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DESIGN OF CONTROL SYSTEM TEMPERATURE ON COOLING TOWER BASED ON PLC

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Abstract

In industry, it is necessary to save water use, so that the output water from the condenser will be recirculated for reuse so that it does not need new water. The output of the condenser in the form of hot water which has a temperature of 45°C needs to be conditioned so that it has a normal temperature. So the Cooling Tower is designed to lower the temperature of the hot water through direct contact with the air. To control the temperature, a PID controller based on PLC Outseal Nano V5.2 is used to adjust the speed of the suction fan so that the value of the process variable matches the set point. The results of the PID controller design using the Direct Synthesis method produce a proportional gain value (Kp) of 5.4, an integral gain (Ki) of 0.08, and a derivative gain (Kd) of 6.9. The direct test results on the prototype with a set point of 38.16°C prove that the response performance of the temperature control system on the Cooling Tower produces a response with the desired performance specifications, namely time constant (τ) of 40 seconds, settling time (ts) of 151 seconds, delay time (td) 25 seconds, overshoot (Mp) 0% and steady state error (ess) 0%. And when testing the prototype which was disturbed in the form of Adding Flow in Hot Water to 34 litre /min and Adding 74°C Hot Water Supply in Hot Water Tank, it showed a fairly good disturbance rejection, namely from both experiments it could quickly return to a steady state

Keywords: Cooling tower, Direct synthesis, PID controller, Temperature.

1. Introduction

Cooling Tower is a heat exchanger equipment that has the function of cooling hot water through contact or contact with air entering from the bottom. When there is contact between hot water and dry air, a certain amount of heat will be released from the hot water to the dry air causing a small portion of the water to evaporate and be sucked in by the suction fan and then discharged into the atmosphere [1].

Cooling towers in industry are usually used to reduce the temperature of the hot water output from the condenser to a normal temperature so that it can be reused [1]. There are several types of cooling towers, namely induced draft and forced draft. In this study the author uses the Cooling Tower induced draft type, where the cooling fan from the Cooling Tower is at the top of the Cooling Tower, where the hot air resulting from direct contact between dry air and hot water in the Cooling Tower is sucked up to the top and discharged into the atmosphere [2].

In reality, the process at the Cooling Tower still has the possibility of interference which can cause the process to not run as desired [3]. So to minimize the disturbance, keep the system running according to the desired condition and correct it automatically according to the desired set point, you can use PID in controlling it. In process control, the most widely used systems at the industrial level are proportional, integral and derivative (PID) controller loops; these are very important alternatives that represent around 90% of the market [4]. Parameter tuning of the PID controller is an essential task [5]. One of the widely used controllers is the Programmable Logic Controller (PLC). PLC is an electronic device that is used to control input and output signals by applying complete logic and algorithms so that the controlled process can run as desired [6].

According to the proportional control survey, integral and derivative stated that 97% is used by the industry in controlling the process [7]. However, the main disadvantages of PID controllers are the possession of proportional and derivative kick, which grades in abrupt spikes and gratuitous overshoot. In a PID controller, the derivative mode recovers stability of the system and enhances the speed of the controller response, however, it makes the plant draw a huge amount of control input [8]. One of the PID controller tuning is Direct Synthesis. This tuning only requires the actual plant model and the desired plant model [9]. The DS (Direct Synthesis) method is to design or tune to get parameter values controller through the correlation of plant parameters on the system closed loop. This method has been used for Steam Temperature Control in Superheater in Power Plants and produces a good performance response, namely an error of 0.41% [10]. Tuning with Direct Synthesis is widely used for tuning the PID controller because it is able to produce a PID controller with a good response and has a good ability to maintain the response at the desired value if there is a disturbance [11]. From various literature studies on Cooling Towers, a research was formed on the design of a temperature control system in a PLC-based induced draft Cooling Tower. This study aims to determine the response of the temperature control system on the Cooling Tower based on the PID parameter value tuning using direct synthesis.

2. Plan Design

In the design of a prototype temperature control system on a Cooling Tower using a PID controller, this aims to determine the results of the PID controller design using the Direct Synthesis method that can be applied to a prototype temperature control system in a PLC-based Cooling Tower. This design is a combination of hardware design and software design.

Figure 1 shows the prototype of the temperature control system in the Cooling Tower. Where the feed used is water that is heated, or its temperature is raised in a hot water tank with a heating element. After being heated the water will be pumped into the Cooling Tower to lower its temperature then the water will be pumped to the next process. To control the water temperature from the Hot Water Tank outlet, a PID controller based on the Outseal Nano V5.2 PLC is used to adjust the speed of the Suction Fan so that the temperature process from the Cooling Tower outlet can match a predetermined set point. Then to detect the temperature at the Cooling Tower outlet using the PT100 RTD sensor and temperature transmitter. The implementation of the Cooling Tower prototype hardware can be seen in Fig. 2.

