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Research Paper

Identification and Optimization Speed Control of BLDC Motor Using Fuzzy Logic Controller

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Abstract

Better performance, such as speed of response, overshoot and steady state error on BLDC motors, needs to be improved continuously through optimization. The first method, is to design the hardware, take the current data, voltage and motor speed through measurement. The data obtained is simulated through the existing tools in Matlab to obtain the mathematical model in the form of transfer function. BLDC motor transfer function obtained, used as the basis for optimizing the fuzzy logic method. The results showed that the stability performance in BLDC motor speed control system showed an improvement after optimization using fuzzy logic.

Keywords: *Instrumentation, fuzzy logic, transfer function, BLDC Motor*

1. Introduction

Brushless Direct Current (BLDC) motors have been widely used in various industrial applications, including transportation, home appliance and office automation, and home industries[1][2]. One form of BLDC motor applications that are used in transportation is as an electric bicycle drive. BLDC motor is widely used because it has many advantages and little loss. The advantages of BLDC motor include high efficiency, easy maintenance and precision control. However, BLDC motors also have the disadvantages of higher cost and heavier weight when compared to Direct Current (DC) motors at same great power[3].

To improve the better performance of the BLDC motor, optimization is required. The optimization process can be done by performing mathematical modeling in the form of transfer function and simulate it. By analyzing the parameters of motor rotation speed, and electric current, we will get the best control strategy to improve system performance[4].

Motor rotation speed parameter, and electric current signal is obtained by designing a BLDC motor drive system connected with arduino microcontroller. The generation of pulse width modulation (pwm) signals from the microcontroller results in changes in voltage and current values. The change of value will cause the change of switching speed of the mosfet transistor which affect the rotation speed of the BLDC motor[5].

BLDC motor used in this study is a motor for electric bicycle drive with 350 Watt power, which is connected with the current and speed sensor. Results of instrumentation on the BLDC motor, then simulated with tools contained in the application program Matlab to obtain mathematical modeling in the form of transfer function.

2. Theoretical Background

A. BLDC Motor

One of the BLDC motor applications in the world of transportation industry is as an electric bicycle drive. BLDC motors include a permanent type of magnet synchronous motor which means the magnetic field is generated by the stator and by the rotating rotor at the same frequency. BLDC motor configurations have 1 phase, 2 phase and 3 phase. In accordance with its type, the stator has the same number of turns and for the 3-phase type motor is the most widely used type of motor. There are two types of stator winding variant, which is trapezoidal and sinusoidal electric motor. This distinction is made on the basis of the interconnection of the coil within the stator winding to provide various types of back emf[6].

The BLDC motor model equation consists of a voltage equation, a torque equation and a motion equation. The stator on a BLDC motor generally has three windings as it does on an induction motor or a permanent magnet synchronous motor. The circuit diagram for stator windings is shown in Fig.1.

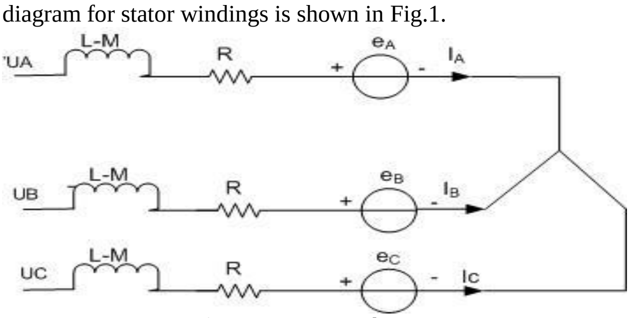

Fig.1: Stator circuit diagram

The voltage equation at different terminals is shown in the following equation [2]:

$$U_A = RI_A + (L - M)\frac{di_A}{dt} + e_A$$
$$U_B = RI_B + (L - M)\frac{di_B}{dt} + e_b$$
$$U_c = RI_c + (L - M)\frac{di_C}{dt} + e_c$$

