Tikrit Journal of Engineering Sciences (2024); 31(3): 192-201
DOI: http://doi.org/10.25130/tjes.31.3.18

IRAQI Academic Scientific Journals

ISSN: 1813-162X (Print); 2312-7589 (Online)

Tikrit Journal of Engineering Sciences

available online at: http://www.tj-es.com

TJES Tikrit Journal of Engineering Sciences

Fuzzy Control of Induction Motor Actuator with Open Loop PID Controller in Water Treatment Plant

Khalaf S. Gaeid [a], **Ahmed F. Abed** [a*], **Hazli Bin Mokhlis** [b], **Ukashatu Abubakar** [c]

a Electrical Department, Engineering College, Tikrit University, Tikrit, Iraq.
b Electrical Department, Engineering College, University of Malaysia, Kuala Lumpor, Malaysia.
c Kano University of Science & Technology, Wudil, Nigeria.

Keywords:
Actuator; Fuzzy Control; Induction Motor; PID Controller; Water Treatment.

Highlights:

- Water Treatment Plants Application: Integration of a fuzzy control system with WTP control for IM actuators in all period of operation.
- Fuzzy Logic Controller (FLC): To optimize the performance of an IM by adjusting control parameters dynamically, based on real-time conditions.
- Open Loop PID Controller: New techniques of open loop PUD with fuzzy control is integrated to perform highest degree of stability compared to the traditional PID controller.

ARTICLE INFO

Article history:

Received	12 Apr.	2023
Received in revised form	17 Oct.	2023
Accepted	20 Feb.	2024
Final Proofreading	29 July	2024
Available online	19 Aug.	2024

Citation: Gaeid KS, Abed AF, Mokhlis HB, Abubakar U. **Fuzzy Control of Induction Motor Actuator with Open Loop PID Controller in Water Treatment Plant**. *Tikrit Journal of Engineering Sciences* 2024; **31**(3): 192-201.
http://doi.org/10.25130/tjes.31.3.18

*Corresponding author:

Ahmed. F. Abed
Electrical Department, Engineering College, Tikrit University, Tikrit, Iraq.

Abstract: To solve the problems in the water plant crisis, intelligent control is a highly potent technique. A fuzzy PID controller with auto-tuner capabilities is used to control the actuator in the power plant circuit. The frequency converter's controller is used with an induction motor (IM) as the actuator to stabilize the water flow across a predetermined distance. Simscape/Matlab 2020a was used to simulate the water plant (WP) circuit with the tank station in the water supply system before it was tested over various distances to gauge its current, speed, torque, and voltage. In the present model, four pump stations were used. The pressures were estimated at different distances, i.e., 40 m, 45 m, and 60 m, from the water treatment plant. In the fuzzy logic controller with 7x7 rules, the Mamdani inference engine was used. All electrical parameters were constant, while the pressure validated the system's stability. The findings demonstrated the circuit's effectiveness and constant pressure within the water treatment circuit.

التحكم الضبابي في مشغل المحرك التعريفي مع وحدة التحكم PID ذات الحلقة المفتوحة في محطة معالجة المياه

احمد فرج عبد غنام[١]، خلف سلوم كعيد[٢]، هزلي بن مخلص[٢]، اكوشاتو ابابابكر[٣]
[١] قسم الهندسة الكهربائية/ كلية الهندسة / جامعة تكريت / تكريت – العراق.
[٢] قسم الهندسة المدنية/ كلية الهندسة /جامعة مالايا / ماليزيا.
[٣] جامعة كانو للعلوم والتكنولوجيا / نيجيريا.

الخلاصة
يعد التحكم الذكي أداة قوية للغاية للتغلب على جميع الصعوبات في أزمة محطة المياه حيث تم استخدام وحدة سيطرة ضبابية مع المسيطر التناسبي التكاملي التفاضلي للاستفادة من قدرات الضبط التلقائي للسيطرة على المحرك في دائرة محطة الطاقة في هذا العمل استخدمت وحدة سيطرة على المحول الترددي مع المحرك الحثي كمشغل لتثبيت تدفق المياه عبر مسافة محددة مسبقًا. تم استخدام Simscape/Matlab 2020a لمحاكاة دائرة محطة المياه مع محطة الخزان في نظام إمداد المياه قبل اختبارها على مسافات مختلفة لقياس التيار والسرعة وعزم الدوران والجهد. كذلك تم استخدام أربع مضخات وتم تقدير الضغوط على مسافات مختلفة (٤٠ م، ٤٥ م، ٦٠ م) من محطة معالجة المياه مع وحدة السيطرة المنطقية الضبابية ذات قواعد 7x7 مع محرك الاستدلال من نوع Mamdani. اظهرت النتائج لهذا العمل قدرة كبيرة على ثبات المعلمات الكهربائية، ثبات الضغط وبالنتيجة استقرار النظام المقترح.

الكلمات الدالة: المحرك؛ التحكم الضبابي؛ المحرك الحثي؛ وحدة التحكم PID؛ معالجة المياه.

1.INTRODUCTION

Since electric energy is a crucial element in daily life, the rate of its use continuously increases, causing a big problem, which in turn motivates the search for alternative energy for conventional energy. Additionally, pollution from using the energy generated for various applications causes another problem [1]. The induction motor is used as an actuator for the water supply pumps. The PID controller is the core of the control system. It always detects the error between input and output and develops the desired signal for the actuator to control the plant [2]. The nonlinear behavior in the closed-loop control system is reduced using fuzzy PID control. The treatment of water refers to a portion of the water supply system that by some means changes the physical, chemical, or bacteriological quality of water. While "purification plant" refers to a portion of the water supply system designated to change the physical, chemical, or bacteriological quality of water before entering the water distribution system [3], which is a major problem for the people in poor countries. Generally, any water treatment plant aims to produce safe water for drinking, tasteful, and suitable for domestic use [4]. Water treatment is performed in the sedimentation and filtration units to purify water. Various diseases and parasites can spread quickly via water. Hence, water has a significant part in the life cycle of some pathogens. However, it is difficult for a completely balanced state to achieve the desired and smooth operation in the water plant control system [5]. The present work modifies the Smith predictor for plant control with asymmetry of response delay. This predictor is improved to be applied to frequency converters for the speed control of “the AC induction motor drives of pumps” used in the water and liquefied petroleum gas supply systems to determine the flow rate of alum solution dosage and water into the raw water and water treatment plants as shown in Fig. 1. The water quality depends on its physical, chemical, and biological properties. Receiving fresh water from rain only by these systems during three months of summer annually is insufficient to fill big reservoirs in main cities. Therefore, water must be obtained from groundwater sources for the remaining months. Unfortunately, in several situations, arsenic pollutes groundwater, as indicated in numerous cities along the coast [7]. Various factors affect water quality and the process of water treatment due to various contaminants in water that may vary in terms of place and time [8].

