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Optimizing BLDC Motor Performance with Advanced Fuzzy Logic PID Controller under Dynamic Load Condition

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Abstract

These days, green technology is a big deal in every nation on the planet, and since electricity is a clean energy, getting this technology is encouraged. Electric motors are used in the majority of applications for power. A motor is used to transform electrical power into mechanical energy; in other words, electric motors are responsible for the majority of the uses of electrical energy. Brushless direct current (BLDC) motors are becoming more and more popular in various applications because of their small size and inexpensive maintenance. The industries can become more dynamic by substituting the BLDC motors. Improved performance from a BLDC motor need control drive assistance in managing its torque and speed. The performance of a BLDC motor under various control scenarios and load types is examined in this research. A sophisticated Fuzzy PID controller and a standard PID controller are contrasted. In real-world applications, the load variations under study are frequent. The evaluation in this paper observes the motor's speed response during the application and removal of loads. BLDC motors often exhibit jerky behavior when loads are removed. The study shows that gradual load changes produce better results than sudden load changes, regardless of the controller used. Additionally, the Fuzzy PID controller significantly reduces jerks during load removal. The speed-torque characteristics show that jerks are minimized with the Fuzzy PID controller during regular load removal.

Keywords: *PID Controller, Brushless DC motor (BLDC).*

1. Introduction

The increasing trend for applications in BLDC (brushless dc) motor is its efficiency, controlled high torque, longer lifetime, low maintenance, and low noise of these motors. BLDC motor offers many advantages over the brushed dc (BDC) motor such as their high efficiency, high torque, low volume and longer life [1]. The speed of the Brushless DC motor can control by making use of the Pulse Width Modulation (PWM), Integral Current (IC), Electro Motive Force (EMF), and Direct Torque Control (DTC) methods. The shape of induced Electro Motive Force is sinusoidal and trapezoidal in its nature. In BLDC motor, the rotor contains the magnets and stator contains the windings. There are no brushes in this motor. There was a forced commutation, which may have altered the current flowing through the rotor's windings. The magnet in this configuration rotates continually while staying still. In order to detect the real rotor position, the BLDC motor is equipped with either internal or external position sensors. Subsequently, the three phase inverter feeds the magnets in the BLDC motor. In the inverter bridge circuit, a rotor position sensor is employed to determine the proper switching sequence (commutated every 600) that activates the semiconductor device. The rotor position is measured by the Hall-Sensor. This Hall sensor mounted on stator [2]. The switching signal determined by rotor position and it maintains the speed during load variation and supply fluctuation

The performance of motors can check their stability at no load and step load. The behavior of BLDC motor has two types of load variation. One is the domestic or industrial load variation another is sudden gradual load variation. In this project, the variation of the speed response obtained at the time of free running condition and at the instant loaded condition along with the sudden removal load. The

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major drawback of BLDC motor is jerks found at the time of loading and unloading condition.

