

A Modified Self Tuning Fuzzy Logic Controller for Brushless Direct Current Motor

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Abstract

BLDC motors are very popular and are exchanging brush motors in various applications. Because the BLDC motor does not need any commutator and due to its superior electrical and mechanical features and its capability to operate in harmful conditions it is more reliable than the DC motor. Conventionally, PI; PID controllers are generally used to control these motors, requiring rotor position sensors (RPS) for starting and for providing the proper commutation sequence to stator windings. The disadvantages of sensed motor control system are increased cost and size of the motor, and required special mechanical arrangement for mounting the sensors. Another problem associated with BLDC motor control is the use of Conventional PI, PID controllers these controllers possess complications under the situations of nonlinearity, load disturbances and parametric variations. This paper presents the design and implementation of a modified self-tuning fuzzy logic controller for the sensor less speed control of brush less dc motors.

Keywords: Modified Self-tuning Fuzzy logic controller (STFLC), Brushless DC motor drives (BLDC), and back-EMF, sensor less, Variable speed drives.

1. INTRODUCTION

Limitations of brushed DC motor overcome by BLDC motors include lower efficiency and susceptibility of the commutator assembly to mechanical wear and consequent need for servicing, at the cost of potentially less rugged and more complex and expensive, BLDC motors offer better speed versus torque characteristics, high dynamic response, high efficiency, long operating life, noiseless operation and higher speed ranges [1]. Due to their favorable electrical and mechanical properties, BLDC motors are widely used in servo applications such as automotive, aerospace, medical, instrumentation, actuation, robotics, machine tools and industrial automation equipment. The Figure 1.1 shows the Electrical Diagram of BLDC Motor. Many machine design and control schemes have been developed. Conventional DC motors are highly efficient and their characteristic make them suitable for use as servomotors.

However, their only drawback is that they need a commutator and brushes which are subject to wear and required maintenance. When the function of commutator and brushes were implemented by solid-state switches, maintenance free motors were realized. These motors are known as brushless dc motors. Furthermore, fuzzy logic controllers (FLCs) have been used to analyze BLDC motor drives [2]. In this paper, a comprehensive simulation model with a modified self-tuning fuzzy logic controller is presented. MATLAB fuzzy logic tool box is used to design the FLC, which is integrated into simulations

with many machine and control schemes have been developed to improve the performance of BLDC motor drives. Boundaries of brushed DC motors overcome by BLDC motors consist of lesser efficiency and susceptibility of the commutator assembly to mechanical wear and subsequent need for servicing, at the cost of potentially less rugged and more complex and expensive control electronics. Simulink [3].

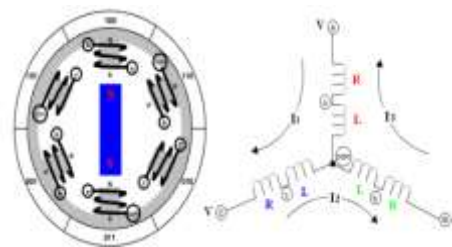


Figure: 1.1 Electrical Diagram of BLDC Motor

Besides, considering that the computational time without affecting the accuracy of the results obtained is very low, it can be said that the proposed method is promising [4]. Previous studies and development of control schemes have made a very good contribution to BLDC motor drives, but the comprehensive approach has not been available for modeling and analysis of fuzzy logic controlled BLDC motor drives.

2. EXISTING SYSTEM

The BLDC motor drive system consists of a dc power supply switched to the stator phase windings of the motor through an inverter by power switching devices. The detection of rotor position will determine the switching sequence of the inverter. Three-phase inverters are generally used to control these motors, requiring a rotor position sensor for starting and for providing the proper commutation sequence to stator windings. These position sensors can be Hall sensors, resolvers, or absolute position sensors.

However, the Hall sensors will lose its sensing capability at the temperature above 125 °C. Therefore Hall sensors are not feasible in high temperature conditions. The drawbacks of sensed motor control system are increased cost and size of the motor, and need special mechanical arrangement for mounting the sensors. Conventionally, three-phase inverters are generally used to control these motors, requiring a rotor position sensor for starting and for providing the proper commutation sequence to stator windings.

