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Response Improvement of BLDC Motor Speed using Extreme Learning Machine Controller

Cries Avian, Bambang Sujanarko, Bambang Sri Kaloko

Abstract— **BLDC motor is the most popular and most widely used in various industrial application or electric vehicle. The BLDC motor was chosen because it have advantages than other types of motor. Some of the advantages are high torque and high efficiency. In the BLDC motor researchs, the most popular is BLDC motor speed controller using intelligent system, but there is not research use Extreme Learning Machine (ELM). In this research will be discussed comparison Extreme Learning Machine (ELM) control and PID in the desired speed. Some parameters for the control system used to assess the performance of each controller. The results indicated that ELM has a better performance than PID in settling time and control system performance assessments.**

Index Terms—**BLDC, ELM, Motor, PID, Speed Control**

I. INTRODUCTION

BLDC is one of the most popular motors applied in various fields, both in the area of industry or electric vehicles [1]. The reason for using this BLDC motor in various fields is because the BLDC motor has advantages in several terms. The several terms are low maintenance requirements and simple maintenance, high torque density, high power to volume ratio, high efficiency, low noise level, low vibration, high dynamic response, high reliability, and excellent control characteristics at various speeds [2].

In the topic of BLDC research, several articles have been published related to research from this BLDC big topic. From some of these studies, if divided into several subtopics, there are research focus classes [3]. First, the research is closely related to how to construct the BLDC motor construction for precise specifications [4]–[8]. The two related controller constructions are used to control BLDC motor, both in aspects of control topology and also hardware design [1], [9], [10]. The third is related to how BLDC motor is combined with renewable energy sources to perform various applications [11], [12], some of which are applied to water pumps [13], [14] and are used to increase energy harvesting in freewheels [15]. The last is how BLDC motor is controlled by various techniques [16]–[21].

In research related to BLDC motor speed control, several techniques have been widely used. Several studies have applied artificial intelligence as an intelligence control on BLDC motor control. Among these studies are BLDC using Fuzzy as a control [20], [22]–[27], then ANFIS [28], PID [26], [29], [30], PI [2], [31], [32] and also Artificial Neural Networks (ANN) [32]. From some of these studies, some studies control the speed of the BLDC motor by controlling PWM generation [33]. However, most control techniques are based on controlling the inverter motor [20], [34], [35]. Intelligence control in several studies that have been mentioned is assigned to control the amount of power used to supply BLDC inverters. The higher the power supplied, the faster the speed of the BLDC motor, and vice versa. However, from existing research, one of the superior intelligence controls in the artificial intelligence is the Extreme Learning Machine (ELM) [36] still not used. Though ELM has several advantages not possessed by other intelligence controls. Some of the advantages of ELM are the high level of accuracy and high speed in processing data. By looking at these advantages, ELM can be utilized in controlling BLDC motors.

Therefore, the purpose of this study is to implement ELM in controlling speed on a BLDC motor. Also, this study will compare the use of other intelligence controls, namely PID, which is very popular to use because of its algorithmic simplicity. The target of this comparison is to find a control system that has a fast time to reach the steady state and also the best performance that will be assessed based on the standard control system performance assessment.

II. SYSTEM SET UP

The control system setup in this study is based on the controlling of the power transfer to the BLDC motor. So to be able to control the rotation of the BLDC motor, it can be adjusted by increasing the power. For increased speed, the power must be increased and to decrease speed, the power must be decreased. Therefore, for the block diagram of this system, it can be seen in the following Fig. 1.

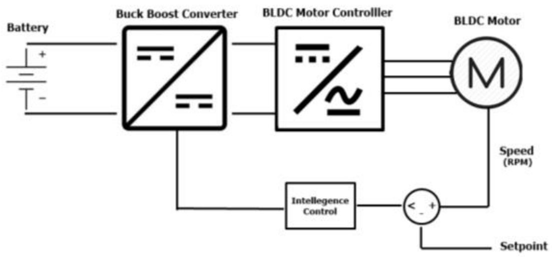

Fig. 1. BLDC Motor Control Diagram Block

In Fig.1, it can be seen that in this system consists of 5 blocks. These blocks include batteries, DC-DC converters

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Cries Avian, Departement of Electrical Engineering, Faculty of Electrical Engineering,Universitas Jember, Jember, Indonesia (e-mail: alzaid.muhammad@gmail.com or 171920201005@student.unej.ac.id).

