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Adaptive Neuro-Fuzzy Inference System (ANFIS) for Controlling Level and Pressure on Deaerator

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Abstrak

Deaerator is one of the most widely used plants in the chemical industry and marine steam power plant. Deaerator is used to eliminate oxygen in water that enters the boiler to avoid corrosion of the boiler pipes. Control of pressure and level in deaerator needs to be done to keep the process well. The purpose of the research is to design a control system that can keep pressure and level of deaerator on the set point un the presence of changes in the load and input systems. Deaerator should be controlled to keep its safety and efficiency. Adaptive Neuro-Fuzzy Inference System (ANFIS) is a combination of fuzzy logic control and neural network. Design of ANFIS requires an input-output data set obtained from a PI controller that is considered as a "teacher" for ANFIS for the learning process. The results of the simulation show that the system using ANFIS controller for controlling pressure and level deaerator in normal set point can produce very small maximum overshoot that is equal to 0% and small IAE value that is 7.898 for pressure, and 157.7 for level compared to PI.

Kata kunci*: Deaerator; level; pressure; ANFIS*

Abstract

[Judul: Sistem kontrol Adaptive Neuro-Fuzzy Inference System (ANFIS) untuk pengendalian level dan pressure pada deaerator]. *Deaerator adalah salah satu plant yang banyak digunakan di industri kimia dan pembangkit listrik tenaga uap. Deaerator berfungsi untuk menghilangkan oksigen dalam air yang masuk ke boiler untuk menghindari korosi pada pipa boiler. Pengendalian tekanan dan level dalam deaerator dilakukan adar keberlangsungan proses berjalan dengan baik. Tujuan penelitian ini adalah merancang sistem kontrol yang dapat menjaga tekanan dan level deaerator pada set point normal meskipun terjadi perubahan beban amuapun masukan pada sistem. Hal tersebut dilakukan untuk menjaga keamanan dan efisiensi kerja deaerator. Adaptive Neuro-Fuzzy Inference System (ANFIS) adalah kombinasi dari kontrol logika fuzzy dan jaringan saraf. Desain ANFIS membutuhkan set input-output data yang diperoleh dari pengontrol PI yang dianggap sebagai "guru" untuk ANFIS segabai proses pembelajaran. Hasil simulasi menunjukkan bahwa sistem yang menggunakan pengendali ANFIS untuk mengendalikan tekanan dan level deaerator pada set point normal dapat menghasilkan overshoot maksimum yang sangat kecil yaitu sebesar 0% dan nilai IAE kecil yaitu 7,898 untuk tekanan, dan 157,7 untuk level dibandingkan dengan PI.*

Keywords*: Deaerator, level, tekanan; ANFIS*

1. Introduction

Deaerator is usually used to remove the oxygen and carbon monoxide in condensation water and heat the condensation water to saturation temperature for boiler (Opriş, 2013; Wang, Meng & Ji, 2014; Wang, Meng & Dong, 2015; Zhao, Yao, & Sun, 2014). Deaerator serves to eliminate the content of O_2 from make-up water which will be pumped into heat exchangers and boilers. The process of removing these gases is by entering steam as a heater that will evaporate the gases in the water. After that, the water that has been through the heating process will be accommodated on the deaerator tank which is part of the deaerator before it flows on the

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boiler. With the heating process in the deaerator, it changes the vapor pressure inside. In addition to controlling the pressure, the water level in the deaerator also needs to be controlled below the permitted charge. Moreover, the water supply to the boiler can continue to be fulfilled. With the multivariable interrelated process, it is difficult to get satisfactory control effect because of the strong coupling between deaerator pressure and deaerator water level. It is necessary to take a corresponding decoupling measure (Wang, Meng & Ji, 2014). Using decoupling in the plant can reduce the interaction between both controlled variables and can produce better control results than without using decoupling.

