]). Unfortunately a good performance cannot be obtained for incorrect membership functions, fuzzy rules and scaling factors. This necessitates the optimization technique of FLC by Genetic algorithm [6]- [8] to achieve optimal solutions of membership function, fuzzy rules and scaling factors. In this paper speed control of series ZCS-QRC fed DC drive is composed of two steps. The first step is conventional control of DC drive by FLC. The second step is optimization of FLC by GA.

2 Analysis of Series FM-ZCS-QRC Fed DC Drive

The QRC with ZCS topology is considered for the present work.Fig.1. shows the circuit diagram of the QRC fed motor.The waveform for the model is shown in fig.2.

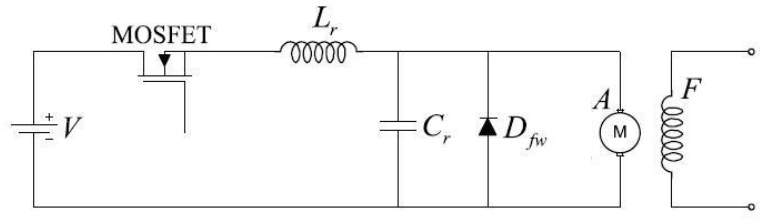


Figure 1: ZCS-Half-wave series quasi-resonant Converter

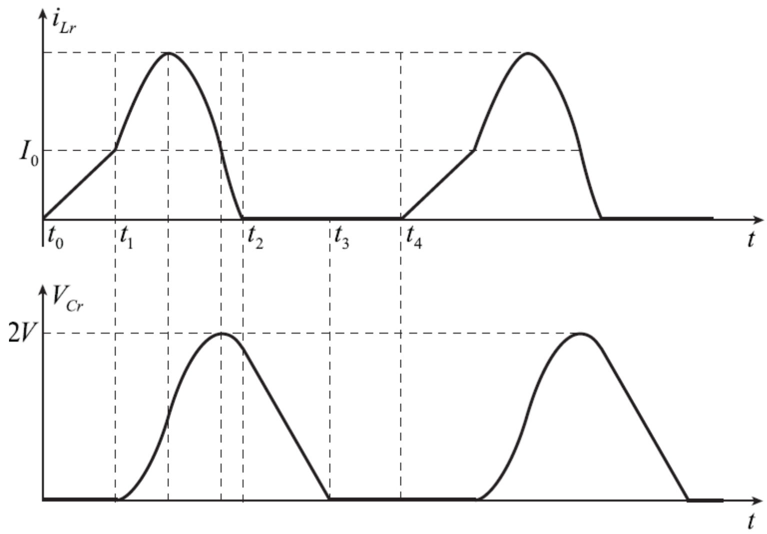


Figure 2: Waveforms for Half wave series ZCS-QRC

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. *MODE 1 : Linear Stage [t0 , t1]* Input current iLr rises linearly and its waveform is governed by the state equation:

$$Lr(diLr/dt) = E \tag{1}$$

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

$$td1 = (LrIa)/E \tag{2}$$

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, Voltage Vcr rises in a sinusoidal fashion.The state equations are

$$Cr(dVcr/dt) = ILr(t)Ia \tag{3}$$

$$Lr(diLr/dt) = EVcr(t) \tag{4}$$

with initial conditions Vcr(0) =0 , iLr(0)= Ia and therefore,

$$iLr(t) = Ia + (E/Z0)sint \tag{5}$$

$$Vcr(t) = E(1 - cost) \tag{6}$$

MODE 3 : Recovering Stage [t2 , t3] Since MOSFET is off at time t2, capacitor begins to discharge through the output loop and Vcr drops linearly to zero at time t3 . The state equation during this interval is

$$Cr(dVcr/dt) = -Ia \tag{7}$$

The duration of this stage td3 (= t3 t2) can be solved with the initial condition Vcr (0) = Vcr

$$td3 = CrVcr/Ia \tag{8}$$

$$td3 = CrE(1 - cos)/Ia \tag{9}$$

MODE 4: Freewheeling Stage [t3 , t4] After t3, output current flows through diode. The duration of this stage is td4 (t4 t3),

