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Research Paper

Implementation of Fuzzy-PID Controller as A DC Motor Speed Controller Based On Arduino UNO

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ABSTRACT: *DC motor (Direct Current) is an electric machine driven by a DC voltage source.The development of high-performance DC motors is very important in industry as well as for other purposes such as yarn spinners (weaving), cranes, lifts, elevators, hair dryers,vacuum cleaners and sewing machines. Therefore, the motor must be controlled preciselyto produce a desired motor performance. Speed controllers are designed for the purpose of controlling the speed of a DC motor to carry out a variety of tasks, consisting of several types of conventional and numerical controllers, controllers can be: proportionalcontroller (P), proportional integral controller (PI), Proportional Derivative (PD) controller, or The combination of the three is proportional integral derivative (PID). The main problem in applying conventional control algorithms (PI, PD, PID) in speed controllers is the non-linearity effect on DC motors. The nonlinear characteristics of the DC motor can degrade the performance of conventional controllers. In general, accurate nonlinear models of DC motors are difficult to find and the parameters obtained from the sistem identification may only be estimated values. In this study, we will compare the response of the PID system which is tuned in a conventional way with the PID tuned by Fuzzy Logic. After testing and analyzing the system response, it was found on the PID controller with a high set point (14000 RPM) the system response at parallel load was slower than the system response with series resistance load, namely at 1Ω load the response to series load was 20 seconds while at parallel load the system response reaches a steady state at 29 seconds. Meanwhile, in the Fuzzy-PID parallel resistive load, thesystem response is faster than the series load, which is 14 seconds at series load and 13seconds at parallel load. When given a different set point, Fuzzy-PID experiences a veryhigh overshoot, which is 2216 RPM at a low set point (4000 RPM) and 1611 RPM at a speed setpoint of 9000 RPM. While the PID controller remains consistent in its responseto changes in setpoints (there is no overshoot). So from all the test results the PID controller is superior to the Fuzzy-PID controller.*
KEYWORDS: *DC Motors, Control Motor, PID Controler, Fuzzy-PID Controler*

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I. INTRODUCTION

Currently, there are many types of DC motors that can be distinguished based on their intended use. Therefore, the motor must be controlled precisely to produce a desired motor performance. A speed controller designed for the purpose of controlling the speed of a DC motor to carry out a variety of tasks, consisting of several types of conventional and numerical controllers, the controller can be: proportional (P) controller, proportional integral controller (PI), Proportional Derivative (PD) controller, or a combination of the three, namely the proportional integral derivative (PID). Proportional - integral - derivative (PID) controllers operate the majority of control systems in the world. It has been reported that more than 95% of controllers in industrial process control applications are PID type because no other controller matches the simplicity, clear functionality, applicability and ease of use offered by PID controllers (Umesh Kumar Bansal and Rakesh Narvey, 2013). The PID controller provides robust and reliable performance for most systems if the PID parameters are set properly.

The field of fuzzy control has made rapid progress in recent years. Thus FLC has become a very active research area and many industrial applications have been reported. In recent times, FLC has developed as an alternative or complementary to conventional control strategies in various engineering fields. Fuzzy control theory usually provides nonlinear controllers capable of performing different complex nonlinear control actions, even for uncertain nonlinear systems. Unlike conventional controls, designing FLC does not require precise knowledge of system models such as poles and zeros of system functions. Mimicking human learning, tracking errors and changing error rates are two important inputs for fuzzy control system design.

Many studies on DC motors have been carried out before, such as the reference for this research, namely Speed Control of DC Motor Using Fuzzy PID Controller (Umesh Kumar Bansal and Rakesh Narvey, 2013), which controls DC motor speed using self-tuning fuzzy PID controller. In this research, fuzzy logic is used to adjust the values of Kp, Ki, and Kd. In this study, we compare the results of the control of the two controllers, namely PID and Fuzzy-PID aiming to find out the best controler. Which is expected to be the basis for research related to DC Motor control.

II. RESEARCH AND METODOLOGY

The block diagram of the system will briefly explain how the DC motor speed control system works. In this study, the input given is the set point value which is the desired DC motor speed value. The Arduino UNO microcontroller is the main data processing system with this tool. The output signal from the IR Proximity sensor will be sent to Arduino for processing so that the desired speed can be produced. The L298N motor driver is assumed to be used as an intermediary for the Arduino output and the DC motor, namely by setting the PWM output value to be forwarded to the DC motor so that DC motor speed control can occur. The DC motor is the plant or object that controls in this study, to test the DC motor speed control, interference is needed to find out whether the control system made is as desired or not. Therefore, in this study, a resistor is used as a motor load. To determine the speed and error value at the speed of the DC motor, a speed sensor is used in this study, namely the IR Proximity sensor module.