Many control methods have been applied to plant deaerators such as research by Peng Wang that used PID neural network decoupling. The results prove that the PID neural network decoupling strategy is more effective in deaerator pressure and water level decoupling control than PID (Wang, Meng & Ji, 2014). Another research using PID neural network decoupling strategy can significantly reduce the overshoot and settling time of condenser water level and deaerator water level and can make the control process much more stable. It is more effective in decoupling control than PID (Wang, Meng & Dong, 2015). In addition, Fuzzy tuning control methods PID and IMC were also used for deaerator control. It could reach settling time faster, i.e. 10s for level and 8 s for pressure, than using IMC control method (Gomathy & Anitha, 2015). Another research comparing Neural Network (NN) with the Extreme Learning Machine (ELM) method found that ELM is better and superior when compared with NN. Based on the time of training, ELM is very fast compared with NN. ELM accuracy in training and validation results has an average error smaller than NN predicted outputs (Mahardhika et al., 2017).

Neural Networks have a well-defined training methodology based on their ability to learn but are limited by the inability to make decisions. In order to best exploit the capabilities of both types of controller, it is possible to utilize a neural network which is trained to perform as a fuzzy logic controller. One system which has been shown to combine the positive aspects of both types of AI controller is the Adaptive Neuro-Fuzzy Inference System (ANFIS) (Darvill, Tisan, & Cirstea, 2015; Jang, Sun, & Mizutani, 1997; Narayan, 2017). This research designs the ANFIS controller to control the level and pressure in the deaerator. The ANFIS learning method uses a PI controller that acts as a "teacher" for the ANFIS controller. The implementation of the controller in this research, as well as the simulation result, is presented in the following sections.

2. Research Method

2.1 Deaerator

Deaerator works by the character of oxygen whose solubility in water will be reduced by the rise in temperature, The O_2 content of the deaerator needs to be removed in order to avoid corrosion but also to avoid fire. From P & ID (Piping and Instrumentation Diagram) deaerator 101U PT. Petrokimia Gresik, degassing section deaerator get input from the makeup water, as shown in Figure 1. There is a process of binding oxygen by giving steam input with a small O_2 content which will bind the large oxygen content contained in makeup water. Steam will be thrown entirely into the air along with the oxygen content that has been tied up. The deaerator also has a condensate water input. The water content of the condensate is H_2O without any mixture of O2. Water output from degassing section deaerator enters storage water tank deaerator. In this paper, the tray type deaerator is used that consists of a domed deaeration section mounted on a horizontal vessel cylinder that serves as a water storage tank from the boiler (Figure 1).

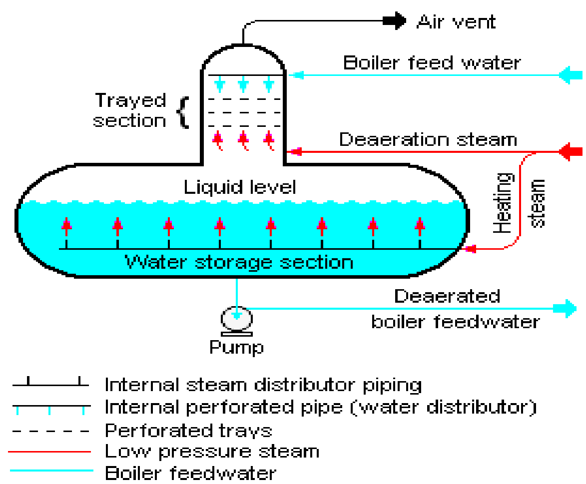

Figure 1. Deaerator process

2.2. Mathematical Modeling of Deaerator

The mathematical model equations for pressure and level can be seen in Equations (1) and (2).

Pressure :

$$P(s) = \frac{h_c}{\frac{(S_w m_w + S_s m_s)}{(S_v \dot{m}_v + S_f \dot{m}_f)} s + 1} Q_c - \frac{h_{mw}}{(S_w T \rho_w Z - S_s T Z \rho_s) s} Q_{mw} \quad (1)$$