$$td4 = Ts - td1 - td2 - td3 \tag{10}$$

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

$$Zn = (L_1/C_1) \tag{11}$$

- resonant angular frequency

$$\omega = 1/(L1C1) \tag{12}$$

- resonant frequency

$$fn = \omega/2\pi \tag{13}$$

3 Fuzzy Logic Controller

Fuzzy Logic Control is derived from fuzzy set theory introduced by Zadeh in 1965. In fuzzy set theory, the transition between membership and non-membership can be gradual. Therefore, boundaries of fuzzy sets can be vague and ambiguous, making it useful for approximate systems. 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. Other advantages of FLC are it can work with less precise inputs, it does not need fast processors,

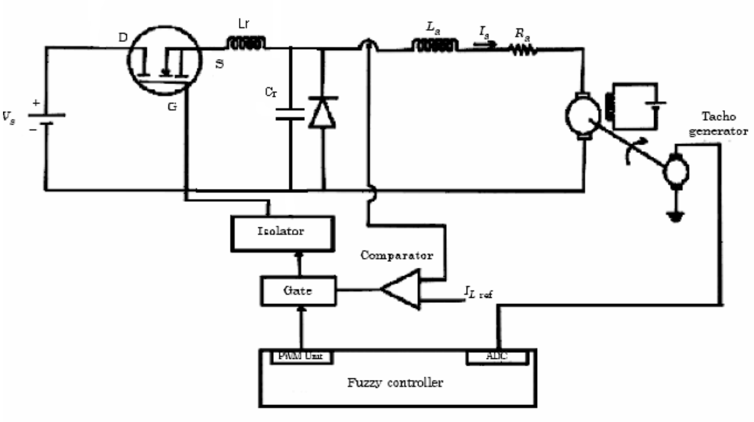


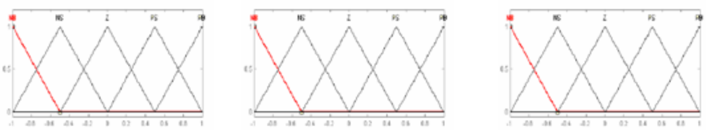
Figure 3: Fuzzy controlled Series ZCS QRC fed DC drive

Table 1: Rule table with 25 rulres

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

it needs less data storage in the form of membership functions and rules than conventional look up table for non-linear controllers; and it is more robust than other non-linear controllers, parallel with the z-network output terminals.

The simplest form of membership function is triangular membership function and it is used here as the reference. As Sugeno type of implication is considered, the singleton membership function is used for the output variable namely the change in duty cycle. The spread of membership functions for the inputs (error and change in error) and output (pulses) are shown in Fig.4.respectively.



(a) Error (b) Change in error (c) Pulses

Figure 4: Triangular membership functions for FLC

The rules for the designed fuzzy controller are given in the Tables 1 .Table 1 uses five linguistic variables for error and change in error with 25 rules. The five sets used for fuzzy variables 'error' and change in error are negative big (NB), negative small (NS), zero (Z), positive big (PB), and positive small (PS). From the rule table, the rules are manipulated as If error is NB and change in error is NB, then output is NB.

4 GA Optimized FLC

Genetic algorithms [9]- [10], which are adopted from the principle of biological evolution, are efficient search techniques that manipulate the coding representing a parameter set to reach a near optimal solution. Hence by strengthening fuzzy logic controllers with genetic algorithms the searching and attainment of optimal fuzzy logic rules and high-performance membership functions will be easier and faster. GAs is used regularly to solve difficult search, optimization and machine-learning problems that have previously resisted automated solutions. They can be used to solve difficult problems quickly and reliably. These algorithms are easy to interface with existing simulations and models, and they are easy to hybridize. GAs includes three major operators: selection, crossover, and mutation, in addition to four control parameters: population size, selection crossover and mutation rate. This paper is concerned primarily with the selection and mutation operators. There are three main stages of a genetic algorithm; these are known as reproduction, crossover and mutation. The flow chart of a genetic algorithm is shown in figure 5.

