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 communicator 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 sensored motor control system are increased cost and size of the motor, and required special mechanical arrangement for mountingthesensors.AnotherproblemassociatedwithBLDCmotorcontrolistheuseof Conventional PI,PID controllers these controllers posses' complications under the situations of nonlinearity, load disturbancesandparametricvariations.Thispaperpresentsthedesignandimplementationofamodified 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 sover come by BLDC motors include lower efficiency and susceptibility of the commutator assembly to mechanical wear and consequent needforservicing,atthecostofpotentially lessruggedand more complex and expense, BLDC motors offerbetterspeedversustorquecharacteristics,high dynamicresponse,highefficiency, longoperating 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 designand control schemes have been developed Conventional DC motors are highly efficient and their characteristic make them suitable for use us 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 comprehensivesimulation modelwith a modified self-tuningfuzzy logic controller ispresented.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 oflesser efficiency and susceptibility of the commutator assembly to mechanical wear and subsequent need for servicing, at the cost of potentially less rugged and more compositeand expensive control electronics.Simulink[3].

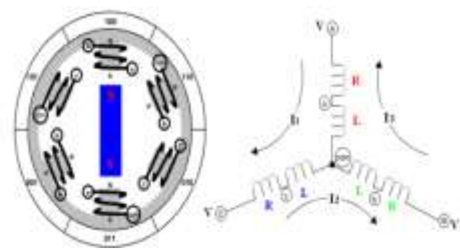

Figure: 1.1Electrical Diagram of BLDC Motor

Besides, consideringthat the computational timewithoutaffectingtheaccuracy of the resultsobtainedis verylow,itcanbesaidthat theproposedmethod ispromising [4]. Previous studiesand developmentof control schemes havemadeaverygoodcontributiontoBLDCmotordrives , butthecomprehensive approachhasnotbeenavailablefor modeling andanalysisoffuzzylogiccontrolledBLDCmotor 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 sensored 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 sensored 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'posses' difficulties under the conditions of nonlinearity, load disturbances and parametric variations.

Another major problem wasrelated 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 posses 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 sensored 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.

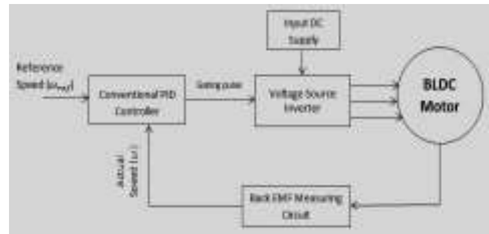

Figure: 2.1 Speed Control of BLDC Motor by PID Controller

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].

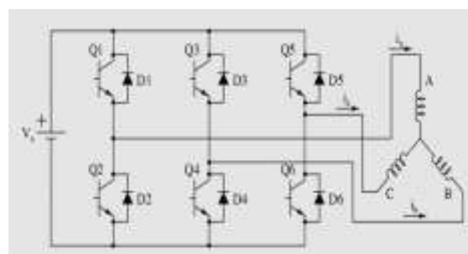

Figure: 3.1 Simplified BLDC Drive Scheme

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 crossingof the phase back EMFcanbe measured,wecanknowwhento commutate the current.SensingmethodsforthePMBLDC 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

Figure4.1 shows theSpeed 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.

