IOSR Journal of Electronics and Communication Engineering (IOSR-JECE)
e-ISSN: 2278-2834,p- ISSN: 2278-8735.Volume 16, Issue 4, Ser. I (Jul. – Aug. 2021), PP 15-22
www.iosrjournals.org

Design And Implementation Of Mamdani Type Fuzzy Inference System Based Water Level Controller

[1]Shakiru Olajide KASSIM, [2]Aishatu Garga Ali, [1]Ibrahim Muhammad Harram
[1]Department of Computer Engineering Technology
[2]Department of Electrical/Electronic Engineering Technology
The Federal polytechnic Damaturu, Yobe State.
Corresponding Author: Shakiru Olajide KASSIM

Abstract

For industrial applications such as boilers in nuclear power plants, textile dying machines, etc., water level control is highly important. In this work, afuzzy logic based simple water level indicator and controller was designed and implemented. For simplicity, the fabricated electronic level indicator defines only two (2) levels; minimum and maximum through use of Light Emitting Diodes (LEDs). The fuzzy logic controller (FLC) was based on Mamdani type Fuzzy Inference System which has two inputs; error in level and rate of change of error with one output; valve position. The fuzzy controller was implemented in MATLAB and then simulated in Simulink to test the behaviour of the system when the inputs change. The response of the fuzzy controller was then compared with a conventional PID controller for system performance check and reliability. The results obtained shows that Fuzzy logic has little overshoot and steady state error and stabilizes quickly providing accurate level control, hence can be used for rapid control with coarse adjustment. This designed controller can be tested with periodically varying liquid level tracking applications.And For better and higher accuracy, an optimized FLC by tuning the fuzzy parameters may be employed in future designs.

***Keywords: Fuzzy logic controller, level control, Mamdani, PID controller, Simulink**.*

Date of Submission: 22-07-2021 Date of Acceptance: 07-08-2021

I. Introduction

Control of liquid level in many industrial processes is often required. It has been recorded that 25% of emergency shutdowns in most industries are caused by poor control of the steam generator water levels. These shutdowns greatly decrease plant availability, consequently productivity. Generally, the flowing of water is supplied via a pump from a storage tank and water flow rate is adjusted with an actuator. The level of liquid is measured through a pressure transmitter. The transmitted pressure data is transferred to control circuit (Moradi, Avval, & Nejad, 2012).

Water level control systems are very complex system, because of the nonlinearities and uncertainties of the systems. There are various approaches to the design of the level controllers. Most commonly used is theconstant gain PI controllers utilized in industries for boiler water level control at the expense of high power operations. However, at low power operations, PI controllers cannot maintain water level properly. Thus, the dire need for performance improvement in existing water level regulators for optimal systems performance.

For ages, in any application of industrial controlling process, PID controller has been widely used due to its simplicity and ease of retuning its online feature(Govinda, Mithunchakravarth, & Dhivya, 2014; Sony, Erwin, & Agung, 2016; Maria, 2011; Zahratul & Syariza, 2016). Though many aspect of a control system can be understood based on linear theory, some nonlinear effect must be accounted (Sony, Erwin, & Agung, 2016). Theoretically, the Stability of PID controller can be guaranteed and zero steady-state tracking error can be achieved for linear plant in steady-state phase. PID control algorithm via Computer simulations have revealed that the tracking error is quite often oscillatory, however, with large amplitudes during the transient phase. Several strategies have been proposed for improvement of the PID controllers' performance, such as adaptive and supervising techniques.

An effective method to deal with disturbances and uncertainties in terms of ambiguity considered is Fuzzy control methodology. Combining fuzzy technology with traditional PID control algorithm (Fuzzy PID controller) gives a more effective artificial intelligence controller (Davood, Seyed, & Faridoon, 2013). Depending on the complexity of Fuzzy Logic Control (FLC) the most common problem which results early is the tuning problem, this because designing and tuning FLCs manually is quite rigorous for the most machine problems especially for nonlinear systems as used in industries. Other design combines both Fuzzy and Neural Network(Stefano, Marco, András, & Franchini, 2005; Daniel, Fakhreddine, & Insop, 2005) for control performance as compared to the use of only Fuzzy Control for reduce system control complexity (Namrata, Ria, & Monica, 2013 ; Ihedioha & Eneh, 2015).

In this work, a water level controller based on mamdani type fuzzy inference system was designed and implemented with results obtained showing that the system provides accurate level control with little overshoot and steady state error but stabilizes quickly on application.

II. Literature Review

Several control approaches has been implemented to achieve water level control in different situations where such is required. Ranging from the PID controllers with different scheming, scheduling or algorithm to the application of intelligent control principles. Though, PID controllers are widely used in industrial control processes but the use of intelligent controllers, such as neural network, fuzzy logic and the combination of the two) has proven to be a better controller.

A formal method of translating subjective and imprecise human knowledge into control strategies is achievable through fuzzy logic control with better system performance (Zahratul & Syariza, 2016). Namrata, Ria, & Monica (2013) analyses the effectiveness of water level control using fuzzy logic, in which the water level sensed is fed to the PIC16 microcontroller with the fuzzy logic programmed in it which controls the water level in the tank using the drain and the feed pumps. Through the set point provided by the user, the water level in the tank is controlled accordingly.

