Self-Tuning Fuzzy PID Design for BLDC Speed Control

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Abstract

Brushless DC motor is an electrical motor has high efficiency and torque, long life, cheap maintenance, but it is a nonlinear so complicated in controlling its speed. The popular control system used is PID control. Many ways of determining PID parameters, but because of BLDC motors have non-linear properties so need the intelligent control techniques in setting up PID parameters. In this paper, a self-tuning fuzzy PID control system embedded in ATMega 16 microcontroller to control the speed of BLDC motor adaptively. The results of self-tuning controller PID with fuzzy logic for fixed speed reference at variation speed 1000-2500 RPM has a good transient response parameter value. On the reference up and down the controller is able to adjust the speed change adaptively. The test of momentary disturbance shows the speed is decreasing about 1 second and can back to set point quickly.
Keywords- BLDC, Speed, Fuzzy, PID, Atmega 16

I. INTRODUCTION

Motor in the manufacturing industry becomes an important part for running the production process. Based on that also, various types of motor has also been developed to fulfill it. DC motor is playing important role nowadays [1]. There are mainly two types of DC motor used in the industry. The first one is the conventional DC motor and the second type is the brushless DC motor (BLDC). A BLDC motor is a type of permanent magnet synchronous motor[2], they do not use brushes for commutation[3]. The stator of BLDC motor is the coil and the rotor is the permanent magnet[4]. BLDC motors have many advantages such as long operating life, smaller volume, high eficiency, higher speed range, high torque, simple system structure[4]. In practice, the design of the BLDCM drive involves a complex process such as modeling, control scheme selection, simulation and parameters tuning[3]. Normally, Proportional Integral derivative controller is an optimum choice for controlling the speed of the BLDC motor. However, it has uncertainty problem due to load as well as in set speed variation[5]. This problem can be alleviated by implementing advanced control techniques such as adaptive control, variable structure control, fuzzy control, and neural network[6]. In this paper proposed Self Tuning Fuzzy PID controller where parameters of PID controller are tuned using fuzzy logic. Fuzzy logic utilizes error and error rate as input of fuzzy system and use Sugeno method in decision making process. The fuzzy output is the value of Kp, Ki and Kd which then this value goes into the calculation of PID algorithm. The are three set fuzzy rule for tuning Kp, Ki, and Kd. The controller can be adapt to any change of parameter by using this set of rules. System response analysis is done through observation of transient response parameters such as rise time (tr), peak time (tp), settling time (ts), overshoot or undershoot (Mp)[7].

II. METHODOLOGY

A. Block Diagram Hardware Design

The main components of the hardware consist of ATMega 16 microcontroller, Electronic Speed Controller (ESC), rotary encoder sensor, low pass filter, and personal computer. All components are assembled like block diagram in Fig.1.

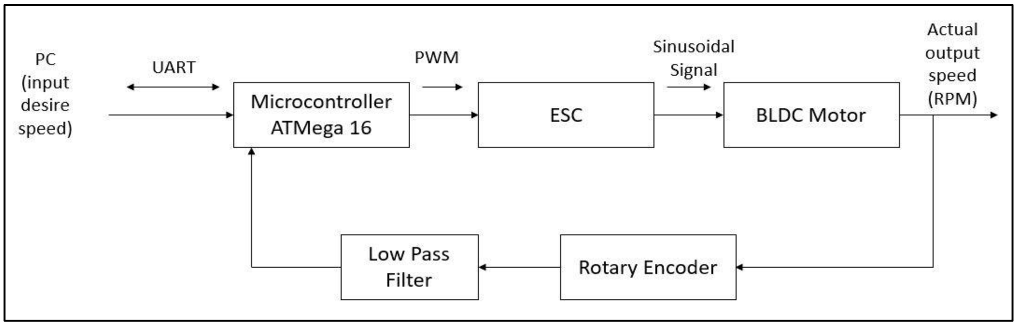

Fig. 1: block diagram hardware design

Data speed in units of rotation per minute (RPM) enter via PC, then PC sends the input to the microcontroller ATMega 16. ATMega 16 process the input data to determine the output signal in the form of a control signal (PID) to further determine the magnitude of PWM in the ESC. ESC will convert PWM into three phase sinusoidal wave which then rotate BLDC motor. Microcontroller ATMega16 also functions to process data from rotary encoder sensor that produces pulses when the motor rotates within a certain time. The result of sensor data processing is then fed into the BLDC control system. At read speed the rotary motor of BLDC requires additional low pass filter to read sensor data for noise removal due to the location of the sensor adjacent to the motor. The ATMega16 microcontroller port allocation is shown in Figure 2.

