International Journal of Engineering & Technology, 7 (4.22) (2018) 154-158

International Journal of Engineering & Technology

Website: www.sciencepubco.com/index.php/IJET

Research paper

Comparison Performance of Robustness Test using Intelligent Fuzzy based Controller for Simulation Study

Zakiah Mohd Yusoff[1], Nur Dalila Khirul Ashar[1], Zuraida Muhammad[2], Noor Fadzilah Razali[1], Shakira Azeehan Azli[1], Amar Faiz Zainal Abidin[3], Khairul Kamaruddin Hasan[1]

[1]Faculty of Electrical Engineering, Universiti Teknologi MARA, Cawangan Johor, Kampus Pasir Gudang,81750 Masai, Johor, Malaysia
[2]Faculty of Electrical Enigneering, Universiti Teknologi MARA, Pulau Pinang,Malaysia
[3]Faculty of Electrical, Universiti Teknikal Malaysia Melaka, Hang Tuah Jaya, 76100 Durian Tunggal, Melaka, Malaysia
**Corresponding author E-mail:zakiah9018@johor.uitm.edu.my*

Abstract

This paper presents a comparison simulation performance of robustness test using intelligent fuzzy based controller in extraction process of essential oil. In this study, the control variable is the steam temperature since it gives large effect to quality of essential oil. Ideally, the aims of control system applications and design the controllers is to ensure the close loop system satisfies performance criteria such as the system must be stable, minimize the effects of disturbances, good set-point tracking which is rapid and smooth response to set point changes. Thus, the robustness test is applied in this study to provide the controller that can produce a smooth control response and also robust to any changes of the operation conditions during running process. The standard performance criteria used to represent dynamic performance are percentage overshoot, rise time, settling time, root mean square error (RMSE) and time on recovering load disturbance. The STFPID controller that was used in controlling steam temperature for extraction process shows the excellent performances based on the result. However, both controllers pass the robustness test with small %OS, RMSE, settling time and rise time.

Keywords: *robustness test, fuzzy based controller, intelligent controller, extraction process, essential oil.*

1. Introduction

The ability of PID control mode to compensate most practical industrial processes has led to their wide acceptance due to the simple structure and ease of implementation. Nevertheless, PID controller will only performed well within limited operating range where tuning was performed unless the process is linear. Unfortunately, even though the control structure seems simple, there were no generic tuning procedures that can sustain satisfactory performance over variation of process types. This drawback has led to continual research in PID control leading to different kind of tuning approaches such as intelligent fuzzy based controllers, model predictive control (MPC), model reference adaptive controller (MRAC), artificial neural networks (ANN), generalized predictive control and adaptive control [1-7]

Control systems using fuzzy PID controller are gaining increasing interest in the research community due to its additional flexibility and superior design performance [8-9].This intelligent control systems can be find in wide applications such as process control [10-11] nuclear reactor control [12], chaos synchronization [13], solar photovoltaic, diesel engine, fuel-cell, aqua electrolyze etc. Fractional calculus has also been integrated with fuzzy logic [14-15] and PSO to enhance their performance. Also, computational intelligence based design for fractional order control systems have been found expedient in different power system applications like automatic voltage regulator [16], two area load frequency control, micro grid frequency control etc. The result shows that the fuzzy controller also shows stronger robustness properties against system parameter variation and rate constraint nonlinearity, than that with the other controller structures [17]. The robustness is a highly desirable property in such a scenario since many components of the hybrid power system may be switched on/off or may run at lower/higher power output, at different time instants [17]. Motivated by the success of such diverse applications of computational intelligence based fractional order control system, an intelligent fuzzy based controller is explored in this paper for the case of steam temperature control in essential oil extraction process.