In a similar work, Daniel, Fakhreddine, & Insop (2005) proposed two intelligent control schemes (fuzzy logic and neural network) for a water level control system. In the fuzzy logic control, Sugeno model was used to control the system while in the neural network control, the approach of Model Reference Adaptive Neural Network Control based on the back-propagation algorithm was applied for training the system. Results shows that to ensure the best performance, in the fuzzy control a number of factors and values need to be online determined heuristically or by trial and error, for example, the membership functions. While for neural network control, the learning parameters and prior well-training is essential for the success of the control.

The superiority of fuzzy logic controllers (FLC) over conventional PID Controllers for water level control was investigated by (Davood, Seyed, & Faridoon, 2013). Here, the Water Level parameters of a Tank are controlled using PID controller and then optimized using FLC. The final results obtained illustrates that the measured maximum overshoot for FLC in comparison with that of PID controller reduced effectively. And that the efficiency of FLC was completely reliable than that of PIDs. Similarly, Ihedioha & Eneh (2015)carried out a study on water level monitoring and control using fuzzy logic. In their work, a controller based on fuzzy logic was implemented and compared with same implemented using Conventional PID controller using the MATLAB/SIMULINK. Results obtained shows clearly that the FLC provides promising results for level control problem with better stability, small overshoot and faster system response as compared to conventional PID Controller.

This water level controller was built using an intelligent controller, which from the reviewed literature has been proven to be more versatile in the control of water level and in most industrial control processes.

III. System Design Methodology

3.1 Intelligent system controller – mamdani-based fuzzy inference system

Theintelligent controller was based on mamdani type fuzzy inference system (FIS) which essentially defines a nonlinear mapping of the input data vector into a scalar output, using fuzzy rules. The mapping process involves input/output membership functions, FL operators, fuzzy if–then rules, aggregation of output sets, and defuzzification(Alshalaa & Issmail, 2013; Zvonko, Predrag, Dragan, & Milan, 2012; Guillaume & Charnomordic, 2015), see figure 1 for the general structure of FIS.

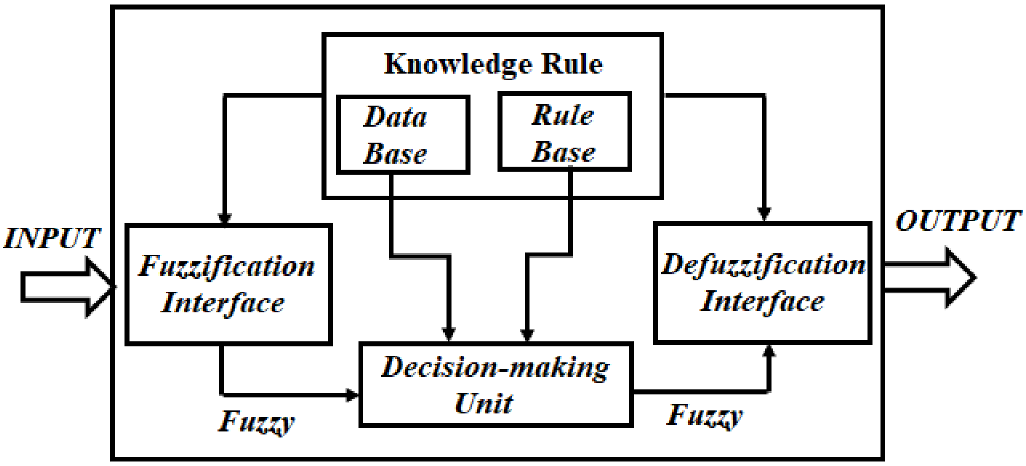


Figure 1: General structure of Fuzzy Inference System. (Alshalaa & Issmail, 2013)

The mamdani-based FIS are widely used by most researchers (Michael & Kiriaki, 2018; Shakuntla, Agarwal, & sandhu, 2020)and accepted for capturing expert knowledge because it allows expert description of a system in more intuitive and human-like manner compared to Takagi- Sugeno based FIS(Arshdeep & Amrit, 2012; Deepa & Ahijit, 2015; Shrivishal, Ashish, Shashank, & Sandeep, 2018; Vandna & Amrit, 2013). Though, both has their specific advantage, the expressive power and interpretability of Mamdani output makes the Mamdani-based FIS widely used for decision support application. Hence, it was being adopted for the controller of water level in this work.

3.2 Implemented Water Level Indicator

Several types of water level indicators have been proposed by many researchers (Reza, Tariq, & Reza, 2010; Anyanwu, Mbajiorgu, & Anoliefo, 2012; Mallikarjun, Nagaraj, Shrikanth, Ali, & Pramod, 2018; Latte, 2017; Kassim & Abatcha, 2016). From most of these works, the electrical sensing devices have been found to be more reliable and easy to fabricate and install. In this work, a level indicator is simulated around the fuzzy logic controller which is based on simple electronic circuit water level indicator with five transistors, having five sensing levels.

