South Asian J. Food Technol. Environ., 6(1): 903-912 (2020)
ISSN 2394-5168 (Print), 2454- 6445(online)
www.sweft.in
DOI: https://doi.org/10.46370/sajfte.2020.v06i01.04

Fuzzy controller based performance analysis of Brushless DC Motor, utilizing MATLAB Simulink environment

Ankit Rawat*[1] and Gaurav Kumar[2]

[1]College of PHT&FP, SVPUAT, Meerut (U.P.)
[2]College of COT, SVPUAT, Meerut (U.P.)

*Email: rawnik@gmail.com

Abstract

This paper presents performance analysis of fuzzy controller based BLDC motor drives under different operating conditions such as change in reference speed, parameter variations and the load disturbance. MATLAB/Simulink environment is used to realize fuzzy logic controller (FLC) for Brushless DC (BLDC) motor drive. BLDC motors are popular nowadays in industrial control, automation and instrumentation system applications. Based on applications the conventional controllers like P, PI and PID controllers are also used in the Brushless DC motor control systems to achieve the desired level of transient and steady state responses. However, the major problem in the conventional PI controller is that if some variations in the parameter and certain load disturbances are occur, conventional controller does not yield the better transient and the steady state responses under the operating conditions. In this paper, the modeling and controlling of fuzzy logic controller is presented its performance shows the error handling capability and usefulness of the fuzzy controller in the control applications.

Keywords: Brushless dc motors (BLDC), Fuzzy logic controller (FLC), Digital signal processor (DSP), Pulse width modulation (PWM).

Paper cited: Rawat, A. and Kumar, G.(2020). Fuzzy controller based performance analysis of Brushless DC Motor, utilizing MATLAB Simulink environment. *South Asian Journal of Food Technology and Environment*, 6(1): 903-912.

Introduction

BLDC motor drives are popular in electric vehicles, chemical industrial applications, robotics, and defense application. In recent years the Brushless dc motors are preferred as small horsepower control motors due to their compact size, high efficiency, low maintenance and reliability in operation (Lee *et al.*, 2003). Conventional PID controllers are being used for some control applications. Practical applications requires near exact mathematical modeling (Ogasawara and Akagi, 1991) of machine to designing the controllers.

The responses of the system are found to be highly nonlinear and complex (Melkote and Khorrami, 1999). As the linear systems are approximated to obtain their mathematical model and the controller are designed for such systems may give the satisfactory as dynamic responses and the transient steady state responses but there is no optimum responses (Grabner *et al.*, 2010). In some of the literature, the system parameters never changes during the operating conditions it has been assumed but for the practical applications the mechanical parameter such as the inertia and the friction changes due to their decoupling inertia elements.

The phase resistance of the BLDC motor slightly changes due to their terminal resistance where there are some changes in winding resistance and on-state resistance of the semiconductor switching devices due to temperature changes during operating conditions. The ratio of no load based on the full load friction and the inertia changes (Shanmugasundram *et al.,* 2009a) from 10-20 times due to decoupling inertia for the positioning applications. The disadvantage for the conventional controllers is load disturbance and the parameter variations etc. The system parameters are such designed that it can provide better transient steady state responses while remain unchanged. In all the system the parameters varies practically for their responses during the operation. This paper deals with the modeling and controlling of fuzzy logic controller based BLDC motor, which compare its performance with the conventional PI controller based brushless DC motor using TMS320LF2407A digital signal processor. Finally experimental results are presented (Shanmugasundram *et al.*, 2009b). At different operating conditions these controllers is investigated for parameter variations and load disturbances.

The modeling of BLDC motor and the different control schemes are discuss in this paper in (Pillay and Krishnan, 1989). The dynamic performance of the BLDC motor system, the effect of change in motor parameters is discussed in (Tu and Ho, 2012; Rahman and Hoque, 1997). In the PI controller several tuning methods are described in (Wang et al., 1999). For the desired results, the several tuning methods are suggested in (Basilio and Matos, 2002) and hence in these methods are adapted for determining PI controller for the parameter gain. While modeling and the dynamic performance analysis of fuzzy logic control (FLC) for various applications in the BLDC motor drive are presented in (Kim and Kim, 2003). The PID based method for the determination of PI controller parameters for achieving the dynamic performance is discussed in (Rubaai and Kankam, 2002). It also based some control schemes to compensate for the dynamic uncertainties in the motor drive. Conventionally the motor used for industrial purposes is brush type of the dc motor drive. Still in the fractional 40 hp range available in the ac motor includes the induction and the brushless dc motors (Krishnan, 1986). BLDC motor utilizes a trapezoidal back EMF and the rectangular stator currents to generate a constant electric torque. Traditionally Hysteresis current controller or pulse width modulation (PWM) current controller is employed to obtain the near rectangular currents flowing into the motor.