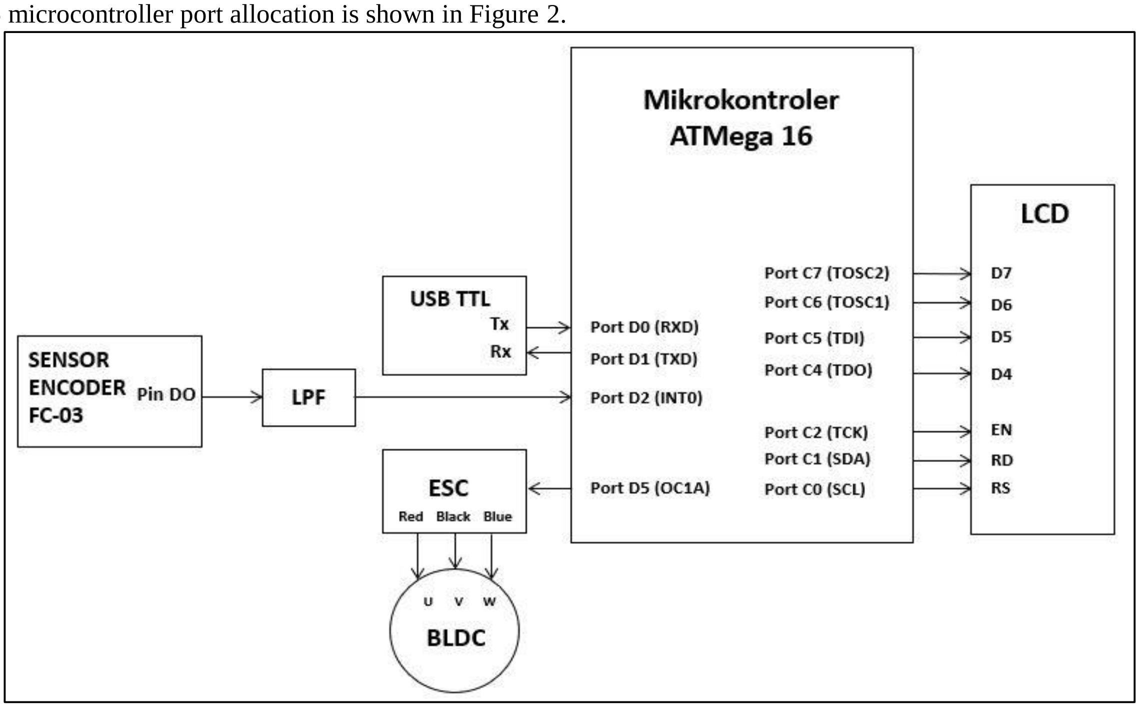

Fig. 2: microcontroller port allocation

Digital Output (DO) of encoder sensor enter to LPF and then conected by port D2 of microcontroler. The D2 port is used as input of the sensor, this port has external interrupt input as communication path for sensor data. Port D5 on the microcontroller or also is called as port of output signal control (OCR1A), OCR1A will go to ESC so that port ESC data cable is connected with port D5. Port C is used as an output port for LCD display, I / O ports on port C are connected to the 16 x 2 LCD. The function of LCD is display data such as reference speed, actual speed, error and PWM pulse. Port D0 and D1 are used as communication path between computer (interface) with microcontroller. The D0 port foot is connected to the Rx pin on the USB to TTL and the D1 port is connected to the Tx pin on the USB to TTL.

B. Controller Design

A fuzzy logic is responsible for tuning parameters Kp, Ki, and Kd. Fuzzy inputs are variable error (real velocity-set point) and rate of error change (previous error-error before)[8]. Fuzzy logic consists of three important processes including fuzzification which serves to convert numeric input values into linguistic values in membership terms, inference mechanisms based on predetermined rule base, and deffuzification to recover numerical values[9]. Rule base is designed based on BLDC motor characteristics. The value of the PID parameters generated by the fuzzy logic then goes into the calculation of the PID algorithm to generate the magnitude of the control signal. The control signal which is the output of the PID controller is then used to play the BLDC motor. The real speed difference of the motor read by the sensor with the desired speed of error, as well as the first derivative of the delta error is used as input for fuzzy logic, and so continuously until the motor reaches the desired set point value and rotates stably. Block diagram of contol system shown by Fig. 3.

