Performance Comparison of PI Control and Fuzzy Logic Control for Speed Control of DC Shunt Motor Using Matlab / Simulink

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***Abstract*— DC motor speed regulation is an important role in the industrial process so it can run easily and efficiently. Even if there is a change in load, the speed of the DC motor must be controlled so that it has a constant speed. A good DC motor speed control system must have a fast and accurate response. However, in reality, it is rare to find a DC motor that has controlled to get a constant speed. This research presents an analytical comparison of PI Control and Fuzzy Logic Control (FLC) with 7 membership functions, for DC shunt motor speed control. To adjust the speed by changing the DC motor input voltage using a buck converter. From the simulation results, when there's a load disturbance in the system, using FLC the speed response of the DC motor is more constant with the average steady-state is at 1.788 seconds and it can reduce the overshoot. Meanwhile, the average steady-state of PI control is at 2.058 seconds and the average overshoot is 1.732% when the system returns to the specified condition. It shows that FLC is better used for DC motor speed control.**

Keywords—DC shunt motor, PI control, fuzzy logic control, matlab, simulink

I. Introduction

In industry, DC motors are widely used as a motor for driving mechanical loads, because of DC motors has greater torque characteristics compared to an induction motor. Besides, the DC motor has a greater speed range than the induction motor, and it's easy to adjust the speed, easy to control, and have high-speed performance. Even if there is a change in load, the speed of the DC motor must be controlled so that it has a constant speed. A good speed control system must have a fast and accurate response. But in reality, it is possible that a DC motor may operate in a non-linear manner due to load changes, inertia drives, and armature current [1]. As the PI control only can control linear plants, then an advanced controller is developed to control non-linear plants, namely the Fuzzy Logic Controller (FLC). FLC is more widely used to control the speed of DC motor because this control has high flexibility when the load changes, and insensitive to DC motor parameters which would normally have to be obtained by performing DC test, AC test [3].

In this paper, a comparison of PI control and FLC with 7 membership function, is used as a close-loop system for DC motor speed control with speed feedback. The speed control system uses a DC-DC converter, buck converter, as the input voltage of a DC motor with changes in the duty cycle according to the desired set point. The comparison of the two controllers is carried out in the three different conditions using MATLAB/Simulink software, to show which controller is better used for speed control of DC shunt motor. Using PI control with one value of Kp and Ki cannot be used at different speed setpoints because it can cause the speed response not maximal [2]. Therefore, using FLC can improve the speed response with one FIS design even though the setpoint is different. The use of FLC can also reduce overshoot/undershoot at the beginning of the response and constant for a short time.

II. Research Methodology

A. DC Shunt Motor

DC motor or direct current motors are usually used as motors to drive mechanical loads. The advantage of using this motor is for speed regulation. The DC shunt motor is a DC motor whose field coil is in parallel with the armature coil as shown in Figure 1 [5]. This type of motor has a relatively constant speed even though the load changes.

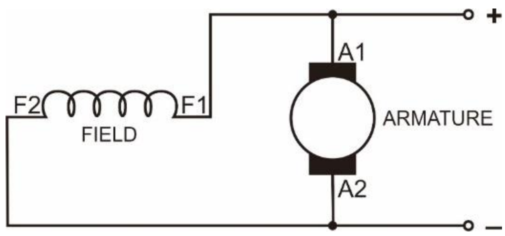


Fig. 1. Topology DC Shunt Motor

Parameters of the DC Shunt-Wound Machine Type 73191 class 0.3 at the Politeknik Elektronika Negeri Surabaya, Lab. Teknik Sistem Tenaga are shown in Table 1.

TABLE I. DC Shunt Motor Parameter

Parameter	Symbol	Value	Unit
Power	P	0.3	kWatt
Speed	n	2000	RPM
Armature Voltage	Va	220	Volt
Armature Current	Ia	1.8	Ampere
Field Voltage	Vf	220	Volt
Field Current	If	0.3	Ampere

Figure 2. shows the uncontrolled speed response. It can be seen that the response close to the nominal motor

nameplate speed 1997 RPM, and rise time = 0.448 seconds, and settling time = 1.867 seconds.