2. Methodology

2.1. Fuzzy Logic Controller Design

The fuzzy logic controller (FLC) is more robust than PID controllers because this controller can cover a much wider range of operating conditions and can operate with white-noise disturbances of different natures. The architecture of the FLC is given in Fig. 1 where the output is denoted by *y(t)*, input to the plant is *u(t)* and the reference input to the FLC is denoted by *r(t)* [18] :

Copyright © 2018 Authors. This is an open access article distributed under the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

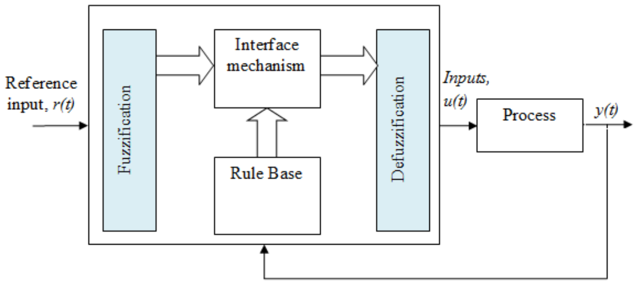

Fig. 1: The architecture of fuzzy set

The inputs, *u(t)* and reference input, *r(t)* are crisp values, which are real numbers, not fuzzy sets [18].The FLC consists of fuzzification, rule-base, inference mechanism and defuzzification components. The fuzzification converts controller inputs into information that the inference mechanism can easily be used to activate and compare with the rules in the rule-base. A rule-base holds the knowledge of the expert's linguistic description of how best to control the system. An inference mechanism also called an inference engine or fuzzy inference evaluates which control rules are relevant to the current time and then decide what the input to the plant should be. The defuzzification converts the conclusions about the inference mechanism into crisp real value of a fuzzy output [19].

2.1.1. Selection of controller input

In designing the fuzzy logic controller, the first step is to take the inputs and determine the degree to which they belong to each of the appropriate fuzzy sets via membership functions. The input is always a crisp numerical value limited to the universe of discourse of the input variable [18]. However, the choice of the inputs to the controller is a crucial job. This is because to make sure the controller will have the proper information in order to make good decisions and have proper control inputs to be able to maintain the system at the desired and achieve high-performance operation. Practically, for most control applications, two inputs were employed, namely an error signal, *e(t)* and change of error (*e(t)*) [20]. These inputs can describe the condition of the step response, whether the error is negative or positive [21-22].

2.1.2. Membership function

A membership function (MF) is a curve that defines how each point in the input space is mapped to a membership value or degree of membership. The input space is referred to as the universe of discourse. The MF must vary between 0 and 1. The membership function is often given the designation of μ [18]

There are many other's choices for the shape of membership functions are possible such as:

- Piecewise linear (triangular and trapezoidal)
- Gaussian distribution function
- Quadratic and cubic polynomial curves
- Sigmoid curve

Different shapes will provide a different meaning of the linguistic values that they quantify [18, 23]. Different researchers choose numerous shapes in various application problems. In most applications of identification and control, triangular and trapezoidal membership functions have proven to be more popular with fuzzy logic theoreticians and practitioners. Their reasons are [23]:

- The simplicity of this function often allows for the prediction and calculation of an output of the fuzzy system.
- The extra smoothness introduced by higher-order fuzzy sets and demanding higher computational consumption is not strongly reflected in the quality of a fuzzy model.

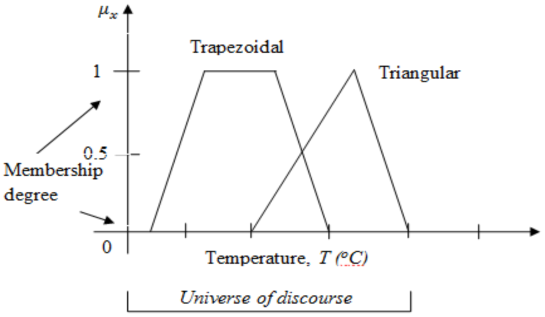

Fig. 2: The triangular and trapezoidal membership function shapes

These considerations are advised in selecting the membership functions [23]:

- Initially, one chooses the width of the membership functions to provide the whole overlap about 12-14 percent.
- In order to improve steady-state accuracy one has to decrease the membership functions' whole overlaps after their initial choice and simulation.
- In order to improve stability characteristics such as oscillation, settling time and overshoot, one has to increase the whole overlap.
- The use of a fuzzy controller with wider membership functions and higher overlap can be recommended in the presence of high disturbances.