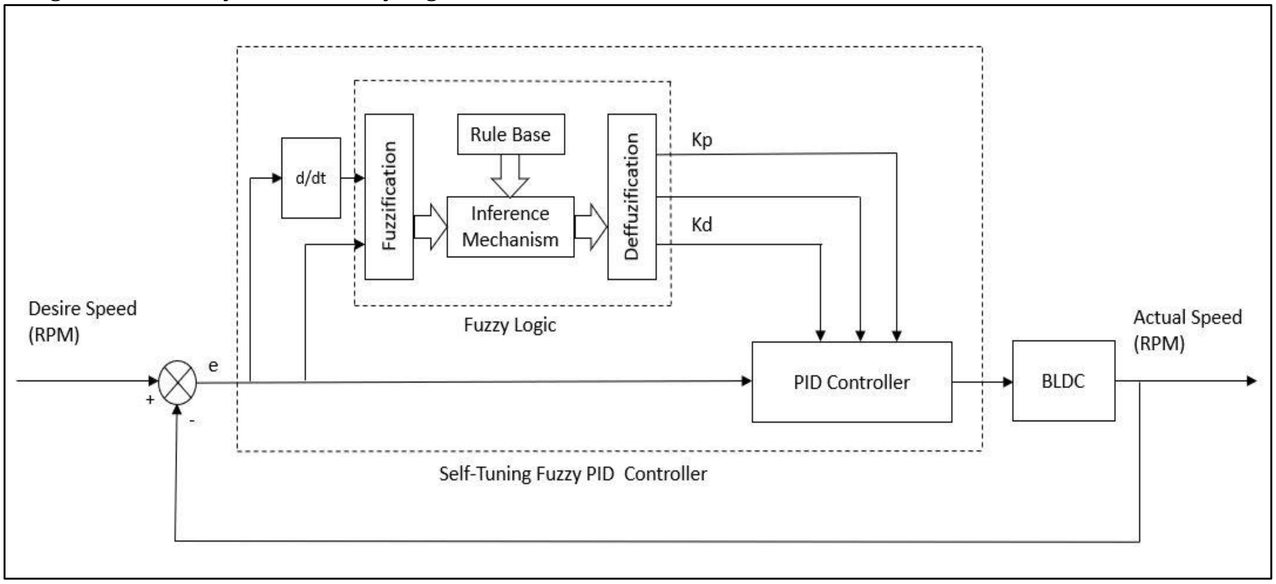

Fig. 3: block diagram control design

The membership function input of fuzzy logic is the set of error and delta error as in Fig. 4 and Fig. 5, they are divided into 5 labels, namely negative big (NB), negative medium (NM), small (S), positive medium (PM) and positive big (PB).

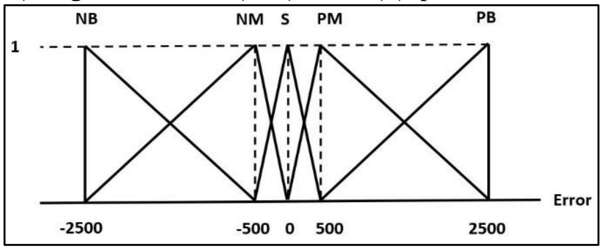

Fig. 4: membership function for error

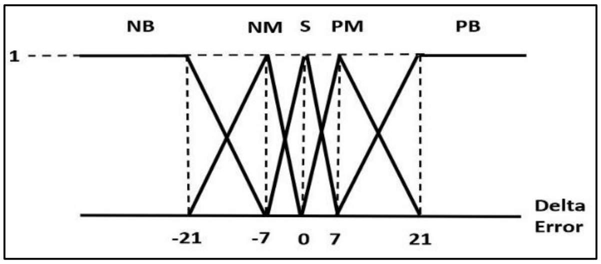

Fig. 5: membership function for delta error

The output membership function of the fuzzy logic as well as created are each of the five labels for Kp, Ki and Kd as shown Fig. 6, Fig. 7, and Fig. 8.