With Laplace transform the BLDC motor transfer function can be written as follows:

$$G_U(s) = \frac{\Omega(s)}{U_d(s)} = \frac{K_T}{L_aJs^2 + (r_aJ + L_aB_v)s + (r_aB_v + K_eK_t)}$$

B. Instrumentation Parameters

Difficulty in knowing the parameters of BLDC motors used as electric bike drivers, such as resistance value, inductance, electronic torque, and mechanical torque, cause mathematical modelling in the form of transfer function not achieved. Therefore, the stage is done to identify a system through measurement. System identification is a process done to get a mathematical model of a system based on data input and output parameters[7]. There are three modeling approaches used to identify a system, ie white box model, gray box model and black box model based on measurement data. Procedures are performed to identify a dynamic system model, as shown in Fig.2. [8].

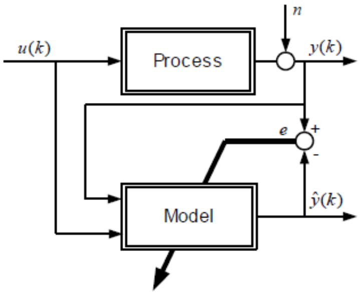

Fig.2: System Identification

The system identification in a model describes the measured relationship between the input signal and the output signal[9]. System identification toolbox (SIT), an application contained in the Matlab program used to model a system mathematically, based on input and output data collection[10].

3. Design Instrumentation And Simulation

A. Instrumentation Design

The block diagram used to perform the measurement of the current signal and motor rotation speed as shown in Fig. 3.

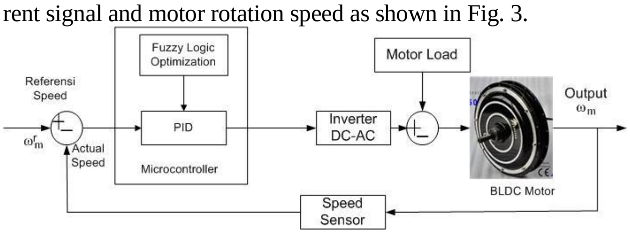

Fig.3: Block Diagram Design Instrumentation

System in Figure 3, can be explained that data retrieval can be done after all hardware is connected properly. The first stage of data retrieval for signal current, voltage, and motor speed. After the data collected the analysis is done by simulating the data into the application program Matlab, namely System Identification Toolbox (SIT).

B. Design Optimization with Fuzzy Logic

Optimization is done with the aim of improving system performance such as speed of response time, overshoot, and steady-state error. In Fig.6 it can be explained that for a BLDC motor the plant will be optimized with a Proportional Integral Derivative (PID) controller. The results will be compared if optimized by using fuzzy logic.

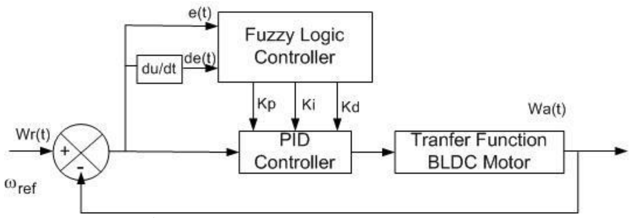

Fig.4: Design Optimization BLDC Motor

Therefore the method used is to obtain mathematical model of BLDC motor transfer function to be optimized with fuzzy logic.

4. Results and Discussion

A. Instrumentation Design

The hardware design results to obtain the measurement data of voltage, current, motor load and motor rotation speed are shown in Fig. 5.

