Comparison between PID controller and fuzzy sliding mode control (FSMC) on super heater system

Mardiljah$^{1,a}$, Abdul Mahatir Najar$^{2,b}$, Didik Khusnul Arif$^{3,c}$

$^{1,2,3}$ Department of Mathematics, ITS, Indonesia

E-mail: "mardiljah@matematika.its.ac.id, "abdulmahatir@untad.ac.id, "didik@matematika.its.ac.id

Abstract. Super heater, a component in a boiler, is an important component in a steam power plant system. It serves to transform the heat into superheated steam to spin a turbine. The steam temperature must be carefully controlled, to ensure good quality of steam. For the best performance of steam power plant (PLTU) 3-4 PJB UP Gresik, Indonesia, the temperature of superheated steam must be achieve 814 K. In this paper was designed PID controller super heater system and analysis of the performance of the system by comparing PID and FSMC. PID Controller can generate steam temperature stable at 814 K. While the FSMC controller generate steam temperature stable at 814.097 K. Thus, it was concluded that PID controller can generates more accurate steam temperature than FSMC. However when the system get a disturbance, FSMC can handle it better than PID controller.

1. Introduction

Indonesia is the fourth largest country in the world in terms of population [1]. Indonesia population comprises more than 39% of the total population of the Southeast Asian countries. With this huge population, Indonesia have high electrical energy demand. To support the country’s power generation, Indonesia is endowed with abundant energy sources. Based on energy sources, there are 5 (five) types of power plant in Indonesia: Steam power plant, diesel power plant, Gas power plant, Hydro power plant and other renewable resources such as solar, geothermal, biomass and wind [2].

The steam power plant (PLTU) is fulfill the major portion of countrys electricity demand. About 85% of electricity consumed in Indonesia is generated by PLTU[3]. PLTU is a power plant that use heat energy to steam the water inside the boiler to achieve certain pressures and temperatures. The steam is used to spin a steam turbine which drives electrical generator.

Super heater, a component in a boiler, is an important component in a steam power plant system. It act as secondary heater which serves to transform the steam from the steam drum into superheated steam. The object of this paper is steam power plant (PLTU) 3-4 PJB UP Gresik, Indonesia.

In order to obtain the best performance, the temperature of superheated steam must be achieve 814 K [4]. Meanwhile if the temperature is too high, it will be dangerous for the plant. So controller is need to ensure safety and efficiency.

Fuzzy sliding mode control (FSMC) is one of the controller forms developed by combining of two controller which are sliding mode control (SMC) and fuzzy logic control (FLC) [5]. In
[6] a new second-order fuzzy sliding mode controller was designed to maximize the conversion efficiency of photovoltaic systems. The performance of the control system is verified through simulation and experiment. The developed system can increase the efficiency up to 1.5%.

In [7] has been developed a fuzzy sliding mode control strategy for offshore container cranes. The objective of this control is to keep the payload in a desired tolerance in harsh condition of the mobile harbor motion during the loading and unloading process. The proposed method is adjusted the discontinuous gain of the sliding control with fuzzy logic. Chattering is further reduced by a saturation function.

In [8] has been designed Static and dynamic Sliding Mode Control applied to drum boiler system. The method proposed in [8] has been successfully applied to system that has uncertain model or parameter.

In [4] has been developed fuzzy sliding mode controller (FSMC) to control steam super heater. This method can generate steam temperature stable very close to the set point.

Besides FSMC there is Proportional Integral Derivative (PID), a control method which is commonly used. It is a classical control system using feedback techniques. The controller input is an error. Error is the difference from the set point (desired output value) to the value of the actual output measurement.

In [9] PI/PID controller has been successfully applied to driver-assist and driver-support systems. To control the car acceleration a PD-Controller is used, and for velocity control a PI-Controller is used. In [10] a controller for coal circulation in thermal power plants based on optimal control theory for bilinear systems with additional integral action has been developed. That controller then compared to PID controller. Because of the simplicity of operation and low cost, PID has become one of the best controllers. In [11] has been presented a review on classical and fuzzy PID controller.

FSMC is commonly used because its robustness while PID controller commonly used because its simplicity of operation and low cost. Therefore, it is interesting to compare those two controller method. In this paper PID controller was designed in order to control the temperature of superheated steam and compare it to FSMC.

2. Research Description
In this section we discuss super heater system and breakdown its mathematical model, PID controller and fuzzy sliding mode controller (FSMC) that applied to super heater system.

2.1. Control System
A control system consists of subsystems and plants (process) assembled in order to obtaining a desired output with desired performance, given specified input[12]. There are two major configurations of control systems: open loop and closed loop.