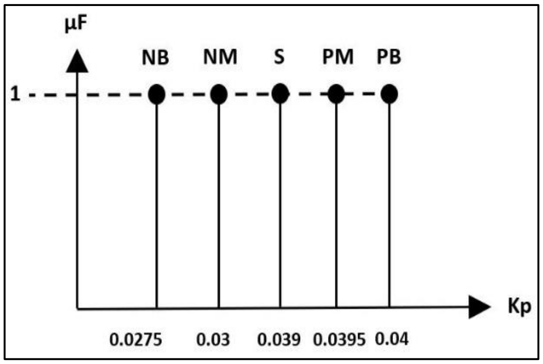

Fig. 6: membership function for Kp

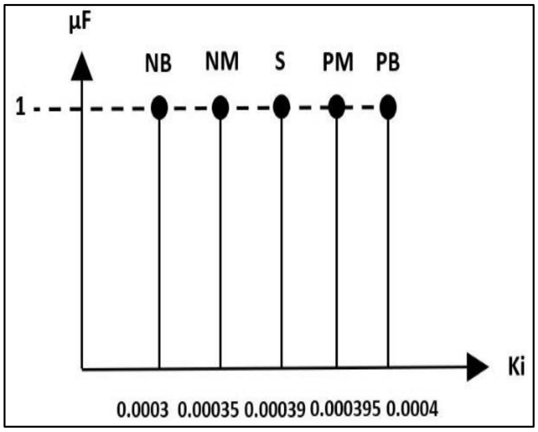

Fig. 7: membership function for Ki

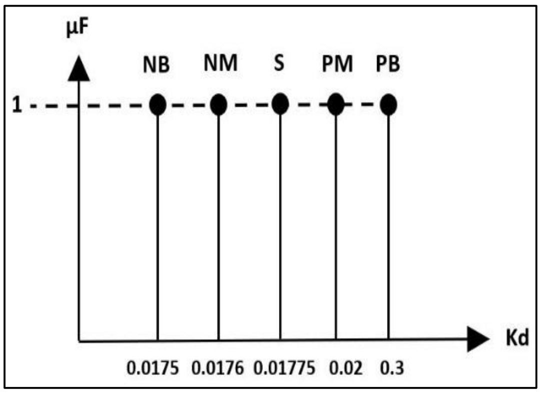

Fig. 8: membership function for Kd

The rule base is based on BLDC motor characteristics, will be used as a reference by fuzzy logic to make a decision. The rule base is divided into 3, the rule base for Kp, Ki, and Kd values as shown by Table I, Table II, and Table III while the inference system used is the minimum inference system. The mixed from membership function of fuzzy input and output results in 25 rule base combinations, but only 16 possible combinations are used in the plant.

Table 1: Rule Base of Kp

e\de	*NB*	*NM*	*S*	*PM*	*PB*
NB	-	*NB*	*NM*	*PM*	-
NM	-	*NB*	*S*	*PM*	-
S	-	*NM*	*S*	*PM*	*PB*
PM	-	*NM*	*S*	*PM*	-
PB	-	*NM*	*PM*	*PM*	-

Table 1: Rule Base of Ki

e\de	*NB*	*NM*	*S*	*PM*	*PB*
NB	-	*NB*	*NM*	*PM*	-
NM	-	*NB*	*S*	*PM*	-
S	-	*NM*	*S*	*PM*	*PB*
PM	-	*NM*	*S*	*PM*	-
PB	-	*NM*	*PM*	*PM*	-

Table 1: Rule Base of Kd

e\de	*NB*	*NM*	*S*	*PM*	*PB*
NB	-	*PB*	*PM*	*NM*	-
NM	-	*PB*	*S*	*NM*	-
S	-	*PM*	*S*	*NM*	*NB*
PM	-	*PM*	*S*	*NM*	-
PB	-	*PM*	*NM*	*NM*	-

III. RESULT AND DISCUSSION

The self-tuning fuzzy PID controller test is performed by providing fixed reference, the reference changes up, the reference changes down, and test to a momentary disturbance.

A. Fixed Reference

Variation reference speed used 2300 RPM. System response of the self-tuning fuzzy PID controller on fixed reference is shown in Fig 9. Self tuning fuzzy PID controller is expected to make BLDC motor rotates at referenced speed stably with steady state errors below 5% and has tr and ts are small or can also be said the system has a fast response. System response of PID controller for fixed reference speeds of 2300 RPM was obtained as shown in Fig. 10, use fixed best PID parameter with trial method, Kp = 0.04, Ki = 0.0004 and Kd = 0.0175. The results of PD controller experiment were used as a comparison of the performance of the self tuning regulator PD controller.

