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Modelling of PID-Fuzzy Controller for Speed Control of Brushless Dc Motor to Improve Steady State Performances

Bigyan Pokharel[1*], Bimal Pandey[1], Ajay K.C.[1], Sangam Gouli[1], Sandeep Dhami[1]
[1] *Department of Electrical Engineering, IOE, Pashchimanchal Campus, Tribhuvan University, Nepal*
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Abstract

Brushless DC Motor is a three-phase permanent magnet motor that requires DC voltage as its supply. This kind of motor is widely used in electric vehicles due to high efficiency and high torque. Electric vehicle that uses brushless DC motor works on dynamic load system with the varied set point. The use of conventional PID controller can't be applied to dynamic load system. If this controller still be applied, the system response to steady state will be long enough and cause the motor has a bad performance. The use of PID- Fuzzy is the solution to solve this problem. In this paper, fuzzy logic based PID controller is modeled to improve the steady state condition of brushless DC motor during dynamic load condition.

Keywords—Brushless DC (BLDC) Motor; Fuzzy Logic; PID Controller; PID-Fuzzy

1. Introduction

Brushless Direct Current (BLDC) motors are one of the motor types that are rapidly gaining popularity. BLDC motors have many advantages over brushed DC motors and induction motors which are better speed versus torque characteristics, high dynamic response, high efficiency, long operating life, noiseless operation, and higher speed ranges. The applications of BLDC motors are widely used in many industries like developments in power electronics technology, manufacturing technology for high performance magnetic materials and modern control theory for motor drives. Modern applications demand accurate speed and position control due to the good electrical and mechanical properties of BLDC motors and many control methods have been developed to improve the performance of BLDC motor drives[1]. The varied set point and dynamic load condition must be considered on electric vehicles. Set point represents a reference speed from throttle and a load changing or dynamic load condition represents a disturbance when the electric vehicle passes the incline. Conventional PID controllers can't perform well in dynamic load conditions [3]. The use of PID-Fuzzy is the solution to solve this problem [2]. Simple PID algorithm and fuzzy logic in case of PID parameter tuning are expected to maintain the steady state condition of brushless DC motor speed at varied set point and dynamic load condition.

The method used in this work is to combine the PID and fuzzy logic. PID becomes the main controller on this system and fuzzy logic is used to tune the parameter of PID. Thus, this method generates steady state response speed control of brushless DC motors applied in electric vehicles.

2. Control Strategy and Methodology

2.1 Control Strategy

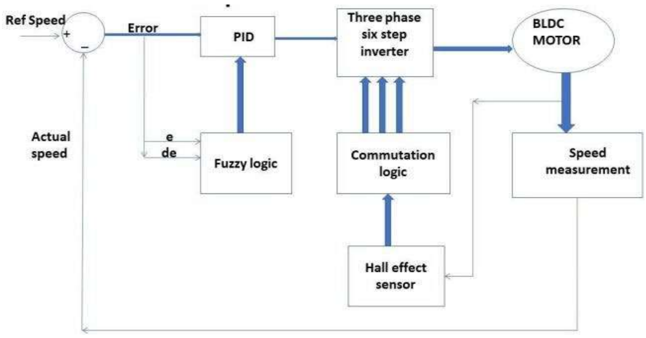

Figure 1: Block Diagram for Speed Control of BLDC motor

There are two loops that used in the block diagram shown in figure 1. The first loop is used for six step inverter commutation and the second loop is used for speed control of brushless DC motor. IGBT or MOSFET based inverter bridge can be used for the inverter topology. Hall Effect sensor on the brushless

*Corresponding author. Tel.: +977- 98672-32-804,
E-mail address: bigyanp027@email.com

energized, the magnetic field will be form and the rotor will rotate. Meanwhile, Hall Effect sensor as a speed sensor serves to obtain the current speed data which will be used to get the error value. PID controller and fuzzy logic is used for speed control of motor and to maintain constant speed during load changes[4].

The speed response of BLDC motor affected together by applied voltage and load torque.

$$\Omega(S)=Gu(S)U_d(S)+G_l(S)\,T_l(S) = \frac{K_T U_d(s)}{LaJs^2+(r_aJ+L_aB_V)s+(r_aB_V+KeK_T)} - \frac{ra+LaS}{LaJs^2+(r_aJ+L_aB_V)s+(r_aB_V+KeK_T)} \quad (1)$$

Where:

U_d : DC bus voltage.

e_A : Phaseback emf.

r_a: Line resistance of winding, $r_a = 2R$.

La: Equivalent line inductance of winding, La = 2(L – M).

J: Rotor moment of inertia.

Tl: Load torque, i : line current.

Ω: Rotor speed.

Bv : Viscous friction coefficient.

Ke : Coefficient of line back-EMF.