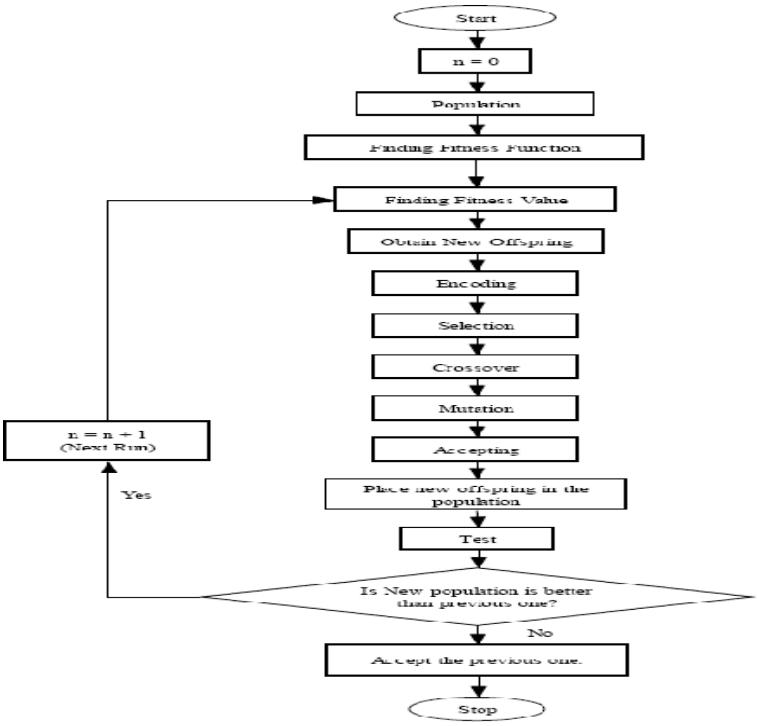


Figure 5: Flowchart for Genetic Algorithm

The steps involved in genetic algorithm are described below.

- Start: Generate random population of n chromosomes (suitable solutions for the problem).
- Fitness: Evaluate the fitness f(x) of each chromosome x in the population.
- New population: Create a new population by repeating following steps until the new population is complete.
  - Selection: Select two parent chromosomes from a population according to their fitness (the better fitness, the bigger chance to be selected).
  - Crossover: With a crossover probability, cross over the parents to form new offspring (children). If no crossover was performed, offspring is the exact copy of parents.
  - Mutation: With a mutation probability, mutate new offspring at each locus (position in chromosome).

- Accepting: Place new offspring in the new population.

- Replace: Use new generated population for a further run of the algorithm
- Test: If the end condition is satisfied, stop, and return the best solution in current population.
- Loop: Go to step 2.

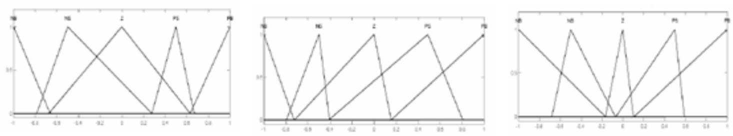
The objective functions IAE (Integral Absolute Error). The main objective of controller is to minimize the error signal or in other words we can say that minimization of performance indices.

$$IAE = \int_0^t |e(t)dt| \tag{14}$$

The fitness value of the chromosome is the inverse of the performance indices. The fitness value is used to select the best solution in the population to the parent and to the offspring that will comprise the next generations. The fitter the parent greater is the probability of selection. This emulates the Evolutionary process of survival of the fittest. Parents are selected using roulette wheel selection method. Fitness function is reciprocal of performance indices. In this paper we have taken the discrete form of ITAE. ITAE is treated as performance indices and fitness function denoted by J can be described as

$$J = 1/(100 + \sum_{K=1}^{N} |\omega ref - \omega m|) \tag{15}$$

The membership functions obtained for error, change in error and pulses for GA optimized FLC are shown in fig.6. The simulation structure of optimized fuzzy speed controller with the IAE is shown in fig.7 & fig.8 respectively.