Bambang Sujanarko, Departement of Electrical Engineering, Faculty of Electrical Engineering, Universitas Jember, Jember, Indonesia

Bambang Sri Kaloko, Departement of Electrical Engineering, Faculty of Electrical Engineering, Universitas Jember, Jember, Indonesia

(buck converters), BLDC motor controllers, BLDC motors and intelligent control systems. In principle, the working of this system is how the motor can be adjusted to fit the setpoint. For adjusting how much the speed value is, it can be achieved by controlling the voltage that supplies the motor controller using buck-boost converter. By using this type of converter, the battery voltage can be increased or decreased from the original nominal value of the battery voltage. The Controlling is carried out by intelligence control which will be compared in this study. The input source or input of intelligence control is an error and delta error that obtained by reducing the desired speed setpoint value to the real value when the motor is controlled (by using Equations (1) and (2)). The component values used in the buck-boost converter are L1 = 200 uH, C1 = 100 uH, R1 = 20, and Fs = 25000 Hz. As for the BLDC motor specifications used in this study can be seen in Fig. 3.

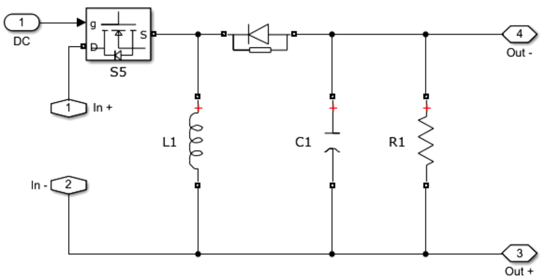

Fig. 2. Buck-Boost Converter Circuit

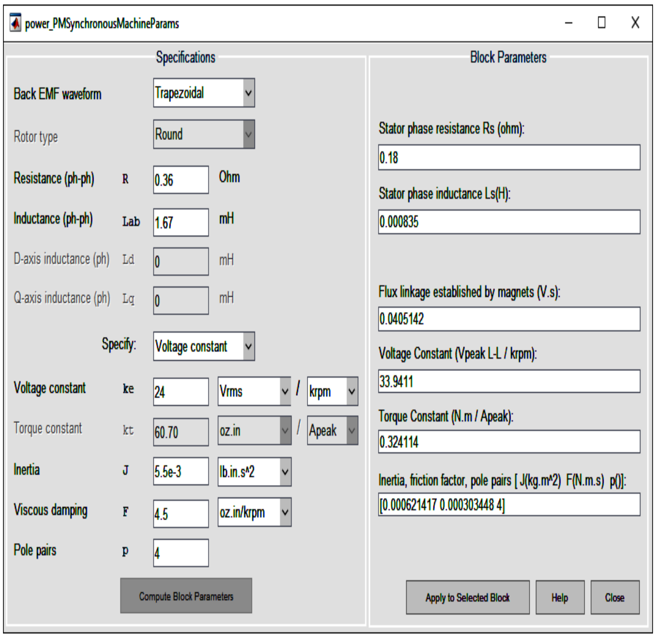

Fig. 3. BLDC Motor Specifications

To realize this system, simulation was formed and the result as shown in Fig. 4. In Fig. 4 show that in this research used a battery with 24V. Also shown that the speed of BLDC motor can set up using a constant block of Matlab Simulink.

