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Simulation Approach to Speed Control of PMBLDC Motor using Various Control Techniques

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ABSTRACT

Conventional Brushless DC Motor (BLDCM) has been widely used in industries because of its properties such as high efficiency, reliability, high starting torque, less electrical noise and high weight to torque ratio. In order to control the speed of BLDCM, a number of controllers are used. Controllers like PI and PID don't have better results. They need to more time to settle down. Although Adaptive Fuzzy controller gives better results than PI, PID controllers, but when compared to fuzzy PID they gives less performance. So, here using fuzzy PID controller for speed controller of BLDC Machine. As simulation results gives that fuzzy PID controller has better control performance than the PI, PID and Adaptive fuzzy controller. The modeling and simulation of BLDC motor have been done using the software package MATLAB/SIMULINK.

KEYWORDS: *BLDCM: Brushless Direct Current Motor, PM: Permanent Magnet, PI controller, PID control, Adaptive fuzzy controller and Fuzzy PID controller.*

I. Introduction

There are mainly two types of dc motors used in industry. The first one is the conventional dc motor where the flux is produced by the current through the field coil of the stationary pole structure. The second type is the brushless dc motor where the permanent magnet provides the necessary air gap flux instead of the wire-wound field poles. BLDC motor is conventionally defined as a permanent magnet synchronous motor with a trapezoidal Back EMF waveform shape.

BLDC motors are rapidly becoming popular in industries such as Electrical appliances, HV AC industry, medical, electric traction, automotive, aircrafts, military equipment, hard disk drive, industrial automation equipment and instrumentation because of their high efficiency, high power factor, silent operation, compact, reliability and low maintenance. The rotation of the BLDC motor is based on the feedback of rotor position which is obtained from the hall sensors [1].To replace the function of commutators and brushes, the BLDC motor requires an inverter and a position sensor.

Industrial drives require acute speed control and hence closed loop system with current and speed controllers coupled with sensors are required. Thus this paper presents a detailed comparison of BLDC motor with PI, PID controller, adaptive fuzzy controller and fuzzy PID controller. The results of these were tabulated and analyzed for all controllers. Finally the performance comparison between PI, PID, adaptive and fuzzy PID controller is done. The graph is plotted with the speed response obtained from the various controllers along with a reference speed of 3000rpm[2].

BLDC motors being non-linear in nature. and they can easily be affected by the parameter variations and load disturbances. So the proper choice of controller gives a better performance by reducing the problem of overshoot, settling time, and fast response. The organization of the paper is as follows. Section 2 deals with the operation and working principle. Section 3 deals with the modeling aspects of the motor and the details of speed controllers were included in Section 4 followed by results and simulation details in Section 5.

II. Principle and Operation of BLDC Motor

Brush Less DC Motor consists of the permanent magnet rotor and a wound stator. These brushless motors controlled using a three phase inverter. The motor requires a rotor position sensor for starting and for providing proper commutation sequence to turn on the power devices in the inverter roller bridge. Based on the rotor position, the power devices are commutated sequentially every 60 degrees[3].

The electronic commutation eliminates the problems associated with the brush and the commutator arrangement, namely sparking and wearing out of the commutator brush arrangement, thereby making a Brush Less DC motor more rugged compared to a dc motor is considered here. The armature current is controlled to generate the brush less dc motor consist of four main parts Power converter, permanent magnet Brush Less DC Motor, sensors and control algorithm[4]. The power converter transforms power from the source to the BLDC Motor which in turn converts electrical energy to mechanical energy.

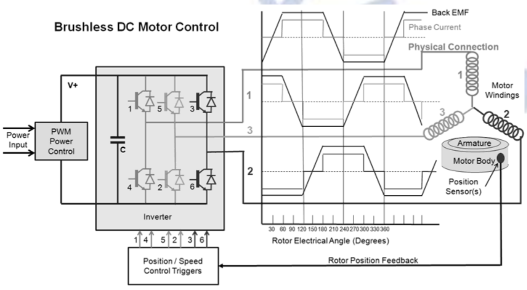

Figure 1: A Separately excited DC motor

Predictive analytics as a valuable tool [2] with which to engineer positive change throughout the student life cycle. As the cost to recruit a student rises, it becomes ever more important to retain students until they graduate, which will:

1. Improve student learning outcomes.
2. Improve retention and graduation rates.
3. Improve the institutional return on investment (ROI) on recruitment costs.
4. Increase operational efficiency.
5. Help the institution demonstrate success in a key area of focus for accrediting agencies and the Federal government.
6. Demonstrate positive efforts to other important entities (e.g., state legislatures that allocate funding to public schools, colleges and universities).

