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# Comparative Study of Different Controllers for Velocity Control in BLDC Motor Using MATLAB/SIMULINK

[1]Girishma Vandanapu, [2]Harsha Kothareddy

[1]Student, Maulana Azad National Institute of Technology, Bhopal, India

[2] Project Engineer, Research Centre Imarat, Hyderabad, India

***Abstract*: This paper is on comparative study of working and variation of different parameters like stability, peak overshoot, rise time, steady state error, etc for different conventional controllers like Proportional (P),Proportional-Integral (PI),Proportional-Integral-derivative (PID) and Fuzzy controllers like Fuzzy logic controller (FLC) and Hybrid Fuzzy PI. Various controllers are designed for speed control of BLDC motor by using different techniques of integration, derivative, Fuzzy Decision making, etc to achieve the desired performance by reducing the peak overshoot, steady state error and sometimes by compromising time taken for computation of loop or memory occupied by controller or cost, etc. A good controller should have reduced overshoot, less rise time and less steady state error. The output response should be approximately similar to input. MATLAB/SIMULINK is used for modeling of motor and implementation of controllers.**

***Keywords:* Brushless DC motor (BLDC), P, PI, PID, FLC, Hybrid-Fuzzy PI controllers.**

## I. INTRODUCTION

The rapid requirement of motor drives with the new technology in the various industries is increasing day by day. There is great demand for efficient variable speed, long term stability and good transient performance of motor drives. BLDC motor is getting popular in recent year because of its high efficiency, high starting torque, and smooth operation and less maintenance due to absence of brush and commutator arrangement. Electronic commutation takes place with the help of VSI inverter which is very efficient. This motor has wide application in industries, instrumentation, aerospace, and robotics. .

The performance of motor is affected by sudden change in unknown load or speed. But as the BLDC motor drive are non linear in nature, they require an improved or modified controller that can adapt a non linear condition and achieve the desired performance .so, the proportional controller cannot control speed of motor due the simplicity of circuit and it produces an error or offset. Although the PI and PID controllers increase the speed of response and reduce the overshoot respectively to achieve desired response but they cannot be tuned to achieve optimum step response under different inertia, load and speed reference. So a decision making device is necessary to control the speed which is performed by FLC and Fuzzy PI controllers by IF_THEN condition. But these controllers occupy more space and they take more time for computation of loop.

The P, PI, PID controllers are implemented by inbuilt blocks in simulink library. FLC and Fuzzy PI are implemented by using tools in Fuzzy control toolbox in simulink library. The results are compared and analysed under tuned condition and a controller is chosen accordingly.

## II. BLDC MOTOR MATHEMATICAL MODEL

BLDC motors are a derivative of the most commonly used DC motor and they share the same torque and speed performance curve characteristics. The only major difference between the two is the use of brushes. BLDC motor is

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brushless synchronous motor with trapezoidal back EMF waveform shape. It has three phase stator winding and permanent magnet rotor. The stator is energized in sequence for the motor to rotate. To get correct sequence hall sensors are used, they sense the rotor position and give accordingly output. Permanent magnet synchronous machine block of simulink is used to implement the BLDC model.

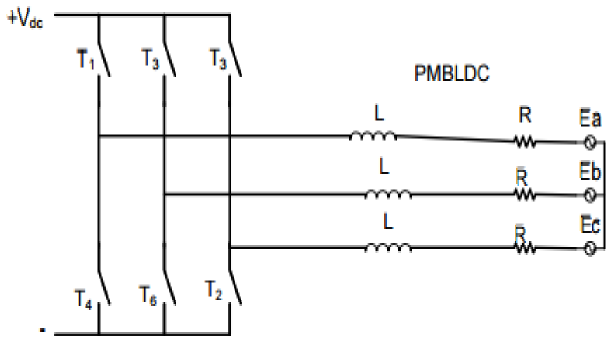



**Fig 1: Three phase bridge inverter network for BLDC**

Above fig shows the equivalent circuit of three phase full-bridge power network for BLDC Motor drive. The characteristics equations of a BLDC motor are given below.