Digital control schemes and the pulse width modulation for the BLDC motor controller for the electric drive application are discussed in (Lai *et al.,* 2004). The performance of BLDC motor for different operating condition, with the necessary improvement in the motor drive is discussed in (Shanmugasundram *et al.,* 2012). However the propose controller which improve the dynamic performance and there is no variation and load disturbance in the motor drive system.

Materials and methods

Block diagram of proposed model

The Fig.1 illustrates the blocks of BLDC motor using FLC speed controller. The motor drive consists of reference current generator, speed controller, position sensor, the PWM current controller, where the motor and IGBT are based on current controlled voltage source inverter. The speed of the motor is compared with the reference value and the speed error is processed in Fuzzy logic controller. The output for this controller is utilized as the reference torque and limit is put on the speed controller output based on the maximum permissible currents through winding. While reference current generator block generates the three phase reference currents utilizing the limited peak current magnitude decided by the position sensor and controller. The references current have the shape of quasi-square wave in phase with respective back EMF and nature of develop torque is constant unidirectional. The motor currents and the reference currents are compared and the switching signals are generated to drive the inverter devices.

Modeling of BLDC motor drive

The BLDC motor drive system which consist of IGBT inverter based on the stator phase winding have constant self-inductance and equal resistance, where the ideal power semiconductor devices are assumed. During the unsaturated mode of motor the devices are assumed ideal and the iron losses are negligible. The phase inductance, phase resistance, and BLDC motor inertia which determine the parameter variation and the load disturbance as to design the conventional controllers. Speed response of the brushless DC motor drive decides the required parameter variation. The magnitude of the three phase current is determined by the reference torque.

$$iref = \frac{Tref}{Kt}$$

Where, K_t is the torque constant. K_t depends on the rotor position and the reference current generator generates the three phase reference current. The Hysteresis current controller maintains the switching signals. In the three phases references currents, switching condition of the inverter output voltage is shown below.

$$Va = \frac{1}{3}[2Sa - Sb - Sc]$$
$$Vb = \frac{1}{3}[Sa - 2Sb - Sc]$$
$$Vc = \frac{1}{3}[-Sa - Sb + 2Sc]$$

The drive system utilized here consists of FLC speed controller, PWM current controller, the reference current generator, BLDC motor and an IGBT inverter. All these components are designed and connected for simulation in real time environment. The Hysteresis current controller generates the switching signals the inverter and the hysteresis-band PWM is basically instantaneous feedback current control limit which generates the PWM where the actual current on the continuous basis tracks the command current within the predefined band limit. Sine wave generated by the control circuit is compared against the reference current. The input variable is change in speed error and speed error, and is calculated by the controller with error. The output variable is the torque component of the reference current $i_{ref..}$

Controlling of BLDC motor drive

It needed the rectangular stator current while controlling the speed of the BLDC motor drive system to produce a constant electric torque. With the small parameters variation technique observer is developed for the speed and position measurements. The state of art is the speed enhancement which depends upon the flux linkage and electromotive force. It enables the performance prediction over the wide range of operating conditions. Hall Effect sensor is utilized which senses the rotor position because Controller must direct the rotor rotation, sensors senses the relative position of rotor w.r.t. stator and generate the requires logic. The controller contains 3 bi-directional drives to high current dc power which are controlled by a logic circuit.

Advanced control is employed by a microcontroller to control speed, manage acceleration and the fine tune efficiently. The phase resistance changed by speed responses also affects the system drive, hence require a suitable controller to improve the dynamic performance. In FLC controller the response of the speed which reduce overshoot and the steady state error to the application requirements. The trapezoidal back emf waveform depends on speed and the rotor angle as shown in Fig.2.

In this FLC based BLDC motor drive system is developed their performance during different conditions to step up the reference speed with different system parameters. It’s insensitive to parameter variations and load disturbance and also it enhance the dynamic capabilities of the motor drive.

