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Control Strategies for BLDC Motor

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ABSTRACT: Brushless DC motors (BLDCM) are mainly used for many industrial applications because of their high efficiency, high torque and low volume with accuracy. This paper developed an improved Adaptive Fuzzy PID controller to control speed of BLDCM. This paper provides an overview of performance conventional PID controller, Fuzzy PID controller and Adaptive Fuzzy PID controller. It is complicated to tune the parameters and get satisfied control characteristics by using normal conventional PID controller. As the Adaptive Fuzzy has the ability to satisfied control characteristics and it is easy for computing. The experimental approach verifies that a Adaptive Fuzzy PID controller has better control performance than the both Fuzzy PID controller and conventional PID controller. The modeling, control and simulation of the BLDC motor have been done using the software package MATLAB/SIMULINK.

KEYWORDS: Brushless DC (BLDC) motors, proportional integral derivative (PID) controller, Fuzzy PID controller, Adaptive 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. As the name implies, BLDC motors do not use brushes for commutation; instead, they are electronically commutated. In practice, the design of the BLDCM drive involves a complex process such as modeling, control scheme selection, simulation and parameters tuning etc. Recently, various modern control solutions are proposed for the speed control design of BLDC motor. These motors are one of the motor types that have more rapidly gained popularity, mainly because of their better characteristics and performance. The Brushless DC motors are widely used in many industrial and traction applications because of its overweighing advantages like high efficiency, high torque, low maintenance, less noise and low volume. Recently, high performance BLDC motor drives are widely used for variable speed drive systems of the industrial applications and electric vehicles. In recent years, brushless dc (BLDC) machines have gained widespread use in electric drives. These machines are ideal for use in clean, explosive environments such as aeronautics, robotics, electric vehicles, food and chemical industries and dynamic actuation. Now a day's electric vehicles and micro electric motor cars in the market mostly adopt BLDC motor. The BLDC motor can act as an alternative for traditional motors like Brushed DC motor, induction motor, switched reluctance motors etc. The brushless DC motor is a synchronous electric motor that from a modeling perspective and looks exactly like a DC motor because motor having a linear relationship between current and torque as well as voltage and rpm. It is an electronically controlled commutation system. In earlier days the controlling system of BLDC motor adopted hall sensor signals to drive the motor. But when disturbance on the hall sensor exists, the misbehavior of the main circuit prompts and motor action unsteady and reliability of the whole controlling system is greatly reduced as well as the cost of controller is increased. In recent years, some of these developments like Proportional Integral (PI) controllers have been implemented for the speed control of BLDC motors. But traditional PI and PID controllers have disadvantages

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and to overcome these disadvantages a new adaptive fuzzy logic control system is developed in MATLAB/Simulink. The performance of proposed system is compared with traditional control systems. We will work on the following Objectives-

- To achieve desired level of performance the motor requires suitable speed controllers.
- To show how control speed is achieved by using proportional-integral-derivative (PID) controller.
- To show how The Fuzzy Logic (FL) approach applied to speed control leads to an improved dynamic behavior of the motor drive system and an immune to load perturbations and parameter variations.

In recent years different modern control techniques increased the quality of automatic control. There are different intelligent techniques, such as neural network, fuzzy logic, neuro-fuzzy logic, genetic algorithm. Among this due to the robustness and simple implementation of neural networks led us to incorporate it in control. Another modern control techniques based on model of the process is, Adaptive fuzzy-PID Control. It has been successfully implemented in many industrial applications, showing good performance and a certain degree of robustness. This led us to study and implement this Adaptive fuzzy-PID for the various applications with above mentioned objectives.

II. MATHEMATICAL MODEL OF BLDC MOTOR

Modeling of a BLDC motor can be developed in the similar manner as a three-phase synchronous machine. Since there is a permanent magnet mounted on the rotor, some dynamic characteristics are different. Consider a cylindrical rotor and the stator have 3 phase winding a, b, and c. The rotor is the permanent magnet rotor, and hence the air gap is uniform. Stator has 3 phases with distributed winding structure with star connected. The dynamic equation of phase a, phase b, phase c, are follows as

$V_{an} = R_s + L\frac{di_a}{dt} + M\frac{di_b}{dt} + M\frac{di_c}{dt} + e_a$-----------------------[1]

$V_{bn} = R_s + L\frac{di_b}{dt} + M\frac{di_c}{dt} + M\frac{di_a}{dt} + e_b$---------------------[2]

$V_{cn} = R_s + L\frac{di_c}{dt} + M\frac{di_c}{dt} + M\frac{di_b}{dt} + e_c$------------------------[3]

Where L is armature self-inductance [H],
M is armature mutual inductance [H],
R is armature resistance [Ω],
V_{an} ,V_{bn} and V_{cn} are terminal phase voltage [V],
i_a, $i_b$and $i_c$are motor input current [A],
e_a , e_b and $e_c$are motor back -EMF [V].