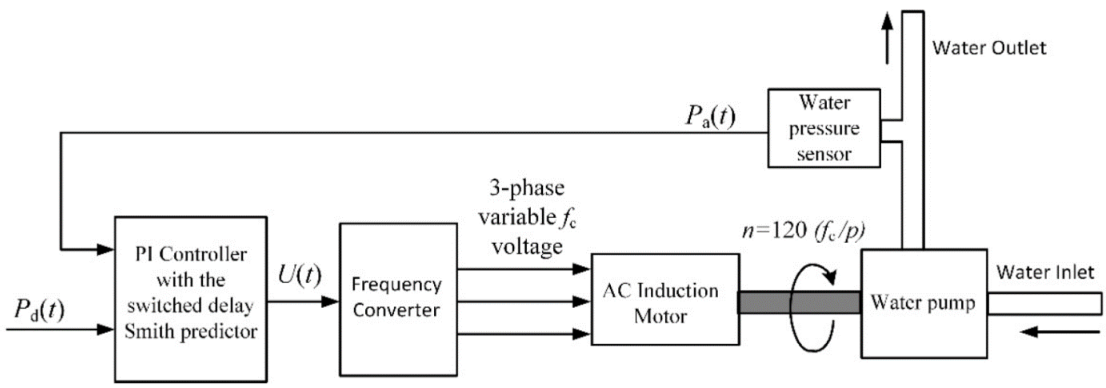


Fig. 1 The Control System of the Water Pump Used in [6].

The control objective is to regulate the concentrations of biochemical oxygen demand (BOD5) and ammonium-ion ($NH+_4$). Existing physical laws are employed to obtain the dynamics of plants [9,10]. A control and automation system must be developed for big systems and crucial infrastructures, such as networks of water pumping, systems of oil, and pipelines of gas. This system should be capable of supervising and monitoring various variables of the process, including flow, pressure, and temperature [11,12]. The definition of limits approved for "the membership function" variable of "error and error variation" is based on the analysis of the system response after running the pump at a speed rate of (60 Hz). At this rate, the maximum pressure was 18 mH2O, and the highest variation in error was 4 mH2O. The structure of the water treatment plant is shown in Fig. 2. The water supply system contains three pumping stations at 45m, 25m, and 30 m, respecting the reference plane. All these stations could pump water in a tank situated at 61 m. All tanks were large enough to estimate the constancy of the fluid level, allowing their modeling to use the block of a constant head tank. Each tank has an initial volume of water set to 100 m^3. Each pumping station had a tank, two centrifugal pumps with parallel installation, and a prime mover rotating at 1700 rpm. Lookup tables were used to specify the pump characteristics. In Fuzzy Theory, two forms of obtainable "fuzzy rule-based models" exist: "non- and additive rules.". The "non-additive rule-based model" is known as the "Mamdani fuzzy inference system (Mamdani FIS)," while the "additive rule-based model" is known as the "Takagi-Sugeno fuzzy inference system (Sugeno FIS)" [13- 15]. MPC is an adaptive control approach for combined sewer systems that recomputes the optimal control iteratively whenever new information about the sewer system state and new rainfall estimates become available [16]. In [17], an MPC was used to control the Barcelona sewer network system based on the benchmark model developed in [18]. The simulation aims to determine the rates of steady-state flow and pressures. Therefore, all pipes are simulated using the block of resistive pipe LP, and no system dynamics are observed. The water supply system is modeled in the Simscape physical-based approach, as shown in Fig. 3.

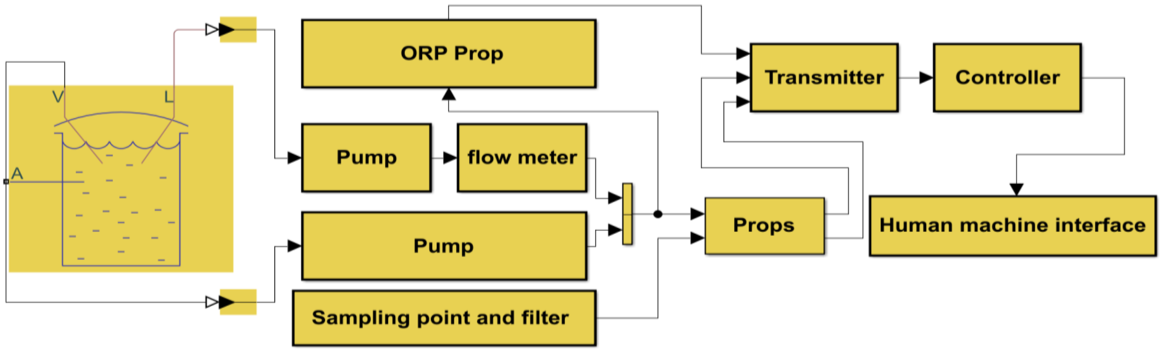


Fig. 2 Water Treatment Plant Structure.