![Diagram block of simple closed loop.](image)

**Figure 1.** Diagram block of simple closed loop.

The block diagram of closed loop is shown in figure 1 where, \( r \) = reference point or desired output; \( y \) = actual output; \( e \) = error (difference between actual output to desired output); \( c \) = control system; \( p \) = plant (process) \( u \) = control input; \( d \) = disturbance.
2.2. Super Heater System

Super heater is a component in boiler that act as secondary heater. It serves to heat up the steam from steam drum. The temperature in super heater must be controlled, to achieve set point. So it can ensure efficiency of boiler operational. System of steam super heater scheme can be seen in the following figure.

![Figure 2. System of steam temperature in super heater](image)

The steam from steam drum enter the super heater then the steam will be heat up using heat supply from the burner. If the temperature exceeds set point it will be dangerous for the turbine. Hence, if the temperature exceeds set point, de-super heater will send out water to lower the hot steam temperature.

Based on the equilibrium energy low, the rate of energy entering the system is proportional to exit rate and the energy accumulated in the system. It can be derived the following equation [4]:

\[
\frac{dT}{dt} = \frac{1}{V_{sh}}\rho (m_{in}(T_{in} - T_{ref}) - m_{out}(T_{out} - T_{ref})) + \frac{Q_{sh}}{c_{p}} + \frac{q_{h}}{c_{p}}
\]

where,

- \(V_{sh}\) = volume super heater;
- \(\rho\) = density;
- \(c_{p}\) = super heater specific heat;
- \(m_{in}\) = rate of incoming steam super heater mass flow;
- \(m_{out}\) = rate of steam super heater mass flow that out;
- \(T\) = temperature that enter to super heater;
- \(T_{out}\) = temperature that out from super heater;
- \(T_{ref}\) = super heater temperature expected;
- \(Q_{sh}\) = heat supply by burner;
- \(q\) = steam de-super heater rate of mass flow;
- \(h\) = de-super heater enthalpy steam.

Block diagram of super heater system is shown in fig.3. The diagram blog is designed based on mathematical model of super heater system.

2.3. Fuzzy Sliding Mode Control

Fuzzy sliding mode control (FSMC) is combination of two controller which are sliding mode control (SMC) and Fuzzy logic control (FLC). FLC inputs are two variables which is obtained from SMC \(S_{p}\) and \(d\). Then the output of FLC is input controller for the plant[13].
FSMC controller works as well as SMC controller which uses sliding surface. Hence, it requires switching function to determine control law as an input of the plant. Control law of FSMC is obtained from fuzzy rules as follows [13].

\[ R^i : \text{if } S_p = L_s, \text{ and } d = L_D, \text{ then } u = L_U. \]  

where, \( i = 1, ..., M; R^i = i\text{-th fuzzy rules; } L_s = \text{Fuzzy values for membership function } S_p \text{ } i\text{-th fuzzy range}; \) \( L_D = \text{fuzzy values for membership function } d \text{ } i\text{-th fuzzy range; and } L_U = \text{the result of } i\text{-th input range that corresponds with fuzzy space.} \)

\[ S_p = \frac{|\dot{e} + \lambda e|}{\sqrt{1^2 + \lambda^2}} \]
\[ d = \sqrt{e^2 - s_p^2} \]

\[ 2.3.1. \text{ Design of FSMC } \]

FSMC is combination of SMC and FLC so to design FSMC controller requires a switching function (S) as follows [15]:

\[ S = \dot{T} + \lambda \bar{T} \]

where,

\[ \bar{T} = T - T_d \]
\[
\dot{T} = \dot{T} - \dot{T}_d
\]

Then the sliding surface is:

\[
\dot{T} + \lambda \dot{T} = S \tag{3}
\]

where sliding surface \( S = 0 \) such that it is obtained equation of \( S_p \) and \( d \) as follows:

\[
S_p = \frac{|\dot{T} + \lambda \dot{T}|}{\sqrt{\dot{T}^2 + \lambda^2}} \tag{4}
\]

\[
d = \sqrt{\dot{T}^2 - S_p^2} \tag{5}
\]

To determine the membership function, the interval of \( S_p \) and interval \( d \) must be known. Then, we was used eq. 4 and 5 to find the maximum and minimum of the value of \( S_p \) and \( d \).

\[
S_p \in [0, 234]
\]

\[
d \in [0, 806]
\]

Based on eq. 4 and 5 we have designed the block diagram of sliding mode control (SMC) on Matlab. using MATLAB.

\[
S_p \text{ and } d \text{ obtained is used as inputs to fuzzy logic controller.}
\]

There are 8 variables on \( S_p \) membership function: Negative Big (NB), Negative Medium (NM), Negative Small (NS), Negative Zero (NZ), Positive Small (PS), Positive Zero (PZ), Positive Medium (PM), Positive Big. The membership functions of \( S_p \) are shown at fig. 6.

