# DESIGN AND IMPLEMENTATION OF MODIFIED FUZZY PI CONTROLLER FOR BLDC MOTOR

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***Abstract—*** *This paper presents performance of the Brushless DC Motor (BLDC) using modified fuzzy tuned PI controller. Usually fuzzy logic controllers are poor under transient conditions. To enhance the dynamic performance of the BLDC drive, a original implementation of speed controller based on modified fuzzy logic control is presented which is termed as modified fuzzy tuned PI controller. A complete simulation of closed loop BLDC drive using modified fuzzy tuned PI controller is simulated successfully using MATLAB / Simulink. The entire BLDC model simulation is divided in to the several independent functional modules such as BLDC module, current control module, PWM module, inverter module and so on. The simulation model of the BLDC motor simulation can be obtained by combining these modules. In order to verify the effectiveness of the modified fuzzy tuned PI controller, the simulation results are compared with other controller (PI and FPI controller). The simulation result shows modified fuzzy tuned PI controller has superior performance than PI and FPI controller.*

***Keywords— BLDC; FLC; PI; FPI; Fuzzy tuned PI***

## 1. INTRODUCTION

In variable-speed control of AC motor drives, utilization of BLDC motor has been widely used because it has simpler structure and lower cost than the other AC motors [5].BLDC motoralso known as electronically commutated motors (ECMs, EC motors) are synchronous motors which are powered by a DC electric source via an integrated inverter, which produces an AC electric signal to drive the motor; additional sensors and electronics control the inverter output [3]. The motor part of a brushless motor is often a permanent magnet synchronous motor, but can also be a switched reluctance motor, or induction motor.

Many machine design and control schemes have been developed to improve the performance of BLDC motor drives[4]. The model of motor drives has to be known in order to implement an effective control in simulation. Analysis of fuzzy logic controlled brushless DC motor drives using MATLAB/Simulink. Initially a fuzzy logic controller is developed using MATLAB Fuzzy-Logic Toolbox and then inserted into the Simulink model[8].The control algorithms, fuzzy logic and PI are compared [2]. The PWM signals are generated by comparing the Hall sensor feedback signals and the motor current. The entire BLDC is control simulation divided in to several independent functional modules such as BLDC module, current control module, PWM module inverter module and so on. The simulation model of the BLDC Drive simulation can be obtained by combining these modules.

Typical Hall-sensor controlled VSI driven BLDC motors, where the inverter operates using 120-Degree commutation method. Rotor position is sensed by Hall Effect sensors embedded into the stator which gives the sequence of phases. Whenever the rotor magnetic poles pass near the Hall sensors, they give a high/low signal, indicating the N or S pole is passing near the sensors [9].The sensor less mode of control is highly advantageous if the motor is operating in dusty or oily environments, where occasional cleaning of Hall sensors is required for proper sensing of rotor position. Further, if the motors rating are very low, the power consumption by the position sensors can substantially reduce the motor efficiency and in compact units such as computer hard disk drives it may not be possible to accommodate position sensors [6].

## 2. MODIFIED FUZZY TUNED PI CONTROLLER

The Modified Fuzzy Tuned PI controller is designed to replace the Fuzzy PI controller [2] which shows in Figure.1 and Figure.2 shows simulation diagram of modified fuzzy tuned PI controller

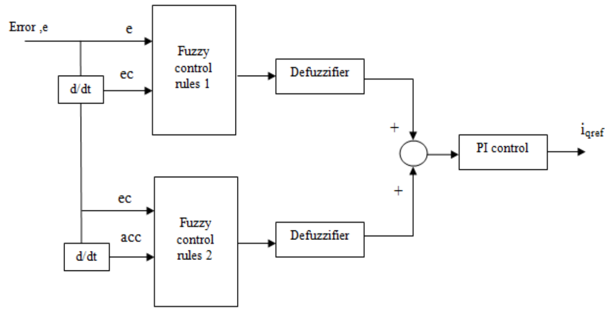



Figure.1 Block Diagram of Modified Fuzzy Tuned PI Controller

The modified fuzzy tuned PI controller uses only two inputs, speed error (e) and rate of change of speed error (etc). But in this model an additional input named ‘accelerated rate of change of error’ (acc) is used to improve the transient response of the system. With these three inputs, the structure of the FLC is composed of two independent parallel fuzzy control blocks, each of which contains the corresponding fuzzy control rules and a defuzzifier. The incremental output of the FLC is formed by algebraically adding the outputs of the two fuzzy control blocks[1].