Va = R.ia(t) + Ea + L dia(t)/dt (1)

Vb = R.ib(t) + Eb + L dib(t)/dt (2)

Vc = R.ic(t) + Ec + L dic(t)/dt (3)

Where, L- armature inductance (H)

R- Armature resistance (OHM)

Va, vb, vc -stator phase voltages (V)

ia , ib, ic –stator phase currents (A)

Ea, Eb, Ec –motor back emf (V)

Back emf of motor in each phase is 120degrees electrical shifted from each other and back emf is a function of rotor position and speed. Equation of each phase emf is given below:-

Ea = Kwf(θe)w (4)

Eb = Kwf(θe -2 π/3) w (5)

Ec = Kwf(θe +2 π/3) w (6)

Where Kw – back emf constant per phase

Θe – rotor angular position in electrical Degree

W – Rotor speed Relation between mechanical and electrical degree Θm =2/ p θe (7)

Where P –no. of pole

Te= ( Ea. ia + Eb. ib + Ec. ic)/w (8)

Te – Tl = Jdw/dt + Bw (9)

Te –total electromagnetic torque (Nm)

Tl –load torque (Nm)

J –inertia of the rotor shaft (Kgm2)

B –friction constant (Nms. Rads-1)

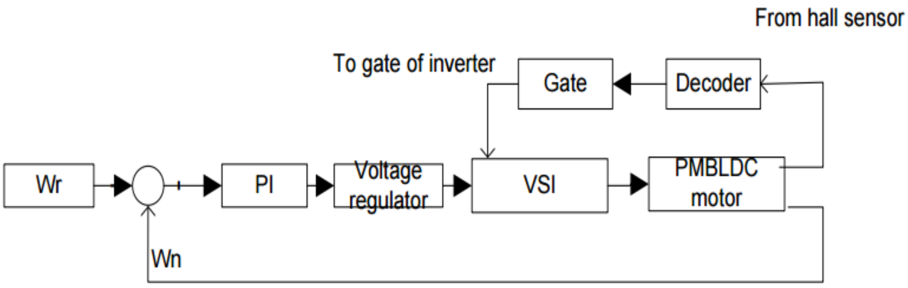



**Fig 2: Block diagram for BLDC control scheme by conventional P, PI, PID controllers**

The block diagram of control scheme by conventional P, PI, and PID controllers is given above, which consist of PID, PMBLDC, VSI, hall sensor, and decoder blocks. In the two close loops shown in the figure, one close loop gives gate pulses to bridge inverter (VSI) in proper sequence and other closed loop controls the speed of motor by changing the inverter voltage.

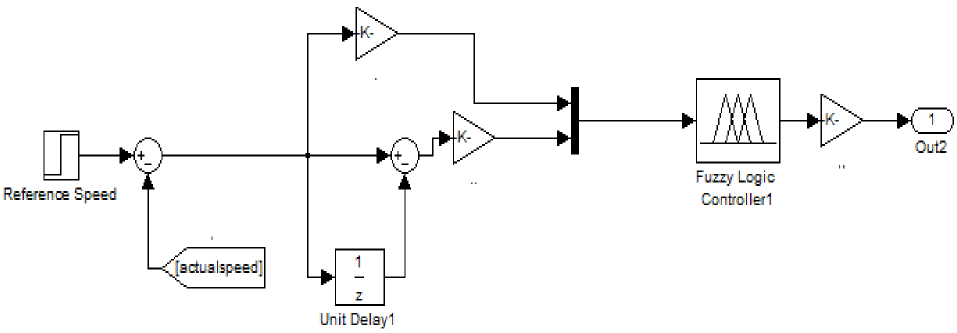



**Fig 3: Block diagram of Fuzzy logic based motor control system**

The above block diagram shows Fuzzy logic based motor control system. 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 degree of high performance motor drive requires high speed and fast response which are not met by conventional controllers. Fuzzy set theory uses a linguistic term, which is defined as a membership function which is based on the property of control variables like speed or torque.

