Analysis of Different Speed Controllers and Implementation of Novel Speed Controller using FPGA for BLDC Motor

Kirti B. Satale, Anagha P. Khedkar

Abstract- BLDC motor controller has significant importance because of inherent properties of motor like high efficiency, low noise operation, maintenance free, etc. Variety of speed controllers like PID, fuzzy PID and adaptive fuzzy PID are reviewed. In adaptive fuzzy PID controller, to have online control, gains of fuzzy PID controller are changed with change in error. After simulating and comparing speed characteristic of different speed controllers, a novel speed controller having less rise time and overshoot will be implemented using FPGA.

Keywords - BLDC motor, Fuzzy logic, PID controller.

I.INTRODUCTION

BLDC motors are special type of DC motors in which brushes are not used for commutation. It uses permanent magnet and accomplishes the switching by electronically switching the polarity of windings. In order to accomplish this in a controlled manner a speed feedback mechanism and electronic controller is required. BLDC motors are widely used for many applications in areas like automation, military, medical and for other appliances etc. Hence, it is important to design low cost and efficient speed controller for BLDC motors.

Many techniques for BLDC motor control have been developed such as PI, PID, fuzzy logic controller, adaptive fuzzy logic controller. Fuzzy logic is based on fuzzy set theory, which is used for many control applications. Fuzzy logic is used with different control techniques as it is more resulting with complex systems in which less numerical data exists and where only imprecise information is available. Fuzzy reasoning provides way to understand system behaviour by allowing interpreting around observed input and output relation of system.

As day by day automation is increasing and also due to special properties of BLDC motor over other motors, control drive of it has significant importance. This study includes various controller designs. In section II literature review of existing controllers is given. Section III introduces BLDC motor, its working principal and some basic mathematical equations for it. Section IV gives overview of design of speed control drive for BLDC motor. In section V simulation model and description of controllers with whole system model is given, which will be simulated using MATLAB/SIMULINK software. Some concluding remarks are given in section VI.

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II. LITERATURE SURVEY

With three PI controllers, fuzzy logic is used to scale speed error and it is shown that fuzzy logic improves speed control of BLDC motor [1]. Because of nonlinearity of PMSM and influence of some uncertain factors as load, disturbance; the conventional PID control system is difficult to live up to ideal control performance hence with PID, PI controllers intelligent system is used for proper tuning of parameters[2].

All controlling designs of BLDC motor also be used for sensor less BLDC motor control. In which back EMF waveform is observed and using different algorithms, speed of BLDC motor can be estimated, which is compared with reference speed. Zero crossing detection of back EMF is one of important technique of sensor less speed detection [3, 4].

N. Parhizkar et al verified that for eliminating overshoot existing in speed and torque response, PI controller is replaced by FLC [5]. Using fuzzy logic an intelligence system as speed control algorithm, improves dynamic performance of system, provides good adaptability and strong robustness whenever system is disturbed [6]. Cost effective reconfigurable digital controller implemented for BLDC motor. In which, performance of motor is changed only by changing code embedded in FPGA [7]. After simulating and comparing dynamic performance of PI and fuzzy based controller it is proved that fuzzy logic controller gives better dynamic response and it is robust [8]. Using fuzzy auto adjust PID control for speed control of BLDC motor, accelerate the response speed of motor, strengthen anti interference ability [9].

In control of motor with sensors mostly hall sensors are used for rotor position detection and hence speed of motor. That calculated speed is compared with reference speed, difference between those taken an error is fed to controller. Here controllers like PID, fuzzy PID, and adaptive fuzzy PID are reviewed. In adaptive fuzzy PID controller, real time control of speed is possible by using various adaptive techniques. Here constant gains of PID controller will be changed according to error signal. As these gains vary, there will be effect on speed control characteristic parameters like rise time, peak overshoot and steady state error. After doing analysis of controllers, controller having batter response will be implemented using digital implementation technique.

The digital implementation of control system, field programmable gate array can also be considered as an appropriate solution in order to boost the performance of controller.

BLDC motor is well suited for digital control methods, thus FPGA is ideal for controlling this motor. Hence after MATLAB/SIMULINK simulation of different controllers a novel controller will be implemented using FPGA.

III. BLDC MOTOR WORKING PRINCIPLE

The name BLDC motor suggests it do not uses brushes for commutation. BLDC motor consists of stator and rotor. Stator is consists of stacked steel laminations with winding placed in slots. Most BLDC motors have three stator windings connected in star fashion. Rotor is made up of permanent magnet and it can be of two to eight pole pairs with alternate north and south. Permanent magnetic material for rotor is chosen based on magnetic field density required in rotor.

