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Fuzzy-PID in BLDC Motor Speed Control Using MATLAB/Simulink

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***Abstract*— Brushless DC motors (BLDC) are one of the most widely used types of DC motors, both in the industrial and automotive fields. BLDC motor was chosen because it has many advantages over other types of electric motors. However, in its application in the market, most of the control systems used in BLDC motors still use conventional controls. This conventional method is easy and simple to apply, but has many weaknesses, one of it is that if the system state changes, then the parameters of the PID must also be changed, so that static and dynamic performance will decrease, causing slow response and frequent oscillations. In this study, the design and simulation of a speed control system for BLDC motors using the Fuzzy-PID method was carried out. The research method is performed through simulation with Matlab / Simulink. The simulation is carried out by providing a speed set point of 650 rpm and used two methods, namely Fuzzy-PID and PI. The test results show that the Fuzzy-PID control can provide better and more stable performance than the conventional PI control. The use of Fuzzy-PID control can reduce speed fluctuation and give torque stability. In the stator current and back EMF (Electromotive Force), Fuzzy-PID has more stable current and voltage than PID which make smaller losses. Furthermore, the proposed method, Fuzzy-PID has faster processing time compared to PID by 6.27%.**

Keywords—BLDC Motor, PID, Fuzzy-PID

I. Introduction

Brushless DC motors (BLDC) are among the most widely used DC motors, both in the industrial and automotive fields. BLDC motors are like and consequently called Permanent Magnet DC Synchronous motors [1]. This type of DC motor does not have a brush and commutator, so BLDC motors require less maintenance and can operate quieter than DC motors [2]. The initial cost of the motor may seem expensive but generally diminishes with time [3]. Due to the special characteristic, the BLDC motor is very common in various industrial and biomedical, and robotic applications which require high torque to weight ratio and precise position control for accuracy [4]. BLDC motor was chosen because it has the characteristics of high efficiency, reliability, wide speed range, large torque, and small power [5][2]. Therefore, it has great theoretical and practical significance to do a lot of research about the brushless DC Motor structure and its controller [6][7].

There are some different control schemes used for the BLDC motor speed control [8]. The control system on a BLDC motor is quite complicated by using several electronic components that are arranged to be able to switch between the three motor phases with precision [9]. There are two types of speed control systems, namely the Open-Loop system and the Closed-Loop system. An open Loop system is a control system whose output has no effect on controlling the action and there is no feedback [10]. On the other side, the BLDC motor control system on the market already uses a closed-loop control system that has a feedback mechanism.

In the market application, most control method in BLDC motors still use conventional controls such as PI (Proportional-Integral) and PID (Proportional-Integral-Derivative) [4] [11]. This conventional control method was chosen because of its simple structure and easy operation [9]. However, this control method still has many weaknesses, such as if the system state changes, the PID parameters must also be changed, so that the static and dynamic performance will decrease, causing slow response and frequent oscillations [12]. Several studies have been developed to produce a reliable and optimal BLDC motor control system. One of the control methods used is fuzzy logic control. This method was chosen because it has the reliability to solve complex and nonlinear problems, is flexible to various problems, and can be combined with other control methods to produce a more optimal system [5].

This research will design and simulate a speed control system for BLDC motors using the Fuzzy-PID method. This test is intended to determine the performance of using Artificial Intelligence, especially Fuzzy Logic in its application in electric motors. Fuzzy logic is used to generate PID parameters (*Kp*, *Ki*, and *Kd*) which are then forwarded to the PID to produce a more reliable and optimal control system. The test results are then compared using the conventional PI method in order to obtain which method is best used to control the BLDC motor speed.

II. Material and Method

A. BLDC Motor

The BLDC motor is a type of permanent magnet synchronous motor, which has a permanent magnet in the rotor and a trapezoidal back-electromotive force (EMF) [13]. BLDC motor has the characteristics of a DC machine by replacing the mechanical commutator and brush with a solid-state switch and there is no electrical connection between the stator and the rotor [14]. BLDC motor construction is shown in Fig. 1.

