Implementation and Performance Analysis of BLDC Motor Drive by various Controllers

SHINGARE SACHIN T.
Student of P. G. Department (Electrical Power System), M. S. S. college of engineeing and technologyJalna, Maharashtra, India,
Sachinshingare1602@gmail.com

K. CHANDRA OBULA REDDY
H.O.D
M. S. S. college of engineeing and technologyJalna, Maharashtra, India,
Chandra6279@gmail.com

Abstract

This paper presents design and simulation of ANFIS controller by comparing it with PID and fuzzy for achieving better performance of BLDC servomotor drive. The performance of ANFIS, fuzzy and PID controller-based BLDC servomotor drives is verified under various operating conditions such as, parameter variations, load disturbance,change in reference speed etc. BLDC servomotors are used in, instrumentation systems, space vehicles, electric vehicles,aerospace , robotics and industrial control applications. In such applications, conventional controllers like P, PI, and PID are being implemented with the BLDC servomotor drive control systems to achieve satisfactory transient and steady-state responses. However, the major problem with the general PID controller is that the tuned gain parameters obtained from the BLDC servomotor drive control systems cannot give better transient and Steady-state responses under different operating conditions such as parameter variations, load disturbances, etc. In this paper, design and implementation of ANFIS controller is presented and its performance is compared with PID controller and Fuzzy controller to show its capability to track the error and usefulness of ANFIS controller in control applications.

Keywords— P ,PI ,PID , ANFIS , BLDC , DC

I. INTRODUCTION

Brushless DC (BLDC) servomotor drives have been widely utilized as a part of air transportation, electric vehicles, and almost in every food and chemical industries. The conventional controllers like P, PI, and PID are being utilized for control applications more than couple of decades. It is key to develop the correct mathematical model, which is a method of simulating real-life situations with mathematical equations to forecast their future behavior for any system or reaction of the system for outlining these controllers but in pragmatic applications, systems are observed to be nonlinear and complex; so they are approximated as direct systems in order to get their mathematical model. The controller intended for such systems can just give satisfactory transient and steady-state responses reactions yet not ideal reactions. In the vast majority of the literature survey, it has been accepted that thesystem parameters never show signs of change during working conditions, however in pragmatic applications the mechanical load parameters, for example, dormancy and rubbing may change because of coupling or decoupling idleness components, and change in load. The phase resistance of the BLDC servomotor may likewise marginally change because of expansion of terminal resistance, change in winding resistance, and on-state resistance of the semiconductor changes because of progress in temperature during working conditions. It has been found that the proportion of no heap to full load contact is 1:15 and the change in snapshot of latency is up to 10–20 times due to coupling or decoupling latency components for regular automation, movement control, and positioning applications. The fundamental weakness of the ordinary controllers is that they can give better transient and consistent state reactions just when the system parameters for which they are planned stay unaltered.

In a large portion of the reasonable systems, parameters of the system change during operation. The execution of these controllers and their reasonableness for wide range speed control of BLDC servomotor drive are explored under various working conditions, for instance, change in reference speed, parameter varieties, and load unsettling influence. The information referred from various literatures for carrying out this study is as follows. The modeling of BLDC motor, estimation of parameters, and control schemes are discussed in [1]–[4]. The effect of change in motor parameters on the performance of the BLDC drive system is discussed in [6], [7] several tuning methods for the PID controllers are described in [7]–[8]. Design, implementation, and performance analysis of fuzzy logic controllers (FLCs) for various applications such as dc servomotor, BLDC motor, gas-turbine plant, servo systems, etc., are presented in [5], Design and implementation of adaptive controllers for improving the performance of dc motors and BLDC drives under different operating conditions are discussed.

This paper is organized into six sections. Section I represents introduction , Section II modeling of BLDC servomotor drive is presented; Section III, design and implementation of PID controller are described; Section IV design and implementation of fuzzy controller are presented, design and implementation of ANFIScontroller are described in Section V and conclusion is presented in Section VI.