The disadvantages of sensed motor control system are increased cost and size of the motor, and need special mechanical arrangement for mounting the sensors. One more problem associated with BLDC motor control was the use of Conventional controllers; these controllers' possess difficulties under the conditions of nonlinearity, load disturbances and parametric variations.

Another major problem was related with the conventional controllers that are widely used in the industry due to its simple control structure and ease of implementation. The Figure 2.1 shows the Speed control of BLDC motor use the PID controller. But these controllers possess difficulties under the conditions of nonlinearity, load disturbances and parametric variations. Traditional control systems are based on the mathematical models in which the control system is described using one or more differential equations that define the system response to its inputs. In many cases, the mathematical model of the control process may not exist, or may be too expensive in terms of computer processing power and memory, and a system based on experimental rules may be more effective. Hence there is a need for intelligent controller.

So an attempt is made to remove the drawbacks associated with sensed control and use of traditional controllers by using sensorless control and fuzzy controller for BLDC motor. Thus this method of sensorless control of BLDC motor was to provide advantages like cost reduction, reliability, elimination of difficulty in maintaining the sensor etc. and developing nonlinear system for fuzzy logic control.

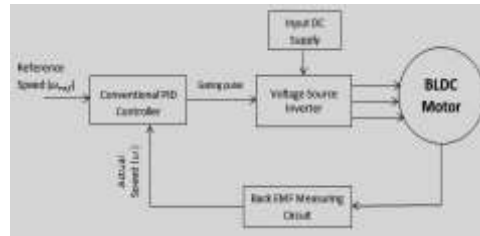


Figure: 2.1 Speed Control of BLDC Motor by PID Controller

3. TECHNIQUES IN SENSORLESS CONTROL

The BLDC motor provides an attractive candidate for sensorless operation because the nature of its excitation inherently offers a low-cost way to extract rotor position information from motor-terminal voltages. A Permanent Magnet brushless drive that does not require position sensors but only electrical measurements is called a sensorless drive [5].

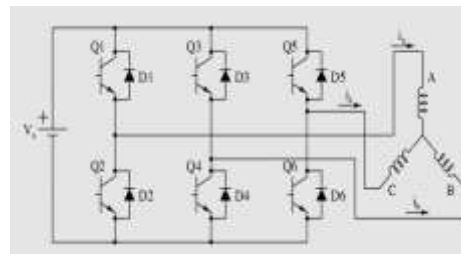


Figure: 3.1 Simplified BLDC Drive Scheme

The Figure 3.1 shows the Simplified BLDC Drive System. For three-phase BLDC motor at one time instant, only two out of three phases are conducting current and the no conducting phase carries the back-EMF. If the zero crossing of the phase back-EMF can be measured, we can know when to commutate the current. Sensing methods for the PMBLDC motors and generators are classified in two categories; direct and indirect back-EMF detection. Direct back-EMF detection methods: the back-EMF of floating phase is sensed and its zero crossing is detected by comparing it with neutral point voltage. The methods can be classified as: Direct back-EMF detection methods are Back-EMF Zero Crossing Detection (ZCD) or Terminal Voltage Sensing and PWM strategies. Indirect back-EMF detection methods: Back-EMF Integration, Third Harmonic Voltage Integration and Free-wheeling Diode Conduction or Terminal Current Sensing [1].

4. PROPOSED SYSTEM

Figure 4.1 shows the Speed Control of BLDC Motor by STFL Controller. It has a brushless dc motor, a voltage source, a voltage regular circuitry, a motor

driver circuit, back-emf detector circuit, optocoupler circuit and a microcontroller board.