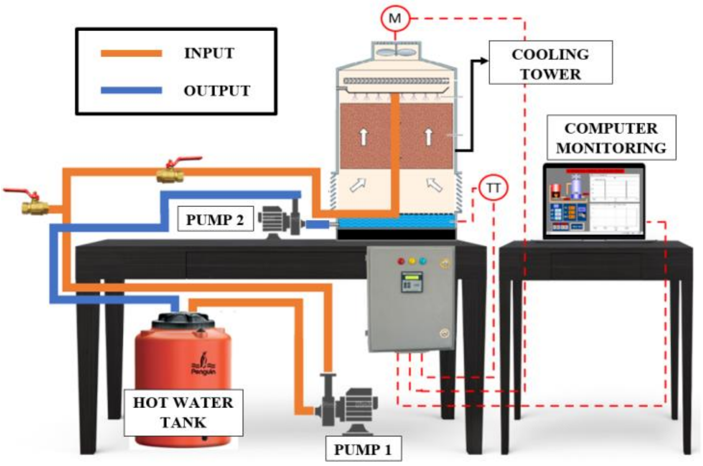


Fig. 1. Prototype cooling tower.

Fig. 2. Implementation of the Cooling Tower prototype hardware.

In the Cooling Tower prototype, the main component used as a controller is PLC Outseal Nano V5.2. This PLC functions as a controller that functions to send signals to the relay to drive pump 1, pump 2 and turn on the heating element. In addition, the controller also functions to send a signal to the BTS7960 driver module to drive the suction fan and functions to receive a PV signal from the PT100 RTD which has been converted by the transmitter. The Outseal Nano V5.2 PLC also communicates via a modbus RTU communication protocol USB cable with a PC on the Haiwell Cloud Scada Develop application. Haiwell Cloud Scada Develop will work as master and PLC Outseal Nano V5.2 as slave. Haiwell Cloud Scada Develop can not only monitor but also give commands to the Outseal Nano V5.2 PLC.

Figure 3 is a wiring diagram for the temperature control system in the Cooling Tower, in order to make it easier to work on the overall wiring contained in the prototype temperature control system in the Cooling Tower. Installation of component wiring must be in accordance with the design that has been made. Errors in the wiring system can result in components not running optimally.

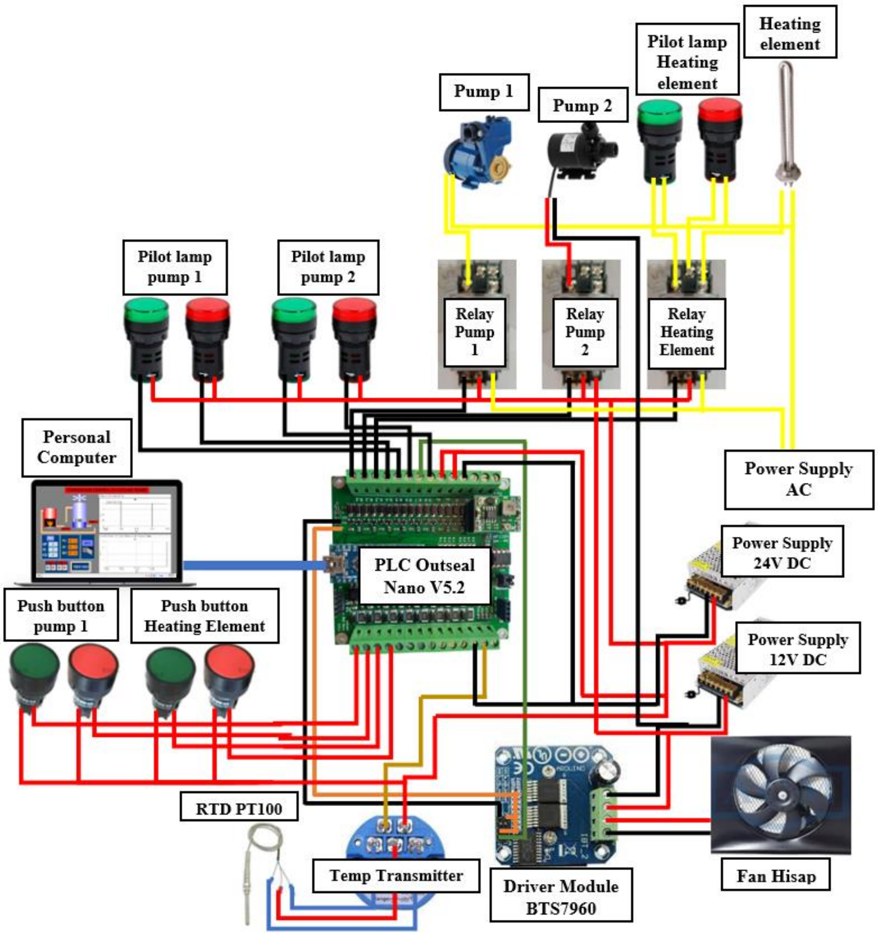


Fig. 3. Wiring Control system components in cooling tower.

There are two software implemented on the prototype temperature control system in the Cooling Tower, namely Outseal Studio and Haiwell Cloud Scada Develop. The Outseal Studio software is used to program the Outseal Nano V5.2 PLC so that it can load controller functions including receiving input from the push button, moving the relay coil and receiving PV signals from the PT100 RTD sensor calculation and sending the MV signal from the PID controller algorithm calculation to the DC Motor. While the Haiwell Cloud Scada Develop software is used to create a temperature control system software interface. The interfacing or monitoring system is carried out through Haiwell Cloud Scada Develop software which reads addresses that have been adjusted to the ladder diagram on the Outseal Nano V5.2 PLC controller. On the monitoring display, the data received by the controller is displayed in the form of numbers and response graphs from set points, process variables, and manipulated variables in real time trends and can see the history of the graph on the historical trend.