In the era of big data,[1,7] the challenges of predictive analytics include the quality of the data, because the prediction model's quality depends on it, the quantity of the data, because limited data provided during the training phase can make the analysis incapable of generalizing the derived knowledge when fed the new data; and the ability to satisfy analytical performance criteria—that is, results must be accurate and make statistical sense, and outcomes must be actionable—so that the analytics can identify the actual necessity for predicting an educational goal[4].

III. DYNAMIC MODELING OF BLDC MOTOR

BLDC motor can be modeled in the 3-phase ABC variables which consist of 2 parts. One is an electrical part which calculates electromagnetic torque and current of the motor. The other is a mechanical part, which generates revolution of the motor.

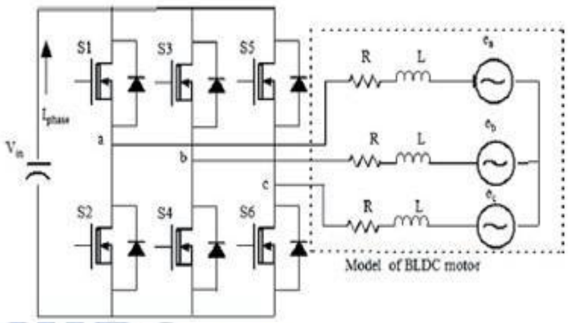

Fig. 2: Mathematical model of BLDC motor

Using KVL the voltage equation from Fig. 3 can be expressed as follows:

$$V_a = RI_a + L*\frac{di_a}{dt} + M*\frac{di_b}{dt} + M*\frac{di_c}{dt} + e_a \ldots.(1)$$

$$V_b = RI_b + L*\frac{di_b}{dt} + M*\frac{di_c}{dt} + M*\frac{di_a}{dt} + e_b \ldots(2)$$

$$V_c = RI_c + L*\frac{di_c}{dt} + M*\frac{di_b}{dt} + M*\frac{di_a}{dt} + e_c \ldots.(3)$$

Where,
L represents per phase armature self-inductance [H],
R represents per phase armature resistance [Ω],
Va , Vb, and Vc indicates per phase terminal voltage [V],
ia , ib and ic represents the motor input current [A],
ea, eb and ec indicates the motor back-EMF developed [V].
M represents the armature mutual-inductance [H].

In case of three phase BLDC motor, we can represent the back emf as a function of rotor position and it is clear that back-EMF of each phase has 1200 shift in phase angle. Hence the equation for each phase of back emf can be written as:

$$ea = Kw\ f(\theta e)\ \omega$$
$$eb = Kw\ f(\theta e - 2\Pi/3)\ \omega$$
$$ec = Kw\ f(\theta e + 2\Pi/3)\ \omega$$

where,
Kw denotes per phase back EMF constant [V/rad.s-1],
θe represents electrical rotor angle [rad],
ω represents rotor speed [rad.s-1].

The expression for electrical rotor angle cab be represented by multiplying the mechanical rotor angle with the number of pole pair's P:

$$\Theta e = \frac{P}{2}\theta m$$

where,
θm denotes mechanical rotor angle[rad]
The summation of torque produced in each phase gives
the total torque produced, and that is given by:

$$Te = \frac{e_a i_a + e_b i_b + e_c i_c}{\omega}$$

Where,
Te denotes total torque output [Nm].
Mechanical part of BLDC motor is represented as follows:

$$Te - Tl = J^*\frac{dw}{dt} + B^*\omega$$

Where,
Tl denotes load torque [Nm],
J denotes of rotor and coupled shaft [kgm2], and B represents the Friction constant [Nms.rad-1].