Implementation of fuzzy controller

The FLC is designed based on a simple analogy between the control surfaces of the FLC and a given PI controller for the same application. Depending on right tuning fuzzy logic controller has a better quality of the speed response when compared to PI control. In case of BLDC motor usually speed control is achieved by using PI controller. PI controllers are popular in the industries due to their simple design and ease of application; these controllers are ineffective in cases such as the nonlinearity, parameter variations and load disturbances. Moreover the Proportional-integral controllers require exact mathematical models. However In the FLC controller can perform with nonlinear systems. The design of traditional control system is essentially based on the linear mathematical model of plant. Adaptive characteristics are inherent in Fuzzy logic controller. Hence a relatively robust performance is achieved by system with load disturbances and uncertainty parameters variation. Fuzzification interface measures the values of input variable. During fuzzification input data converts into suitable linguistic values. The inputs of the fuzzy controller are expressed in several linguistic values. As shown in Fig.3 the seven triangular fuzzy membership functions are utilized.

As these levels can be described as Positive big (PB), Positive medium (PM), Positive small (PS) Negative small (NS), Negative medium (NM), Negative big (NB) or in other levels. Fuzzy set describes each level.

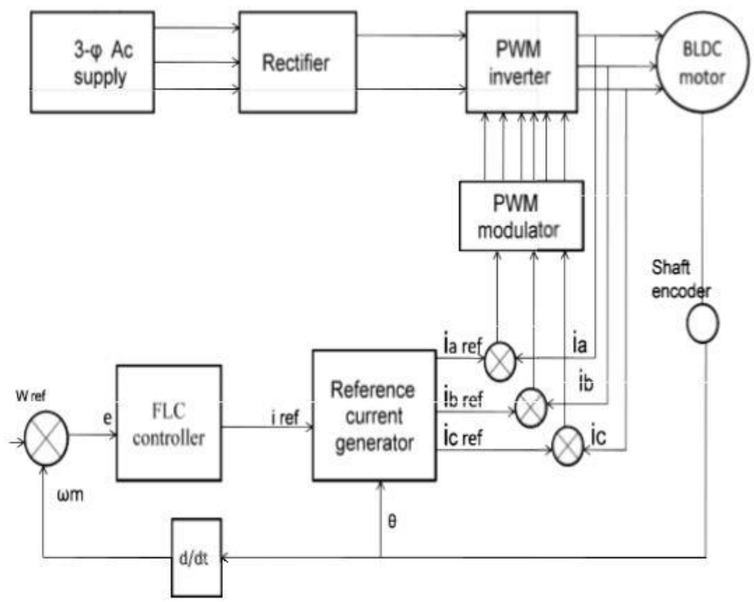

Fig. 1: Block Diagram of BLDC Motor using FLC

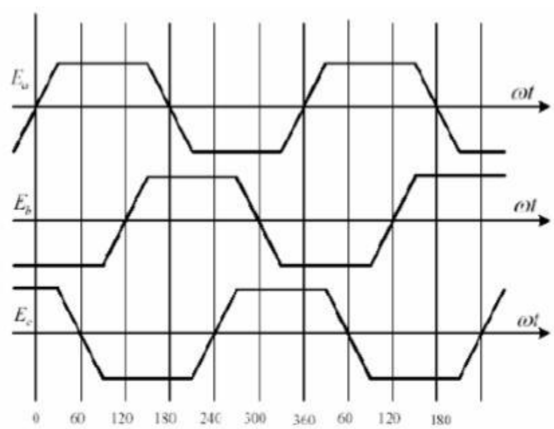

Fig.2: Three phase trapezoidal back emf of BLDC motor

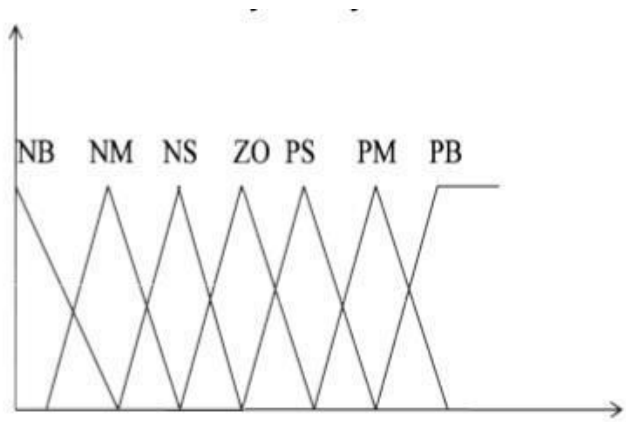

Fig: 3: Seven Level s Fuzzy Membership Function

Fuzzy set is a generalization of the indicator function in classical sets in fuzzy Membership Function. Fuzzy logic control emphasis on the degree of truth as an extension valuation. Often degrees of truth are confused with probabilities, in reality they are conceptually different, because unlike probability dependency on condition the fuzzy truth tells membership in defined sets, Knowledge Base comprises data base and a rule based linguistic control.