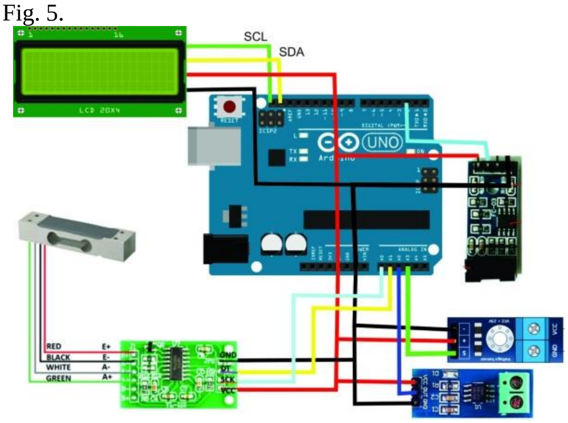

Fig.5: Design Results hardware design

Sensors used in measurement data collection include current sensors, voltage, load and motor rotation speed. The sensor serves to take input and output data. The input data used in this study include current, voltage, and load. While data output taken data in the form of rotational speed of motor. The hardware design results are shown in Fig. 6

.

Fig.6: Hardware Design Results

After that done taking input and output data from hardware design result, and the result is as follows:

Table.1: BLDC Motor Identification and Results

PWM	I1(A)	I2 (A)	I3 (A)	V1 (V)	V2 (V)	V3 (V)	RPM
177	0,12	0,07	0,91	0	10	45	0
179	0,78	0,28	0,59	45	0	15	346
181	0,3	0,25	0,3	0	0	0	273
183	0,07	0,81	0,81	20	0	45	273
185	0,96	0,01	1,12	30	10	0	280
187	0,04	0,15	1,44	30	20	0	283
189	0,59	1,02	0,59	20	45	0	290
191	0,01	0,22	0,3	0	45	20	296

193	0,3	0,7	0,54	0	45	15	310
195	0,62	0,25	0,7	0	45	25	316
197	0,2	0,28	1,02	30	0	0	323
199	0,2	0,01	1,18	15	0	0	330
201	0,25	0,49	0,41	10	45	0	330
203	0,07	0,52	1,49	45	30	0	343
205	0,38	0,07	0,07	0	10	25	343
207	0,2	0,28	0,2	0	0	0	353
209	0,46	0,65	1,31	15	45	0	356
211	1,2	0,28	1,04	45	0	0	366
213	0,99	0,41	0,49	0	40	40	370
215	0,01	0,09	0,96	35	35	0	373

In Table 1.Shows the measurement results for BLDC motor speed control. From these data indicate the instability of the motor rotation speed value, which adjusts the magnitude of voltage and current values.

Furthermore, the measurement data for input and output were analyzed using toolbox identification software to obtain the mathematical model in the form of transfer function of the BLDC motor plant. The transfer function is a system defined as the ratio between output and input. In Fig.7, shows the stages of data processing input and output of BLDC motor to obtain the transfer function.

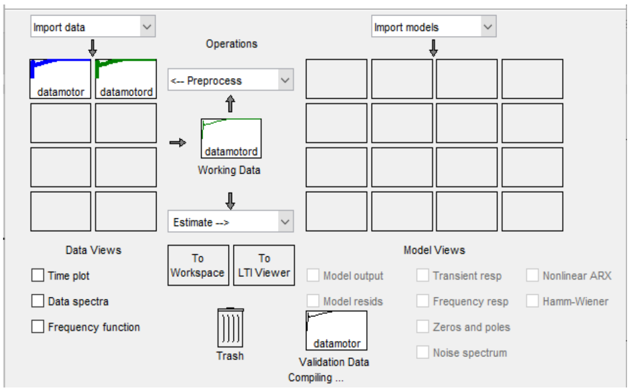

Fig.7: System Identification Toolbox Process

After the process of processing and analysis then obtained mathematical modeling in the form of transfer function, as shown in Fig.8.'