(a) Error (b) Change in error (c) Pulses

Figure 6: GA Optimized membership functions

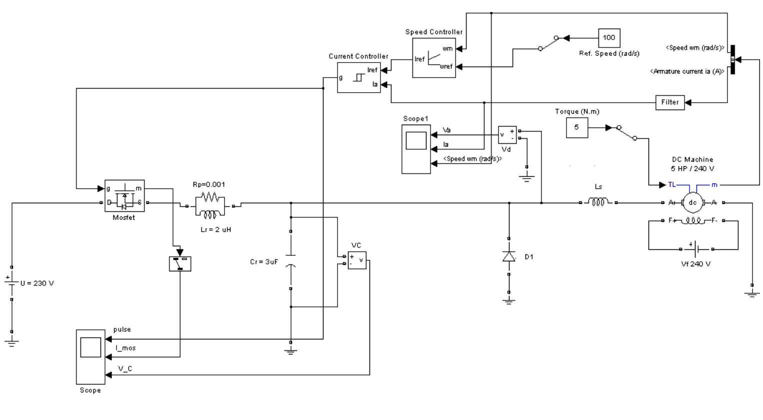


Figure 7: Simulated structure of GA based FLC of series ZCS-QRC fed DC drive

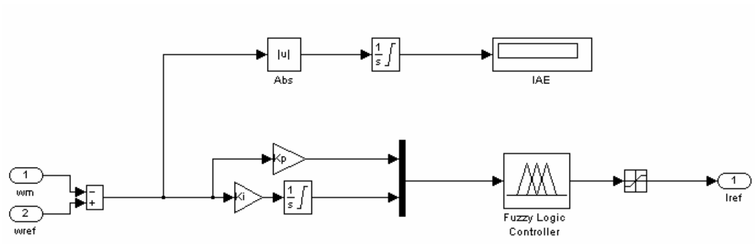
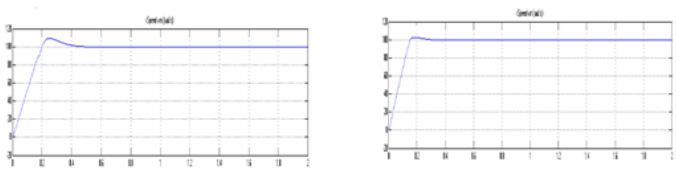


Figure 8: Simulated structure of Optimized Fuzzy speed controller

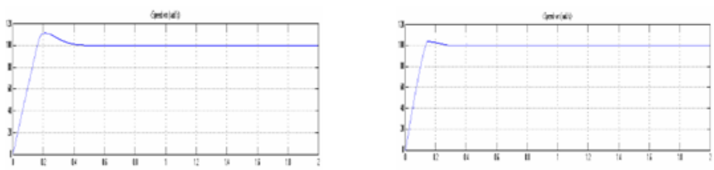
5 Simulation Results

The closed loop operations of series FM-ZCS-QRC fed DC drive has been simulated. Controlling the freewheeling period using the controller regulates the speed of the drive. The speed variations for sudden load disturbances are shown for increased load torque and decreased load torque in fig.9 and fig.10 respectively. It can be said that the speed remains constant even for various disturbances of load torque.



(a) with Fuzzy speed controller (b) with GA optimized Fuzzy speed controller

Figure 9: Speed response for increase in load torque



(a) with Fuzzy speed controller (b) with GA optimized Fuzzy speed controller

Figure 10: Speed response for decrease in load torque

6 Conclusion

We design the speed controller of the Series FM-ZCS-QRC in two steps. In step one the conventional FLC is designed and simulated and second step optimization of membership function ,fuzzy rules and scaling factors of FLC by Genetic algorithm is considered. The simulation results show that the optimal fuzzy logic controller is functioning better than a conventional FLC in terms of the rise and settling time. Hence it can be concluded that the GA optimized FLC implemented in ZCS-QRC fed drive enhances the drive robustness by reducing the transient time and steady state error and superior than the conventional fuzzy controller.

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