3. System Control

The temperature control system in this Cooling Tower uses a feedback control configuration type. The temperature control system in the Cooling Tower aims to control the water temperature in the Water Basin Cooling Tower in order to achieve the desired value. The block diagram of the temperature control system design in the Cooling Tower with PID controller can be seen in Fig. 4.

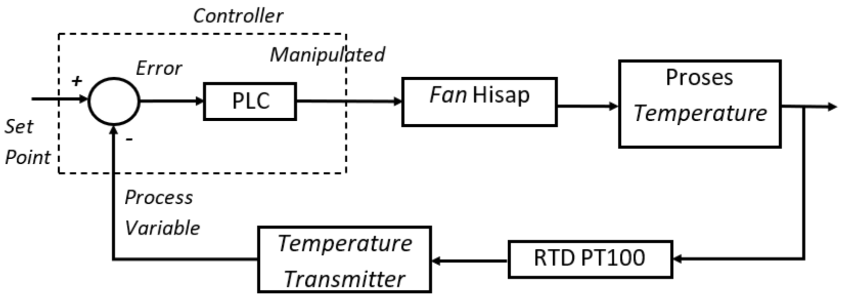


Fig. 4. Block diagram of temperature control system in cooling tower.

From Fig. 4 it can be seen that there are components of the temperature control system in the Cooling Tower, namely the controller, suction fan, sensor, and process temperature. To reach the present value, the suction fan speed needs to be controlled. When the temperature is above the set point value, the speed of the suction fan is increased or accelerated. Conversely, when the temperature is below the set point value, the speed of the suction fan is reduced or slowed down.

The main controller of the Cooling Tower prototype is PLC Outseal Nano V5.2. The input from the control calculation is the process value obtained from the temperature calculation derived from the PT100 RTD temperature sensor which has been connected to the Outseal Nano V5.2 PLC. Because the control process in this study uses PID-based control, to determine the parameters of the control mode, calculations are needed to find the process transfer function or mathematical modelling of the RTD temperature sensor, process temperature and DC motor. Then determine the transfer function of the plant from the product of the transfer function of process temperature and DC motor. After getting the plant transfer function, the next step is to calculate the KP, KI, and KD parameters to control the output process so that it can run according to the expected controller parameter values.

4. Sensor Transfer Function

In the prototype temperature control system in the Cooling Tower using a 3 wire RTD PT100 sensor and a PT100 transmitter which functions to convert the resistance signal into an analog signal of 4 – 20 mA so that it can be received by the PLC Nano V.5.2. According to the modelling of the temperature transmitter with a 3-wire RTD sensor, it can be obtained using the following equation [12]:

$$G_T = \frac{1}{(N_\tau S + 1)} \tag{1}$$

If it is known that the time constant of the 3-wire RTD sensor with a measurement range of 0 - 100℃ is 0.3 second, the gain temperature transmitter is obtained:

$$G_T = \frac{1}{(N_\tau S + 1)} = \frac{1}{(0{,}3S + 1)}$$

5. Process Temperature Transfer Function

Thermal systems can be analysed in terms of resistance and capacitance because thermal resistance (R) and thermal capacitance (C) are distributed throughout the substance [13]. To find the values of C and R obtained by the following equation:

a. Determining the value of thermal resistance (R) can use the following equation [13]:

- Flow Rate steady state pump (G) = 30 ℓ/min = 0.51 kg/s
- Specific heat of water on range temperature 25 - 45℃ = 4180 kJ/kg. K = 0.2388 kcal/kg.℃.

So that the value of thermal resistance:

$$R = \frac{1}{G \; x \; c} = \frac{1}{0.51\frac{\text{kg}}{\text{s}} \text{ x } 0.2388 \text{ kcal/kg.℃}} = 8.15 \text{ ℃.s/kcal}$$

b. Determining the value of thermal capacitance (C) can use the following equation [13]:

- Specific heat of water on range temperature 25 - 45℃ = 4180 kJ/kg. K = 0.2388 kcal/kg.℃.
- Mass of liquid in tank (M): $\rho \times V$ = 1000 kg/m^3 × 0.032 m^3 = 32 kg

So that the value of thermal capacitance:

$$C = M \times c = 32 \text{ kg} \times 0.2388 \text{ kcal/kg.℃} = 7.696 \text{ kcal/℃}$$

So from the value of thermal resistance and thermal capacitance value obtained transfer function process using the following equation [13]:

$$G_{Process} = \frac{R}{RCs+1} = \frac{8.15}{8.115 \times 7.696\, s+1} = \frac{8.15}{62.72s+1}$$

In fact, the response of the temperature control system at the Cooling Tower can be affected by disturbances in the form of changes in the water supply flow rate at the inlet, temperature increases in the Hot Water Tank and others. As for calculating the gain disturbance can use the following equation [13]:

$$G_{Distrubance} = \frac{1}{RCs+1} = \frac{1}{8.15 \times 7.696s+1} = \frac{1}{62.72s+1}$$

6.Motor DC Transfer Function

At the time of testing the motor, a linear region or motor working point was found at a voltage of 3.54 V to 10.34 V, each of which was in a steady state. From the graph it can be seen that when given a voltage of 3.54 V the motor has an average speed of 726.4 rpm on the tachometer measurement. And when given a voltage of 10.34 V and shows an average speed of 1993 rpm on the tachometer. The results of the DC motor speed test response can be seen in Fig. 5.