III. MECHANISM BRUSHLESS DC (BLDC) MOTOR

Introduction Brushless dc (BLDC) motors are preferred as small horsepower control motors due to their high efficiency, silent operation, compact form, reliability, and low maintenance. However, the problems are encountered in these motor for variable speed over last decade continuing technology development in power semiconductors, microprocessors, adjustable speed drivers control schemes and permanent-magnet brushless electric motor production

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have been combined to enable reliable, cost-effective solution for a broad range of adjustable speed applications. Household appliances are expected to be one of fastest-growing end-product market for electronic motor drivers over the next five years [1]. The major appliances include clothes washer's room air conditioners, refrigerators, vacuum cleaners, freezers, etc. Household appliance have traditionally relied on historical classic electric motor technologies such as single phase AC induction, including split phase, capacitor-start, capacitor–run types, and universal motor. These classic motors typically are operated at constant-speed directly from main AC power without regarding the efficiency. Consumers now demand for lower energy costs, better performance, reduced acoustic noise, and more convenience features. Those traditional technologies cannot provide the solutions. Review on brushless dc motor modeling recent research has indicated that the permanent magnet motor drives, which include the permanent magnet synchronous motor (PMSM) and the brushless dc motor (BDCM) could become serious competitors to the induction motor for servo applications. The PMSM has a sinusoidal back emf and requires sinusoidal stator currents to produce constant torque while the BDCM has a trapezoidal back emf and requires rectangular stator currents to produce constant torque. Some confusion exists, both in the industry and in the university research environment, as to the correct models that should be used in each case. The PMSM is very similar to the standard wound rotor synchronous machine except that the PMSM has no damper windings and excitation is provided by a permanent magnet instead of a field winding. Hence the d, q model of the PMSM can be derived from the well-known [9] model of the synchronous machine with the equations of the damper windings and field current dynamics removed.
As is well known, the transformation of the synchronous machine equations from the abc phase variables to the d, q variables forces all sinusoidal varying inductances in the abc frame to become constant in the d, q frame. In the BDCM motor, since the back emf is no 4 sinusoidal, the inductances do not vary sinusoidally in the abc frame and it does not seem advantageous to transform the equations to the d, q frame since the inductances will not be constant after transformation. Hence it is proposed to use the abc phase variables model for the BDCM. In addition, this approach in the modeling of the BDCM allows a detailed examination of the machine's torque behavior that would not be possible if any simplifying assumptions were made. The d, q model of the PMSM has been used to examine the transient behavior of a high performance vector controlled PMSM servo drive [2]. In addition, the abc phase variable model has been used to examine the behavior of a BDCM speed servo drive [3]. Application characteristics of both machines have been presented in [4]. The purpose of this paper is to present these two models together and to show that the d, q model is sufficient to study the PMSM in detail while the abc model should be used in order to study the BDCM.

IV. SPEED CONTROL STRATEGIES OF BLDC MOTOR

The ac servo has established itself as a serious competitor to the brush-type dc servo for industrial applications. In the fractional-to-30-hp range, the available ac servos include the induction, permanent-magnet synchronous, and brushless dc motors (BDCM) [5]. The BDCM has a trapezoidal back EMF, and rectangular stator currents are needed to produce a constant electric torque. Typically, Hysteresis or pulse width-modulated (PWM) current controllers are used to maintain the actual currents flowing into the motor as close as possible to the rectangular reference values. Although some steady-state analysis has been done [7], the modeling, detailed simulation, and experimental verification of this servo drive have been neglected in the literature. It is shown that, because of the trapezoidal back EMF and the consequent no sinusoidal variation of the motor inductances with rotor angle, a transformation of the machine equations to the well-known d, q model is not necessarily the best approach for modeling and simulation. Instead, the natural or phase variable approach offers many advantages. Because the controller must direct the rotor rotation, the controller needs some means of determining the rotor's orientation/position (relative to the stator coils.) Some designs use Hall Effect sensors or a rotary encoder to directly measure the rotor's position. The controller contains 3 bi-directional drivers to drive high-current DC power, which are controlled by a logic circuit. Simple controllers employ comparators to determine when the output phase 5 should be advanced, while more advanced controllers employ a microcontroller to manage acceleration, control speed and fine-tune efficiency. Controllers that sense rotor position based on back-EMF have extra challenges in initiating motion because no back-EMF is produced when the rotor is stationary. The design of the BLDCM servo system usually requires time consuming trial and error process, and fail to optimize the performance. In practice, the design of the BLDCM drive involves a complex process such as model, devise of control Scheme, simulation and parameters tuning. In a PID controller has been proposed for BLDCM.

