

Design of Temperature Control in Air Conditioner Using Self-Tuning PID Based on Fuzzy-Mamdani

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Abstract— Air Conditioner (AC) is a form of technological advancement in air conditioning. The consumption of AC in society is also very high at 48% using AC for 8-12 hours per day. This data is according to the Indonesian Consumers Foundation (YLKI). There are many factors behind this very long use. In this article try to see the AC factor that has not efficiently obtained the temperature setpoint value causing excessive use. When the AC gets the setpoint from the remote control. The actuator component in the form of a Peltier will work to achieve that value. This design will be carried out in order to create a PID control that performs tuning with the Fuzzy-Mamdani method in order to obtain the appropriate PID coefficient value. The test results from the Self-Tuning PID controller have a faster steady state time in all tests. In each test of the fixed reference value. The test of the changing reference value. and the test with the disturbance signal in the form of a step Self-Tuning PID have a faster time of 6.273 s. 3.364s and 5.4545s respectively. For the performance evaluation index, the Self-Tuning PID controller tends to have smaller ISE, IAE, and ITAE values in each test compared to the existing PID controller.

Keywords: Fuzzy logic, PID, fuzzy tuning, temperature.

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I. INTRODUCTION

The technology that is developing today has provided convenience for humans in various fields. including the air conditioning industry. Advances in cooling technology have resulted in significant innovations in recent years. Each existing innovation has the same goal. which is to accelerate the cooling process. improve system efficiency. and reduce energy consumption (Liu et al., 2016) These two important missions—accelerating the cooling process and energy efficiency—are targets that need to be achieved in the use of air conditioning technology. (Attia Rezeki and Saleh 2015)

The technology developed to improve the quality of air cooling is called an air conditioner (AC). The function of an air conditioner is to regulate the room temperature with a setpoint temperature. The ideal condition for an air conditioner is a system that quickly reaches the setpoint temperature and has efficient energy consumption. (Zhou et al., 2020)

In controlling the temperature of an air conditioner. the factor that accelerates the AC in reaching the setpoint is the control system used. In this design. a Proportional Integral Derivative (PID) control is used (Ambroziak and Chojecki, 2023). The self-tuning PID control utilizes Fuzzy logic to obtain the values of the proportional. integral. and derivative coefficients (Zhai Dong and Hu, 2024). This control method enables the automatic adjustment of PID

parameters based on system conditions. thereby improving the overall control performance.

This research aims to design a temperature control system for air conditioners to achieve optimal room cooling using an automatic self-tuning PID control method while minimizing energy consumption. As part of this design. a Peltier cooler is used as the temperature control actuator (AFSHARI, 2020). The main focus of this research is to reach a temperature setpoint of 23°C from an initial room temperature of 25°C. By achieving the objectives of this design. it is expected that the air conditioner will operate more efficiently. reduce energy waste. and contribute to energy-saving efforts in both household and commercial sectors.

II. METODE

The methodology of this research is adapted to the stages. with the research flow following the steps in the system design process. There are two main stages in this study: the design of the Plant model and the design of the self-tuning PID controller using Fuzzy-Mamdani.

A. Model Plant Air Conditioner

This system has a transfer function and delay time taken from the journal. The empirical formula for the air conditioner is as follows (Xie and Long, 2015a).

$$G(s) = \frac{Ke^{-\tau s}}{Ts+1} \quad (1)$$

Keterangan:

G(s): Transfer function process control

K : Gain

T : Time constant

τ : Time delay

For the transfer function formula of this system, the following formula is used:

$$G(s) = \frac{0.13}{18s+1} e^{-1.8s} \quad (2)$$

The simulation of this PID controller aims to observe the system response with the expectation that the simulation can represent the actual Plant. During the simulation process, error data and delta error from the system are collected. This simulation system is used to obtain the appropriate range for inputs and outputs. Therefore, adjustments to the PID controller parameters can be made to improve system performance, ensuring that the designed system produces better results. The basis for determining the values of K_p , K_i , and K_d is obtained from the journal, and the values are as shown in the equation below (Xie and Long 2015b).

$$K_p = 40 \quad (3)$$

$$K_i = 2.169 \quad (4)$$

$$K_d = 17 \quad (5)$$

Simulink in the MATLAB application is run to observe the system response and evaluate the performance of the controller. The simulation results will provide important data, such as error values and delta error; both are necessary to analyze system performance. The simulation will be conducted starting from an initial temperature of 25°C towards a setpoint of 23°C. The system response is shown in Figures 1 to 3.