Level :

$$L(s) = \frac{h_{mw}}{(S_w T \rho_w Z - S_s T Z \rho_s) s} Q_{mw} \quad (2)$$

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Where,

h_c	=	enthalpy of condensate
h_{mw}	=	enthalpy of makeup water
$\dot{m}_c$	=	Condensate flow rate
$\dot{m}_{mw}$	=	makeup water flow rate
S_w	=	entropy of water
S_s	=	entropy of steam in
S_v	=	entropy of steam out (vapor)
S_f	=	entropy of water out (flow out)
m_w	=	water mass
m_s	=	steam mass
$\dot{m}_v$	=	steam out (vapor) flow rate
$\dot{m}_f$	=	water out (flow out) flow rate
Q_c	=	condensate flow rate
Q_{mw}	=	make up water flow rate

By inserting the physical parameter values of the deaerator, the transfer function is shown in Equations (3), (4) and (5).

$$\frac{P(s)}{Q_c(s)} = \frac{2585.8}{169.4\,s+1} \tag{3}$$

$$\frac{P(s)}{Q_{mw}(s)} = \frac{649.87}{-1331313.1s} \tag{4}$$

$$\frac{L(s)}{Q_{mw}(s)} = \frac{649.87}{-1331313.1s} \tag{5}$$

2.2. Decoupling

Decoupling is a dynamic element that is added to the MIMO (Multiple Input Multiple Output) control systems which aims to minimize the interaction effects between two loops resulting in two loops that do not interact with each other. Decoupling transforms the MIMO model into SISO (Single Input Single Output) form to facilitate the analysis and design of the controller(Stephanopoulos, 2001; Zhou, Deng, & Duan, 2017; Zhang et al., 2016). The decoupling control for the process of controlling the system with two inputs and two outputs is shown in Figure 2.

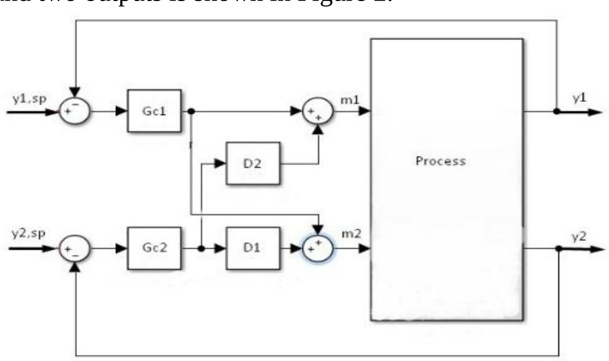


Figure 2. Decoupling System on MIMI 2x2

Separate analyses are performed on each input-output, therefore the value of decoupling D_{12} and D_{21} are shown in equation 6 and 7.

$$D_{12} = -\frac{G_{12}}{G_{11}} \tag{6}$$

$$D_{21} = -\frac{G_{21}}{G_{22}} \tag{7}$$

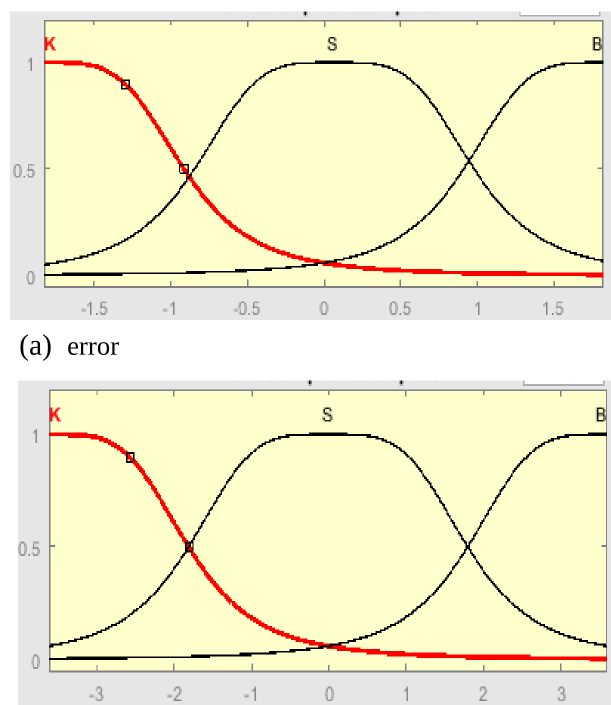
The decoupling equation used is then:

$$Decoupler = -\frac{G_{12}}{G_{11}}$$

$$= -\frac{110.088\,s+649.87}{3442629223.2s} \tag{8}$$

2.3 Adaptive Neuro-Fuzzy Inference System (ANFIS)

Following is the membership functions and rules that are used to control the level and pressure on the deaerator. The membership function used is the generalized bell-type for both pressure and level as shown in Figure 3 and 4 while the rules are shown in Figure 5 and 6.