II. MODELING OF BLDC SERVOMOTOR DRIVE SYSTEM

The BLDC servomotor drive system consisting of BLDC servomotor and IGBT inverter is modeled [1]–[4], based on the assumptions that all the stator phase windings have equal resistance per phase; constant self and mutual inductances; power semiconductor devices are ideal; iron losses are negligible; and the motor is unsaturated. The equivalent circuit of the BLDC servomotor drive system is shown in Fig. 1.

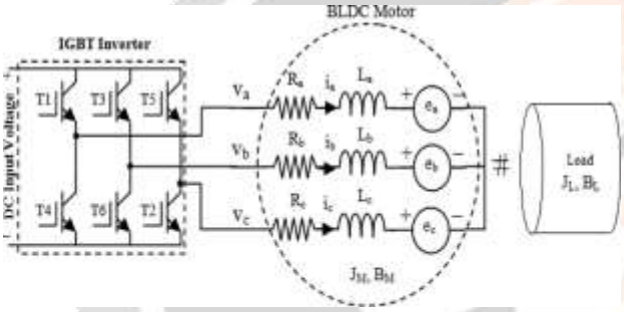

Figure. 1. Equivalent Circuit of TheBLDC Servomotor Drives System.

The line to line voltage equations are expressed in matrix form as

$$\begin{bmatrix} V_{ab} \\ V_{bc} \\ V_{ca} \end{bmatrix} = \begin{bmatrix} R & -R & 0 \\ 0 & R & -R \\ -R & 0 & R \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} + \begin{bmatrix} L-M & M-L & 0 \\ 0 & L-M & M-L \\ M-L & 0 & L-M \end{bmatrix} \times \frac{di}{dt} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} + \begin{bmatrix} e_a - e_b \\ e_b - e_c \\ e_c - e_a \end{bmatrix}. \quad (1)$$

Since the mutual inductance is negligible as compared to the self-inductance, the aforementioned matrix equation can be rewritten as

$$\begin{bmatrix} V_{ab} \\ V_{bc} \\ V_{ca} \end{bmatrix} = \begin{bmatrix} R & -R & 0 \\ 0 & R & -R \\ -R & 0 & R \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} + \begin{bmatrix} L & -L & 0 \\ 0 & L & -L \\ -L & 0 & L \end{bmatrix} \times \frac{di}{dt} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} + \begin{bmatrix} e_a - e_b \\ e_b - e_c \\ e_c - e_a \end{bmatrix} \quad (2)$$

where L and M are self-inductance and mutual inductance per phase; R is the stator winding resistance per phase; ea, eb , and ecare the back EMFs of phases a, b, and c, respectively; ia, ib ,and icare the phase currents of phases a, b, and c, respectively. The electromagnetic torque developed by the motor can be expressed as

$$Te= (eaia+ ebib+ ecic)/\omega = KtI \ldots .(3)$$

Where ia= ib= ic= Iωis the angular velocity in radians per second, and Ktis the torque constant.

Since this electromagnetic torque is utilized to overcome the opposing torques of inertia and load, it can also be written as

$$Te= T_L+ J_M d\omega /dt+B_M w \qquad (4)$$

Where TL is the load torque, JM is the inertia, and BM is the friction constant of the BLDC servomotor.

The load torque can be expressed in terms of load inertia JL and friction BL components as

$$T_L=J_L*dw/dt+BLw \qquad (5)$$

The output power developed by the motor is

$$P = Te\omega \qquad (6)$$

$$E = ea= eb= ec= Kb\omega \qquad (7)$$

Where Kb is back EMF constant, E is back emf per phase, and ω is the angular velocity in radians per second.

The parameters that are likely to vary during the working conditions are R, JM, JL, BM and BL. These parameters can influence the speed response of the BLDC servomotor drive system. Increase in the value of energy storage inertia elements JM and JL will increase the settling time of the speed response or vice versa. The decrease in the values of power consuming friction components BM and BL will increase the deceleration time of the speed response or vice versa. Another parameter, which is likely to vary during working conditions is phase resistance of the BLDC servomotor due to addition of terminal resistance, change in resistance of phase winding, and change in on-state resistance of IGBT switches due to change in temperature. The change in phase resistance can also affect the speed response of the BLDC servomotor drive system. Mixed combination of inertia, friction, and phase resistance of the BLDC servomotor may lead to large overshoots that are undesirable in most of the control applications. Therefore, the BLDC servomotor drive system needs suitable controllers such as PID, Fuzzy or ANFIS controllers to speed up the response, reduce overshoot, and steady-state error not to meet up the applications requirements. In this paper, PID, Fuzzy and ANFIS controller-based BLDC servomotor drive isdeveloped and their performance is investigated during different operating conditions such as step change in reference speed, different system parameters, and sudden load disturbance.