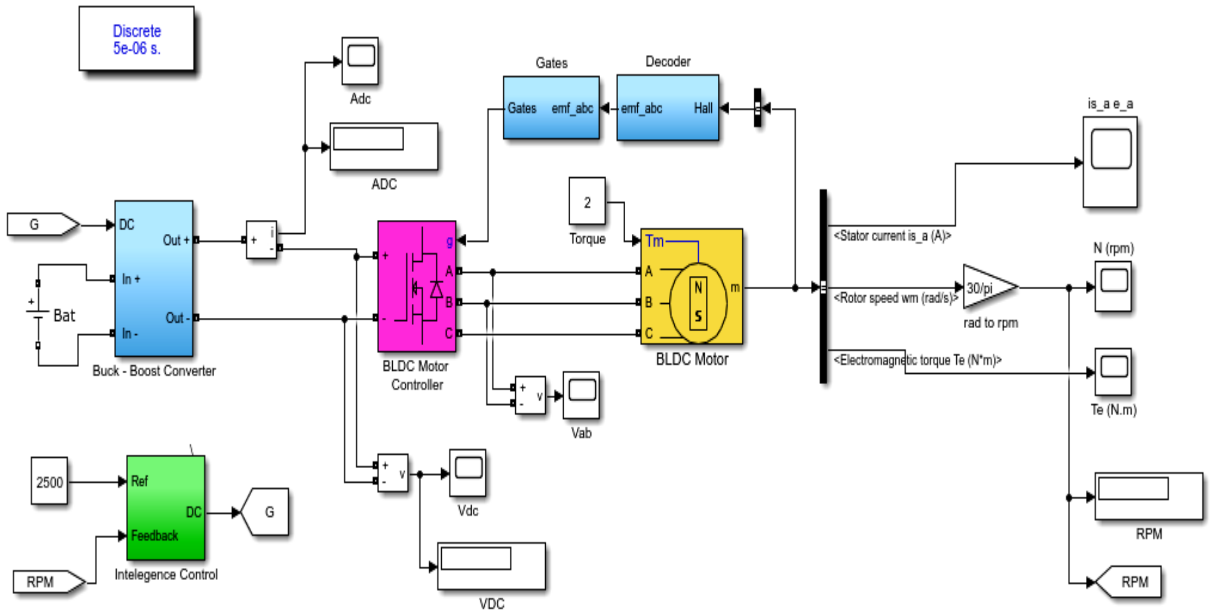

Fig. 4. Simulation of BLDC Motor

III. Intellegence Control Strategy

For use intelligence control, the system must be set so that the intelligent control system used can work as desired. In this research, the control system used is a closed-loop control system, so that there are two inputs and one control output. The two inputs are error and delta error, while the output is the value of the duty cycle (DC) used to control the buck-boost converter. Because this system uses two different control systems, namely PID and ELM, there are two different control block models. This can be seen in Fig. 5 for PID and Fig. 6 for ELM. The difference in control blocks is due to the various output characteristics of each intelligence control. The PID output can be used directly. This is because PID will respond to every error change with the equations and variables Kp, Ki and Kd. However, for ELM, the output cannot be used directly but must be added to the previous output value.

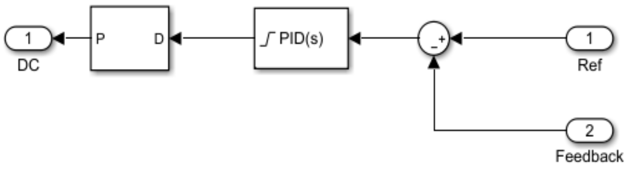

Fig. 5. Full Block of PID

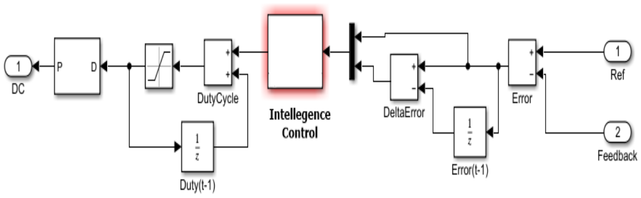

Fig. 6. Full Block on ELM

$$e = Ref - Feedback \quad (1)$$

$$de = e_{(t-1)} - e_o \quad (2)$$

Where e = error, ref is the reference (setpoint), the feedback is the output value of the motor, de is the delta error, $e_{(t-1)}$ the previous error value and e_o is the current error value. Because the simulation is using Simulink Matlab, then the equation converted to an Error and DeltaError block. Then that two variabel integrated into a mux component before entering into the black box intelligence control.

Then after the value is calculated to get error and delta error value, that value will be processed by the intelligence control. For the output of intelligent control in the value of duty cycle that will be used to control the buck-boost converter. Because the system used is a close loop control system model, then the output can be obtained by using the equation:

$$Out = Out_{(t-1)} + Out_o \quad (3)$$

Where Out = output value, $Out_{(t-1)}$ is the previous output value, and Out_o is the current output value. Because the output value with the close-loop model can exceed the standard range of the value of the duty cycle, then before entering into the PWM generator block, the output value is limited by constraints 0 - 0.87. Equation (3) does not apply to the PID control system. This is because the PID output can be used directly to control the buck-boost converter. However, the PID output will still be constrained to the value of 0.87.

IV. TESTING SCENARIO

For test the control system that will be used, the system will change the value of the speed setpoint. This change is done by changing the setpoint. The setpoint will change to increase and to decrease the speed in some time cycles with a fixed torque (motor load) value. The purpose of this test is to know the ability of the system. The target is to know how fast it can achieve a steady-state with fixed displacement torque. For the order of speed transfer in this test are as follows: 500 RPM increases up to 4000 RPM with a difference of 500 RPM per increase, then decreases from 4000 RPM to 500 RPM with 500 RPM per decrease, then from 500 RPM to 3000 RPM than to 500 RPM, then to 2000 RPM and finally to 4000 RPM. The torque used in the testing scenario is 2 Nm.