Hall sensors working on Hall Effect principle are used for rotor position detection depending on hall voltage generated in them as rotor pole passes nearer to hall sensor. Hall sensors are embedded into stator in BLDC motor as shown in figure 1. According to sequence of hall sensors stator windings are energised in sequence.

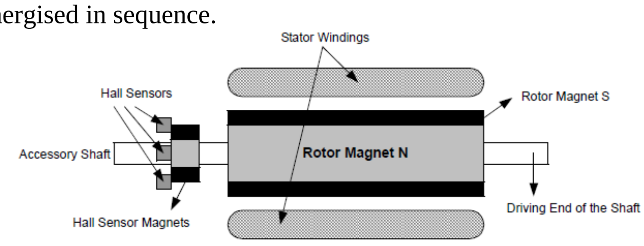

Figure 1.BLDC motor with hall sensors [5]

Each commutation sequence has one of winding energised to positive power, the second winding energised to negative and the third is in a non-energised condition. General circuit of BLDC motor with power converter is shown in fig. 2. The speed and torque of motor depend on strength of magnetic field generated by energised windings of motor, which depend on current through them. Therefore adjusting the stator winding voltage will change motor speed.

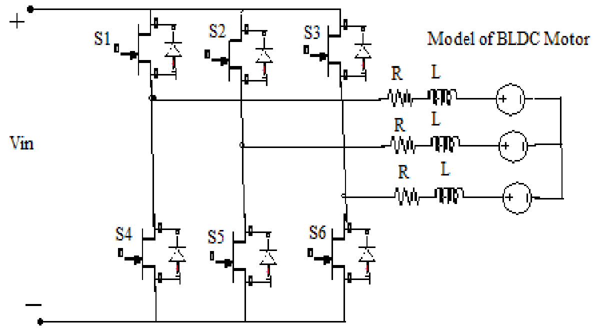

Figure 2.Configuration of BLDC motor drive system

The analysis of BLDC motor is represented by following equations:

In equation 1, v_a, v_b and v_c are phase voltages,

i_a, i_b and i_c are the phase currents,

e_a, e_b and e_c are phase back-EMF waveforms.

R is phase resistance.

L is self-inductance of each phase and M is mutual inductance between any two phases.

$$\begin{bmatrix} va \\ vb \\ vc \end{bmatrix} = \begin{bmatrix} R & 0 & 0 \\ 0 & R & 0 \\ 0 & 0 & R \end{bmatrix} \begin{bmatrix} ia \\ ib \\ ic \end{bmatrix} + \begin{bmatrix} L-M & 0 & 0 \\ 0 & L-M & 0 \\ 0 & 0 & L-M \end{bmatrix} \frac{d}{dt} \begin{bmatrix} ia \\ ib \\ ic \end{bmatrix} + \begin{bmatrix} ea \\ eb \\ ec \end{bmatrix}$$

(1)

Electromagnetic torque can be given as:

$$T_e = (e_a i_a + e_b i_b + e_c i_c) / \omega_r \quad (2)$$

Where ω_r is mechanical speed of the rotor.

The electrical speed ω_e is related to mechanical speed for a motor with P number of poles is:

$$\omega_e = (p/2)\, \omega_r \quad (3)$$

IV. BLDC MOTOR SPEED CONROL

As shown in fig. 3, basic speed control system of BLDC motor consist of four blocks as controller, inverter, BLDC motor and speed measurement unit. Speed is measured using hall sensors which are embedded on stator. Controller can be of various types as PI, PID, fuzzy PID, adaptive fuzzy PID etc. Measured and reference speed are given to controller where difference between speeds is taken as an error. Controller works on that error and gives output to inverter block which decides which winding of BLDC motor is getting on. As per sequence of inverter gates windings of BLDC motor are getting on or off and hence field changes takes place and according to that rotor position will change. In this way speed can be controlled.