## III. CONTROLLERS

### A. Proportional controller (P):

A controller with proportional control action always has a continuous linear relation between output of controller m and error signal e. Its equation can be written as,

M(s) =Kp E(s) (10)

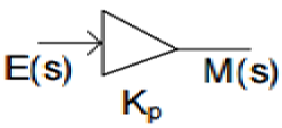



**Fig 4: Block diagram of P controller**

Where,

M(s)-actuating signal

E(s)- error signal

Kp- proportional gain constant

The demerit of P-controller is that it exhibits a permanent residual error known as offset error. A high value of Kp reduces error but it effect stability

**B. PI controller:**

The control action of PI controller is defined by M(s) = (KP + Ki /s). E(s) (11)

Where Ki= integral constant

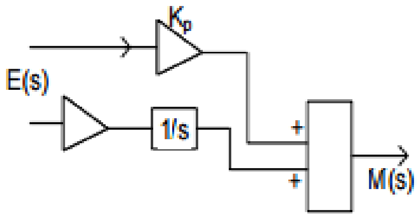



**Fig 5: Block diagram of PI controller**

This controller has advantage of both P and I controller. It increases speed of response and reduces offset error created by p controller. But if the controller is connected to higher order system it creates stability problems.

**C. PID controller:**

The control action of PID controller is defined by equation given below.

M(s) = (Kp + Ki /s + sKd). E(s) (12)

The block diagram of PID controller is shown below.

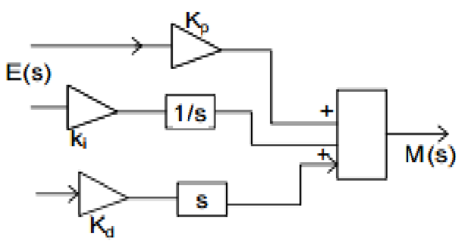



**Fig 6: Block diagram of PID controller**

Where, Kd= derivative constant

PID controllers are most widely used in industries because of the reduced number of tuning parameters and these parameters can easily change without changing any hardware.

**D. FUZZY LOGIC CONTROLLER:**

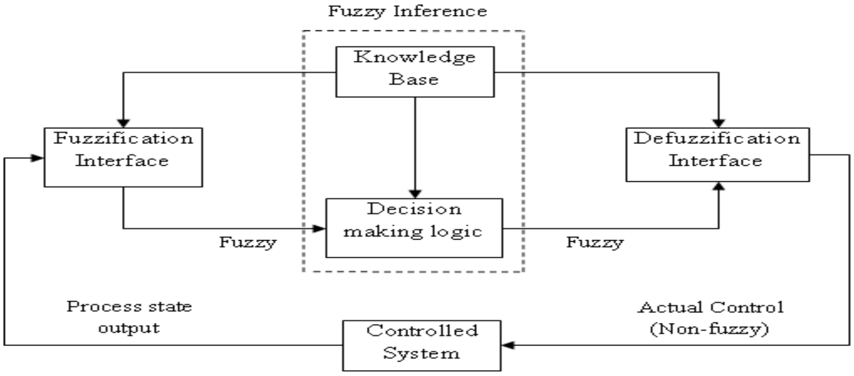



**Fig 7: Block diagram of Fuzzy logic controller**

Fuzzy theory is a rule based decision making method which helps to process like a human controlling with expertise gain from the experience. Based on the error and change in error of system, the fuzzy set is formulated from element which has degree of membership. The controller consists of Fuzzifier, inference engine, Defuzzifier and Rule base. Fuzzifier converts and transforms the measured input of the system (i.e. the error signal) into the linguistic values (i.e. membership function). Then rule base (IF_THEN type) must be used in order to take an action for each combination of control variables. The Inference engine utilizes Mandani fuzzy interference method to processes the rule base. The output membership function obtained from the inference engine is converted into the crisp values by Defuzzifier. Rule base used in simulation to control the speed of the BLDC motor is shown in Table-1. Some advantages of fuzzy logic system in control application are high degree of tolerance, smooth operation, fast learning capability etc.