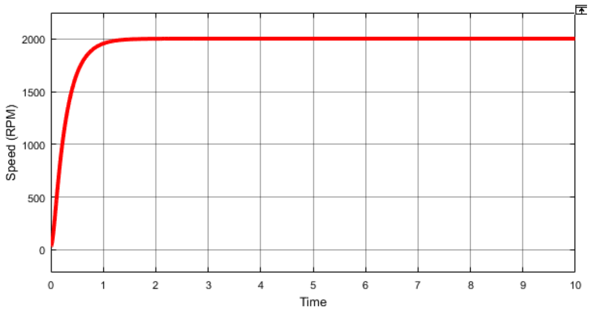


Fig. 2. Uncontrolled DC Motor Response

One way to regulate motor speed is by voltage regulation method called The Ward Leonard System. This method provides such control and involves another generator to drive a motor.

B. Buck Converter

Buck converter is a DC-DC converter that is able to reduce the voltage so that the output voltage will be smaller than the input voltage. Buck converter works with the principle of switching control which later called the duty cycle. In this system, the buck converter duty cycle regulates the DC motor input voltage to change the speed of the DC motor as feedback from the controller to match the specified setpoint. The efficiency of the buck converter is up to 95% and the self-adjusting circuit [6].

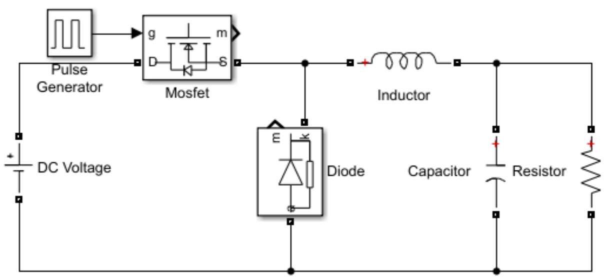


Fig. 3. Topology Buck Converter

The main components of buck converter are MOSFET / IGBT, diodes, inductors, and capacitors. Figure 3 is the equivalent circuit of a buck converter. The following equation is to design the component value of the buck converter.

$$Vo = D \times Vin \quad (1)$$
$$L = Vo\,(1 - D) / \Delta iL \times f \quad (2)$$
$$C = \Delta iL / 8 \times f \times \Delta Vo \quad (3)$$

The meaning of the symbol above is as follows.

Vo	= Output Voltage	(Volt)
Vin	= Input Voltage	(Volt)
D	= Duty Cycle	(%)
L	= Inductor	(H)
C	= Capacitor	(F)
f	= Frequency	(Hz)

So, after all the values for each component are calculated using equations 1, 2, and 3, the buck converter design parameters can be seen in Table 2.

TABLE II. BUCK CONVERTER PARAMETER

Parameter	Symbol	Value	Unit
Input Voltage	Vin	220	Volt
Duty Cycle	D	80	%
Inductor	L	2.2	mH
Capacitor	C	7.1	µF
Switching Frequency	f	40	kHz

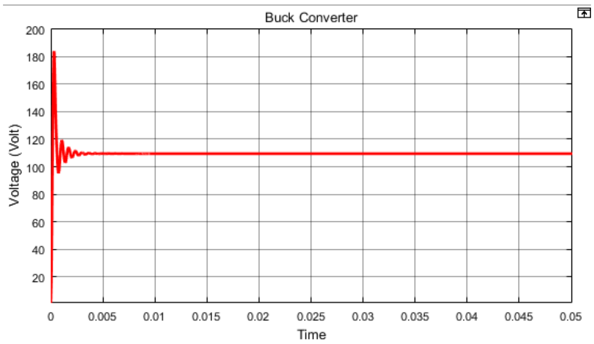


Fig. 4. Buck Converter Response

Figure 4 is the result of the buck converter output voltage signal at the duty cycle = 50%. There is a high spike at the beginning of the wave. To reduce the spike, the buck converter circuit can be given a snubber circuit.