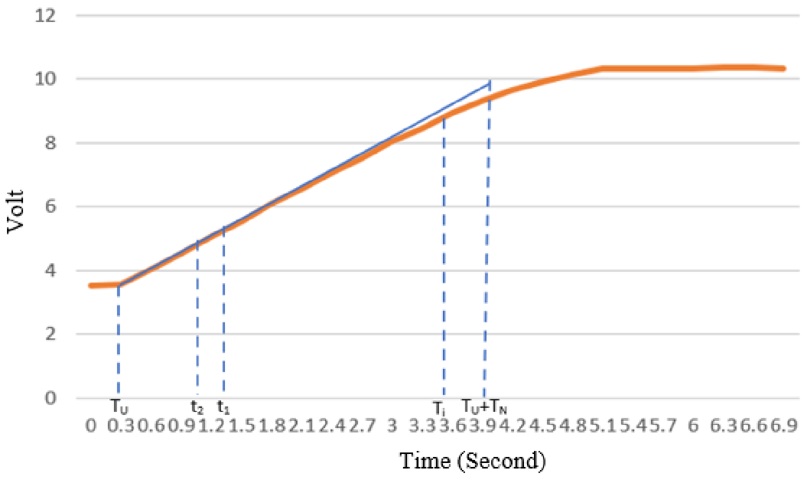


Fig. 5. Results response speed motor DC.

From Fig. 5, the motor speed measurement with a tachometer, mathematical modelling can be obtained using the Strejc's method as follows [14]. From the graph of the results of the DC Motor speed response, the following parameters are obtained:

- $T_U = 0.3$
- $T_N = 3.9 - T_U = 3.9 – 0.3 = 3.6$
- $t_1 = 1.3$
- $Input\ (A) = 701.7$ rpm
- $Output\ Steady\ State\ (OSS) = 1993$ rpm

a. Determining the value of τ:

$$\tau = \frac{T_U}{T_N} = \frac{0.3}{3.6} = 0.08$$

b. Determining the value of n from the table below and from the resulting value τ, it can be seen in the table that the value of n is 2.

Table 1. Factor n Strejc's method system model.

n	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
τ	0.104	0.218	0.319	0.41	0.493	0.57	0.642	0.709	0.773
y_i	0.264	0.327	0.359	0.371	0.384	0.394	0.401	0.407	0.413

c. Determine the time constant:

$$\tau_{ST} = \frac{t_1}{n-1} = \frac{1.3}{2-1} = 1.3$$

d. Determine the ratio of steady state output and input or gain:

$$K = \frac{OSS\ (Output\ steady\ state)}{A(input)} = \frac{1993}{701.7} = 2.84$$

So from the above data obtained a DC Motor mathematical model as in the following equation:

$$G_{motor\ DC}(S) = \frac{K}{(\tau_{ST1}S+1)n} = \frac{2{,}84}{(1.3s+1)2} = \frac{1.42}{(1{,}3s+1)}$$

7. PID Controller Design using Direct Synthesis Method

Based on the transfer function process and the transfer function of the DC motor, a transfer function plant is obtained as follows:

$$G_{Plant} = G_{process}\ x\ G_{Motor\ DC}$$

$$G_{Plant} = \frac{8.15}{(62.72s+1)} \times \frac{1.42}{(1.3s+1)}$$

$$G_{Plant} = \frac{11{,}57}{(81.53s^2+64.02s+1)}$$

From the plant transfer function, it can be seen that it is a second order transfer function. The desired output response specification for the control system is the response output with a settling time ts (± 0.5%) of about 5 seconds, ess = 0 (zero offside) and has no overshoot. The stages in the design of the PID controller with the direct synthesis method are as follows [15]:

- $t_s^*(\pm 0.5\%) = 5\tau^* \cong 5$ Seconds

  $\tau^* = \frac{5}{5} = 1$ Second
- $G_{Plant} = \frac{11.57}{(81.53S^2+64.02S+1)} \cong \frac{C(s)}{U(s)} = \frac{K}{\frac{1}{\omega_n{}^2}s^2+\frac{2\zeta}{\omega n}s+1}$

Based on the equation below, the values of ζ, ω_n and K can be determined in the following [16]:

- $K = 11.57$
- $\frac{1}{\omega_n{}^2} = 81.53$

  $\omega_n = \sqrt{\frac{1}{81.53}} = 0.11$
- $\frac{2\zeta}{\omega n} = 64.02$

  $\zeta = \frac{64.02\ x\ \omega_n}{2} = \frac{64.02\ x\ 0{,}11}{2} = 3.52$

Determine the time integral, time derivative, proportional gain, integral time, and derivative time.

- $\tau_i \quad = \frac{2\zeta}{\omega n} = \frac{2 \times 3.52}{0.11} = 63.6$
- $\tau_d \quad = \frac{1}{2\, x\, \zeta \times \omega n} = \frac{1}{2 \times 3.52 \times 0.11} = 1.28$
- $Kp \quad = \frac{\tau i}{\tau * \times K} = \frac{63.6}{1 \times 11.57} = 5.4$
- $Ki \quad = \frac{Kp}{\tau i} = \frac{5{,}4}{63{,}6} = 0.08$
- $Kd \quad = Kp \times \tau_d = 5.4 \times 1.28 = 6.9$

The calculation of the PID controller transfer function can be obtained with the following equation [17]:

$$Gc = Kp\,(1 + \frac{Ki}{s} + Kds) = Kp\,(1 + \frac{1}{\tau is} + \tau ds)$$

$$= 5.4\ (1 + \frac{1}{63.6s} + 1.29s)$$

$$= \frac{5.4\, s + 0.08 + 6.9\, s^2}{s} = \frac{6.9\, s^2 + 5.4\, s + 0.08}{s}$$