2. Methodology

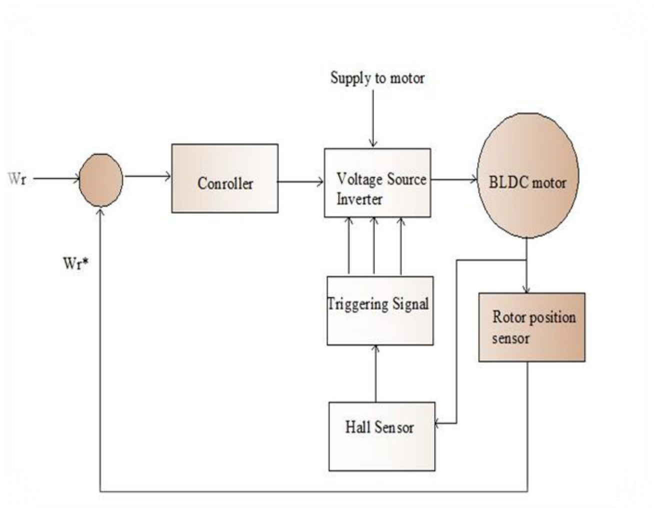

Figure 1 Block Diagram of the System

Figure 1 illustrates the usage of two control loops for BLDC motor speed regulation. The inverter gate signal and the EMF are synchronised via the inside loop. A second loop, located outdoors, modifies the DC bus voltage to regulate the speed. Six power transistors located in the drive circuit of the speed control's three-phase power converter are used to energise the BLDC motor. Three-Hall sensors are built into the stator of BLDC motors to detect the rotor position, which is then utilised to determine the MOSFET transistor switching sequence [3]. Reference current generated by the reference current generator and information signal vector of the back EMF generated by the decoder block in conjunction with the hall sensor. Switching the motor to the other direction, we have to give opposite current.

2.1.Controller

The electronics circuit known as an electronic speed control, or ESC, manages and controls the speed of an electronic motor. It might also offer dynamic braking and motor reversing. Both BDC and BLDC motors need the various kinds of speed controllers. A BDC motor's armature voltage can be changed to adjust the motor's speed. It takes a different operating principle for a BLDC motor. By altering the timing of the pulses given to the motor's several windings, the speed of the motor may be changed.

2.2.Voltage Source Inverter

When discussing power electronics, the term "inverter" refers to a class of power conversion circuits that transform dc voltage or dc current sources into ac voltage or current. Voltage source inverters find application in electronics frequency changers, adjustable speed drives (ASD) for AC motors, and uninterruptible power supply units (UPS).

2.3.BLDC Motors

One kind of permanent magnet synchronous motor is the brushless DC motor (Figure 2). Compared to other motors, the BLDC motors perform better in terms of increased torque, low speed range, high power density, lower maintenance, and reduced noise. They are further divided into two types based on the shape of the induced EMF: sinusoidal and trapezoidal [4-6].

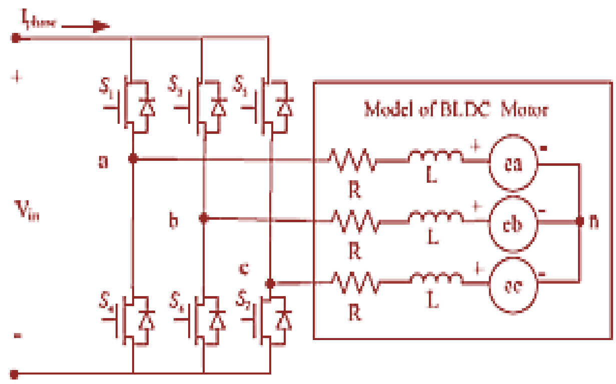

Figure 2 Model of BLDC Motor

2.4.Hall-Effect Sensor

The position sensors are Hall-effect sensors. To switch off the BLDC motor that is electronically controlled. In order for the BLDC motor to rotate, the stator windings need to energise sequentially [7]. The Hall Sensors built inside the stator are used to sense the position of the rotor. The rotor magnetic poles will indicate if the N or S pole is approaching the Hall sensor by sending out a high or low signal when they do. The precise communication sequence can be ascertained by combining these Hall Sensor signals.

2.5.PID Controller

A PID controller operates with the feedback mechanism [8]. In a feedback control system, the output sensed from output side. The two types of

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feedback control system:1) Positive feedback system and 2) Negative feedback system. The positive feedback used to increase the size of the input but the negative feedback system is decrease the size of the input. The standard feedback control loop is to correct the error between measured process variable and desired value [9-11]. The control system demands small peak time, small rise time, small maximum peak-overshoot percentage, small settling time and minute steady state error. A proportional-integral-derivative (PID) controller is a method of the feedback control loop. This method is composing of three controllers:

1. Proportional controller (PC)
2. Integral controller (IC)
3. Derivative controller (DC)

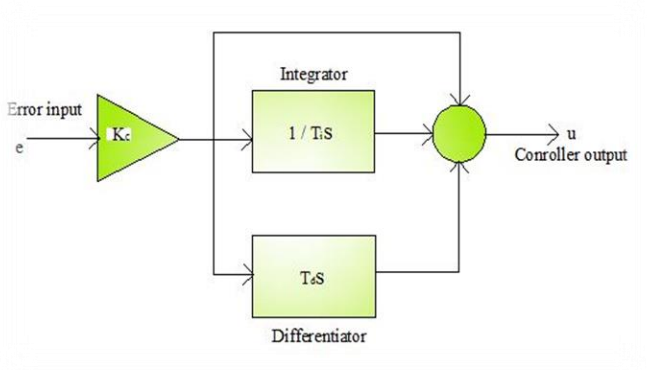

Figure 3 PID Control System

Fig 3 shows atypical structure of a PID control system. The error signal e (t) is use to generate the proportional, integral, and derivative actions, with the resulting signal is Weighted and summed to form the control signal u (t) applied to the model. The transfer function of PID controller is

- **G(S) = (U(S))/(E(S))**
- **G(S) = KP + KI/S + KDS = (KP^2 + Ki + KdS)/S**

2.6.Fuzzy PID Controller

In the Fuzzy PID controller (Figure 4), the Fuzzy-tuner is used to tuning of parameters of PID controller. Tuner-parameters are KP, KI and KD. A non-linear mapping from the error and derivative of the error is to tune by fuzzy inference system (FIS) i.e. PID parameters generated by FIS [12].

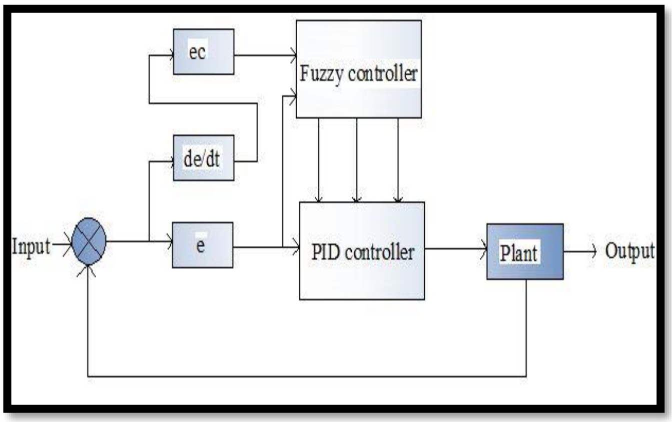

Figure 4 Fuzzy PID Controller

The self-tuning fuzzy PID controller receives the error 'e' as input, and uses fuzzy control rules to derive the error, change in error 'de/dt', or rate of change in error 'ec'. The tuning parameters are KP, KI, and KD. A fuzzy PID controller that self-tunes is configured by those rules. 'e' and 'ec', the fuzzy relationship between the PID controller's parameters, are obtained using the fuzzy controller. A controller is getting better by modifying the MFs and rules. There is one output controller and two input controllers in fuzzy MF. The values are categorised into seven levels: \NB, NM, NS, ZO, PS, PM, PB}; negative big, negative medium, negative small, zero only, positive small, positive medium, and positive big. The MFs of input as error ('e'), error control ('ec'), and output as 'u' are used to pick the function type 'trimf'. (Refer Figure 5a, b, & c).