C. PI Control

One of the control to control DC motor speed is PI control. PI control is a combination of control P (Proportional) and controls I (Integral). Control Proportional has the advantage of fast rise time, and control Integral has the advantage to minimize errors. To get the output with fast rise time and small error, then the two controls P and I are combined into PI control.

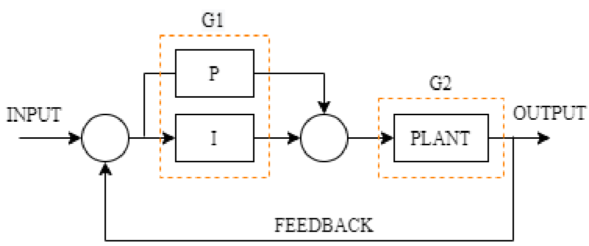


Fig. 5. Basic Structure of PI Control System

It is a generic control loop feedback mechanism and used as a feedback controller [4]. Referring to the block diagram in Figure 5, the calculation is done mathematically using the following equation.

$$G1 = Kp\,((\tau i \times \tau d \times S^2) + \tau iS + 1) / \tau iS \quad (4)$$

Usually, in the PI control, there is a control Derivative (D), but control D is not necessary used when the system[8]:
1. Do not require a fast response.
2. There is no visible disruption during the system running.
3. There is only a capacitive or inductive energy storage.
4. There is a large delay in the system.

Based on the calculation of Kp and Ki in Equation 4, the values of Kp = 1.05 and Ki = 8.22. DC shunt motor speed control system simulation with PI control shown in Figure 6.

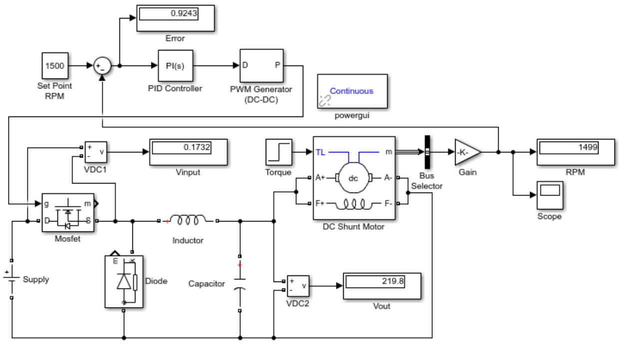


Fig. 6. DC Shunt Motor Simulation Controlled by PI Control

D. Fuzzy Logic Control

To improve or exchange conventional control techniques, one of the intelligent techniques developed by Zadeh, namely fuzzy logic control is widely applied to control various conditions and applications. Because this control can learn faster about various conditions. Analytically, the FLC defuzzification method proved to be equivalent to a non-linear PI control [4].

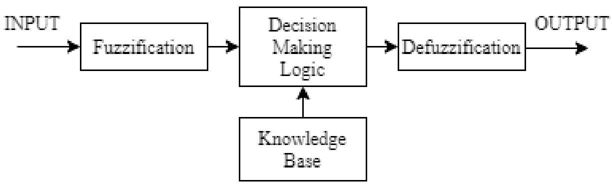


Fig. 7. Fuzzy Logic Control Diagram

From FLC basic structure in Figure 7, we can learn that:
1. The fuzzification process is to converting analog quantities into fuzzy inputs.
2. Fuzzy Inference System (FIS) is an application of the rule base generated in the fuzzification process.
3. The defuzzification process is to determine a crisp output value. In the defuzzification process, all fuzzy output values effectively modify the output membership function.

At the initial stage, the membership function for fuzzy input must be determined. Because the DC motor speed regulation system is a fuzzy one that changes the duty cycle value of the PWM switching when the load changes. Then the membership function input must represent the error and delta error values. In this study, two inputs were used, namely error (setpoint – present value) and delta error (current error – previous error).

