Implementation and Performance Analysis of BLDC Motor using FLC Controller

M.S Evangelin Blessy [1-]Mr.M.Murugan [2]
[1]PG Scholar [2]Assistant Professor
Department of Electrical and Electronics Engineering,
K.S.Rangasamy College of Technology, Tiruchengode, Tamilnadu, India
[1]msevang25blessy@gmail.com [2]marimurugan81@gmail.com

***Abstract*— This paper presents the Implementation and the performance analysis of BLDC motor using Fuzzy logic control for achieving the improved dynamic performance of the Brushless DC (BLDC) motor drive. The performance of fuzzy and the PI controller based BLDC motor drives is investigated under the different operating conditions such as change in reference speed, parameter variations and the load disturbance. BLDC motors are used in industrial control, automation and instrumentation system applications. Based on other applications the conventional controllers like P, PI and PID controllers are used in the BLDC motor drive control systems to achieve the desired level of transient and steady state responses. However, the major problem in the conventional PI controller there is some variations in the parameter and some load disturbances are occur and do not yield the better transient and the steady state responses under the operating conditions. In this paper, the implementation of fuzzy logic controller which is presented its performance and which it compared with the PI controller shows the error 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).**

I INTRODUCTION

The brushless dc motor drives have been widely used in electric vehicles, robotics, and food and chemical industrial applications. In recent years the Brushless dc motors are preferred as small horsepower control motors due to their high efficiency, reliability and low maintenance [1]. The conventional controllers are being used for some control applications. The mathematical model is essential to the system for designing the controllers in practical applications [2]. The responses of the system are found to be complex and nonlinear form [3]. 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 [4]. 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 [5] 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 which are designed and it can provide better transient steady state responses while remain unchanged. Almost in the system the parameters changes practically for their responses during the operating conditions. In this paper the modeling and controlling of fuzzy logic controller based BLDC motor which compare its performance with the PI controller based BLDC motor drive using TMS320LF2407A digital signal processor (DSP) is described and experimental results are presented [6]. At different operating conditions these controllers is investigated during such as parameter variations and load disturbances are occur. The information gathered from other various literatures as follows.

The implementation of BLDC motor and the different operating control schemes [7]. The dynamic performance of the BLDC motor system, the effect of change in motor parameters and the dynamic response is focus on [8], [9]. In the PI controller several tuning methods are described and each turning level is different in [10]. For the desired results, the several tuning methods are suggested in [11] and hence in these methods are adapted for determining PI controller for the parameter gain. While implementing for the dynamic performance analysis of fuzzy logic control (FLC) for various applications in the BLDC motor drive are presented in [12]. The PID based method for the determination of PI controller parameters for achieving the dynamic performance while using PI there is some disturbance occur [13]. It also based some control schemes to compensate for the dynamic uncertainties in the motor drive.

The motor has established itself to the brush type of the dc motor drive for the industrial applications. In the fractional 30 hp range available in the ac motor include in the induction and the brushless dc motors [14]. The BLDC motor has a trapezoidal back EMF and the rectangular stator currents are needed to produce a constant electric torque. Typically pulse width modulation (PWM) current controller or

Hysteresis current controller are used to maintain the actual currents flowing into the motor to close as possible to the rectangular reference values.

The pulse width modulation and digital control schemes for the BLDC motor controller for the electric application are discussed in [15]. The performance of BLDC motor operating at different condition for the improvement of the motor drive is discussed in [16]. However the proposed controller which improve the dynamic performance and there is no variation and load disturbance in the motor drive system.