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V. PID SPEED CONTROL FOR BLDC MOTOR MECHANISM

The combination of proportional, integral and derivative control action is called PID control action. PID controllers are commonly used to regulate the time-domain behavior of many different types of dynamic plants. These controllers are extremely popular because they can usually provide good closed-loop response characteristics. Consider the feedback system architecture that isshown in Fig. 1 where it can be assumed that the plant is a DC motor whose speed must be accurately regulated [1].

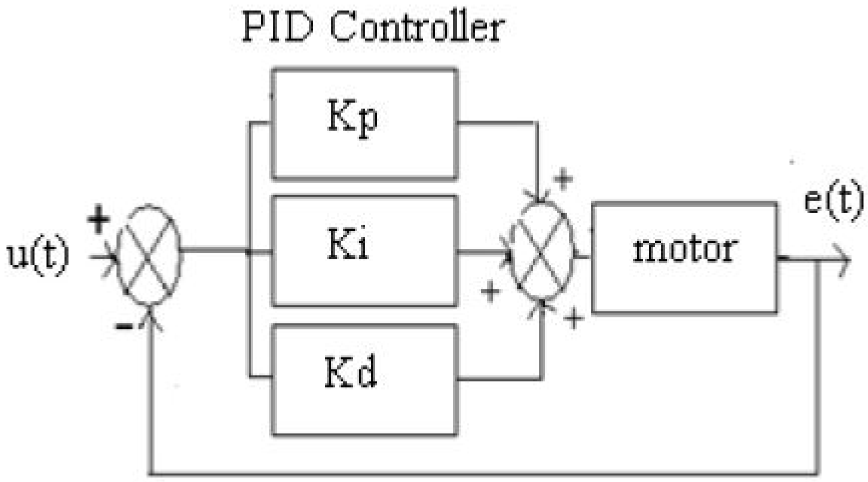

Fig 1.PID controller

The PID controller is placed in the forward path, so that its output becomes the voltage applied to the motor's armature the feedback signal is a velocity, measured by a tachometer .the output velocity signal C (t) is summed with a reference or command signal R (t) to form the error signal e (t). Finally, the error signal is the input to the PID controller [8].

u== $K_p e + K_i \int edt + Kd\frac{de}{dt}$

$$f(x) = a_0 + \sum_{n=1}^{\infty}\left(a_n \cos\frac{n\pi x}{L} + b_n \sin\frac{n\pi x}{L}\right)$$

VI. FUZZY-PID SPEED CONTROL OF BLDC MOTOR

Input and output are non-fuzzy values. The basic configuration of FLC is featured in Figure 2. In the system presented in this study, Mamdani type of fuzzy logic is used for speed controller. Inputs for Fuzzy Logic controller are the speed error e(k) and change in speed error ce(k). Speed error is calculated with comparison between reference speed, ωref and the actual speed,

ωact e(k) = ωref – ωact

(1) ce(k) =e(k) – e(k-1)

$$A = \pi r^2$$

(2) The output of the fuzzy controller u(k) is given by: u(k) = e(k) – ce(k).

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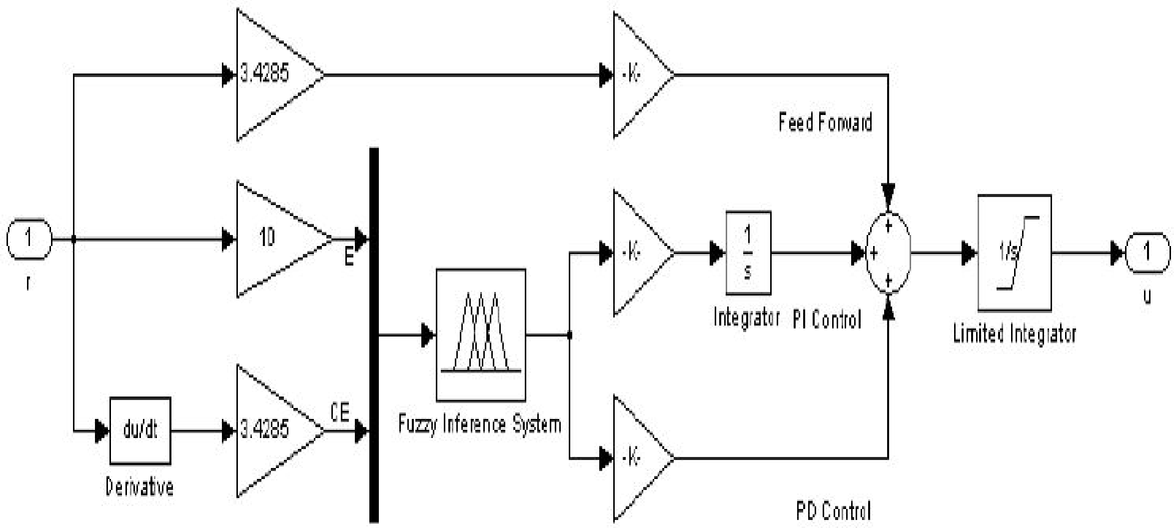