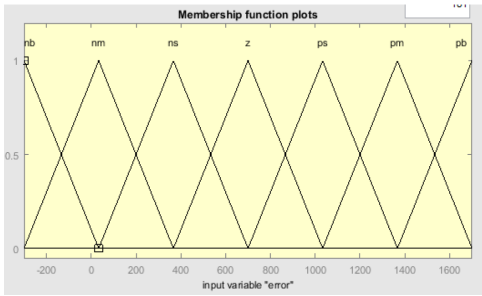


Fig. 8. Design Membership Function Input Error

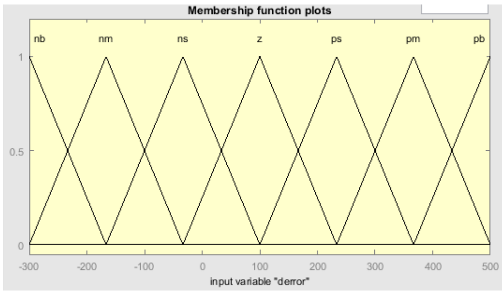


Fig. 9. Design Membership Function Input Delta Error

Membership function error and delta error, PB represents Positive Big, PM represents Positive Medium, PS represents Positive Small, Z represents Zero, NS represents Negative Small, NM represents Negative Medium, and NB represents Negative Big.

TABLE III. RULE BASE

	NB	NM	NS	Z	PS	PM	PB
NB	onb	onb	onb	onm	ons	onl	oz
NM	onb	onb	onm	ons	onl	oz	opl
NS	onb	onm	ons	onl	oz	opl	ops
Z	onm	ons	onl	oz	opl	ops	opm
PS	ons	onl	oz	opl	ops	opm	opb
PM	onl	oz	opl	ops	opm	opb	opb
PB	oz	opl	ops	opm	opb	opb	opb

The rule base will be used as a rule to regulate the output of the duty cycle using a membership of 7, which is expected to produce better control.

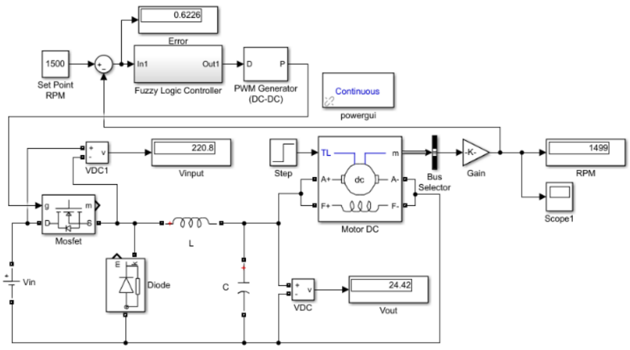


Fig. 10. DC Shunt Motor Simulation Controlled by Fuzzy Logic Controller

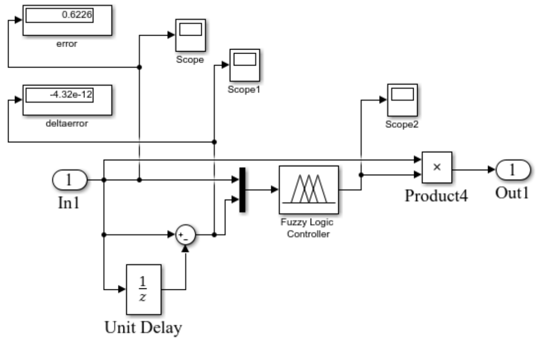


Fig. 11. Subsystem Fuzzy Logic Control

III. Simulation Result

Performance comparison simulation between PI control and FLC for DC shunt motor speed control is done using MATLAB/Simulink. The buck converter circuit as a motor input voltage and speed as a feedback controller.

A. *An Uncontrolled Condition*

An uncontrolled condition or commonly known as the open-loop test aims to determine the characteristics of the DC motor. The duty cycle value of the pulse generator used by the buck converter is adjusted so that the speed is following the expected speed reference 1500 RPM. With this open-loop test method, the DC motor operated at a reference speed without load and a controller. The response result from this condition then becomes the initial parameter for designing a good controller.