8. Observation of Response Controller using Simulink MatLab

To determine the response characteristics of the temperature control system in the Cooling Tower with the PID parameters that have been obtained, it can be simulated using Simulink MatLab as follows (Fig. 6):

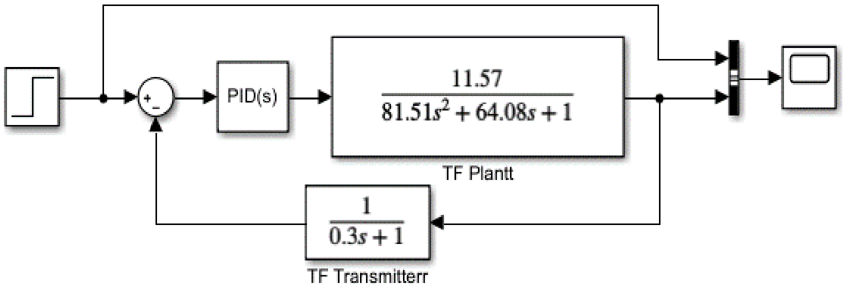
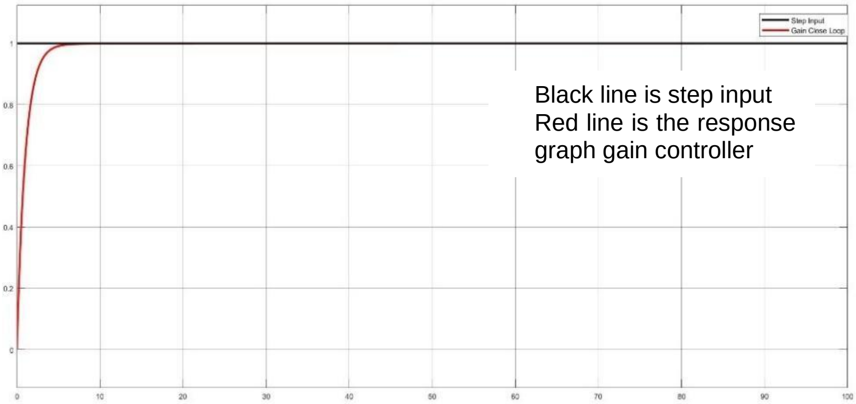


Fig. 6. Simulink using PID controller.

The results of the Simulink temperature control system on the Cooling Tower using a PID controller can be seen in Fig. 7.

In Fig. 7, it can be seen that the response specifications for the temperature control system in the Cooling Tower using the PID controller are shown in Table 2.

In fact, the response of the temperature control system at the Cooling Tower can be affected by disturbances in the form of changes in the water supply flow rate at the inlet, temperature increases in the Hot Water Tank and others. Therefore, a simulation of the temperature control system in the presence of a disturbance needs to be done to determine the performance of the controller. The Simulink temperature control system in the Cooling Tower using a PID controller in the presence of a disturbance can be done as shown in Fig. 8.



Black line is step input
Red line is the response
graph gain controller

Fig. 7. Chart Response using PID controller.

Table 2. Specification response PID controller.

Specification	Value
Time Constant (s)	1.022
Settling Time (s)	4.1367
Delay Time (s)	0.721
Overshoot (%)	-
Error Steady Stated (%)	-

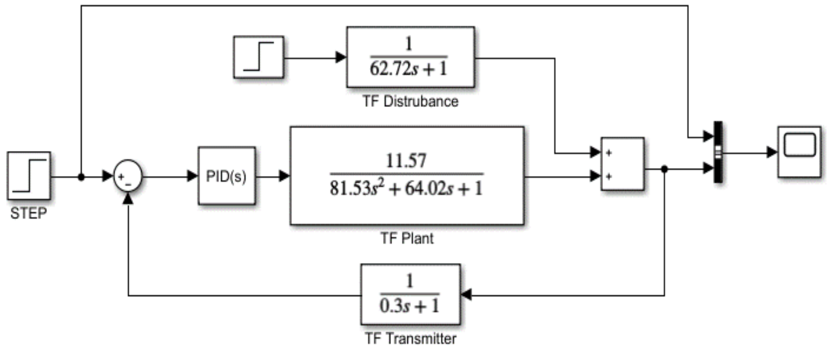


Fig. 8. Simulink using PID controller with disturbance.

In Fig. 9 it is known that the response of the temperature control system in the Cooling Tower using a PID controller after being disturbed for 500 seconds produces a response graph like the picture. After testing the PID parameters using the Simulink simulation on MatLab and producing a good response, then the parameters are tested directly on the prototype.

9. Test Results

After getting the PID parameters, then testing the prototype so that the results of the graph and response specifications are obtained. The first test is done by giving a fixed set point of 38.16°C. The results obtained can be seen in Fig. 10.