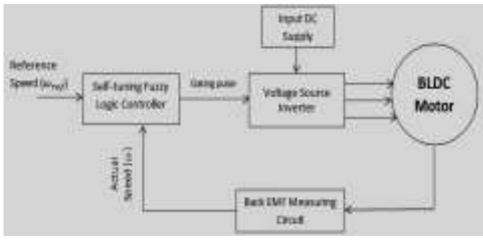

Figure: 4.1Speed Control of BLDC Motor by STFL Controller

In Figure ,ωref. isthe reference speed(rad/sec), ω isan actual rotor speed (rad/sec), uisthe controlsignalusedto reference moment(N-m);Vdcisthesupply voltageoftheinverter (Volt).In speedcontrolloopasshowninthe block diagram, thereference speedandtheactualmotorspeedis comparedand the errorsignal 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)andchangeinerror (CE) arethe inputs forthefuzzy controllerwhereastheoutputofthe controller ischange in duty cycle (ΔDC). The error isdefinedasthe difference betweentheref speedand actualspeed,the change in error is defined as the differencebetween the present error andpreviouserrorandthe output,Change induty- cycle ΔDCiswhich**c**ouldbe either positive or negative isaddedwiththe existingduty-cycleto determinethenewduty-cycle(DCnew)Figure 4.2 showsthebasicstructureoffuzzylogiccontroller. The fuzzy controlleriscomposedofthefollowing four elements: fuzzification, fuzzy rule-base, fuzzyinference engineand defuzzification[7].

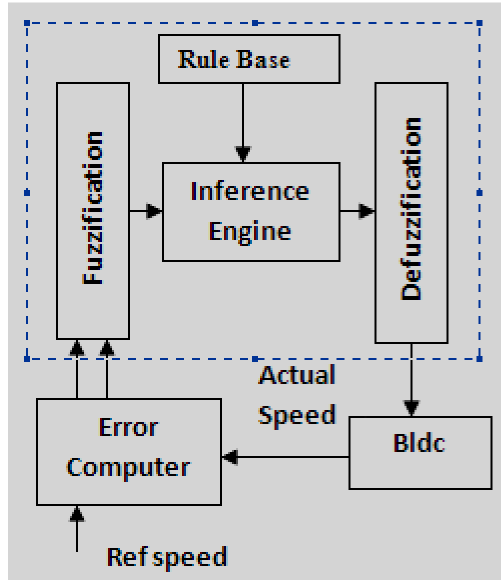

Figure: 4.2 Fuzzy Logic Controller

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+1500rpm.Theuniverseofdiscourseforerroris -1500rpmto+1500rpmandforthechangein duty cycle,definedas-100%and+100%.In order toachievefaster control actionand simplification, the inputs and output are normalized to +/-100 rpm, +/-100 rpm and +/-100 respectively.The membershipfunctionsused for inputs andoutputaregiven in figure 4.3.

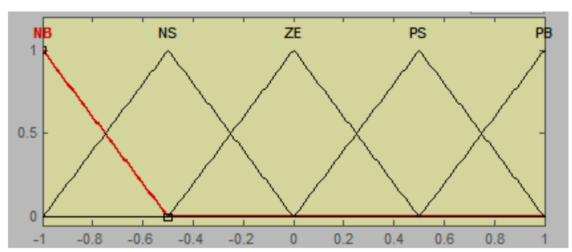

Figure: 4.3 Membership Function

4.2 Fuzzification

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

4.3 Rulebase andInference engine

A rule base (a set of If-Then rules), which contains a fuzzylogic quantification of theexpert's linguisticdescription of how to achieve control action. Once the ruleshavebeen established,afuzzylogicsystemcanbeviewedas amappingfrominputstooutputs.Rulesmay be providedby expertsorcanbeextractedfrom numericaldata.The performance of the controller canbeimproved by adjustingthemembership function and rules.Differenttypesof inferentialprocedurestohelpus understandthingsor tomakedecisions,there are manydifferentfuzzy logicinferentialprocedures. The Table 4.1 shows the rule base of fuzzy logic controller. Thefuzzy inferenceoperationisimplementedby 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 Table1.

Table:4.1 Rule Base

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

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

Wherezis the defuzzified value, μ(x) is the Membership value ofmember. [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,1ABridge 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	MicrocontrollerPIC16F877A 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.