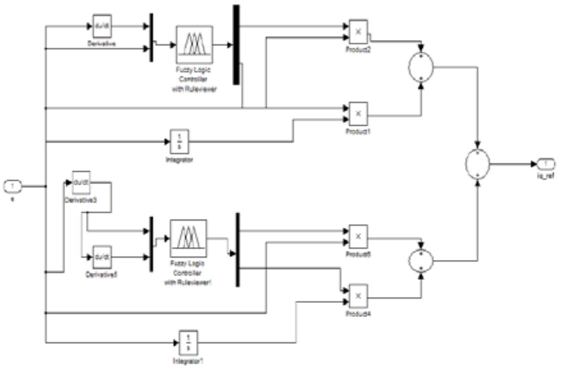


Figure.2 Simulation of modified Fuzzy Tuned PI controller

The fuzzy inference of modified fuzzy tuned PI controller is based on the fuzzy rule table set previously [2]. So the algorithm of fuzzy inference is not complex. The parameters of PI can be adjusted on-line, which can be changed through the inquiry to fuzzy control rules table saved a forehand in the computer. The calculated speed of controller is very quick, which can satisfy the rapid need of controlled object. The control algorithm of traditional PI controller can be described as,

$$u(k) = kP\, e(k) + kI\int e(k)$$

Where, kP is the proportional gain, kIis the integral gain and e (k) is the speed error.

The design algorithm of Fuzzy PI controller in this paper is to adjust the kp and ki parameters online through fuzzy inference based on the speed error (e) and rate of change of speed error (ec) to make the control object attain the good dynamic and static performances.

1. *The input variables and output variables:*

Speed error (e) and rate of change of speed error (ec) are used as fuzzy input and the proportional constant kP, the integral constant kI are the fuzzy output and Figure.3 shows Fuzzy tool box which has input and output.

2. *Fuzzy language of input and output variables:*

The fuzzy variable of input variable e is E and ec is EC. The fuzzy variable of output variable kp and ki are KP and KI.The fuzzy sets of E and EC are all defined as {NB,ZO,PB}, where NB, ZO and PB represent Negative Big, Zero, and Positive Big respectively.

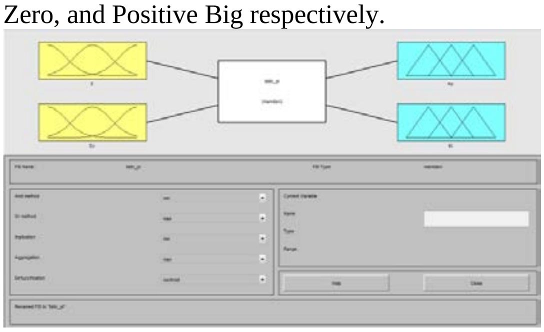


Figure.3 Fuzzy Tool Box

The fuzzy sets of KP and KI are defined as {Z, S, M, B}, where Z, S, M and B represent Zero, Small, Medium and Big. The membership functions of E, EC, KP and KI are triangular distribution functions. The membership functions for each variable are shown in Figure.4 and Figure 5.

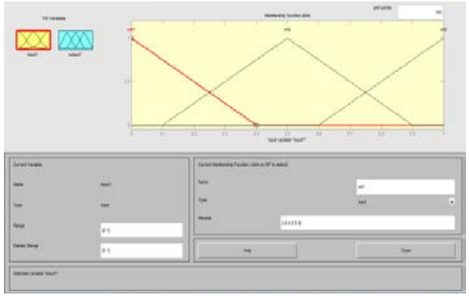


Figure.4 Input Membership Function

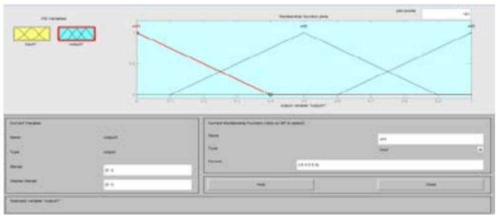


Figure.5 Output Membership Function

### 3. FUZZY RULES REGULATIONS:

The principle of designing fuzzy rules is that the output of controller can make the system output response dynamic and static performances optimal. The fuzzy rules are generalized as Table I and Table II according to the expert in BLDC motor system and simulation analysis of the system. The Mamdani inference method is used as the fuzzy inference mode.