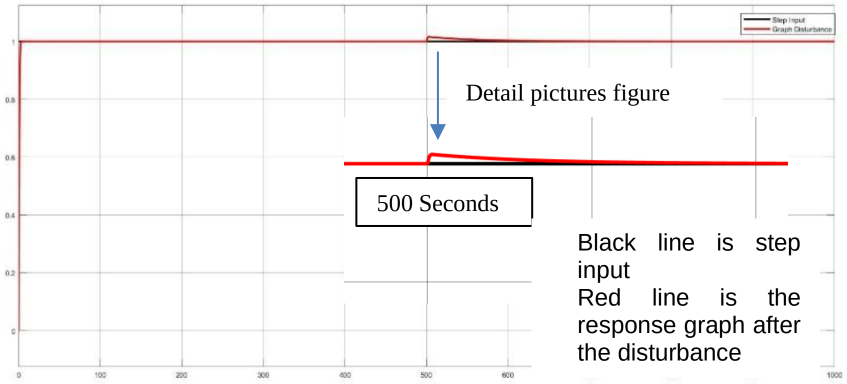


Fig. 9. Chart response using PID controller with disturbance.

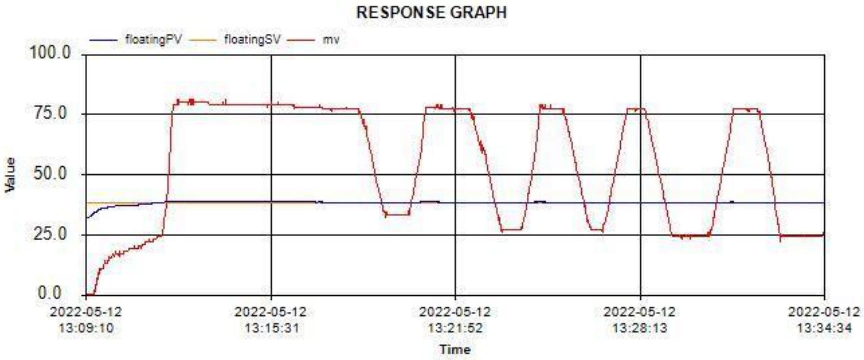


Fig. 10. Response system at set point 38.16 ℃.

The second test is by lowering the Set Point 38.16℃ to 36.51℃. The results obtained can be seen in Fig. 11.

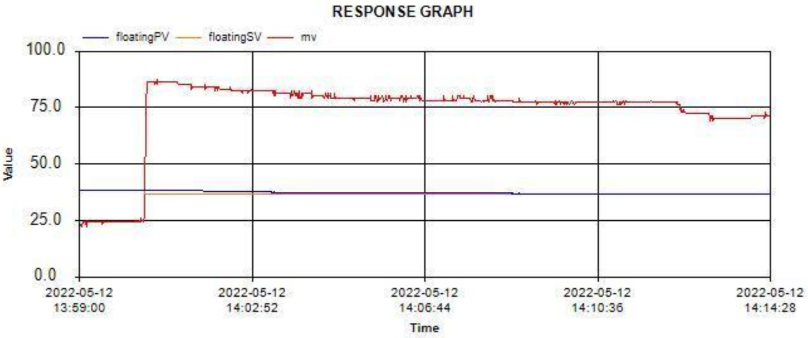


Fig. 11. Response system at set point 38.16℃ to 36.51℃.

The third test is carried out by giving disturbance to the process by increasing the flow in hot water to 34 ℓ/min at the set point of 38.16℃. This is to simulate when the valve at the Cooling Tower inlet is disturbed which results in the flow of hot water entering the Cooling Tower experiencing an increase in flow rate. The results obtained can be seen in Fig. 12.

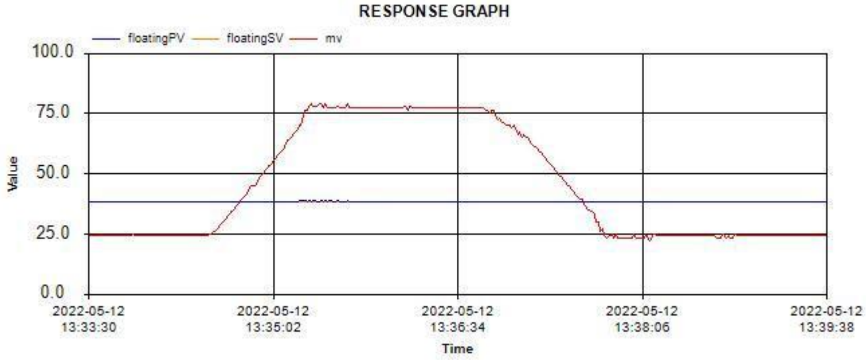


Fig. 12. Response system at the time of disturbance by adding flow in hot water to 34 ℓ /min.

The fourth test was carried out by providing disturbance to the process by adding 74℃ hot water supply in the hot water tank and making the hot water tank temperature rise again by 45℃ at the set point 38.16℃. This is to simulate when the Hot Water Tank is disturbed by an increase in the temperature of the hot water. The results obtained can be seen in Fig. 13.

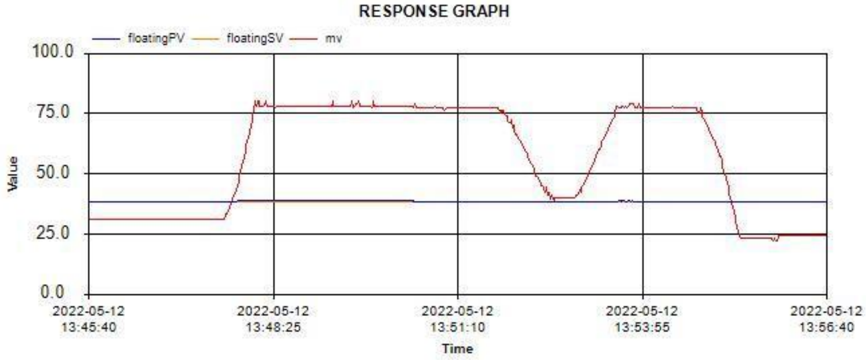


Fig. 13. Response system at the time of disturbance by adding 74℃ hot water supply in hot water tank.