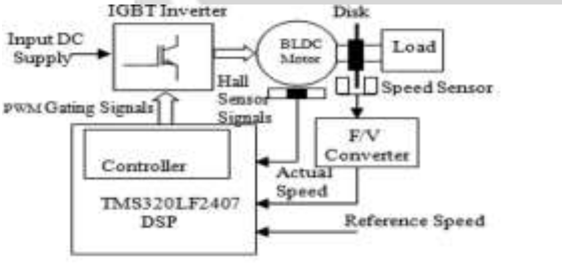

Figure.2. Block Diagram of The Experimental Setup.

The block diagram of the experimental setup is shown in Figure. The experimental setup consists of four major components. They are IGBT power inverter, BLDC servomotor with loading arrangement, speed, phase voltage and phase current sensing circuits, and DSP. The BLDC servomotor is an electronically commutated motor. The built-in hall sensors generate three signals according to the rotor position. These signals are decoded to identify the rotor position and energize the appropriate windings by switching the appropriate switches in the IGBT power inverter. The hall sensor signals are applied as input to the DSP through buffer IC. The gating signals generated by the DSP for the IGBT switches are also applied through buffer IC.

The PWM control technique is used to control the voltage applied across the windings in order to control the speed of the motor. The choice of 20- kHz PWM signal is made because of the absence of acoustic noise during the motor operation. The duty cycle of the 20-kHz signal generated by the DSP is varied to control the average current and average voltage of the phase windings, and hence the torque produced by the motor. The duty cycle of the devices is controlled based on the output. The dc signal output of F/V converter is given as one of the input to analog-to-digital converter (ADC) of the DSP processor to determine the actual speed of the motor. The reference speed is set through a potentiometer and voltage follower and it is given as another input to the ADC converter to determine the reference speed. The function of the DSP processor is to compute the error and change in error, store these values, compute the Sliding Mode controller output, determine the new duty cycle for the switching devices, and perform electronic commutation. The PWM signals are generated for the IGBT switching devices using EVA module components such as timers, PWM channels, etc.

III. DESIGN AND IMPLEMENTATION OF PID CONTROLLER

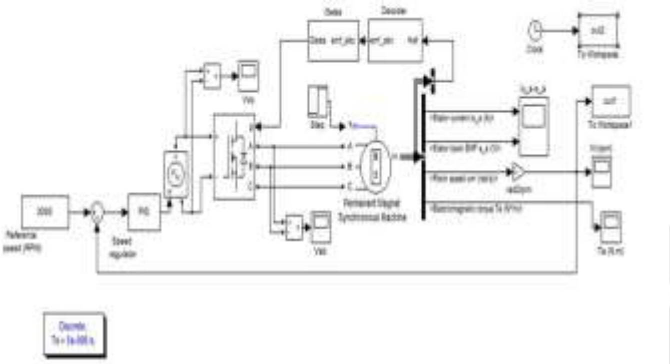

Figure 3. Simulation of PID Controller

Proportional-Integral-Derivative controllers are widely used in industrial control systems as they require only few parameters to be tuned. The PID controllers have the capability of eliminating steady-state error due to integral action and can anticipate output changes due to derivative action when the system is subjected to a step reference input. The most popular PID tuning method is the Ziegler–Nichols method, which relies solely on parameters obtained from the system step response. The block diagram of the experimental set-up used for implementing controller is shown in Fig. 2. The continuous control signal u(t) of the PID controller is given by

$$u(t)= K_p(e(t) + (1/T_i) \int e(t)dt + T_d\, de(t)/dt) \qquad \ldots(8)$$

where, $K_p$is the proportional gain, $T_i$is the integral time constant, T_d is the derivative time constant, and e(t) is the error signal.