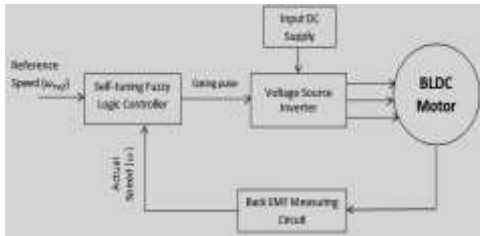


Figure: 4.1 Speed Control of BLDC Motor by STFL Controller

In Figure 4.1, ω_{ref} is the reference speed (rad/sec), ω is an actual rotor speed (rad/sec), u is the control signal used to reference moment (N-m); V_{dc} is the supply voltage of the inverter (Volt). In speed control loop as shown in the block diagram, the reference speed and the actual motor speed is compared and the error signal is obtained. These signals are employed in fuzzy controller and reference current is produced for control system. The current control loop regulates the BLDC motor current to the reference current value generated by the speed controller. The current control loop consists of reference current generator, PWM current control unit and a three phase voltage source inverter (VSI). Position of the BLDC motor is obtained by employing zero crossing back emf detection method and thus eliminating position sensor requirement [6].

4.1. Design of Fuzzy Controller

Error (E) and change in error (CE) are the inputs for the fuzzy controller whereas the output of the controller is change in duty cycle (ΔDC). The error is defined as the difference between the reference speed and actual speed, the change in error is defined as the difference between the present error and previous error and the output, Change in duty-cycle ΔDC is which could be either positive or negative is added with the existing duty-cycle to determine the new duty-cycle (DC_{new}) Figure 4.2 shows the basic structure of fuzzy logic controller. The fuzzy controller is composed of the following four elements: fuzzification, fuzzy rule-base, fuzzy inference engine and defuzzification [7].

4.2 Fuzzification

Fuzzy logic uses linguistic variables instead of numerical variables. The process of converting a numerical variable into a linguistic variable is called fuzzification [7].

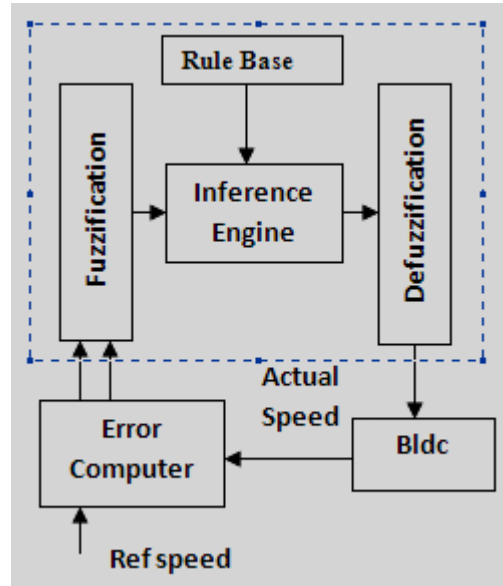


Figure: 4.2 Fuzzy Logic Controller

The fuzzifier includes two parts: choice of membership function and choice of scaling factor. The fuzzy variables error, change in error and change in duty-cycle are quantized using the linguistic terms NB, NS, ZE, PS, and PB (negative big, negative small, zero, positive small, and positive big respectively).

The motor maximum range of speed is 0-1500 rpm. The possible range of error is -1500 to +1500 rpm. The universe of discourse for error is -1500 rpm to +1500 rpm and for the change in duty cycle, defined as -100% and +100%. In order to achieve faster control action and simplification, the inputs and output are normalized to +/-100 rpm, +/-100 rpm and +/-100 respectively. The membership functions used for inputs and output are given in figure 4.3.

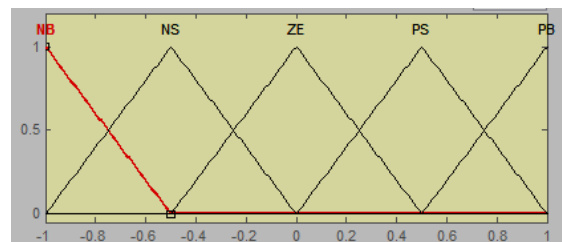


Figure: 4.3 Membership Function

4.3 Rulebase and Inference engine

A rule base (a set of If-Then rules), which contains a fuzzy logic quantification of the expert's linguistic description of how to achieve control action. Once the rules have been established, a fuzzy logic system can be viewed as a mapping from input to outputs. Rules may be provided by experts or can be extracted from numerical data. The performance of the controller can be improved by adjusting the membership function and rules. Different types of inferential procedures to help us understand things or to make decisions, there are many different fuzzy logic inferential procedures. The Table 4.1 shows the rule base of fuzzy logic controller. The fuzzy inference operation is implemented by using the 25 rules.