The result of the performance system will be known for processing the data. So in this research, the researchers will store data (data logging) when the simulation is running. The data saved is error value data and simulation time. Both of these variables will be used to be analysed using the assessment parameters, namely IAE, ISE, ITAE and MAE [37].

V. RESULT AND DISCUSSION

The results of the speed test will be divided into two parts. First part is to test each performance of intelligent control to get information about response system. It is like a overdamp, overshoot, rise time and settling time. The second discussion is to test the results use performance control system assesment (IAE, ISE, ITAE and MAE) [37].

A. *Response System*

For the first discuss is talking about the responses generated by each intelligence control. In the first test, the system will control using the PID control system that has been tuned to determine the value of Kp, Ki and Kd using the Nichols-Zeigler method [38]. The results of the tuning process obtained values of Kp = 30, Ki = 750 and Kd = 0.3. After the value is obtained, then the value is entered into the PID, and the system is run. The results of this test can be seen in Fig. 8 – Fig. 9.

From Fig. 8, it can be seen that the PID has successfully reached the specific setpoint value by the user. Although it can be seen at the current speed (500 RPM - 3500RPM), the system has improved beyond the longer one compared to the previous cycle. Likewise, at the time of extreme decreasing (3500 RPM - 500 RPM) where the system experienced an overdamp, which is also quite long compared to the previous cycle. To see more detail, Fig. 9 is the cycle time for overshoot / overdamp responses.

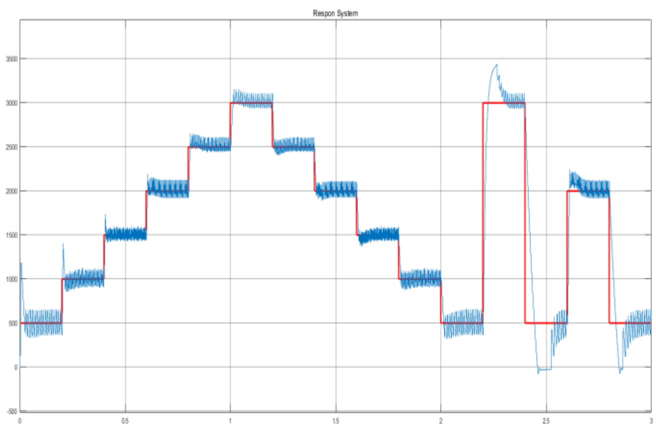

Fig. 7. System Response of PID

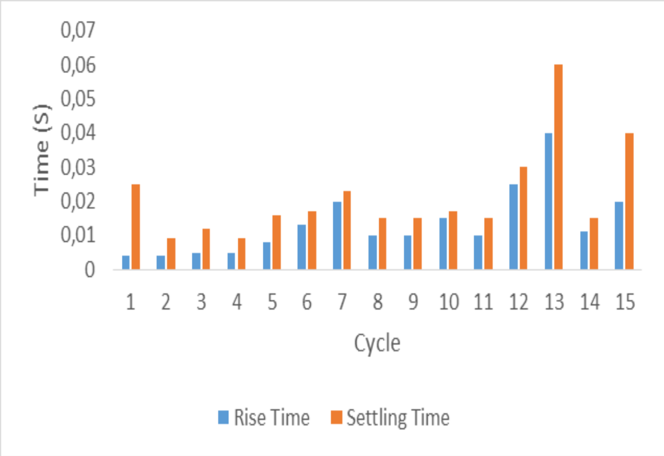

Fig. 8. Settling Time on PID

Next is the test for the ELM control system. Before the ELM can be used, the ELM needs a training process. This training process is needed because ELM is the development of ANN, which only has one layer. So in this study, ELM will also be trained using data obtained from data that has been created by researchers. The structure of the built ELM network can be seen in Figure 9, where the ELM is built with a single layer consisting of 10 neurons. Input from ELM is two, namely Error and DeltaError. The output from ELM is only one, namely the duty cycle that is used to control the buck-boost converter. The results of the ELM training process in this research have an accuracy of 99.7% of all the data that has been trained. As for the results of ELM testing, it can be seen in Fig. 10 – Fig.11.