The rule base characterized the control policy and control targets. Control policy is implemented domain experts knowledge by means of a set of linguistic control rules. Kernel of FLC is the Decision Making logic. Human decision making capability can be simulated based on fuzzy concepts and of inferring fuzzy control actions employing fuzzy implication and the rules of inference. The frequent revaluation of the stored data states leads to inference engine control, hence control scheme dynamic structure of the program. Unlike most of traditional procedural control the computation is more a qualified data driven.

Table.1 is used to achieve the given rules. Based on the behavior of human operators and error, fuzzy variables selected the fuzzy rules base that can assure the stability and steady state with relatively low error.

In fuzzy logic defuzzification is the process of producing a quantifiable result from given fuzzy sets for corresponding membership degrees. These will have a certain number of rules which transform a number of variables into fuzzy rule designed as to decide the pressure to apply the certain predefined result. Defuzzification is interpreting into predefined specific decision or real values. The processing stage based on IF-THEN statements comprises a group of logic rules, where it's IF part is known the antecedent and the THEN part is known as the consequent. Typical fuzzy control systems have several rules.

The membership function for input variable of change in error, error and the output variable of the reference torque are as in fig. Here the Fuzzy Membership Function for Input Variable as input1 is shown in the Fig 5. The Fig.4 shows the Fuzzy Membership Function for Input Variable as Variation in Error. Output Reference Torque as output variable is shown in the Fig.6.

To improve the dynamic capability and to overcome the problem the FLC is preferred. The fuzzy logic controller requires two inputs, the error in speed in the speed obtained by difference between the reference speed and actual speed another input is error change, which is the change between present error and previous error. Fuzzy logic controller gives the output based on the inputs to trigger the inverter switch

Input to fuzzy logic controller changes when the load changes. Indicator function in classical sets is generalized by membership function of fuzzy sets. The membership functions utilized are of error change, error, and reference torque.

Simulation model of proposed method

Closed loop fuzzy controller model is simulated, designed and is presented below. Fuzzy logic controller is used to simulate diagram of BLDC motor as shown in Fig. 7. The gate pulses are applied from the hall signals and the DC source is applied to the inverter input. Inverter output is applied to the BLDC motor. Fuzzy logic controller is used Instead of PI controller for the speed regulation. The speed error is applied as the input for the Fuzzy controller. Fuzzy Logic Controller output is utilized as a reference current signal generation which when compared with the actual current gives hysteresis controller.

Table.1: Fuzzy Rule Base

e/ce	NB	NM	NS	ZO	PS	PS	PB
NB	NB	NB	NB	NM	NS	ZO	PS
NM	NB	NB	NB	NM	NS	ZO	PS
NS	NB	NB	NM	NS	ZO	PS	PM
ZO	NB	NM	NS	ZO	PS	PM	PB
PM	NS	ZO	PS	PM	PB	PB	PB
PB	ZO	PS	PM	PB	PB	PB	PB