BLDC motors are widely used in various electronic components, especially in electric vehicles. This is because BLDC motors have various advantages over other motors, namely wide torque range, high speed, high efficiency, good dynamic response, strong, no-slip, and others [14]. The motor specification that used in this research is described in Table 1.

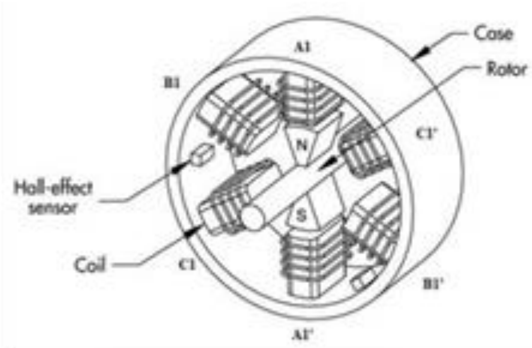

Fig. 1. BLDC Motor Construction [7]

TABLE I. BLDC MOTOR SPECIFICATION

Specification	Value
Voltage	48 V
Power	1 kW
Speed Max	700 RPM

The electrical part of the system is governed by equation (1) [15]:

$$V_{dc} = iR + L\frac{di}{dt} + E \quad (1)$$

where,

Vdc = voltage applied in DC
L = winding inductance
R = winding Resistance
E = back emf of the motor

The mechanical part of the motor is governed by torque equation as:

$$T_e = J\frac{d\omega}{dt} + B\omega + T_L \quad (2)$$

where,

Te = Electromagnetic torque in Nm
J = Moment of inertia
ω = Angular speed
B = Friction coefficient
T_L = Load torque

B. Various BLDC Control Scheme

Several studies have been conducted to combine the Fuzzy control system with other control systems for application in BLDC motor drives. Some of the studies that have been carried out are as resumed in Table 2.

TABLE II. VARIOUS FUZZY BASED CONTROL SCHEME

Ref	Year	Control	Methods
[16]	2017	Fuzzy Sliding Mode Controller	Constant of Sliding Mode Control law is varied by Fuzzy Logic Controller
[17]	2017	Particle Swarm Optimized Fuzzy Logic Controller	Torque control of BLDC motor based on PSO and Fuzzy Logic controller.
[18]	2017	Whole Fuzzy Controller	Fuzzy controller based on continuity intelligent weight function.
[19]	2016	Interval Type-2 Fuzzy Logic Controller	Type-2 Fuzzy allows to model the effects of uncertainty in the rule based fuzzy system.
[20]	2016	Hybrid Fuzzy Sliding Mode Controller	Fuzzy consolidated sliding mode controller with moving weight condition.
[21]	2016	Improved variable universe Fuzzy PID	PSO based scale factor parameters in offline optimization for reduced tuning time
[22]	2014	Compensated Fuzzy Neural Network controller	Hybrid System Combining Advantage of Compensation Logic and Neural Network
[23]	2013	PID Sliding Mode Fuzzy Controller	PID tuning by Sliding mode fuzzy for chattering elimination & improved response
[24]	2012	Hybrid PI controller	Fuzzy pre-compensator is used to modify controller to compensate output variation
[25]	2011	Extended Kalman Filter (EKF) - Fuzzy-Neural – Network Controller	EKF filters the noise in the error and delta error and prevents controller to process noise at cost of delayed response
[26]	2011	Sliding Mode Control and fuzzy control scheme.	Control efforts proportional to distance from sliding surface for chattering dismissal
[27]	2008	Parallel Fuzzy PID Controller	Three parallel Fuzzy sub-controller that update the value of PID gains online
[28]	2005	Emotional learning based Neuro-Fuzzy Controller	Supervisory learning algorithm (as Critic) controls the network behavior
[29]	2004	Genetic Algorithm (GA) based Fuzzy Controller	GA based optimization and Online tuning of fuzzy parameters for robust performance.
[30]	2001	Adaptive Neuro - Fuzzy Inference System (ANFIS)	Neuro structured learning algorithm find appropriate fuzzy logic rule, then parameter learning algorithm to fine tune membership function and other parameters

Some of research in the Table 2 above, have prove that Fuzzy Logic Controller (FLC) can work as well with the other control methods. The combination of FLC with the other methods give some benefit such as increasing the efficiency, effectivity, performances and accuration of the test result. However, the combination cannot applicated in all of plant, so the combination should be adjusted with the plant used.