Fig.2. Simulation **of Fuzzy PID Controller**

The fuzzy logic controller was used to produce an adaptive control so that the motor speed, ωact can accurately track the reference speed, ωref . The most important things in fuzzy logic control system designs are the process design of membership functions for inputs, output and the process design of fuzzy if-then rule knowledge based.

IX. PROPOSED SYSTEM

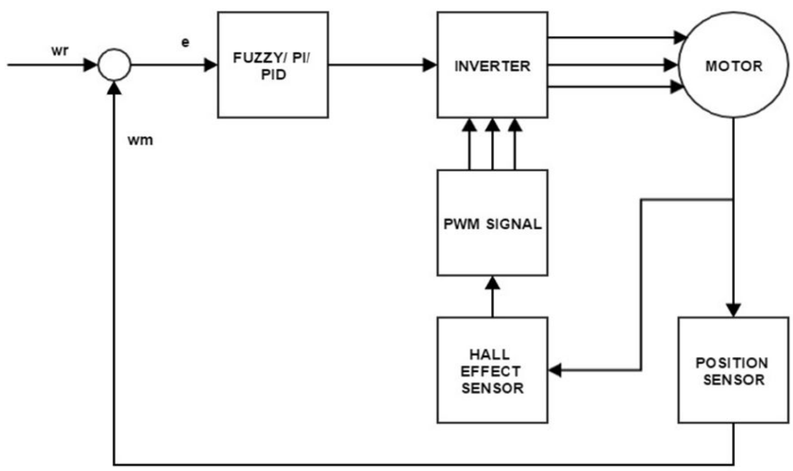

Fig.3. Basic block diagram of proposed system

The basic block diagram of BLDC motor control system is as shown in fig 3. As shown in figure it consists of adaptive fuzzy logic control, three phase inverter circuit, BLDC motor, Hall Effectsensor to measures the reference current patter which is provided by inverter, and position sensor to measure speed of motor. Output control signal is measured and compared with reference control signal.

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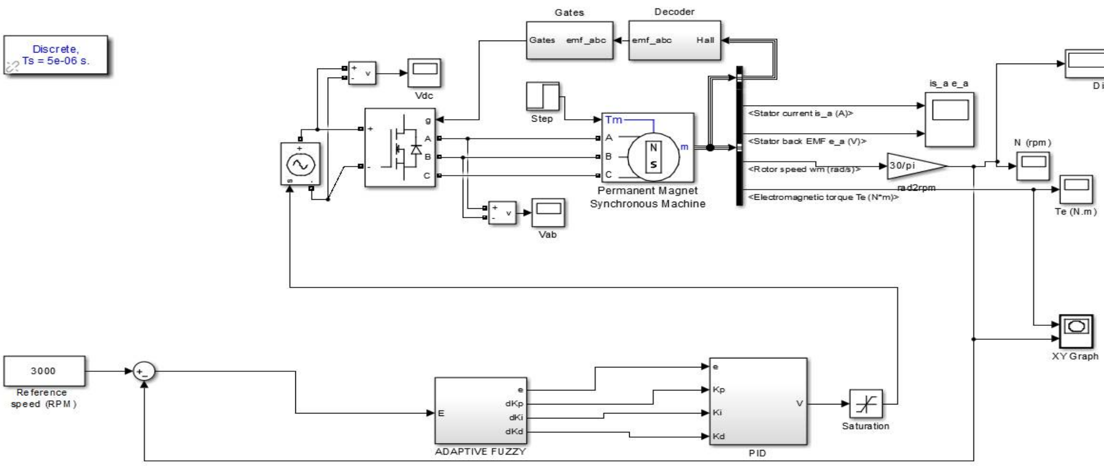
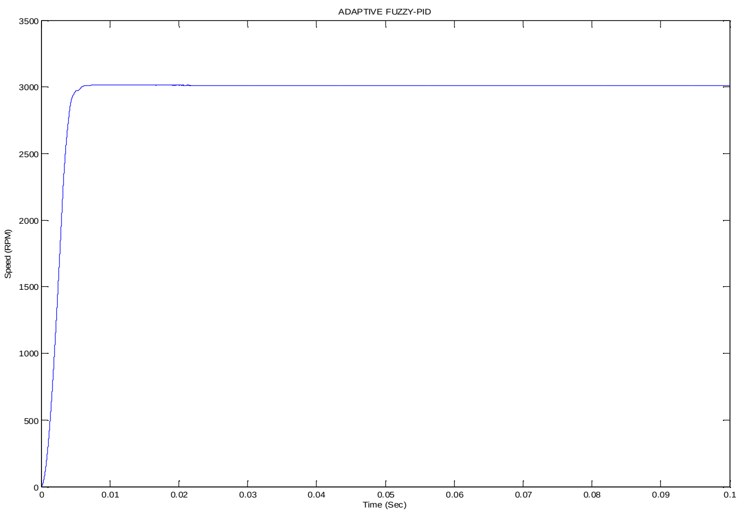