**Table I: Rule base for design of FLC controller**

| | | EC | | | | |
|---|---|---|---|---|---|---|
| | | NL | NS | Z | PS | PL |
| E | PL | | PL | | NL | NL |
| | PS | PS | Z | NS | NL | NL |
| | Z | PL | PS | Z | NS | NL |
| | NS | PL | PL | PS | Z | NL |
| | NL | PL | PL | | PS | |

**E. FUZZY PI CONTROLLER:**

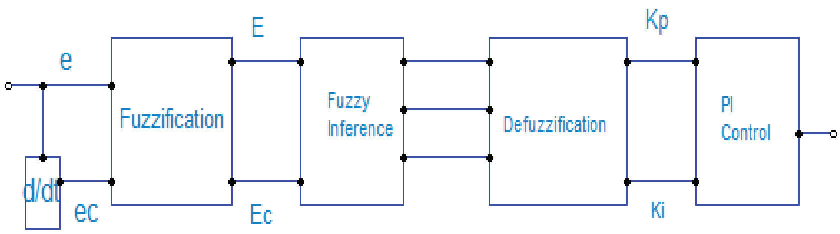



**Fig 8: Block diagram of Fuzzy PI controller**

Where e is the error signal and ec is the rate of change of error. FLC occupies more memory and takes more time for simulation. So, Fuzzy PI controllers are designed to overcome those drawbacks. The conventional PI controller is replaced by Fuzzy PI controller to improve the performance of a system. It calculates the speed of controller with agility. So, it takes less time for computation and occupies less memory. The design algorithm of proposed system is just to adjust the KP and KI parameters based on the speed error e and rate of change speed error to control the speed in static and dynamic condition.

## IV. RESULTS

**A. Simulation model and results for conventional controllers:**

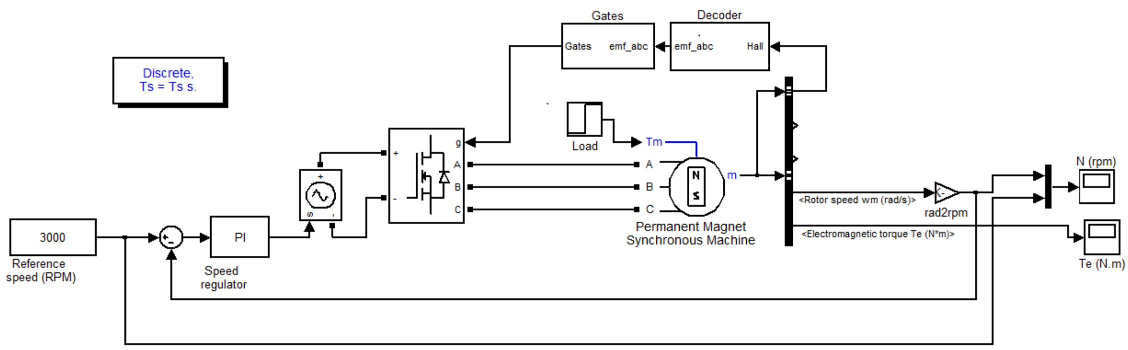
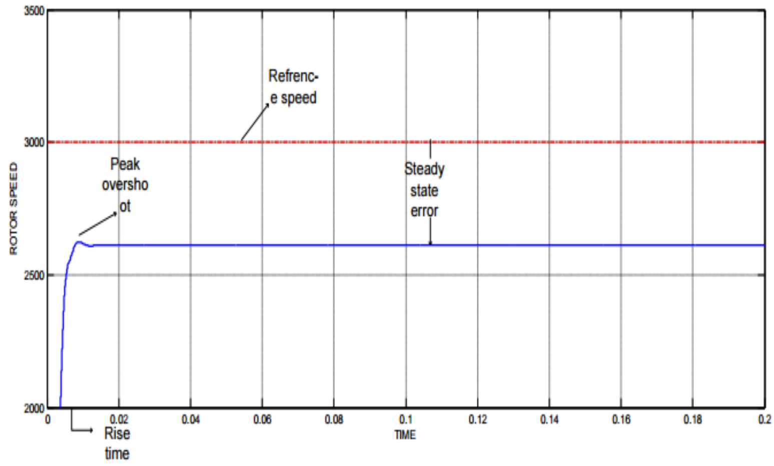
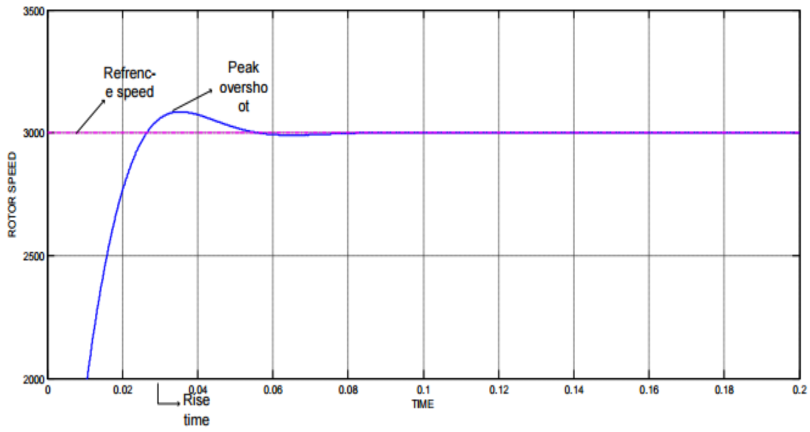