C. *Fuzzy Logic Controller*

Fuzzy Logic is a branch of Artificial Intelligence (AI) that has been used since 1965 until now. Fuzzy is still chosen because of its reliability to solve complex and nonlinear problems, its flexibility to various problems and can be combined with other control methods to produce a more optimal system [5]. Fuzzy logic uses basic rules to produce fuzzy output, namely the IF-THEN rule, where IF is an antecedent and THEN is a consequence [31]. In the fuzzy method, there are 4 main components, namely [5]:

- *Fuzzifier*: Fuzzifier is used to map the value / price of variables in the real world into fuzzy sets.
- *Knowledge base*: The knowledge base contains control system knowledge as a guide for evaluating the state of the system to obtain control output as desired by the designer.
- *Fuzzy inference engine*: Fuzzy inference engine translates fuzzy statements in the rule base into mathematical calculations (fuzzy combinational).
- *De-Fuzzification*: Defuzzification can be defined as the process of changing Fuzzy quantities which are presented in the form of output Fuzzy sets with a membership function to regain their crisp form.

The block diagram of the Fuzzy control system can be observed in Fig. 2.

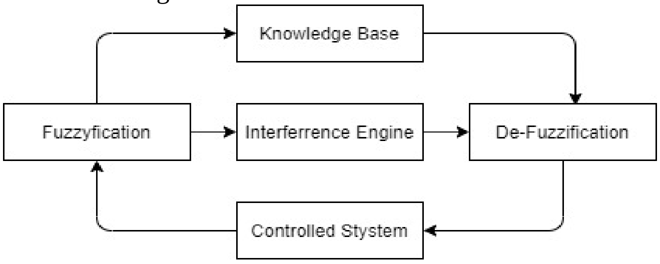

Fig. 2. Block diagram of fuzzy logic controller [5]

D. *Fuzzy-PID Block Diagram*

The block diagram of the Fuzzy-PID control can be seen in Fig. 3. In this structure, 3 Fuzzy Logic Control blocks are used, each of them has the same input, namely error and delta-error. Meanwhile, the output of each fuzzy block is *Kp*, *Ki* and *Kd*. This output is then processed using the PID control to adjust the output voltage from the power source that supplies the BLDC motor.

Since there is five fuzzy membership for each input; therefore, the fuzzy rules used are 25 rules. These rules can be seen in Table 3. Where DB: Decrease Big; DS: Decrease Small; NC: No Change; IS: Increase Small and IB: Increase Big. While the set of membership functions of the input variables (error and delta error) can be observed in Fig. 4 and Fig. 5.