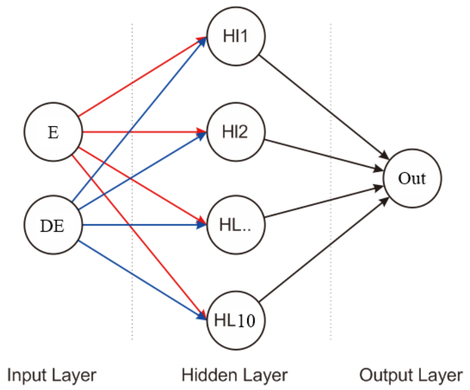

Fig. 9. ELM Network Structure

From Fig. 9, it can be seen that the PID successfully followed the specific setpoint value by the user. Even though it can be seen that when the speed is raised extreme (500 RPM - 3500RPM), the system experiences longer overshoot compared to the previous cycle. Likewise, at the time of extreme decreasing (3500 RPM - 500 RPM) where the system experienced an overdamp, which is also quite long compared to the previous cycle. Fig. 10 is the cycle time for the overshoot / overdamp response, while the reaction from the PID control output can be seen in Fig. 11.

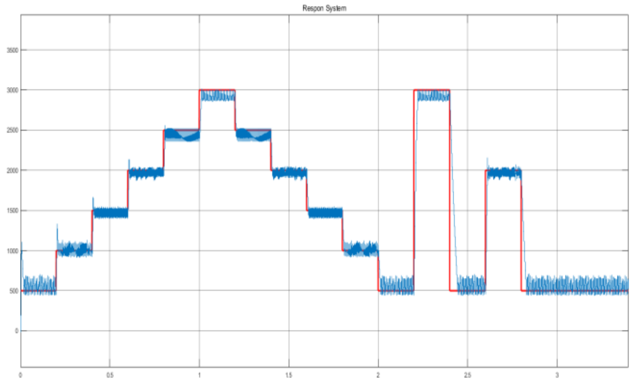

Fig. 10. System Response of ELM

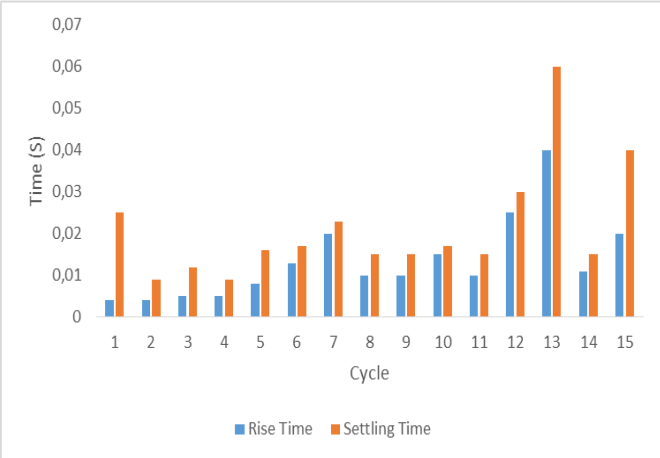

Fig. 11. Settling Time on ELM

From several results that have been obtained, it shows that ELM has a shorter cycle in achieving steady state compared to PID. This can be observed from the results of the ELM control response during cycle speed switching. This comparison will be evident in the event of extreme increases and extreme decreases in each intelligence control. Fig. 12 is a comparison picture of the time needed for the system to reach a steady state (settling time) in each control system.

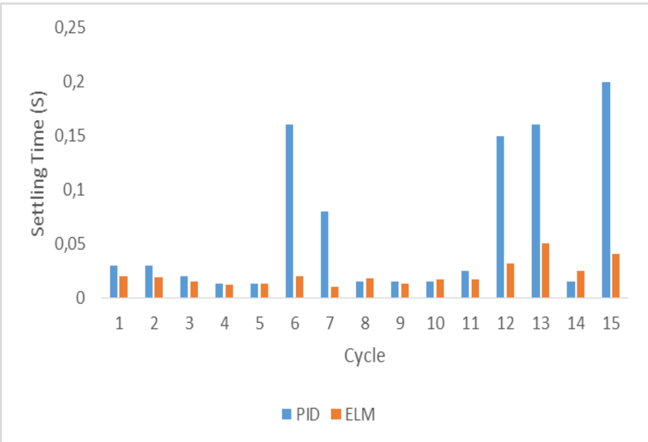

Fig. 12. Comparison of Settling Time on PID and ELM

Besides, when compared to the overshoot and overdamp values in each control system, it can be seen that ELM has a smaller overshoot and overdamp value compared to PID. This can be seen in Figure 12, which is a significant comparison of overshoot and overdamp values in each control system.