3.3 Mathematical Model of the Water Level Reservoir

In this design, the water supply is through a pump from an underground reservoir while the rate of water flow is adjusted with an actuator. Liquid level in the reservoir is measured via a pressure transmitter, whose transmitted pressure data is transferred to control circuit. The mathematical model of the system is represented by a first order differential equation.

$$\frac{d\text{ɦ}(\boldsymbol{t})}{dt} = -A_c\frac{\sqrt{2g\text{ɦ}(\boldsymbol{t})}}{A} + \frac{1}{A}\upsilon(\boldsymbol{t}), \qquad \ldots.. \qquad (\mathbf{1})$$

where, $\upsilon(\boldsymbol{t})$ is the input flow (control input);
$\text{ɦ}(\boldsymbol{t})$ is the liquid level (the output of the plant);
g=9.8 m/s2 is acceleration due to gravity;
A_c is cross-sectional area of the output pipe; and
A is cross-sectional area of the tank given by the equation:

$$A = a\,\text{ɦ}(\boldsymbol{t}) + \boldsymbol{b}^{\mathbf{2}} \qquad \ldots.. \qquad (\mathbf{2})$$

3.4 System Simulation with Fuzzy Logic

3.4.1 System fuzzy logic design

The system controller is Mandani based which was designed via MATLAB/Simulink using the Fuzzy Logic toolbox. The simulation employs rule base in linguistic terms, with two inputs and one output parameter.
The two inputs are:

- liquid level error $\boldsymbol{\varepsilon}(\boldsymbol{t}) = \text{ɦ}(\boldsymbol{t}) - \text{ɦ}_{\boldsymbol{d}}$(where, $\boldsymbol{\varepsilon}(\boldsymbol{t}) \in [-\mathbf{1}, +\mathbf{1}]$)and
- liquid level changerate$\dot{\boldsymbol{\varepsilon}}(\boldsymbol{t}) = \dot{\text{ɦ}}(\boldsymbol{t})$(where, $\dot{\boldsymbol{\varepsilon}}(\boldsymbol{t}) \in [-\mathbf{1}, +\mathbf{1}]$).

While the output parameter is the control angle of inlet valve $\upsilon(\boldsymbol{t})$, ($\upsilon(\boldsymbol{t}) \in [-\mathbf{1}, +\mathbf{1}]$).

3.4.2 System fuzzification

To fuzzify the inputs and output variables, triangular membership functions are selected. For each of the two inputs, three fuzzy sets are taken while five fuzzy sets are taken for the output variable. The system fuzzification processes with y-axis as membership values are as presented in the figures below.

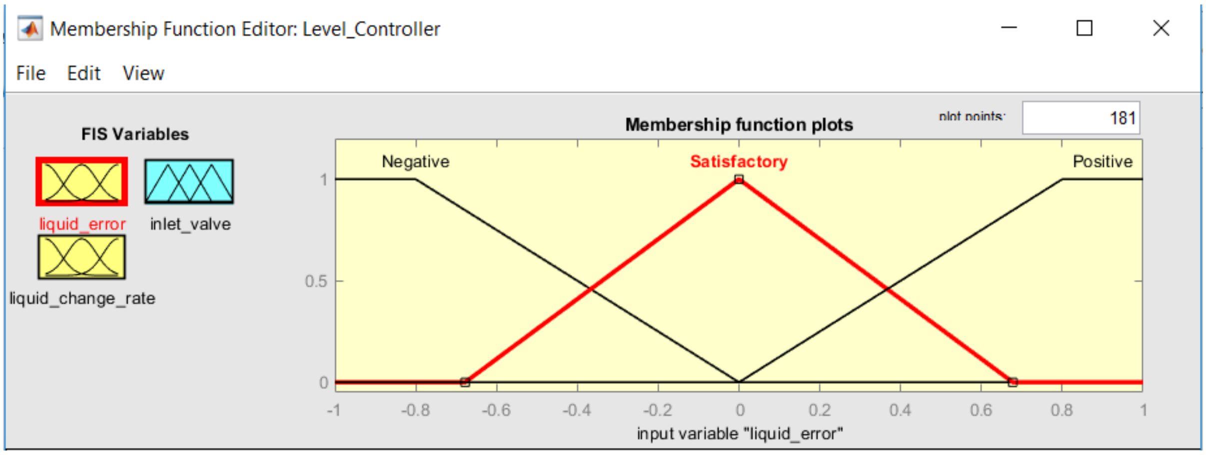


Figure 2: Input Variable “Liquid Level Error [$\varepsilon(t)$]” fuzzification.

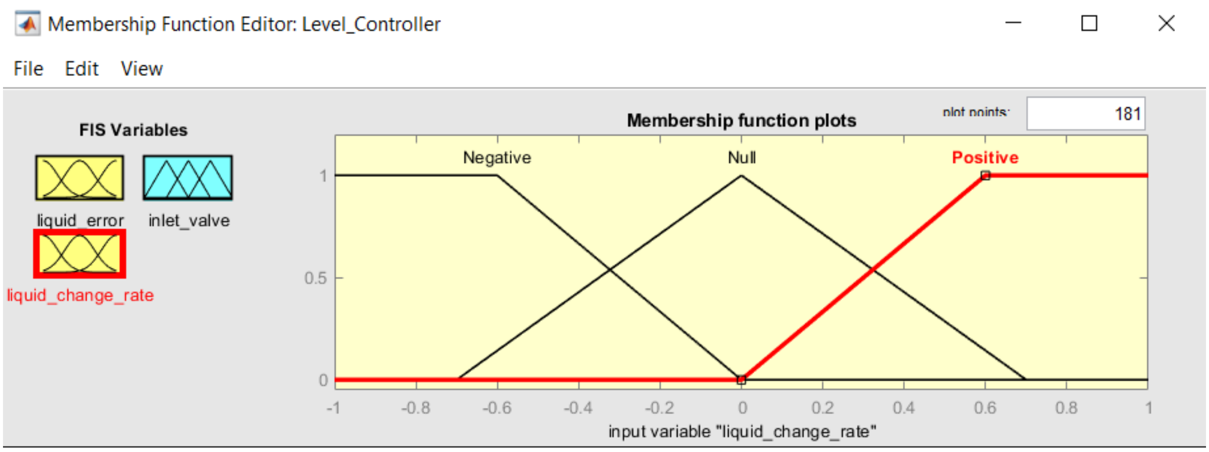


Figure 3: Input Variable “Liquid Level Change Rate [$\dot{\varepsilon}(t)$]” fuzzification.