TABLE I. BLDC MOTOR SPECIFICATION

e\de	**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

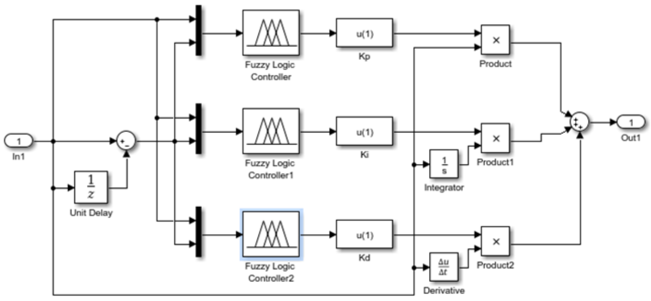

Fig. 3. Block diagram of Fuzzy-PID

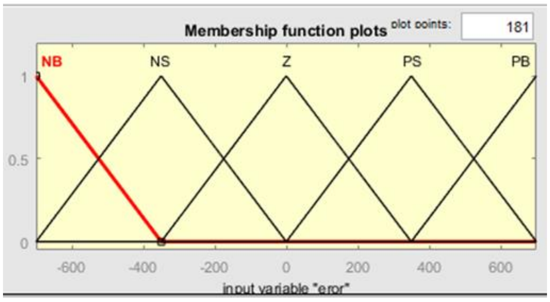

Fig. 4. Membership Fungtion of error input

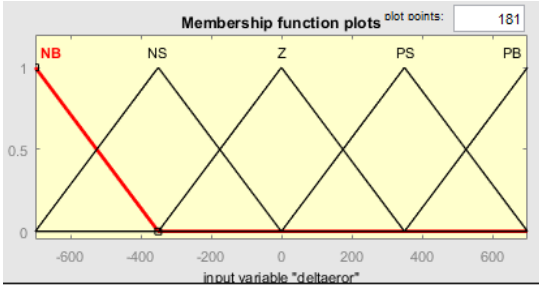

Fig. 5. Membership Fungtion of delta-error input

The Fuzzy block diagram for output of *Kp*, *Ki* and *Kd* are shown in Fig.6, Fig.8 and Fig. 10, respectively. Whereas, Fig.7, Fig.9 and Fig. 11 shows the Membership function of output *Kp*, *Ki* and *Kd* respectively.

- FLC for Kp

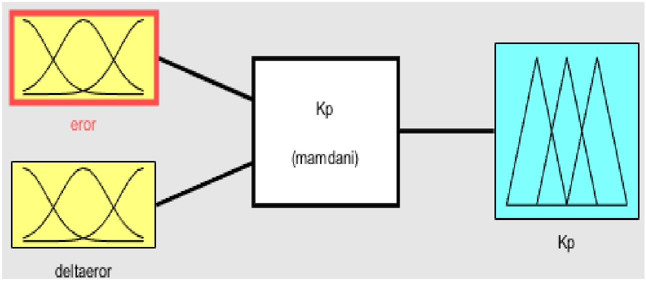

Fig. 6. Block fuzzy for Kp output

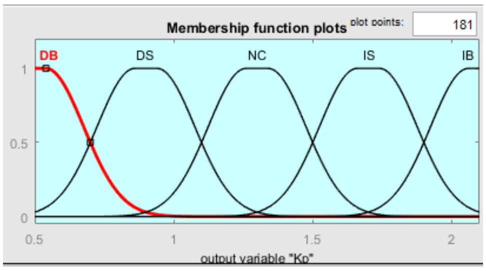

Fig. 7. Membership function of Kp output

- FLC for Ki

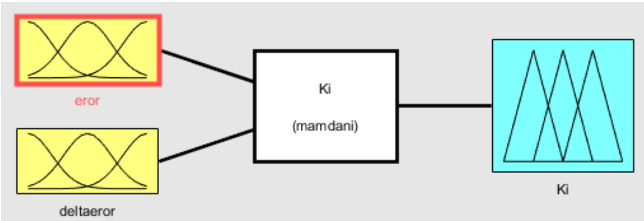

Fig. 8. Block fuzzy for Ki output

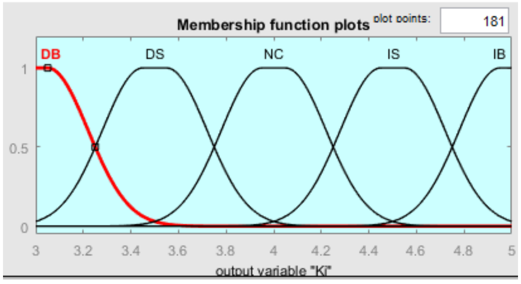

Fig. 9. Membership function of Ki output

- FLC untuk Kd

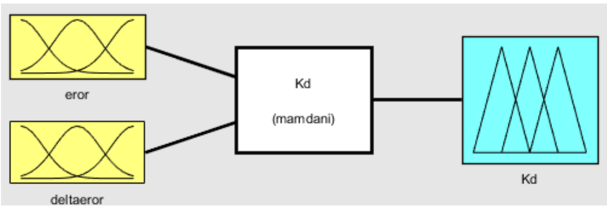

Fig. 10. Block fuzzy for Kd output

III. RESULT AND DISCUSSION

The simulation is carried out by providing a speed set point at 650 rpm. The simulation was carried out by comparing two methods, namely Fuzzy-PID and the conventional PI method. The plant of this circuit is a brushless DC motor (BLDC) 48V 1kW with a maximum speed of 700 rpm. Fig. 12 shows the simulation block of the proposed Fuzzy-PID control method in MATLAB Simulink.