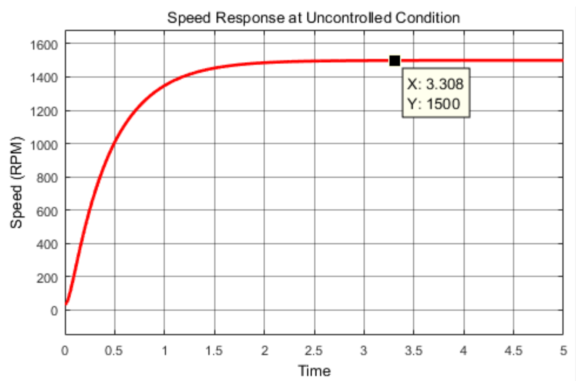
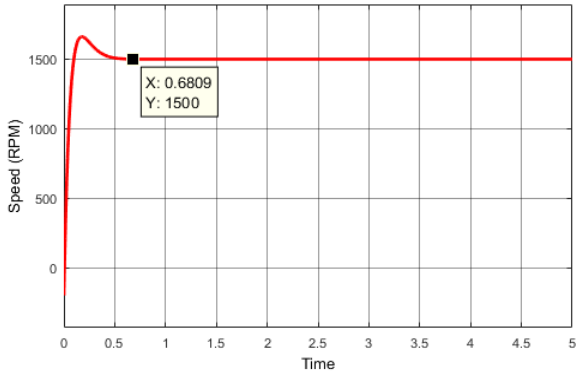


Fig. 12. Speed Response at Uncontrolled Condition

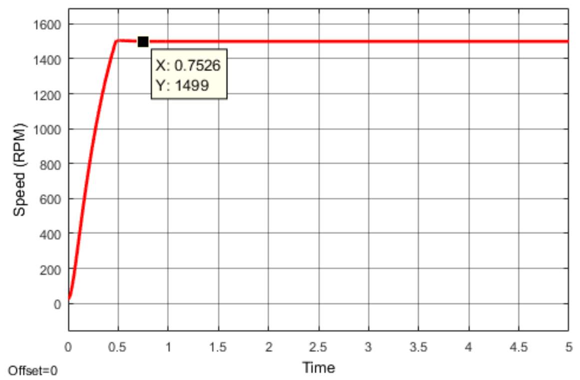
The simulation results of the uncontrolled condition can be seen in Figure 12. The duty cycle is set at 68.92% so that is following the reference speed 1500 RPM. Rise time = 0.725 seconds, settling time = 3.308 seconds, and steady-state at 1500 RPM, this parameters will be used to design a closed-loop controller.

B. *A No-Load Condition*

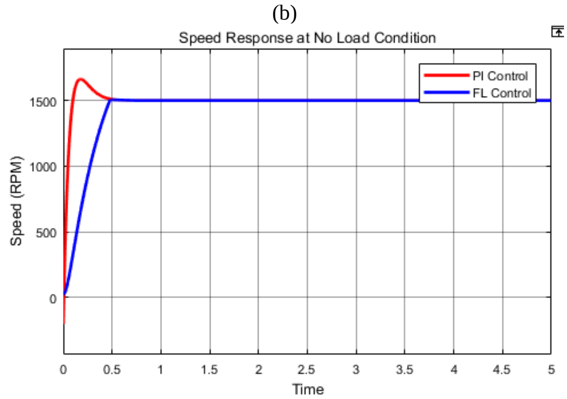
A no-load condition is a buck converter that is connected to a DC motor plant and it's been controlled without any additional load with a speed setpoint of 1500 RPM.