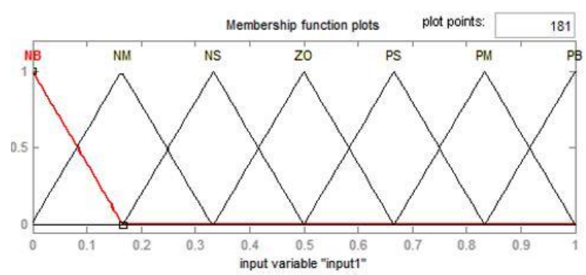

Fig.4: Input Variable Error as Fuzzy Membership Function

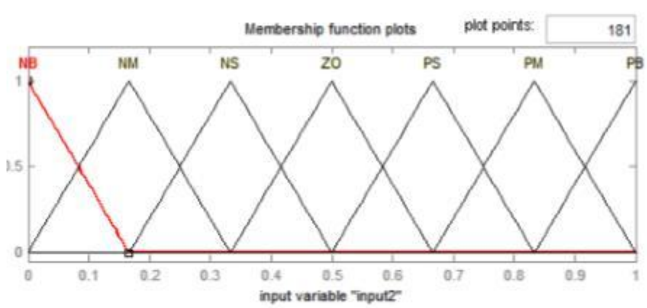

Fig.5: Fuzzy Membership Function for Input Variable Change in Error

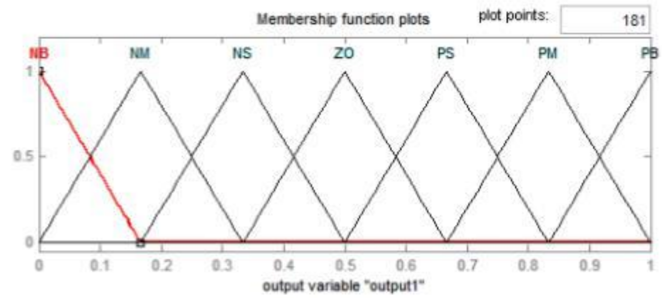

Fig.6: Fuzzy Membership Function for Output Reference Torque

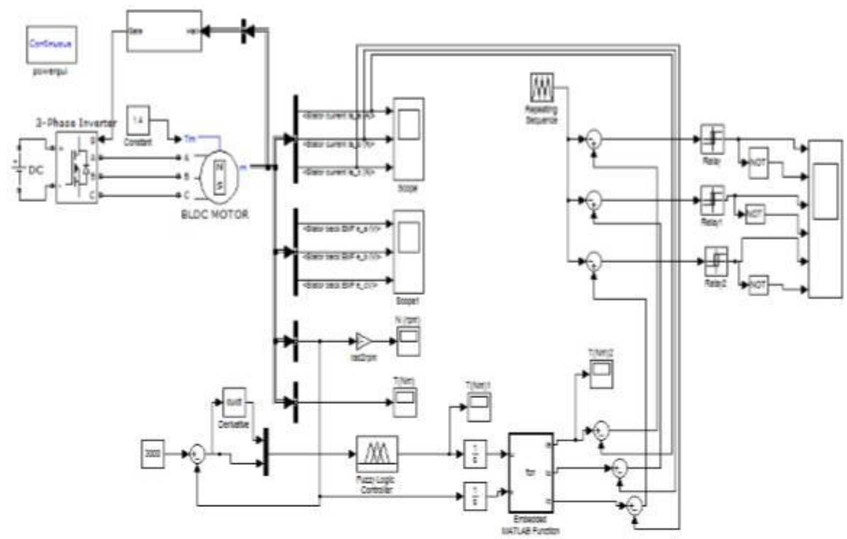

Fig.7: Simulation Diagram of BLDC motor using Fuzzy Logic controller

Results and Discussion

The speed response of the brushless DC drive system using FLC controller is as shown in Fig.7. The reference speed is set at 400rpm with the motor at rest stage with a settling time 0.02 seconds. Motor speed reaches the reference speed with a % overshoot of 6.667 with PI speed. The phase currents during the time of starting getting transient due to zero initial phase back emfs of machine. When the speed reaches reference speed, phase currents attains the reference current. For fuzzy logic controller the motor speed attains reference speed with settling time of 0.03 seconds, without any considerable overshoot and zero steady state error in speed. And phase currents are attaining to steady value, when actual current attains the reference value of current.

The speed of the BLDC motor attains 3000rpm. The Fig. 10 shows the electromagnetic torque variation of BLDC motor using fuzzy logic controller and the maximum value of rotor speed is 31 rpm. Time taken by rotor speed is to settle is 2.23sec. When using fuzzy logic controller in the feedback circuit based on its present error, it performs the operation and gives the output quantity. The speed response of the BLDC drive with FLC speed controller of the drive is faster than that of PI controller response. The PI controller shows an overshoot in speed, which is not desirable. The drive takes highest of permissible current to start the motor from standstill condition. The result clearly proves that the response of the drive is relatively faster with FLC controller than that of the PI controller. Improved speed response in this work is of great value to industrial applications.