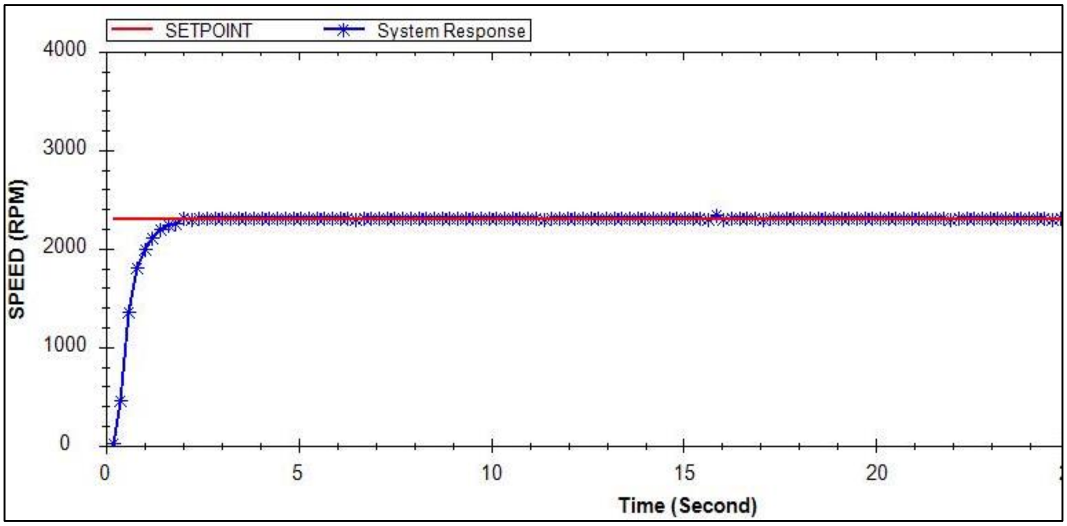

Fig. 9: system response for 2300 RPM use self-tuning fuzzy PID controller

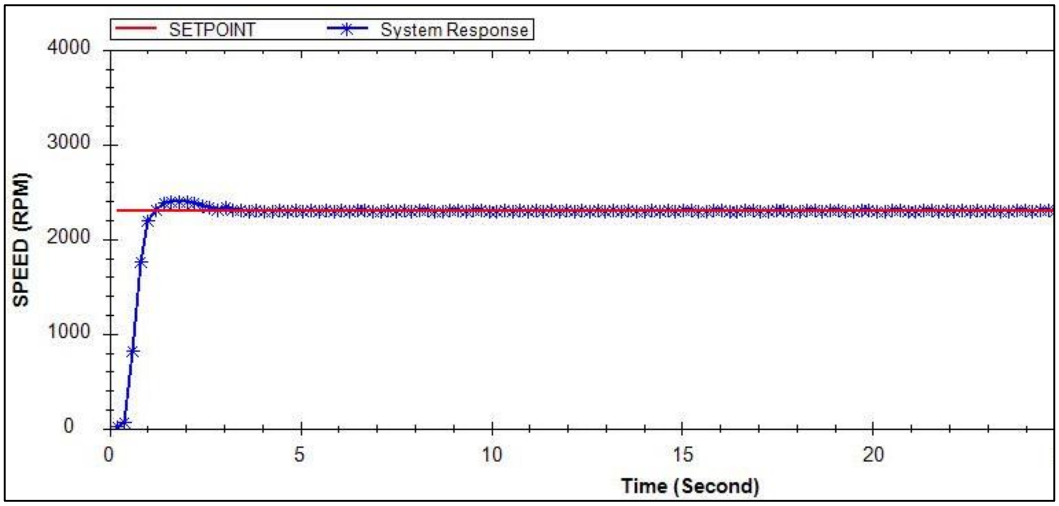

Fig. 10: system response for 2300 RPM use PID controller

The Self-tuning fuzzy PID at 2300 RPM has the system response tr = 1.828 s, tp = 2.234 s, ts = 3.453 s, Mp = 3.42 %, ess = 0.93 %, the self-tuning fuzzy PID controller is capable of rotating the BLDC motor at fixed reference quickly and stable because it has a small rise time and steady state error for the three test variations that is below 5%. Whereas in the PID controller, the plant has a transient response of tr = 1.625 s, tp = 2.234 s, ts = 4.671 s, Mp = 4.34 %, and steady state error 0.6 %. The graph of PID controller show that system has a rise time and error steady state value smaller than respon of self-tuning fuzzy PID controler, but self-tuning fuzzy PID reach a steady state condition quickly and overshoot value smaller than PID controler. This prove that the self-tuning fuzzy controler has better performance than PD controler for rotate the BLDC at 2300 RPM where motor starting rotate from 0 RPM until this referenced speed.

B. The Reference Changes up

This test is performed to determine the ability of the system in following the reference changes up. The reference speed is increased by 1500 RPM at 10 seconds from 1000 RPM to 2500 RPM as shown in fig. 11 for the self-tuning fuzzy PID controller and fig 12 for PID controller. This experiment is expected to make BLDC motor can adapt the speed changes quickly.