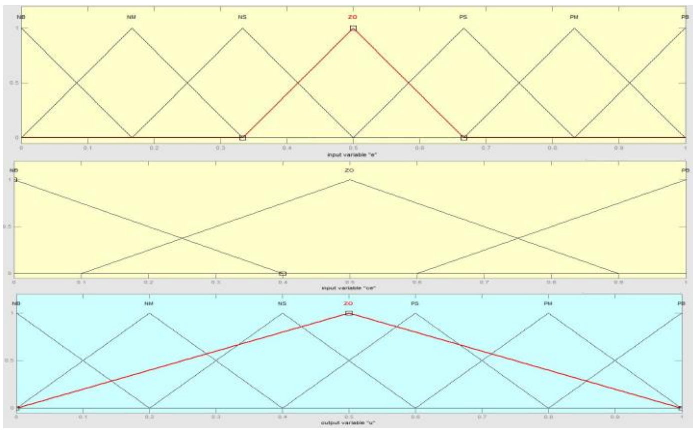

Figure 5 a) Membership Function of Error 'e' b) Membership Function of Error Control 'ec' c) Membership Function of Output 'u'

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3. Implementation

3.1.BLDC Simulink Model with PID Controller

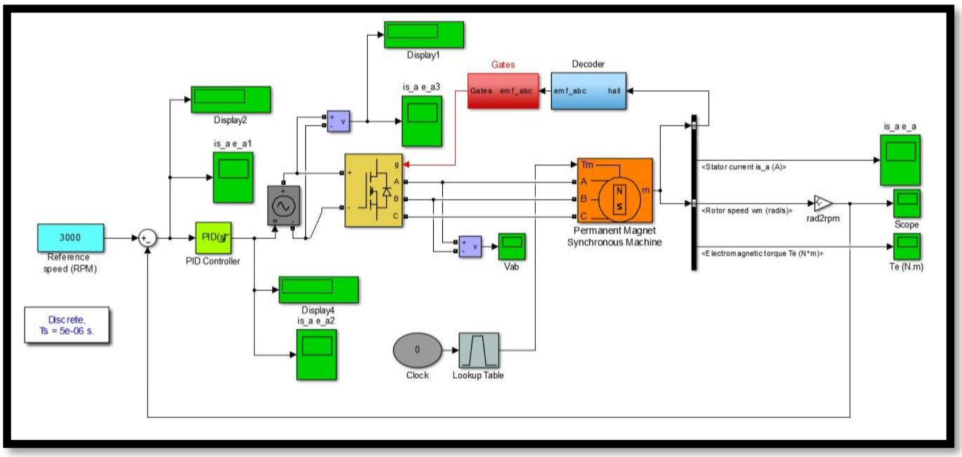

Figure 6 **BLDC Simulink Model with PID Controller**

3.2.BLDC Simulink Model with FUZZY-PID Controller

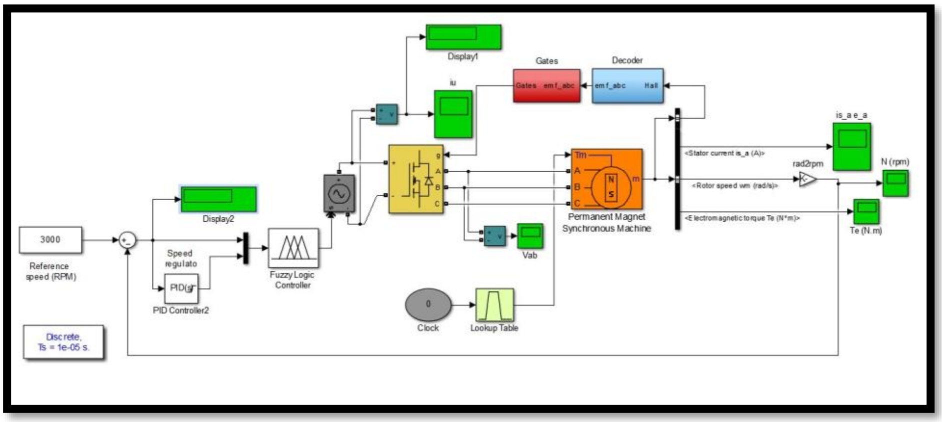

Figure 7 **BLDC Simulink Model with FUZZY-PID Controller**

In this method, the controller used in the model is Fuzzy-PID controller is as shown in fig 7. This model contain voltage source, MOSFET bridge, BLDC motor, decoder & encoder logic, mechanical load, PID controller and Fuzzy logic controller (Figure 6). The motor speed, when compared with the reference speed of 3000 rpm using a comparator, is then sent to both a PID controller and a Fuzzy Logic Controller (FLC). The FLC receives two inputs: one from the comparator and another controlled input from the PID controller. A Controlled Voltage Source (CVS), which powers the inverter circuit, receives the FLC's output. The MOSFET/diode inverter circuit's gate/decoder (Hall sensor), which is triggered by the rotor's location, controls the firing or gate pulses. A Permanent Magnet Synchronous Motor (PMSM) is connected to the output of the inverter circuit. Measured output from the PMSM includes back electromagnetic force, rotor speed, and electromagnetic torque. The Decoder/Gate block receives one set of these outputs and uses them to create the gate pattern for the inverter circuit. The simulation runs in a variety of operational scenarios, including loading applications, initiating a load, and removing a load [13].