II BLOCK DIAGRAM OF PROPOSED MODEL

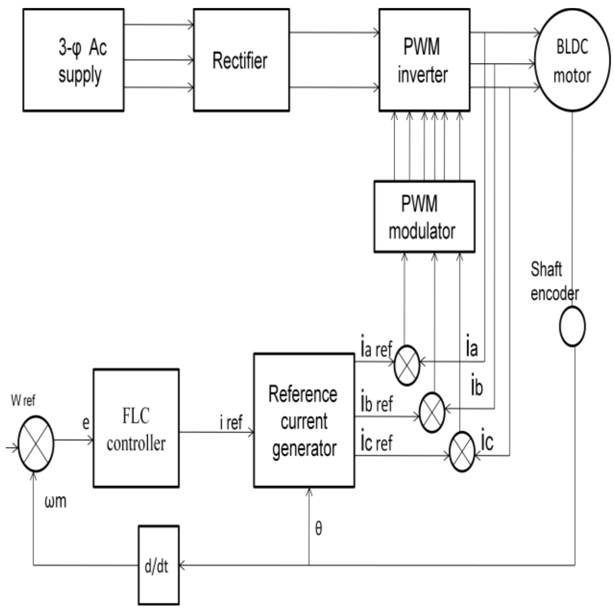

Fig. 1 Block Diagram of BLDC Motor using FLC

The Fig.1 describes the block diagram of BLDC motor using FLC. The motor drive consists of speed controller, reference current generator, the PWM current controller, position sensor, were the motor and IGBT based current controlled voltage source inverter. The speed of the motor is compared with the reference value and the speed error is processed in FLC speed controller. The output for this controller is considered as the reference torque and the limit is put on the speed controller output depending on the permissible maximum winding currents.

While the reference current generator block this generates the three phase reference currents using the limited peak current magnitude decided by the controller and the position sensor. The references current have the shape of quasi-square wave in phase with respective back EMF and also develop the constant unidirectional torque. The PWM current controllers which regulates the winding currents within the small band around. The reference currents the motor currents are compared with the reference currents and the switching commands are generated to drive the inverter devices.

III IMPLEMENTATION OF BLDC MOTOR DRIVE

The BLDC motor drive system which consist of IGBT inverter based on the stator phase winding have equal resistance and constant self inductance were the power semiconductor devices are ideal. When the motor is unsaturated the devices are ideal and the iron losses are negligible. The phase resistance, phase inductance and inertia of BLDC motor which determine the parameter variation and the load disturbance as to design the conventional controllers. The parameter depends upon the speed response of the BLDC motor drive. It increase the energy storage element will improve the settling time of the speed response or vice versa. The magnitude of the three phase current is $iref$ is determined by the reference torque $Tref$.

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

Where Kt is the torque constant. Kt depends on the rotor position and the reference current generator generates the three phase reference current. The Hysteresis current controller contributes the switching signals. In the three phase's 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 considered here consists of fuzzy speed controller, the reference current generator, PWM current controller, PMBLDC motor and an IGBT inverter. All these components are modeled and integrated for simulation in real time conditions. The Hysteresis current controller contributes to 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 continually tracks the command current continually tracks the command current within the hysteresis-band. The control circuit generates the reference current as sine wave and it compared with actual phase current wave. The input variable is speed error (e), and change in speed error is calculated by the controller with error. The output variable is the torque component of the reference current $i_{ref.}$

IV DESIGN AND IMPLEMENTATION OF BLDC MOTOR DRIVE

While designing the speed of the BLDC motor drive system it needed the rectangular stator current to produce a constant electric torque. With the small parameters perturbation technique observers is developed for the position and the speed measurements of the current. The state of art is the speed enhancement which depends upon the electromotive force and the flux linkage. It established the performance prediction over the wide range of operating conditions. The Hall Effect sensor which senses the rotor position because the controller must direct the rotor rotation were the controller which needs the rotor position relative to the stator coils. The controller which contains 3 bi-directional drives to high current dc power which are controlled by a logic circuit.

To determine the advanced controller employ a microcontroller to manage acceleration, control speed and the fine tune efficiency. The speed responses which change the phase resistance also affect the system drive. It needs the 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 based on the function of speed ω_m and the rotor position angle θ_r in Fig.2.