(a)



(b)



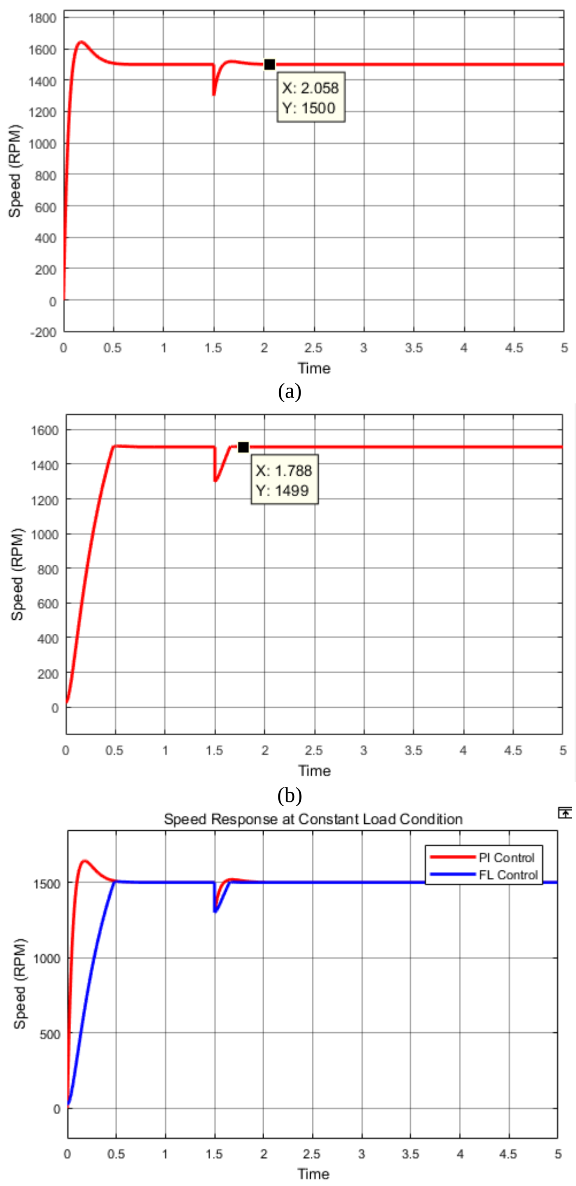
(c)

Fig. 13. Speed Response at No Load Condition (a) Using PI Control (b) Using FLC (c) Comparison of Two Controllers

From the results of the comparative response in Figure 13 (c), it is known that in PI control response there is an overshoot at the beginning of the response but the rise time is faster (a) compared to a system controlled by FLC which tend to rise longer (b).