(a) error

(b) delta error

Figure 3. Membership function for pressure

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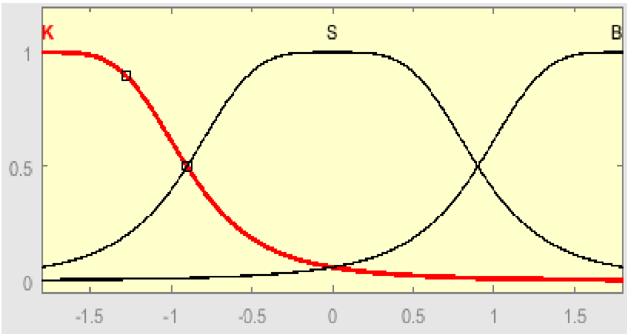
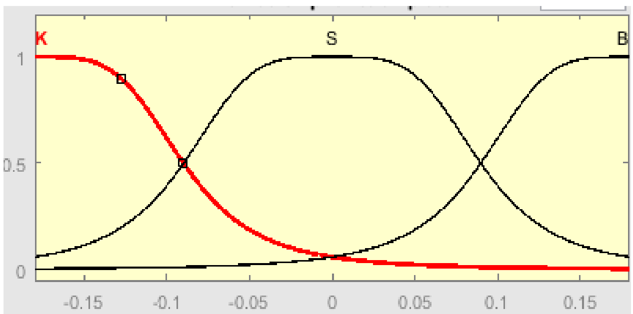


(a) error



(b) delta error

Figure 4. Membership function for lever

1. If (error is K) and (deltaerror is K) then (u(k) is u(k)1) (1)
2. If (error is K) and (deltaerror is S) then (u(k) is u(k)2) (1)
3. If (error is K) and (deltaerror is B) then (u(k) is u(k)3) (1)
4. If (error is S) and (deltaerror is K) then (u(k) is u(k)4) (1)
5. If (error is S) and (deltaerror is S) then (u(k) is u(k)5) (1)
6. If (error is S) and (deltaerror is B) then (u(k) is u(k)6) (1)
7. If (error is B) and (deltaerror is K) then (u(k) is u(k)7) (1)
8. If (error is B) and (deltaerror is S) then (u(k) is u(k)8) (1)
9. If (error is B) and (deltaerror is B) then (u(k) is u(k)9) (1)

Figure 5. Rule of pressure

1. If (error is K) and (deltaerror is K) then (u(k) is u(k)1) (1)
2. If (error is K) and (deltaerror is S) then (u(k) is u(k)2) (1)
3. If (error is K) and (deltaerror is B) then (u(k) is u(k)3) (1)
4. If (error is S) and (deltaerror is K) then (u(k) is u(k)4) (1)
5. If (error is S) and (deltaerror is S) then (u(k) is u(k)5) (1)
6. If (error is S) and (deltaerror is B) then (u(k) is u(k)6) (1)
7. If (error is B) and (deltaerror is K) then (u(k) is u(k)7) (1)
8. If (error is B) and (deltaerror is S) then (u(k) is u(k)8) (1)
9. If (error is B) and (deltaerror is B) then (u(k) is u(k)9) (1)

Figure 6. Rule for level

3. Results and Discussions

The test was performed by determining the normal set point of 1.825 kg / cm^2 for pressure control and 1.8 m for level control. Variations of testing conducted were testing of increasing set point, decreasing set point, and interference test. The tests aim to determine the ANFIS controller performance against the changes that often occur in the deaerator system.