$$u(k)=u(k-1)+K_1\times e(k)+K_2\times e(k-1)+K_3\times e(k-2) \qquad \ldots (9)$$

Where $u(k - 1)$ is the previous control output, $e(k - 1)$ is the previous error, and $e(k - 2)$ is the error preceding $e(k - 1)$. The constants K1, K2, and K3 are given by

$$K_1 = K_p+ TK_i/2 + K_d/T \qquad \ldots. (10)$$

$$K_2 = -K_p- 2K_d/T + TK_i/2 \qquad \ldots. (11)$$

$$K_3 = K_d/T \qquad \ldots. (12)$$

$$K_i = K_p /T_i \qquad \ldots. (13)$$

$$K_d= K_p T_d \ldots. (14)$$

$$T = 1/f \qquad \ldots. (15)$$

Where f is the sampling frequency and T is the sampling rate.

IV. FUZZY LOGIC CONTROLLER

Fuzzy rationale is a type of numerous esteemed rationales in which reality estimations of variables might be any genuine number somewhere around 0 and 1. By differentiation, in Boolean rationale, reality estimations of variables may just be 0 or 1. Fuzzy rationale has been stretched out to handle the idea of halfway truth, where reality quality may extend between totally genuine and totally false. Besides, when etymological variables are utilized, these degrees might be overseen by particular capacities. Normally fuzzy rationale control framework is made from four noteworthy components exhibited on Figure fuzzification interface, fuzzy induction motor, fuzzy principle grid and defuzzification interface.

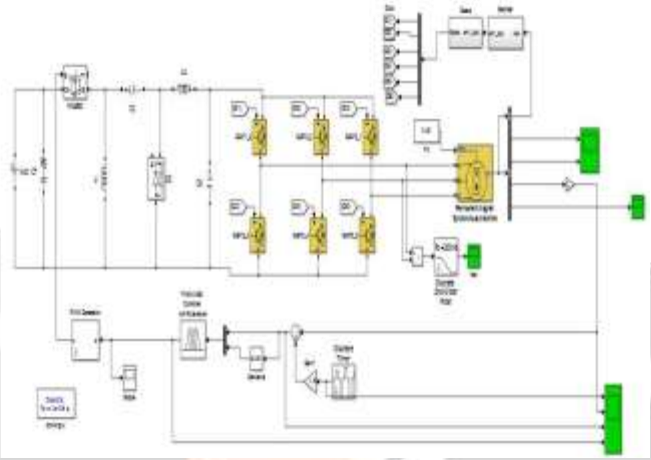

Figure 5: Simulation of Fuzzy Controller

- The fuzzy rationale investigation and control strategies shown in Figure 3 can be depicted
- Receiving one or expansive number of estimations or other appraisal of conditions existing in some system that will be dissected or controlled.
- Processing all inputs as indicated fuzzy "assuming then" standards, which can be communicated in basic dialect words, and consolidated with conventional non-fuzzy preparing.
- Averaging and weighting the outcomes from all the individual principles into one single output choice or sign in which chooses what to do or advises a controlled system what to do. The outcome output sign is an exact defuzzified system. First of all, the different level of output (high speed, low speed etc.) of the platform is defined by specifying the membership functions for the fuzzy sets.

A fuzzy inference system and a back spread calculation. For a normal fuzzy deduction, the parameters in the participation capacities are generally controlled by experience or the experimentation technique. The adaptive neuro-fuzzy induction system can beat this burden through the way toward figuring out how to tailor the participation capacities to the info/output information keeping in mind the end goal to represent these sorts of varieties in the information values, as opposed to self-assertively picking parameters connected with a given enrollment work. This learning strategy works also to that of neural systems.

V. RESULTS AND CONCLUSION

A. Results:

The experimental results obtained for BLDC servomotor drive under different operating conditions such as step change in reference speed, different inertia of the system, different phase resistance of the BLDC servomotor, and with load disturbance are done and below figure show the results with PID, Fuzzy and ANFIS controller.