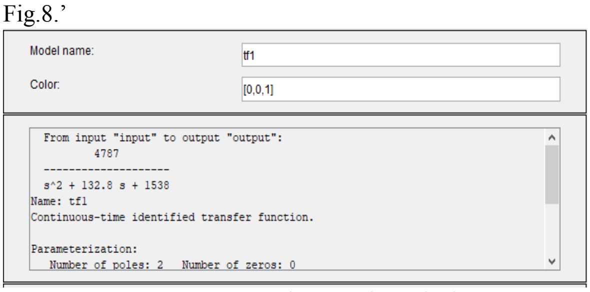

Fig.8: Results identification of transfer function

Fig.8 shows the mathematical modeling in the transfer function for the BLDC motor plant, which is:

$$G(s) = \frac{4787}{s^2 + 132.8\,S + 1538}$$

The acquired transfer function is used as a basis for optimization with PID controller, and fuzzy logic controller. In Figure 9, shows

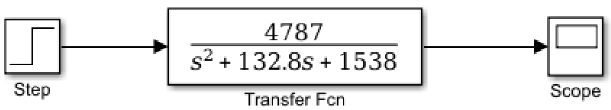

Fig.9: Block Diagram of Open Loop System

After being simulated with step-unit input, with simulation time of 10 s, the result shown is shown in Fig. 10.

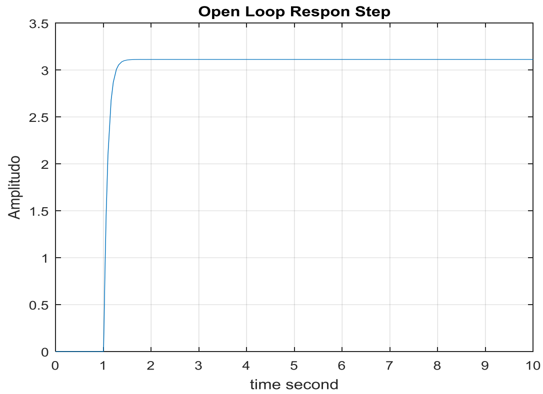

Fig.10: Unit Step Response

From the plot above, it can be explained that the system response when in the first second, the position of the moving motor changes the input signal until the response enters the steady state.

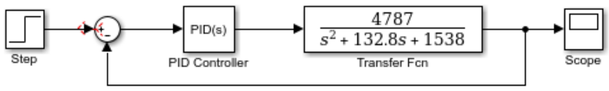

Fig.11: Block Diagram of PID Controller System

Once simulated with close loop system optimized by conventional method that is using PID controller. The result is shown in Fig. 12.

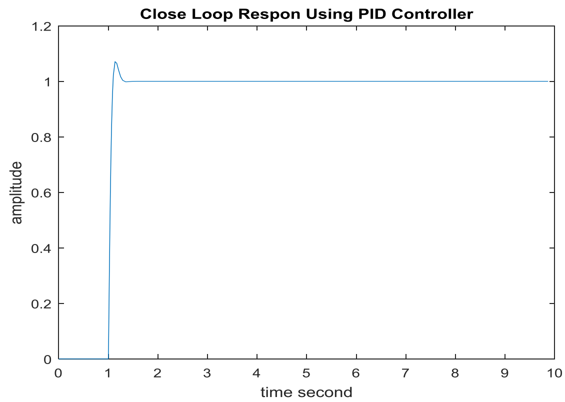

Fig.12: Close Loop Response Using PID Controller

In Fig. 12, the system uses a PID controller, with setting values for Kp = 0,51429, Ki = 10,7136 and Kd = 0.0019418. The result shows the instability of the 1st-second, and then the system is stable.

B. Optimization Using Fuzzy Logic Controller

The performance of the controller depends on the value of Proportional, Integral, and Derivative parameters (P, I and D). In order to parameterize the PID it requires experimentation and high knowledge (expert knowledge). There are several steps that need to be considered to get a fuzzy output, such as fuzzification, determining membership functions, rule evaluation, and defuzzification. Fuzzification process conducted with the aim to change the input variables that are not fuzzy crisps to the fuzzy set where in this process crisps which are variable; error and delta error converted into fuzzy variables using techniques membership functions (MF). The membership function consists of five sets which are NB: Negative Big, NS: Negative Small, ZE: Zero, PS: Positive Small and PB: Positive Big.