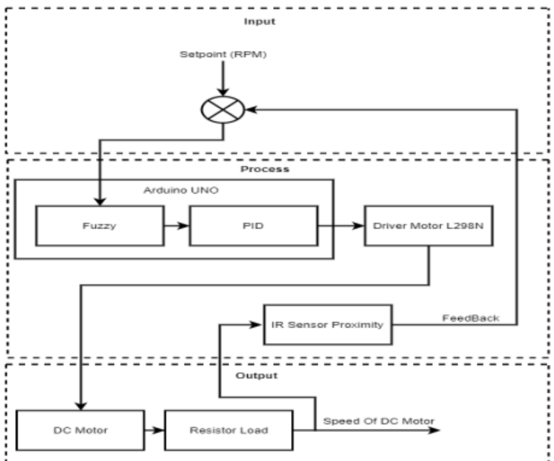

Figure 1 : The System Work Block Diagram

To find out the characteristics of the system made and how it responds to a change in load, so it takes a load. The load used in this study is the load resistor. There are two types of loads to be tested, namely resistor loads with series circuits and resistor loads with parallel circuits. The schematic of the load circuit is drawn by proteus 8.0 and can be seen in Figure 2.

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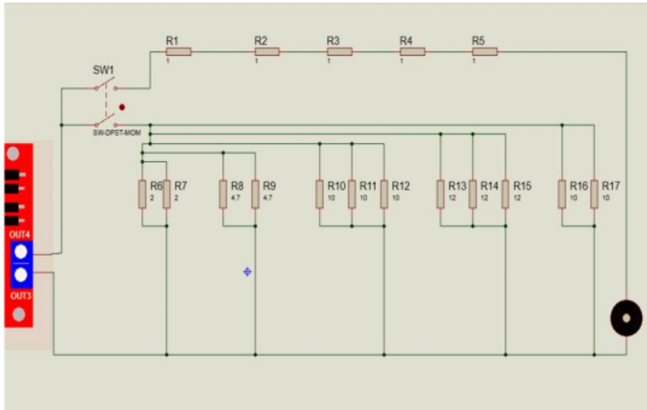

Figure 2 : Resistor Load Design

In designing the PID controller, tuning is done using the 2nd Zieghler-Nichols method. The tuning of the Zieghler-Nicols method is done by giving a proportional variable value from 0 to a critical value of Kp in a closed loop state with no load, so that an output that continuously oscillates periodically is obtained.

The process starts with the microcontroller initializing ports and sensors. After the sensor and all ports are initialized then the next process is to enter the PID parameter values, namely Kp, Ki and Kd. After the PID parameter has been inputted, the desired speed set point value will be inputted. After the above process is carried out, the motor will show the response generated from the controller, if the PID parameter value is inputted accordingly, it will produce a motor rotational speedy response which is at the setpoint value that was previously inputted. Figure 3 will show in a simple way how the PID controller system works in this study.

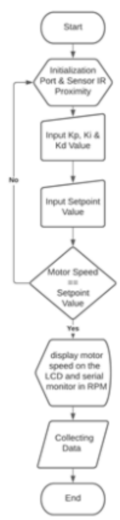

Figure 3 : Flowchart of PID Kontroler

Basically the Fuzzy-PID controller is a PID controller whose PID parameters (Kp, Ki, Kd) are tuned using fuzzy logic. The process of designing this Fuzzy controller is first Fuzzification with six membership sets, the signal that is fuzzified is an error signal. Furthermore, defuzzification using Center Of Area (COA). All these Fuzzy controller designs are designed in Matlab 2015 software. Fuzzification, Rule base, and defuzzification are made first by clicking Apps on the toolbar, then in the search field type "fuzzy", then select Fuzzy System Designer. Fuzzy controller design in this study can be seen in Figures 4.

Table 1 : Aturan Logika Fuzzy

Error	**M**	**K**	**RR**	**B**	**SB**	**SSB**
Kp	KPM	KPRR	KPB	KPSB	KPSB	KPSSB
Ki	KISSB	KISB	KIB	KIB	KIRR	KIRR
Kd	KDM	KDK	KDRR	KDB	KDSB	KDSSB

Legend :
- M = Minus
- K = Small
- RR = Average
- B = Big
- SB = Very Besar
- SSB = Largest

With a fuzzy inference system as follows.With a). is the error membership function, b). is the membership function KP, c). is the membership function Ki, and d). is the membership function of Kd. The fuzzy design mode is Mamdani fuzzy, with a triangular membership function representation. Fuzzy input is in the form of an error value which is the difference between the speed setpoint value and the speed value of the sensor reading.

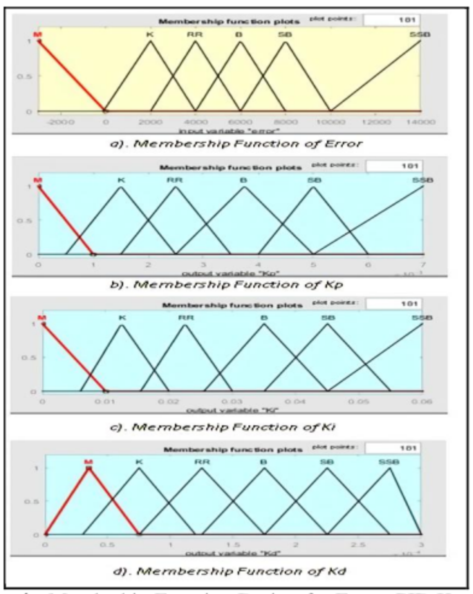

Figure 4 : Memberhip Function Design for Fuzzy-PID Kontroler

III. RESULT AND DISCUSSION

This test is carried out to determine whether the microcontroller is in good condition or damaged. Tests are carried out by connecting LEDs that are arranged in parallel, one of which is connected to the Arduino pin. This test aims to check whether the I/O works in accordance with the system job description. The following is the Arduino program used in the test.