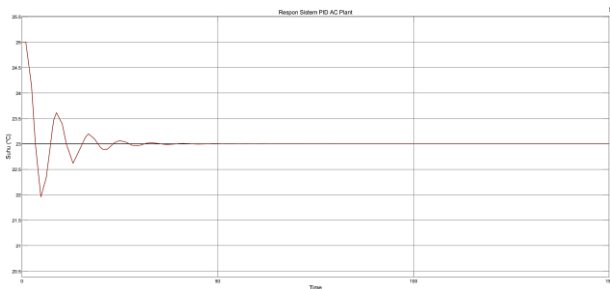


Figure 1. Delta Error Sistem Kontrol PID AC Plant

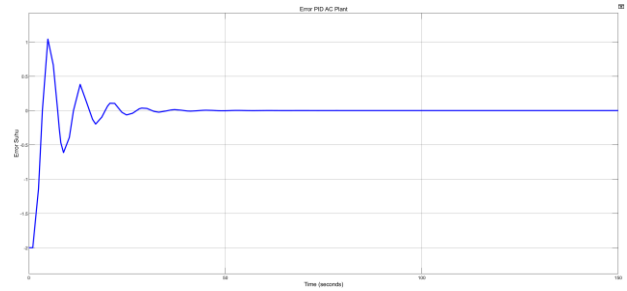


Figure 2. AC Plant PID Control System Error

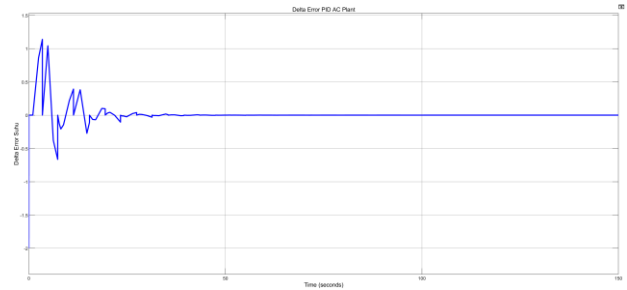


Figure 3. Delta Error PID AC Plant Control System

The error and delta error responses of the PID controller for the AC Plant will serve as the basis for determining the input range of the self-tuning PID controller with Fuzzy-Mamdani. The error range, as shown in Figure 5, indicates a range up to -2. Considering that in practice the AC is used down to a temperature of 19°C, this is set as the range for the self-tuning PID controller, starting from -9 to 9. For the delta error, it will be taken from the midpoint of the error values, so the delta error range starts from -4.5 to 4.5. The purpose of expanding this range is to create a system with a control range that matches the typical temperature usage of the AC.

B. Design of Self-Tuning PID

The design of the Fuzzy-Mamdani self-tuning PID controller uses temperature as its input, which is called the setpoint (SP). Furthermore, the Fuzzy controller will use error and delta error as inputs. The outputs of the Fuzzy-Mamdani are the values of K_p , K_i , and K_d , which will be used as control signals for the AC plant. The final output from the plant is the temperature, called the Process Variable (PV) (He and Li, 2020). The PV will then be fed back and its difference from the SP will be calculated. The feedback temperature will be obtained from a KSD9700 bimetal thermal thermostat sensor; this system is also referred to as a closed-loop system. The block diagram can be seen in Figure 4.