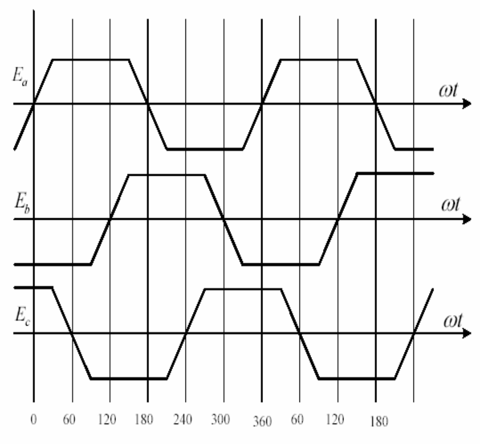

Fig.2 Trapezoidal back emf of three phase BLDC motor

In this fuzzy controller based BLDC motor drive system is developed their performance during different conditions to step up the reference speed with different system parameters. It avoids the load disturbance and parameter variations and also it improve the dynamic performance of the motor drive.

V DESIGN AND IMPLEMENTATION OF FLC

The FLC is designed based on a simple analogy between the control surfaces of the FLC and a given Proportional-Integral controller for the same application. Fuzzy logic control may improve the quality of the speed response when compared to PI control. In case of permanent magnet motors usually speed control is achieved by using Proportional-Integral (PI) controller. PI controllers are widely used in the industry due to their simple control structure and ease of implementation these controllers have difficulties where there are some control complexity such that the nonlinearity, load disturbances and parameter variations. Moreover the PI controllers require precise linear mathematical models. In the Fuzzy logic controller it can model nonlinear systems. The design of conventional control system essential is normally based on the mathematical model of plant.

Fuzzy logic controller has adaptive characteristics. The adaptive characteristics can achieve robust performance to system with uncertainty parameters variation and load disturbances. In Fuzzification interface measures the values of input variable. It performs the function of fuzzification that converts input data into suitable linguistic values. The inputs of the fuzzy controller are expressed in several linguist levels. As shown in Fig.3 the seven of fuzzy membership function.

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. Each level is described by fuzzy set.

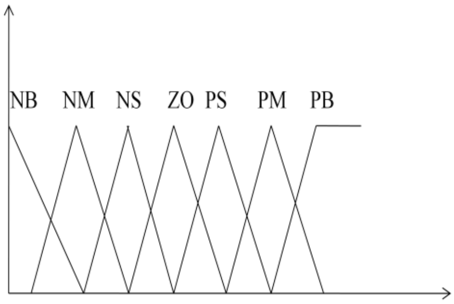

Fig: 3 Seven Levels Fuzzy Membership Function

In fuzzy Membership Function of a fuzzy set is a generalization of the indicator function in classical sets. In the fuzzy logic control it represents the degree of truth as an extension valuation. Knowledge Base consist data base and a linguistic control rule base. The database provides necessary definitions, which they are used to define linguistic control rules.

The rule base characterized the control goals and control policy of the domain experts by means of a set of linguistic control rules. The Decision Making logic is the kernel of an FLC. It has the main capability of simulating human decision making based on fuzzy concepts and of inferring fuzzy control actions employing fuzzy implication and the rules of inference in fuzzy logic. The computation is often qualified as the data driven in contrast to the more traditional procedural control.

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

Table.1 Fuzzy Rule

Table.1 is used to frame the given rules. Based on the fuzzy variables selected the observation of the behavior of human operators and error the fuzzy rules base that can ensure the stability and steady state precision.

Defuzzification is the process of producing a quantifiable result in fuzzy logic given fuzzy sets corresponding membership degrees. It is typically needed in fuzzy control systems. These will have a specific number of rules that transform a number of variables into fuzzy rule designed as to decide the pressure to apply the result. Defuzzification is interpreting the membership degrees of the fuzzy sets into specific decision or real values. The processing stage is based on a collection of logic rules in the form of IF-THEN statements, where it have the IF part is called the antecedent and the THEN part is called the consequent. Typical fuzzy control systems have many rules.