The three Fuzzy Rules are represented as follows,
IF (speed error is NB) and (change in speed error is NB) THEN (speed variation is NB)
IF (speed error is NS) and (change in speed error is NB) THEN (speed variation is NB)
IF (speed error is PS) and (change in speed error is NB) THEN (speed variation is NS)
Likewise 25 rules are defined. The same set of rules could be presented in a sliding mode format, a more compact representation given in Table 1.

Table:4.1 Rule Base

E \ CE	NB	NS	ZE	PS	PB
NB	NB	NS	ZE	PS	PB
NS	NB	NS	ZE	PS	PB
ZE	NB	NS	ZE	PS	PB
PS	NB	NS	ZE	PS	PB
PB	NB	NS	ZE	PS	PB

4.4 Defuzzification

Finally the fuzzy output is converted into real value output by the process called defuzzification. Centroid method of defuzzification is used because it can be easily implemented and requires less computation time. The defuzzified output is obtained by the following equation

$$z = \frac{\sum_{x=1}^n \mu(x)x}{\sum_{x=1}^n \mu(x)}$$

Where z is the defuzzified value, $\mu(x)$ is the Membership value of member. [8]

5. PROPOSED HARDWARE SYSTEM

Table No. 5.1 List of Components for Prototype Model

Components	Specifications & Range
BLDC Motor	Rated voltage 12Volts, 0.5A, 1500 RPM.
Power Supply Unit	Step down Transformer 230/24-0-24V, 1A Bridge Rectifier IC MICRLW10M, Capacitor 100V, 1000uF, Inductor 1mH.
Driver Circuit	Multi Output Step down Transformer 230/12V 6 Output, Driver IC TLP250 Capacitor 25V 470uF, Diode IN4007
Control Circuit	Microcontroller PIC16F877A Bridge Rectifier MICRLW10M Voltage Regulator IC LM7805C Capacitor 25V 470uF, 100uF
Power Circuit	MOSFET IRF840

The Table 5.1 shows the list of components for prototype model. The hardware for the proposed model is designed and the components were selected according to the circuit rating.

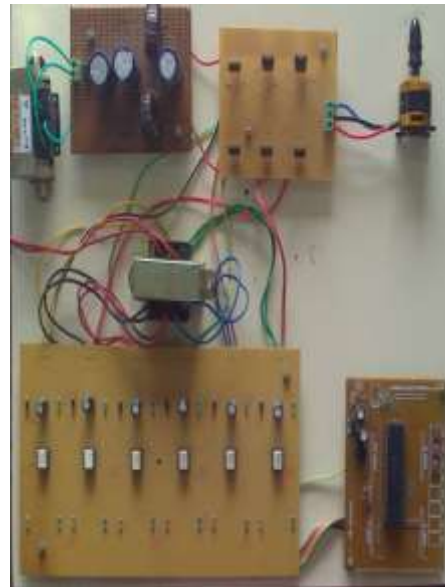


Figure: 5.1 Hardware Model

The proposed model is implemented for a speed control system to control the Brushless DC motor speed at desired set point through the technique of modified self-tuning fuzzy logic controller which is designed in the platform of MATLAB/Simulink and also the same have been implemented and tested for a 12volt Brushless DC motor.

The figure 5.1 shown the hardware model. The proposed hardware system can be implemented. It consists of Power supply, Inverter, Microcontroller, Voltage regulator, driver circuit, rectifier and BLDC motor. In this project 230V input ac supply is stepped down to 12V ac by using step down transformer and this 12V ac supply is converted into 12Vdc by a rectifier and this is applied to the power circuit. The power circuit was controlled by PIC microcontroller. It generates the gate pulses to the switches in the power circuit with respect to the reference speed set in the output ports of the microcontroller. So that now the power circuit makes the motor to run at a desired speed.

6. RESULTS AND DISCUSSION

6.1 PID Controller Output

MATLAB Simulink based Fuzzy Logic Controller for BLDC Motor Simulation results provide the comparison of conventional PID Controller and a modified self-Tuning Fuzzy Logic Controller performance. This section describes the following simulation results.