3.1 Normal Set Point

This test was performed by giving the system input with a normal set point value of 1.825 kg / cm^2 for pressure control and 1.8 m for level control. The result of the system response is shown in Figures 7 and 8. The response of each control to the deaerator plant by testing of the normal set point is summarized in Table 1. From Table 1 it can be seen that the pressure control using ANFIS controller has a rise time of 5.0311s, 13.9643 s for settling time, maximum overshoot approaches 0 %, and IAE 7.898. On the other hand, PI controller with $K_p = 0.09$ and $K_I = 0.006$ produces rise time of 0.0834s, settling time of 10.9975 s, maximum overshoot 7.87 %, and IAE 7.93.

Moreover, the level control using ANFIS yields rise time of 196.6964 s, settling time of 371.2379 s, maximum overshoot approaches 0 %, and IAE 157.7. The usage of PI controller with $K_p = -20$ and $K_I = -5$ produces rise time of 21.5045 s, settling time of 836.341 s, maximum overshoot 75.3193%, and IAE 233.1.

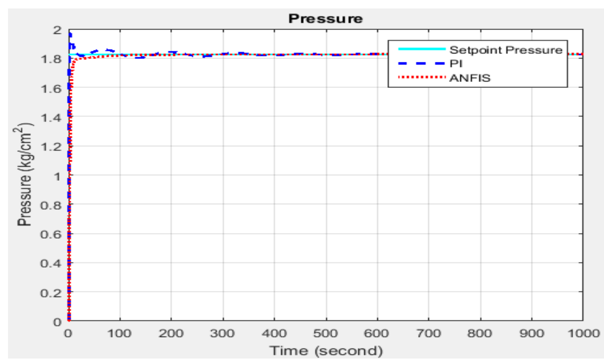


Figure 7. Pressure control response with SP=1.825 kg/cm^2

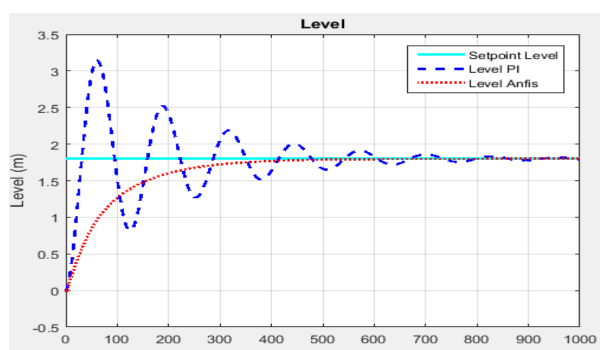


Figure 8. Level control response with SP=1.8 m

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Table 1. Comparison of each control response with normal setpoint

	Control Method	Rise Time (second)	Max Overshoot (%)	Settling Time (Second)	IAE
Presure	PI	0.0834	7.87	10.9975	7.93
	ANFIS	5.0311	0	13.9643	7.898
Level	PI	21	75.3193	836.341	233.1
	ANFIS	196.6964	0	371.2379	157.7

3.2 Increasing Setpoint

In this test, the set point value is increased by 0.2 kg/cm^2 from the normal set point to 2.025 kg / cm^2 for pressure control. While to control the level, set point value is increased by 0.2 m to 2.0 m. The result of system response can be seen in Figure 11 and Figure 12 while the response of control for increasing set point can be seen in Table 2. Table 2 shows that using ANFIS controller for pressure control has rise time of 3.0573 s, 1004 s for settling time, maximum overshoot 11.849%, and IAE 18.55. While the PI controller produces rise time of 3.0116 s, settling time 1004 s, maximum overshoot 19.896%, and IAE 27.61. In case of the level controlling, ANFIS control yields rise time of 128.4964 s, settling time of 1831.1s, maximum overshoot 12.955%, and IAE 180. PI controller produces rise time of 19.7702 s, settling time of 1831.1s, maximum overshoot 96.386%, and IAE 260.7.