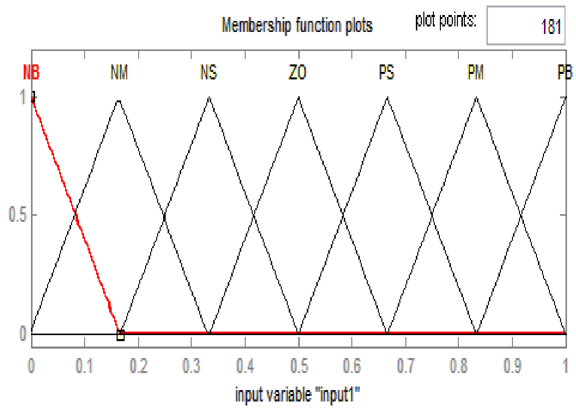

Fig.4 Fuzzy Membership Function for Input Variable Error

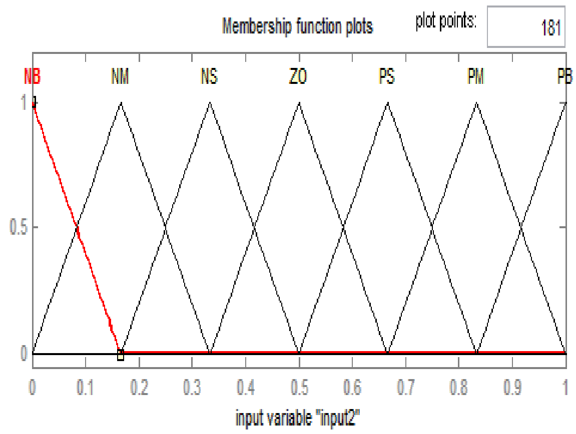

Fig.5 Fuzzy Membership Function for Input Variable Change in Error

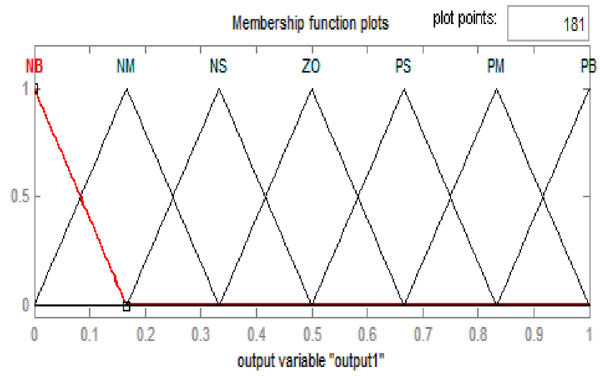

Fig.6 Fuzzy Membership Function for Output Reference Torque

The membership function input variable of error, change in error and the output variable of the reference torque are shown. Here the Fuzzy Membership Function for Input Variable as input1 is shown in the Fig4. The Fig.5 shows the Fuzzy Membership Function for Input Variable as input2 as Change in Error. The Fuzzy Membership Function for Output Reference Torque as output variable is shown in the Fig.6.

To improve the dynamic performance and to overcome the problem the FLC is used. The fuzzy logic controller gets two inputs, one is error in speed in speed which is the difference between the actual speed and reference speed and another one is change in error, which is the difference between present error and previous error. Based on the inputs the fuzzy logic controller gives the output to trigger the inverter switch when the input to fuzzy logic controller varies when the load varies. The membership function of a fuzzy set is generalization of the indicator function in classical sets. The membership function input variable of error, change in error and the output variable of reference torque.

VI SIMULATION MODEL OF PROPOSED METHOD

The simulation model of closed loop fuzzy controller is designed and it is presented below. The Fig.7 shows the simulation diagram of BLDC motor using fuzzy logic controller. The DC source is connected to the inverter input and the gate pulses are given from the hall signals. From the inverter the output is given to the BLDC motor. Instead of PI controller Fuzzy logic controller is used for the speed regulation.

The speed error is given as the input for the Fuzzy Logic Controller. The speed error is computed by comparing the reference speed and the actual speed of the BLDC motor. Fuzzy Logic Controller output is used for the reference current generation which is compared with the actual current and given to the hysteresis controller.