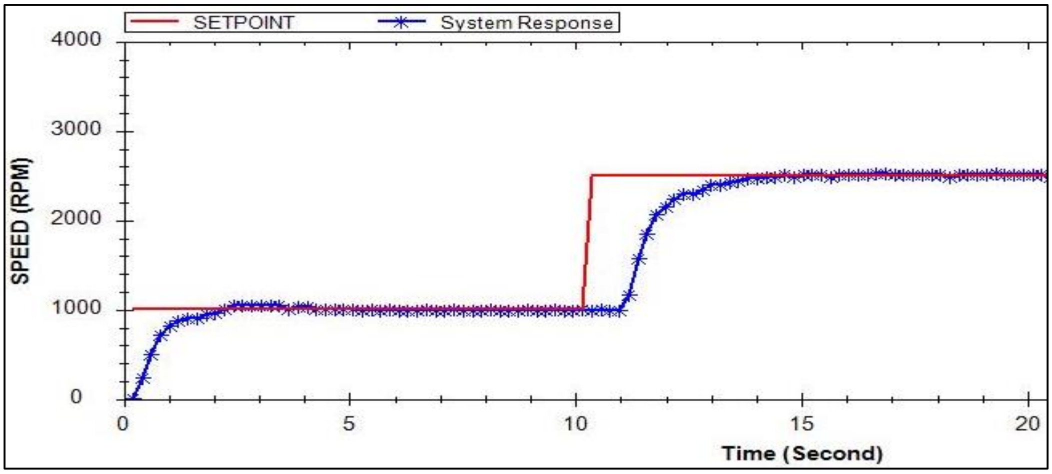

Fig. 11: system response of the reference changes up use self-tuning fuzzy PID controller

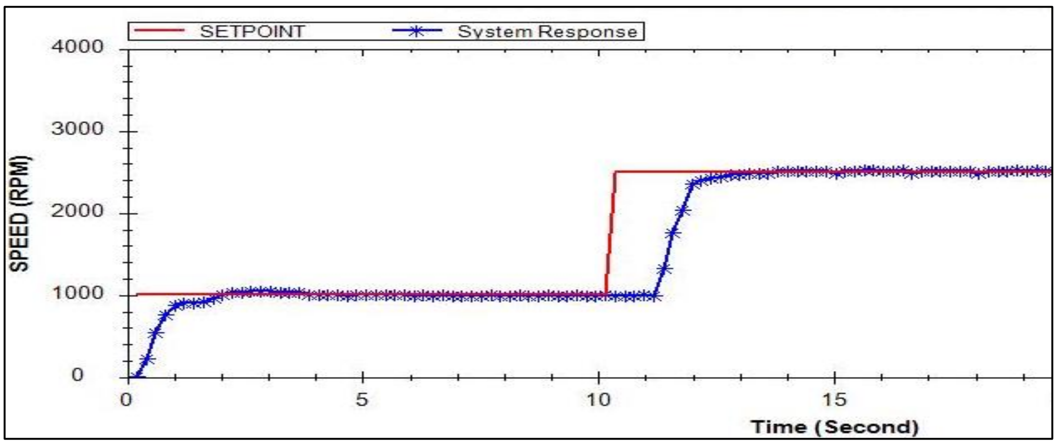

Fig. 12: system response of the reference changes up use PID controller

On the reference changes up, the response of self-tuning fuzzy PID controller is shown Fig. 11, it is known that the plant is able to adjut speed changes adaptively with tr = 3.656 s, ts = 4.062 s, Mp = 0 %. Similarly, in response of PID controller, when the speed is increased from 1000 to 2500 RPM, the plant still able to follow the set point change, from Fig. 12 known parameter values tr = 4.469 s, ts = 4.672 s, Mp = 0 %. This prove that the self-tuning fuzzy PID controller and PID controler can make the plant adjust the set point when increase, but the self-tuning fuzzy PID controler has better performance than PD controler for rotate BLDC motor at reference changes up because it the rise time and settling time are smaller.

C. The Reference Changes Down

This test is performed to determine the ability of the system in following the reference changes down, input speed increased from 1000 RPM to 2500 RPM at 10 seconds. Then observing the system response when the set point is down from 2500 RPM to 1000 RPM, the graph of the system response to the down speed is shown Fig.13 for use self-tuning fuzzy PID controller, As a comparison has also been tested using a PID controller are shown in Fig. 14 at similar condition.