Kt: Coefficient of line torque constant.

M: Mutual linkage, assume M= 0.

2.2 Methodology

PID-Fuzzy is a controller to optimize the work of PID controllers when the set point and load are dynamic[5]. Fuzzy logic works to determine Kp, Ki and Kd parameters. PID-Fuzzy has two inputs consisting of error and delta error, and three outputs are Kp, Ki, and Kd. The PID-Fuzzy control scheme is shown in figure 2. Sugeno fuzzy type was chosen in this study because defuzzification process is simpler than Mamdani type.

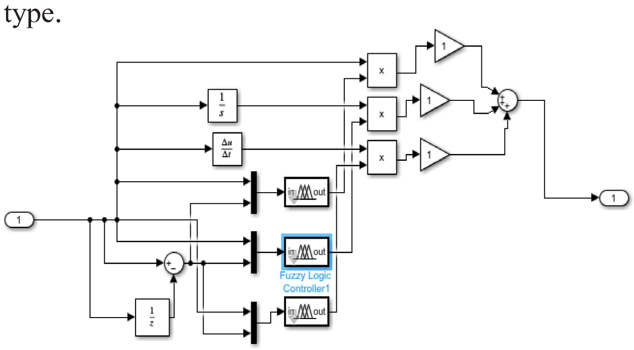

Figure 2: Modelling of PID-Fuzzy

Figure 7 depicts the overall PID-Fuzzy control system for the brushless DC motor, and Table 1 lists the technical data for the motor. Two inputs make up the Sugeno fuzzy type design, that is, the error and delta error depicted in figure 3.

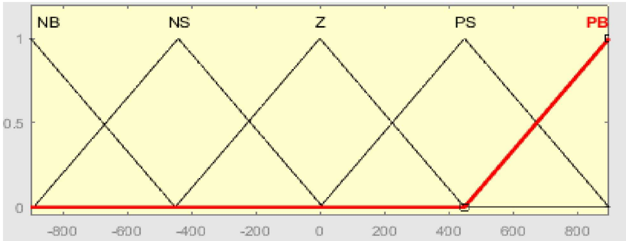

Figure 3: Membership Function for error and delta error

Where, NB, NS, Z, PS, and PB, respectively, stand for Negative Big, Negative Small, Zero, Positive Small, and Positive Big.

Fuzzy output consists of three output. Three outputs are available: one for Kp, one for Ki, and one for Kd. Figures 4, 5, and 6 display the membership function output of the Kp, Ki, and Kd parameters respectively.

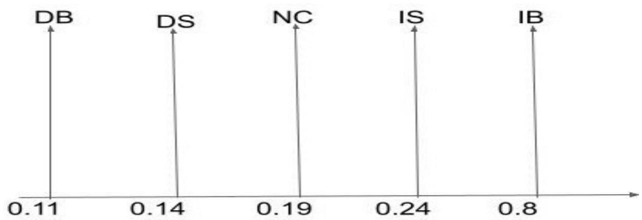

Figure 4: Membership function for Kp

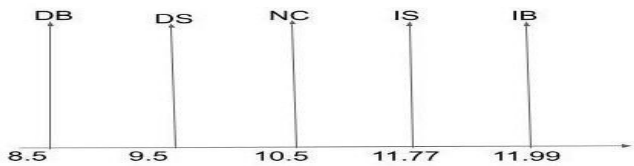

Figure 5: Membership function for Ki

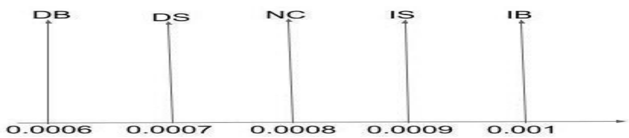

Figure 6: Membership function for Kd

Where, respectively, DB, DS, NC, IS, and IB stand for Decrease Big, Decrease Small, Not Change, Increase Small, and Increase Big. The Ziegler Nichols approach is used to extract the parameter values for Kp, Ki, and Kd at fuzzy output from the results of system tuning. For fuzzy output, the parameter value serves as a reference. Table 2 displays the rule base for the Sugeno type for the Kp, Ki, and Kd parameters.