2.1.3. Interface rules

The rule-based is a set of linguistic statement. In rule-based inference systems, the universes are partitioned using concepts, modelled via sets. Reasoning is then based on expressions of logical relationships between the concepts: "IF-THEN" rules. The vast majority of if-then rules used in fuzzy control and identification, and represented such as in equation (1) [19]:

$$\boldsymbol{if}\ premise\ \boldsymbol{then}\ consequent \qquad (1)$$

$$R_i \quad If\ \tilde{x}\ is\ \tilde{P}, then\ \tilde{y}\ is\ \tilde{Q} \qquad (2)$$

where $\tilde{x}$ is a linguistic variable defined on universe χ, $\tilde{P}$ is a linguistic value described by fuzzy set *P* defined on universe χ, $\tilde{y}$ is a linguistic variable on universe $\mathcal{Y}$, and $\tilde{Q}$ is a linguistic value described by fuzzy set *Q* defined on universe $\mathcal{Y}$. The first part of the statement "$\tilde{x}$ is $\tilde{P}$" is called the premise of the rule, sometimes called antecedents and the second part of the statement "$\tilde{y}$" is "$\tilde{Q}$" is called the consequent of the rule, sometimes called actions. In a fuzzy system, sometimes there may be more than one part upon the premise, which is the rule *Rj* denoted as [19-20].

2.1.4. Defuzzification

The function of the defuzzification is to convert the collection of recommendations on all rules into crisp real value of a fuzzy output. In order to get one crisp output, all the recommendations will be combined by taking a weighted average of the various recommendations [19]. The choice of the defuzzification procedure depends mainly on personal preference. There are many methods in deffuzification procedure such as the mean of maxima, height deffuzification, center average (CA), first-of-maxima, and centre-of-largest-area defuzzification. However, the centre-of-area method also known as the centre- of-gravity (COG) method is the most well-known defuzzification method [24]. This method gives better accuracy and faster computation time [21]. The COG method determines the centre of the area under the combined membership function. Equation (3) expressed the COG defuzzification as [21, 23]:

$$U = \frac{\sum_{i=1}^{l} U_i \mu(y)}{\sum_{i=1}^{l} \mu(y)} \tag{3}$$

where U_i is the centre of the output membership function, and $\mu(y)$ is the degree of fulfilment.

2.2. Hybrid Fuzzy PID Controller

In this study, we implemented the hybrid fuzzy PID controller to control the steam temperature of the extraction process in hydro diffusion system. Fig. 3 shows the Simulink block diagram of hybrid fuzzy PID using Matlab software. The connection diagram and control surface of fuzzy PID using triangular and trapezoidal shapes is shown in Fig. 4 and Fig. 5, respectively. The detail explanation on experiment design and robustness test implementation for fuzzy PID can be found in our previous study [7, 24].