The inference can be written as "IF A AND B THEN C". For example "IF E is NB AND EC is PB THEN KP is S, KI is M".KP and KIare written the same as 9 fuzzy condition statements.

TABLE I CONTROL RULES FOR KP

| E/EC | NB | ZO | PB |
|---|---|---|---|
| NB | B | B | M |
| ZO | M | Z | B |
| PB | M | B | B |

TABLE II CONTROL RULES FOR Ki

| E/EC | NB | ZO | PB |
|---|---|---|---|
| NB | B | B | M |
| ZO | M | Z | B |

| | | | |
|---|---|---|---|
| PB | M | B | B |

The output variable can be obtained by the MIN - MAX inference. The weighted average method is adopted for defuzzification.Figure.6 and Figure.7 shows the rule editor and rule Viewer Output while simulation running at 3000rpm rotor speed.

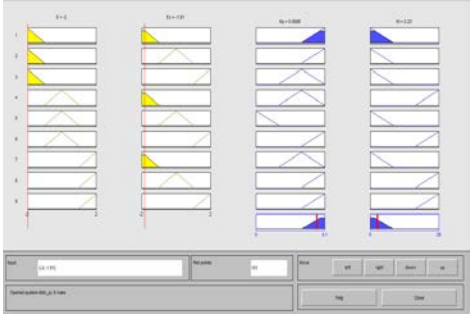
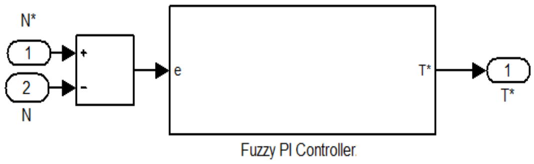


Figure.7 Rule Viewer




## 4. SIMULATION MODEL OF BLDC BASED ON MATLAB

In this MATLAB simulation module, The block diagram and simulation diagram of BLDC motor using Modified fuzzy Tuned PI control is shown in Figure.8 and figure 9. The total system consists of speed loop, current loop, Hysteresis controlled inverter and BLDC motor.

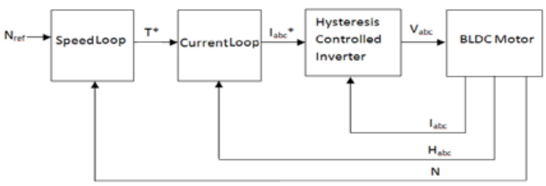



Figure.8 Block diagram of BLDC motor using modified fuzzy Tuned PI control

Speed loop of BLDCM drive is shown in Figure.10. It consists of two inputs such as reference speed and measured speed.

Error of reference speed and measured speed is given to the Modified Fuzzy Tuned PI controller. Its output is reference torque of T*.

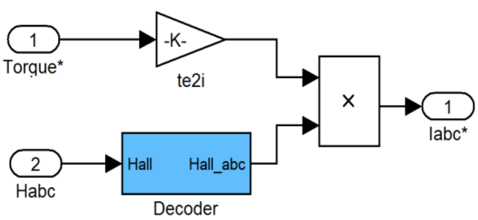



Figure.11 Current loop of BLDC motor

The current loop of BLDC motor is shown in Figure.11 It consists of two inputs such as Torque* and Habc. Its output is reference current Iabc. Habc is the Hall effect sensor signals from the motor. It decoded by decoder into Ha,Hb and Hc. Reference torque from the modified fuzzy tuned PI controller is converted into current and multiplied with position signals to produce reference current Iabc*

Hysteresis Controlled Inverter consists of a Hex bridge inverter and Hysteresis controller which shows in Figure.11 and Figure 12. Reference current from current loop and actual current from motor are compared to produce a current error. Hysteresis controller receives current error and produces three pulses based on error .These pulses are used to trigger the upper switches in the three arms. The pulse to the upper switch in the arm is inverted and given to the lower switch in the arm. From the inverter three phase voltage is taken out [7].