Table 1: BLDC Motor Parameters

Parameter	Symbol	Value
Moment of inertia	J	0.01kgm^2
Damping constant	B	0.2 Nm
Stator resistance per phase	R	0.013 ohm
Stator phase inductance	L	0.00022 H
Back EMF flat area	A	120 Degree
Maximum rotor induced back EMF	K	9.6 V
Speed of rotor	N	900 RPM
voltage	V	48 V

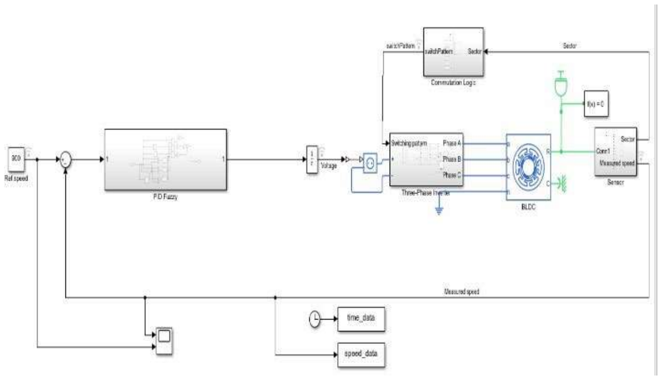

Figure 7: Simulink Model for speed control of BLDC motor using PID-FUZZY

Rule base for Sugeno type k_p, k_i and k_d parameters is shown in Table 2.

Table 2: Rule base for Sugeno type k_p, k_i and k_d parameters

de / e	NB	NS	Z	PS	PB
NB	DB	DB	DB	DS	NC
NS	DB	DB	DS	NC	IS
Z	DB	DS	NC	IS	IB
PS	DS	NC	IS	IB	IB
PB	NC	IS	IB	IB	IB

3. Results and Discussion

The simulation is performed by using 48V; 1KW BLDC motor, with nominal speed of 900 rpm. Figure 8, figure 9 and figure 10 show output response from without controller, PID and PID-Fuzzy respectively at set point 900 rpm.

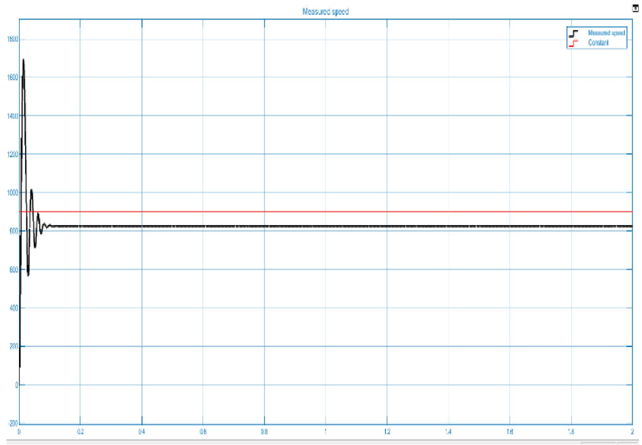

Figure 8: Output Response without Controller

Figure 8 shows output response of closed loop control of BLDC Motor without controller. Output response has the rise time of 0.0157sec, settling time of 0.376 sec, overshoot of 19.55% and peak time of 1.1 sec.

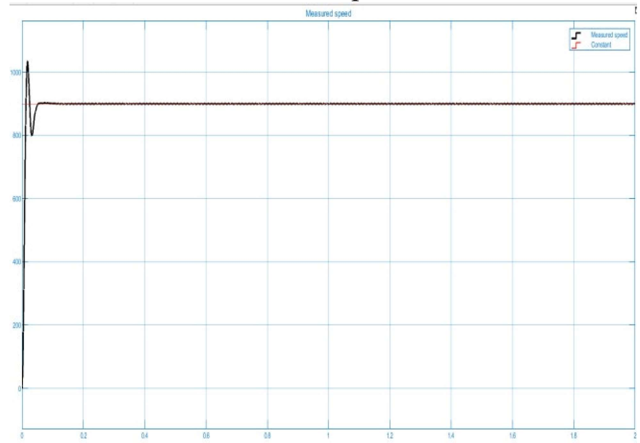

Figure 9: Output Response with PID Controller

Figure 9 shows output response of closed loop control of BLDC Motor with PID controller. Output response has the rise time of 0.0210 sec, settling time of 0.07448sec, overshoot of 15.41% and peak time of 0.0258 sec

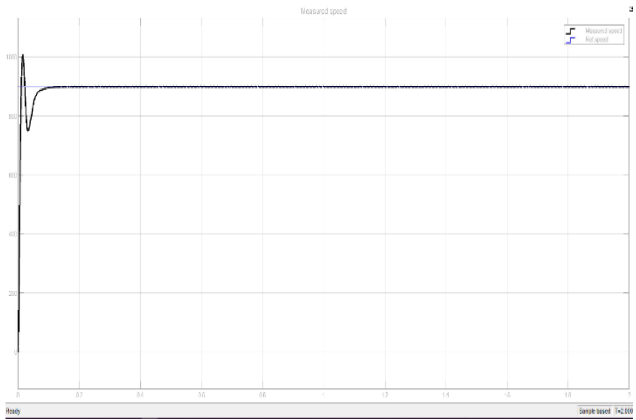

Figure 10: Output Response with PID-Fuzzy Controller

Figure 10 shows output response of closed loop control of BLDC Motor with PID-Fuzzy controller. The response shows rise time of 0.0072sec, settling time of 0.0663 sec, peak time of 0.0154sec and overshoot of 11.927%.