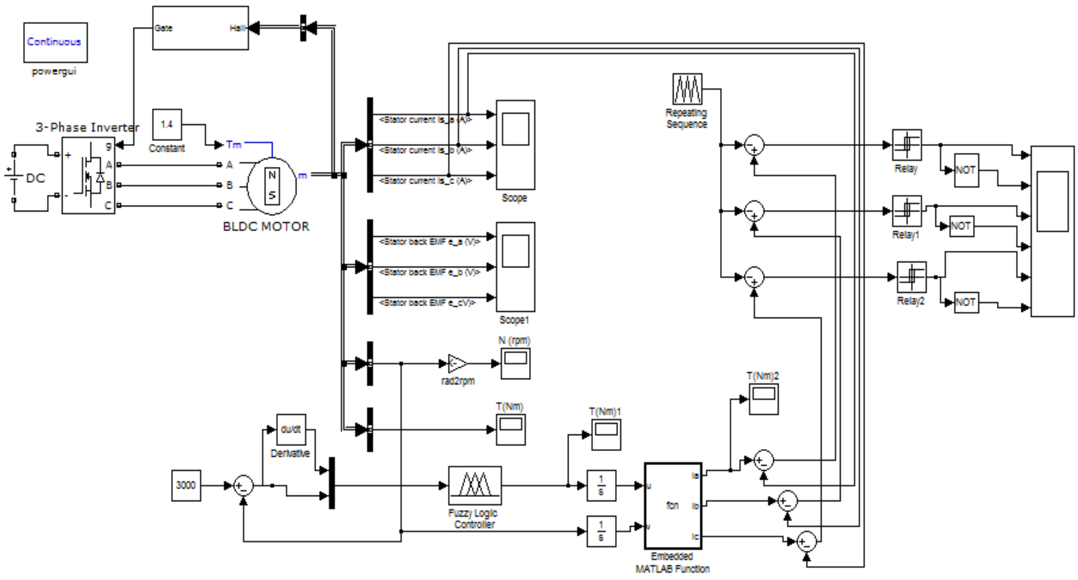

Fig.7 Simulation Diagram of BLDC motor using Fuzzy Logic controller

VII RESULTS AND DISCUSSION

The speed response of the BLDC drive system using fuzzy logic controller is shown in Fig.10. With the motor at rest stage the reference speed is set at 400rpm with a settling time 0.02 seconds the motor speed which reaches the reference speed with a percentage overshoot of 6.667 with PI speed controller. The phase currents at the time starting getting transient due to initial phase back emfs machine are zero. After the speed reaching reference speed, phase currents are reaches the reference current. For FLC the motor speed reaches reference speed with settling time of 0.03 seconds, out any appreciable overshoot and zero steady state error in speed. And phase currents are settling to steady state, when actual current reaches the reference current.

The speed of the BLDC motor settles at 3000rpm after implementing FLC. The Fig.11 shows the electromagnetic torque of BLDC motor using FLC and the peak value of rotor speed is 31 rpm. The settling time of the rotor speed is 2.23sec.When using FLC controller in the feedback circuit based on its present error and the FLC it performs the operation and gives the output signal. The speed response of the BLDC drive with conventional PI controller response of the drive is slower than that of FLC speed controller. The former controller shows an overshoot in speed response, which is undesirable. The drive takes maximum permissible current to start the motor from standstill. The results prove that the response of the drive is faster with FLC controller than the conventional PI controller. Improved response in case of FLC controller is of immense help to industrial applications.