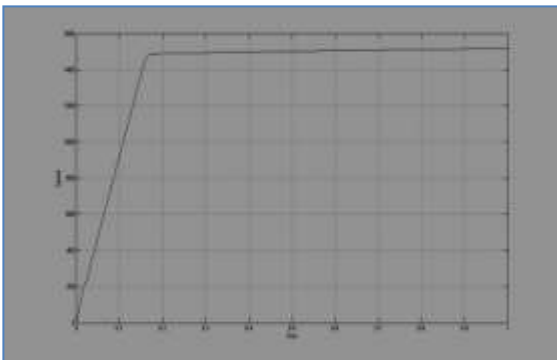
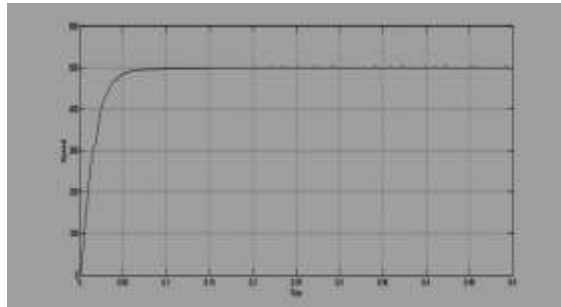


Figure: 6.1 PID Controller Speed (1500RPM) Output Waveform

The above figure 6.1 shows output waveform of the PID closed loop speed control of BLDC motor response. It provides comparison of set point speed and desired speed. The PID Controller response is drawn between motor speed and simulation time. Here set point speed value is 1500 RPM the desired output speed is attained after 0.172 sec with PID Speed Controller parameters. The table 6.1 shows the various set speed and settling time in conventional PID Controller and the Fuzzy Logic Speed Controller. Compare to conventional PID Controller and Fuzzy Logic Controller speed settling time is very low.

6.2 Fuzzy Controller Output

The following figures 6.2, 6.3, 6.4, shown the output waveform of Self-tuning fuzzy logic speed control of Brushless DC motor in various speed responses. It provides comparison of set point speed and desired speed. The FLC Controller response is



drawn between Motor speed and simulation time. The table 6.1 shows the comparison of set speed and motor speed settling time.

Figure: 6.2 FLC Speed (500 RPM) Output Waveform

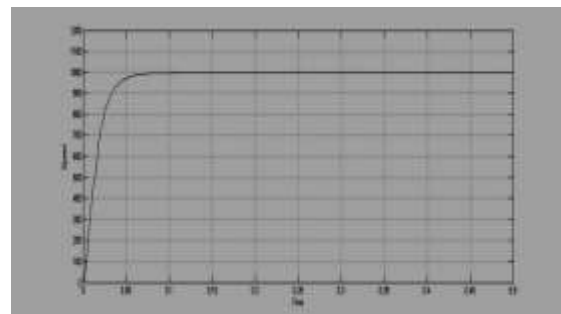


Figure: 6.3 FLC Speed (1000 RPM) Output Waveform

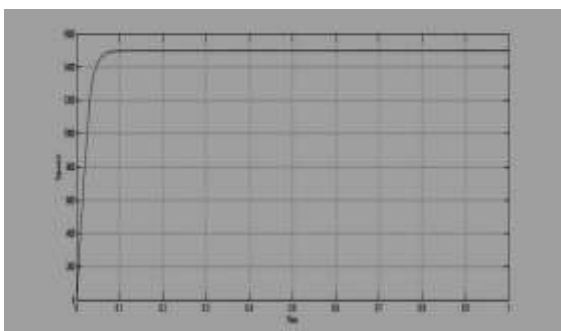


Figure: 6.4 FLC Speed (1500 RPM) Output Waveform

6.3 Comparative Study of Result

The table 6.1 is representing the conventional PID Controller and Fuzzy Self-tuning Controller according to the Tuning and settling time of the controller the desired speed is obtained. The Self-

tuning Fuzzy Logic Controller performance is better than conventional PID Controller.

The bellow table shows the various set speed and settling time in conventional PID Controller and Fuzzy Logic Speed Controller. Compared to conventional PID Controller the Fuzzy Logic Controller settling time is very low.