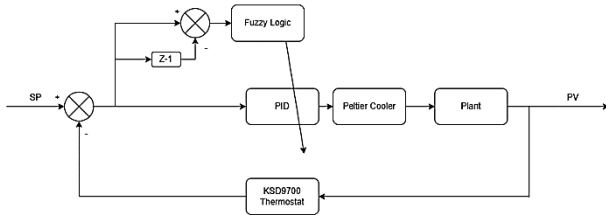


Figure 4. Block Diagram of Self-Tuning PID with Fuzzy-Mamdani

The Fuzzy-Mamdani control in this design will use error and delta error as inputs. The difference between the setpoint (SP) and the process variable (PV) produces the error value, and the difference between the current error and the previous error produces the delta error value. These two inputs will be fuzzified using seven membership functions for each input, with each membership function shaped as a triangle. The aggregation process will use the Maximum method. The defuzzification process is the final step to produce outputs in the form of K_P , K_I , and K_D values (Belman-Flores et al., 2022). The defuzzification method used to convert fuzzy quantities into crisp values is the Centroid method. The outputs from the Fuzzy-Mamdani controller will be the K_P , K_I , and K_D values, which will serve as control signals for the AC Plant (Firmansyah and Astutik, 2024). This process will continue until the system reaches the setpoint and stabilizes. The flowchart of the self-tuning PID with Fuzzy-Mamdani operation is shown in Figure 5. (Khokhar et al., 2020)



Figure 5. Flowchart of Self-Tuning PID with Fuzzy-Mamdani

C. Membership Function of Input and Output

In the design of the PID controller with Fuzzy-Mamdani tuning, there are two inputs, namely error and delta error, and three outputs, which are K_P , K_I , and K_D . The membership functions for both inputs and outputs are triangular functions (Furizal Sunardi

and Yudhana, 2023). Both the outputs and inputs will have seven membership functions each. The determination of the membership functions for controlling from 25°C to the setpoint of 23°C is based on the temperature range of the AC that may be used, with a lower limit of 16°C, which has a difference of 9°C from the room temperature (25°C). Therefore, the error range for this design is $[-9, 9]$. The membership function range for delta error is determined based on Figure 3, resulting in a delta error range of $[-1.5, 1.5]$. The basis for determining the range values of K_P , K_I , and K_D is obtained from the journal, and their values are given according to equations 3 to 5 (Zhou et al., 2020).

This design will place the PID constant values as the midpoint values. Thus, based on the above equations, the ranges are obtained as $K_P [0, 80]$, $K_I [0, 4]$, and $K_D [0, 35]$. It is expected that the system will have a wide control coverage corresponding to the expanded input range of the system.

The membership functions for the error are Negative Big (NB), Negative Medium (NM), Negative Small (NS), Zero (Z), Positive Small (PS), Positive Medium (PM), and Positive Big (PB) with a range of $[-9, 9]$. The membership functions can be seen in Figure 6.

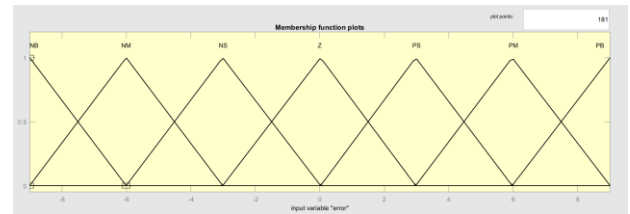


Figure 6. Membership Function of Error

The membership functions for the delta error are Negative Big (NB), Negative Medium (NM), Negative Small (NS), Zero (Z), Positive Small (PS), Positive Medium (PM), and Positive Big (PB) with a range of $[-1.5, 1.5]$. The membership functions can be seen in Figure 7.

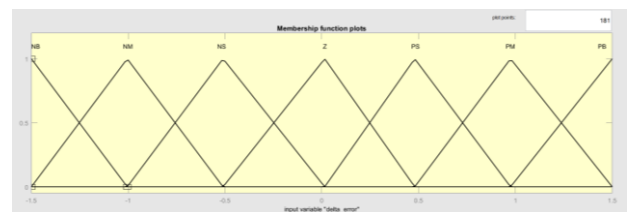
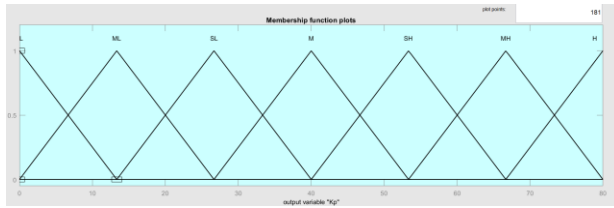
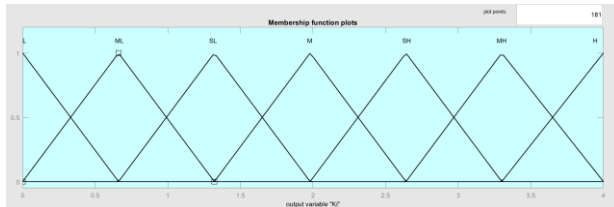