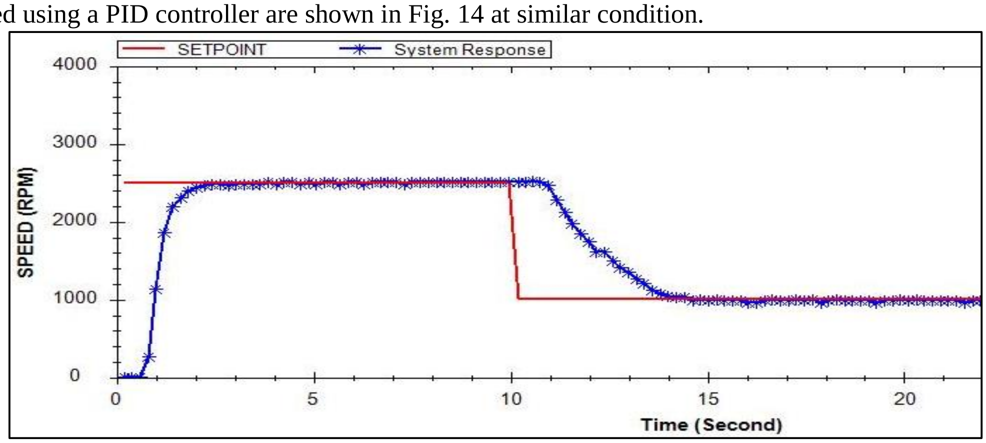

Fig. 13: system response of the reference changes down use self-tuning fuzzy PID controller

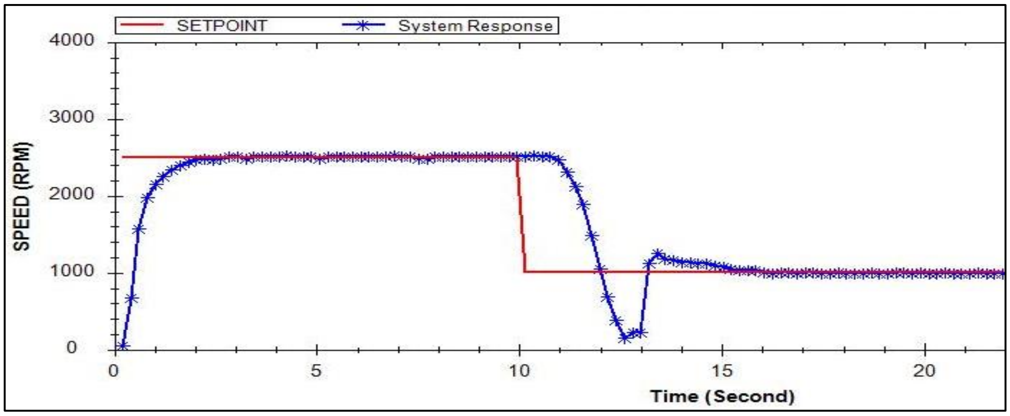

Fig. 14: system response of the reference changes down use PID controller

Fig 13 and Fig 14 show difference result. Result of self-tuning fuzzy PID controler terlihat lebih bagus dibandingkan grafik respon dari kontroler PID in Fig. 13. Respon system of self tuning shows that system has tr = 3.656 s, ts = 6.5 s, undershoot = 1.42 % and it has tr = 2.031 s, ts = 6.094 s, undershoot = 63.57 % for use PID controller when reference change down from 2500 RPM go to 1000 RPM. This prove that self-tuning fuzzy PID controller has a better performance than PID controller because can minimize undershoot in the PD controller from 63.57% to 1.42% with the small rise time and settling time.

D. Momentary Disturbance

Tests on the effect of disturbances on the speed control system is done by providing a momentary disturbance, by providing instant braking on the BLDC motor at speed 2500 RPM so that the motor speed dropped. The controller is expected to be able restore speed quickly according to set point after experiencing disturbances in the form of braking.