IV. Speed Controllers

Many drive systems today employ a conventional controller such as a PID-type controller. This method works well, but only under a specific set of known system parameters and load conditions. However, deviations of the system parameters or load conditions from the known values cause the performance of the closed-loop system to deteriorate, resulting in larger overshoot, larger rise time, longer settling times and possibly, an unstable system. It should be noted that the system parameters such as the system inertia and damping ratio might vary over a wide range due to changes in load conditions. Generally, a PID speed controller could be tuned to a certain degree in order to obtain a desired performance under a specific set of conditions. Less than ideal performance is then observed when these operating conditions vary. Thus, there is a need for other types of controllers, which can account for nonlinearities and are somewhat adaptable to varying conditions in real time. Other methods are now being employed, such as fuzzy logic, inorder to achieve a desired performance level.

a) PID CONTROLLER

A controller that combines concept of Proportional, Integral and Derivative terms by taking the sum of product of error multiplied by corresponding gains[4-5]. The output of PID controller can be mathematically

$$C(s) = (Kp + Ki/s + s^*Kd)^*e(t)$$

Where Kp denotes the proportional gain,
Ki denotes the integral gain and
Kd denotes the derivative gain

b) FUZZY CONTROLLER

Fuzzy logic control (FLC) is a rule based controller. It is a control algorithm based on a linguistic control strategy which tries to account the human's knowledge about how to control a system without requiring a mathematical model. The approach of the basic structure of the fuzzy logic controller system is illustrated in Fig.3.

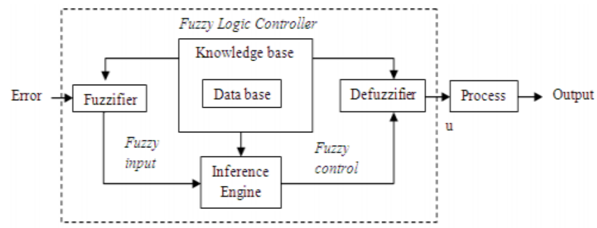

Fig. 3: Basic structure of Fuzzy logic controller

It uses linguistic variables instead of numerical variables. The process of converting a numerical variable(real number or crisp variables) into a linguistic variable(fuzzy number) is called Fuzzification. Here the inputs for Fuzzy Logic controller are the speed error (E) and change in speed error (CE). Speed error is calculated with comparison between reference speed and the actual speed. This controller is used to produce an adaptive control so that the motor speed can accurately track the reference speed. The reverse of

Fuzzification is called Defuzzification.

The use of Fuzzy Logic Controller (FLC) produces required output in a linguistic variable (fuzzy number). According to real world requirements, the linguistic variables have to be transformed to crisp output. The membership function is a graphical representation of the magnitude of participation of each input. There are different memberships functions associated with each input and output response. Here the trapezoidal membership functions are used for input and output variables. The number of membership functions determines the quality of control which can be achieved using fuzzy controller. As the number of membership function increases, the quality of control improves. As the no. of linguistic variables increases, the computational time and required memory increases. The most common shape of membership functions is triangular, although trapezoidal and bell curves are also used, but the shape is generally less important than the number of curves and their placement[6]. Tables are numbered with Roman numerals.

The processing stage is based on a collection of logic rules in the form of IF-THEN statements, where the IF part is called the "antecedent" and the THEN part is called the "consequent". It consists of a data “base” and a linguistic (fuzzy) control rule base. The data base provides necessary definitions, which are used to define linguistic control rules and fuzzy data manipulation in an FLC. The rule base characterizes the control goals and control policy of the domain experts by means of a set of linguistic control rules. Decision making logic is the kernel of an FLC. Important things in fuzzy logic control system designs are the process design of membership functions for input, outputs and the process design of fuzzy if-then rule knowledge base. Fig 5 shows the membership function of speed error (E), change in speed error (CE)[7]. Here we are using MAMADANI Fuzzy function. In this function two inputs and one output is used.