10. Analysis

The temperature control system on the Cooling Tower prototype works based on the value of the set point temperature output from the Cooling Tower prototype that has been determined. To achieve the set point value, the temperature that comes out of the measurement results or the detection results from the PT100 RTD sensor will be calculated with the set point value and the parameters for controlling the temperature in the Cooling Tower and involving PID parameters in it. When there is an error value, the PID controller will make corrections by changing the MV value on the DC motor. So, the value of the PID parameter in this process affects the response of the temperature control system in the Cooling Tower.

Based on the testing on the prototype, it was found that the Cooling Tower prototype can control the process variable at a temperature limit of 37.27℃ to 39.18℃. This is because the capacity of the suction fan on the Cooling Tower prototype has a maximum speed of 2167 rpm. While the maximum capability of the temperature control system on the Cooling Tower prototype when giving the first disturbance is to increase the flowrate of hot water at the Cooling Tower inlet by 34 l /minute, this is because the maximum flow rate of the pump that is read on the flow metre is 34 l /minute. When giving the second disturbance, which is to add hot water supply to the Hot Water Tank with hot water that has a temperature of 74 ℃ this is because if the added hot water has a temperature higher than 74 ℃, the Cooling Tower prototype will take a longer time to complete. process variable or PV returns to steady state or returns to set point.

Table 3. Specification response set point at 38.16 ℃.

Specification	Value
Time Constant (s)	40
Settling Time (s)	151
Delay Time (s)	25
Overshoot (%)	-
Error Steady Stated (%)	-

After testing the Cooling Tower temperature control system, it can be seen that the PID controller response designed using the Direct Synthesis method can adjust the value of the manipulated variable so that the process variable can catch up and match the set point value. The resulting response has performance specifications according to the initial design, namely zero offset and has no overshoot, but the results of the time constant and settling time are slower than the initial design. In testing the set point, it can be seen that the response process variable is stable at a predetermined set point and the PID controller can maintain the process variable at the set point well.

After simulating with Simulink on MatLab, it is known that PID controller tuning using Direct Synthesis after being given a disturbance produces an overshoot of 16% and returns to steady state for 219.5 seconds. Meanwhile, during testing on the prototype, disturbance was given in 2 ways. First, increase the flowrate of hot water at the Cooling Tower inlet of 34 l /min with the aim of simulating when the flow of hot water increases in flow rate. Second, by adding hot water supply to the Hot Water Tank with hot water having a temperature of 74 ℃ as much as 6.4 l with the aim of simulating when the Cooling Tower inlet temperature increases in temperature.

In the first disturbance test, by increasing the flowrate of hot water at the Cooling Tower inlet of 34 l /min at the set point of 38.16 ℃ it produces an overshoot of 0.68% and returns to steady state for 92 seconds. In the second disturbance test, by adding hot water supply to the Hot Water Tank with hot water with a temperature of 74 ℃ as much as 6.4 l at the set point of 38.16 ℃ it produces an overshoot of 0.99% and returns to steady state for 190 seconds.

So it can be concluded that the PID controller uses Direct Synthesis tuning with parameters KP = 5.4, Ki = 0.08, and Kd = 6.9 according to the temperature control system in the Cooling Tower and produces a good and fast response, because the response from the process variable can be maintained at the set point. properly and when a disturbance occurs in the process, the process variable can return to a predetermined set point value.

11. Conclusions

In making the Cooling Tower prototype, the main components include PLC Outseal Nano V5.2, PT100 RTD sensor, temperature transmitter, BTS7960 driver module, 12V DC Suction Fan. These components have been successfully implemented into a complete prototype of the Cooling Tower.

The results of the PID controller design using the Direct Synthesis method with a design time constant (τ) of 1 second, settling time (ts) of 5 seconds, overshoot (Mp) of 0% and steady state error (ess) of 0%, resulting in a proportional gain value (Kp) of 5.4, integral gain (Ki) of 0.08, and derivative gain (Kd) of 6.9.

The interfacing or monitoring system is carried out through Haiwell Cloud Scada Develop software which reads addresses that have been adjusted to the ladder diagram on the Outseal Nano V5.2 PLC controller. On the monitoring display, the data received by the controller is displayed in the form of numbers and response graphs from set points, process variables, and manipulated variables in real time trends and can see the history of the graph on the historical trend.

Based on the test results using Simulink MatLab against the PID controller with the Direct Synthesis method, it produces a response that is in accordance with the desired performance specifications. Simulink MatLab produces a time constant (τ) of 1.022 seconds, a settling time (ts) of 4.1367 seconds, an overshoot (Mp) of 0% and a steady state error (ess) of 0%.

The direct test results on the prototype prove that the response performance of the temperature control system at the Cooling Tower produces a response with the desired performance specifications, namely time constant (τ) of 40s, settling time (ts) of 151s, delay time (td) of 25s, overshoot (Mp) of 0% and the error steady state (ess) is 0%. And when there is a disturbance, the test results on the prototype show a fairly good disturbance rejection.