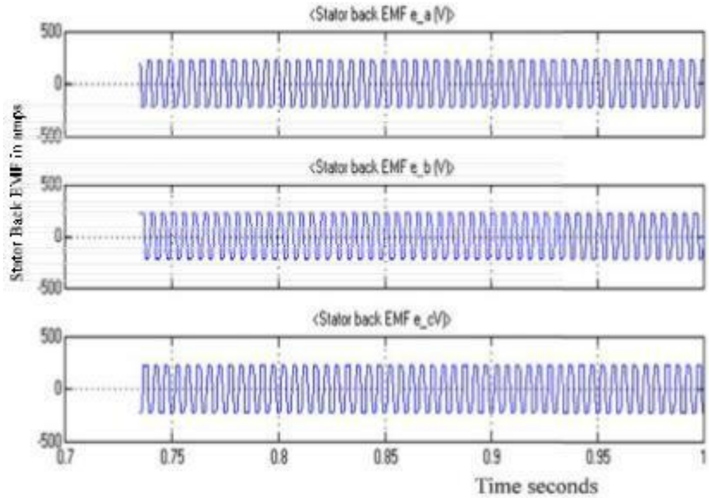

Fig: 8: Stator Back EMF of BLDC motor using FLC

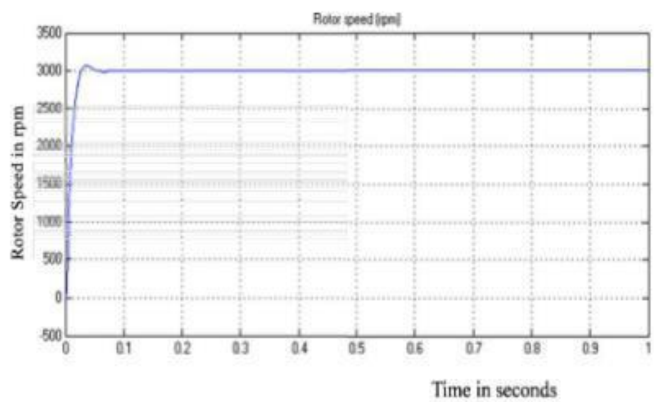

Fig: 9: Speed Response of BLDC motor using FLC

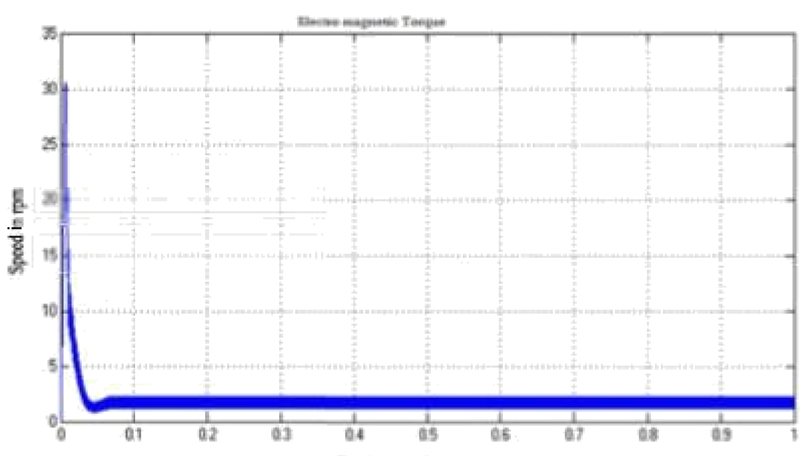

Fig: 10: Electromagnetic Torque of BLDC Motor using FLC

Conclusions

The FLC controller is designed for the BLDC motor drive to enhance the dynamic performance and to improve the speed characteristic of the drive. The simulation has been carried out for various operating conditions using FLC controller & conventional PI controller. The simulation results from the two controllers are compared on the basis of rise time & settling time for steady state and for dynamic state for sudden variation in load and set speed change. A FLC controller has been employed for the speed control of BLDC motor drive and the performance of a fuzzy controller is improved. Effectiveness of the controller is proved by performance prediction capability over a wide range of operating conditions. Fuzzy logic controller enhances the quality of the speed response compared to conventional PI controller. While using FLC Controller the dynamic capabilities is enhanced and based on the advantages parameter change and load perturbation are controlled. Thus the results by the FLC Controller are better than the conventional PI controller.