3.3 Decreasing Setpoint

In this test, set point value is decreased by 0.2 kg / cm^2 from the normal set point to 1.625 kg / cm^2 for pressure control. While to control the level, set point value is decreased by 0.2 m to 1.6 m. The result of system response is shown in Figure 11 and 12 while each response of control for decreasing set point can be seen in Table 3. Table 3 shows that using ANFIS controller for pressure control produces rise time of 3.0573 s, 1004 s for settling time, maximum overshoot 11.849 %, and IAE 18.55. While the PI controller has a rise time of 3.0116 s, settling time 1004 s, maximum overshoot 19.896 %, and IAE 27.61. Then for controlling the level using ANFIS, it yields rise time of 128.4964 s, settling time of 1831.1 s, maximum overshoot 12.955 %, and IAE 180. Moreover, using a PI controller produces rise time of 19.7702 s, settling time of 1831.1 s, maximum overshoot 96.386%, and IAE 260.7.

Table 2. Comparison of each control response for increasing setpoint

	Control Method	Rise Time (second)	Max Overshoot (%)	Settling Time (Second)	IAE
Presure	PI	5.976	1.0893	1003.9	27.44
	ANFIS	94.025	0.16	1003.9	16.15
Level	PI	23.411	57.2	1521.9	259.8
	ANFIS	1188.9	0	1364.7	178.4

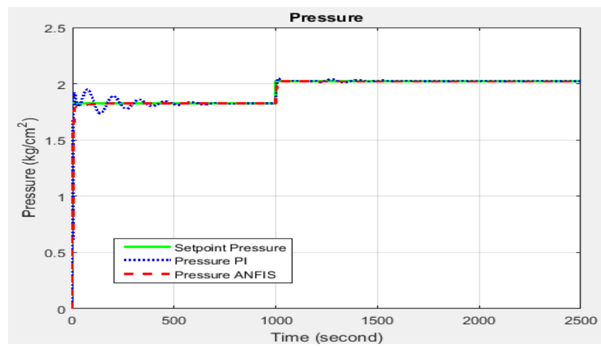

Figure 9. Pressure control response with increasing set point

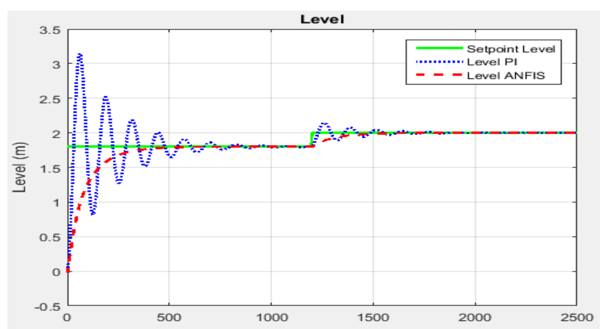

Figure 10. Level control response with increasing set point

Table 3. The comparison of each response control for decreasing set point

	Control Method	Rise Time (second)	Max Overshoot (%)	Settling Time (Second)	IAE
Presure	PI	3.0116	19.896	1004	27.61
	ANFIS	3.0573	11.849	1004	18.55
Level	PI	19.7702	96.386	1831.1	260.7
	ANFIS	128.4964	12.955	1697.9	180

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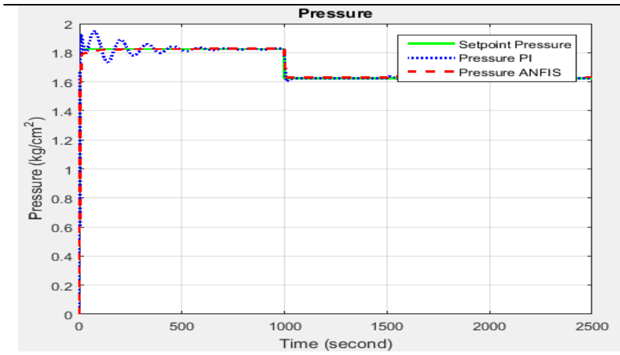