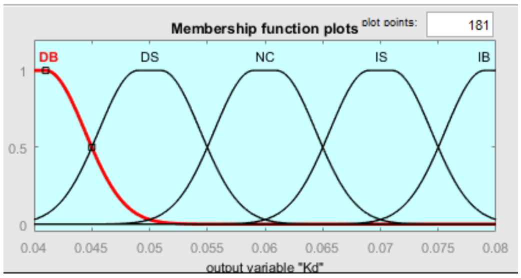

Fig. 11. Membership function of Kd output

Based on Fig. 13, it can be observed that the Fuzzy-PID control is able to provide a good response to reach the desired set point. By using the Fuzzy-PID method, steady-state speeds can be achieved at 0.3 seconds without significant overshoot and fluctuation. On the other side, the conventional PI method can reach a steady-state point at 0.2 seconds but with very high fluctuations and experiencing overshoot up to 180 rpm.

In the electromagnetic torque, Fig. 14 shows that the Fuzzy-PID method produces a stable torque graph, where the torque decreases with the increasing speed of the motor. The torque reaches a constant point at 5 Nm when the motor reaches a steady-state speed. While the PI method provides an unstable graph of torque with high enough fluctuation and overshoots up to 35 Nm before the steady-state speed is reached.

Fig. 15 shows that the current and back voltage resulted from Fuzzy-PID is quite stable during the motor operation. In contrast, when using the PI method, there are fluctuations in the current and reverse voltage EMF on the stator. This resulted in system instability and resulted in a lot of losses.