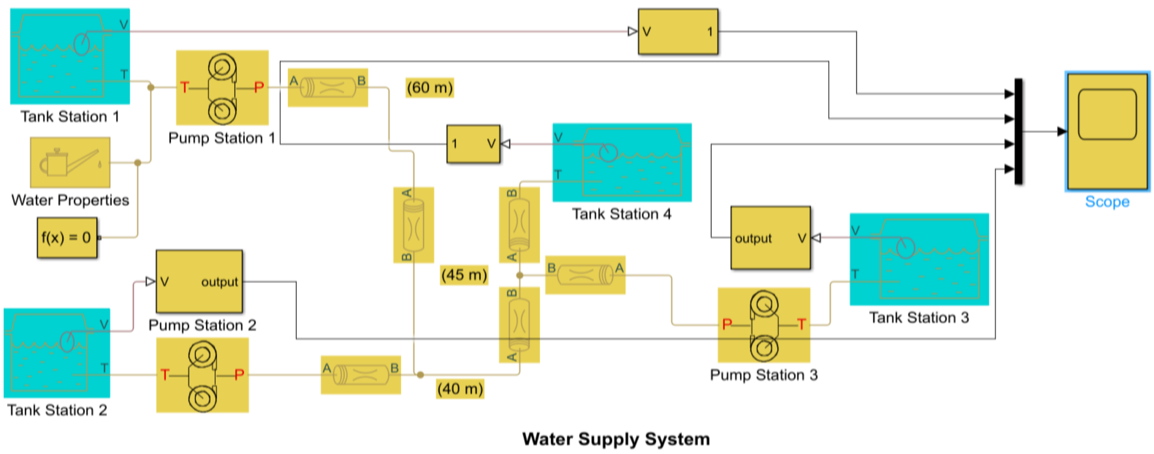


Fig. 3 Water Supply Modeling with Simscape.

The pipes are unaffected in the simulation results by the fluid volume value, inserted just for information purposes. During simulation, this value may be negative, indicating its inadequacy for properly operating the system. Through observing the simulation results, the fluid shortage can be determined. For computational robustness, the computation of pressure loss in the connecting pipe is performed using the same equations used in the Fixed Orifice block:

$$q = \sqrt{\frac{1}{K} * A_p} * \sqrt{\frac{2}{\rho}} * \frac{p_{loss}}{(p^2{}_{loss}+p^2{}_{cr})^{1/4}} \qquad \textbf{(1)}$$

Where

P_{loss}, P_{cr}, ρ, Ap, q are the pressure loss, critical pressure, fluid density, pipe area, and flow rate, respectively. The tank station in the water supply system is shown in Fig. 4.

2.FUZZY LOGIC CONTROLLER

The "input linguistic variables" include "negative big (NB), negative medium (NM), negative small (NS), zero (Z), positive small (PS), positive medium (PM), and positive big (PB)." In contrast, the membership function variable of output depends on the acceleration ramp of the frequency inverter used for driving the pump set, where the maximum frequency of rotation is 4 Hz. The "output linguistic variables" include "Decrease Small (DS), Decrease Medium (DM), Decrease Big (DB), Zero (Z), Increase Big (IB), Increase Medium (IM), and Increase Small (IS)". The rules should be elaborated to attain a first-order response with an error near zero. These features are required when studying the system, as a high overhang and a fast increase in the acting signal induce an excess rotation. Accordingly, a transitory pressure in the water supply network ruptures the ducts and accessory devices, cavitates, and damages the electric motor due to seasonal overcurrent during this period [19]. For optimizing "the fuzzy system," the MATLAB tool "Surface Viewer" was used to run the simulation, where (Input1) refers to the difference between the value obtained in the sensor minus the set point (error). In (Ouput1), the output value of PWM controls the RPM actuator (the peristaltic pump). Figure 5 shows the response of the corresponding curve. Ebhasim Mamdani proposed the system of Mamdani fuzzy inference to control "a steam engine" and "boiler combination" using a set of linguistic control rules obtained from experienced human operators. For each rule in this system, the output is "a fuzzy logic set". Figures (6) and (7) illustrate the rules of fuzzy controllers (trapezoidal functions) established in line with the operator experience. The Mamdani fuzzy logic designer is shown in Fig.8. Table 1 clarifies the variables used as "input functions of the fuzzifier system" and "output functions of the defuzzified system".

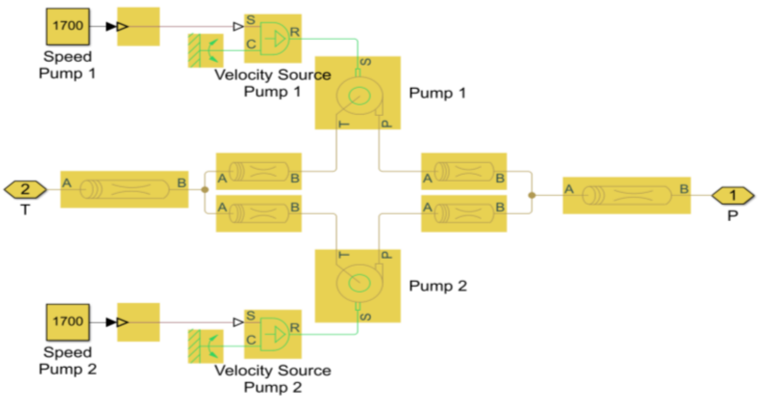


Fig. 4 Tank Station Modeling.

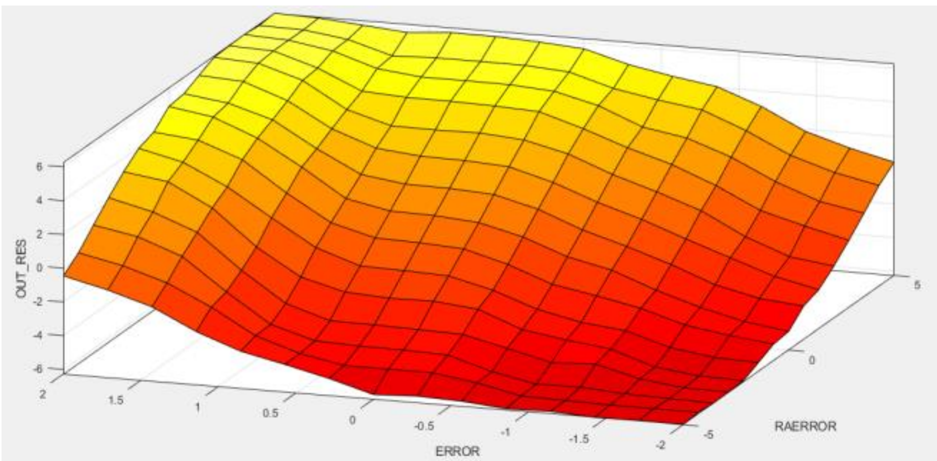


Fig. 5 The Surface of Error and Rate of Error Response.