Fig.4 Adaptive Fuzzy PID Controller

Adaptive Fuzzy PID controller used in this paper is based on two input and three output. The overall structure of used controller is shown in Fig. 4. In Fuzzy PID controller have three outputs which are Kp, Ki and Kd. Error speed (E) and Change in error speed (CE) as fuzzy control input and fuzzy outputs are ΔKp, ΔKi, Δkd.

VII. EXPERIMENTAL RESULTS

ADAPTIVE-FUZZY PID
SPEED



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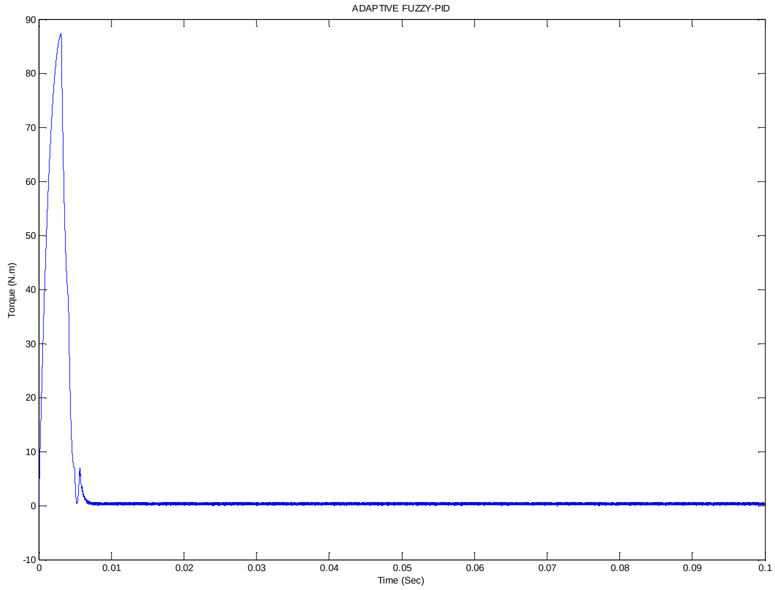
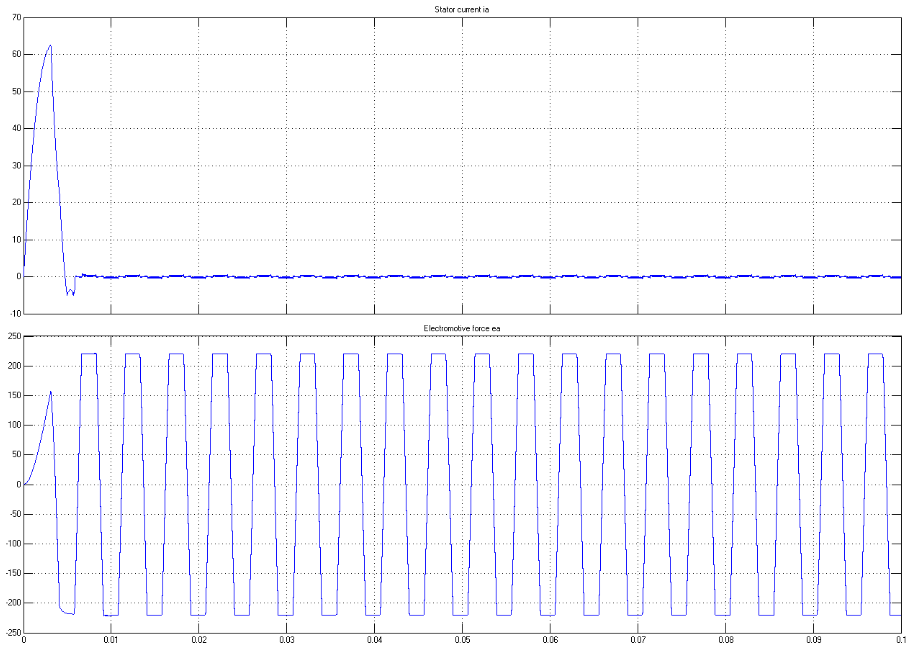
TORQUE