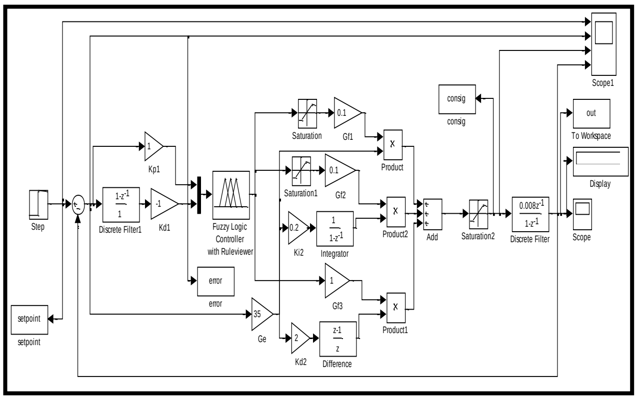

Fig. 3: The simulink block diagram of hybrid fuzzy PID controller

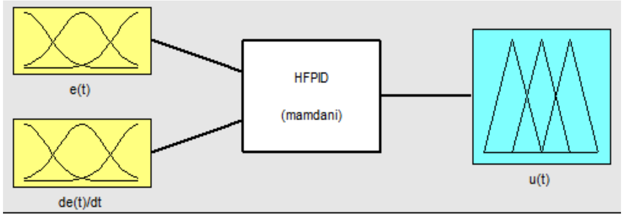

Fig. 4: The connection diagram of a fuzzy PID controller

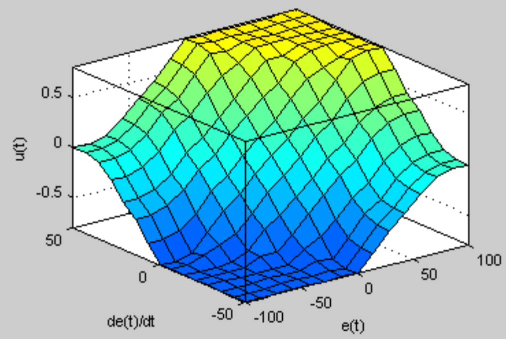

Fig. 5: The control surface of fuzzy PID

2.3. Self-tuning Fuzzy PID Controller

The robustness test performance of fuzzy PID was compared with the self-tuning fuzzy PID controller. Fig. 6 shows the simulink block diagram using self-tuning controller to regulate the steam temperature in hydro diffusion system. . The detail explanation on experiment design and robustness test implementation for self-tuning fuzzy PID can be found in our previous study [25].

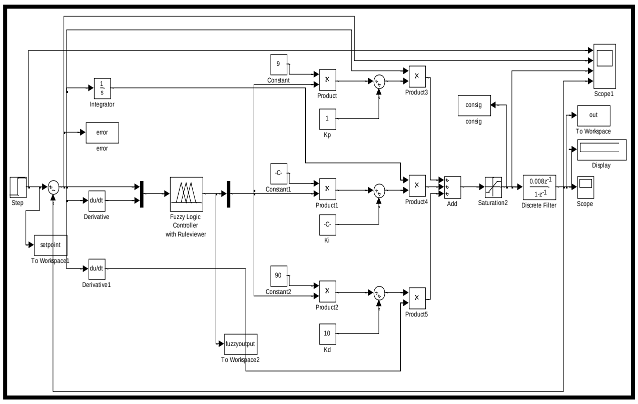

Fig. 6: The simulink block diagram of self-tuning fuzzy PID

Fig. 7 shows the connection diagram of the fuzzy system by implementing Mamdani based fuzzy inference system. Fig. 8 illustrated the control surface of self-tuning fuzzy PID controller, respectively.