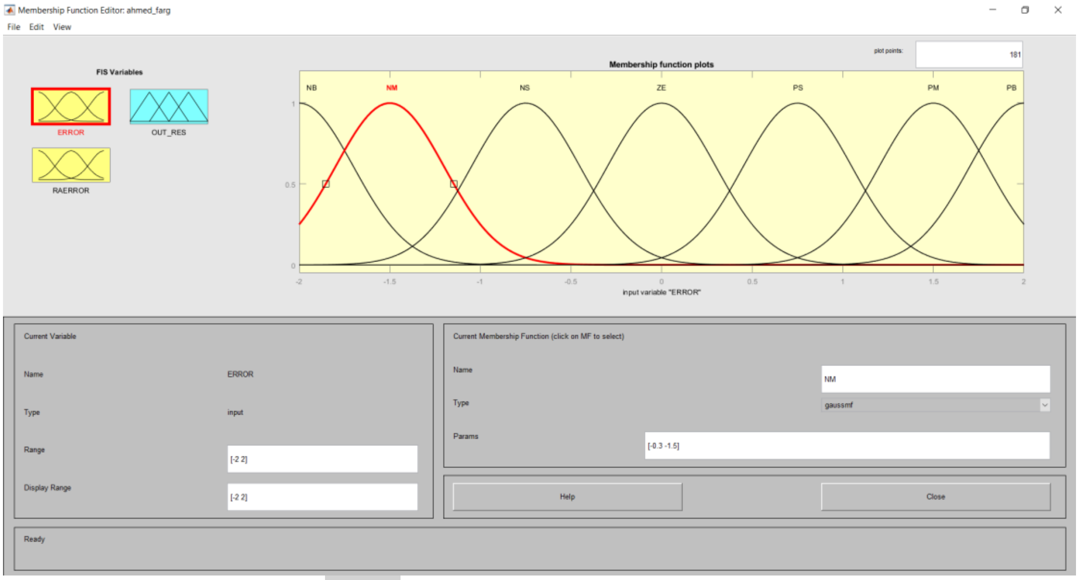


Fig. 6 Fuzzy Controller Error Input.

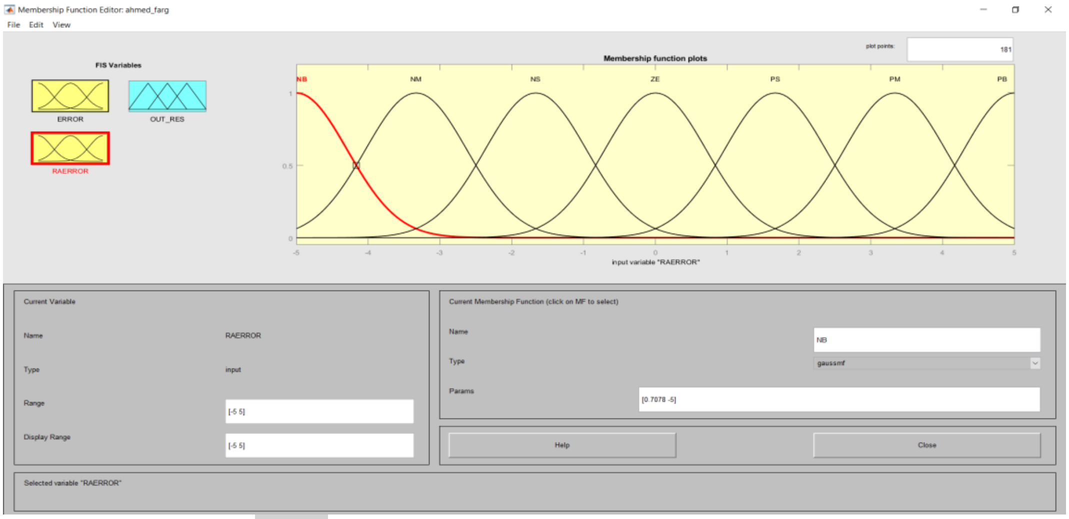


Fig. 7 Fuzzy Controller Rate of the Error Input.