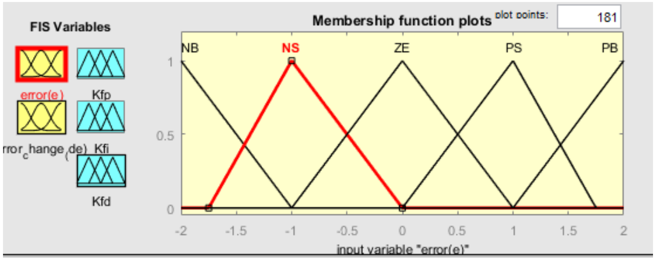

Fig.13: Input variables of fuzzy logic error

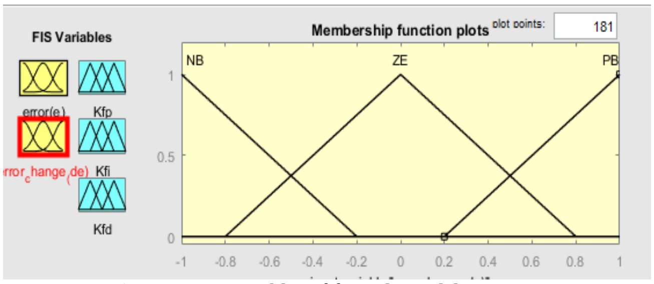

Fig.14: Input variables of fuzzy logic delta error

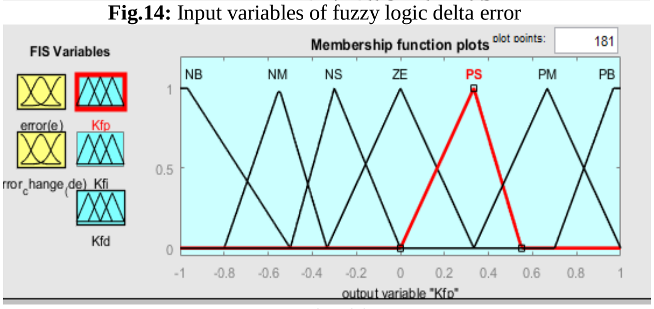

Fig.15: Output variables Kfp of fuzzy logic delta error

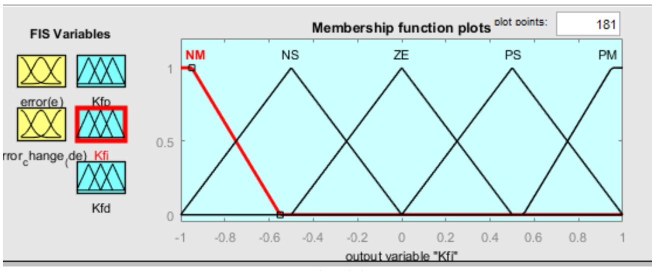

Fig.16: Output variables Kfi of fuzzy logic delta error

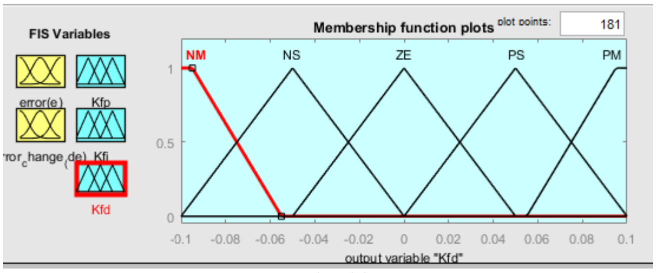

Fig.17: Output variables Kfd of fuzzy logic delta error

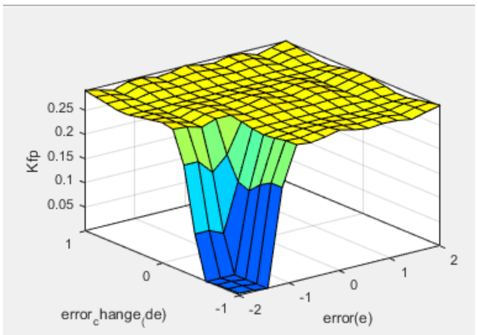

Fig.18: Surface view of Kfp fuzzy controller

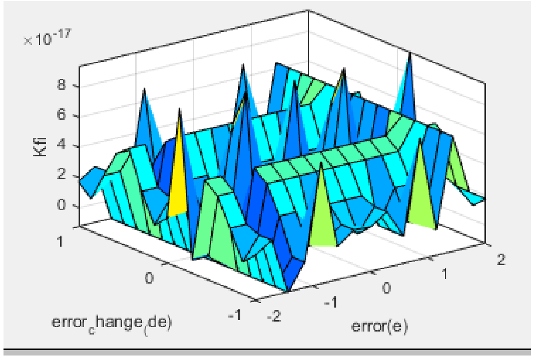

Fig.19: Surface view of Kfi fuzzy controller

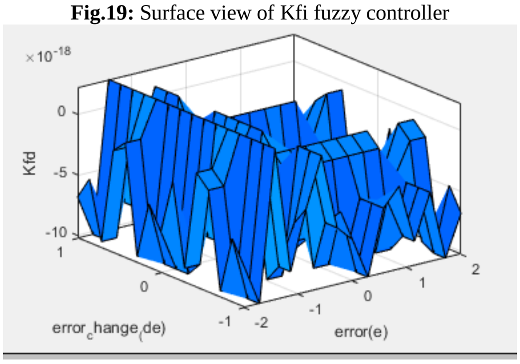

Fig.20: Surface view of Kfd fuzzy controller

Fig.18-20, shows the surface generation of the rule of membership fuzzy logic controller, which is a combination of two inputs and three outputs. Then the result of the rule membership function is simulated in fuzzy logic controller optimization design as shown in Fig. 21.

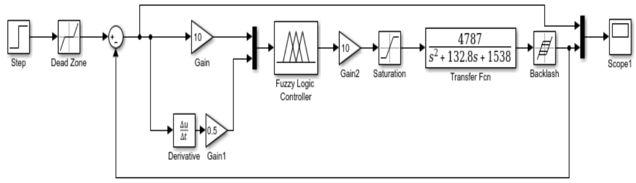