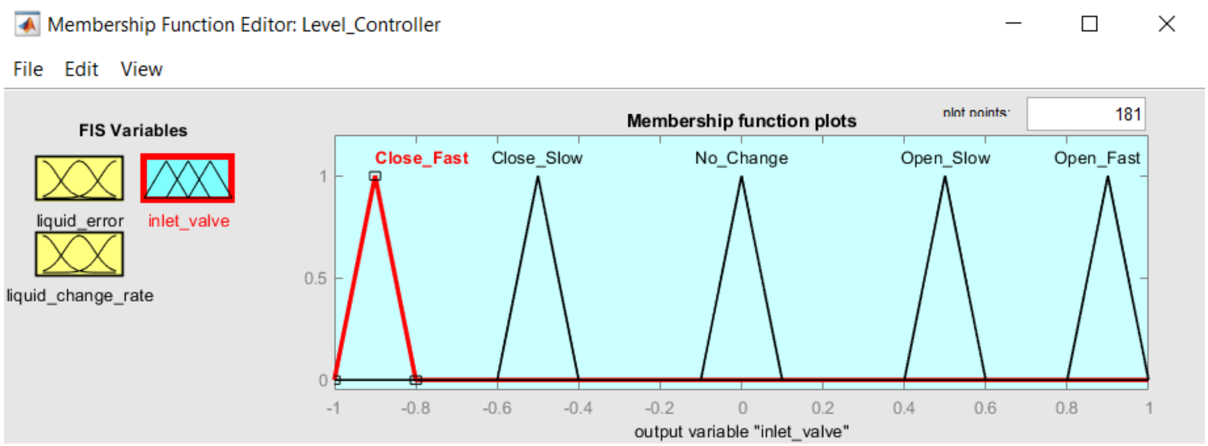
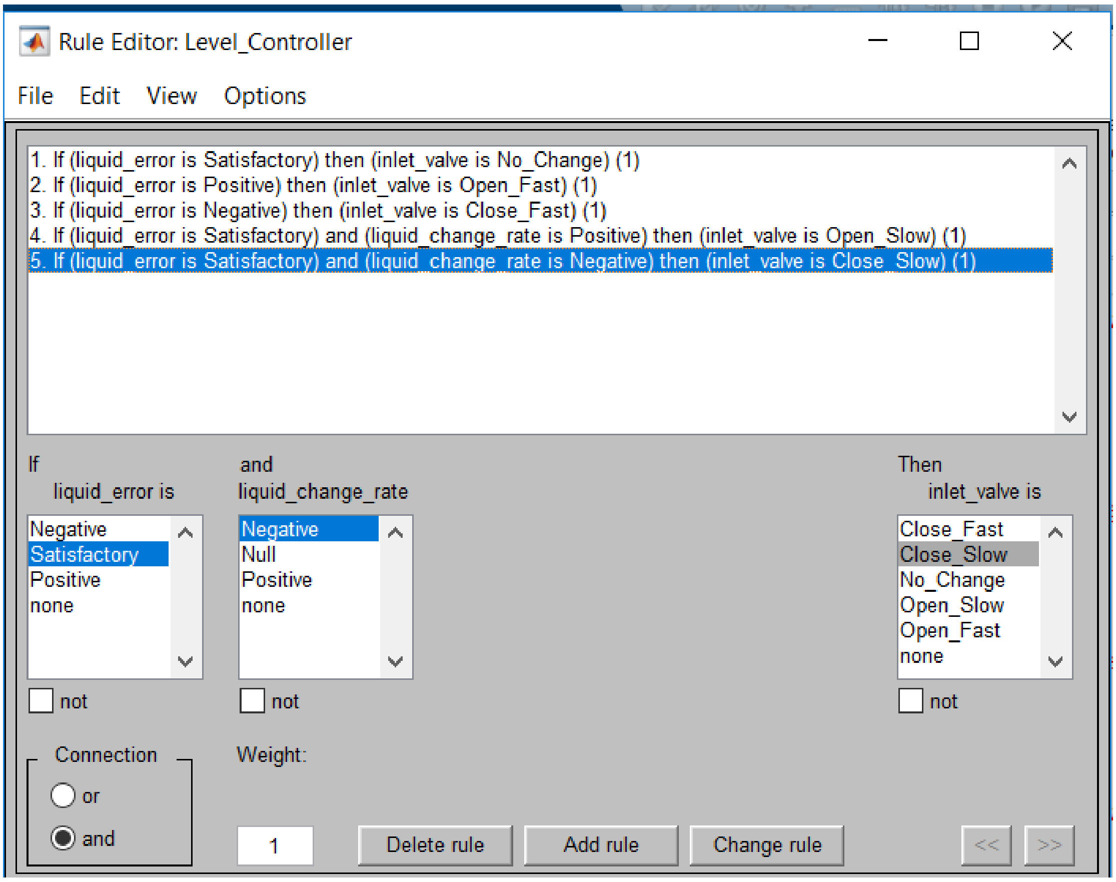


Figure 4: Output Variable “Inlet Valve [$\upsilon(t)$]” fuzzification.