Stator current and EMF



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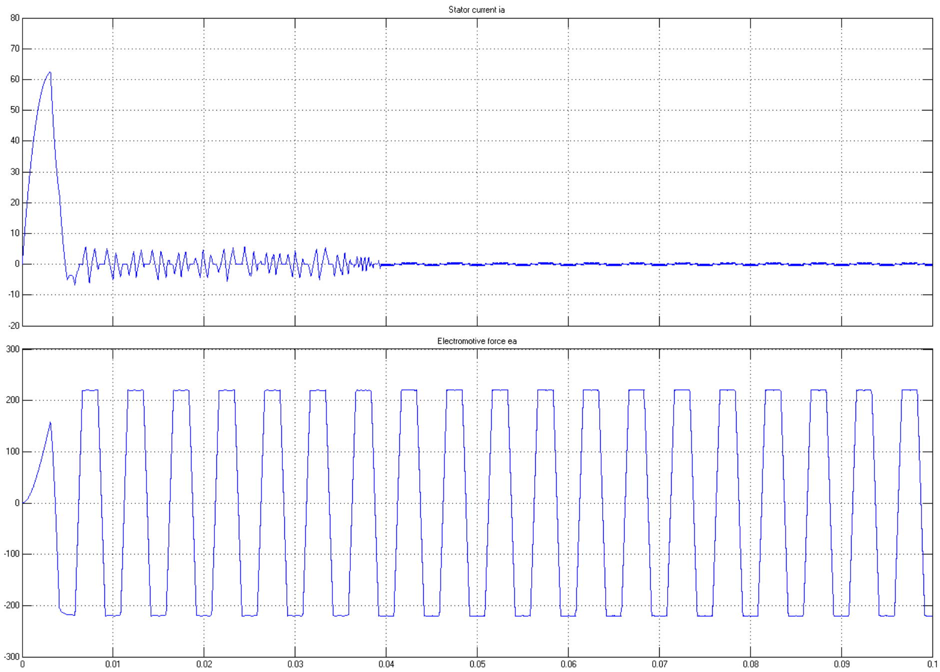
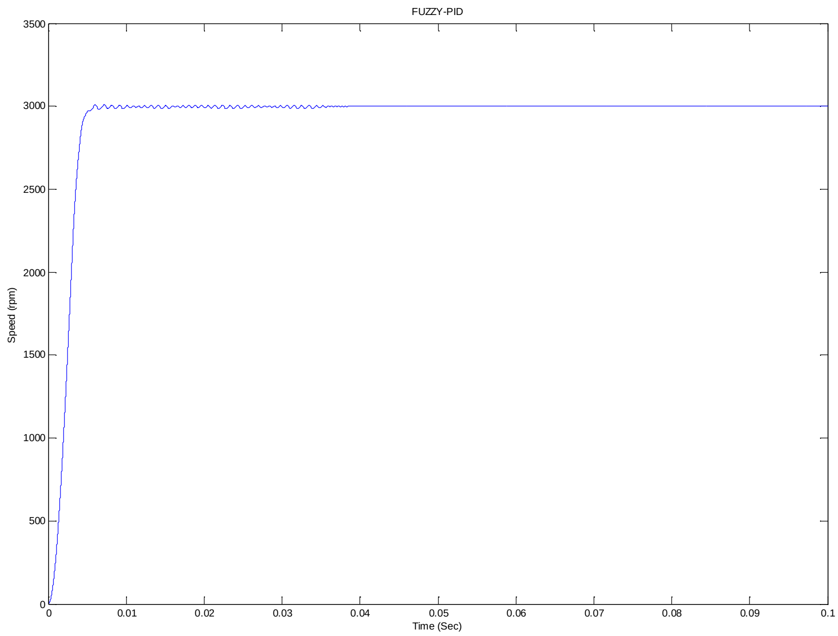
FUZZY-PID
Stator Current and EMF