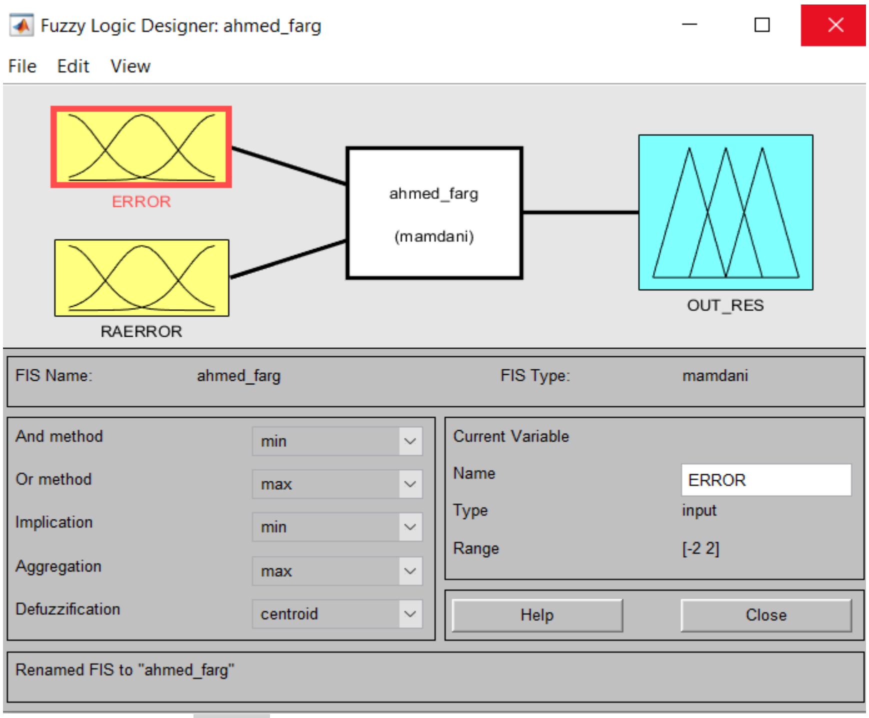
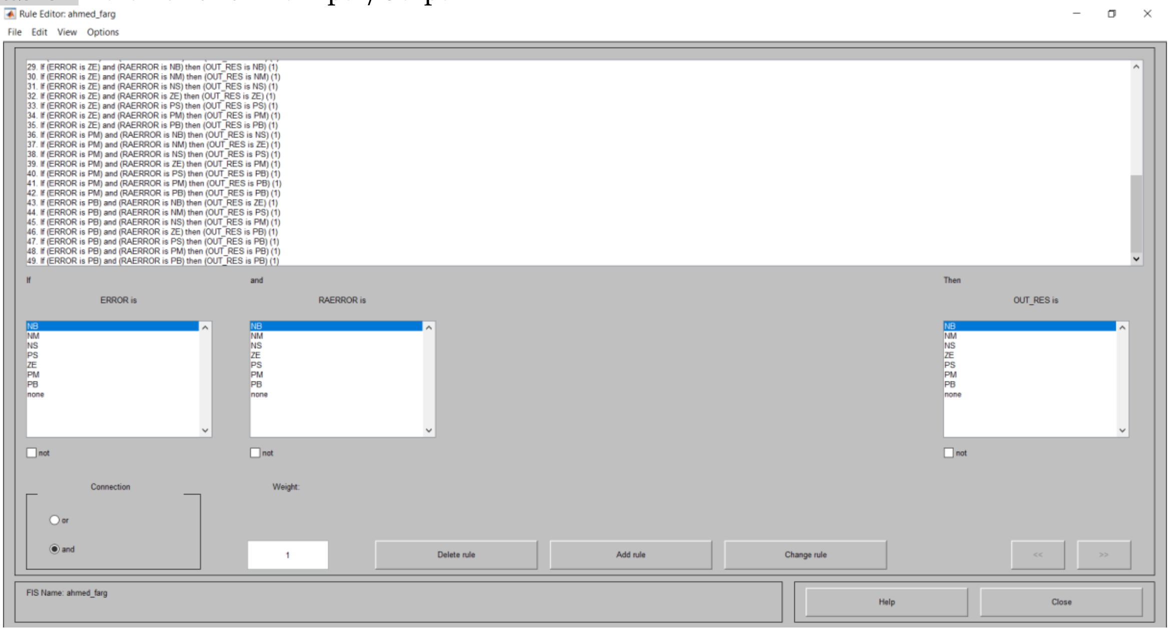


Fig. 8 Fuzzy Controller Implementation.

Table 1 Rule Editor of the Input/Output.



3.OPEN LOOP PID AUTOTUNER

The open-loop PID auto-tuner block is used for tuning the controller of PID in real-time against a physical plant to attain a definite bandwidth and margin of phase without a parametric plant model or an initial design of the controller. For a known plant model in Simulink, an initial design of PID can be obtained using this block. The test signal consists of sine and signals of step perturbation added to the top of the input of the nominal plant and measured at the beginning of the experiment. If the plant is part of "a feedback loop," the loop is opened by the block throughout the experiment. When the experiment ends, tuning the "PID controller" parameters depends on the estimated frequency of plant responses near the open loop bandwidth [20].

4.RESULTS AND DISCUSSION

"The block diagram of the closed-loop control system" is shown in Fig. 9. The "Block diagram of the water-supply control system" is based on the variable speed AC induction motor drive employed by the frequency converter. The control system is used for maintaining the preferred pressure of water, irrespective of the water consumption. The rule viewer fuzzy controller is shown in Fig. 10. When running the experiment (start/stop positive), the test signals are injected into the plant by the block. This block measures the response of the plant at output. These signals are used by this block for estimating the plant frequency response at numerous frequencies surrounding the bandwidth targeted for tuning, as shown in Fig.11. In Fig. 12, the percentage of the vertical axis shows that estimating the plant response frequency is close to completion. Normally, after the beginning of the experiment, this value quickly increased to approximately 90%. Then, it progressively converged to a higher value and when stabilizing at 100%, the experiment was stopped. The optimal values of the PID gains can be estimated directly from the output of the PID open loop auto-tuner, as shown in Fig. 13. Figure 14 shows the step of response with the fuzzy controller. The overshoot was zero, and the rise time was very fast, with an accurate rise time of 0.8 sec. The IM current waveform was very smooth without any distortion, as shown in Fig. 15. Figures 16 and 17 show the system's voltage and torque variations, respectively. In both figures, a smooth response proves the effectiveness of the proposed algorithm. Finally, the pressures at various distances, i.e., 40 m, 45m, and 60 m, estimated from the water treatment plant are shown in Fig. 18. Constant pressure is another approve of the given system stability.

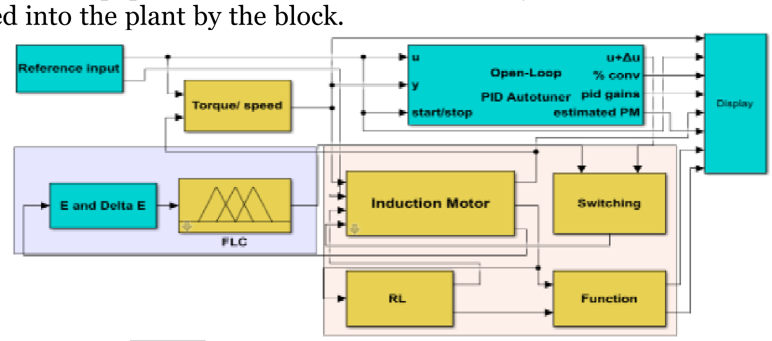


Fig. 9 Block Diagram of the Control System.