Table 1 : The Results of Microcontroller Test

No	Pin	LED												
		1	2	3	4	5	6	7	8	9	10	11	12	13
1	1	on	off	off	off	off	off	off	off	off	off	off	off	off
2	2	off	on	off	off	off	off	off	off	off	off	off	off	off
3	3	off	off	on	off	off	off	off	off	off	off	off	off	off
4	4	off	off	off	on	off	off	off	off	off	off	off	off	off
5	5	off	off	off	off	on	off	off	off	off	off	off	off	off
6	6	off	off	off	off	off	on	off	off	off	off	off	off	off
7	7	off	off	off	off	off	off	on	off	off	off	off	off	off
8	8	off	off	off	off	off	off	off	on	off	off	off	off	off
9	9	off	off	off	off	off	off	off	off	on	off	off	off	off
10	10	off	off	off	off	off	off	off	off	off	on	off	off	off
11	11	off	off	off	off	off	off	off	off	off	off	on	off	off
12	12	off	off	off	off	off	off	off	off	off	off	off	on	off
13	13	off	off	off	off	off	off	off	off	off	off	off	off	on

Power supply testing is carried out to ensure that the power supply used will not be a problem that will affect the system later. The test is carried out by measuring the output voltage and current from the power supply used with no load and with load. The results of the tests carried out can be seen in table 3 below.

Table 2 : The Results of the Power Supply Test

Input	Without Load		With Load		ΔV & I		Evidence
	V	I	V	I	V	I	
Whole System	9,27	0	9,25	0,6	0,02	0,6	Healthy
Microcontroller	5,00	0	4,73	0,02	0,47	0,02	Healthy
DC Motor	7,20	0,65	7,30	0,63	0,1	0,02	Healthy

Sensory testing is carried out to determine whether the sensor is in good condition or damaged. In testing the IR Proximity sensor, there are 2 tests, namely testing running sensors on the system and sensor calibration. The running sensor test is done by uploading the program to Arduino and observing the pulse sensor through the Arduino serial plotter. Meanwhile, sensor calibration is carried out so that sensor readings are more accurate.

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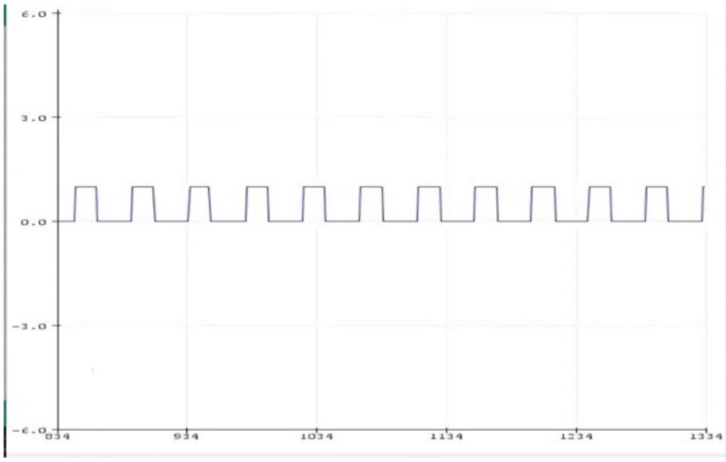

Figure 5 : Pulse display generated by IR proximity sensor

The second test was conducted to determine the error between the speed sensor readings and the factory-made digital tachometer. It aims to calibrate the IR Proximity sensor. To do this test, you do this by running a DC motor with the IR Proximity sensor installed. Then compare the speed readings read by the IR Proximity sensor with the results read by the digital tachometer.

Table 3 : The Result of IR Proximity Sensor Test

No.	Input PWM (% duty cycle)	IR Proximity Sensor Reading (RPM)	Pembacaan Sensor Digital Tachometer (RPM)	Error (RPM)
1.	0	0	0	0
2.	20	6427	6348	79
3.	40	12488	12561	73
4.	60	15666	15706	40
5.	80	17125	17458	333
6.		∑IR =51706	∑TM =52073	∑E=525
7.	Rata - Rata	10341,2	10414,6	105

%Error = ∑E∑TM x 100% →(1)

= 52552073 x 100%

= 1,01 %

Error calculation of the IR proximity sensor readings is shown in equation 1. with ∑IR is total number of IR readings sensors, ∑TM is total number of readings tachometer and ∑E is total error.

In testing the sensor in table 4, it can be seen that the output of the IR Proximity sensor readings with a digital tachometer has a difference in the speed readings (error) up to 333 RPM. The biggest speed difference occurs when the motor rotates with a PWM input of 80%. This happens because the vibration of the motor shaft is no longer straight which causes vibrations in the sensor and affects sensor readings.

(1) **3.1 PID Controller Testing**

DC motor testing with a PID controller is intended to show whether the controller made is running properly. The point is that when the motor is given control in the form of a PID controller, then no matter how much load is given to the motor, the resulting speed output will remain the same as the given speed input.

This test is done by looking at the system response given by the DC motor when the DC motor is given a predetermined setpoint input along with the load (resistor). This test also shows the effect of PID on the rotational speed of a DC motor.

The determination of PID parameters, namely Kp, Ki and Kd, were carried out using the Ziegler-Nichols method. After finding the best PID controller parameters. Then tested on the speed of the DC motor. This test is carried out to prove that the output speed will be the same as the input or setpoint given even though different loads are given. The response of the PID control system is as follows.