Figure 7. Membership Function of Delta Error

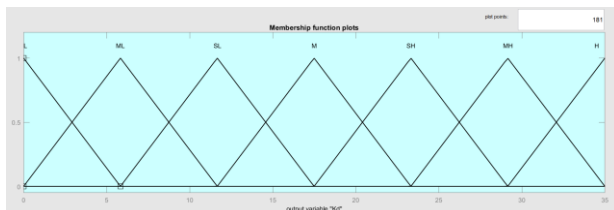
The membership functions for the K_P are Negative Big (NB), Negative Medium (NM), Negative Small (NS), Zero (Z), Positive Small (PS), Positive Medium (PM), and Positive Big (PB) with a range of $[0, 80]$. The membership functions can be seen in Figure 8.


Figure 8. Membership Function of K_p

The membership functions for the K_i are Negative Big (NB). Negative Medium (NM). Negative Small (NS). Zero (Z). Positive Small (PS). Positive Medium (PM). and Positive Big (PB) with a range of [0.4]. The membership functions can be seen in Figure 9.


Figure 9. Membership Function of K_i

The membership functions for the K_D are Negative Big (NB). Negative Medium (NM). Negative Small (NS). Zero (Z). Positive Small (PS). Positive Medium (PM). and Positive Big (PB) with a range of [0.35]. The membership functions can be seen in Figure 10.


Figure 10. Membership Function of K_D

D. Rules Fuzzy

This design has 49 rules. taking into account the functions of each control component: Proportional. Integral. and Derivative (PID). For the K_p rules. they are based on its function. which is to speed up the system response. If the error is large and the delta error is small. indicating that the system is still far from the setpoint but approaching it quickly. then a large K_p is required. If both the error and delta error are large. indicating that the system is far from the setpoint and moving away from it. then a large K_p is also required. If both the error and delta error are small. indicating that the system is close to the setpoint and stable. then a medium K_p is needed. If the error and delta error indicate that the system is close to the setpoint but changing rapidly. then a small K_p is required to avoid overshoot. This explanation is presented in Table 1. (Abdrakhmanov et al., 2024a)

Table 1. Determination of Fuzzy Rules on K_p Output

$e/\Delta e$	NB	NM	NS	Z	PS	PM	PB
NB	H	H	MH	MH	SH	M	M
NM	H	H	MH	SH	SH	M	SL
NS	MH	MH	MH	SH	M	SL	SL
Z	MH	MH	SH	M	SL	ML	ML
PS	SH	SH	M	SL	SL	ML	ML
PM	SH	M	SL	ML	ML	ML	L
PB	M	M	ML	ML	ML	L	L

The K_i rules are based on its function. which is to eliminate steady-state error. If the error is large and the delta error is small. indicating that the system is still far from the setpoint but approaching it quickly. then a small K_i is required. If both the error and delta error are large. indicating that the system is far from the setpoint and moving away from it. then a large K_i is required. If both the error and delta error are small. indicating that the system is close to the setpoint and stable. then a medium K_i is needed. If the error is small but the delta error is large. indicating that the system is close to the setpoint but changing rapidly. then a small K_i is required to avoid overshoot. This explanation is presented in Table 2. (Abdrakhmanov et al., 2024b)