Fig. 10 Fuzzy Viewer Rules Response.

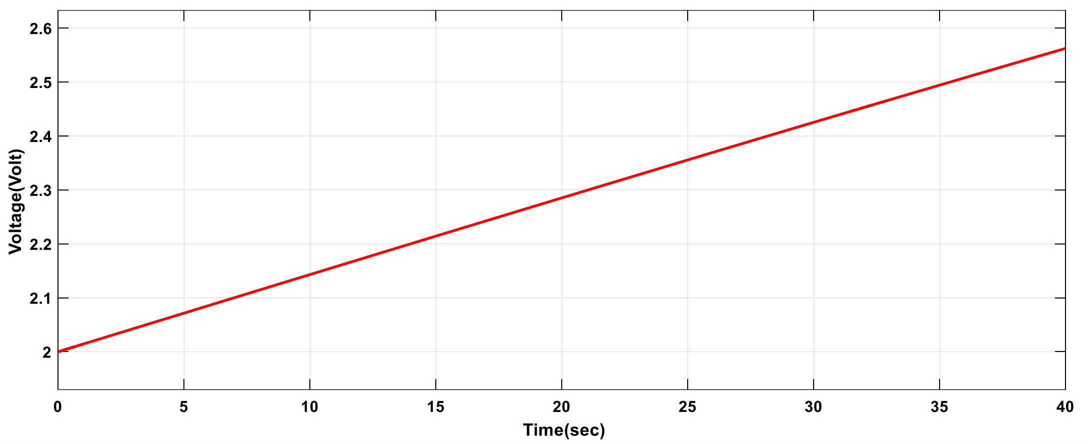


Fig. 11 Voltage Indication of the PID Controller.

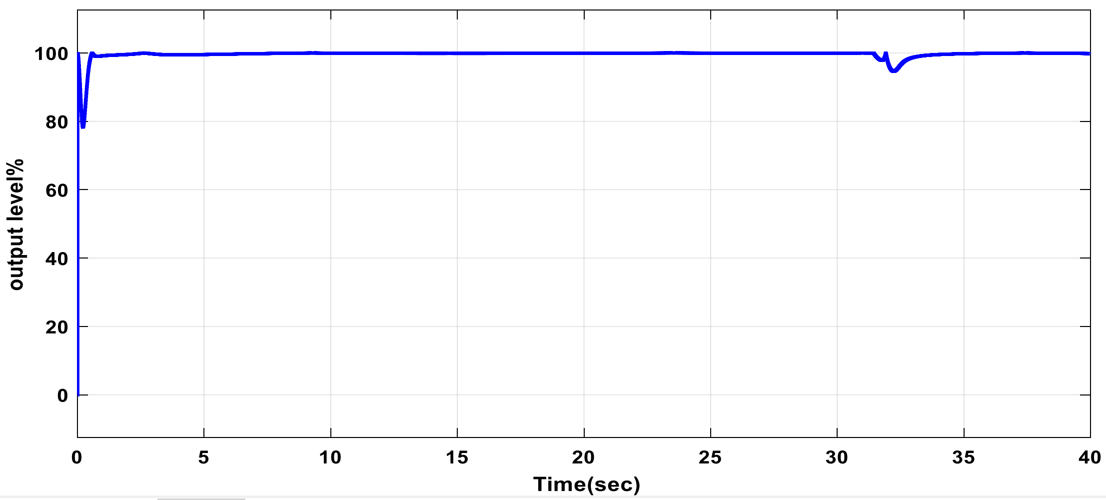


Fig. 12 Indication of the Completion of Plant Frequency Response.

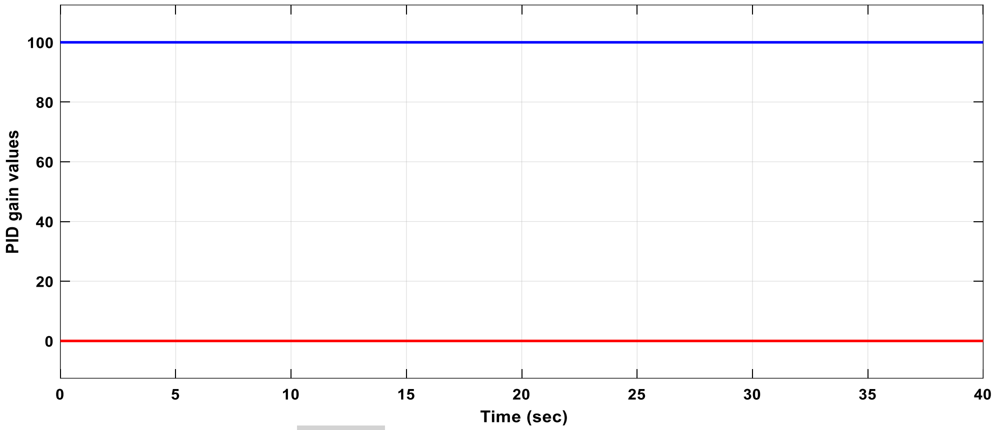


Fig. 13 Optimal PID Gain Values.

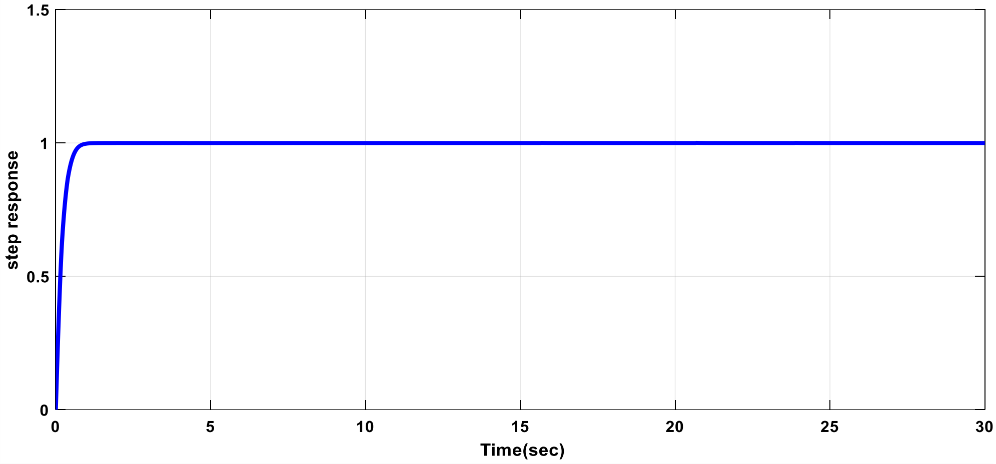


Fig. 14 Step Response of the Control System.