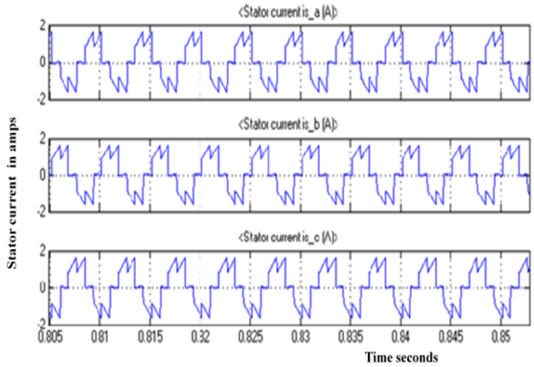

Fig: 8 Stator currents variation of BLDC motor using FLC

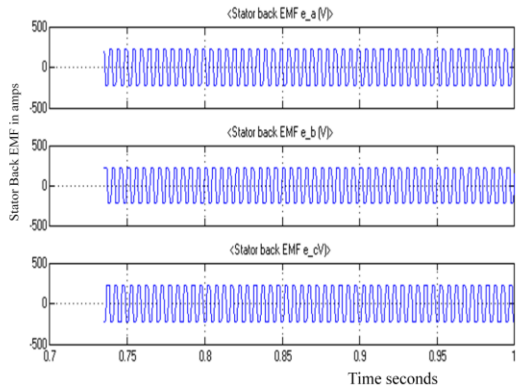

Fig: 9 Stator Back EMF of BLDC motor using FLC

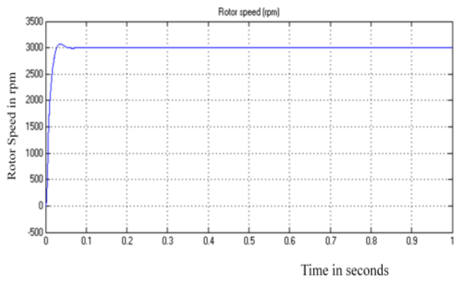

Fig: 10 Speed Response of BLDC motor using FLC

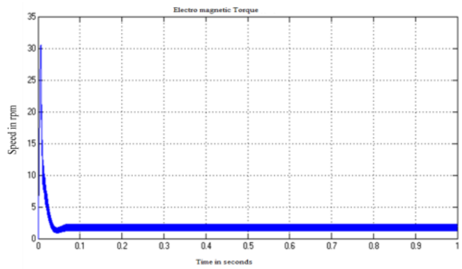

Fig: 11 Electromagnetic Torque of BLDC Motor using FLC

VI CONCLUSION

The FLC controller is implemented in the BLDC motor drive to improve the dynamic performance and to enhance the speed of the motor system. The simulation has been carried out for different operating conditions using conventional PI controller and FLC controller. The simulation results of the two controllers are compared based on the settling time and rise time for steady state condition and for dynamic condition sudden change in load and set speed variation. A fuzzy logic controller (FLC) has been employed for the speed control of PMBLDC motor drive and the performance of a fuzzy controller is improved. Effectiveness of the model is established by performance prediction over a wide range of operating conditions. Fuzzy logic control improved the quality of the speed response when compared to PI control. While using Fuzzy Logic Controller the dynamic performance is improved and based on the advantages parameter variation and load disturbance are controlled. Thus the performance of the Fuzzy Logic Controller is better than the other controller.

ACKNOWLEDGMENT

A project of this nature needs co-operation and support from many persons for the successful completion. In this regard, I am fortunate to express my heartfelt thanks to Associate Professor **M.MURUGAN, M.E., (Ph.D).,** for her effective leadership, encouragement and guidance in the project.

REFERENCES

[1] B.-K. Lee, T.-H. Kim, and M. Ehsani, “On the feasibility of four-switch three-phase BLDC motor drives for low cost commercial applications:Topology and control,” *IEEE Trans. Power Electron.*, vol. 8, no. 1, pt. 1, pp. 164–172, Jan. 2003

[2] S. Ogasawara and H. Akagi, “An approach to position sensorless drive for brushless dc motors,” *IEEE Trans. Ind. Appl.*, vol. 27, no. 5, pp.928–933, Sep. 1991.

[3] H. Melkote and F. Khorrami, “Nonlinear adaptive control of directdrive brushless dc motors and applications to robotic manipulators,”*IEEE/ASME Trans. Mechatronics*, vol. 4, no. 1, pp. 71–81, Mar. 1999.

