CHAPTER 6

PSpice SIMULATION OF FUZZY LOGIC CONTROL OF QRC FED DC SERVOMOTOR

6.1 INTRODUCTION

In this chapter, a fuzzy based speed controller for quasi-resonant DC-DC converter supplying a DC servomotor is presented. Fuzzy controllers can perform well even for those systems where linear control techniques fail. The controller implementation is relatively simple and can guarantee a fast and stable small signal response compared to standard regulators. This chapter deals with the modeling and simulation of fuzzy speed controller using PSpice (Latha 2000) for the speed control of buck-boost CF-ZVS-QRC feeding a DC servomotor.

6.2 PSpice MODELING AND DESIGN OF FUZZY LOGIC CONTROLLER

Fuzzy logic is a relatively new discipline of science and engineering. It is used to generate simple, intuitive, rule based control systems. Fuzzy logic combines the simplicity of digital systems with the information richness of analog circuitry. An example for a fuzzy logic control rule is: “If the error is low AND the error rate is high, then the output is low”. This intuitive approach of designing a controller is often advantageous for non-linear and poorly defined systems.

The general structure of fuzzy logic controller (FLC) is represented in figure 6.1 and comprises of three principal stages namely fuzzification stage for the generation of fuzzy signals, rule application stage to combine the fuzzy signals based on rules and defuzzification stage for the calculation of an analog output value.
6.2.1 Fuzzification stage

Fuzzification is the process of transforming the crisp control variables to corresponding fuzzy variables. The error and change in error have been selected as controller inputs for the present problem. Linguistic variables used are NB, NS, Z, PS and PB which stand for negative big, negative small, zero, positive small and positive big respectively. The fuzzy membership functions are generated using ETABLE devices and the fuzzy signal generator is shown in figure 6.2. An ETABLE device is a voltage controlled voltage source with a look up table for the control function. They are available in the analog behavioral modeling (ABM) library of PSpice. The five fuzzy membership functions PB, PS, Z, NS and NB are generated from an analog input signal. Each input signal for the fuzzy system is treated in this manner. The information content of the fuzzy signals is higher than digital signals since they are not pure input / output levels. Fuzzy membership functions correlate the output value of a fuzzy signal to the analog input signal. The output signals indicate the degree of membership of the input signal. Trapezoidal membership function is chosen with some overlap between neighbouring signals. For example, the TABLE attribute of the E_Zero device in figure 6.2 is (-1.5, 0) (-0.5,100) (0.5,100) (+1.5, 0). This makes the output zero for...
input voltages below -1.5V and above +1.5V, and 100V when the input voltage lies in between -0.5V and +0.5V. Between -1.5V and +1.5V the output voltage is determined by linear interpolation between the corner points. The output of the fuzzy signal generation circuit is shown in figure 6.3. The range of the input signal for the circuit in figure 6.2 is from -5V to 5V. The amplitude of the fuzzy signal is conveniently fixed at 100V for 100% signal amplitude.

6.2.2 Derivation of control rules

Fuzzy control rules are obtained from the analysis of the system behavior. The selected control rules are described as:

i) When the control variable is far from the set value, the corrective action done by the controller must be strong, in order to have the dynamic response as fast as possible. The control rule is, “If error is positive big OR error rate is positive small then output is 1”

ii) When the control variable is close to the set point, the corrective action shall be mild. The selected control rule is, “If error is positive small OR error rate is negative small then output is 0.5”.

iii) When the control variable is equal to the reference value the control law is, “If error is zero AND error rate is zero then output is 0.4”.

The control laws are implemented using the fuzzy Boolean operators. The fuzzy AND function returns the minimum value and the fuzzy OR function returns the maximum value. A test circuit with triangular and trapezoidal membership function (custom) symbols as shown in figure 6.4 is modeled to study the effect of fuzzy Boolean operators. The response of the test circuit is shown in figure 6.5 and the results exactly match with the theoretical results.
Figure 6.2  PSpice Circuit for the generation of fuzzy membership functions
Figure 6.3 Trapezoidal fuzzy membership functions
Figure 6.4 PSpice circuit diagram of fuzzy signal generator and fuzzy Boolean functions
Figure 6.5 Effects of fuzzy AND and OR operators
6.2.3 Defuzzification Stage