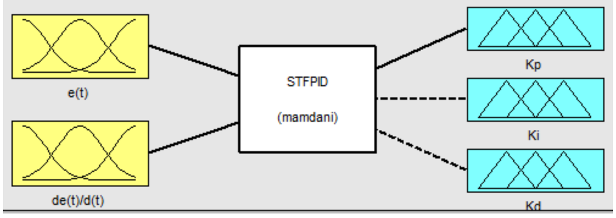

Fig. 7: The connection diagram of a self-tuning fuzzy PID controller

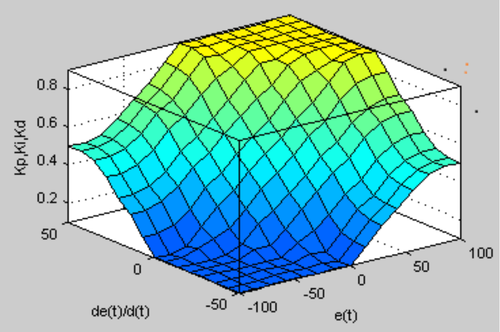

Fig. 8: The control surface of self-tuning fuzzy PID

3. Result and Discussion

3.1. Set point tracking

Fig. 9 presents the combination result for set point tracking test for all proposed controllers. Generally, the proposed PID, HFPID-3, HFPID-5, HFPID-7, STFPID-3, STFPID-5 and STFPID-7 controllers show a satisfactory result because can track the changes in set point whether in small or large set point change. The control signal for all designed controllers is between 0 V to 5 V, until the output achieve the desired set point. Overall, hybrid fuzzy and self-tuning fuzzy offer better performances in terms of rise time, settling time and RMSE compared with the PID controller. Tables 1, 2 and 3 are summarized the analysis performance for set point change at 60 °C, 80 °C and 90 °C, respectively.

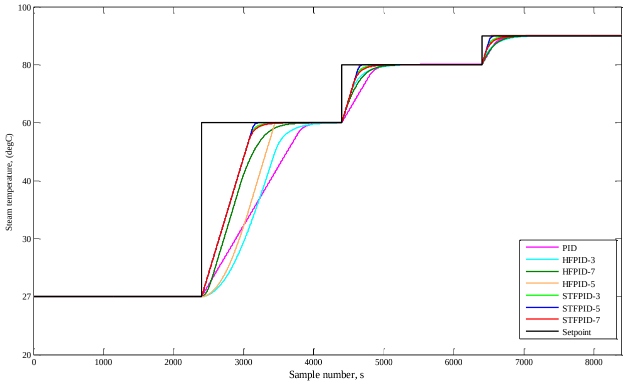

Fig. 9: Output for all proposed controllers on set point tracking test (simulation)

Table 1 shows the detail analysis for comparison of simulation performance of PID, HFPID-3, HFPID-5, HFPID-7, STFPID-3, STFPID-5 and STFPID-7 controller to track the set point change (at set point 60 ^{o}C). Based on analysis, it shows that at set point 60 ^{o}C, the STFPID-5 provides the best performance compared with other controllers. The STFPID-5 produced very encouraging results where the rise time less 571 s, settling time less 756 s and RMSE less 0.2469 than the PID controller. Meanwhile, the HFPID-5 shows the best performance among HFPID schemes by producing the rise time less 485 s, settling time less 461 s and RMSE less 0.1952 s than PID controller.

Table 1: Analysis for comparison of simulation performance of PID, HFPID-3, HFPID-5, HFPID-7, STFPID-3, STFPID-5 and STFPID-7 on set point tracking (set point 60 ^{o}C)

No	Controller	Rise time, (s)	Settling time, (s)	%OS	RMSE
1	PID	1171	1498	0	0.2927
2	HFPID-3	799	1431	0	0.1833
3	HFPID-5	686	1037	0	0.0975
4	HFPID-7	702	1120	0	0.1224
5	STFPID-3	600	804	0	0.1000
6	STFPID-5	600	742	0	0.0458
7	STFPID-7	600	847	0	0.1192
HFPID-5 compared with PID		485 s (>8 min)	461 s (>7 min)	-	0.1952
STFPID-5 compared with PID		571 s (>9 min)	756 s (>12 min)	-	0.2469
STFPID-5 compared with HFPID-5		86 s (>1 min)	295 s (>5 min)	-	0.0517

Table 2 shows the detail analysis for comparison of simulation performance of PID, HFPID-3, HFPID-5, HFPID-7, STFPID-3, STFPID-5 and STFPID-7 controller on tracking the set point change (at set point 80 ^{o}C). It shows that at set point 80 ^{o}C, the HFPID-5 and SFTPID-5 provide the comparable performances. The HFPID-5 shows the best performance among HFPID schemes by producing rise time less 261 s, settling time less 390 s and RMSE less 0.1523 s than PID controller. The STFPID-5 produced very significant results where the rise time less 216 s, settling time less 369 s and RMSE less 0.1735 than the PID controller.