3.4.3 System controller rule creation

Five rules were created for the system controller to make up the rule base, this are clearly shown in the rule editor window given in figure 5 below.



1. If (liquid_error is Satisfactory) then (inlet_valve is No_Change) (1)
2. If (liquid_error is Positive) then (inlet_valve is Open_Fast) (1)
3. If (liquid_error is Negative) then (inlet_valve is Close_Fast) (1)
4. If (liquid_error is Satisfactory) and (liquid_change_rate is Positive) then (inlet_valve is Open_Slow) (1)
5. If (liquid_error is Satisfactory) and (liquid_change_rate is Negative) then (inlet_valve is Close_Slow) (1)

If liquid_error is: Satisfactory
and liquid_change_rate: Negative
Then inlet_valve is: Close_Slow
Connection: ○ or ● and
Weight: 1

Figure 5: Created rules for the system

3.5 System Model

The Simulink models of the implemented of the water reservoir system and level controller are shown in figures 6 and 7.

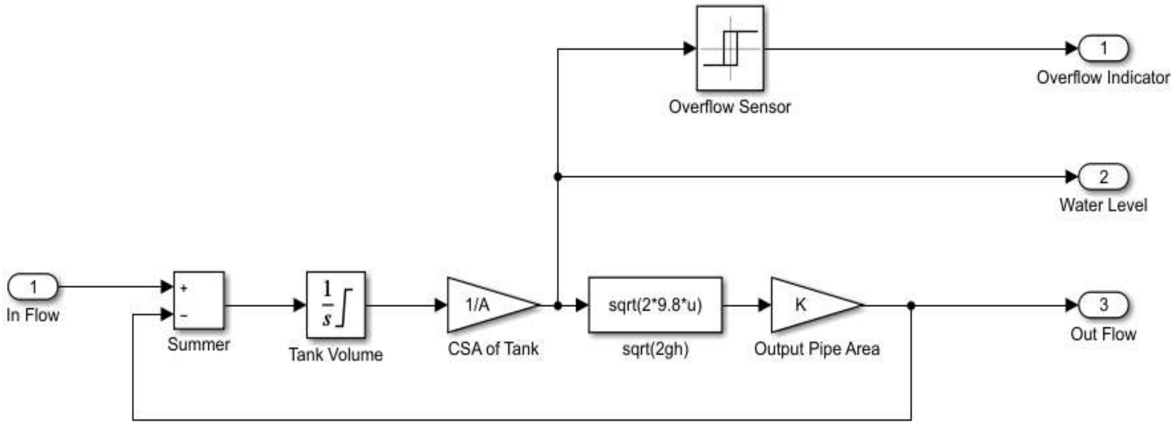


Figure 6: Simulink models of the water reservoir system

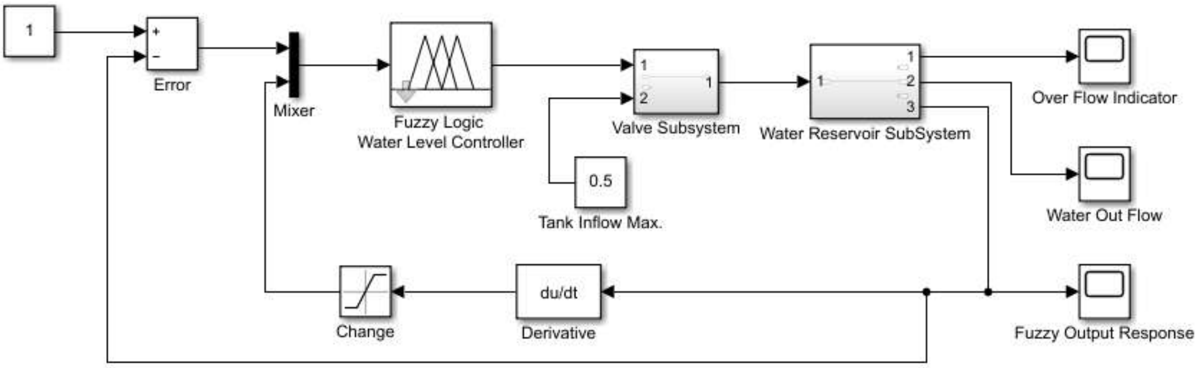
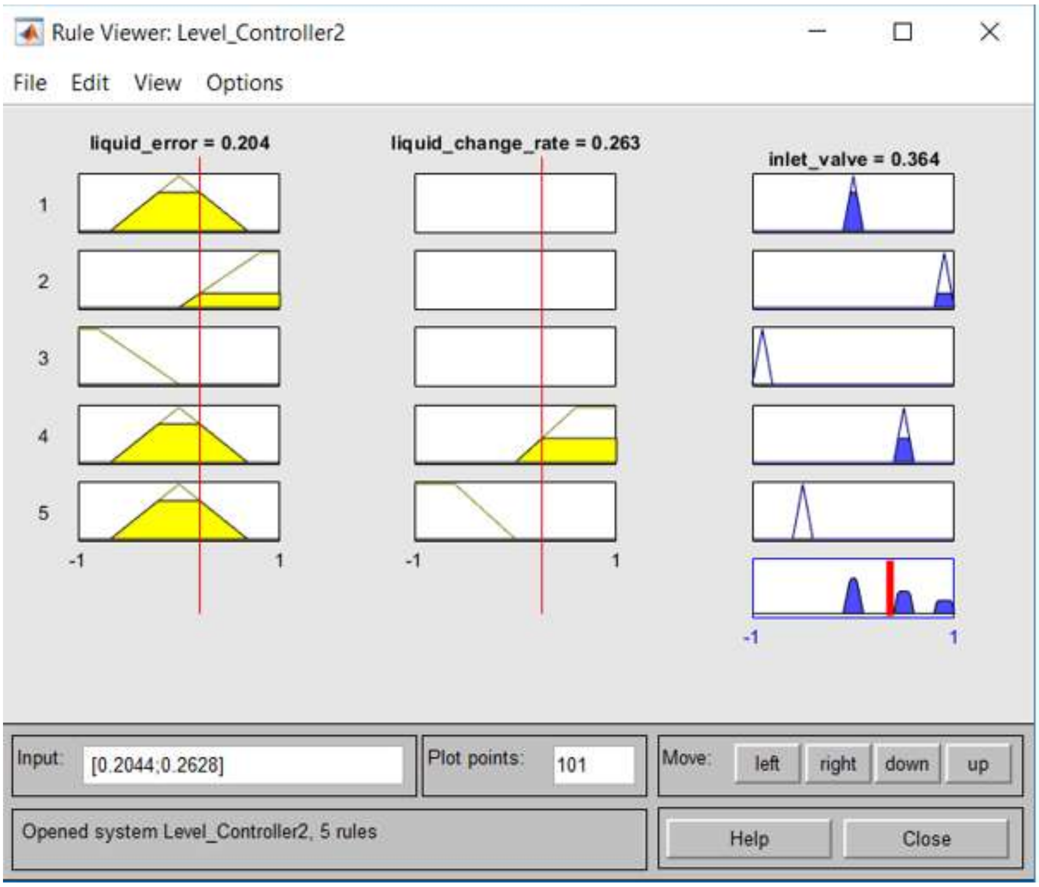


Figure 7: Simulink model of the Fuzzy Water Level Controller

4.0 Results and Discussion

The system was simulated considering the three fuzzy levels for each of the two inputs and five levels for the output parameter. Rule base was activated to follow-up the desired liquid level. The fuzzification and defuzzification process was shown by rule viewer (figure 8). The 3-D graphical realization of the fuzzy rule is shown by the surface viewer (figure 9).

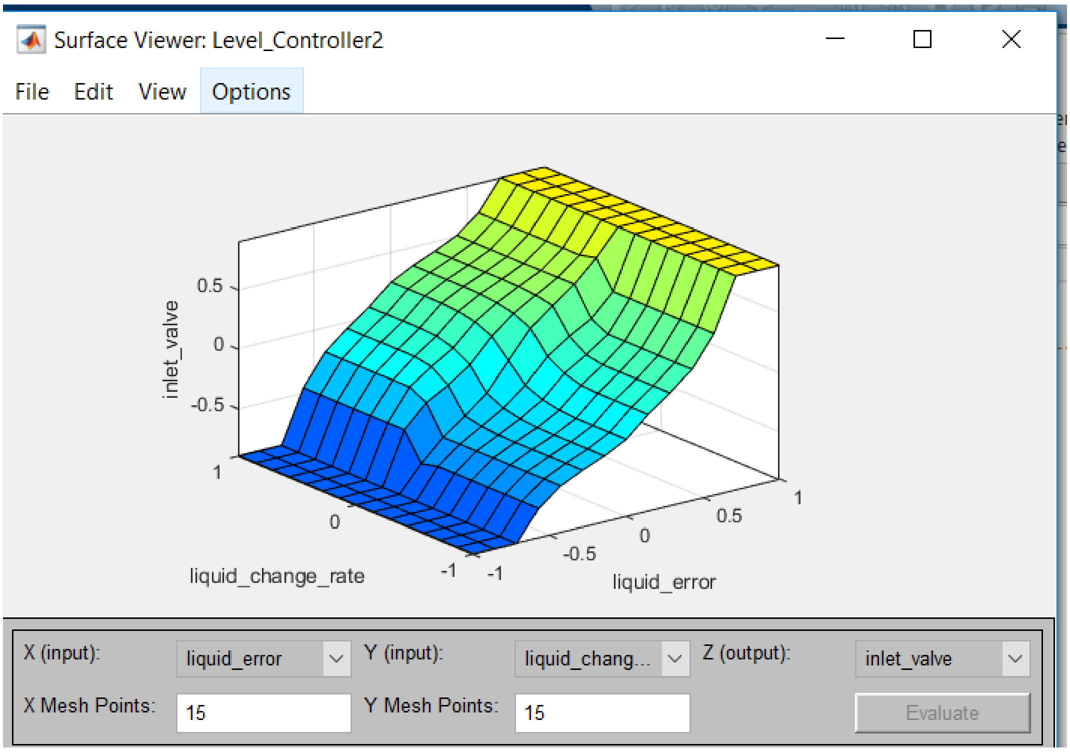


Input: [0.2044;0.2628]