References

1. Basilio, J.C. and Matos, S.R. (2002). Design of PI and PID controllers with transient performance specification. *IEEE Transactions on Education*, 45(4): 364–370.
2. Grabner, H., Amrhein, W., Silber, S. and Gruber, W. (2010). Nonlinear feedback control of a bearingless brushless dc motor. *IEEE/ASME Transactions on Mechatronics*, 15(1): 40–47.
3. Kim, J.W. and Kim, S.W.(2003). Design of incremental fuzzy PI controllers for a gas-turbine plant. *IEEE/ASME Transactions on Mechatronics*, 8 (3): 410–414.
4. Krishnan, R. (1986). Selection criteria for servo motor drives. Proceeding of IEEE IAS Annual Meeting. pp. 301-308
5. Lai, Y.S., Shyu, F.S. and Chang, Y.H. (2004). Novel loss reduction pulse width modulation technique for brushless dc motor drives fed by MOSFET inverter. *IEEE Transactions on Power Electronics*, 19(6): 1646–1652.
6. Lee, B.K., Kim, T.H. and Ehsani, M. (2003). On the feasibility of four-switch three-phase BLDC motor drives for low cost commercial applications: Topology and control. *IEEE Transactions on Power Electronics*, 8 (1): 164–172.
7. Melkote, H. and Khorrami, F. (1999). Nonlinear adaptive control of direct drive brushless dc motors and applications to robotic manipulators. *IEEE/ASME Transactions on Mechatronics,* 4 (1): 71–81.
8. Ogasawara, S. and Akagi, H. (1991). An approach to position sensorless drive for brushless dc motors. *IEEE Transactions on Industry Applications*, 27(5): 928–933.
9. Pillay, P. and Krishnan, R. (1989). Modeling, simulation, and analysis of permanent-magnet motor drives, part ii: The brushless dc motor drive. *IEEE Transactions on Industry Applications*, 25(2): 274–279.
10. Rahman, M.A. and Hoque, M.A.(1997). On-line self-tuning Ann-based speed control of a PM DC motor. *IEEE/ASME Transactions on Mechatronics*, 2(3): 169–177.
11. Rubaai, D.R., and Kankam, M.D. (2002). Laboratory implementation of a microprocessor-based fuzzy logic tracking controller for motion controls and drives. *IEEE Transactions on Industry Applications*, 38(2): 448–456.
12. Sathyan, A., Milivojevic, N., Lee, Y.J., Krishnamurthy, M. and Emadi, A. (2009). An FPGA-based novel digital PWM control scheme for BLDC motor drives. *IEEE Transactions on Industry Electronics*, 56(8): 3040–3049.
13. Shanmugasundram, R., Zakariah, K.M. and Yadaiah, N. (2009a). Low-cost high performance brushless dc motor drive for speed control applications. Proceeding of IEEE Int. Conf. Adv. Recent Technol. Commun. Comput, Kottayam, India, Oct. 27–28, 2009a, pp. 456– 460.
14. Shanmugasundram, R., Zakariah, K.M. and Yadaiah, N. (2009b). “Digital implementation of fuzzy logic controller

for wide range speed control of brushless dc motor. Proceeding of IEEE Int. Conf. Veh. Electron. Safety, Pune, India, Nov. 10–12, 2009b, pp. 119–124.

15. Shanmugasundram, R., Zakariah, K.M. and Yadaiah. N. (2012). Modelling, simulation and analysis of controllers for brushless direct current motor drives. *Journal of Vibration Control* (Online). Pp. 1–15.
16. Tu, Y.W. and Ho, M.T. (2012). Robust second-order controller synthesis for model matching of interval plants and its application to servo motor control. *IEEE Transactions on Control Systems Technology*, 20(2): 530–537.
17. Varatharaju, V.M., Mathur, B.L. and Udhyakumar, K. (2010). Speed control of PMBLDC motor using MATLAB/Simulink and effects of load and inertia changes. Proceeding of 2nd Int. Conf. Mech. Electr. Technol., Sep. 10–12, 2010, pp. 543–548.
18. Wallace, K. and Spee, R. (1990). The effects of motor parameters on the performance of brushless DC drives. *IEEE Transactions on Power Electronics*, 5(1): 2–8.
19. Wang, Q., Lee, T., Fung, H., Bi, Q. and Zhang, Y. (1999). PID tuning for improved performance. *IEEE Transactions on Control Systems Technology*, 7(4): 457– 465.
20. Wu, H.X., Cheng, S.K. and Cui, S.M. (2005). A controller of brushless DC motor for electric vehicle. *IEEE Transactions on Magnetics*, 41(1): 509–513.

Received	: January, 2020
Revised	: March, 2020
Published	: June, 2020