Whereas in Table 1 is information that contains the average values of rising time, settling time and overshoot and overdamp.

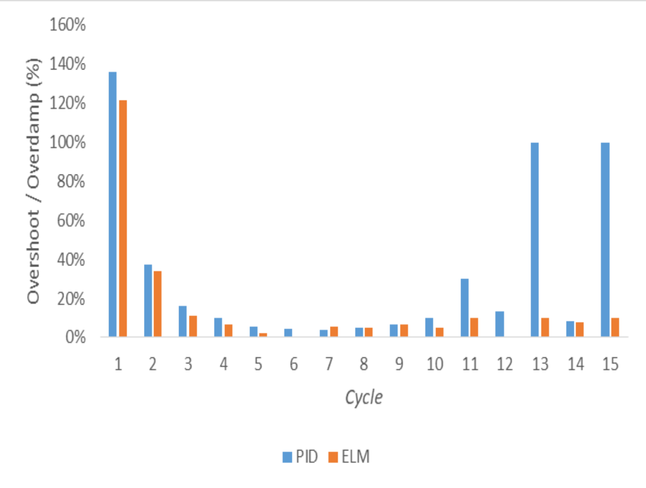

Fig. 13. Comparison of Overshoot and Overdamp on PID and ELM

Table 1. Comparison of Average Performance on PID and ELM

Parameter	**PID**	**ELM**
Average Rise Time	0.041	0.013
Average Settling Time	0.063	0.021
Average Overshoot / Overdamp	32%	16%

From this phenomenon, it can be seen that several things can cause the cause of the longer settling time and the high value of overshoot / overdamp on PID. First, it could be due to incorrect Kp, Ki and Kd values even though specific methods have been used. The second because PID is a control system whose output is the result of an equation that combines the variables Kp, Ki and Kd with the error value. So whatever happens to the PID output is the response of the equation that has been combined with these two variables. This is different from ELM. ELM is formed based on the experience of its users. So that the output value from ELM is not a value derived from a particular equation, but the ELM output value is the training value that has been designed by the user to be able to complete the plant that it has formed as well as possible. This is commonly known as the Expert System. That is the reason why PID has a slower response compared to ELM.

B. System Control Performance Assessment

Next is the result based on the standard assessment for the control system. To find out the level of performance of the control system that has been designed, it need measurement parameters of control system. So, in this research, some standard parameters is used [39]. The system control performance parameter that is used including IAE, ISE, ITAE and MAE [40]. Because to be able to use this parameter several system variables need to be calculated, so when running a simulation, researchers do logging data on the error value and simulation time. By utilising the data logging, we can find out the value of several parameter values, as shown in Table 2.

Table 2. Comparison of Average Performance Based on Full Control Systems on PID and ELM

Parameter	**PID**	**ELM**
IAE	362.86	340.84
ISE	21e4	18e4
ITAE	702.25	647.38
MAE	112.76	99.887

From Table 2 it can be seen that ELM has good performance compared to PID. This can be seen from the IAE, ISE and ITAE standard values owned by ELM, where ELM has a smaller value compared to PID. Besides that, ELM also has good stability. This can be seen from the small MAE value generated.

VI. CONCLUSION

In this article, researchers have tested the speed regulation of a BLDC motor using intelligence control. To be able to control the speed of a BLDC motor, this is done by adjusting the amount of power entering the motor inverter. Therefore the buck-boost converter is used in this study. Buck-boost converter will set the duty cycle value to produce the desired amount of power. The higher the incoming power, the higher the speed that will be generated. Vice versa. To be able to do this setting, two intelligence controls are used. First is PID and the second is ELM. The purpose of this study is to compare the use of the two intelligence controls by using several parameters of the control system performance testing.

From the results of the research that have been obtained, it shows that ELM has better performance compared to PID. This can be seen in terms of the settling time needed to achieve a steady-state. Besides that, the overshoot and overdamp values obtained by using ELM have a smaller value than the PID. When viewed from control system performance parameters, ELM also has a better value than PID. The advantage of this ELM is obtained because ELM is an expert intelligence control. This means that ELM is a control system which in its management process is based on user knowledge. This is different from PID, where PID is a control system that utilises certain mathematical functions. However, ELM has a weakness in requiring users to train data first. If the user does not have the ability to observe the data that will be used for ELM data training, it will be challenging to achieve a good control system. This is different from PID, which only requires tuning in three variables (Kp, Ki and Kd). Therefore, this control system can be developed into a more Expert system, such as the use of Expert PID.

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