Plot points: 101

Opened system Level_Controller2, 5 rules

Figure 8: Rule Viewer



X (input): liquid_error
Y (input): liquid_chang...
Z (output): inlet_valve
X Mesh Points: 15
Y Mesh Points: 15

Figure 9: 3-D graphical realization of the fuzzy rules

The water level fuzzy logic controller response on simulation is shown in figure 10, it shows that for water of 1.5 m, the controller stabilizes at the desired water level very quickly. It also shows that the controller takes time (few seconds) to respond so that the water level plunges (out flows), and the over flow is negligibly minima or rather no over flow at all.

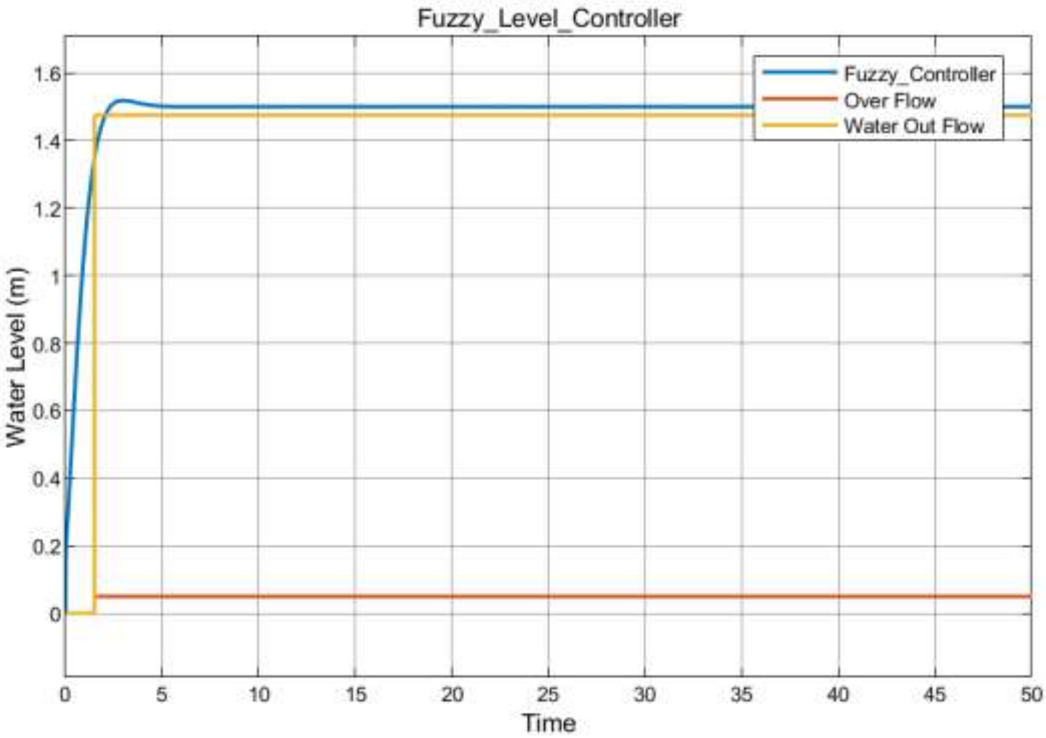


Figure 10: Response of the Water Level fuzzy Logic Controller

IV. Conclusion

This work presents the control of water level using mamdani based fuzzy inference system i.e. fuzzy controller. The general design via MATLAB/Simulink for the level controller was proposed and the design controller was simulated with remarkable results. From the work, the fuzzy logic controller as seen in the response shows little overshoot with steady state error (reduced settling time), and stabilizes quickly providing a significantly accurate level control. This shows that fuzzy controller can be used for rapid control (coarse adjustment). For better accuracy, an optimized FLC by tuning the fuzzy parameters may be employed.

References

[1]. Alshalaa, A. S., & Issmail, M. E. (2013). Comparison of Mamdani and Sugeno Fuzzy Interference Systems for the Breast Cancer Risk. International Journal of Computer and Information Engineering, 7(10), 1343-1347.

[2]. Anyanwu, C. N., Mbajiorgu, C. C., & Anoliefo, E. C. (2012, March). Design and Implementation of a Water Level Controller. Nigerian Journal of Technology (NIJOTECH), 31(1), 89-92.

[3]. Arshdeep, K., & Amrit, K. (2012, May). Comparison of Mamdani-Type and Sugeno-Type Fuzzy Inference Systems for Air Conditioning System. International Journal of Soft Computing and Engineering (IJSCE), 2(2), 323-324.

[4]. Daniel, W., Fakhreddine, K., & Insop, S. (2005). Water Level Control by Fuzzy Logic and Neural Networks. IEEE Conference on Control Applications.