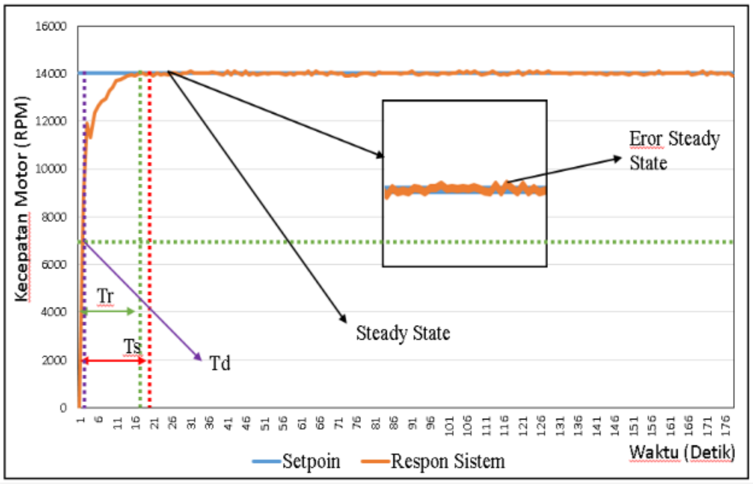

Figure 6 : System response PID controller with 1Ω. Load

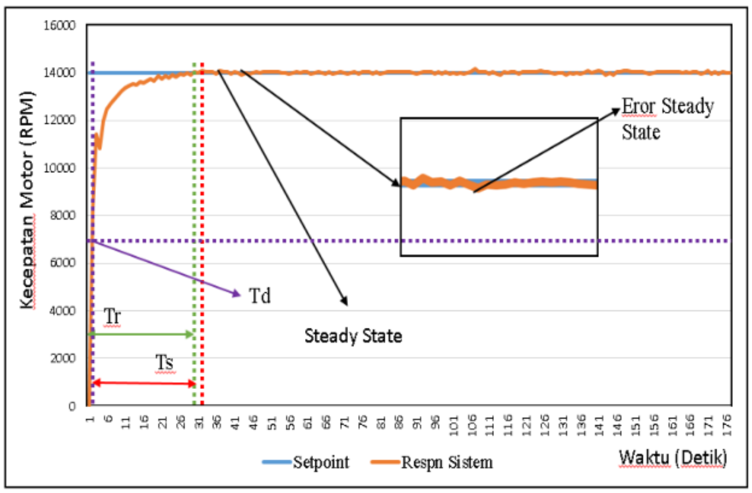

Figure 7 : System response PID controller with 2Ω. Load

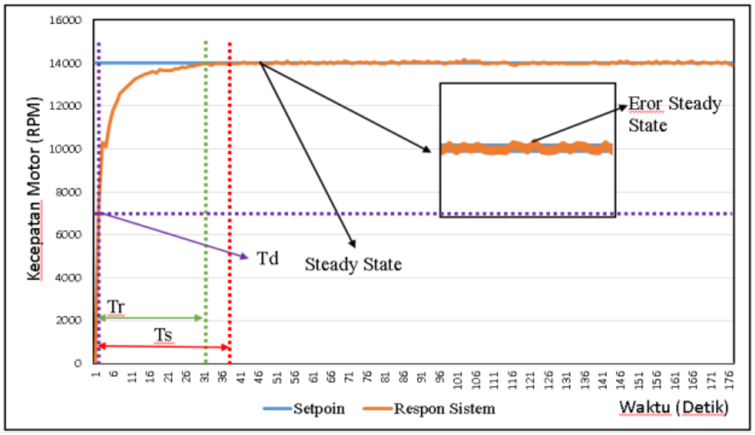

Figure 8: System response PID controller with 3Ω. Load

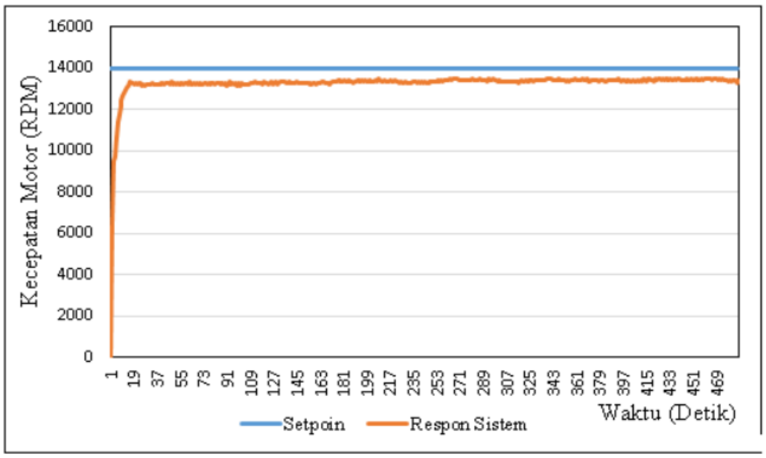

Figure 9 : System response PID controller with 4Ω. Load

Testing with a load of 4 ohms and 5 ohms, the motor is no longer able to reach the setpoint. This is because the load torque has exceeded the motor torque so the motor cannot reach the desired speed.