Figure 11. Pressure control response with decreasing set point

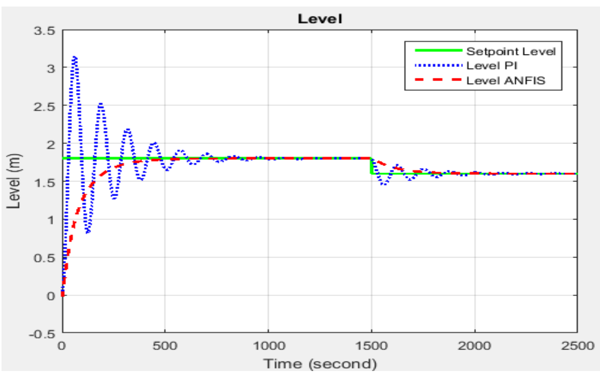

Figure 12. Level control response with decreasing setpoint

3.4 Test of Step Signal Disturbance

Testing of the disturbance is done on the system with the normal set point with additional disturbance in the form of step signal at 1500 seconds. The purpose of this test is to know the performance of the controller in response to disturbances that occur in the system when a disturbance exists in the form of step signals of 1.825 kg / cm^2 for pressure and 1.8 m for the level. The system responses are shown in Figures 13 and 14, while the response of each control by interference test is presented in Table 4. Table 4 shows that ANFIS controller for pressure control has a rise time of 0.0561 s, 1502.9 s for settling time, maximum overshoot 42.4944 %, and IAE 149.2. While the PI controller produces rise time of 0.0565 s, settling time 1503,9 s, maximum overshoot 41.5512 %, and IAE 10.77. Then for controlling the level using ANFIS, it yields rise time of 199.0588 s, settling time of 1799 s, maximum overshoot 28.4234 %, and IAE 218.7. PI controller produces rise time of 21.0301 s, settling time of 2082 s, maximum overshoot 77.5745 %, and IAE 342.5.

Table 4. Comparison of each response control with step signal disturbance

	Control Method	Rise Time (second)	Max Overshoot (%)	Settling Time (Second)	IAE
Presure	PI	0.0565	41.5512	1503.9	10.77
	ANFIS	0.0561	42.4944	1502.9	149.2
Level	PI	21.0301	775745	2082	342.5
	ANFIS	199.0588	28.4234	1799	218.7

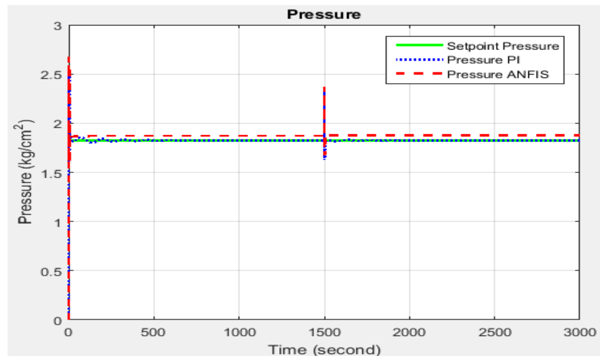

Figure 13. Pressure control response with step signal disturbance

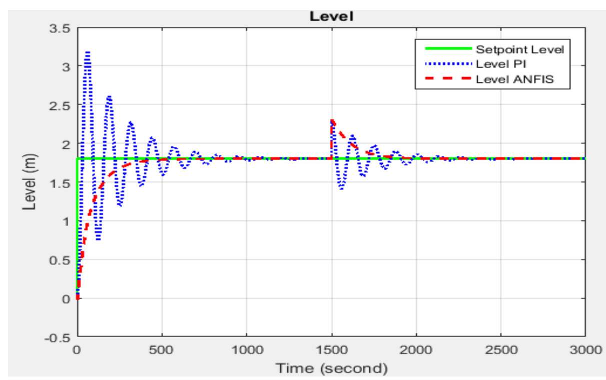

Figure 14. Level control response with step signal disturbance

4. Conclusions

Pressure and level control on the deaerator yield very small maximum overshoot that approaches 0% and small IAE value of 7.898 for pressure, 157.7 for level compared to PI in normal set point (with $K_p = 0.09$, $K_I = 0.006$ for pressure and $K_p = -20$, $K_I = -5$ for level). Pressure and level control response with increasing set point using ANFIS can achieve faster settling time, i.e. 1003.9s for pressure and 1364.7s for level, smaller maximum overshoot of 0.16% for pressure and 0% for the level and smaller IAE that is 16.15 for pressure and 178.4 for level than PI. The test of