[4] H. Grabner, W. Amrhein, S. Silber, and W. Gruber, “Nonlinear feedback control of a bearingless brushless dc motor,” *IEEE/ASME Trans. Mechatronics*, vol. 15, no. 1, pp. 40–47, Feb. 2010.

[5] R. Shanmugasundram, K. M. Zakariah, and N. Yadaiah, “Low-cost high performance brushless dc motor drive for speed control applications,” in Proc. IEEE Int. Conf. Adv. Recent Technol. Commun. Comput., Kottayam, India, Oct. 27–28, 2009, pp. 456–460.

[6] R. Shanmugasundram, K. M. Zakariah, and N. Yadaiah, “Digital implementation of fuzzy logic controller for wide range speed control of brushless dc motor,” in Proc. IEEE Int. Conf. Veh. Electron. Safety, Pune, India, Nov. 10–12, 2009, pp. 119–124.

[7] P. Pillay and R. Krishnan, “Modeling, simulation, and analysis of permanent-magnet motor drives, part ii: The brushless dc motor drive,” IEEE Trans. Ind. Appl., vol. 25, no. 2, pp. 274–279, Mar./Apr. 1989.

[8] M.Murugan, R.Jeyabharath and P.Veena, “Stability analysis of BLDC Motor based on Input Shping” International Journal of Engineering and Technology, Vol No.5, Nov 2013, pp -4339-4348

[9] C. Basilio and S. R. Matos, “Design of PI and PID controllers with transient performance specification,” IEEE Trans. Edu., vol. 45, no. 4, pp. 364–370, Nov. 2002.

[10] J.-W. Kim and S. W. Kim, “Design of incremental fuzzy PI controllers for a gas-turbine plant,” IEEE/ASME Trans. Mechatronics, vol. 8, no. 3, pp. 410–414, Sep. 2003.

[11] Rubaai, D. Ricketts, and M. D. Kankam, “Laboratory implementation of a microprocessor-based fuzzy logic tracking controller for motion controls and drives,” IEEE Trans. Ind. Appl., vol. 38, no. 2, pp. 448–456, Mar./Apr. 2002.

[12] R. Krishnan, “Selection criteria for servo motor drives,” in Proc.IEEE IAS Annu. Meeting, 1986, pp. 301-308.

[13] Y.-S. Lai, F.-s. Shyu, and Y.-H. Chang, “Novel loss reduction pulse width modulation technique for brushless dc motor drives fed by MOSFET inverter,” IEEE Trans. Power Electron., vol. 19, no. 6, pp. 1646–1652, Nov. 2004

[14] R. Shanmugasundram, K. M. Zakariah, and N. Yadaiah. (2012, May). Modelling, simulation and analysis of controllers for brushless direct current motor drives. J. Vib. Control [Online]. pp. 1–15.

[15] V. M. Varatharaju, B. L. Mathur, and K. Udhyakumar, “Speed control of PMBLDC motor using MATLAB/Simulink and effects of load and inertia changes,” in Proc. 2nd Int. Conf.Mech. Electr. Technol., Sep. 10–12, 2010, pp. 543–548.

[16] H.-x.Wu, S.-k. Cheng, and S.-m. Cui, “A controller of brushless DC motor for electric vehicle,” IEEE Trans. Magn., vol. 41, no. 1, pp. 509–513, Jan. 2005.

[17] M.Murugan, R.Jeyabharath and P.Veena, “An Effective Active Clamp Resonant DC Link for BLDCM Drive System”, European Journal of Scientific and Research, Vol No.88, October 2012, pp 475-483

[18] ASathyan, N. Milivojevic, Y.-J. Lee, M. Krishnamurthy, and A. Emadi, “An FPGA-based novel digital PWM control scheme for BLDC motor drives,” IEEE Trans. Ind. Electron., vol. 56, no. 8, pp. 3040–3049, Aug. 2009.