Table 5 : Response data of the pid controller system at a speed of 14000 rpm

No.	Load	*Rise time*	Settling Time	Steady State *Error*
1.	1Ω	17s	20s	103 RPM
2.	2Ω	30s	32s	89 RPM
3.	3Ω	31s	38s	89 RPM
4.	4Ω	-	-	-
5.	5Ω	-	-	-

(2) **3.2 Fuzzy-PID Controller Testing**

Fuzzy-PID controller testing aims to determine the response of the plant when using fuzzy logic as a PID parameter tuning (Kp, Ki and Kd). The results of testing the response of this system will be compared with the PID controller, which is destined by tuning the Zieghler-Nichols 2nd method. The response of the Fuzzy-PID controller system can be seen in Figures 13 to 16. Fuzzy-PID controller testing is the same as PID controller testing, namely by providing a load that is varied from 1Ω to 5Ω.

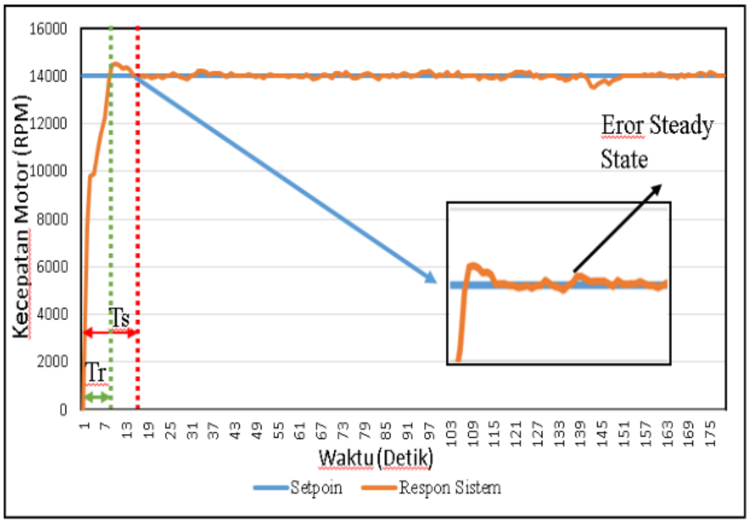

Figure 10 : Fuzzy-PID system response with 1Ω. Load

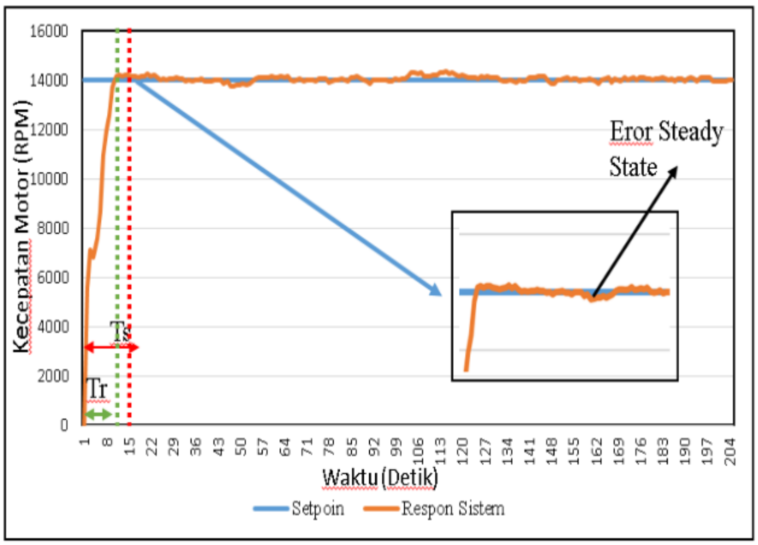

Figure 11 : Fuzzy-PID system response with 2Ω. Load

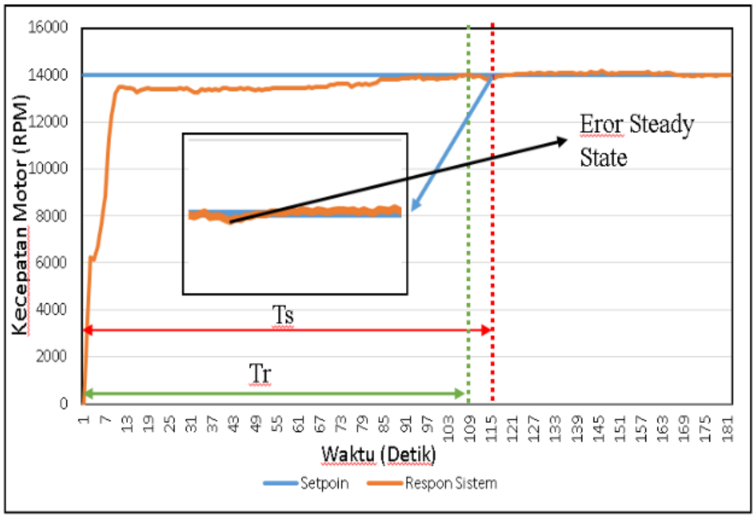

Figure 12 : Fuzzy-PID system response with 3Ω. Load

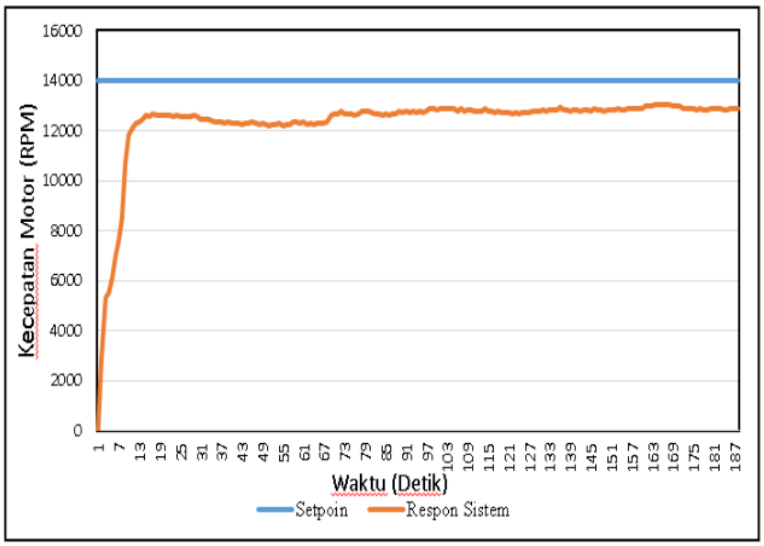

Figure 13: Fuzzy-PID system response with 4Ω. Load

Not different from PID, Fuzzy-PID controller at 4Ω load no longer reaches the setpoint. Because the 4Ω load can no longer reach the setpoint, the test at 5Ω load is not carried out.

(3) **3.3 Fuzzy-PID Controller Testing**