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decreasing set point by using ANFIS controller in pressure and level control can achieve faster settling time of 1004s for pressure and 1697.9s for level, smaller maximum overshoot of 11.849% for pressure and 12.955% for level and smaller IAE that is 18.55 for pressure and 180 for level compared with PI. In the test with step signal disturbance on pressure control, the ANFIS controller cannot reach set point after responding disturbance even though it is moving toward set point, while at level control by using ANFIS controller can reach faster settling time with smaller maximum overshoot and IAE value than PI. For normal set point testing, using ANFIS controller for pressure can reach settling time faster that is 13.9643s in comparison with PID Neural Network that is 160s. Controlling pressure and level using ANFIS need a longer time to reach a setting time, i.e. 13.9643s for pressure and 371.2379s for level, compared by using Fuzzy-PID which requires 10s for level and 8s for pressure to reach settling time. As a result, the usage of ANFIS has been successfully improving the deaerator performance.

References

Darvill, J., Tisan, A., Cirstea, M. (2015). An ANFIS-PI based boost converter control scheme. *2015 IEEE 13th International Conference on Industrial Informatics (INDIN)*, 632–639. https://doi.org/10.1109/INDIN.2015.7281809

Gomathy, S., Anitha, T. (2015). Deaerator Storage Tank Level & Deaerator Pressure Control Using Soft Computing Deaerator Storage Tank Level & Deaerator Pressure Control Using Soft Computing. *International Journal for Science and Advance Research in Technology*, *1*(January 2015).

Jang, J.-S. R., Sun, C.-T., Mizutani, E. (1997). *Neuro-fuzzy and soft computing: a computational approach to learning and machine intelligence*. New Jersey: Prentice Hall.

Mahardhika, W. P., Soeprijanto, A., Syaiin, M., Wibowo, S., Kurniawan, R., Herijono, B., Kaloko, B. S. (2017). Design of Deaerator Storage Tank Level Control System at Industrial Steam Power Plant with Comparison of Neural Network (NN) and Extreme Learning Machine (ELM) Method, *International Symposium on Electronics and Smart Devices*, 40–45.

Narayan, J. (2017). ANFIS Based Kinematic Analysis of a 4-DOFs SCARA Robot. *4th IEEE Internatonal Conference on Signal Processing. Computing and Control (ISPCC 2k17)*.

Opriş, I. O. A. N. A. (2013). A deaerator Model. In Recent Advances in Continuum Mechanics, Hydrology and Ecology, Energy, Environmental and Structural Engineering Series–14, *WSEAS International Conference*, Rhodes Island, Greece.

Stephanopoulos, G. (2001). *Chemical Process Control An Introduction to Theory and Practice*, Cambridge: Massachusets Institute of Technology.

Wang, P., Meng, H., Ji, Q. (2014). PID Neural Network Decoupling Control of Deaerator Pressure and Water Level Control System, *Proceedings of the 2014 IEEE International Conference on Robotics and Biomimetics December 5-10, 2014, Bali, Indonesia*, 2298–2303.

Wang, P., Meng, H., Dong, P., D. R. (2015). Decoupling Control Based on PID Neural Network for Deaerator and Condenser Water Level Control System. *IEEE Proceedings of the 34th Chinese Control Conference July 28-30, 2015*, Hangzhou: China, 2298–2303.

Zhang, Y., Chai, T., Wang, D., Chen, X., (2016). Virtual Unmodeled Dynamics Modeling for Nonlinear Multivariable Adaptive Control With Decoupling Design. *IEEE Transactions On Systems, Man, And Cybernetics: Systems*, *2168–2216*.

Zhao, J., Yao, Z., Sun, L. (2014). New Type of Parallel Deaerator's Water Level and Pressure Control. *2014 International Symposium on Computer, Consumer and Control*, 143–145. https://doi.org/10.1109/IS3C.2014.48

Zhou, H., Deng, H., & Duan, J. (2017). Hybrid Fuzzy Decoupling Control for a Precision Maglev Motion System. *IEEE/ASME Transactions on Mechatronics*, *23*(1), 389–401. https://doi.org/10.1109/TMECH.2017.2771340

doi: 10.14710/teknik.v40n2.22087