Speed



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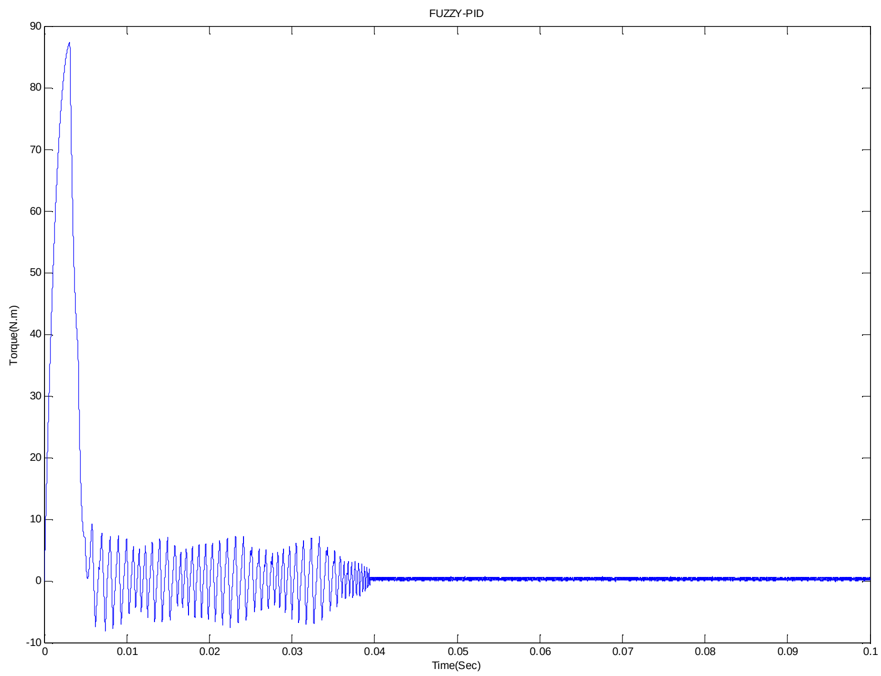
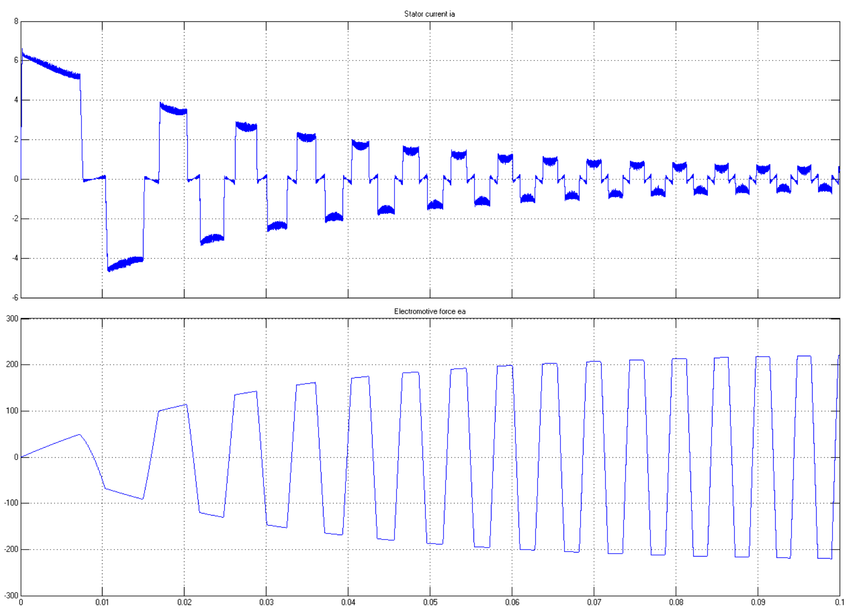
Torque