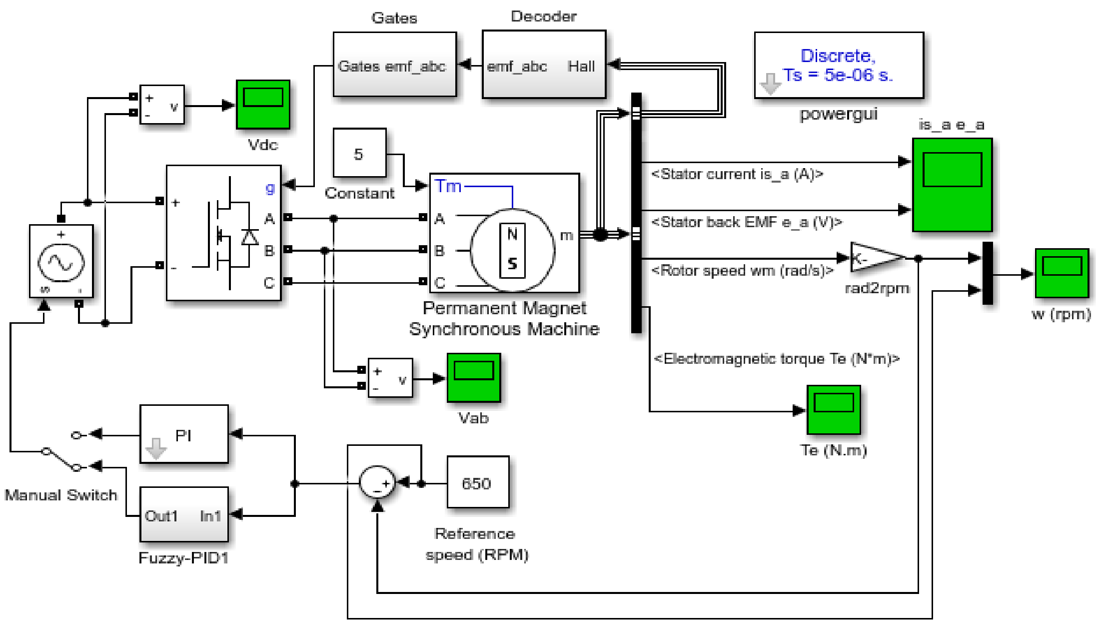

Fig. 12. Fuzzy-PID BLDC Control in MATLAB Simulink

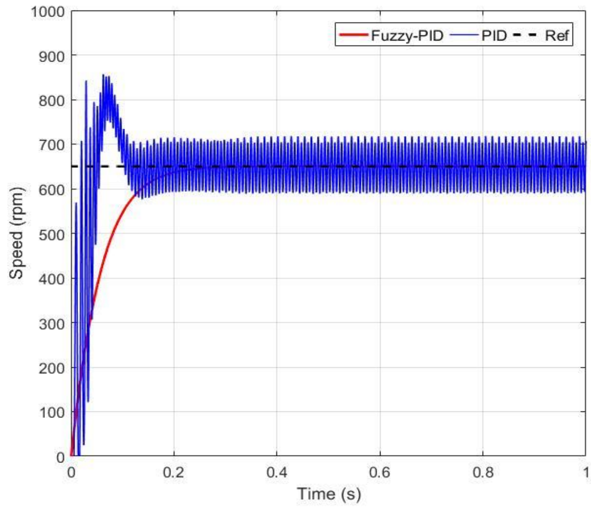

Fig. 13. Speed profile

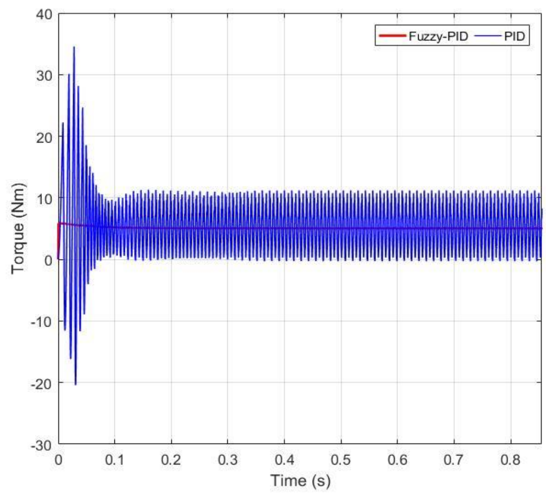

Fig. 14. Electromagnetic torque

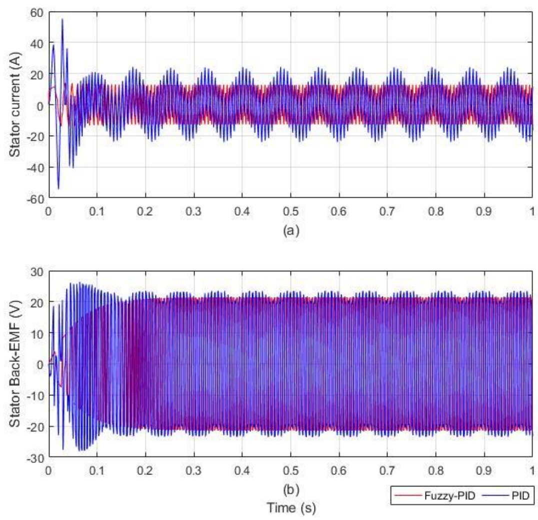

Fig. 15. Stator Current & Back EMF

The simulation time for each method is resumed in Table IV. It clearly shown that Fuzzy-PID has faster processing time compared to PID by 6.27%. Therefore, the overall result show that Fuzzy-PID is better than PID.

TABLE II. BLDC MOTOR SPECIFICATION

Method	Simulation Time (s)
Fuzzy-PID	29.58
PID	31.56

IV. CONCLUSIONS

The design and simulation of the Fuzzy-PID control system on BLDC speed control have been successfully carried out. Based on the simulation, the Fuzzy-PID control can provide better and more stable speed performance than using the conventional PI control. The use of Fuzzy-PID control can reduce speed fluctuation and give better torque stability so that the BLDC motor can operate more reliably. In the stator current and back EMF, Fuzzy-PID has more stable current and voltage than PID which make smaller losses. Furthermore, the proposed method, Fuzzy-PID has faster processing time compared to PID by 6.27%.

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