Table N: 6.1 Comparative Studies of Set Speed and Settling Time

S.No	Speed (RPM)	Conventional PID (Settling Time)	Fuzzy Controller (Settling Time)
1	500	0.075	0.067
2	750	0.091	0.071
3	1000	0.123	0.078
4	1250	0.145	0.081
5	1500	0.172	0.086

7. CONCLUSION AND FUTURE SCOPE

7.1 Conclusion

This project aims at improving the performance of the Brushless DC motor speed control using modified self-tuning fuzzy logic controller. The conventional PID Controller parameters need to be constantly adjusted in order to achieve better control performance. Fuzzy Self-tuning Controller can automatically adjust control parameters in accordance with the speed error and change in speed error. Fuzzy Controller has smaller overshoot, small steady state error and less rising and settling time than conventional PID Controller and has better dynamic response properties and steady-state properties.

The project presents a Modified Self-Tuning Fuzzy Logic Controller to ensure excellent reference tracking of Brushless DC motor drives. The Fuzzy Logic Controller is enhanced the speed regulation of this type of drives over both starting and load disturbance periods. The Brushless DC motor response when controlled by Fuzzy Logic Controller is superior to that corresponding to the conventional PID Controller.

7.2 Future Scope

The Matlab/Simulink based simulation for speed control of Brushless DC motor has been done which can be implemented in hardware to observe actual feasibility of the approach applied in this project. This technique can be extended to others types of motors (Permanent Magnet DC motor, Stepper motor). The Brushless DC motor speed control can be implemented in other soft computing

technique like Genetic Algorithm, Particle Swarm Optimization technique.

REFERENCES

- [1] P.Yedamale, Brushless DC (BLDC) Motor Fundamentals. Chandler, AZ: Microchip Technology, Inc., last access; March 15, 2009.
- [2] R.Akkaya, A.A.Kulaksız, and O Aydogdu, DSP implementation of a PV system with GA-MLP-NN based MPPT controller supplying BLDC motor drive, *Energy Conv.and Management* 48, 210-218, 2007.
- [3] Tan Chee Siong, Baharuddin; M.Fayzul; M.Faridun N.T, Study of Fuzzy and PI Controller for Permanent-Magnet Brushless DC Motor Drive, *IEEE International Power Engineering and Optimization Conference. PEOCO 2010*.
- [4] C.W.Hung; C.T.Lin, and C.W.Liu, An Efficient Simulation Technique for the Variable Sampling Effect of BLDC Motor Applications, *IECON 2007*, pp. 1175-1179, 2007
- [5] José Carlos Gamazo-Real Ernesto Vázquez-Sánchez and Jaime Gómez-Gil "Position and Speed Control of Brushless DC Motors Using Sensorless Techniques and Application Trends Sensors 2010."
- [6] Omar Aydogdu, Ramazan Akkaya, "An effective Real coded GA based fuzzy controller for speed control of a BLDC motor without speed sensor" *Turk jElectEng & CompSci*, Vol.19, No.3, 2011.
- [7] M.R. Alizadeh Pahlavani, M. Barakat "Comparison between Fuzzy and Adaptive Fuzzy Controllers for Speed Control of BLDC Motors" *26th International Power System Conference PSC 2011*
- [8] R. Shanmugasundram, K. Muhammed Zakariah, and N. Yadaiah, "Digital Implementation of Fuzzy Logic Controller for Wide Range Speed Control of Brushless DC Motor", *ICVES 2009*.
- [9] Ahamed Rubaai, Marcel J. Castro-Sitiriche and Abdul R. (2008) "DSP Based laboratory Implementation Hybrid Fuzzy PID controller using genetic optimisation of high performance Motor drives", *IEEE Transactions on Industry Applications*, Vol.44, No.6, pp.1977-1986.
- [10] Bakal J.W, Ajit J. More (2008) "Speed Control of Permanent Magnet Brushless DC Motor Using Fuzzy Logic Controller-Hardware Implementation" *International Journal of Engineering and Computer Science*, Vol.8, No.4. pp. 431-438