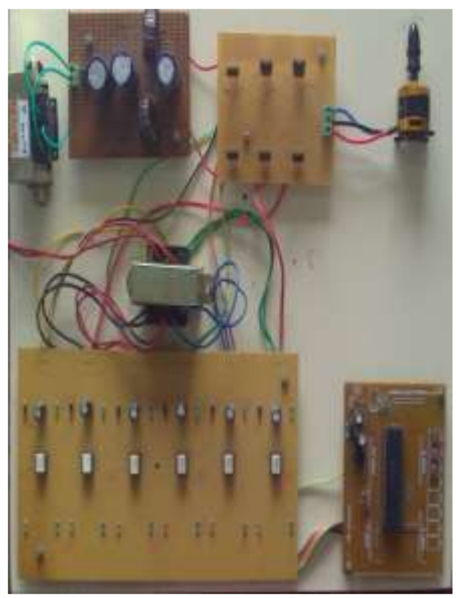

Figure: 5.1 Hardware Model

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 ofPower 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.

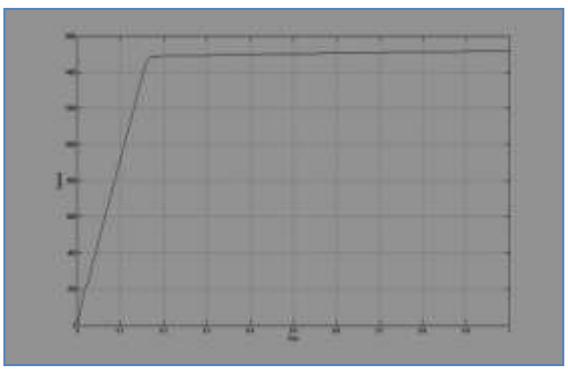

Figure: 6.1 PID Controller Speed (1500RPM) Output Waveform

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.

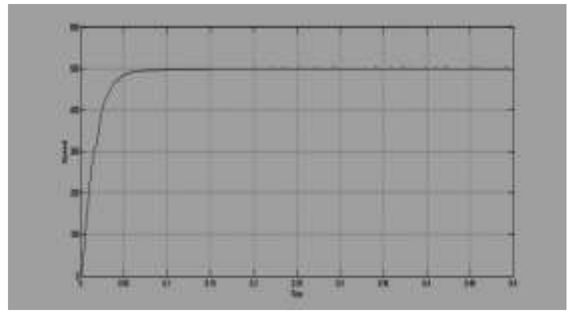

Figure: 6.2 FLC Speed (500 RPM) Output Waveform

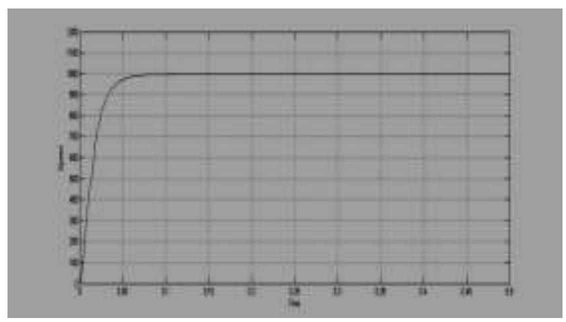

Figure:6.3 FLC Speed (1000 RPM) Output Waveform

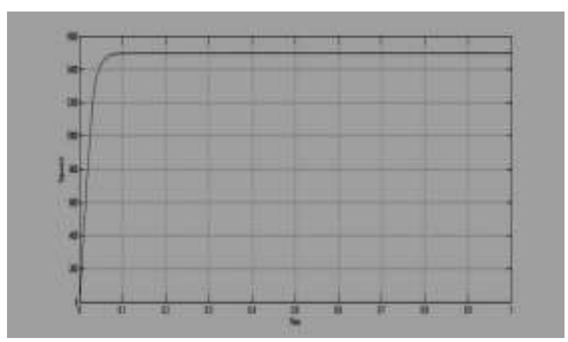

Figure: 6.4 FLC Speed (1500 RPM) Output Waveform

6.3Comparative 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 andFuzzy Logic Speed Controller. Compared to conventional PID Controller the Fuzzy Logic Controller settling time is very low.

Table N: 6.1 Comparative Studiesof 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.

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