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4. Results

4.1. PID Controller

4.1.1. Speed Response Curve

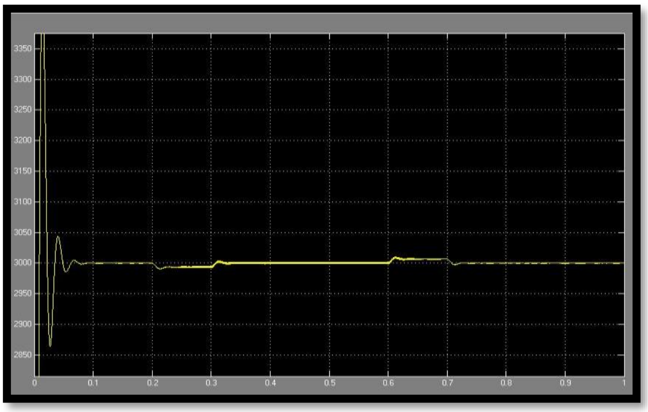

Figure 8 Speed Response Curve with PID Controller

4.1.2. Current Response Curve

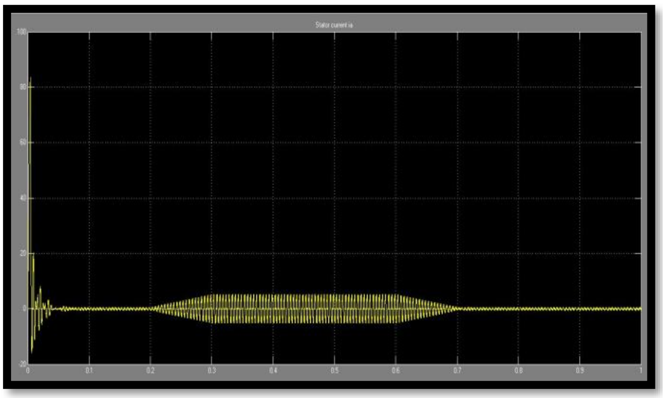

Figure 9 Current Response Curve with PID Controller

4.1.3. Torque Response Curve

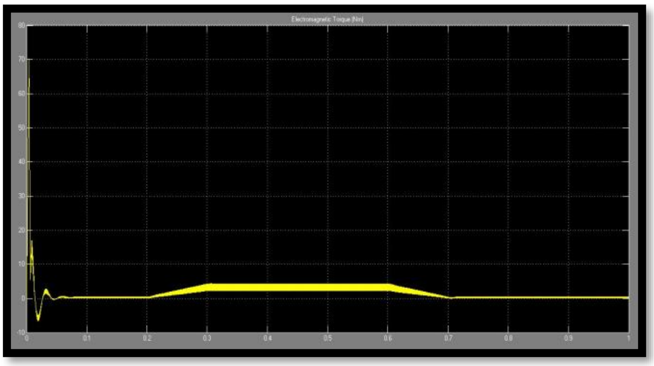

Figure 10 Torque Response Curve with PID Controller

4.2. FUZZY-PID Controller

4.2.1. Speed Response Curve

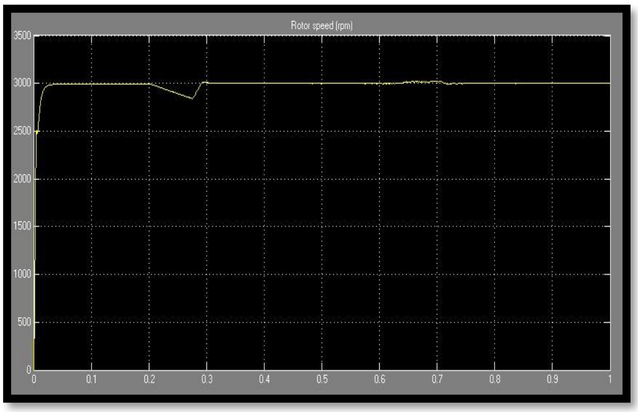

Figure 11 Speed Response Curves with FUZZY-PID Controller

4.2.2. Current Response Curve

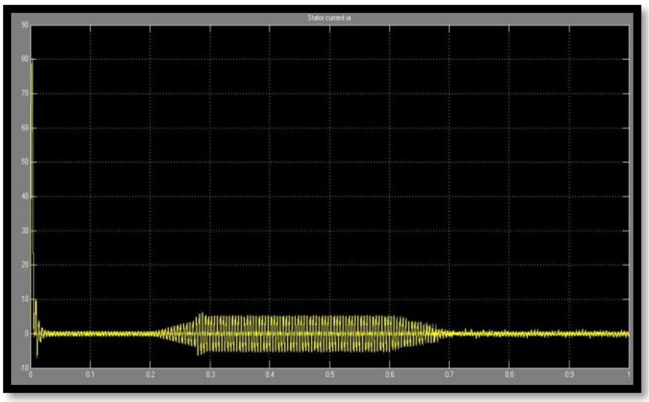

Figure 12 Current Responses Curve with FUZZY- PID Controller

4.2.3. Torque Response Curve

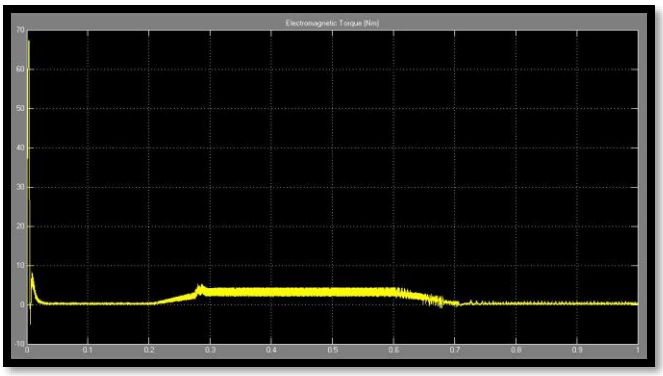

Figure 13 Torque Response Curves with FUZZY - PID Controller

Conclusion

In this project, a BLDC drive model was developed using MATLAB software to assess its speed performance with both PID and Fuzzy PID controllers. The motor's behavior was evaluated under sudden load variations, gradual load changes, and constant load conditions. The findings revealed that the BLDC drive performs optimally with gradual load changes. The tuning parameters, such as peak overshoot, peak undershoot, peak time, rise time, and settling time, are greatly improved by the Fuzzy PID controller. A significant drawback of BLDC motors is the jerking motion during load application and removal. This issue is more effectively mitigated by the Fuzzy PID controller compared to the PID controller. Simulation results also show that current ripple and torque ripple are minimized, which enhances the overall performance of the drive. Results are shown in Figure 8 to 13.

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