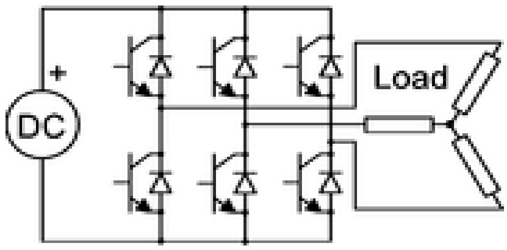



Figure.12 Three Phase Inverter with star connected load

The PWM current controllers [12] are widely used. The switching frequency is usually kept constant. They are based in the principle of triangular carrier wave of desire switching frequency and is compared with the error of controlled signal. The error signal obtained from the sum of reference signal generated in the controller and the negative of the actual motor current feed back from the motor [5]. The voltage signal obtained triggers the gates of the voltage source inverter to generate the desire output. If the error command is greater than the carrier, the inverter leg is held switched to the positive polarity. When the error command is less, the inverter leg is switched to negative polarity. This will generate the PWM signal and the output voltage of the inverter is proportional to the current error command.

## 5. SIMULATION RESULTS

The simulation model of BLDC motor using modified fuzzy tuned PI controller has been developed in MATLAB environment with Simulink.

The parameters of BLDC used in this simulation model are,

| | |
|---|---|
| Stator Resistance | Rs = 2.875 ohm |
| Stator Phase inductance | Ls = 0.423 H |
| Moment of Inertia | J = 0.03982 Kg.m2 |
| Rotor flux linkage | φf= 0.175 Wb |
| Number of poles | P = 6 |

The E and Ec values corresponding KP ,K I values are tabulated in table III.The variations in speed drop, restoration, time, and peak overshoot of BLDC motor using modified fuzzy tuned PI controller is observed under various speed and compared. The simulation results of BLDC motor at 3000 rpm and comparison of different controller are shown in Figure.13 to Figure.18 and Figure.19.The performance of the BLDC motor based on the proposed scheme has been improved.