To see the difference in system response of the two controllers, a comparison graph is made as follows.

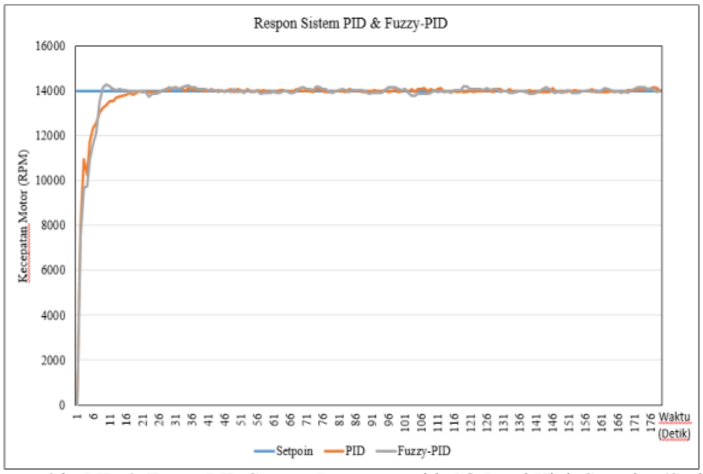

Figure 14 : PID & Fuzzy-PID System Response with 1Ω Load High Setpoint (Series)

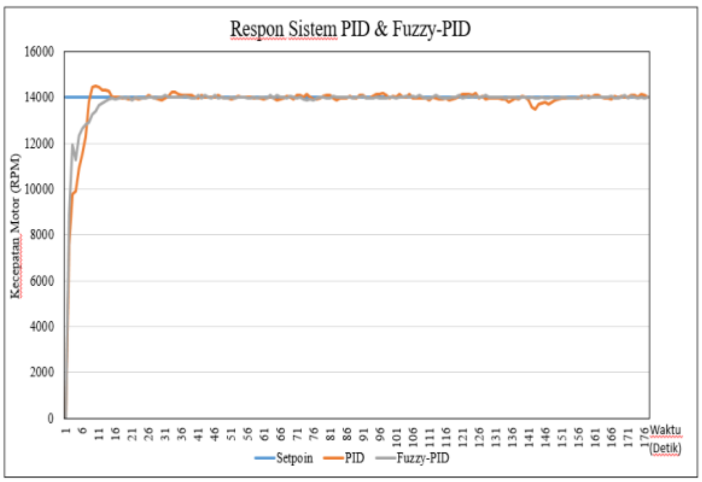

Figure 15 : PID & Fuzzy-PID System Response with 1Ω Load High Setpoint (Parallel)

Load 1Ω (Parallel) Based on the test results, the resistance load which is connected in series and parallel has a different character, where these two types of load have the same form of system response in each controller. However, with a different system response speed. On the PID controller with a high setpoint (14000 RPM) the system response in parallel load is slower than the system response with a series resistance load, namely at 1Ω load the response at series load is 20 seconds while at parallel load the system response reaches a steady state at 29 seconds. Meanwhile, the Fuzzy-PID parallel resistance load is faster than the series load, which is 14 seconds in series load and 13 seconds in parallel load. So that the Fuzzy-PID controller is better at controlling the plant with parallel loads while the PID is the opposite. Fuzzy-PID is superior to PID in controlling the plant at high speed and low load. The results of the comparison of system responses can be seen in the following table.