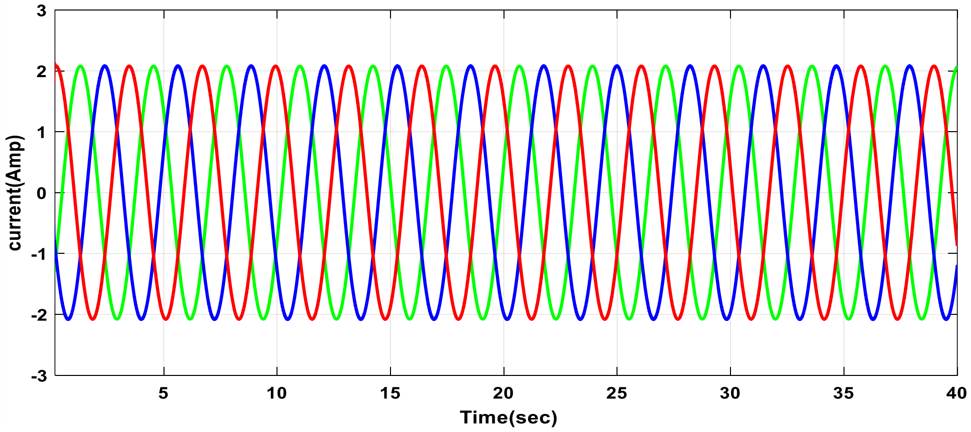


Fig. 15 Current Waveform of the IM.

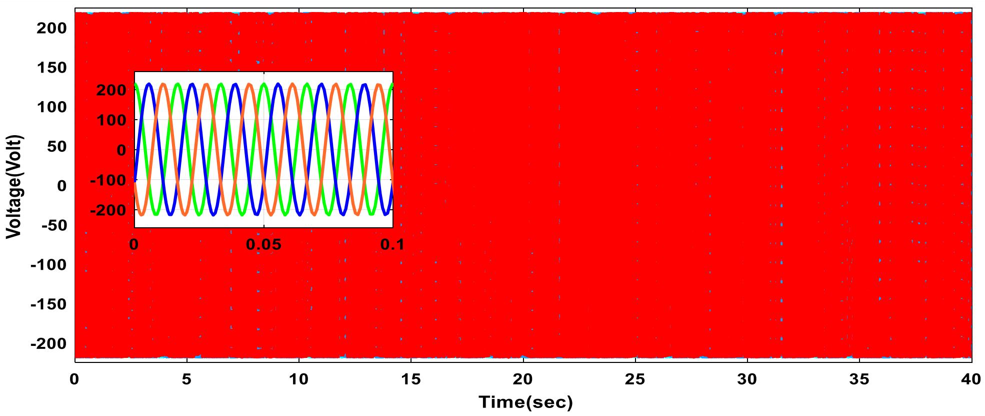


Fig. 16 Voltage Waveform of the IM.

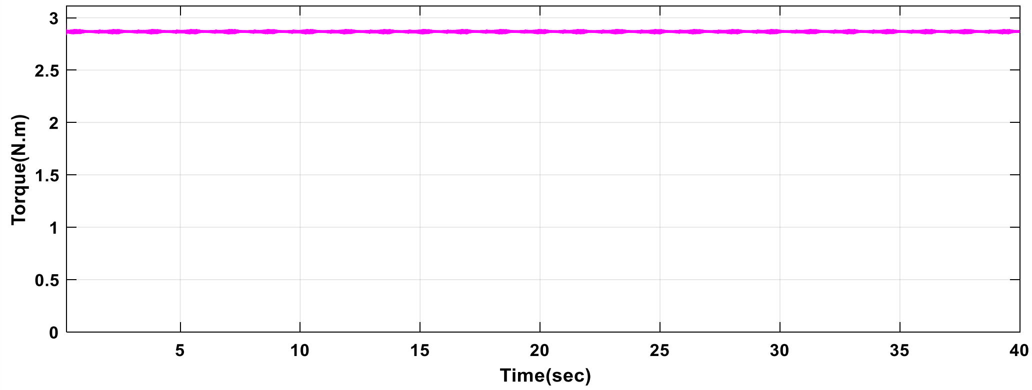


Fig. 17 Torque waveform of the IM.

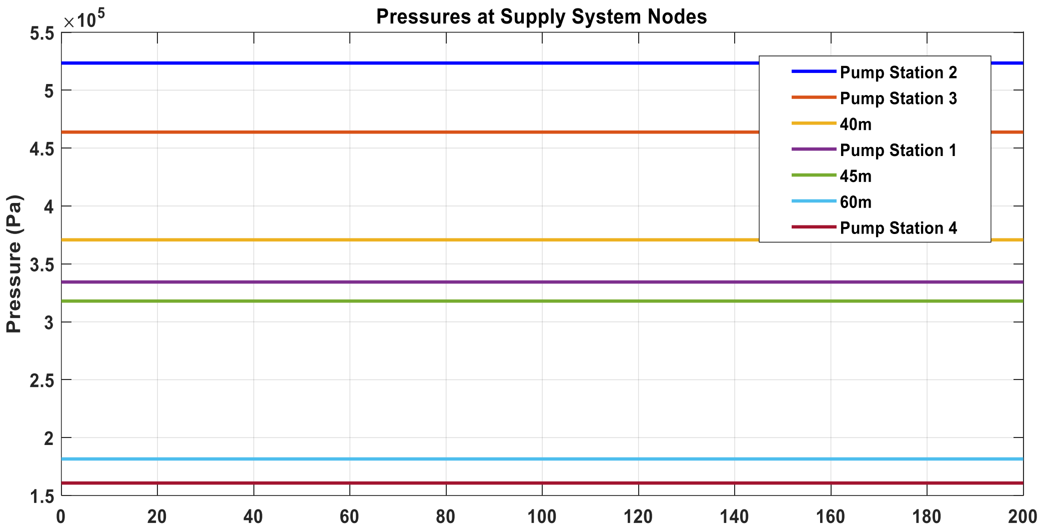


Fig. 18 Pressures at Various Distances from the Inlet Reference Input.