FUZZY MAMADANI FUNCTIONS:

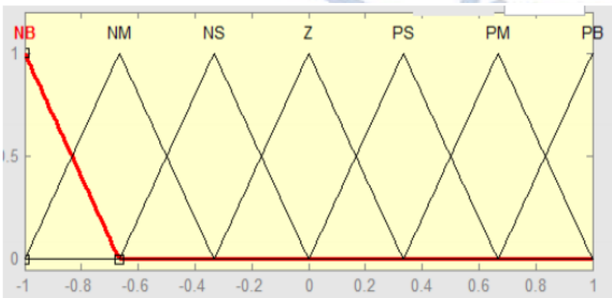

Fig -4: Membership functions for error and change in error

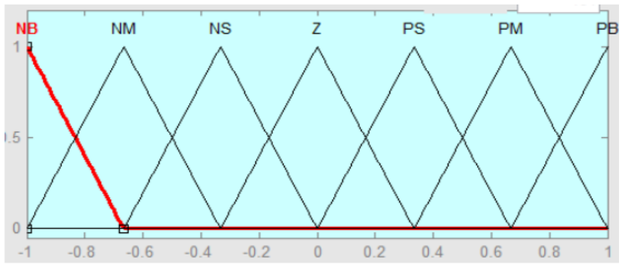

Fig -5: Membership functions for output

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 [6].

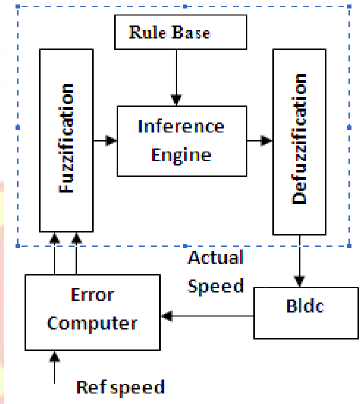

Fig.6 Fuzzy flow chart

In practice, one or two types of membership functions are enough to solve most of the problems. The next step is to define the control rules. There are no specific methods to design the fuzzy logic rules[8]. However, the results from PI controller give an opportunity and guidance for rule justification. Therefore after thorough series of analysis, the total 49 rules have been justified as shown in Table 1.

E\CE	NB	NM	NS	Z	PS	PM	PB
NB	PB	PB	PM	PM	PS	PS	NS
NM	PB	PM	PM	PS	PS	Z	NS
NS	PM	PM	PS	Z	Z	NS	NS
Z	PM	PS	PS	Z	NS	NS	NM
PS	PS	PS	Z	NS	NS	NM	NM
PM	PS	Z	NS	NS	NM	NM	NB
PB	Z	NS	NS	NM	NM	PB	NB

Table.1

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 defuzzification[9] 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, μ(x) is the membership value of member x [5].

V. SIMULATION AND RESULTS

The Simulink model of BLDC motor developed based on the mathematical equations is shown in Fig.7 This Simulink model consists of an inverter block, hall signal generation block, main BLDC model block and controller block. The main BLDC model block[10], further consist of a current generator block; speed generator block and emf generator block.

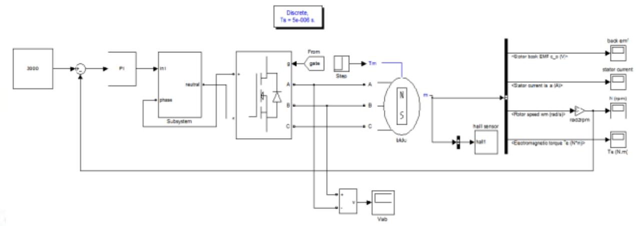

Fig.7 simulink diagram

Here simulation is carried out for four cases. In case 1 BLDC with PI control, Case 2 BLDC with PID Control on increase in load torque, Case 3 BLDC with adaptive Fuzzy Control on Increasing Load and case 4 with fuzzy PID. The motor parameters chosen for the simulation based on the mathematical equations has been given in Table2.

Parameters	Specification
Number of Pole Pairs, P	4
Supply Voltage. V_{dc}	12V
Armature Resistance, R	1 Ω
Self Inductance, L	20mH
Motor Inertia, J	0.005kgm^2
EMF constant, K_e	.763 (V/rad)
Torque Constant, Kt	.345 Nm/A

Table 2

Fig.8 shows the no load speed of the motor with PI control, motor is achieving a speed of 3000 rpm. And other fig.9 gives PID control and fig.10 gives adaptive fuzzy and fig.11 gives fuzzy PID controller for the given BLDC motor. The simulation of BLDC motor with various controllers outputs are given below.