Table 2: Analysis for comparison of simulation performance of PID, HFPID-3, HFPID-5, HFPID-7, STFPID-3, STFPID-5 and STFPID-7 on set point tracking (set point 80 ^{o}C)

No	Controller	Rise time, (s)	Settling time, (s)	%OS	RMSE
1	PID	416	639	0	0.2147
2	HFPID-3	386	672	0	0.0854
3	HFPID-5	200	249	0	0.0624
4	HFPID-7	381	631	0	0.910
5	STFPID-3	228	425	0	0.0877
6	STFPID-5	200	270	0	0.0412
7	STFPID-7	260	484	0	0.0883
HFPID-5 compared with PID		216 s (>4min)	390 s (>6 min)	-	0.1523
STFPID-5 compared with PID		216 s (>4 min)	369 s (>6 min)	-	0.1735
STFPID-5 compared with HFPID-5		-	-21 s	-	0.0212

Table 3 shows the detail analysis for comparison of simulation performance of PID, HFPID-3, HFPID-5, HFPID-7, STFPID-3, STFPID-5 and STFPID-7 controller to track the set point change (at set point 90 ^{o}C). Based on analysis, it shows that at set point 90 ^{o}C, the HFPID-5 provides the best performance compared with other controllers. The HFPID-5 shows very significant results by producing the rise time less 170 s, settling time less 341 s and RMSE less 0.1566 s than PID controller. The STFPID-5 produced the best performance among STFPID schemes where the rise time less 164 s, settling time less 306 s and RMSE less 0.1795 than the PID controller.

Table 3: Analysis for comparison of simulation performance of PID, HFPID-3, HFPID-5, HFPID-7, STFPID-3, STFPID-5 and STFPID-7 on set point tracking (set point 90 ^{o}C)

No	Controller	Rise time, (s)	Settling time, (s)	%OS	RMSE
1	PID	270	468	0	0.2182
2	HFPID-3	362	639	0	0.0480
3	HFPID-5	100	127	0	0.0616
4	HFPID-7	319	548	0	0.0730
5	STFPID-3	181	386	0	0.0774
6	STFPID-5	106	162	0	0.0387
7	STFPID-7	228	449	0	0.0800
HFPID-5 compared with PID		170 s (>2 min)	341 s (>5 min)	-	0.1566
STFPID-5 compared with PID		164 s (>2 min)	306 s (>5 min)	-	0.1795
STFPID-5 compared with HFPID-5		-6 s	-35 s	-	0.0229

3.2. Load Disturbance

Fig. 10 shows the simulation results that have been combined for all developed controllers for the comparison purposed on recovering load disturbance test. From the Figure 10, it is clearly shown that before the loads are introduced, all controllers exhibit a good output and able to meet desired set point. However, when the disturbance is suddenly added during running process, it is greatly affected the output for all controller schemes. The desired steam temperature drop and recovery process appear. The detail performance's evaluation for each controller design based on time required on recovering load disturbance is tabulated in Table 4.

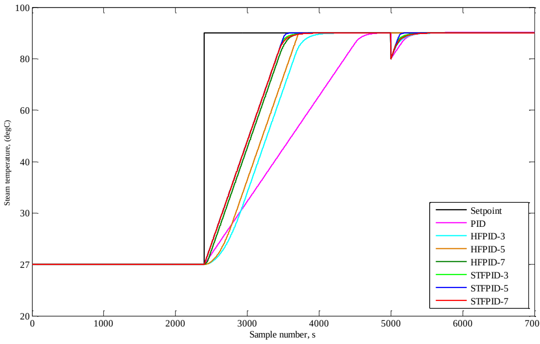

Fig. 10: Output for all proposed controllers on recovering load disturbance test (simulation)

Table 4: Analysis performance for simulation of PID, HFPID-3, HFPID-5, HFPID-7, STFPID-3, STFPID-5 and STFPID-7 controller on recovering load disturbance