[5]. Davood, M. S., Seyed, H. A., & Faridoon, S. (2013, January). Comparative Study between Tank's Water Level Control Using PID and Fuzzy Logic Controller. Advances in Intelligent Systems and Computing (AISC), 195, 141–153. doi:10.1007/978-3-642-33941-7-15

[6]. Deepa, B., & Ahijit, M. (2015, March-April). Comparative Analysis of T- Sugeno and Mamdani Type Fuzzy Logic Controller for PMSM Drives. International Journal of Engineering Research and General Science, 3(2), 495-507. Retrieved May 25th, 2021, from www.ijergs.org

[7]. Govinda, K. E., Mithunchakravarth, B., & Dhivya, N. (2014). Enhancement of PID Controller Performance for a Quadruple Tank Process with Minimum and Non-Minimum Phase Behaviors. 2nd International Conference on Innovations in Automation and Mechatronics Engineering, (ICIAME 2014). 14, pp. 480-489. Procedia Technology.

[8]. Guillaume, S., & Charnomordic, B. (2015, February 27th). Fuzzy inference systems: an integrated modelling environment for collaboration between expert knowledge and data using Fispro. Expert Systems with Applications, Elsevier, 39(10), 8744-8755. doi:10.1016/j.eswa.2012.01.206

[9]. Ihedioha, A. C., & Eneh, I. (2015, November). Water Level Monitoring and Control Using Fuzzy Logic System. International Research Journal of Engineering and Technology (IRJET), 2(8), 1382 - 1395. Retrieved from www.irjet.net

[10]. Kassim, S. O., & Abatcha, G. H. (2016, November). Design, Construction and Implementation Water Level Indicator with Auto-Refill and Numeric Display. Sahel International Multi-disciplinary Journal, 1(2), 6-19.

[11]. Latte, M. R. (2017). Low Cost Automatic Water Level Control for Domestic Applications with Digital Display. International Journal of Engineering Research and Technology, 10(1), 601-604. Retrieved December 15, 2020

[12]. Mallikarjun, G. H., Nagaraj, S. N., Shrikanth, B. J., Ali, A. S., & Pramod, G. (2018). Flexible Automatic Water Level Controller and Indicator. World Journal of Technology, Engineering and Research, 3(1), 359-366.

[13]. Maria, J. M. (2011). PID Control of Water in a Tank June 2011. University of Gavle, Department of Electronics/Telecommunications, Faculty of Engineering and Sustainable Development. Sweden: Unpublished.

[14]. Michael, T., & Kiriaki, K. (2018). Rapeseed for Biodiesel Production: A Mamdani-type Fuzzy Inference System. Journal of Scientific and Engineering Research (JSERBR) , 5(5), 252-259.

[15]. Moradi, H., Avval, M., & Nejad, F. (2012). ‘Sliding mode control of drum water level in an industrial boiler unit with time-varying parameters: A comparison with H-∞ robust control approach’. Journal of Process Control, 22(1), 1844-1855.

[16]. Namrata, D., Ria, M., & Monica, S. M. (2013 , June-July). Design and Implementation of a Water Level Controller using Fuzzy Logic. International Journal of Engineering and Technology (IJET), 5(3), 2277-2285.

[17]. Reza, S. K., Tariq, S. A., & Reza, S. M. (2010). Microcontroller Based Automated Water Level Sensing and Controlling: Design and Implementation Issue. World Congress on Engineering and Computer Science 2010 (WCECS 2010), 1, pp. 220-224. San Francisco, USA. Retrieved March 23, 2021, from https://www.researchgate.net/publication/49586673

[18]. Shakuntla, B., Agarwal, S. K., & sandhu, K. S. (2020). Implementation of Mamdani Type FIS and PI Based 3-Legged VSI Controller for an Asynchronous Generator (AG). 7th International Conference on Signal Processing and Integrated Networks (SPIN) (pp. 733-738). Auckland University of Technology: 2020 IEEE Xplore. doi:10.1109/SPIN48934.2020.9070945

[19]. Shrivishal, T., Ashish, U., Shashank, K., & Sandeep, Y. (2018, October 29th). Analysis and Comparison of Different Fuzzy Inference Systems Used in Decision Making for Secondary Users in Cognitive Radio Network. Wireless Personal Communications, 104, 1175–1208. doi:10.1007/s11277-018-6075-9

[20]. Sony, C. P., Erwin, S., & Agung, S. W. (2016). Design and Implementation of Water Level Control Using Gain Scheduling PID Back Calculation Integrator Anti Windup. International Conference on Control, Electronics, Renewable Energy and Communications (ICCEREC) (pp. 101-104). IEEE.

[21]. Stefano, A., Marco, F., András, B., & Franchini, M. (2005). Water Level Forecasting through Fuzzy Logic and Neural Network Approaches. Hydrology and Earth System Sciences Discussion, (pp. 1107–1145,). Retrieved from www.copernicus.org/EGU/hess/hessd/2/1107/

[22]. Vandna, K., & Amrit, K. (2013, May). Comparison of Constant SUGENO-Type and MAMDANI-Type Fuzzy Inference System for Load Sensor. International Journal of Soft Computing and Engineering (IJSCE), 3(2), 204 - 207.

[23]. Zahratul, L. E., & Syariza, A.-R. (2016, June). Performance Comparison of PID Tuning by Using Ziegler-Nichols and Particle Swarm Optimization Approaches in a Water Control System. Journal of Informatiom and Communication Technology (ICT), 15(1), 203–224.

[24]. Zvonko, S., Predrag, A., Dragan, P., & Milan, N. (2012, March 7th). Application of fuzzy logic into process of decision making regarding selection of managers. African Journal of Business Management, 6(9), 3221-3233. doi:10.5897/AJBM11.1500