For PI controller speed as:

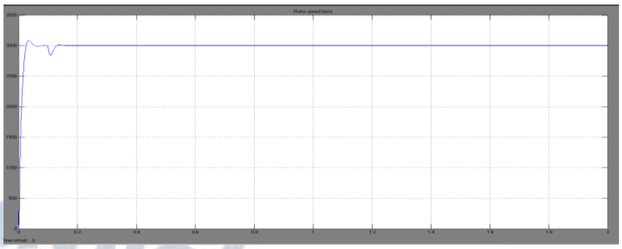

Fig.8 Speed vs Time

For PID controller speed as:

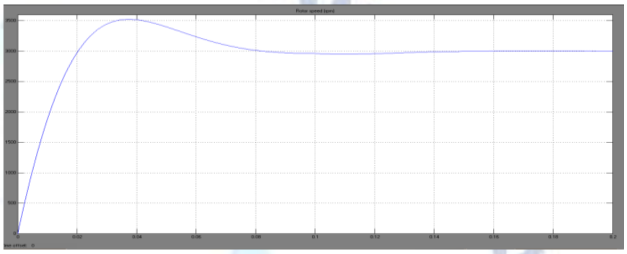

Fig.9 Speed vs Time

For adaptive fuzzy controller speed as:

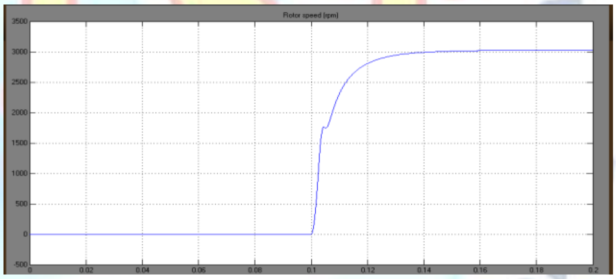

Fig.10 Speed vs Time

For fuzzy PID controller speed as:

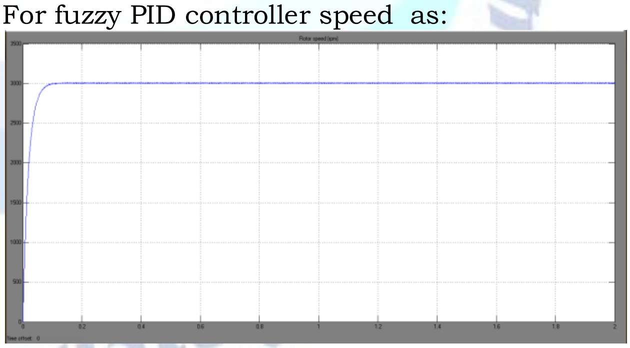

Fig.11 Speed vs Time

For PI controller stator current and back emf as:

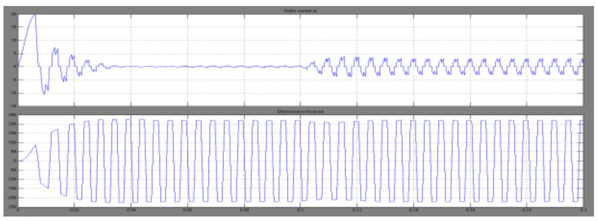

Fig 12.Stator current vs time & emf vs time

For PID controller stator current and back emf :

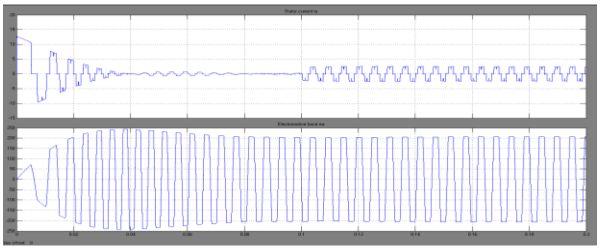

Fig.13 Stator current vs time & emf vs time

For adaptive fuzzy controller stator current and back emf as:

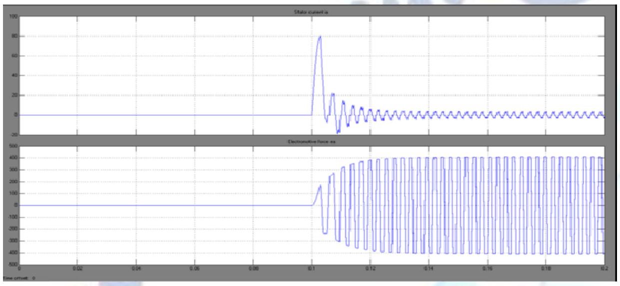

Fig.14 Stator current vs time & emf vs time

For fuzzy PID stator current and back emf as:

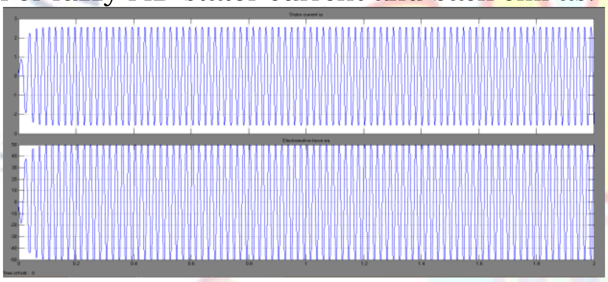

Fig.15 Stator current vs time & emf vs time

For PI controller torque as:

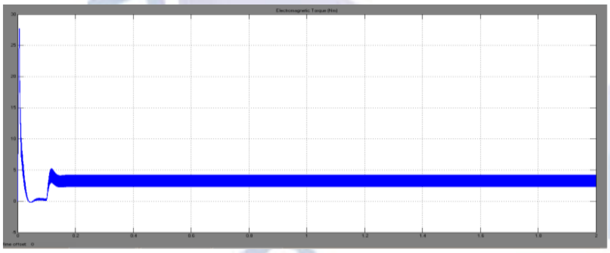

Fig 16. Torque vs Time

For PID controller torque as:

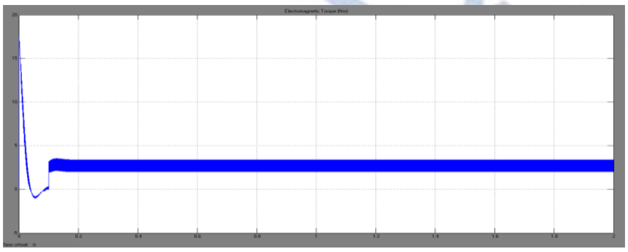

Fig 17. Torque vs Time

For adaptive fuzzy controller torque as:

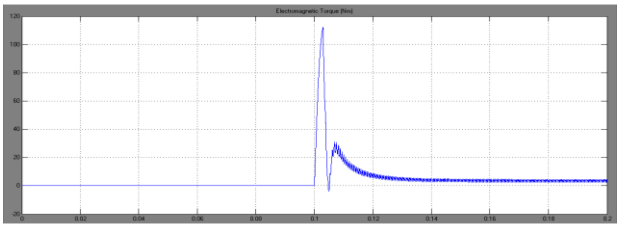

Fig 18. Torque vs Time

For fuzzy PID controller torque as:

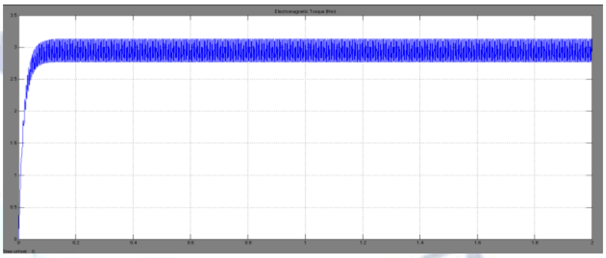

Fig 19. Torque vs Time

Earlier the value of current is high, and once the speed reaches rated value, the magnitude of current will decreases.

To evaluate the performance of BLDC motor, a number of measurements are taken[8]. The transient performance results of Conventional PID controller and Fuzzy logic controller of three phases BLDC Motor is shown in below Table 3.

We consider the following characteristics Rise Time and Settling time.

Table 3

CONTROLLERS	RISETIME	SETTLING TIME	CONTROLLER USAGE
PI	0.05	0.18	proportionate value
PID	0.03	0.16	Decreases exceed value
ADAPTIVE FUZZY	0.14	0.14	Stabilizes the system
FUZZY PID	0.10	0.10	Decreases harmonics

VI. Conclusion

The performance of three phase BLDC motor with PI, PID, Fuzzy PID and Adaptive fuzzy controllers are analyzed. The performance of the four controllers are compared on the basis of various control system parameters such as steady state error, rise time, peak overshoot, recovery time and settling time. It is found that the control concept with fuzzy PID controller outperforms another controllers in most of the aspects. Simulation results of the four controllers have been presented.

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