**Fig 9: Simulation model for conventional controllers**



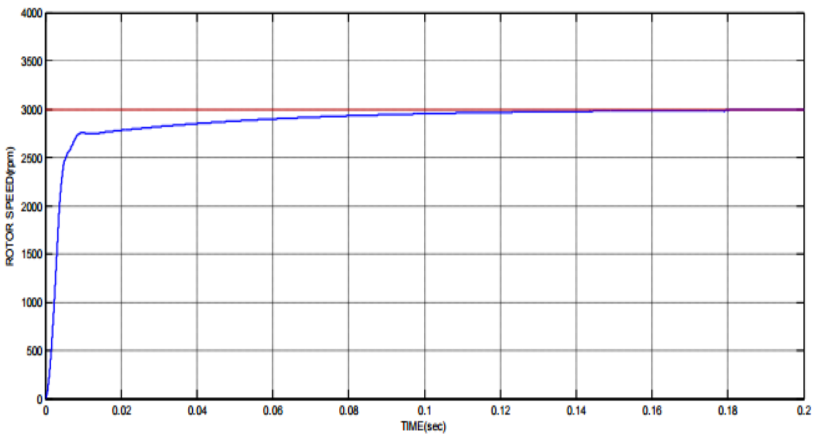

**Graph 1: speed response of motor by P controller**

From above figure, it can be observed that the rise time increases, peak overshoot decreases, steady state error increases and stability worsen by implementation of P controller.




**Graph 2: speed response of motor by PI controller**

From above figure, it can be observed that the rise time increases, peak overshoot increases, steady state error decreases and stability worsen by implementation of PI controller.




**Graph 3: speed response of motor by PID controller**

From above figure, it can be observed that the rise time decreases, peak overshoot decreases, steady state error decreases and stability is better (if Kd is small) by implementation of PID controller.