Table 2. Determination of Fuzzy Rules on K_i Output

$e/\Delta e$	NB	NM	NS	Z	PS	PM	PB
NB	L	L	ML	ML	SL	M	M
NM	L	L	ML	SL	SL	M	M
NS	L	ML	SL	SL	M	SH	SH
Z	ML	ML	SL	M	SH	MH	MH
PS	ML	SL	M	SH	SH	MH	H
PM	M	M	SH	SH	MH	H	H
PB	M	M	SH	MH	MH	H	H

The K_D rules are based on its function. which is to dampen oscillations and overshoot. If the error is large and the delta error is small. indicating that the system is still far from the setpoint but approaching it quickly. then a small K_D is required. If both the error and delta error are large. indicating that the system is far from the setpoint and moving away from it. then a large K_D is required. If both the error and delta error are small. indicating that the system is close to the setpoint and stable. then a medium K_D is needed. If the error is small but the delta error is large. indicating that the system is close to the setpoint but changing rapidly. then a small K_D is required to avoid overshoot. This explanation is presented in Table 3. (Abdrakhmanov et al., 2024a)

Table 3. Determination of Fuzzy Rules on K_D Output

$e/\Delta e$	NB	NM	NS	Z	PS	PM	PB
NB	SH	SL	L	L	L	ML	SH
NM	SH	SL	L	ML	ML	SL	M
NS	M	SL	ML	ML	SL	SL	M

Z	M	SL	SL	SL	SL	SL	M
PS	M	M	M	M	M	M	M
PM	H	SL	SH	SH	SH	SH	H
PB	H	MH	MH	MH	SH	SH	H

The rules are a combination of Table 1 to Table 3 using the AND function. The rules will produce the values of K_P , K_I , and K_D . In this control system design, a total of 49 rules are used. (Abdelghany Elnady and Ibrahim, 2023).

III. RESULTS AND DISCUSSION

The Self-Tuning PID Fuzzy-Mamdani controller system will be tested with variations including a constant reference value (setpoint), changes in the reference value (setpoint), and the controller being subjected to disturbance signals in

the form of steps. All three variations will have a setpoint of 23°C with an initial temperature of 25°C. The designed self-tuning PID controller will be compared with the setpoint of 23°C as well as the response of the PID AC Plant. This system design is expected to achieve a fast steady-state time and a smaller performance evaluation index compared to the PID AC Plant controller. The block diagram of the Self-Tuning PID Fuzzy-Mamdani control used in this design is shown in Figure 11. (Xie Yan and Zeng, 2022)

The design of the self-tuning PID control integrates proportional, integral, and derivative control. This approach aims to produce an optimal control signal. The PID structure used in this design is an ideal independent PID, where each PID parameter operates separately without influencing each other. (Lahlouh et al. 2021).