No	Controller	$T_{min,}$ °C	Recovery time ,s
1	PID	80	270
2	HFPID-3	80	235
3	HFPID-5	80	198
4	HFPID-7	80	166
5	STFPID-3	80	182
6	STFPID-5	80	105
7	STFPID-7	80	228
HFPID-7 compared with PID		-	104 s (>1 min)
STFPID-5 compared with PID		-	165 s (>2 min)
STFPID-5 compared with HFPID-7		-	61 s (>1 min)

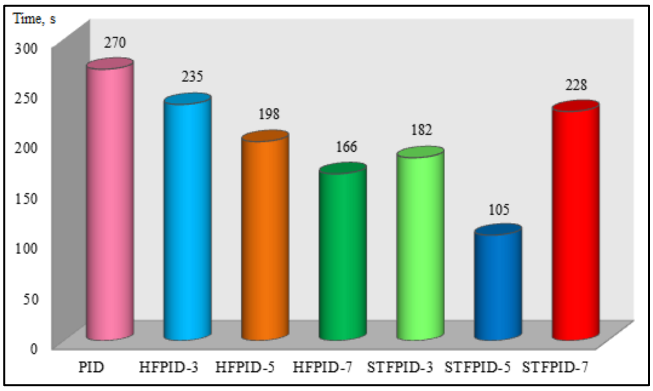

Fig. 11: Comparison of time required for all proposed controller on recovering load disturbance

Fig. 11 shows the comparison of time required for PID, HFPID-3, HFPID-5, HFPID-7, STFPID-3, STFPID-5 and STFPID-7 on recovering load disturbance that was suddenly added during running process, respectively. Statistical analysis in Table 4 and Fig. 11 revealed that the good robustness of HFPID and STFPID since PID controller takes the longest time on recover load disturbance with 270 s. The time taken for HFPID-3, HFPID-5, and HFPID-7 are 235 s, 198 s, and 166 s, accordingly. It is apparent that for hydro diffusion system using a hybrid controller scheme, the steam temperature drop resulting from the disturbance rejection is greatly suppressed, and recovery process is significantly shortened by increasing the number of membership function. From the data, we can see that STFPID-5 scheme shows the superior performance compared to other controllers. It is indicated from the fastest load disturbance recover, which is 105 s. The STFPID-5 takes 165 s and the HFPID-7 takes 104 s less than PID controller to returns to the set point. Overall, the average time required for the recovery process is around 105 s to 270 s.

3. Conclusions

The STFPID controller that was used in controlling steam temperature for extraction process shows the excellent performances based on the result. However, both controllers pass the robustness test with small %OS, RMSE, settling time and rise time.

Acknowledgement

It is acknowledged that this project is supported by UiTM Kampus Pasir Gudang, and FRGS under project code: 600-IRMI/FRGS 5/3 (154/2019).