### B. SIMULATION MODEL OF FLC CONTROLLER:

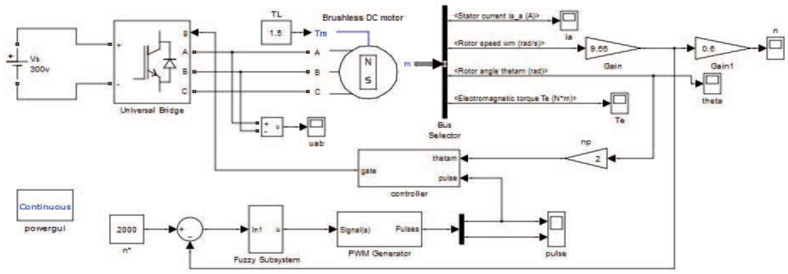



**Fig 10: Simulation model of FLC controller**

### C. SIMULATION MODEL OF FUZZY-PI CONTROLLER:

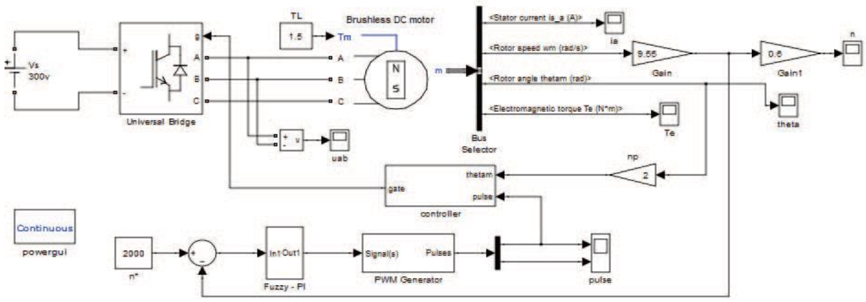
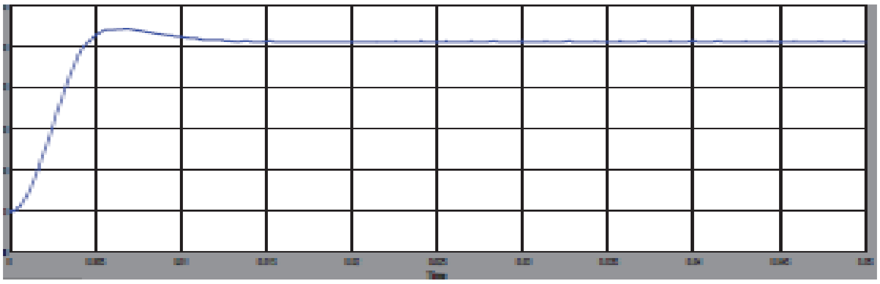


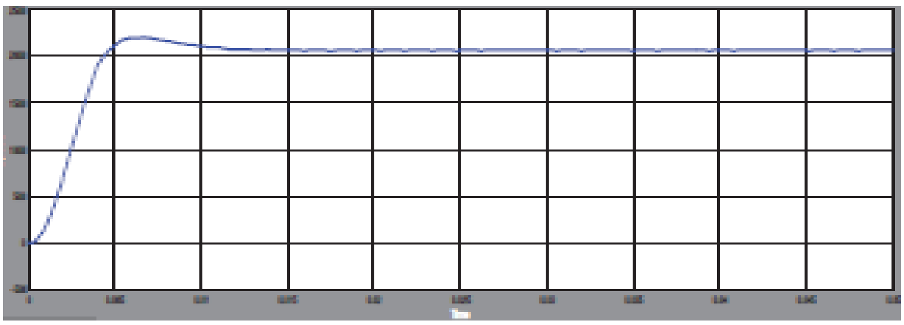

**Fig 11: Simulation model of Fuzzy-PI controller**

### D. SPEED RESPONSE OF FUZZY CONTROLLERS:



**Graph 4: Speed response of motor by FLC controller**

The speed response of motor by implementation of simple FLC is shown in above graph. It is a graph between speed Vs time. As compared to conventional controllers, FLC has better characteristic. Speed response is smooth with less overshoot for FLC compared to that of conventional controllers.



**Graph 5: Speed response of motor by Fuzzy-PI controller**

The speed response of motor by implementation of Fuzzy-PI is shown in above graph. It can be observed that the response has much more reduced overshoot and rise time compared to conventional and FLC controllers.

## V. CONCLUSION

Performance of BLDC drive system using P, PI. PID, FLC, Fuzzy-PI controllers are compared and it is observed that the degree of high performance motor drive requires high speed and fast response which are not met by conventional controllers. So, FLC controllers are designed to respond dynamically to changes using rule base. But these controllers occupy more space and take more time for computation. These drawbacks are overcome by Fuzzy-PI controller. So, it can be observed that Fuzzy-PI performance is better than FLC and conventional controllers. The performance of motor drive can be enhanced by using optimal parameters of controller through different techniques.

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