The method of testing and combining the fuzzy rules in a specified manner for making a decision is referred to as defuzzification. The defuzzification process gives a crisp control variable based on fuzzy control variable and knowledge base. Many techniques are available for defuzzification. In the present work, the height defuzzification procedure is followed and it gives the crisp control variable as the ratio of weighted sum of fuzzy control variables to the sum of fuzzy control variables. The weight for each fuzzy control variable is chosen from the knowledge base to give the desired output. The crisp control variable $V_{\text{out}}$ is expressed as

$$V_{\text{out}} = \frac{V(\text{IN}1) + V(\text{IN}2) + V(\text{IN}3)}{V(\text{IN}4) + V(\text{IN}5) + V(\text{IN}6)}$$ (6.1)

The defuzzification stage is modeled as a voltage controlled voltage source.

6.2.4 Fuzzy Logic Controller

Figure 6.6 shows the fuzzy controller block. The input signals to the fuzzy controller are the error and the error rate signal. An “error integral” signal is generated and added to eliminate steady state error. However the gain of the integrator is set to a very low value so that the integrator does not make any significant contributions to the dynamics of the system. The low pass filter on the input of the differentiator consisting of $R_{\text{lp}}$ and $C_{\text{lp}}$ protects against excessive slew rates of the set point signal. The $\frac{d}{dt}$ function used in the differentiator block generates the derivative of error signal with respect to time.

6.3 APPLICATION OF FUZZY CONTROL TO QRC FED DC SERVOMOTOR

The basic structure of a quasi-resonant converter fed DC servomotor using fuzzy controller is shown in figure 6.7. A fuzzy based speed controller has been
Figure 6.6 Block diagram of the fuzzy controller
proposed to handle the nonlinear operating conditions existing in the characteristics of the converter.

Figure 6.7 Block diagram of the QRC fed DC servomotor using fuzzy controller

The converter is represented by a block (QRC) and its output voltage is applied to the armature of DC servomotor. The speed error (Δω) and the rate of change of speed error (Δω) are the input variables to the fuzzy controller. The signal from the controller is then compared in PWM modulator with a sawtooth waveform whose frequency is equal to the switching frequency of QRC. The PWM modulator generates the pulse of desired duty ratio for the QRC switches.

6.3.1 Simulation of Fuzzy controlled QRC fed DC Servomotor

The speed of DC servomotor changes with load torque. A closed loop fuzzy control system is proposed to maintain a constant speed under load and set point disturbances. The PSpice circuit model of closed loop system for CF-ZVS-QRC fed DC servomotor is shown in figure 6.8.
The fuzzy block represents the fuzzy speed controller. This is a user-defined block and its internal circuit is already shown in figure 6.6. Speed error is given at the point “in”. The output of fuzzy logic controller available in pins, “out+” and “out-” are given to PG block pins L1+, L1-, L2+ and L2-. The PG block generates pulses of desired duty ratio to keep the speed equal to the reference value.

6.3.2 Simulation Results

The dynamics of the fuzzy controlled QRC fed DC servomotor is studied by applying a step change in the voltage source $V_{Reference}$. The motor is made to run at the speed of 1000 rpm with 20% load. A step increase in set speed from 1000 rpm to 1200 rpm is applied at $t = 120$ msec and the response of the fuzzy logic controller obtained by simulation is shown in figure 6.9(a). The response of the system is also studied for load torque variations by making a step change in load torque of 50% applied at $t = 200$ msec and the results are shown in figure 6.9(b). In both the cases the speed settles at the reference value within 10 msec after a step disturbance is effected. It
Figure 6.9 (a) Simulation of fuzzy speed controller for change in set speed
Figure 6.9 (b) Simulation of fuzzy speed controller for a 50% step increase in the load
is found that the PI speed controller system takes 20 msec to settle down to the reference value whereas the fuzzy controller takes only 10 msec for the same operating condition.

6.4 CONCLUSION

The closed loop fuzzy controlled of CF-ZVS-QRC fed DC servomotor has been simulated. A PSpice model of the fuzzy controller has been developed using the ABM library and applied for the speed control of CF-ZVS-QRC fed DC servomotor. Controlling the free wheeling period of the resonant inductor using a fuzzy controller regulates the speed of the motor. The speed variations for sudden change in load and set point are studied. It is observed that the fuzzy controller is able to maintain the output speed equal to the reference value when load torque is suddenly changed and the settling time is much less when compared to the PI controller. The dynamics of the system can be improved by modeling more number of fuzzy rules.