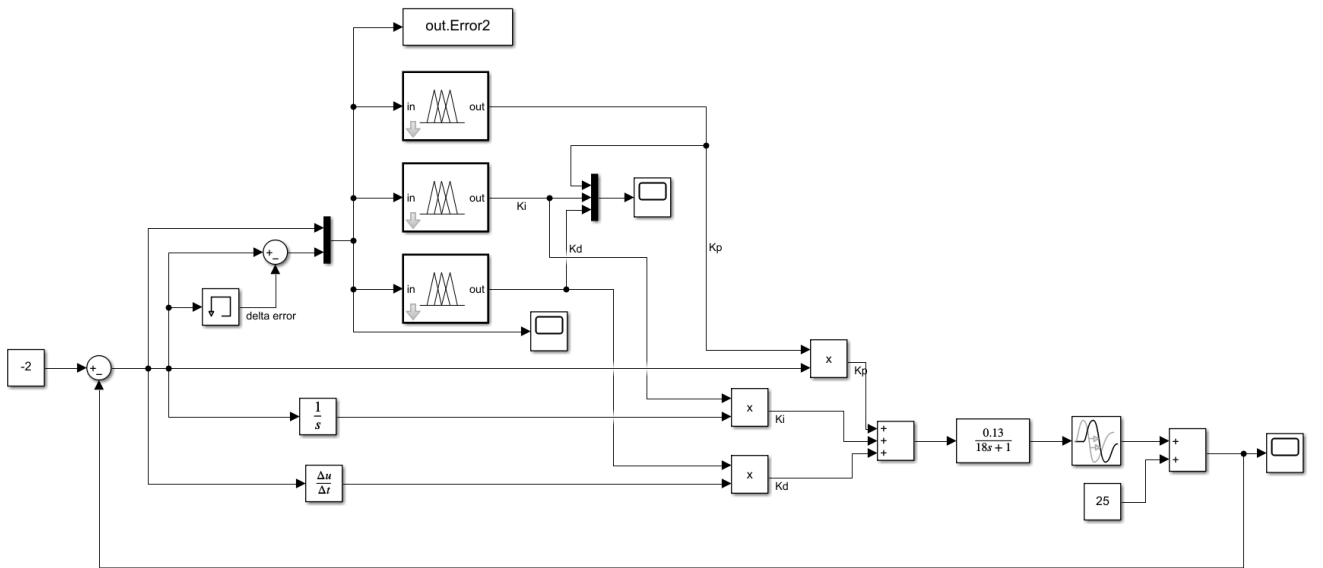


Figure 11. Block Diagram of Self-Tuning PID on MATLAB

System performance evaluation is carried out using performance indices. The selection of performance indices is adjusted to the process being analyzed so that focus can be given to specific aspects of system performance. This approach allows the system to be designed and optimized to meet the desired specifications. The performance indices used as references include ISE, IAE, and ITAE. These indices serve as parameters to assess the performance of the control system. Each index can be calculated using the equations described in the following section (Maghfiroh et al., 2021).

Integral of the Square Error (ISE)

$$ISE = \int_0^{\infty} e^2(t) dt$$

Integral of Absolute Magnitude Error (IAE)

$$IAE = \int_0^{\infty} |e(t)| dt$$

Integral of Time multiplied by the Absolute Error (ITAE)

$$IAE = \int_0^{\infty} |e(t)| dt$$

A. System Response Test Results with Fixed Reference Value

In this first variation, the self-tuning PID controller will be tested with a fixed reference value, with a setpoint of 23°C starting from an initial temperature of 25°C. The comparison will begin with the system response, steady-state time, and performance evaluation indices.

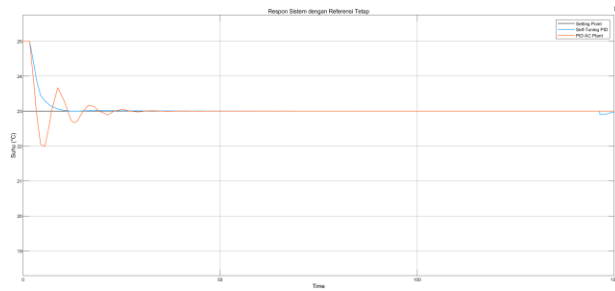


Figure 12. System Response with Fixed Reference

The system response results with a fixed reference show a better system performance with no overshoot and a faster response compared to the PID AC Plant. The system response for this test variation can be seen in Figure 12. The comparison between the two will be made by comparing the steady-state time and performance evaluation indices of IAE, ISE, and ITAE. The results are presented in Table 4.

Table 4. Results of System Response Test with Fixed Reference Value

Respos Sistem	Steady State Time (s)	ISE	IAE	ITAE
Kontroler PID AC Plant	17.216	12.68	11.22	67.52
Kontroler Self- Tuning PID	10.943	11.4	8.141	67.01

The Self-Tuning PID controller shows better system response values compared to the PID AC Plant controller. The Self-Tuning PID system response reaches steady state faster by 6.273 seconds than the PID AC Plant. The system response indicates that the Self-Tuning PID controller has a better response, as shown in Table 4.

In terms of performance evaluation indices, the Self-Tuning PID controller has smaller ISE and IAE values compared to the PID AC Plant. For ITAE, the difference is very small and can be neglected. This indicates that the system response has better performance evaluation. The test with a fixed reference value shows that the Self-Tuning PID controller is better based on the time to reach steady state and its performance evaluation indices, as presented in Table 4.