References

[1] Y. Kansha, L. Jia, and M.-S. Chiu, "Self-tuning PID controllers based on the Lyapunov approach," Chemical Engineering Science, vol. 63, pp. 2732 – 2740, 2008.
[2] C.-F. Hsu and B.-K. Lee, "FPGA-based adaptive PID control of a DC motor driver via sliding-mode approach," Expert Systems with Applications, vol. 38, pp. 11866-11872, 2011.
[3] J. Flores-Cerrillo and J. F. MacGregor, "Latent variable MPC for trajectory tracking in batch processes," Jounal of Process Control, vol. 15, pp. 651-663, 2005.
[4] M. Tajjudin, M. H. F. Rahiman, N. Ishak, H. Ismail, N. M. Arshad, and R. Adnan, " Adaptive Steam Temperature Regulation for Essential Oil Extraction Process " International Journal of Control Science and Engineering vol. 2, pp. 111-119, 2012.
[5] X. Wu, et al., "Fuzzy modeling and predictive control of superheater steam temperature for power plant," ISA Transactions, vol. 56, pp. 241-251, 2015/05/01/ 2015.
[6] H. Hu, et al., "Feedforward DMC-PID cascade strategy for main steam temperature control system in fossil-fired power plant," in 2017 29th Chinese Control And Decision Conference (CCDC), 2017, pp. 3087-3091.
[7] Z. M. Yusoff, et al., "Steam temperature control of hydro-diffusion essential oil extraction system using hybrid-fuzzy plus PID controller," in 2014 IEEE Conference on Systems, Process and Control (ICSPC 2014), 2014, pp. 105-110.
[8] Monje CA, Chen YQ, Vinagre BM, Xue D, Feliu V. Fractional-order systems and controls: fundamentals and applications. London: Springer; 2010.
[9] Caponetto R, Dongola G, Fortuna L, Petras I. Fractional order systems: modeling and control applications, Vol. 72. Singapore: World Scientific Publishing; 2010.
[10] Das S, Pan I, Das S. Performance comparison of optimal fractional order hybrid fuzzy PID controllers for handling oscillatory fractional order processes with dead time. ISA Trans 2013;52(4):550–66.
[11] Das S, Pan I, Das S, Gupta A. Improved model reduction and tuning of fractional-order PIλDm controllers for analytical rule extraction with genetic programming. ISA Trans 2012;51(2):237–61
[12] Das S, Pan I, Das S. Fractional order fuzzy control of nuclear reactor power with thermal-hydraulic effects in the presence of random network induced delay and sensor noise having long range dependence. Energy Convers Manag 2013;68:200–18
[13] Das S, Pan I, Das S, Gupta A. Master-slave chaos synchronization via optimal fractional order PIλDm controller with bacterial foraging algorithm. Nonlinear Dyn 2012;69(4):2193–206.
[14] Efe MO. Fractional fuzzy adaptive sliding-mode control of a 2-DOF direct-drive robot arm. Syst Man Cybern Part B: Cybern IEEE Trans 2008;38(6):1561–70.
[15] Delavari H, Ghaderi R, Ranjbar A, Momani S. Fuzzy fractional order sliding mode controller for nonlinear systems. Commun Nonlinear Sci Numer Simul 2010;15(4):963–78
[16] Das S, Pan I. On the mixed H2/H1 loop shaping trade-offs in fractional order control of the AVR system. Ind Inf IEEE Trans 2014;10(4):1982–91.
[17] I. Pan, et al., "Tuning of an optimal fuzzy PID controller with stochastic algorithms for networked control systems with random time delay," ISA Transactions, vol. 50, pp. 28-36, 2011.
[18] "Fuzzy Logic Toolbox," R. 2007a, Ed.: MathWorks Inc., 2007.
[19] J. H.Lilly, Fuzzy control and identification: John Wiley & Sons, Inc., Hoboken, New Jersey, 2010.
[20] C. Cheng and M.-S. Chiu, "Robust PID controller design for nonlinear processes using JITL technique," Chemical Engineering Science, vol. 63, pp. 5141 -- 5148, 2008
[21] Z. Yusuf, "Fuzzy logic control for glycerin bleaching temperature control," Msc of Electrical Engineering, Universiti Teknologi Mara, Shah Alam, 2012.
[22] A. Ohata, K. Furuta, and H. Nita, "Identification of nonlinear ARX model with input and output dependent coefficients," in Computer Aided Control System Design, 2006 IEEE International Conference on Control Applications, 2006 IEEE International Symposium on Intelligent Control, 2006 IEEE, 2006, pp. 2577-2582.
[23] L. Reznik, Fuzzy controllers, 1 ed. Oxford: Newnes, 1997
[24] Z. M. Yusoff, et al., "Hybrid fuzzy plus PID controller of hydro-diffusion steam distillation essential oil extraction system: Design and performance evaluation," AIP Conference Proceedings, vol. 1774, 2016.
[25] Z. M. Yusoff, et al., "Self- tuning fuzzy PID controller using online method in essential oil extraction process," in 6th International Conference on Computing and Informatics, ICOCI, 2017, pp. 208-214.