Table 6 : Data Response System of PID and Fuzzy-PID Controller at a High Speed (Series)

No.	Beban	*Time delay*		*Rise time*		Settling Time		Steady State *Error*	
		FPID	PID	FPID	PID	FPID	PID	FPID	PID
1.	1Ω	4s	1s	8s	17s	14s	20s	155 RPM	103 RPM
2.	2Ω	6s	1s	12s	30s	15s	32s	261 RPM	89 RPM

3.	3Ω	7s	2s	109s	31s	115s	38s	34 RPM	89 RPM
4.	4Ω	- s	- s	- s	-	- s	-	RPM	-
5.	5Ω	- s	- s	- s	-	- s	-	RPM	-

Table 7 : Data Response System of PID and Fuzzy-PID Controller at a High Speed (Parallel)

No.	Beban	*Time delay*		*Rise time*		Settling Time		Steady State *Error*	
		FPID	PID	FPID	PID	FPID	PID	FPID	PID
1.	1Ω	1s	1s	8s	28s	13s	29s	141 RPM	164 RPM
2.	2Ω	2s	1s	8s	29s	17s	30s	155 RPM	257 RPM
3.	3Ω	5s	2s	11s	44s	25s	46s	261 RPM	196 RPM
4.	4Ω	-s	- s	-s	- s	-s	- s	RPM	0 RPM
5.	5Ω	-s	- s	-s	- s	-s	- s	RPM	0 RPM

From the test results, when given a different setpoint Fuzzy-PID experienced a very high overshoot, namely 2216 RPM at a low setpoint (4000 RPM) and 1611 RPM at a speed setpoint of 9000 RPM. While the PID controller remains consistent in its response to changes in setpoints (there is no overshoot). So that the PID controller is superior to setpoint changes compared to the Fuzzy-PID controller. The system response can be seen in Figure 4.65 to Figure 4.69.

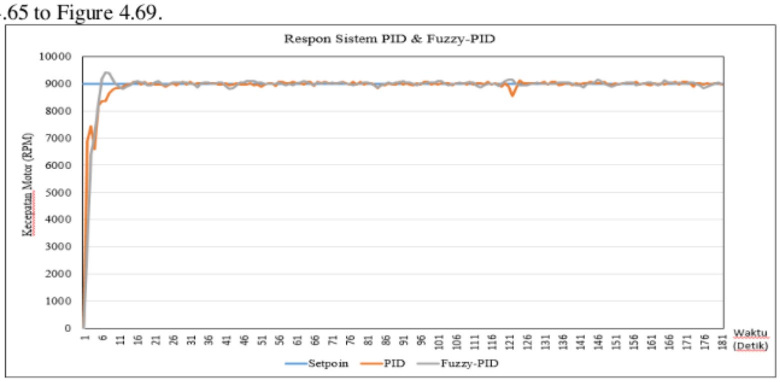

Figure 16 : Response System PID & Fuzzy-PID Controller at High Setpoint with 1Ω Load(Parallel)

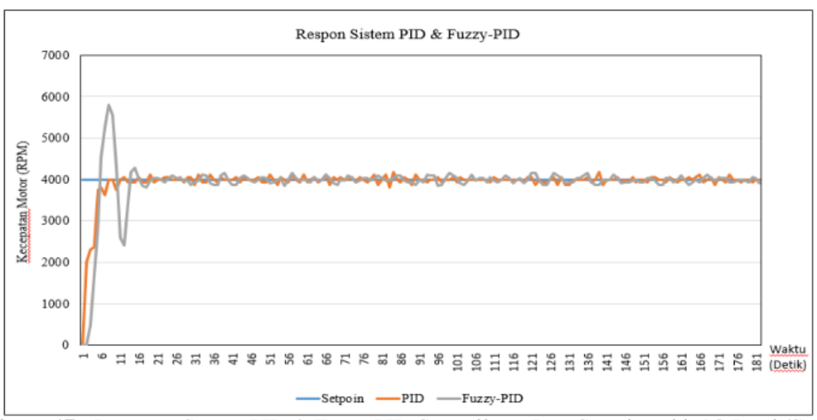

Figure 17 : Response System PID & Fuzzy-PID Controller at Low Setpoint with 1Ω Load (Seri)

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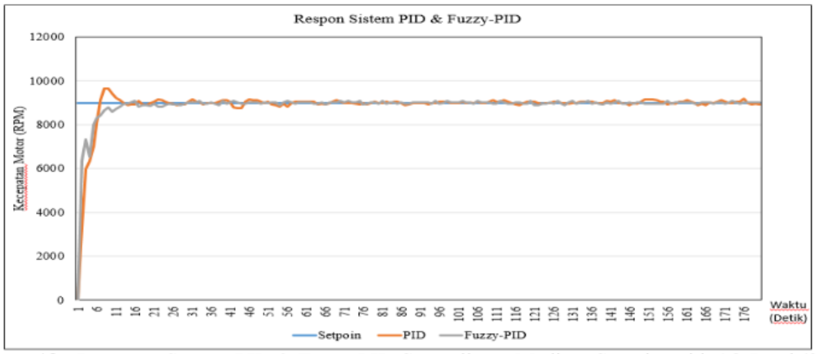

Figure 18 : Response System PID & Fuzzy-PID Controller at Medium Setpoint with 1Ω Load (Seri)

For more details can be seen in the following table of system response analysis results.