Fig.21: Design of PID Optimization by Fuzzy Logic

The simulation results of the design optimization fuzzy logic controller, shown in Fig.22.

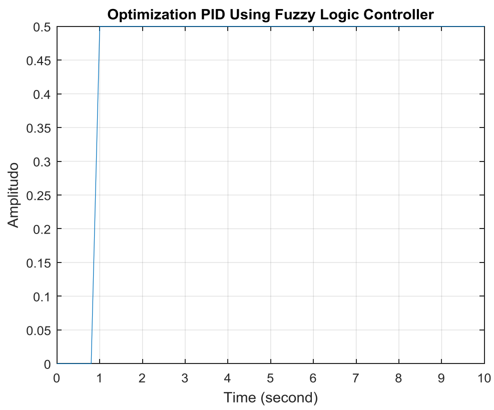

Fig.23: Optimization of PID Controller Using Fuzzy Logic

Fig. 23, also shows the optimization process of PID controller by using fuzzy logic controller. The process of fuzzy logic controller in BLDC motor speed control system can improve stability, reduce overshoot, and faster reach steady state.

5. Conclusion

The process of controlling the speed control of the BLDC motor for the type of electric bike begins with the identification system to know the mathematical modeling in the form of transfer function. The transfer function obtained was used as the basis for optimizing by using PID controller. Fuzzy logic controller to get the system performance then optimizes the PID controller. The results show that the transfer function has been found to increase stability, reduce overshoot, and increase steady state achievement.

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