Below figure shows output of BLDC servomotor by connecting the PID controller. When load is connected to motor at that time speed of motor decreases, because of PID controller after some time period speed come to it’s original value.

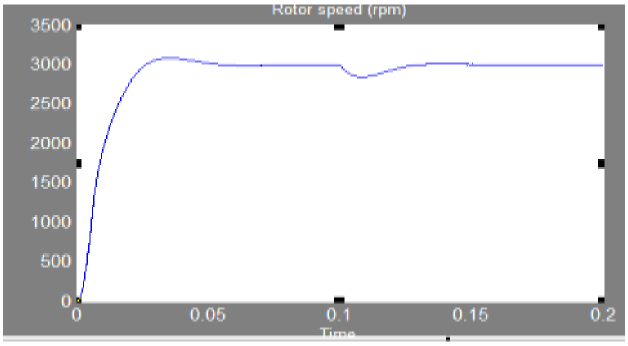

Figure. 7Output of BLDC Drive ByUsing PID Controller

While we apply the Fuzzy controller on place of PID controller and load is connected to motor then settling time of motor is reduced. That is time required to come motor at its original state when Fuzzy controller is connected is less as

compare to PID is less. Below figure shows the output of Fuzzy controller.

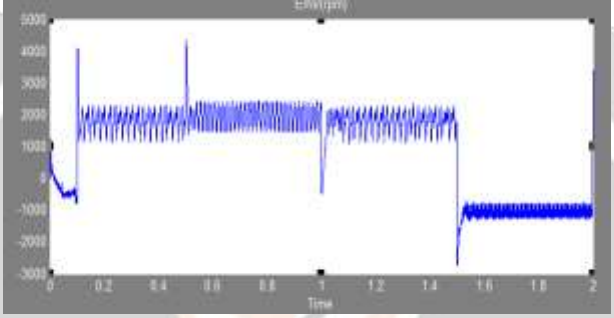

Figure.8.Outputof BLDC Drive By Using Fuzzy Controller

Finally in this paper we have to compare the output of ANFIS controller with Fuzzy controller. The ANFIS controller gives more accuracy and effective out than Fuzzy and PID controller, below figure shows the comparison of Fuzzy controller and ANFIS controller by connecting to the BLDC motor drive.

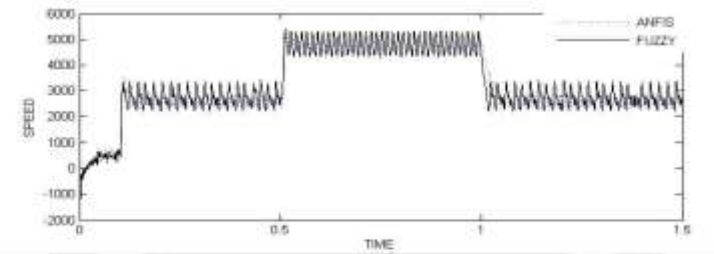

Figure.9.Outputof BLDC Drive By Using Fuzzy and ANFIS Controller

VI. CONCLUSION

The PID, fuzzy and ANFIS control techniques are successfully implemented for the BLDC servomotor drive system. The effect of parameter variations on the performance of the BLDC servomotor drive system is investigated with experimental results. However, the speed response of fuzzy controller-based BLDC servomotor drive is found to be better than the speed response of PID controller-based BLDC servomotor drive, and the speed response of ANFIS controller-based BLDC servomotor drive is found to be better than the speed response of PID and Fuzzy controller therefore, PID controller-based BLDC servomotor drive failed to provide improved performance under parameter variations of the system. But, the experimental results clearly show that fuzzy and ANFIS controller based BLDC servomotor drivecan provide an improved speed response with consistently same rise time, and settling time when the system is subjected to load disturbance, parameter variations, and step change in reference speed. Since the ANFIS control system is easy to design and implement, effective in dealing with the uncertainties and parameter variations, and has better overall performance, ANFIS controller-based BLDC servomotor drive system may be preferred over PID and Fuzzy controller-based BLDC servomotor drive for automation, robotics, position and velocity control systems, and industrial control applications.

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