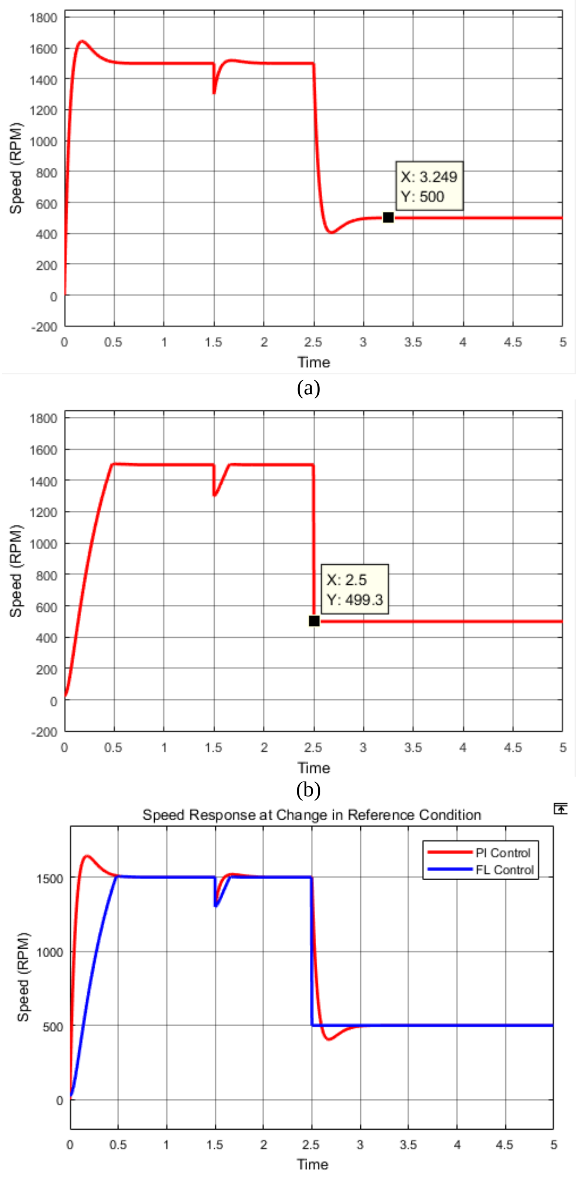
C. *An Additional Load Condition*

An additional load condition is a buck converter that is connected to a DC motor plant with a load torque of 200 Nm at 1.5 seconds at a constant speed of 1500 RPM and it's been controlled.



(a) (b) (c)

Fig. 14. Speed Response at Additional Load Condition (a) Using PI Control (b) Using FLC (c) Comparison of Two Controllers



(a) (b) (c)

Fig. 15. Speed Response at Sudden Setpoint Changes Condition (a) Using PI Control (b) Using FLC (c) Comparison of Two Controllers

From the results of the comparative response in Figure 14 (c), it is known that increasing the load suddenly at a certain time causes the speed drop for a moment. By using the PI control, it is faster to return the speed dropped due to load to the setpoint speed even though there is a momentary overshoot of 1.2% to the second steady-state at 2.058 seconds (a) compared by using FLC, although it is not as fast as PI control, the speed is more constant when it goes to the second steady-state at 1.788 seconds (b).

D. A Sudden Setpoint Change Condition

A change in setpoint condition is a buck converter that is connected to a DC motor plant with a sudden change speed setpoint from 1500 RPM to 500 RPM at 2.5 seconds and it's been controlled.

From the results of the comparative response in Figure 15 (c), sudden setpoint changes, speed response controlled by PI there is an undershoot of 1.998% for a moment before steady-state at setpoint 500 RPM in 3.249 seconds (a). Meanwhile, by using FLC, the speed response is more constant and precise at 2.5 seconds when the setpoint changes (b).

E. A Comparison of PI and Fuzzy Logic Control

To observe the difference in the speed response of the DC motor that has been controlled, three different conditions were made:

1. A no-load condition.
2. An additional load condition.
3. A sudden setpoint change condition.

From the three conditions above, we can learn that FLC can learn faster against sudden change conditions compared to PI control. When there is a change in the setpoint or a system has a varying setpoint like in the speed control, PI control is not recommended because it can cause an overshoot/undershoot at different setpoints. Whereas FLC design can be used at various setpoints and the output response remains constant.

TABLE IV. RESPONSE COMPARISON DATA

PI Control				
Setpoint (RPM)	**Actual Speed (RPM)**	**Over shoot (%)**	**Rise Time (ms)**	**Settling Time (s)**
1500	1500	1.999	59.307	0.6809
Fuzzy Logic Control				
Setpoint (RPM)	**Actual Speed (RPM)**	**Over shoot (%)**	**Rise Time (ms)**	**Settling Time (s)**
1500	1499	0.505	342.412	0.7526

Response comparison data in Table 4 shows that the DC shunt motor speed control is better using FLC because it can reduce overshoot/undershoot as happened to PI control. But consequently, the rise time in FLC is longer than the rise time in PI control.

IV. CONCLUSION

Conclusions that can be drawn from the simulation results and comparison of PI control and Fuzzy Logic Control analysis, that to control the speed of the DC shunt motor it is better to use FLC. The results of the speed response show that FLC can learn faster against conditions/load changes with the smaller overshoot 0.505%. As when using the PI control, the average of overshoot is 1.732% when there are load changes. In terms to compare the rise time and the settling time, using FLC is longer than the PI control. With a better FIS design, the result of the FLC time response will be better than PI control. And also in PI control to reduce overshoot/undershoot, derivative control (Kd) can be used. The DC motor speed control is better using FLC because it can reduce the overshoot/undershoot which can shorten the lifetime of the DC motor.

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