Nomenclatures

A	Input, rpm
c	Specific heat of water, kJ/kg. K, kcal/kg.℃
C	Thermal capacitance, kcal/℃
ess	Error steady state, %
FloatingPV	The change graph of the process variable
FloatingSV	A graph of the set value or the value we want
G	Flow rate steady state pump, ℓ/min, kg/s
Gc	Gain PID controller
$G_{Distrubance}$	Gain disturbance
$G_{MotorDC}$	Motor DC transfer function
G_{Plant}	Transfer function plant
$G_{process}$	Process temperature transfer function
G_T	Temperature transmitter gain
K	The ratio of steady state output and input

K_d	Derivative gain
K_i	Integral gain
K_P	Proportional gain
M	Mass of liquid in tank, m^3, kg
Mp	Overshoot, %
MV	Manipulated variable (A graph of changes from the final control element or in this study in have the shape of a suction fan)
N_τ	Time constant temperature transmitter, s
OSS	Output steady state, RPM
R	Thermal resistance, ℃.s/kcal
T_1	Time 1, s
T_d	Time delay, s
T_N	Time end, s
t_s^*	Settling Time, s
T_U	Time up, s
V	Volume in tank, m^3

Greek Symbols

ρ	Density of water, kg/m^3
τ_{ST}	Time steady stated, s
τ_i	Time integral, s
τ_d	Time derivative, s
τ / τ_*	Time constant, s

Abbreviations

DS	Direct Synthesis
PID	Proportional, Integral, Derivative
PLC	Programmable Logic Controller

References

1. Septefni, V.I. (2018). Design of cooling tower type induced draft controlled swivel speed fan. *Final project* - TF 145565. D3 Instrumentation Engineering, Department of Instrumentation Engineering, Faculty of Vocation, Institut Teknologi Sepuluh Nopember.
2. Novianarenti, E.; Setyono1, G.; and Safitra, A.G. (2019). Experimental study of the performance characteristic of an induced draft cooling tower with variates fillings. *IOP Conference Series: Materials Science and Engineering*, 462, 012027.
3. Sajona, J.; Velilla, W.; Fábregas, J.; and Palencia, A. (2022). Fuzzy gain scheduling: comparison of the control strategy. *Journal of Engineering Science and Technology* (*JESTEC*), 17(2), 1356-1368.
4. Barbieri, G.; Quintero, G.; Cerrato, O.; Otero, J.; Zanger, D.; and Mejia, A. (2021). A mathematical model to enable the virtual commissioning simulation of wick soilless cultivations. *Journal of Engineering Science and Technology* (*JESTEC*), 16(4), 3325-3342.

5. Alla, R.R.; Lather, J.S.; and Pahuja, G.L. (2017). Comparison of PI controller performance for first order systems with time delay. *Journal of Engineering Science and Technology* (*JESTEC*), 12(4), 1081-1091.
6. Widharma, I.G.S.; and Bali, P.N. (2021). *Kajian pustaka pemanfaatan plc dalam dunia industri*. Politeknik Negeri Bali.
7. Setiawan, I. (2008). *Kontrol PID untuk proses industri*. PT Elex Media Komputindo
8. Babu, V.S.; and Sundar, K.S. (2019). Design of fractional order pid controller for agc loop in a deregulated power system with RFB and IPFC units. *Journal of Engineering Science and Technology* (*JESTEC*), 14(2), 763-783.
9. Gozali, R.M.B. (2005). Desain kontrol pid dengan metoda tuning direct synthesis untuk pengaturan kecepatan motor DC. *Teknoin*, 10(4), 283-293.
10. Ahusda, P.; Astrowulan, K.; and Fatoni, A. (2021). Metode direct synthesis pada kontrol cascade untuk pengendalian temperatur steam di superheater pada power plant. Retrieved October 5, 2022, from https://123dok.com/document/yn9p7vjq-metode-direct-synthesis-kontrol-cascade-pengendalian-temperatur-superheater.html
11. Hu, W.; Xiao, G.; and Cai, W.-J. (2011). PID controller design based on two-degrees-of-freedom direct synthesis. *Proceedings of the* 2011 *Chinese Control and Decision Conference* (*CCDC*). Mianyang, China, 629-634.
12. Sarabeevi, G.M.; and Beebi, M.L. (2017). Temperature control of shell and tube heat exchanger system using internal model controllers. *Proceedings of the* 2016 *International Conference on Next Generation Intelligent Systems* (*ICNGIS*). Kottayam, India, 1-6.
13. Ogata, K. (2010). *Modern control engineering*. Pearson.
14. Septiarini, A.D. (2018) *Pemodelan matematika kecepatan motor DC menggunakan identifikasi dengan metode* 2S. Diploma thesis, Institut Teknologi Sepuluh Nopember.
15. Sinaga, A.P.B.; and Pramudijanto, J. (2014). Perancangan dan Implementasi kontroler PID untuk Pengaturan Autonomous Car-Following. *Jurnal Teknik Pomits*, 3(1), 2337-3539.
16. Fachrul, A. (2015). *Respon waktu dan respon frekuensi* (*Time response and frequency response*). Program Studi Teknik Elektronika, Jurusan Teknik Elektronika, Fakultas Teknik Universitas Negeri Yogyakarta.
17. Lafta, F.A.; Hasan, I.A.; and Mohammed, M.J. (2021). Pid-pso controller for pv panel system identification models on ANFIS and NN-NARX system. *Journal of Engineering Science and Technology* (*JESTEC*), 16(6), 4505-4517.