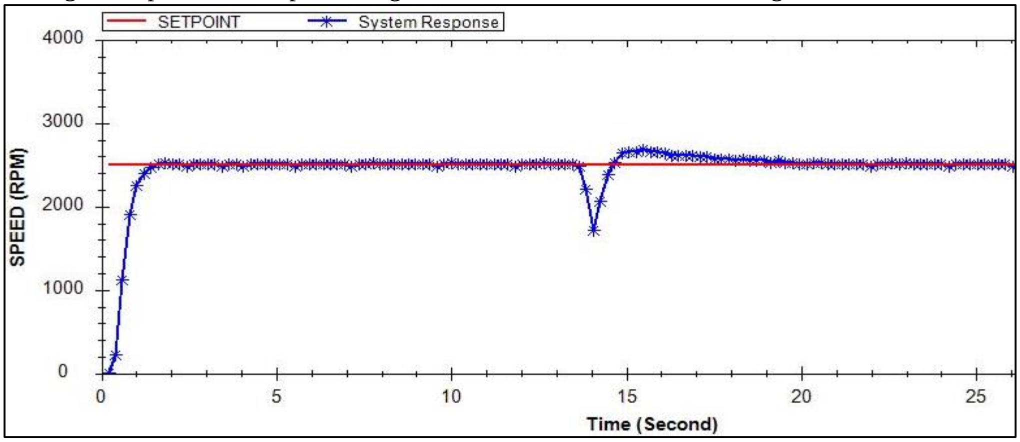

Fig. 15: system response for momentary disturbance

Testing a momentary disturbance at 13.203 seconds at Fig. 15 resulted in BLDC motor speed dropped to 1714.4 RPM for 1 second, after 1 second self-tuning fuzzy PID controller attempted to return output to setpoint by giving larger PWM causing overshoot when second to 15.5 by 7,148% or 2678,7 RPM and system reach steady state state again at second 20,156. Based on the testing of the momentary disturbance proves that the control of self-tuning PID with fuzzy logic able to overcome the instantaneous disturbance that occurs on the BLDC motor.

IV. CONCLUSIONS

The self-tuning fuzzy PID controller has better performance than PID controler in fixed PID parameter value. The self-tuning fuzzy PID can follow reference speed adaptively, either at fixed speed reference, the reference is changes up or down, also able to overcome the momentary disturbance from outside such as braking. In fixed speed reference testing, the self-tuning fuzzy PID can rotate BLDC motor at 2300 RPM with system response are tr = 1.828 s, tp = 2.234 s, ts = 3.453 s, Mp = 3.42 %, ess = 0.93 %. In reference canges up, the self-tuning PID controller rise time and settling time are smaller, tr = 3.656 s and ts = 4.062 s. In reference changes down self-tuning fuzzy PID can minimize undershoot at the PID controller from 63.57 % become to 1.42 %. A momentary disturbance drop motor speed for 1 second and make overshoot until 7.148 %. Further development can be done for this research by trying the variation of input membership function and other fuzzy logic output to make PID parameter tuning more accurate and also many other intelligent control system development which can be used for tuning PID parameters such as PID gain scheduling, hybrid PID ANFIS or optimal PID.

REFERENCES

[1] E. Gowthaman, S. K. Dhinakaran, and T. Sabarinathan, "Speed Control of Permanent Magnet Brushless DC Motor Using Speed Control of Permanent Magnet Brushless DC Motor Using Hybrid Fuzzy Proportional plus Integral plus Derivative Controller a Proportional Hybrid Fuzzy Integral plus Derivative Controller," Energy Procedia, vol. 117, pp. 1101–1108, 2017.
[2] A. Varshney, D. Gupta, and B. Dwivedi, "Speed response of brushless DC motor using fuzzy PID controller under varying load condition," J. Electr. Syst. Inf. Technol., vol. 4, pp. 310–321, 2017.
[3] R. Kandiban and R. Arulmozhiyal, "Design of Adaptive Fuzzy PID Controller for Speed control of BLDC Motor," Int. J. Soft Comput. ang Eng., vol. 2, no. 1, pp. 386–391, 2012.
[4] H. E. A. Ibrahim, F. N. Hasan, and A. O.Shomer, "Optimal PID control of a brushless DC motor using PSO and BF techniques," Ain Shams Eng. J., vol. 5, no. 2, pp. 391–398, 2014.
[5] K. Premkumar and B. V Manikandan, "Bat algorithm optimized fuzzy PD based speed controller for brushless direct current motor," Eng. Sci. Technol. an Int. J., vol. 19, no. 2, pp. 818–840, 2016.
[6] A. A. El-samahy and M. A. Shamseldin, "Brushless DC motor tracking control using self-tuning fuzzy PID control and model reference adaptive control," in Ain Shams Engineering Journal, 2016.
[7] K. Ogata, Modern Control Engineering, Third Edit. Tom Robbins, 1997.
[8] R. D. Utomo, Sumardi, and E. D. Widianto, "Control system of train speed based on fuzzy logic controller," in ICITACEE 2015 - 2nd International Conference on Information Technology, Computer, and Electrical Engineering: Green Technology Strengthening in Information Technology, Electrical and Computer Engineering Implementation, Proceedings, 2016, pp. 256–261.
[9] J. Yan, M. Ryan, and J. Power, Using Fuzzy Logic. Pretince Hall, 1994.