B. System Reference Simulation with Reference Changes

In this second variation, the self-tuning PID controller will be tested with changes in the reference value, starting with a setpoint of 23°C from an initial temperature of 25°C. The reference value will be changed by applying step input signals at 30 seconds and 100 seconds. At 30 seconds, the setpoint will be changed to 24°C, and at 100 seconds, the setpoint will

be changed to 22°C. The comparison will begin with the system response, steady-state time, and performance evaluation indices.

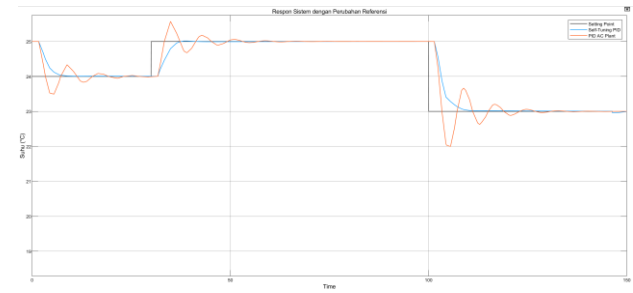


Figure 13. System Response with Reference Changes

The Self-Tuning PID system response takes longer to reach the setpoint but stabilizes faster compared to the PID AC Plant, as seen from the smaller steady-state time. This is an important consideration because it is expected that with changes in the reference (setpoint), the system can respond quickly to these changes, reach the setpoint, and remain stable at that setpoint. The system response can be seen in Figure 13.

Table 5. Results of System Response Test with Reference Changes

Respos Sistem	Steady State Time (s)	ISE	IAE	ITAE
Kontroler PID AC Plant	14.261	19.11	22.76	1456
Kontroler Self- Tuning PID	10.897	16.9	15.61	958.5

The Self-Tuning PID controller demonstrates better system response compared to the PID AC Plant controller. The Self-Tuning PID achieves steady-state faster by 3.364 seconds than the PID AC Plant. The system response indicates that the Self-Tuning PID controller performs better, as shown in Table 5.

Regarding performance evaluation indices, the Self-Tuning PID controller has smaller ISE, IAE, and ITAE values compared to the PID AC Plant, indicating superior system performance. Testing with changing reference values confirms that the Self-Tuning PID controller is better in terms of steady-state time and performance indices, consistent with the data in Table 5.

C. System Response Test with Step Disturbance

In this third variation, the self-tuning PID controller will be tested with a disturbance signal in the form of a step input, with a setpoint of 23°C starting from an initial temperature of 25°C. The step disturbance signal will be applied to change the setpoint to 22°C for 1 second at 50 seconds. The comparison will begin with the system response,

steady-state time, and performance evaluation indices. The block diagram of the self-tuning PID

with the step disturbance signal can be seen in Figure 14.