5.CONCLUSIONS

The current study concludes that water purification facilities are crucial to daily life. One factor in improving water treatment plant efficiency is consistent parameters and smooth operation. To maintain the operational conditions, a fuzzy PID controller performs better. Finally, Simscape is a potent method for modeling the water treatment plant elements.

REFERENCES

[1] Mahmmoud ON, Mehdi SR, Gaeid KS, Al-Tameemi ALS. **Solar Cell Split Source Inverter for Induction Motor with Computer Control**. *International Journal of Power Electronics and Drive Systems* 2023; **14**(1): 174-184.

[2] Gaeid KS, Homod RZ, Al Mashhadany Y, Al Smadi T, Ahmed MS, Abbas AE. **Describing Function Approach with PID Controller to Reduce Nonlinear Action**. *International Journal of Electrical and Electronics Research* 2022; **10**(4):976-983.

[3] Guven AH, Ersahin ME, Ozgun AB, Ozturk I, Koyuncu I. **Energy and Material Refineries of Future: Wastewater Treatment Plants.** *Journal of Environmental Management Volume* 2023; **329**: 117130, (1-6).

[4] Salih RA, Ghdhban II, Wahid AK. **Evaluation of a Number of Water Treatment Plants in Kirkuk Governorate Using the Water Quality Index (WQI)**. *Tikrit Journal of Engineering Sciences* 2018; **25**(1): 49–59.

[5] Jassim AH, Hussein AA, Abbas LF. **The Performance of a Three-Phase Induction Motor under and Over Unbalance Voltage**. *Tikrit Journal of Engineering Sciences* 2022; **28**(2): 15–32.

[6] Baskys A. **Switched-Delay Smith Predictor for the Control of Plants with Response-Delay Asymmetry.** *Sensors* 2023; **23**(1): 258, (1-17).

[7] Larroca FP, Olschewski ES, Quino-Favero J, Huamaní JR, Castillo Sequera JL. **Water Treatment Plant Prototype with pH Control Modeled on Fuzzy Logic for Removing Arsenic Using Fe(VI) and Fe(III)**. *Water* 2020: **12**: 2834, (1-13).

[8] Kaleeswari K, Johnson T, Johnson C, Vijayalakshmi C. **Analysis of Fuzzy Logic Based Control Model for Water Treatment Plant in Indian**

Scenario. *International Journal of Pure and Applied Mathematics* 2018; **119**(9): 11-20.

[9] Chakravarty SP, Roy A, Roy P. **Control of Activated Sludge Treatment Process Using Pre-Compensated Multi-Variable Quantitative Feedback Theory - Based Controller**. *Transactions of the Institute of Measurement and Control* 2022; **44**(2): 506-522.

[10] Cao W, Yang Q. **Online Sequential Extreme Learning Machine Based Adaptive Control for Wastewater Treatment Plant**. *Neurocomputing* 2020; **408**(1): 169–175.

[11] Quevedo J, Chen H, Cugueró MÀ, Tino P, Puig V, Garciá D, Yao X. **Combining Learning in Model Space Fault Diagnosis with Data Validation / Reconstruction: Application to the Barcelona Water Network.** *Engineering Applications of Artificial Intelligence* 2014; **30**: 18–29.

[12] Flores TKS, Villanueva JMM, Gomes HP, Catunda SYC. **Indirect Feedback Measurement of Flow in a Water Pumping Network Employing Artificial Intelligence.** *Sensors* 2021; **21**(1):75, (1-15).

[13] Suraj G, Pabitra KB, Belqasem A, Sudhakar BT, Sajal KD. **Modelling, Simulation and Performance Comparison of different Membership Functions Based Fuzzy Logic Control for an Active Magnetic Bearing System**. *The Journal of Engineering* 2023; e12229:1-20.

[14] Ren GP. **Design of Interval type-2 Fuzzy Controllers for Active Magnetic Bearing Systems**. *IEEE/ASME Transactions on Mechatronics* 2020; **25**(5):2449–2459.

[15] Carvalho CF, Oliveira FD, Molina LF, Cavalini AAJ, Steffen V. **Fuzzy Robust Control Applied to Rotor Supported by Active Magnetic Bearing**. *Journal of Vibration and Control* 2021; **27**(7–8): 912–923.

[16] Lund NSV, Falk AKV, Borup M, Madsen H, Steen MP. **Model Predictive Control of Urban Drainage Systems: A Review and Perspective Towards Smart Real-Time Water Management.** *Critical Reviews in Environmental Science and Technology* 2018;**48**(3): 279–339.

[17] Pedersen EB, Herbertsson HR, Niemann H, Poulsen NK, Falk AKV. **Model Predictive Control of Sewer Networks**. *13th European Workshop on Advanced Control and Diagnosis (ACD 2016)* 17–18 November 2016; Lille, France: p. 1-12.

[18] Ochoa D, Riaño-Briceño G, Quijano N, Martinez OC. **Control of Urban Drainage Systems: Optimal Flow Control and Deep Learning in Action.** *American Control Conference (ACC)* 2019; Philadelphia, PA, USA. IEEE: p. 1-6.

[19] Camboim MM, Villanueva MM, Souza DP. **Fuzzy Controller Applied to a Remote Energy Harvesting Emulation Platform.** *Sensors* 2020; **20**; 5874, (1-18).

[20] Lee SW. **Practical Feedback Loop Analysis for Voltage-Mode Boost Converter**. Application Report No. SLVA057. Texas Instruments 2014.