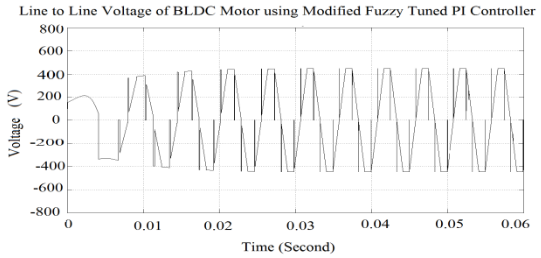



Figure.14 Line Volage Vab of BLDC motor

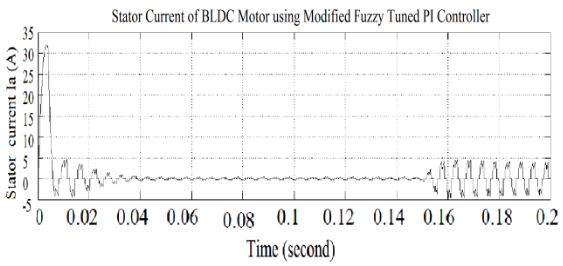



Figure.15 Stator Current Ia of BLDC motor

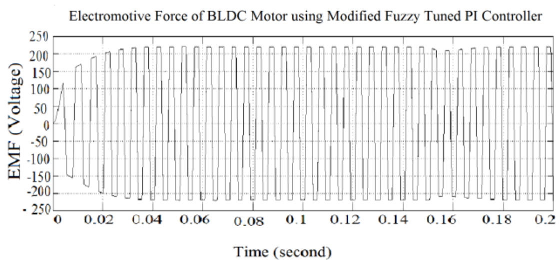



Figure.16 Electromotive Force of BLDC motor

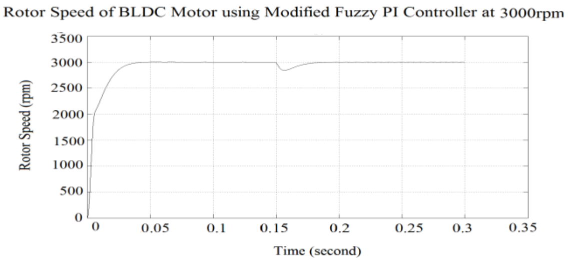



Figure.17 Rotor Speed of BLDC motor at 3000 rpm

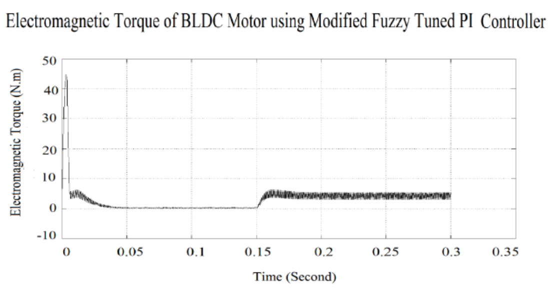



Figure.18 Electromagnetic Torque of BLDC motor

TABLE IV COMPARISONS OF DIFFERENT CONTROLLER

| **Reference Speed** | **Speed Drop under load (%)** | | | **Restoration Time after load (second)** | | | **Peak Over Shoot (%)** | | |
|---|---|---|---|---|---|---|---|---|---|
| | ***PI*** | ***Fuzzy PI*** | ***Modified Fuzzy Tuned PI*** | ***PI*** | ***Fuzzy PI*** | ***Modified Fuzzy Tuned PI*** | ***PI*** | ***Fuzzy PI*** | ***Modified Fuzzy Tuned PI*** |
| 500 | 29.2 | 25.2 | 24.4 | 0.03 | 0.07 | 0.04 | 0 | 0 | 0 |
| 1000 | 15.6 | 13.9 | 12.1 | 0.03 | 0.07 | 0.04 | 0 | 0 | 0 |
| 1500 | 11 | 10.3 | 8.6 | 0.03 | 0.1 | 0.05 | 0.466 | 0 | 0 |
| 2000 | 8.95 | 8.45 | 6.95 | 0.05 | 0.1 | 0.05 | 1.25 | 0 | 0 |
| 2500 | 7.8 | 7.2 | 5.6 | 0.06 | 0.12 | 0.05 | 2.2 | 0 | 0 |
| 3000 | 6.9 | 6.5 | 5 | 0.08 | 0.17 | 0.05 | 3.13 | 0 | 0 |

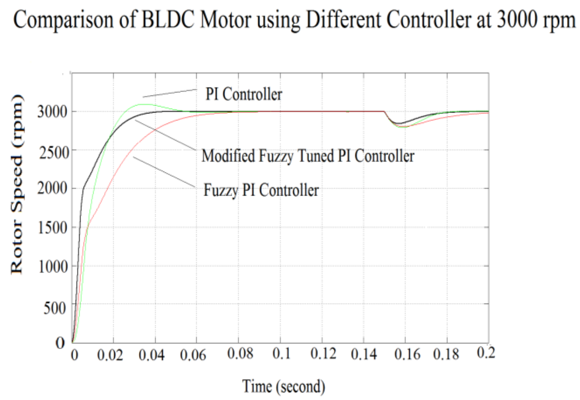



Figure.19 Comparison of BLDC motor at 3000rpm

## 6. CONCLUSION

In this paper a novel desirable simulation of closed loop control system for BLDC motor is proposed. The three types of controllers, PI Controller,Fuzzy PI controller and modified fuzzy tuned PI controller are compared and tabulated in table IV. In BLDC motor, modified fuzzy tuned PI controller is used for speed controller and their performances are compared. The performance differences due to the all the three types of controllers are examined forvarious speed. The simulation results proved that PI controller has more Peak overshoot while speed increases. PI controller and fuzzy PI controller have more speed drop with poor performance under load disturbances with increase in restoration time. The proposed modified fuzzy tuned PI controller gives better speed response with less speed drop with less restoration time. The transient response of speed under load changes using modified fuzzy tuned PI controller is better than PI and fuzzy PI controller with less settling time to reach rated speed. The proposed controller is suitable for industrial applications to maintain constant speed under loaded condition in machining operations.