The performance of conventional PID and PID-Fuzzy for speed response of brushless DC motor is compared on the basis of Rise Time (s), Settling Time (s), Peak time (s) and Overshoot (%) as shown in Table 3.

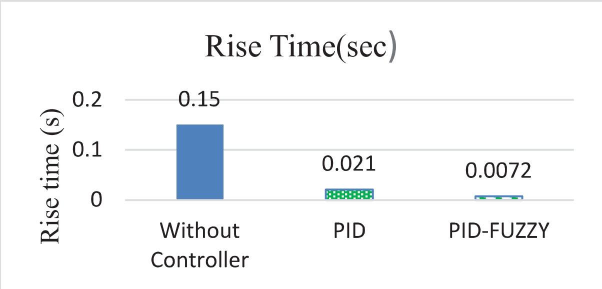

Figure 11: Comparison of rise time

Figure 11 shows that PID-Fuzzy controller has fast rise time in comparison to PID and without controller. Hence, it can improve the performance of BLDC motor.

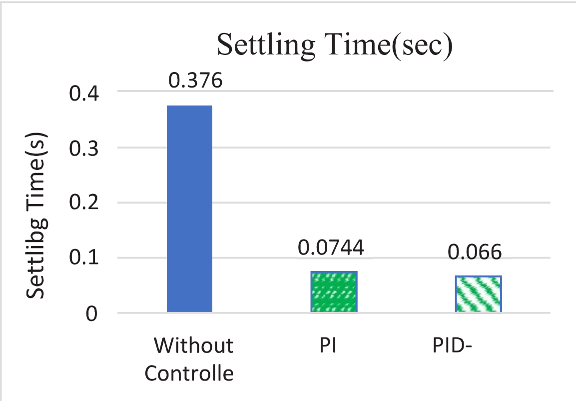

Figure 12: Comparison of settling time

Figure 12 shows that PID-Fuzzy controller has fast settling time in comparison to PID and without controller.

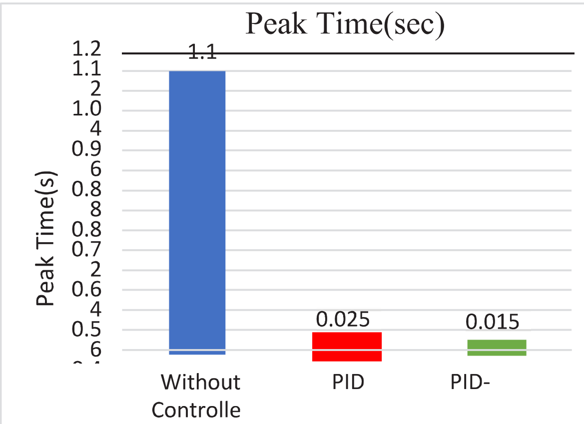

Figure 13: Comparison of peak time

Fig.13 shows that PID-Fuzzy controller has fast peak time in comparison to PID and without controller. Hence, it improves the performance of BLDC motor

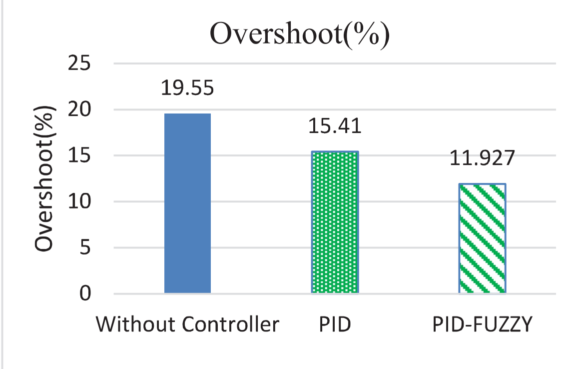

Figure 14: Comparison of % overshoot

Figure 14 shows that PID-Fuzzy controller has less % overshoot in comparison to PID and without controller.

Table 3: Comparison between fuzzy PID and PID controller

Parameter	Without controller	PID controller	PID-Fuzzy controller
Rise Time	0.15	0.0210	0.0072
Settling Time	0.376	0.07448	0.0663
Peak Time	1.1	0.0258	0.0154
Max% Overshoot	19.55	15.41	11.927

4. Conclusions

The modeling of Fuzzy based controller for speed control of brushless DC motor has been performed in MATLAB. The simulation result shows that the PID parameters tuned by fuzzy logic can improve the performance of brushless DC motor speed. PID- Fuzzy produces better performance than conventional PID. Performance of PID-Fuzzy controller indicates that the response can reach steady state condition faster than conventional PID controller.

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