PID
Stator Current



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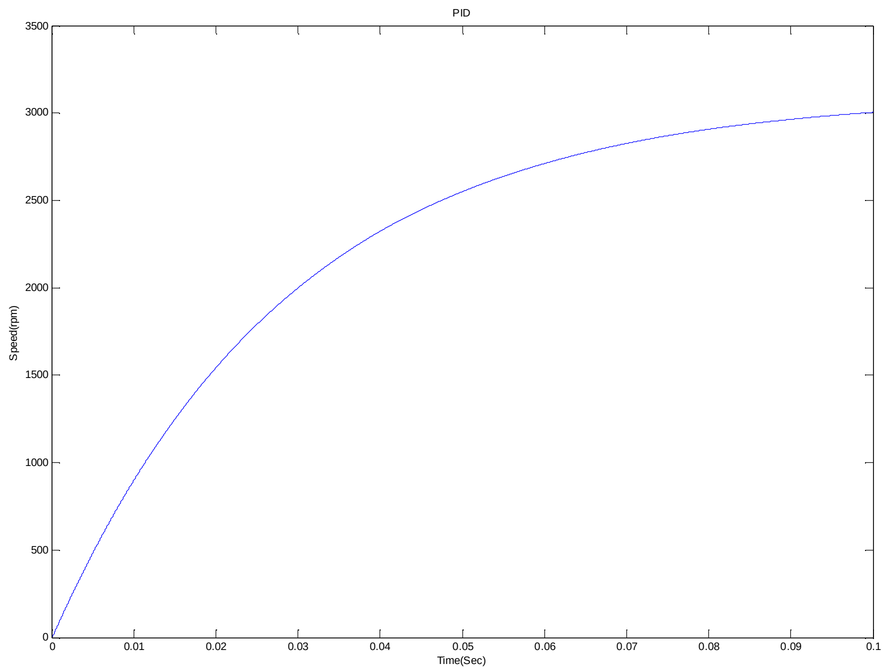
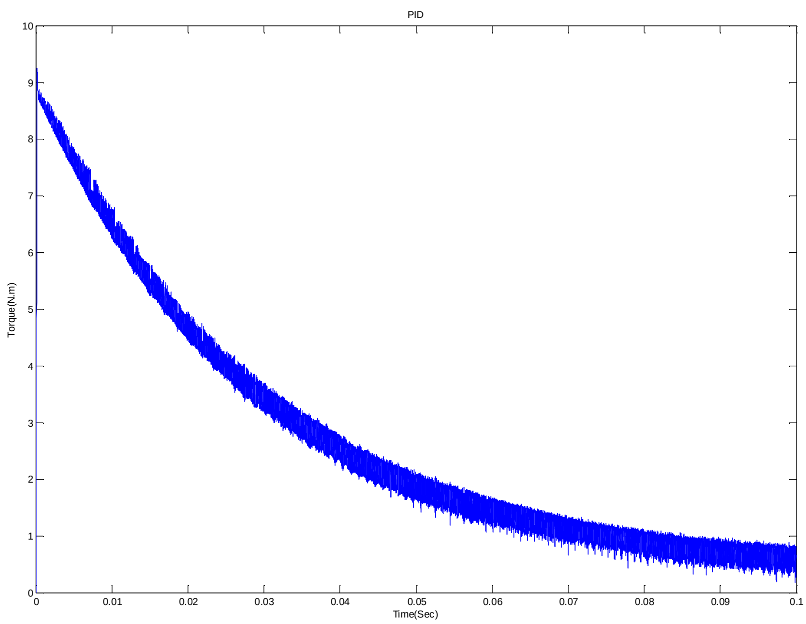
Speed



Torque



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COMPARISON TABLE

Parameters	Adaptive fuzzy-PID	Fuzzy-PID	PID
Overshoot (%)	0	9	0
Rise time(Sec)	0.005945	0.00584	0
Peak time(Sec)	0.005975	0.006035	0
Settling time(Sec)	0.007225	0.03683	0.09875

IX. CONCLUSION

Accurate performance of a motor is desired feature for any industrial application. As the age of motor increases its performance also deceases with aging, so it is desired to evaluate the performance of motor from time to time for efficient operation. The conventional method for calculating output performance indices are quite time consuming. The PID based approach algorithm worked satisfactory for the test system. The important observations made during the studies are,

- The solution time for proposed PID approach is only a fraction of time taken by conventional algorithm.
- A proportional controller Kp will have the effect of reducing the rise time and reduce but never eliminate the steady state error.
- An internal controller Ki will have the effect of eliminate the steady state error but it may make the transient response worse.
- A derivative controller Kd will have the effect of increasing the stability of the system and reducing the overshoot and improve the transient response.
- The output performance obtained by normalized value in PID is very close and near to accuracy.
- MATLAB used for simulation of entire project is sophisticated and user friendly software.
- It must be mentioned that the efficiency of the speed algorithm can be improved by using more efficient learning techniques and dynamic weight selection algorithm.

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