## REFERENCES


[1] Ananthamoorthy N.P and Baskaran K (2013), 'Modelling,Simulation and Analysis of Fuzzy Logic controllers for Permanent Magnet Synchronous Motor Drive'International Review on Modelling and Simulationsvol. 6, no.1 ,pp.75–82.

[2] Ananthamoorthy N.P and Baskaran K (2013), 'Speed And Torque Control Of Permanent Magnet Synchronous Motor Using Hybrid Fuzzy Proportional Plus Integral Controller'Journal of Vibration and Control,pp.1–17.

[3] Atef Saleh Othman Al-Mashakbeh (2009), 'Proportional Integral and Derivative Control of Brushless DC Motor', European Journal of Scientific Research, vol.35 no.2 pp.198-203.

[4] Bharathi.Y.H, B.R. Rekha, P. Bhaskar, C.S. Parvathi and A.B. Kulkarni (2008), 'Multi-input Fuzzy Logic Controller for Brushless dc Motor Drives', Defence Science Journal, Vol. 58, No. 1, pp. 147-158.

[5] Chung-Wen Hung, Jen-Ta Su, Chih-Wen Liu, Cheng-Tsung Lin and Jhih-Han Chen (2010), 'Fuzzy Gain Scheduling PI Controller for a Sensorless Four Switch Three Phase BLDC Motor', IEEE conference on Applied Power Electronics pp. 420-424.

[6] Dawid Makieła (2011), 'Sensorless Control of High-Speed PM BLDC Motor', IEEE conference on Industrial Electronics, pp. 722-727.

[7] Gencer. C and M. Gedikpinar (2006), 'Modeling and simulation of BLDCM using MATLAB/ Simulink', Journal of Applied Sciences 6(3). pp. 688-691.

[8] Juli Singh (2012), 'Analysis The Speed Control Of BLDC Motor Drive Using Sensors', International Journal of Engineering Research and Applications, pp. 2868-2884.

[9] MadhusudhanaRao. G, B.V.SankerRam, B.Smapath Kumar and K.Vijay Kumar (2010) 'Speed Control of BLDC Motor Using DSP', International Journal of Engineering Science and Technology, Vol. 2(3), pp. 143-147.

[10] Mehmet Cunkas and Omer Aydogdu (2010), 'Realization Of Fuzzy Logic Controlled Brushless Dc Motor Drives Using Matlab/Simulink', Mathematical and Computational Applications, pp. 218-229 .

[11] Purna Chandra Rao. A, Y. P. Obulesh and Ch. Sai Babu (2012), mathematical modeling of BLDC motor with closed loop speed control using PID controller under various loading conditions', ARPN Journal of Engineering and Applied Sciences, vol. 7, no. 10, pp. 1321-1328

[12] Shekeena and P. V. R. L. Narasimham (2012), 'Hybrid Control of Brushless DC Motor For Variable Speed Applications' , International Journal of Computer Science and Management Research Vol 1 Issue 3, 492- 496.

[13] Si Xiaoping, Wang Jidong (2010), 'A Vector-control System Based on Fuzzy Selftuning PID controller for PMSM', IEEE conference on E-Product E-Service and E-Entertainment, pp. 1-4.

[14] Sonali U. Madankar and. M. A. Gaidhane (2011), 'Study and Simulation of Fuzzy Logic Based Speed Control of Multi Level Inverter Fed PMBLDC Drives', International conference on Advanced Computing, Communication and Networks'11, pp. 737-740

[15] Tan Chee Siong, Baharuddin Ismail, Siti Fatimah Siraj, Mohd Faridun Naim Tajuddin, Noor Shahida Jamoshid, MohdFayzul Mohammed (2010), 'Analysis of Fuzzy Logic Controller for Permanent Magnet Brushless DC Motor Drives', Proceedings of 2010 IEEE Student Conference on Research and Development (SCOReD 2010), 13 - 14 Dec 2010, pp. 436-431

[16] Tan Chee Siong, Baharuddin Ismail, Siti Fatimah Siraj, Mohd Faridun Naim Tajuddin, Noor Shahida Jamoshid, MohdFayzul Mohammed (2010), 'Implementation of Fuzzy Logic Controller for Permanent Magnet Brushless DC Motor Drives', proceeding IEEE International Conference on Power and Energy (PECon2010), pp. 462-467