Tabel 8: Data Response System of PID and Fuzzy-PID Controller at a Medium Speed (Seri)

No.	**Beban**	***Time delay***		***Rise time***		**Settling Time**		**Steady State *Error***	
		FPID	PID	FPID	PID	FPID	PID	FPID	PID
1.	1Ω	5s	3s	7s	11s	13s	13s	164 RPM	140 RPM
2.	2Ω	6s	3s	7s	12s	20s	16s	113 RPM	149 RPM
3.	3Ω	7s	4s	7s	12s	23s	17s	104 RPM	149 RPM
4.	4Ω	8s	4s	7s	19s	25s	21s	44 RPM	79 RPM
5.	5Ω	9s	5s	10s	19s	27s	23s	44 RPM	79 RPM

Tabel 9: Data Response System of PID and Fuzzy-PID Controller at a Medium Speed (Parallel)

No.	**Beban**	***Time delay***		***Rise time***		**Settling Time**		**Steady State *Error***	
		FPID	PID	FPID	PID	FPID	PID	FPID	PID
1.	1Ω	5s	3s	6s	7s	14s	14s	100 RPM	180 RPM
2.	2Ω	6s	3s	7s	9s	18s	12s	224 RPM	116 RPM
3.	3Ω	7s	4s	8s	11s	23s	13s	104 RPM	116 RPM
4.	4Ω	8s	4s	9s	14s	25s	16s	100 RPM	59 RPM
5.	5Ω	10s	5s	11s	19s	30s	29s	100 RPM	60 RPM

As can be seen in the table above, at the medium setpoint, it is 9000 RPM. The system response generated by the PID controller is better in controlling Time Delay. This can be seen in the PID response which has a smaller Time Delay compared to the Time Delay of the Fuzzy-PID controller. As for Rise Time Fuzzy-PID is superior with almost all changes having a Rise Time of 7 seconds. And for the Time Settling of both controllers, PID is superior with an average time of 18 seconds to reach steady state.

Table 4.18 shows the results of the system response analysis of the two controllers. In contrast to series loads where PID excels in system response speed to reach steady state, parallel loads are the opposite. In parallel load, PID only excels in controlling Time Delay, while for Time Rise and Time Settling, the Fuzzy-PID controller is superior. However, the Fuzzy-PID controller at the medium setpoint has a very high overshoot. The overshoot produced by the Fuzzy-PID controller at the moderate setpoint reaches 1360 RPM. As for the low speed table, the results of the analysis of the system response are as follows.

Tabel 10: Data Response System of PID and Fuzzy-PID Controller at a Low Speed (Seri)

No.	**Beban**	***Time delay***		***Rise time***		**Settling Time**		**Steady State *Error***	
		FPID	PID	FPID	PID	FPID	PID	FPID	PID
2.	2Ω	6s	3s	7s	9s	18s	12s	224 RPM	116 RPM
3.	3Ω	7s	4s	8s	11s	23s	13s	104 RPM	116RPM

4.	4Ω	8s	4s	9s	14s	25s	16s	100 RPM	59 RPM
5.	5Ω	10s	5s	11s	19s	30s	29s	100RPM	60 RPM

Tabel 11: Data Response System of PID and Fuzzy-PID Controller at a Low Speed (Parallel)

No.	Beban	*Time delay*		*Rise time*		Settling Time		Steady State *Error*	
		FPID	PID	FPID	PID	FPID	PID	FPID	PID
1.	1Ω	5s	4s	6s	12s	17s	18s	168 RPM	176 RPM
2.	2Ω	6s	6s	7s	12s	17s	42s	108 RPM	176 RPM
3.	3Ω	7s	6s	8s	18s	20s	23s	160 RPM	176 RPM
4.	4Ω	7s	7s	9s	20s	20s	32s	220 RPM	301 RPM
5.	5Ω	8s	7s	9s	24s	20s	32s	220 RPM	112 RPM

For low speed, the resulting system response is the same as the medium setpoint. Where the Fuzzy-PID controller is superior to the PID controller in parallel load. At a low setpoint (4000 RPM) the PID controller is still superior in managing the resulting time delay, both in series and parallel loads. The main weakness of the Fuzzy-PID controller at low setpoints is that there is a very high overshoot in the resulting response. The resulting overshoot reaches 2216 RPM.

IV. CONCLUSIONS

From the results of testing and analysis of the implementation of DC Motor speed regulation with a Fuzzy-PID controller, the following conclusions can be drawn:

1. The resistive load which is arranged in series and parallel has a different character, in both types of load it has the same form of system response in each controller. However, with a different system response speed. On the PID controller with a high set point (14000 RPM) the system response in parallel load is slower than the system responds with a series resistance load, namely at 1Ω load the response at series load is 20 seconds and at parallel load the system response reaches a steady state at 29 seconds. Meanwhile, in the Fuzzy-PID parallel resistive load, the system response is faster than the series load, which is 14 seconds on series load and 13 seconds to parallel load. So that the Fuzzy-PID controller is better at controlling the plant with parallel loads while the PID is the opposite. Fuzzy-PID is superior to PID in controlling the plant at high speed and low load.
2. When given a different set point, Fuzzy-PID experiences a very high overshoot, which is 2216 RPM at a low set point (4000 RPM) and 1611 RPM at a speed set point of 9000 RPM. While the PID controller remains consistent in its response to changes in setpoints (there is no overshoot). So that the PID controller is superior to setpoint changes compared to the Fuzzy-PID controller.
3. At the 9000 RPM and 4000 RPM setpoints, the system response from Fuzzy-PID at series load is slower than the response generated by the PID controller. Where Fuzzy-PID is only superior to a faster rise time. The fastest settling time, the lowest steady state error and the smallest overshoot are in the system response from the PID controller. Whereas in parallel load only 4000 RPM setpoint from Fuzzy-PID

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