While the membership function have 4 variables: Zero (Z), Small (S), Medium (M), and Big (B). The membership function of \( d \) is shown at fig.7.

Generally the value of control input \( u \) is determined by adjust the ability of \( q \) (steam de-super heater rate of mass flow). In this case the interval of \( u \) is 0 to 10. The membership function of \( u \) is shown at fig. 8.

We have designed Fuzzy sliding mode control (FSMC) using phase plane that determined by \( S_p \) and \( d \) to obtain fuzzy value of \( u \). General rule of fuzzy is shown at table 1.

Design of FSMC using MATLAB which is based on formulation and fuzzy rule above is shown in fig. 9.

The design of FSMC control system requires Gain 1, Gain 2 and Gain 3 which were obtained by trial and error. Thus, we have Gain 1 = 0.0076, Gain 2 = 0.0001, and Gain 3 = 0.7.
Table 1. General Fuzzy Rule of FSMC

|  | NB | NM | NS | NZ | PZ | PS | PM | PB |
|---|---|---|---|---|---|---|---|---|
| Sp | B  | PB | PB | PB | NB | NB | NB | NB |
|   | M  | PB | PB | PB | PM | NB | NB | NB |
|   | S  | PB | PB | PM | PS | NS | NM | NB |
|   | Z  | PB | PM | PS | PZ | NZ | NS | NM |

2.4. PID Controller

PID controllers is a controller which has three main components, there are Proportional (P), Integrator (I), and Derivative (D). It is a control loop feedback mechanism commonly used in industrial control systems. The output of the PID controller is determined by:

\[
u(t) = K \left( e(t) + \frac{1}{\tau_I} \int_0^t e(t) dt + \tau_D \frac{d}{dt} e(t) \right)
\]  

(6)
where,

\[ u(t) = \text{control variable}; \]
\[ K = \text{proportional constant}; \]
\[ \tau_I = \text{integral time constant}; \]
\[ \tau_D = \text{derivative time constant}; \]
\[ e(t) = \text{error} \]

PID controller continuously calculates an error \( e(t) \) as the difference between a desired set point and measured process variable and applies a correction based on proportional, integral and derivative terms [17].

PID is an acronym of proportional, integral and derivative words, makes up control output from the effect of three mathematical expressions. The formula PID is defined as [16]:

\[
P + I \times \frac{1}{s} + D \times \frac{N}{1 + N \times \frac{1}{s}}
\]  

(7)

where,

\[ P = \text{proportional parameter}; \]
\[ I = \text{integral parameter}; \]
\[ D = \text{derivative parameter}; \]
\[ N = \text{filter coefficient}. \]

Since mathematical model of the plant can be derived, then it is possible to apply various design techniques for determining parameters of the controller that will meet the transient and steady-state specifications of the systems[18]. The process of selecting the controller parameters to meet given performance specifications is known as controller tuning. We used MATLAB auto tuning to determine the control parameters.

3. Simulation and Analysis

In this simulation, we used FSMC compared to PID controller. The aims of this simulation is to know the performance of each controller and which controller is more robust. In order to know which controller is more robust, we use pulse and square signal as disturbance which represent overheating that caused by after burning phenomena around the super heater tube. The simulation was used parameter values shown below[15]:

![Figure 9. Fuzzy Sliding Mode Controller Block Diagram](image-url)
Table 2. Parameter and its value

| Parameter | Value |
|-----------|-------|
| $V_{sh}$  | 21.45 |
| $\rho$    | 50.4  |
| $c_p$     | 2822  |
| $m_{in}$  | 152.77|
| $m_{out}$ | 160.27|
| $T_{ref}$ | 814   |
| $Q_{sh}$  | 77103935|
| $h$       | 83562 |

Figure 10. Performance of PID controller(a) and FSMC(b) on super heater system without disturbance.

Fig. 10 shows that without any disturbance the PID controller can generate steam temperature stable at 814 K, while The FSMC can generate steam temperature stable at 814.097 K.

In order to see the robustness of the controller, FSMC and PID controller were simulated with external disturbance. Impulse signal is a signal appearing at short time. It represents a disturbance in short time from the outside of the system. The simulation is given this disturbance on the control system using FSMC and PID controller.

Firstly, the impulse signal disturbance was given at 125th second. It represent something happen in outside of the super heater system that make a disturbance to the system. The result is shown in fig. 11(a), FSMC is more robust than PID controller. PID controller required 111 seconds to get stable after the disturbance ended up. While, FSMC required 75 seconds.