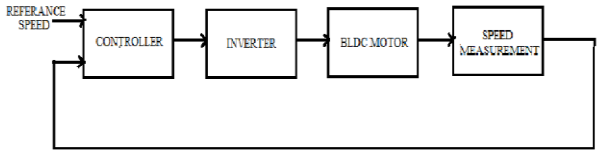

Figure 3 .Block diagram speed control of BLDC motor

In closed loop control system we are interested in four major characteristics of closed loop step response. Those are:

a)Rise time:

The time it takes for plant output to rise beyond 90% of desired level.

b)Overshoot:

How much peak level is higher than steady state, normalised against steady state.

c)Steady state error:

The difference between desired output and steady state output.

d)Settling time:

The time it takes for system to converge to its steady state.

A. PID Controller

Error signal is input to PID controller. Error signal is difference between reference speed and measured speed. The letter P, I and D stands for P-Proportional, I-Integral and D-Derivative. Transfer function of most basic PID controller is

$$C(S) = K_P + \frac{KI}{S} + K_D S \quad (4)$$

$$C(S) = \frac{KDS^2 + KPS + KI}{S} \quad (5)$$

Where, K_P- Proportional gain, K_I- Integral gain and K_D- Derivative gain.

Output of PID controller given to control plant is sum of proportional gain times magnitude of error, integral gain times integral of error and derivative gain times derivative of error.

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$$U = K_P e + K_I \int e\,dt + K_D \frac{de}{dt} \qquad (6)$$

Where, e is error.

B.Fuzzy and Adaptive Fuzzy PID Controller

In fuzzy logic controller before PID controller fuzzy logic is used. Fuzzy logic consist of three basic steps as fuzzification, decision making using knowledge base and defuzzification which is shown in fig. 4.

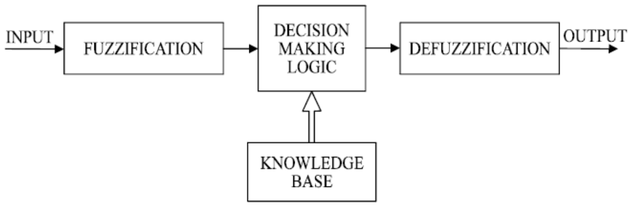

Figure 4 .Fuzzy logic controller

Inputs error and change in error are fuzzified using fuzzy set theory and fuzzification process. Fuzzy set is represented by a membership function defined on universe of discourse. Universe of discourse is space where fuzzy variables are defined [7] [8]. For this system, seven different variables will be defined are NB- Negative Big, NM- Negative Medium, NS- Negative Small, Z- Zero, PS- Positive Small, PM- Positive Medium and PB- Positive Big. Defuzzzification is process in which fuzzy variables are again translated into regular format.

In both fuzzy PID and PID controller K_P, K_I, and K_D are constant. But for adaptive fuzzy PID controller these constants vary with respect to change in error. In adaptive fuzzy PID controller with fuzzy PID controller a subsystem used to decide how to vary the constants according to change in error and hence speed. Hence in adaptive fuzzy PID controller, real time speed control of BLDC motor is possible.

V. SPEED CONTROLLERS

Fig. 5 shows SIMULINK model of whole system. In that BLDC motor is modeled using basic equations of BLDC motor. Speed is calculated using T_e and T_l which are electric and load torque respectively. Ideal bridge module provides phase voltages U_a, U_b, and U_c to motor. Motor speed changes with change in these voltages. This will be done using speed controller. Speed controller is of various types as PID, PI, fuzzy logic used with PID or PI and also any of advanced intelligence logic used with basic controllers.

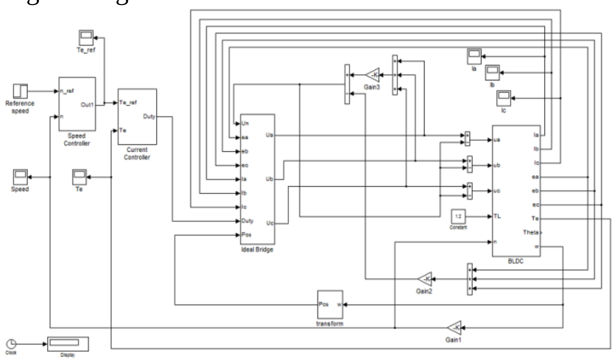

Figure 5 .SIMULINK model of BLDC motor drive

A.PID Controller

Basic PID controller module is shown in fig. 6. In PID controller gains are K_p, K_i and K_d will be varied either by manual method or ZN method to get output response with less rise time and overshoot.