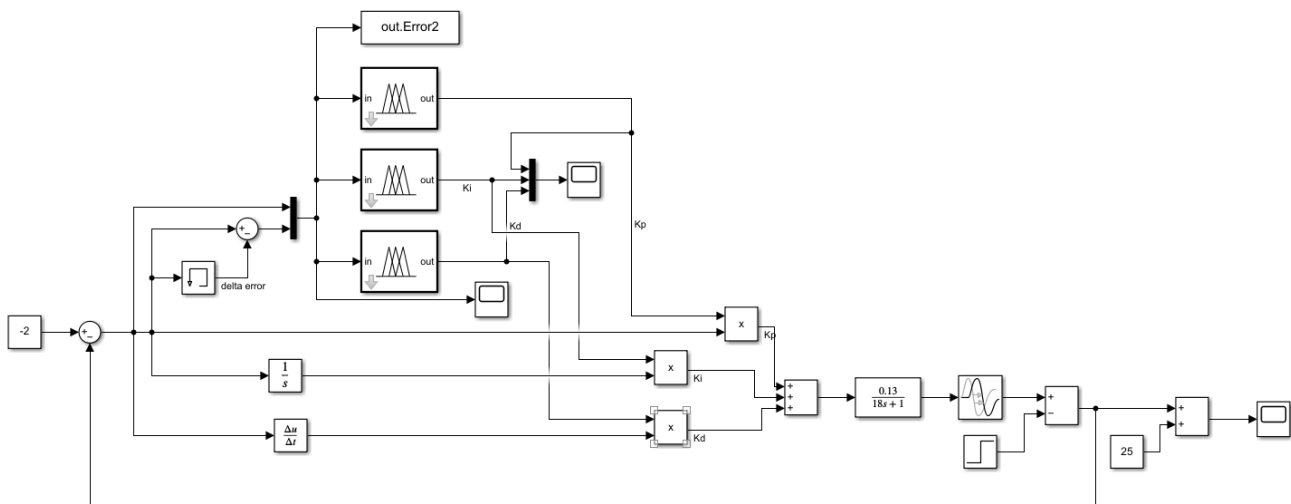


Figure 14. Block Diagram of System with Step Disturbance

This test aims to measure the reliability of the controller in responding to disturbances and its ability to return to the original setpoint after the disturbance at 50 seconds. The test will also include parameters such as steady-state time and performance evaluation indices.

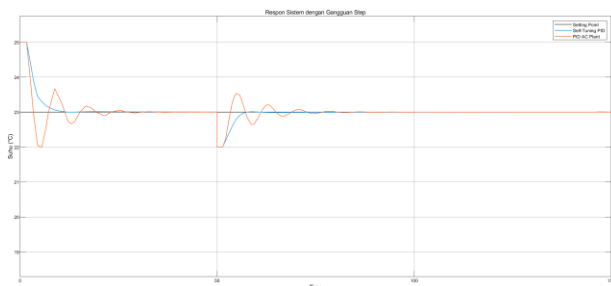


Figure 15. System Response with Step Disturbance

The Self-Tuning PID system response shows a graph that tends to be stable and has minimal overshoot compared to the PID AC Plant. Even when a disturbance occurs at 50 seconds, the signal can stabilize more quickly back to the initial setpoint without experiencing overshoot. This can be observed in Figure 15.

The Self-Tuning PID controller demonstrates better system response values compared to the PID AC Plant controller. The Self-Tuning PID system response reaches steady state faster by 5.4545 seconds than the PID AC Plant. The system response indicates that the Self-Tuning PID controller has a better response, as shown in Table 6.

In terms of performance evaluation indices, the Self-Tuning PID controller has smaller ISE, IAE, and ITAE values compared to the PID AC Plant, indicating that the system response has better

performance evaluation. Testing with changing reference values shows that the Self-Tuning PID controller is better based on the time to reach steady state and its performance evaluation indices. This is consistent with Table 6.

Table 6. Result of System Response Test with Step Disturbance

Respons System	Steady State Time (s)	ISE	IAE	ITAE
Kontroler PID AC Plant	15.1535	15.96	17.26	410.6
Kontroler Self-Tuning PID	9.699	14.19	11.75	239.5

IV. CONCLUSION

In the test with a fixed reference value (setpoint), the Self-Tuning PID controller demonstrated superior performance with a faster steady-state time by 6.273 seconds and smaller performance evaluation indices (ISE, IAE, and ITAE) compared to the PID AC Plant controller. In this case, the Self-Tuning PID controller is more effective in reducing overshoot and reaching steady state faster.

In the test with changing reference values (setpoints), the Self-Tuning PID controller showed advantages in system response with a fast steady-state time of 3.364 seconds and smaller performance evaluation indices compared to the PID AC Plant controller. The Self-Tuning PID controller is the best choice for tests involving changes in reference values.

In the test with step disturbances, the Self-Tuning PID controller performed better with a faster steady-state time of 5.4545 seconds and smaller

performance evaluation indices compared to the PID AC Plant controller. The Self-Tuning PID controller is the best choice for systems tested with step disturbances.

Overall, the Self-Tuning PID controller offers excellent performance in maintaining stability by minimizing overshoot and undershoot during the control process. Although the system response appears slightly slower based on the graphs from each test, the time difference is relatively small. Therefore, this controller is very suitable for application in air conditioner temperature control systems that require minimal overshoot and a quick transition to steady state.

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