For the second disturbance square signal was used. Square signal is a signal appearing at certain time interval. It represents a disturbance from the outside of the control system at time interval. The simulation is given this disturbance using FSMC and PID controller. In this simulation, the signal disturbance was given at 125th until 135th second. It represent something happen in outside at certain interval time of the super heater system that make a disturbance to the system. The result is shown in fig.11(b), FSMC is more robust than PID controller. PID controller required 120 seconds to get stable after the disturbance ended up. While, FSMC required 84 seconds.
4. Conclusion

Based on the result of analysis and simulation, both of those controller can be applied on the super heater system. PID controller can generate temperature closer to the set point. PID Controller can generate steam temperature stable at 814 K, while the FSMC controller generate steam temperature stable at 814.097 K. However, FSMC is more robust than PID controller when the system got a disturbance.

In this paper trial and error method is used to determine PID controller parameters and fuzzy gain. For further work, other methods can be considered to obtain better result.

References
[1] Wikipedia, List of countries and dependencies by area, 2017. [Online]. Available: http://en.wikipedia.org/w/index.php?title=List_of_countries_and_dependencies_by_area&oldid=591403632. [Accessed: 25-Oct-2017].
[2] PT Deloitte Konsultan Indonesia, 35,000 MW: A Light for the Nation, Indonesia, 2016.
[3] F. Wikipedia, List of power stations in Indonesia, 2017. [Online]. Available: https://en.wikipedia.org/wiki/List_of_power_stations_in_Indonesia. [Accessed: 25-Oct-2017].
[4] Mardlijah, M. Septiani, and T. Mudjiati, Desain sistem kendali temperatur uap superheater dengan metode fuzzy sliding mode control, LIMITS, vol. 13, no. 1, pp. 3748, 2016.
[5] R. Palm, D. Driankov, and H. Hellendoorn, Model Based Fuzzy Control: Fuzzy Gain Schedulers and Sliding Mode Fuzzy Controllers. Springer-Verlag, Berlin, 1997.
[6] M. R. Mojallizadeh and M. A. Badamchizadeh, Second-order fuzzy sliding-mode control of photovoltaic power generation systems, Sol. Energy, vol. 149, pp. 332340, 2017.
[7] Q. H. Ngo, N. P. Nguyen, C. N. Nguyen, T. H. Tran, and Q. P. Ha, Fuzzy sliding mode control of an offshore container crane, Ocean Eng., vol. 140, no. May 2016, pp. 125134, 2017.
[8] T. Herlambang, E. Apriliani, and H. Cordova, Desain Pengendalian Ketinggian Air dan Temperatur Uap pada Sistem Steam Drum Boiler dengan Metode Sliding Mode Control (SMC), Institut Teknologi Sepuluh Nopember, 2010.
[9] M. Nentwig and P. Mercorelli, PD / PID-switching Control as a Human-Machine Interface for a Semi-Autonomous Driver in Automobiles, in 12th IFAC Proceedings, 2009, pp. 497504.
[10] P. Niemczyk and J. D. Bendtsen, Improved coal grinding and fuel flow control in thermal power plants, in 18th IFAC World Congress, 2011, pp. 70187023.
[11] V. Kumar, B. C. Nakra, and A. P. Mittal, A Review of Classical and Fuzzy PID Controllers A Review on Classical and Fuzzy PID Controllers, Int. J. Intell. Control Syst., vol. 16, no. 3, pp. 170181, 2011.
[12] N. S. Nise, Control Systems Engineering, Sixth Edit. Pamonon: John Wiley & Sons,Inc, 2011.
[13] M. Y. Hsiao, T. H. S. Li, J. Z. Lee, C. H. Chao, and S. H. Tsai, Design of Interval Type-2 Fuzzy Sliding-Mode Control, Inf. Sci., vol. 178, no. 6, pp. 16961716.
[14] I. R. R, Analisis dan Perancangan Sistem Pengendali pada Inverted Pendulum Menggunakan Metode Fuzzy Sliding Mode Control, Surabaya, 2008.
[15] M. Septiani and Mardlijah, Metode Sliding Mode Control (SMC) pada Sistem Temperatur Uap Super heater di PLTU 3-4 PT. PJB UP Gresik, Surabaya, 2015.

[16] A. K and H. T, PID Controllers: Theory, Design, and Tuning, Second. Instrument Society of America, 1995.

[17] G. G and K. E, A comparison of Fuzzy Logic and PID Controller for a single-axis tracking system, Springer Open J. Renew. Wind. Water, Sol., 2016.

[18] K. Ogata, Modern Control Engineering (Fifth Edition), Fifth. Prentice Hall, 2010.