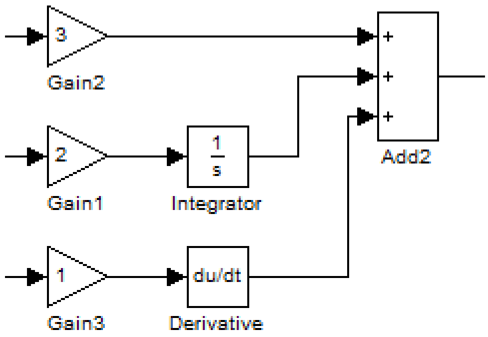

Figure 6 .PID controller module

B.Fuzzy PID Controller

Fig. 7 shows PID controller using fuzzy logic controller. Fuzzy logic controller is a block in which fuzzy membership functions are defined using FIS editor, which is shown in fig. 8. Fuzzy sets are defined for input as well as output. In those inputs and outputs rules are defined using rule editor.

In this controller, two inputs error and change in error are given to FLC to give one output. 7 membership functions are defined for inputs and outputs as NB, NM, NS, Z, PS, PM and PB. Using rule editor window shown in fig. 8, if-then rules are defined for relation of inputs and output. Rules are given in table 1 where for two inputs one output is obtained using 49 rules for control strategy.

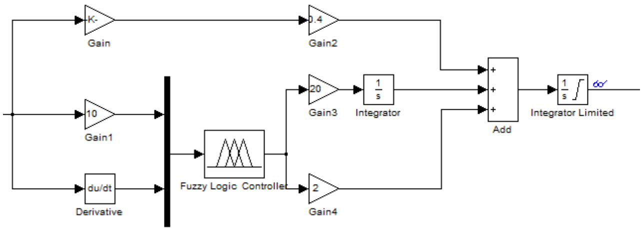

Figure 7.Fuzzy PID controller

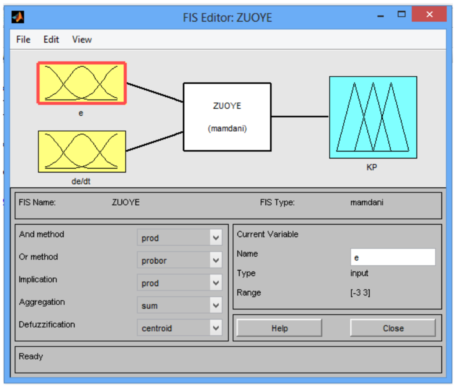

Figure 8 .FIS editor

Table 1 .Fuzzy rules

CE / E	NB	NM	NS	Z	PS	PM	PB
NB	NB	NB	NB	NB	NM	NS	Z

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NM	NB	NB	NB	NM	NS	Z	PS
NS	NB	NB	NM	NS	Z	PS	PM
Z	NB	NM	NS	Z	PS	PM	PB
PS	NM	NS	Z	PS	PM	PB	PB
PM	NS	Z	PS	PM	PB	PB	PB
PB	Z	PS	PM	PB	PB	PB	PB

C.Adaptive Fuzzy PID Controller

As per name, it is defined to adapt its output as per change in input. As shown in figure 9, in this controller two inputs are given to FLC and three outputs are taken from it. Those outputs are K_P, K_I and K_D. Similar to fuzzy PID controller, here also 7 fuzzy membership functions are defined for each input and output. These linguistic variables are related to form 49 fuzzy rules for each output.

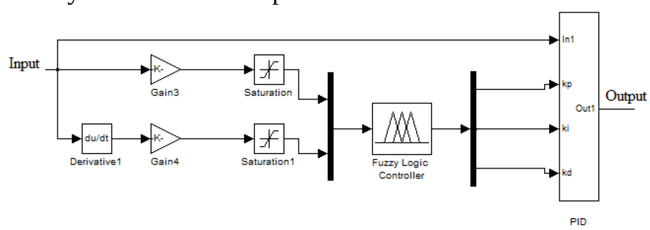

Figure 9.Adaptive fuzzy PID controller

Outputs of FLC are given to subsystem block where PID controller will be designed whose gains vary with change in inputs error and change in error. $\Delta K_{P,}$ ΔK_I and ΔK_D will be the outputs of subsystem.

VI. CONCLUSION

Reviewing existing speed controllers for BLDC motor it comes to know that fuzzy logic is used with basic controllers to have better system performance. In adaptive fuzzy PID controller constant gains of PID controller will be varied according to change in error. As those gains will be varied real time, it is prediction that in speed control characteristics there will be less rise time and less peak overshoot is obtained. A novel controller having better speed control characteristics will be implemented using FPGA.

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